Universidade do Minho
Escola de Engenharia

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Adaptation of the methodology SBTool for sustainability assessment of high school buildings in Portugal - SAHSB^{PT}

April, 2020

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Doctoral Thesis in Sustainable Built Environment

Work performed under the supervision of:
Professor Dr. Maria Manuela de Almeida
Professor Dr. Luís Bragança

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Tatiana Saraiva

Guimarães, October 2019

DECLARATION

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

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RESUMO

Décadas atrás, a única exigência para construir um edifício era dar aos homens as condições certas para a execução de suas atividades. Atualmente existem amplas preocupações relacionadas com a sustentabilidade em edifícios. Os objetivos da União Europeia no programa Horizonte 2020 visam reduzir o impacto ambiental através de estratégias como a melhoria da eficiência energética e a utilização de tecnologias renováveis. Com relação à meta do desenvolvimento sustentável - que integra dimensões ambientais, sociais e econômicas relacionadas à preservação do planeta e à integridade dos consumidores - vários tipos de ferramentas de certificação de sustentabilidade são atualmente usados na indústria da construção, por exemplo, Sustainable Building Tool SBTool (Sustainable Building Tool), LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method). Existem metodologias internacionais de sustentabilidade desenvolvidas especificamente para escolas secundárias e metodologias específicas para a realidade portuguesa, como Natura Domus, LiderA e SBtool^{PT} (Sustainable Building Tool, Portugal). Atualmente, com a preocupação em Portugal em requalificar as escolas, tornou-se necessário desenvolver uma metodologia específica para os edifícios escolares de acordo com a realidade portuguesa. A importância de uma metodologia específica que avalie a sustentabilidade do ambiente escolar é reduzir os impactos ambientais desses edifícios, desenvolver as condições de conforto ambiental dos alunos, melhorar o aprendizado e a qualidade de vida e aumentar a conscientização dos alunos sobre sustentabilidade. Este trabalho destaca a metodologia SBTool que é empregada em vários países e pode ser adaptada às instituições de ensino secundário como base para a formulação de cidadãos responsáveis e o desenvolvimento de um país. O principal objetivo deste estudo é adaptar uma ferramenta de avaliação da sustentabilidade já existente (SBTool^{PT}), mantendo alguns indicadores enquanto modifica e adiciona outros, de forma a desenvolver uma metodologia específica para a Avaliação da Sustentabilidade dos Edifícios Escolares do ensino secundário em Portugal - SAHSB^{PT}. Para atingir esse objetivo, outras metodologias que já incorporam parâmetros relativos ao ambiente escolar são analisadas, como as LEED BD + C Schools, BREEAM Education 2008 e o SBTool for K12 Schools. Pretendeu-se testar a viabilidade e validar esta nova versão da metodologia, aplicando-a a um edifício escolar em Guimarães, Portugal. Para tanto, foram adotadas as seguintes estratégias: pesquisa bibliográfica; estudo profundo do sistema SBTool; estudo dos indicadores de sustentabilidade, categorias e dimensões das metodologias sustentáveis; aplicação da metodologia ao edifício do ensino médio da Escola Secundária Francisco de Holanda, construído pela Empresa Parque Escolar. Este trabalho também pretendeu iniciar o estudo para adaptar esta metodologia a todas as regiões brasileiras, começando com as análises específicas para escolas em Juiz de Fora, Minas Gerais, Brasil. Foram aplicados questionários sobre conforto ergonómico, térmico, visual, acústico e de qualidade do ar, e outros aspetos relacionados com a tomada de consciência sobre questões de sustentabilidade nas escolas portuguesas. O mesmo questionário foi aplicado em dois edifícios do ensino secundário em Juiz de Fora – Colégio Academia e Colégio de Santa Catarina - para entender qual a diferença entre as realidades portuguesa e brasileira em relação às condições de conforto. Foi feita uma comparação entre os resultados das duas escolas, comprovando a necessidade da elaboração de uma metodologia para diferentes regiões. Este estudo também demonstrou a necessidade de incluir aspetos ergonómicos nas metodologias de avaliação de sustentabilidade dos edifícios escolares.

Palavras-chave: SBTool, edifícios escolares, ferramentas de avaliação de sustentabilidade, sustentabilidade.

Adaptation of the methodology SBTool for sustainability assessment of high school buildings in Portugal - SAHSB^{PT}

ABSTRACT

Decades ago, the only requirement to construct a building was to give men the right conditions for the performance of their activities. Nowadays, there are major concerns related to sustainability in buildings. With regard to the objective of sustainable development in buildings—which integrates economic, social, and environmental dimensions relating to the comfort of consumers and the protection of the earth—several forms of sustainability assessment are currently used in the construction industry e.g., the Sustainable Building Tool (SBTool), the LEED (Leadership in Energy and Environmental Design) and the BREEAM (Building Research Establishment Environmental Assessment Method). There are international sustainability assessment tools planned specifically for school buildings and tools specific to the reality of Portugal, such as SBtool^{PT} (Sustainable Building Tool, Portugal), Natura Domus and LiderA (Leading the Environment for Sustainable Construction). Currently, with the concern in Portugal to requalify high schools, it has become required to elaborate a specific sustainable building tool for school environments according to the reality of Portugal. The imporancet of a specific methodology thar asses sustainability for the school environment is to reduce the environmental impacts of these buildings, develop the conditions of environmental comfort of students, improving learning and quality of life, increase the awareness of student about sustainable This work emphasizes the SBTool methodology that is applied in several countries and can be adjusted to high school buildings as the basis for the development of a country. The main purpose of this thesis is to adapt an already existing methodology of sustainability (SBTool^{PT}), maintaining some indicators while adding and modifying others, to elaborate a method specifically dedicated to the Sustainability Assessment of High School Buildings in Portugal—SAHSB^{PT}. To achieve this goal, other methodologies that already include parameters relating to the school environment are analysed, such as the SBTool for K–12 Schools, LEED Building Design and Construction School (LEED BD + C Schools) and BREEAM Education 2008. It was intended to test the viability and validate this new methodology version by applying it to a school building in Guimarães, Portugal. For that purpose, the following strategies were adopted: literature review; deep study of the SBTool system; study of the sustainability indicators, categories, and dimensions of sustainable methodologies; application of the methodology to the high school building of Escola Secundária Francisco de Holanda, built by *Parque Escolar.* This work also intended to start the study to adapt this methodology to Brazil, beginning with the specific analyses of two schools in Juiz de Fora, Minas Gerais, Brazil. Questionnaires about ergonomic, thermal, visual, acoustics and air quality comfort, and other sustainability awareness aspects were applied in the Portuguese school, to determine the weight of each comfort indicator according to the Portuguese reality. The same questionnaire was applied in two high school buildings in Juiz de Fora – Academia School and Santa Catarina School – to understand the difference between those Portuguese and Brazilian realities regarding comfort conditions. A comparison between the results of the three schools was made, proving the necessity of the elaboration of a methodology for different regions. This study also demonstrated the need to include ergonomic aspects in the sustainability assessment methodologies of school buildings.

Keywords: SBTool, school buildings, sustainability assessment tools, sustainability

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SARAIVA, T. S.; SILVA, E.M.; ALMEIDA, M. and BRAGANÇA, L. 2019. Comparative study of Environmental Comfort Indicators for School Buildings in Sustainability Assessment Tools: schools in the Amazon region and in the Southeast region of Brazil 2019. Sustainability 2019, 11(19). 5216. https://doi.org/10.3390/su11195216

SARAIVA, T. S.; ALMEIDA, M.; BRAGANÇA, L. and BARBOSA, M. T. 2019. Verification of the Adequacy of the Portuguese Sustainability Assessment Tool of High School Buildings, $SAHSB^{PT}$, to the Francisco de Holanda High School, Guimarães. Sustainability 2019, 11, 4559, 2019. https://doi.org/:10.3390/su11174559

SARAIVA, T. S.; ALMEIDA, M. and BRAGANÇA, L. 2019. Adaptation of the SBTool for Sustainability Assessment of High School Buildings in Portugal—$SAHSB^{PT}$. Applied Sciences 2019, 9, 2664. https://doi.org:10.3390/app9132664

SARAIVA, T. S.; ALMEIDA, M.; BRAGANÇA, L. and BARBOSA, M. T. 2019. The Inclusion of Sustainability Awareness indicator in sustainability Assessment tool for High School Buildings. Sustainability, 2019, 11(2), 387; https://doi.org/10.3390/su11020387

SARAIVA, T. S.; ALMEIDA, M.; BRAGANÇA, L and BARBOSA, M. T. 2018. Environmental Comfort Indicators for School Buildings in Sustainability Assessment Tools. Sustainability, v. 10, p. 1849, 2018. https://doi.org/10.3390/su10061849

SARAIVA, T. S.; Almeida, M. and Bragança, L. 2015. The importance of the category of consciousness and education for sustainability in methodologies for ecoefficiency in school buildings. Proceedings of EURO ELECS 2015. Guimarães. Portugal. ISBN 978-989-96543-8-9.

SARAIVA, T. S.; Almeida, M. and Bragança, L . 2015. Analysis and selection of indicators for a methodology for sustainability assessment of school buildings based on SBTool. Proceedings of EURO ELECS 2015. Guimarães. Portugal. ISBN 978-989-96543-8-9.

GLOSSARY OF ACRONYMS

ABNT Brazilian Association for Technical Standards;

ADP Abiotic Depletion Potential;

AQUA High Quality Environment,

AIFF Association for the Competitiveness of Industries of Forestry;

AP Acidification;

APCOR Portuguese Cork Association;

ASHRAE American Society of Heating Refrigeration Air Conditioning Engineers;

BCA Building and Construction Authority;

BEA Building Energy Analysis;

BSA Building Sustainability Assessment;

BRAIE National Programme of Evaluation of Environmental Impacts of Buildings;

BRE Building Research Establishment;

BREEAM Building Research Establishment Environmental Assessment Methodology;

BSA Building Sustainability Assessment;

CASBEE Comprehensive Assessment System for Built Environment Efficiency;

CDW Construction and Demolition Waste;

CECAS Center for Climate Studies and Sustainable Environments;

CED Cumulative Energy Demand systems;

CEDEI Center for Interamerican Studies;

CELPA Association of Paper Industry;

CIEPs Integrated Centre for Public Education;

DD Development Density;

DGNB German Society for Sustainable Construction;

EU European Union;

ECS Buildings Energy Certification System;

EP Eutrophication;

EPBD Energy Performance of Buildings Directive;

EPE Enterprise Parque Escolar;

EPI Environmental Performance Index;

EMS Environmental Management System;

ERCB Ecoprofile for Building and Effective Resource of Commercial Buildings;

FLEGT Forest Law Enforcement Governance and Trade;

FFDP Non-renewable Primary Energy

FHHS Francisco de Holanda High School;

FLDM Average of day light factor;

FSC Forest Stewardship Council;

GBC Green Building Council;

GBTool Green Building Tool;

GFAI Gross Floor Area Index;

GHG Green House Gases;

GW Greywater;

GWP Global Warming Potential;

HQE High Environmental Quality;

HVAC Heating, Ventilation, and air Conditioning;

IAQ Indoor Air Quality;

IEQ Indoor Environmental Quality;

iiSBE International Initiative for Sustainable Built Environment;

INBEC Brazilian Institute of Continuing Education;

IPCC Intergovernmental Panel on Climate Change;

ISO Internacional Standards;

IST Lisbon Technical Institute;

JAEES Administrative Board of the Loan for Secondary Education;

LCA Life cycle analysis;

LEED Leadership in Energy and Environmental Design;

LEED BD+C Schools - Leadership in Energy and Environmental Design for School;

LIHT Laboratory of Immunogenetics and Histocompatibility;

MCS Management Control System;

NABER National Australian Built Environment Rating System;

NBR Brazilian Standard;

OECD Organization for Economic Co-operation and Development;

ODP Stratospheric Ozone Depletion;

POCP Photochemical Ozone Creation;

PGS Potential Management of Mechanical Systems;

PINUS Center Association for the Recovery of Pine Forest;

PV Photovoltaic;

PMEES Modernization of Schools for Secondary Education;

PEFC Program for the Endorsement of Forest Certification Schemes;

PROCEL National Program for the Conservation of Electric Energy;

PTAL Public Transport Accessibility Level;

QAE Qualidade Ambiental do Edifício - Building Environmental Quality;

RW Rainwater;

RWH Rainwater Harvesting;

REH Energy Performance Regulation of Residential Buildings;

RECS Energy Performance Regulation of Trade and Service Buildings;

RCE Energy Certification Network;

RCCTE Regulation of Thermal Behavior Characteristics of Buildings

RSB Residential Solar Block;

RSECE Regulation for Energy Systems and Air Conditioning in Buildings;

SBTool Sustainable Building Tool;

$SBTool^{PT}$ Sustainable Building Tool – Portugal;

$SBTool^{PT}$ STP for Office Building - Sustainable Building Tool Portugal;

SCE National Certification System for Energy and Indoor Air Quality in Buildings -

SE Spatial Efficiency;

SESC Serviço Social do Comércio, Social Service of Business;

SGE Enterprise Management System;

SGS Société Générale Surveillance;

SRI Solar Reflectance Index;

UNCED United Nations Conference on Environment and Development;

UNFCCC2 United Nations Framework Convention on Climate Change;

USP São Paulo University;

TDM Transportation Demand Management;

VOC Volatile organic compound;

VPA Voluntary Partnership Agreements;

WEEE Waste Electrical and Electronic Equipment;

WWF World Wide Fund for Nature;

ZEB Zero Energy Building;

ZAV Zero Accident Vision.

CHAPTER 1

Introduction

1.1. Scope

The concept of sustainable development was first formalized in 1987 in the Brundtland report, as "the one that aims to fulfil the needs of present generation without compromising the capability of future generations to fulfil their own needs". Since then, the governments of several countries sought to lead society towards sustainable development. However, it became perceptible that the world's sustainability nowadays is lower than it was fifty years ago, making it evident that there is still a long path to go through in order to reduce the consequences of the lack of sustainability in our current society (WCED, 1987).

In the 1970's and 1980's, the polluting effects in the atmosphere grew from a local to a global scale, affecting the entire planet. Consequently, economic and social issues began to be increasingly more connected with the environmental protection. Several measures were taken towards the environmental preservation, many of those related to the sustainable construction of buildings. Presently, as a result of the environmental and energy consumption problems, the adoption of sustainability concerns is no longer a choice, but a necessity.

The construction sector is traditionally the main responsible for the consumption of natural resources and materials, with a significant production of CDW (Construction and Demolition Waste) and negative environmental impacts on the planet. Therefore, when projecting a building, it is essential to act in accordance with the sustainability requirements from the early design stages of the project elaboration, as it is at this moment that the priorities are set, therefore, future problems can be avoided. In the same way, the existing buildings should be refurbished or renewed following the same principles in order to achieve a reduction of energy and water consumption, as well as providing a better quality of life for users.

Charles Kibert (1994) introduced the concept of sustainable construction as being the “creation and responsible management of a healthy built environment, taking in consideration the ecological principles and the efficient use of the resources." Sustainable construction ought to seek a balance between the environmental, social, and economic levels in the construction sector (Kibert, 1994).

Several advances have been elaborated with the objective of maximize sustainable construction, mainly in the study and increase of tools for the assessment of the sustainability of constructions. As a consequence of the use of these tools, it is possible to improve the sustainability of building construction (Mateus & Bragança, 2011). These tools also distinguish between sustainable and unsustainable performs, thus simplifying conscientious choices in projects and in construction stages (Saraiva et. al, 2019b).

Some countries have developed tools, such as CASBEE (Comprehensive Assessment System for Built Environment Efficiency, Japan), NABERS (National Australian Built Environment Rating System, Australia), BREEAM (Building Research Establishment Environmental Assessment Method, United Kingdom), LEED (Leadership in Energy and Environmental Design, United States), SBTool (Sustainable Building Tool, Canada) and HQE (Haute Qualité Environnementale—High Environmental Quality, France), that allow for sustainability assessments of buildings (Bernardi et. al, 2017). These tools were elaborated with the intention of being adjusted to all types of buildings. However, the necessity for creating tools for specific constructions such as offices, residences, hospitals, shopping centers, and so on was progressively recognized (Saraiva et. al, 2019b).

BREEAM, LEED and SBTool methodologies have made on specific systems for school constructions, such as BREEAM Education (2008), LEED BD + C: Schools (2013) and SBTool for K–12 schools. This is important, since the environment of schools is distinct. Teachers and students spend several hours a day surrounded by the school’s environment, and therefore, this specific environment has a major effect on their quality of life (Saraiva et. al, 2019b).

Along with the maintenance of the school constructions, the sustainable refurbishment of these constructions, in terms of the quality of life of students and teachers, better indoor air quality, optimization of water consumption, improvement of health, energy efficiency, learning conditions, decrease of emission of greenhouse gases and minimization of costs, is essential (Kats et.al, 2005 and Saraiva et al., 2019b).

No sustainability assessment exists for school constructions that is suitable to the Portuguese reality and aids the requalification of schools. This thesis aims to study the significance of the use of sustainability indicators to influence and improve strategies for the refurbishment of school constructions, considering the sustainability assessment methodology of SBTool^{PT}, which is based on the international SBTool methodology developed by iiSBE - International Initiative for a Sustainable Built Environment (Saraiva et. al, 2019b).

Adapting this tool makes a rubric that is specifically appropriate to the assessment of the sustainability of Portuguese high school buildings, which is relevant, because there is currently no such specific methodology created in this country for this intention. Thus, this research adapts the SBTool methodology for the Sustainability Assessment of High School Buildings in Portugal, creating a methodology tailored for Portuguese High Schools — the SAHSB^{PT} methodology. SAHSB^{PT} will support designers and architects with the development of sustainability in the project design phase or in the rehabilitation of school buildings (Saraiva et. al, 2019b).

The SBTool^{PT} methodology was designate, because it permits a larger possibility for adapting the indicators assessed in each dimension, considering the construction practicality, building site, and its typology, representing better flexibility and also decreasing subjectivity, which makes it more adjustable in relation to other more extensive and rigid systems (Barbosa et al., 2013). Additionally, because the SBTool^{PT} was created in Portugal, it is the methodology most appropriate to practical application according to Portuguese reality (Saraiva et al. 2019b).

This thesis also intended to evaluate high school buildings, which correspond in Portugal to the high school education, attended by children between 15 and 18 years old (10th to 12th grade). The high schools were chosen because children attending them are at the end of their basic studies, so they are more mature and can better understand the concept and principles of sustainability.

In Portugal, the high school chosen to test this methodology, Francisco de Holanda High School (Escola Secundária Francisco de Holanda, FHHS), is a school that has been refurbished by the *Parque Escolar*, the company engaged in the last decade by the Portuguese government to build modern, efficient and comprehensive schools with first-class infrastructures. The study was developed for the Portuguese reality and took it into account, using SBTool^{PT} as the base methodology that has already been adapted to other building typologies, in accordance with the Portuguese reality. Portugal has great experience in developing sustainability assessment methodologies (Mateus, 2010).

Questionnaires about ergonomic, thermal, visual, acoustic and air quality comfort, and a questionnaire about the awareness of sustainability were applied at the school in Guimarães, Portugal. These questionnaires were used to measure the comfort and the level of awareness of sustainability that the high school students possessed, as well as to support the definition of the weights given to these indicators.

This work also aimed to initiate the analysis of the possibilities regarding an application of the SBTool methodology in Brazilian schools. Due to the size and heterogeneity of the Brazilian territory, and taking into account that this is an exploratory study, it was decided to limit the study to the analysis of schools in the city of Juiz de Fora, Minas Gerais and Macapá, Amapá and only a few specific indicators related to the school environment were analysed.

The choice of this city of Juiz de Fora had to do with the fact that it is very similar to Guimarães in terms of climate, with similar average annual temperature and average annual humidity. The characteristics of the buildings and the layouts of the classrooms are also very similar, a fact resulting from the Portuguese colonization of two centuries ago. The reason why the city of Macapá was chosen to begin the development and implementation of a sustainability assessment tool in Brazil has to do with the fact that the author of this thesis lives in in Macapá, which facilitates the research.

The developmental part of this thesis, chapters 5, 6, 7, 8 and 9, is based on the articles published by the author and supervisors of this research, as described below:

- The articles "Environmental Comfort Indicators for School Buildings in Sustainability Assessment Tools. Sustainability" (Saraiva et al. 2018) and "The Inclusion of Sustainability Awareness indicator in sustainability Assessment tool for High School Buildings" (Saraiva et al., 2019a) are referred in Chapter 5, "Identification of indicator weights", and Chapter 8 of this thesis, "Exploratory study of the application of the methodology to Juiz de Fora schools".

- The article "Adaptation of the SBTool for Sustainability Assessment of High School Buildings in Portugal—SAHSB^{PT}" (Saraiva, 2019b) is referred in the Chapter 6 of this thesis.

- The article "Verification of the Adequacy of the Portuguese Sustainability Assessment Tool of High School Buildings, SAHSB^{PT} to the Francisco de Holanda High School, Guimarães" (Saraiva et al., 2019c) is referred in Chapter 7 of this thesis.

- The article "Comparative study of Environmental Comfort Indicators for School Buildings in Sustainability Assessment Tools: schools in the Amazon region and in the Southeast region of Brazil" (Saraiva, 2019d) is referred in Chapter 9 of this thesis.

1.2. Objectives

The main objective of this research was to define indicators and categories for the elaboration of a Sustainability Assessment methodology of High School Buildings in Portugal (SAHSB^{PT}) in accordance with the principles and concepts of the SBTool international methodology.

The specific objectives of this work were:

- Study and adapt building sustainability assessment (BSA) tools that already incorporate specific parameters for school buildings, such as LEED, BREEAM, and SBTool.
- Apply the SAHSB^{PT} Methodology to a Portuguese school. The results should be useful to test the viability of the methodology in Portugal.

- Start the assessment of sustainability in school buildings in Brazil, through the analysis of two schools in Juiz de Fora, MG and Macapá, AP, evaluating some indicators, such as indicators of comfort (indoor air quality, thermal comfort, visual comfort, acoustic comfort and ergonomic comfort) and sustainability awareness indicator just in Juiz de Fora high schools.

1.3. Organization of the thesis

The Thesis is organized in ten chapters:

CHAPTER 1 - INTRODUCTION

The first chapter is a brief introduction to the subject of this work, stating the objectives and the organization of the thesis.

CHAPTER 2 - SUSTAINABILITY IN HIGH SCHOOL BUILDINGS

The second chapter covers the state-of-the-art on the subject. Some relevant concepts and a brief history of sustainability and sustainable construction are introduced, followed by a review of the literature that deals with the central themes of this research. In this part of the work were also mentioned the most commonly utilized building sustainability assessment tools, such as LEED, BREEAM, CASBEE, AQUA and SBTool, among others. The purpose was to analyse the indicators and their weights in order to help elect the indicators to be included in the adaptation and development of this methodology.

It was necessary to study the main effects that arise during the construction phase of the buildings to analyse sustainable construction. Since this is an extremely wide matter, there are many indicators that can be included in this analysis. The SBTool methodology and its adaptation to SBTool^{PT} STP for Office Buildings were reported with more detail since they were the methodologies used as basis in this work. Nevertheless, in the first stage of this work, examples of environmental methodologies used in schools, such as SBTool for K-12 Schools, BREEAM Education and LEED BD+C for Schools, were reported because these have already been applied to some school buildings in other countries.

The second chapter also includes a brief review of the building sustainability assessment methodologies used both in Brazil and in Portugal. It includes also a short introduction to the high schools in Juiz de Fora, Brazil, and to the schools refurbished by *Parque Escolar*, Portugal, since these are the research subjects of this thesis.

CHAPTER 3 – METHODOLOGY FOLLOWED IN THE THESIS

This chapter describes the methodology followed in this thesis to reach the objectives.

CHAPTER 4 - SYSTEM STRUCTURE AND CONTENT

This chapter is dedicated to the presentation of the development of the SBTool^{PT} adaptation for school buildings. Based on the literature review, BSA methodologies developed exclusively for schools as SBTool for K-12 Schools, BREEAM Education and LEED BD+C for Schools were analysed to help select which parameters and indicators to use in the assessment of the sustainability of school buildings.

CHAPTER 5 –IDENTIFICATION OF THE WEIGHTS OF THE INDICATORS USED IN THE SAHSB^{PT} METHODOLOGY

In this chapter, each indicator was attributed according to the environmental, economic and social reality of the chosen region. It also shows the results of the application of the questionnaires on comfort and sustainability awareness in the high school Francisco de Holanda in Guimarães, Portugal, which led to the definition of the weights to be applied to the new two indicators proposed in this thesis.

CHAPTER 6 – BASIS FOR THE PREPARATION OF THE EVALUATION GUIDE – SUSTAINABILITY ASSESSMENT OF HIGH SCHOOL BUILDINGS IN PORTUGAL – SAHSB^{PT}

This chapter assists in the elaboration of the guide to the improvement of sustainability in school buildings in Portugal, the SBTool^{PT} for Schools Buildings, SAHSB^{PT} methodology. Some indicators are already in the SBTool^{PT}H and SBTool^{PT} STP for Office Buildings, therefore, there were just reported in the Suplementary Material.

CHAPTER 7 – APPLICATION OF SAHSBT^{PT} METHODOLOGY TO A CASE STUDY - FRANCISCO DA HOLANDA HIGH SCHOOL

In this chapter, the SAHSB^{PT} methodology was applied to the Francisco de Holanda high school building in Guimarães, Portugal, in order to verify the adequacy and applicability of the benchmarks used.

CHAPTER 8 - EXPLORATORY STUDY OF THE APPLICATION OF THE METHODOLOGY TO BRAZILIAN HIGH SCHOOLS

In this chapter, the same questionnaires about comfort and sustainability awareness were applied in two high schools in Juiz de Fora, Brazil (Academia School and Santa Catarina School), and these results were compared with the Portuguese results with the purpose of analysing the difference between both realities, as well as to introduce the methodology in Brazil.

CHAPTER 9 - COMPARATIVE STUDY OF ENVIRONMENTAL COMFORT INDICATORS IN THE SOUTHEAST AND IN THE AMAZON REGION IN BRAZIL

In this chapter, the same questionnaires about comfort were applied in two high school buildings in Juiz de Fora, Academia School and Santa Catarina School, and in two schools in Macapá, Tiradentes School and Professor Gabriel Almeida Café School, to understand the difference between these two regions of the Brazilian reality regarding comfort conditions. A comparison between the results of the four schools was made, proving the necessity of the elaboration of a specific methodology for each Brazilian region.

CHAPTER 10 - CONCLUSIONS AND FINAL CONSIDERATIONS

This last chapter presents the interpretation, analysis, explanation and conclusion of the research, and also some elements for the future studies about this methodology according to the Brazilian reality.

CHAPTER 2

Sustainability in High School Buildings

All construction types have different features. Thus, it is required to develop specific sustainability tools to address those different functions and traits. A school building has specific particularities that have to be considered with respect to implementing aspects of sustainability. For instance, as it is a place designed to provide learning environments and learning spaces for the education of students, adolescents and children, it involves a more rigid comfort level geared towards a younger population. Additionally, it is essential to plan construction in order to decrease environmental effects by using the proper technology and equipment (Saraiva et. al, 2019b).

This chapter describes concepts and history about sustainability and the main aspects that present a relationship between Portuguese and Brazilian high schools. It also embraces the main methodologies of sustainability assessment for the school environment and their characteristics, as well as the main procedures used for schools in both countries. The analysis of this information aided in the choice of the base methodology used in this thesis.

2.1. Concept of Sustainability

It is important to clarify the difference between the terms sustainability, sustainable development, sustainable construction and the definition of Green Building.

The term "sustainability" is employed mainly in academia, while "sustainable development" is employed in political contexts. However, both allude to philosophical and moral conceptions regarding the relationship between the human-being and nature. Not very often a term has spread and developed as quickly and deeply as the concept of "sustainability", being nowadays present in several fields of study and reaching a prominent popularity (Vogt, 2010).

Sustainable development regards the anthropocentrism, favouring a progressive change without threatening institutional reforms, technological advancement and the established authorities. The term “Sustainability” is related with the biocentrism, a point of view that places human-beings within a natural context and as a part of a greater ecosystem, focusing on behavioural changes, restrictions, and emphasizing fundamental values (Hilderberg, 2010).

The growing debate about global environmental problems is in evidence in several spheres of society. The concern about the future of the planet is employed as a political slogan, giving rise to new laws, and encouraging academic research that meet this purpose, besides increasing the number of government agencies concerned with this subject. The twentieth-first century is considered to be the "century of sustainable development" (Reidel, 2010).

Sustainability has been interfering with the policies and the economy of society. Whilst this subject was achieving great popularity, it also gave rise to doubts regarding the balance between the several aspects that embrace economic, social and environmental issues (Reidel, 2010). "Sustainability is a new kind of environmental policy, because it cares not only about the current economic and social environmental protection, but also with the responsibility for future generations" (Freericks et al., 2010).

Sustainable development is a holistic concept, a challenging policy target that embraces different domains of intervention, combining environmental, economic and social aspects (Rydin et al., 2003). This concept goes beyond the protection of the environment, it also incorporates the concern for the future generations and the long-term integrity and health of the environment (Mateus & Bragança, 2006), as well as the concerns about preservation of biodiversity, quality of life and social cohesion. The concept of sustainable development has achieved worldwide prominence in 1970 after the proclamation of the Year of the Environment by the United Nations, which resulted from society’s awareness and concern about the shortage of natural resources (Castanheira, 2013).

Through sustainability, the three elements, environmental, social and economic, must be preserved with equilibrium (WCED, 1987). According to Swarup, the best sustainability results are achieved when all stakeholders are committed: project team, building contractor and owner (Swarup et al., 2011). Therefore, sustainability supports architects and engineers with the possibility of bequeathing a better future in the field of construction (Martek et al., 2018).

The main aim of sustainable construction is "the creation and responsible maintenance of a healthy built environment, based on an efficient utilization of resources and in ecological principles" (Kibert, 1994). The seven principles of sustainable construction, according to the ICB (International Council for Building) are: (i) reduce resource consumption, (ii) reuse resources, (iii) use recyclable resources, (iv) protect nature, (v) eliminate toxic products, (vi) analyse life cycle costing, and (vii) guaranteeing quality. These principles must be applied throughout the life cycle of a building, from the early stage of design to demolition/deconstruction (Kibert, 2005).

A “Green Building” can be defined as being a construction that seeks to minimize the environmental impacts and to improve the preservation of local, regional and global ecosystems throughout its lifetime. Additionally, "Green Building” optimizes its performance, maximizes the efficiency of the management of resources and minimizes the risks to human health and to the environment. There are several aspects to consider in a “Green Building” such as health issues, community impacts, life-cycle perspective and environmental sustainability (Zuo & Zhau, 2007).

There are several reasons why “Green Buildings” should be chosen instead of traditional buildings, such as sustainability, cost and life quality (Zuo & Zhao, 2007). The benefits related to sustainability are already well publicized and can be summarized in some aspects, such as the improvement of urban biodiversity and ecosystem protection, the results of the reuse and recycle of materials (Bianchini, 2012), energy efficiency, reduction in the use of water or in the emissions of carbon dioxide (Coelho, 2012).

2.2. Sustainability overview

This section discusses historical aspects and main events related to sustainability and sustainable construction for a better understanding on this subject, which supports the development of this research.

The Planet Earth has about five billion years, and throughout its history has undergone many transformations in different aspects. However, the last 12,000 years are associated with the progress of humanity and society and, throughout this progress and impelled by population growth, humans aimed to make possible for all people to enjoy the benefits of that same progress.

Mankind gradually abandoned the nomad lifestyle and started to organize itself in small civilizations that, impelled by the development, grew to be the basis of the cities. In the late XVIII and early XIX century, because of the industrial revolution, there was a sudden demographic explosion, followed by a growing concern about the inappropriate use of natural resources.

The discussions on environmental issues began with the foundation of the Club of Rome, in 1968. After four years, a small group of professionals in the field of construction associated with scientists made clear their intentions with the publication of the report "The limits to growth" (UNEP, 2000).

Environmental problems have become the object of worldwide discussion in 1972, the year in which the Stockholm Conference took place. As a result, regular evaluations on the effects of demographic explosion and economic growth began gradually being proposed, intending to find corrective measures for the negative environmental impacts that these had been causing. Subsequently, the obligation to improve and protect the environment for the benefit of current and future generations was established, as well as the compulsory recognition by the governments of their responsibility for environmental damages (Miana, 2010).
In 1992, in Rio de Janeiro (Brazil), a conference denominated "United Nations Conference on Environment and Development (UNCED)" has become a symbol of the responsibility of every country in the world towards sustainability. It called for urgent attention to the conservation of

all forms of life on Earth and promoted actions for better environmental quality, through the cooperation of all the countries involved in order to create a global environmental policy capable of allowing sustainable development (Von Weizsäcker, 1992).

As a consequence of this conference, in 1997 emerged the document called “Agenda 21”, which is a guide for the creation of national strategies and policies of development. It represents the action plan of the United Nations aiming the sustainable development in the 21st century (Pinto, 1999). This document was signed by several countries that participated in this Conference, and who compromised themselves to elaborate local, regional and national policies for the development, having as basis the recommendations contained in this document and adapting them to the local context in which they would be applied (Pinto, 1999). In the same year, the United Nations Framework Convention on Climate Change (UNFCCC2) led to the Kyoto Protocol, which intended to establish goals for the reduction of greenhouse gas emissions (Hildemberg, 2010).

The World Summit for Sustainable Development took place in Johannesburg in 2002 and pointed out the existence of flaws in the implementation of the global strategy for sustainable development. It also assumed the commitment towards social responsibility besides ensuring a fair distribution of costs and benefits resulting from the economic and social globalization in progress (Hens & Nath, 2003).

The environmental impact caused by the construction sector has increased these past few decades. The activities inherent to the construction industry are at the top of the list of the main responsible for pollution, producing around 40% of world’s total emission of Green House Gases (GHG) and 180 million tons of waste per year (OECD, 2003). It is also responsible for the consumption of 25-40% of the energy and 50% of the raw materials extracted from earth in the member countries of OECD (Organization for Economic Co-operation and Development) (Gervásio, 2010).

As a response to these problems, a few initiatives started to emerge and led to the first methodologies for the assessment of sustainability for constructions. Over the years, there was a progress and several BSA methodologies were created.

Since the rating system has profound impact on the results of the evaluation, there has been a special attention on the evaluation studies and on the strategies utilized to allocate the credits and questions assessed. These methodologies are adapted according to the region and the country in question (Lee, 2013) and aim to contribute to a reduction of the overall environmental impact.

Above were described some important facts and concepts related to the topic addressed in this work, in order to locate and facilitate the understanding of the subject of this thesis. Next, some aspects of the basic education in Portugal and Brazil will be reported, as well as the characteristics of the mentioned regions.

2.3. Characterization of Portuguese and Brazilian schools

In this subchapter, some fundamental characteristics of Portuguese school buildings are analysed. Some more information will also be provided about the context in which the research and the application of the methodology developed within this work are being conducted. Additionally, some fundamental characteristics of Brazilian school buildings are presented in order to set the basis for the future development of the Brazilian methodology for the sustainability assessment of schools in Brazil.

2.3.1 High schools built by Parque Escolar-Portugal

There are quite a few methodologies of sustainability assessment in Portugal, such as BREEAM and LEED. These tools has no certification system specific to Portuguese high school buildings. Other systems have been adapted and developed according to the requirements reality and need of Portugal, such as SBtool^{PT}, LiderA and Natura Domus. (Saraiva et al., 2019b). Therefore, there is a need to elaborate this methodology to meet this need. In this sub-chapter it is reported the history of school buildings in Portugal and are presented data about the number of students, typology and construction materials of school buildings.

In the government of Costa Cabral in 1844, primary education was mandated and, in 1852, with Fontes Pereira de Mello, was created the Technical Education, with the objective of assisting in the progress of Portugal through the specific formation for a profession. At that time, the first school buildings and the rules with which they had to comply with were established. These determined the technical conditions to which all the school buildings would have to observe in terms of construction, aeration, definition of spaces, health requirements, location and lighting conditions (Warwick, 2008).

In the nineteenth century, the first types of buildings were those of "Conde Ferreira", with one or two rooms suitable for 50 students. The second type of buildings was that of the architect Adães Bermudes, whose schools had independent entrances for boys and girls, with two rooms. In the years of the dictatorship, in the mid-twentieth century, the schools were constructed having construction processes, materials (granite, shale or brick) and climatic characteristics specific to each region. In addition, at the end of the 19th century, the first high schools were built in Portugal (Portal Parque Escolar, 2018).

With the creation of the Administrative Board of the Loan for Secondary Education (Junta Administrativa do Empréstimo para o Ensino Secundário, JAEES) in 1928, school buildings were characterized by strong robustness incorporating innovative technologies such as cast iron in columns, steel in beams and constructive systems of reinforced concrete. In 1938, technical schools and high schools were built with walls of stone masonry (Portal Parque Escolar, 2018).

In 1963, the Portuguese government signed a contract with the Organization for Economic Cooperation and Development (OECD) to optimize solutions in the field of school construction. In this period, prefabricated building materials with reinforced concrete porticated structure were used with slabs of the same material and walls filled with painted brick masonry panels (Alegre, 2009).

With the increase in school attendance after the revolution of 1974, there was a need to reformulate the Portuguese school system. In the democratic period that followed, a great effort was made to refurbish existing buildings and construct new ones, with the support of the State in accordance with the new conceptions of education (Neothemi, 2009).

Currently, Portugal has an area of 92,212 km² and a population of 10,320 million. It has 1,819 schools, with 616 high schools, and 1,629,116 students, from which 307,984 are high schools students (Pordata, 2018).

The age of the high school students varies, in average, between 15 and 18 years old (10th to 12th grade), being this equivalent to the third cycle of basic education. In this country, the classes in high schools usually start at 9 in the morning and end at 3:30 in the afternoon, with breaks in the middle of the morning and for lunch time. Some schools work by turns: in the morning from 8 am to 1 pm and in the afternoon from 1:15pm to 6:15pm. Each class has 25 hours of lessons per week.

This country incorporates a total of 477 schools whose construction began at the end of the XIX century. 23% of the schools were built until the end of the 1960s, and the remaining 77% correspond to the period of expansion of the school network. 46% of the schools were built in the 1980s, due to the increase of the compulsory schooling, from six to nine years (Pordata, 2018).

These schools form a heterogeneous group in terms of construction quality, in terms of conditions and in terms of the architectural and morphological type of buildings. Although the network of school buildings is mainly composed of solutions deriving from the utilization of standardized projects, there are buildings with a recognized asset value. There are also some projects with innovative solutions related to construction and space (Portal Parque Escolar, 2018).

On January 3rd, 2007, the Resolution of the Council of Ministers number 41/2007 approved the Program of Modernization (PMEES). This program proposed to increase the educational facilities in Portugal, that were underdeveloped when compared to the European criteria, and to offer a motivating and gratifying learning environment to students (Decreto Lei 41/2007). This Decree-Law deals with the management, development, planning and implementation of the modernization program of the public high schools. It has three main objectives (Decreto Lei 41/2007):

- Create an effective and efficient system of management of school buildings.
- Open the school to the community, redirecting the school towards urban environments;
- Improve buildings, promoting a culture of learning;

The PMEES intended to place education in Portugal in a position of global reference. The PMEES included interventions in 332 of the 447 high schools, corresponding to 74% of all high schools in Portugal. In 2007, *Empresa Parque Escolar* (EPE) was created for this objective, is carrying out the renovation and construction works of the Portuguese high schools (Publico.PT, 2018 and Saraiva et al., 2019b).

Francisco de Holanda High School (FHHS) was initially built to be an industrial school. In 1959, a major renovation took place with the creation of its main building with three floors. In 2011, there were other major renovations carried out by the *Parque Escolar* and the school still uses a great part of the resources and equipment installed by the company. The school represents the current standard of school construction in Portugal (Portal Parque Escolar, 2018) and it is a "Portuguese standard high school". The description of this school is made in chapter 7.

2.3.2. High Schools – Juiz de Fora, Minas Gerais, and Macapá, Amapá, Brazil

In Brazil, until the beginning of the republican period, the government's concern was for the formation of the ruling elites, concentrating efforts on the creation of higher schools. From 1889, the year of the Proclamation of the Republic, the government began the construction of the first buildings specifically targeted for education, however, the government continued to privilege the dominant classes. In the first two decades of the Republic, school buildings mainly adopted the eclectic style, using standard projects. In school buildings, these projects followed the same organization in the plan, with small variations or identical facades, set in different regions (Correa et al., 1991).

The architectural program included classrooms and a few administrative environments, arranged with the symmetry of the plant, containing large porches to facilitate independent entrances, separating girls and boys, and seeking to maximize the control of internal movement and access (Farias, 1998).

After 1930, the Brazilian public education has come to operate at the national level. As a result, school buildings stand out as important examples of the first phase of the modern movement, abandoning bi-lateral symmetry, including combinations of geometric solids of pure lines without ornamentation, and introducing the sunscreens as a shading solution.

The use of materials such as concrete, glass and iron demonstrates the advances of an industrial production, and marks the existence of a mass architecture, adequate to solve social problems, such as the construction of schools and housing. Modern architecture continued to be adopted in the construction of school buildings during the 40s / 50s. The 1970s are marked by the standardization of criteria for a school project methodology (Cavaliere, 1999).

The CIEPs (Centro Integrado de Educação Pública, Integrated Centre for Public Education) were created in Rio de Janeiro during the 80s and 90s. These are full-time public schools, with their own administrative and pedagogical conceptions, which aim to promote a quality leap in the fundamental state education. During this time, 506 CIEPs were built across the state (Cavaliere, 1999).

With a standardized architecture, derived from pre-fabrication processes, CIEPs present the image of modernity, offering the popular classes the opportunity of a higher quality school. The project adopts the module as marking and rhythm of the facade. The institutional image is clear, with its linear and grandiose appearance.

Nowadays, there is no specific federal program related to the architecture of schools, but rather a specific legislation for sizing, number of students and climate, among other factors. School buildings are made according to the specific needs of each region.

Brazil is a country with large dimensions, with a great cultural, economic and climatic diversity. Therefore, it would be necessary to have several specific sustainability assessments for each region. In this work, the city of Juiz de Fora and Macapá were the chosen cities to start the study on the SBTool methodology in Brazil. For this reason, in this sub-chapter are reported some characteristics related to these cities.

The city of Juiz de Fora is in the south-eastern region of Brazil, in the state of Minas Gerais, in the Zona da Mata of the state, and the area of the city is 1.437 km², with an estimated population, in 2014, of 550.710. It is located 255 km from the capital Belo Horizonte and 183 km from the city of Rio de Janeiro. The climate is tropical, warm and humid, with the average annual temperature of 20.6 ºC (IBGE, 2017). The schools of Juiz de Fora, as it happens throughout Brazil, are divided into federal, state and municipal schools.

The two schools evaluated in this research in Juiz de Fora, Minas Gerais, specifically the Colégio Santa Catarina (Santa Catarina School) and Colégio Cristo Redentor (Cristo Redentor School), are the best and most traditional private schools in the city, both have existed for over 100 years. The Colégio Santa Catarina was built in 1900 by the German Sisters, who dedicated themselves to the education of the children of the German Colony.

The Colégio Cristo Redentor (Academia de Comércio) was founded in March 1891 by farmers and industrialists, and it was the first institute of superior education of commerce in Brazil (JFminas, 2018). The description of these high schools can be found in chapter 8.

The city of Macapá is located in the state of Amapá, in the northern region of Brazil, the Amazon region, located on the equator line (Latitud 0°). The distance between Macapá and Belém (Capital of Pará) is 331 km, which can be traveled by boat, taking around 24 hours, or by plane, 1 hour. Access by land does not exist as the two cities are cut by the Amazon River. The state of Amapá is separated from the other states of Brazil by the Amazon River, which hinders the entry of all types of products, interfering with the development of the city (Silva, 2019, Saraiva et al., 2019d).

The estimated population, in 2018, is 493.634 and the area of the city is 6.564 km² (IBGE, 2018). The climate of the region is humid equatorial, divided into only 2 seasons: winter, occurring from December to May, with an average humidity of 80% and temperatures between 22 and 36 °C; and summer, the dry season, from June to November with an average humidity of 70% and temperatures between 26 and 40 °C (Santos, 2012).

The surveys on environmental comfort were conducted in two traditional schools in the city of Macapá (Amapá), namely the Tiradentes School and the Gabriel Almeida Café School, both of which were founded in the 1970s (Saraiva et al., 2019d).

The activity times in Brazilian high schools usually occur in three shifts: morning (7 am to 12 am), afternoon (1 pm to 6 pm) and night (7 pm to 11 pm). The minimum annual hours defined by the Law of Directives and Bases of National Education for the basic education is 800 hours per year, spread over a minimum of 200 days of school days. Through these data, it can be observed that a student stays in school around 5 hours a day.

After being briefly described the characteristics of the school buildings in Portugal and Brazil, the main sustainability assessment methodologies existing nowadays are presented, therefore, it is possible to get an idea of what exists in terms of methodologies for constructions, serving as the basis for the methodology that is being adapted in this work.

2.4. Sustainability Assessment Methodologies

This section regards to the sustainability assessment methodologies of buildings, in order to give an overview of the state of the art on this subject. These methodologies aim to provide guidance, through sustainability indicators, about the construction practices that can be more propitious to achieve sustainability in construction by monitoring the performance of a building, thus being highly important to disseminate the importance of employing these practices (Ding, 2008).

Many systems for the assessment of buildings in the field of sustainability can be found in literature, having been created as a way of helping to mitigate the consequences of the world energy crisis in the decade of 1970. Some attained greater international prominence, namely LEED (Leadership in Energy and Environmental Design), which was developed in the United States, BREEAM (Building Research Establishment Environmental Assessment Methodology) in the United Kingdom, HQE (Haute Qualité Environnementale) in France, and SBTool (Sustainable Building Tool, iiSBE), developed by a group of experts from twenty-two countries belonging to the iiSBE – international initiative for a Sustainable Built Environment (Marques, 2007).

According to Addis (2010), these methodologies have their own criteria for presenting the environmental information, aiming to provide reliable and standardized environmental information about construction materials and its components, to identify the environmental effects of these throughout their lifecycle and to reduce the problems related to the performance of these materials in buildings.

Methodologies for sustainability assessment are in constant evolution, struggling to surpass their limitations and achieve a better balance between different dimensions of sustainability. They must be transparent, practical and flexible enough to be easily adapted to the constant development of technology and to the different types of buildings. Many countries have already, or are in the process of developing, specific assessment methodologies adapted to each region (Mateus & Bragança, 2011). The most used methodologies are briefly presented bellow (Gu et al., 2006).

The most popular assessment methods are LEED (US) and BREEAM (UK), representing the continents to which they belong. The methodology SBTool (iiSBE) is the basis of the SAHSB^{PT} methodology proposed in this work. These three methodologies will be reported in the following paragraphs.

BREEAM was developed in the United Kingdom in 1990. This is the most antique BEA (Building Energy Analysis) method and is widely used in the construction sector in the United Kingdom. More than 2,000 buildings have been evaluated until 2012 (BREEAM, 2012). The newest version of BREEAM is BREEAM UK New Construction 2014.

This methodology evaluates the performance of the buildings, in aspects such as energy consumption, transport, pollution, soil and water use, raw materials, health and well-being. The countries affiliated to this program are: United Kingdom, Germany, Netherlands, Norway, Spain and Sweden (BREEAM, 2012).

It possesses distinctive and exclusive versions for each of the affiliate countries, which adapt the local conditions to their assessment and evaluate the buildings of each specific country, thus creating a distinctive subgroup of methodologies but keeping its international standard as a whole and wide group. Its latest version is the BREEAM New Construction 2014, which is employed as a reference model for similar systems developed in Norway, Singapore, Canada, Hong Kong and New Zealand (Lee, 2013).

There is also BREEAM International, which is a methodology created for the evaluation of buildings in non-affiliated countries that intend to be evaluated following the criteria of this methodology.
It is a methodology that examines three key areas: local aspects; indoor environmental aspects; and the use of resources. The criteria are evaluated and then separated, so that it can be performed the classification of the environmental performance index (EPI-Environmental

Performance Index), which defines the classes of performance in the construction sector (Silva, 2003).

The BREEAM has also elaborated some specific methodologies for specific sectors, namely: offices (BREEAM Offices), multi-occupancy residential buildings (BREEAM Eco Homes and Multi-Residential), prisons (BREEAM Prisons) industries (BREEAM Industrial) hospitals (BREEAM Healthcare), commerce (BREEAM Retail) Schools (BREEAM Education) residential renovation (BREEAM Domestic Refurbishment), Neighbourhood (BREEAM Communities) (BREEAM, 2012).

This system seeks to sensitize and increase the knowledge of the professionals of the construction industry in issues related to environmental problems; to act as an alert to the constructers, making them aware that they generate a large environmental impact and trying to make them reduce that impact; to encourage the creation of friendly buildings combined with the concern for the health of the residents and indoor environmental quality (BREEAM, 2012).

BREEAM provides an assessment made by external audit, performed by qualified evaluators trained by BRE (Building Research Establishment), who set down the evaluation methodology and its specific objectives. The purpose is to encourage environmental practices, starting from the moment of design and going through the phases of implementation and maintenance, in order to reduce the environmental impact of buildings, to elaborate new criteria and standards related to environmental protection and to alert the designers, owners, operators and users about the benefits of constructions with less environmental impacts (Silva, 2003).

LEED (Leadership in Energy and Environmental Design) was developed in the United States of America between 1994 and 1998, and was displayed by the Green Building Council (USGBC). It is the BEA method widely used in this country, besides being used in more than 135 countries; it is a relatively simple rating system (Gu et al., 2006). Its latest version is the LEED V4 Guide 2013 (LEED V4, 2013).

It covers many types of constructions, such as residential buildings, government buildings, office buildings, recreational facilities, laboratories and factories (Lee, 2013), being named, for each specific case, as LEED New Construction, LEED Existing Building, LEED for

Commercial Interior, LEED Core & Shell, LEED for Schools, LEED for Neighbourhood Development and LEED Healthcare (USGBC, 2018).

LEED, according to Addis (2010), has a system of evaluation and classification based on several prerequisites and credits. Some of these credits deal with questions about the reduction of residues and the waste through the recycling and reuse of materials and building components. Some examples of these credits are: reuse of the building, construction waste management, reuse of materials, recycled content, use of local materials and renewable materials.

The simplest method available and affordable to be used as a tool for project development is LEED (Silva, 2003). It has a simple structure and has been developed according to performance specifications and not prescriptive criteria, having as reference the optimized energy consumption and environmental principles consolidated in recognized recommendations and standards. Based on the number of points achieved, a project can earn four different LEED rating levels, such as Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), Platinum (80+ points) (USGBC, 2018).

The research led by UNICAMP (University of Campinas, Brazil) in coordination with the National Programme of Evaluation of Environmental Impacts of Buildings (BRAiE) resulted in the employment of this system in the state of São Paulo, with the intention of being adapted and implemented for validation in other regions of Brazil (Scott et al., 2000).

SBTool (Sustainable Building Tool), former GBTool, was developed in 1998 by a group of technicians from twenty-two countries of iiSBE (International Initiative for Sustainable Built Environment). A feature that differentiates SBTool from other BSA systems is that this method is designed to be adapted to different technologies, priorities, building construction traditions and the cultural values of each region and country (iiSBE, 2005).

According to Addis (2010), the SBTool was developed to be used as an international tool, having as its main aim the environmental and energy assessment of construction projects. This system pursues to provide a more scientific methodological basis, taking into consideration some priorities such as the regional traditions in the construction sector of different countries and the local cultural values and technologies. This system differentiates itself by being part of a new generation of evaluation systems (Silva, 2003).

The methodologies described above are grouped into categories and dimension indicators. Categories are the aggregation of the levels of performance obtained in the indicators, expressing the final classification of the behaviour of the building at the level of this category. Dimensions are the aggregation of the levels of performance obtained in the categories of a dimension, expressing the final classification of the behaviour of the building at the level of that dimension. The global sustainability level of a building is the aggregation of the levels of performance obtained in the dimension expressing the final classification of the overall behaviour of the building at the level of the evaluation of the sustainability.

The BREEAM evaluation system in coordination with LEED and SBTool provide a starting point for the elaboration of other methodologies for environmental certification of buildings. The indicators used in SBTool possess different weights according to the weighting coefficients defined at national level in conjunction with the local relevance of each indicator. BREEAM and LEED, on the other hand, are based on credits, and the maximum number of credits for each indicator is related to their weight in the general credit system.

Among the other evaluation systems, there are a few worthy of being mentioned due to their relevance and expression worldwide.

- AQUA (*Alta Qualidade Ambiental High Environmental Quality*) was developed in Brazil in 2008. This methodology is an adaptation to the Brazilian reality of the French system HQE. It has the participation of ABNT (*Associação Brasileira de Normas* Técnicas – Brazilian Association for Technical Standards) and the support of teachers from the Department of Engineering of the University of São Paulo. This system was developed by the Carlos Alberto Vanzolini Foundation, in partnership with the Escola Politécnica of USP (Polytechnic School of São Paulo), and released in 2007 (Fundação Vanzolini, 2007).

The main objective of AQUA is to reduce environmental impacts through the employment of a conscious management of projects, relying and focusing on two important points, which are the seeking for a satisfactory indoor environment (Comfort and Health) and the control of the outdoor environmental impacts (Eco construction and Eco management) (Zambrano, 2004).

The criteria for the evaluation of the buildings are: guarantee of the indoor air quality in order to improve the comfort and health of the occupants; combination of the physical design with the environment; management of the energy consumption of the project in accordance with the environmental costs; preservation of natural resources through the optimization of their utilization; control of the environmental impact on the surroundings of the building and permission of an integrated choice of the techniques to be adopted in the building (Zambrano, 2004).

The AQUA system has also adopted the four major categories for the evaluation of sustainable buildings developed by other methodologies, which are Health, Eco Management, Eco Construction and Comfort.

The reference for the assessment of these categories is based on the Enterprise Management System, which evaluates the environmental management system established by the responsible for the enterprise and determines the EQE (*Environmental Quality of the Enterprise*). It verifies the technical and architectonical performance of the construction through quantitative elements, which use measuring processes, evaluation methods and calculations, and qualitative elements, through descriptions and the analysis of the adopted measures (ASSOHQE, 2013).

- HQE (*Haute Qualité Environnementale* - High Environmental Quality) was developed in France in 1996. It applies to all phases of the project and can evaluate in-use buildings. It integrates sustainable development, environmental evaluation and social and economic aspects (Zambrano, 2004). It verifies the technical and architectonical performance of construction through quantitative measurement elements, evaluation methods and calculations, and qualitative elements, through descriptions and analysis of the adopted measures (ASSOHQE, 2013).

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) was developed in Japan, in 2001, by committees belonging to industrial, academic and governmental sectors. It contains a variety of assessment tools applicable for different stages of the building (planning, design, conclusion, operation and renewal). It is the most complex BSA system, able to control all the situations but, at the same time, it is extremely hard to apply (Murakami et al., 2002). CASBEE covers almost all types of construction and, therefore, is widely used in Japan. The latest version of CASBEE for new building dates from 2015 (CASBEE, 2015).

- Green Star was created by the Green Building Council (GBC) in Australia in 2003. It is a national voluntary rating system that evaluates the environmental performance of the buildings. This system was developed for different construction types and phases, covering the market segment of commercial offices and existing buildings (Gu et al., 2006).

- NABER (National Australian Built Environment Rating System) was developed in 1996 in cooperation with the industry sector and the Department of Environment and Estate of Australian Government (NABERS, 2005). It is the first system of comprehensive classification of Australian environmental performance.

- Ecoprofile was developed in Norway in 1996. It is based on two previous methods, Ecoprofile for Building and Effective Resource of Commercial Buildings (ERCB). The Ecoprofile for Building is divided into three main components: external environment, resources, and internal climate (Pettersen, 2000).

- The PromisE was developed in Finland aiming to assess and classify the environmental performance of existing buildings. It is divided into four categories: use of natural resources, human health, environmental risks management and ecological consequences. The system is designed to meet different demands, such as apartment buildings, offices and other buildings. This system is used as a guideline for setting environmental targets in projects, also taking into consideration the social development at the community level (VTT PromisE, 2013).

- DGNB (*Deutsche Gesellschaft für Nachhaltiges Bauen* - German Society for Sustainable Construction) was developed in Germany in 2009, considering that different regions require different solutions, namely in environmental, social, cultural, technical, legal, political and economic aspects. This system is flexible and adapted to different regions and types of buildings, meeting the market demands. DGNB provides information regarding regions, economic situation, norms and standards for different types of construction (DGNB, 2011).

- BCA (Green Mark Scheme – Building and Construction Authority) was developed in 2005 by the Singaporean Government in order to boost sustainability in urban areas. It evaluates five areas: reuse of water, energy efficiency, development of projects and management of new buildings, environmental innovations and indoor environmental quality (Building and Construction Authority, 2005).

Several sustainability assessment methodologies, as shown in Figure 2.1 and described in the previous paragraphs, were created in order to make possible to assess the performance of the buildings. The creation of these methodologies was followed by an inherent necessity of assessing their indicators, thus leading to the creation of systems that can standardize those indicators.

Systems such as LenSe (LenSe, 2008), OPENHOUSE (OPENHOUSE, 2011) and SUPERBUILDING (SUPERBUILDING, 2012) were created in an attempt to organize, compare and assist in the choice of the methodology that better suits each case.

Figure 2.1. Several Sustainability Assessment Methodologies in the world (Berardi, 2015)

As shown in Figure 2.1., there are different methodologies for assessing the sustainability of buildings used in many countries. In the following sub-chapter, some specific methodologies for school buildings will be fully described and compared in this document, in order to assist in the accretion of categories and indicators to be used in the methodology that is being adapted in this work.

2.5. Building sustainability assessment methodologies adapted to school buildings

After the previous description of the most common sustainability assessment tools for buildings, some methodologies for sustainability assessment exclusively applied to the construction of schools will now be mentioned, with the main objective of selecting the most appropriate aspects for the methodology developed in the framework of this work.

2.5.1. LEED BD+C Schools

Currently, the LEED methodology for sustainable buildings is the most used methodology worldwide. In this methodology, certification is given through the overall performance of the building, which is the sum of the scores of all dimensions. Therefore, the building can achieve a good overall performance, even if one of the categories does not reach the expected results.

LEED V4 is the new improvement of the U.S. Green Building Council's LEED rating system. LEED V4 includes a technical update to the rating system requirements and an improvement of the reference guide, credit documentation and certification. This methodology addresses twenty-one different adaptations of the market sector (LEED V4, 2013).

The LEED method evaluates a building through the analysis of seven prerequisites and credits. In what to the prerequisites and credits for LEED certification is concerned, these are the following (LEED V4, 2013):

- enhance environmental justice, social equity and community life quality;
- enhance individual human health and well-being;
- protect and restore water resources;
- protect, enhance and restore biodiversity and ecosystem services;
- build a greener economy;
- reverse the contribution to the global climate change and promote cycles of sustainable and regenerative material resources.

LEED for Building Design and Construction (LEED BD+C) includes projects of new construction or major building renovations. At least 60% of the gross floor area of the projects must be completed by the time of certification (except for LEED BD+C: Core and Shell). In LEED BD+C: Schools, buildings must be made up of core and ancillary learning spaces on K-12 (from kindergarten to 12th grade) school grounds.

As previously mentioned, the SAHSB^{PT} methodology developed in this work is based on the SBTool^{PT}H methodology, and more specifically on SBTool^{PT} STP for Office Buildings methodology. In this sense, it is important to investigate which indicators from this methodology are similar to the ones used in other methodologies especially developed for school buildings in order to make a comparative analysis and to identify the most suitable indicators to include in the SAHSB^{PT} methodology.

Table 2.1 shows all categories and indicators of LEED BD+C for Schools and the corresponding indicators from SBTool^{PT} STP for Office Buildings. LEED BD+C for Schools has 42 indicators and only 14 are not included in SBTool^{PT} STP for Office Buildings, thus demonstrating that there are many similarities between these methodologies.

Table 2.1. List of indicators used by LEED BD+C for Schools and SBTool^{PT} STP for Office Buildings

Location and transportation	LEED BD+C Schools	SBTool^{PT}STP Office Buildings
	Credit 1 LEED for Neighbourhood Development Location	No
	Credit 2 Sensitive Land Protection	I4 Sustainable location
	Credit 3 High Priority Site	No
	Credit 4 Surrounding Density and Diverse Uses	No
	Credit 5 Access to Quality Transit	I25 Accessibility to public transport
	Credit 6 Bicycle Facilities	I22 Mobility plan
	Credit 7 Reduced Parking Footprint	No
	Credit 8 Green Vehicles	No
Sustainable Sites	Prerequisite 1 Construction Activity Pollution Prevention	No
	Prerequisite 2 Environmental Site Assessment	No
	Credit 1 Site Assessment	I5 Local biodiversity protection, construction
	Credit 2 Site Development - Protect or Restore Habitat	I5 Local biodiversity protection, c
	Credit 3 Open Space	No
	Credit 4 Rainwater Management	I17 Storm water management
	Credit 5 Heat Island Reduction	I2 Heat Island Effect
	Credit 6 Light Pollution Reduction	No
	Credit 7 Site Master Plan (Schools)	No
	Credit 8 Joint Use of facilities	No
Water Efficiency	Prerequisite 1 Outdoor Water Use Reduction	I15 Water consumption
	Prerequisite 2 Indoor Water Use Reduction	I15 Water consumption

Table 2.1. List of indicators used by LEED BD+C for Schools and SBTool^{PT} STP for Office Buildings (continuation)

Water Efficiency	Prerequisite 3 Building-Level Water Metering	I13 Environmental management plan
	Credit 1 Outdoor Water Use Reduction	I15 Water consumption
	Credit 3 Indoor Water Use Reduction	I15 Water consumption
	Credit 4 Cooling Tower Water Use	No
	Credit 5 Credit Water Metering	I13 Environmental management plan
Indoor Environmental Quality	Prerequisite 1 Minimum Indoor Air Quality Performance	I18 Indoor air quality
	Prerequisite 2 Environmental Tobacco Smoke (ETS) Control	No
	Prerequisite 3 Minimum Acoustical Performance	I21 Acoustic Comfort
	Credit 1 Enhanced Indoor Air Quality Strategies	I18 Indoor air quality
	Credit 2 Low-Emitting Materials	I18 Indoor air quality
	Credit 3 Construction Indoor Air Quality Management Plan	No
	Credit 4 Indoor Air Quality Assessment	I18 Indoor air quality
	Credit 5 Thermal Comfort	I19 Thermal Comfort
	Credit 6 Interior Lighting	I20 Visual Comfort
	Credit 7 Daylight	I20 Visual Comfort
	Credit 8 Quality Views	No
	Credit 9 Acoustical Performance	I21 Acoustic Comfort
Energy and Atmosphere	Prerequisite 1 Fundamental Commissioning and Verification	I9 Commissioning
	Prerequisite 2 Minimum Energy Performance	I7 Energy consumption
	Prerequisite 3 Building-Level Energy Metering	I13 Environmental management plan
	Prerequisite 4 Fundamental Refrigerant Management	I13 Environmental management plan
	Credit 1 Enhanced Commissioning	I13 Environmental management plan
	Credit 2 Optimize Energy Performance 1	I7 Energy consumption
	Credit 3 Advanced Energy Metering	I13 Environmental management plan
	Credit 4 Demand Response	I7 Energy consumption I13 Environmental management plan
	Credit 5 Renewable Energy Production	I8 Renewable Energy
	Credit 6 Enhanced Refrigerant Management	I13 Environmental management plan
	Credit 7 Green Power and Carbon Offsets	I13 Environmental management plan
Materials and Resources	Prerequisite 1 Storage and Collection of Recyclables	I11 Materials with recycled content
	Prerequisite 2 Construction and Demolition Waste Management Planning	I13 Environmental management plan
	Credit 1 Building Life Cycle Impact Reduction	I4 Sustainable location I10 Reuse of materials
	Credit 2 Building Product Disclosure and Optimization— Environmental Product Declarations	I1 Life cycle environmental impacts
	Credit 3 Building product disclosure and optimization – sourcing of raw materials	I6 Certificated wooded materials I10 Reuse of materials I11 Materials with recycled content
	Credit: 4 Building product disclosure and optimization – material ingredients	I1 Life cycle environmental impacts I13 Environmental management plan
	Credit 5 Construction and Demolition Waste Management	I10 Reuse of materials I11 Materials with recycled content I12 Construction and demolition wastes

Chapter 4 of this document addresses the choice of the indicators that are included in the SAHSB^{PT} methodology. One of the methods that helped in the choice of indicators was the application of a form with key questions to experts on sustainability issues, as explained in Chapter 3. Table 2.1 assisted in the preparation of this form, where the indicators of LEED BD+C for Schools that do not belong to SBTool^{PT} STP for Office Buildings are attached.

2.5.2. BREEAM Education 2008

The methodology BREEAM Education was designed specifically for the assessment of the following educational establishments: schools (elementary, middle school and academies), colleges (further and higher education/vocational colleges), pre-school (nursery schools and children's centres), institutions such as the learning resource centres, student union, teaching facilities, laboratory/workshop/studio, student residential accommodations (Multi-Residential) or a mixture of these types (BREEAM Education, 2008).

BREEAM Education assesses school buildings and includes a diverse range of sustainable issues, related to the impacts of buildings on the environment, social and economic aspects at global, regional, local and indoor levels. For each topic there are "credits" available when specific levels of performance are achieved (BREEAM Education, 2008).

All indicators and categories of BREEAM Education and the corresponding indicators from SBTool^{PT} STP for Office Buildings are presented in Table 2.2. BREEAM Education has 83 indicators and 33 are not included in SBTool^{PT} STP for Office Buildings, thus demonstrating that there are reasonable similarities between the methodologies.

Table 2.2. List of indicators used by BREEAM Education and SBTool^{PT} STP for Office Buildings

		Issue Title BREEAM Education	SBTool^{PT} STP for Office Buildings
Management	Man 1	Commissioning	I9 Commissioning
	Man 2	Considerate Constructors	No
	Man 3	Construction Site Impacts	I5 Local biodiversity protection during construction
	Man 4	Building User Guide	I13 Environmental management plan
	Man 5	Site Investigation	I5 Local biodiversity protection during construction
	Man 6	Consultation	I13 Environmental management plan
	Man 7	Shared facilities	No
	Man 8	Security	I23 Occupants security
	Man 9	Publication of building information	No
	Man 10	Development as a learning resource	No
	Man 11	Ease of maintenance	I13 Environmental management plan
	Man 12	Life cycle costing	I24 Life cycle costs
Health and Wellbeing	Hea 1	Daylighting	I20 Visual Comfort
	Hea 2	View Out	No
	Hea 3	Glare Control	No
	Hea 4	High frequency lighting	No
	Hea 5	Internal and external lighting levels	I20 Visual Comfort
	Hea 6	Lighting zones and controls	No
	Hea 7	Potential for Natural Ventilation	I18 Indoor air quality
	Hea 8	Indoor Air Quality	I18 Indoor air quality
	Hea 9	Volatile Organic Compounds	I18 Indoor air quality
	Hea 10	Thermal Comfort	I19 Thermal Comfort
	Hea 11	Thermal Zoning	No
	Hea 12	Microbial Contamination	I18 Indoor air quality
	Hea 13	Acoustic Performance	I21 Acoustic Comfort
	Hea 16	Drinking Water	No
	Hea 17	Specification of Laboratory Fume Cupboards	No
Energy	Ene 1	Reduction of CO_2 Emissions	I7 Energy consumption
	Ene 2	Sub-metering of Substantial Energy Uses	I13 Environmental management plan
	Ene 3	Sub-metering of High Energy Load and Tenancy Areas	I13 Environmental management plan
	Ene 4	External Lighting	I7 Energy consumption
	Ene 5	Low or Zero Carbon Technologies	I8 Renewable Energy
	Ene 6	Building fabric performance and avoidance of air infiltration	I7 Energy consumption 19 Thermal Comfort
	Ene 7	Cold Storage	I7 Energy consumption
	Ene 8	Lifts	I7 Energy consumption
	Ene 10	Free Cooling	I7 Energy consumption I19 Thermal Comfort
	Ene 11	Energy Efficient Fume Cupboards	No
	Ene 12	Swimming pool ventilation and heat loss	I7 Energy consumption
	Ene 19	Energy Efficient Laboratories	No
	Ene 20	Energy Efficient IT Solutions	No
Transport	Tra 1	Provision of Public Transport	I25 Accessibility to public transport
	Tra 2	Proximity to amenities	No
	Tra 3	Cyclist Facilities	I22 Mobility plan
	Tra 4	Pedestrian and Cyclist Safety	I22 Mobility plan
	Tra 5	Travel Plan	No
	Tra 6	Maximum Car Parking Capacity	No
	Tra 7	Travel Information Point	No
	Tra 8	Deliveries and Manoeuvring	No
Water	Wat 1	Water Consumption	I15 Water consumption
	Wat 2	Water Meter	I13 Environmental management plan

Table 2.2. List of indicators used by BREEAM Education and SBTool^{PT} STP for Office Buildings (continuation)

Water	Wat 3	Major Leak Detection	I15 Water consumption
	Wat 4	Sanitary Supply Shut Off	I15 Water consumption
	Wat 5	Water Recycling	I16 Water treatment and Recycling
	Wat 6	Irrigation Systems	I15 Water consumption
Materials	Mat 1	Materials Specification (Major Building Elements)	I13 Environmental management plan
	Mat 2	Hard Landscaping and Boundary Protection	I13 Environmental management plan
	Mat 3	Re-Use of Façade	I10 Reuse of materials
	Mat 4	Re-Use of Structure	I10 Reuse of materials
	Mat 5	Responsible Sourcing of Materials	I1 Life cycle environmental impacts I6 Water treatment and Recycling
	Mat 6	Insulation	I19 Thermal Comfort
	Mat 8	Designing for Robustness	No
Waste	Wst 1	Construction Site Waste Management	I12 Construction and demolition wastes I13 Environmental management plan
	Wst 2	Recycled Aggregates	I11 Materials with recycled content
	Wst 3	Recyclable Waste Storage	I11 Materials with recycled content I13 Environmental management plan
	Wst 4	Compactor / Baler	I13 Environmental management plan
	Wst 5	Composting	I13 Environmental management plan
Land use and Ecology	LE 1	Reuse of Land	I4 Sustainable location
	LE 2	Contaminated Land	I4 Sustainable location
	LE 3	Ecological Value of Site and Protection of Ecological Features	I4 Sustainable location I5 Local biodiversity protection during construction
	LE 4	Mitigating Ecological Impact	I5 Local biodiversity protection during construction
	LE 5	Enhancing Site Ecology	No
	LE 6	Long Term Impact on Biodiversity	No
	LE 7	Consultation with Students and Staff	No
	LE 8	Local Wildlife Partnership	No
Pollution	Pol 1	Refrigerant GWP – Building Services	No
	Pol 2	Preventing Refrigerant Leaks	No
	Pol 3	Refrigerant GWP – Cold Storage	No
	Pol 4	NOx emissions from heating source	No
	Pol 5	Flood Risk	No
	Pol 6	Minimising Watercourse Pollution	No
	Pol 7	Reduction of Night Time Light Pollution	No
	Pol 8	Noise Attenuation	No
Innovation	Inn 1	Innovation	No

As mentioned in the previous section, chapter 4 of this document addresses the choice of indicators that are included in the SAHSB^{PT} methodology, and one of the methods that helped in the choice of indicators was the application of a form with key questions to experts on sustainability issues. Therefore, Table 2.2. assisted in the preparation of this form, where BREEAM indicators that do not belong to SBTool^{PT} STP for Office Buildings are attached.

BREEAM was the first tool related to the analysis and certification of sustainability in buildings, and is widely used. However, there are some obstacles related to its design. This tool cannot be applied at the construction stage and is only applicable to the building and its site, without considering the whole area influenced by the building under analysis.

There is little concern related to the evaluation of user comfort and the weights concerning the thermal performance, as it only considers the environmental dimensions (Ferreira et al., 2014). The economic dimension is not considered, removing the purpose of building sustainability, which should be a balance between economic, environmental and social aspects.

The methodology elaborated in this work, SAHSB^{PT}, intends to put the economic aspects in balance with the social and environmental aspects, as well as to emphasize the comfort aspects, aiming to balance the indicators in order to meet the requests of the users of high schools in Portugal. The economic, environmental and social impacts that construction can exert on a global basis were also considered.

2.5.3. SBTool for K-12 Schools

The SBTool has influenced the development of many national systems and is currently being used in Portugal, Spain, Japan, Korea and Austria, among others. This method is generic and must be adapted to local constraints before being used (iiSBE, 2012).

All indicators and categories of SBTool for K-12 Schools and the corresponding indicators from SBTool^{PT} STP for Office Buildings are shown in Table 2.3. SBTool for K-12 Schools has 107 indicators and 39 are not included in SBTool^{PT} STP for Office Buildings, therefore demonstrating that there are reasonable similarities to this methodology.

Table 2.3. List of indicators used by SBTool for K-12 schools and SBTool^{PT} STP for Office Buildings

		SBTOOL FOR K 12 SCHOOLS	SBTool^{PT}-STP for Office Buildings
A Site Regeneration and Development, Urban Design and Infrastructure	A1 Site Regeneration and Development	A1.1 Use of land with previously high ecological sensitivity or value	I5 Local biodiversity protection during construction
		A1.2 Use of land with previously high agricultural value	I4 Sustainable location
		A1.4 Use of previously contaminated land for development	I4 Sustainable location
		A1.5 Remediation of contaminated soil, groundwater or surface water	No
		A1.6 Shading of building(s) by deciduous trees.	No
		A1.7 Use of vegetation to provide ambient outdoor cooling	No
		A1.8 Reducing irrigation requirements through the use of native plantings	No
		A1.9 Provision of public open space(s)	No
		A1.10 Provision and quality of children's play area(s)	No
		A1.12 Provision and quality of bicycle pathways and parking	I22 Mobility plan
		A1.13 Provision and quality of walkways for pedestrian use	I22 Mobility plan
	A2. Urban Design	A2.1. Development Density of Project	I3 Land use efficiency
		A2.2 Reducing need for commuting transport through provision of mixed uses	No
		A2.3 Impact of orientation on the passive solar potential of building(s)	I20 Visual Comfort
		A2.5 Impact of site and building orientation on natural ventilation of building(s) during warm season	I18 Indoor air quality
		A2.6 Impact of site and building orientation on natural ventilation of building(s) during cold season(s)	I18 Indoor air quality
	A3. Project Infrastructure and Service	A3.6 Provision of solid waste collection and sorting services	I12 Construction and demolition wastes
		A3.8 Provision of split grey / potable water services	I16 Water treatment and Recycling
		A3.9 Provision of surface water management system	I17 Storm water management
		A3.10 On-site treatment of rainwater, storm water and grey water	I17 Storm water management
		A3.11 On-site treatment of liquid sanitary waste	I16 Water treatment and Recycling
		A3.13 Provision of on-site parking facilities for private vehicles	No
		A3.14 Connectivity of roadways	No
		A3.15 Provision of access roads and facilities for freight or delivery	No
		A3.16 Provision and quality of exterior lighting	I23
B. Energy and Resource Consumption	B1 Total Life Cycle No-Renew Energy	B1.1 Embodied non-renewable energy in original construction materials	I1 Life cycle environmental impacts
		B1.3 Consumption of non-renewable energy for all building operations	I7 Energy consumption
	B2 Electrical peak	B2.1 Electrical peak demand for building operations	No
	B3 Use of Materials	B3.1 Degree of re-use of suitable existing structure(s) where available	I10 Reuse of materials
		B3.3 Material efficiency of structural and building envelope components	No
		B3.4 Use of virgin non-renewable materials	No
		B3.5 Use of finishing materials	No

Table 2.3. List of indicators used by SBTool for K-12 schools and SBTool^{PT} STP for Office Buildings (continuation)

	B4 Use of potable water/storm water/grey water	B4.3 Use of water for occupant needs during operations	I13 Environmental management plan
		B4.4 Use of water for irrigation purposes	I15 Water consumption
		B4.5 Use of water for building systems	I15 Water consumption
C Environmental Loadings	C1 Greenhouse Gas Emissions	C1.1 GHG emissions from energy embodied in original construction materials	I1 Life cycle environmental impacts
		C1.2 GHG emissions from energy embodied in construction materials used for maintenance/replacement	I1 Life cycle environmental impacts
		C1.3 GHG emissions from primary energy used for all purposes in facility operations	I1 Life cycle environmental impacts
		C1.4 GHG emissions from primary energy used for project-related transport	I1 Life cycle environmental impacts
	C2 Other Atmospheric Emissions	C2.1 Emissions of ozone-depleting substances during facility operations	No
		C2.2 Emissions of acidifying emissions during facility operations	I1 Life cycle environmental impacts
		C2.3 Emissions leading to photo-oxidants during facility operations	I1 Life cycle environmental impacts
	C3 Solid and Liquid Wastes	C3.2 Solid non-hazardous waste from facility operations sent off the site	I12 Construction and demolition wastes
		C3.5 Liquid effluents from building operations that are sent off the site	I5 Local biodiversity protection construction
	C4 Impacts on Project Site	C4.3 Recharge of groundwater	I5 Local biodiversity protection construction
		C4.4 Changes in biodiversity on the site	No
		C4.5 Adverse wind conditions at grade around tall buildings	No
	C5 Other Local and Regional Impacts	C5.1 Impact on access to daylight or solar energy potential of adjacent property	No
		C5.3 Impact of building user population on peak load capacity of public transport system	No
		C5.4 Impact of private vehicles used by building population on peak load capacity of local road system	No
		C5.5 Potential for project operations to contaminate nearby bodies of water	No
		C5.6 Cumulative (annual) thermal changes to lake water or sub-surface aquifers	No
		C5.7 Contribution to heat Island effect from roofing, landscaping and paved areas	I2 Heat island effects
		C5.8 Degree of atmospheric light pollution caused by project exterior lighting system	No
D Indoor Environmental Quality	D1 Indoor Air Quality and Ventilation	D1.1 Pollutant migration between occupancies	I18 Indoor air quality
		D1.3 Mould concentration in indoor air	No
		D1.4 Volatile organic compounds concentration in indoor air	I18 Indoor air quality
		D1.5 CO_2 concentrations in indoor air	I18 Indoor air quality
		D1.6 Effectiveness of ventilation in naturally ventilated occupancies during Summer	I18 Indoor air quality
		D1.7 Effectiveness of ventilation in naturally ventilated occupancies during Spring/Fall	I18 Indoor air quality
		D1.8 Effectiveness of ventilation in naturally ventilated occupancies during Winter	I18 Indoor air quality
		D1.9 Air movement in mechanically ventilated occupancies	I18 Indoor air quality
		D1.10 Effectiveness of ventilation in mechanically ventilated occupancies	I18 Indoor air quality
	D2 Air Temp. Relative. Humidity	D2.1 Appropriate air temperature and relative humidity in mechanically cooled occupancies	I19 Thermal Comfort
		D2.2 Appropriate air temperature in naturally ventilated occupancies	I19 Thermal Comfort

Table 2.3. List of indicators used by SBTool for K-12 schools and SBTool^{PT} STP for Office Buildings (continuation)

<table>
<tr><td rowspan="7"></td><td rowspan="3">D3 Daylighting and Illumination</td><td>D3.1 Appropriate daylighting in primary occupancy areas</td><td>I20 Visual Comfort</td></tr>
<tr><td>D3.2 Control of glare from day lighting.</td><td>No</td></tr>
<tr><td>D3.3 Appropriate illumination levels and quality of lighting</td><td>I20 Visual Comfort</td></tr>
<tr><td rowspan="4">D4 Noise and Acoustics</td><td>D4.1 Noise attenuation through the exterior envelope</td><td>I21 Acoustic Comfort</td></tr>
<tr><td>D4.2 Transmission of facility equipment noise to primary occupancies</td><td>I21 Acoustic Comfort</td></tr>
<tr><td>D4.3 Noise attenuation between primary occupancy areas</td><td>I21 Acoustic Comfort</td></tr>
<tr><td>D4.4 Appropriate acoustic performance within primary occupancy areas</td><td>I21 Acoustic Comfort</td></tr>
<tr><td rowspan="20">E
Service Quality</td><td rowspan="3">E1 Safety and Security</td><td>E1.8 Occupant egress from tall buildings under emergency conditions</td><td>I23 Occupants security</td></tr>
<tr><td>E1.9 Maintenance of core building functions during power outages</td><td>I23 Occupants security</td></tr>
<tr><td>E1.10 Personal security for building users during normal operations.</td><td>I23 Occupants security</td></tr>
<tr><td rowspan="4">E2 Functionality and efficiency</td><td>E2.5 Provision of exterior access and unloading facilities for freight or delivery</td><td>No</td></tr>
<tr><td>E2.6 Efficiency of vertical transportation system.</td><td>No</td></tr>
<tr><td>E2.7 Spatial efficiency</td><td>I3 Land use efficiency</td></tr>
<tr><td>E2.8 Volumetric efficiency</td><td>No</td></tr>
<tr><td rowspan="4">E3 Controllability</td><td>E3.1 Effectiveness of facility management control system.</td><td>I13 Environmental management plan</td></tr>
<tr><td>E3.2 Capability for partial operation of facility technical systems</td><td>I9 Commissioning
I13 Environmental management plan</td></tr>
<tr><td>E3.3 Degree of local control of lighting systems.</td><td>No</td></tr>
<tr><td>E3.4 Degree of personal control of technical systems by occupants</td><td>I13 Environmental management plan</td></tr>
<tr><td rowspan="5">E4 Flexibility and Adaptability</td><td>E4.1 Ability for building operator or tenant to modify facility technical systems</td><td>I14 Flexibility and adaptability</td></tr>
<tr><td>E4.2 Potential for horizontal or vertical extension of structure</td><td>I14 Flexibility and adaptability</td></tr>
<tr><td>E4.3 Adaptability constraints imposed by structure or floor-to-floor heights</td><td>I14 Flexibility and adaptability</td></tr>
<tr><td>E4.4 Adaptability constraints imposed by building envelope and technical systems</td><td>I14 Flexibility and adaptability</td></tr>
<tr><td>E4.5 Adaptability to future changes in type of energy supply.</td><td>I14 Flexibility and adaptability</td></tr>
<tr><td rowspan="4">E5 Optimization and Maintenance of Operating Performance</td><td>E5.1 Operating functionality and efficiency of key facility systems</td><td>I9 Commissioning</td></tr>
<tr><td>E5.2 Adequacy of the building envelope for maintenance of long-term performance.</td><td>I9 Commissioning</td></tr>
<tr><td>E5.3 Durability of key materials</td><td>No</td></tr>
<tr><td>E5.6 Retention of as-built documentation</td><td>No</td></tr>
<tr><td rowspan="8">F
Social, Cultural and Perceptual Aspects</td><td rowspan="4">F1 Social Aspects</td><td>F1.1 Access for mobility-impaired persons on site and within the building</td><td>I22 Mobility plan</td></tr>
<tr><td>F1.2 Access to direct sunlight from living areas of dwelling units</td><td>I20 Visual Comfort</td></tr>
<tr><td>F1.3 Visual privacy in principal areas of dwelling units</td><td>No</td></tr>
<tr><td>F1.4 Access to private open space from dwelling units</td><td>No</td></tr>
<tr><td rowspan="2">F2 Culture and Heritage</td><td>F2.2 Impact of the design on existing streetscapes.</td><td>No</td></tr>
<tr><td>F2.3 Maintenance of the heritage value of the exterior of an existing facility</td><td>No</td></tr>
<tr><td rowspan="2">F3 Perceptual</td><td>F3.1 Impact of tall structure(s) on existing view corridors</td><td>No</td></tr>
<tr><td>F3.2 Quality of views from tall structures.</td><td>No</td></tr>
</table>

Table 2.3. List of indicators used by SBTool for K-12 schools and SBTool^{PT} STP for Office Buildings (continuation)

		F3.3 Sway of tall buildings in high wind conditions.	No
		F3.7 Access to exterior views from interior	No
G Cost and Economic Aspects	G1 Cost and Economics	G1.1 Construction cost	I24 Life cycle costs
		G1.2 Operating and maintenance cost	I24 Life cycle costs
		G1.3 Life-cycle cost	I24 Life cycle costs
		G1.5 Affordability of residential rental or cost levels	No

As mentioned in the previous sections 2.5.1 and 2.5.2, chapter 4 of this document addresses the choice of the indicators that are included in the SAHSB^{PT} methodology. Therefore, Table 2.2. assisted in the preparation of the form, where the indicators for SBTool for K-12 Schools that do not belong to SBTool^{PT} STP for Office Buildings are attached.

The comparison between the SBTool^{PT} STP for Office Buildings and SBTool for K-12 Schools supports the identification of the most appropriate indicators to be considered in the methodology being developed within this work, the SAHSB^{PT} methodology. The comparative analysis between the indicators is demonstrated in chapter 4.

The following sub-chapter presents some examples of school buildings that have received a sustainability certificate in Portugal and in Brazil.

2.5.4. Examples of application of BSA tools in Portuguese and Brazilian school buildings

This section presents an overview of the BSA methods used in Portugal and Brazil, as well as some examples of these systems applied to school buildings in these countries.

2.5.4.1. Building Sustainability Assessment methods in Portugal

As a result of the Conference of Rio de Janeiro in 1992, the European Commission established the European Conference on Sustainable Cities in 1994, seeking to set foundations for the implementation of the Agenda 21 adapted to the European reality. That resulted in the Chart of European Cities, which established practices and policies for sustainable development (Commission of the European Communities, 1994).

In 1993, the Lisbon Summit took place in Lisbon, where the European Commission sought to broaden the vision of sustainable development, turning it into a long-term perspective (Santos, 2007). The National Strategy for Sustainable Development of Portugal was published in 2002 and updated in 2005 aiming at making Portugal one of the most competitive countries of the European Union in terms of environmental quality and social responsibility until 2015 (Torgal & Jalali, 2007).

The number of residential buildings in Portuguese cities has doubled between 1970 and 2000. Currently, Portugal applies some international BSA systems, which have been previously cited, namely LEED, BREEAM and SBTool. Other methodologies have been adapted and developed according to the reality of Portugual, such as $SBtool^{PT}$, Natura Domus and LiderA (Portal da Construção Sustentável, 2018). None of these methodologies have any certification system specific for Portuguese school buildings.

An example of a school building certified in Portugal by the LEED system is the Porto Business School, University of Porto (Figure 2.2.), which achieved the GOLD level. This building is the largest school building in Europe with this level of certification and one of the four buildings with LEED certification in Portugal (Noticias.up, 2014). This was the first Portuguese school building, and the second of the Iberian Peninsula, to achieve this level of certification.

Figure 2.2. Porto Business School, University of Porto

The NATURA DOMUS system was developed by SGS (Societe Generale of Surveillance) in 2005 and it is available in Portugal since 2008. Together with Domus Qual, it deals with the quality and sustainability of a building, acting on four levels: design, construction, demolition or rehabilitation and resource management (Portal da Construção Sustentável, 2018). NATURA DOMUS methodology does not have any school building certified in Portugal.

SBTool^{PT} is a tool that allows the evaluation, recognition and certification of buildings sustainability, based on the international tool SBTool. It was released in 2009, developed by the University of Minho and approved by iiSBE (Portal da Construção Sustentável, 2018). SBTool^{PT} does not have any school building certified in Portugal, as its current versions does not apply to this building typology.

LiderA is a sustainability assessment system, developed in 2005 by IST (Instituto Superior Técnico de Lisboa), available since 2009 and it is now on its 2.0 version. This is a Portuguese voluntary system that seeks to provide an efficient and integrated assistance. LiderA evaluates and certificates the sustainability of buildings, since the design phase until the use phase. It works at strategic levels, project levels and management levels (LiderA, 2005).

In 2009, the Centro Escolar Alcanede, in the city of Santarém (Figure 2.3), was evaluated using LiderA and achieved a level A classification (LiderA, 2012). In the same year, the Centro Escolar Jardim de Baixo (Santarém) was certificated using the Design and Construction and Operating Certificate, with level A (LiderA, 2012). The Centro Escolar Sacapeito (Santarém), in 2011, was also evaluated and achieved the same level as the previous one – Level A with LiderA (LiderA, 2012).

Figure 2.3. Alcanede school center, Santarém (LiderA, 2012)

2.5.4.2. Building sustainability assessment methods in Brazil

Nowadays, several building promoters that are looking for sustainability certification in Brazil are looking for resources from funding agents, also looking to acquire licenses from the government relying on the availability of many financing agents or governmental entities that invest and encourage green buildings. The sustainability certifications as LEED, AQUA and PROCEL already operate in Brazil for a few years. The English BREEAM certifications and German DGNB have just started to be offered for companies in Brazil, which search for authentication in terms of sustainable construction (Portal Itambé, 2018).

In Brazil, $LEED_{TM}$ was the first Certification of Sustainability to be utilized, in 2007. Based on a research coordinated by UNICAMP, the outlining of the methodology has started to be employed in São Paulo, soon being implemented for validation in other regions of Brazil (Silva et al, 2000). LEED was the first sustainability certification for buildings utilized in Brazil, therefore, it is currently the most widespread in the country (USGBC, 2013).

In 2011, Brazil has become the fourth country to register for LEED certification. According to Matos (2014), until 2014, LEED had already assessed 903 projects in Brazil, of which 185 are certified and 718 are still registered in the certification process (GBC, 2014). The south-eastern region has the largest number of evaluated buildings (about 82% of certificates and 78% of registered projects). LEED for schools is still not frequently used in Brazil, as shown in Table 2.4. and Table 2.5.

Table 2.4. Certification LEED Panorama / Brazil (Matos, 2014)

REGION	**CHARACTERISTIC**		**TOTAL FOR REGION**	**TYPE OF CERTIFICATION**			
	Certification	**Registers**		**LEED**	**LEED Silver**	**LEED Gold**	**LEED Platinum**
North	3	15	18	3	0	0	0
Northeast	11	41	52	4	7	0	0
Midwest	2	24	26	0	0	2	0
Southwest	152	559	711	33	49	64	6
South	17	79	96	1	7	9	0
∑	185	718	903	41	63	75	6
Median	37,0	143,6	180,6				

Table 2.5. Types of Certification LEED Panorama / Brazil (Matos, 2014)

VERSIONS LEED	**REGION**					∑
	North	Northeast	Midwest	Southeast	South	
LEED CS	6	18	11	325	48	408
LEED NC	3	27	11	254	39	334
LEED EB_OM	9	2	2	56	3	72
LEED-CI	0	2	0	53	4	59
LEED-RETAIL	0	1	1	16	0	18
LEED ND	0	1	1	2	1	5
LEED for schools	0	1	0	2	1	4
LEED HC	0	0	0	3	0	3
TOTAL						903

The only school in Brazil to receive the certification LEED with a Golden performance level is the Colegio Positivo International (Figure 2.4.), in Curitiba (PR) (Ecodesenvolvimento, 2012).

Figure 2.4. Colegio Positivo International, in Curitiba (Ecodesenvolvimento, 2012)

The school Walter Heime of Rio de Janeiro won the Silver Certificate with LEED. Other schools are already registered and are waiting for the certification, such as the Sede of INBEC (Instituto Brasileiro de Educação Continuada, Brazilian Institute of Continuing Education), Fortaleza, Ceará; SESC (Serviço Social do Comércio, Social Service of Commerce), CEDEI (Center for Interamerican Studies) school, São Paulo; UFPR (Universidade Federal do Paraná, Federal University of Paraná) – LIHT (Laboratório de Imunogenética e Histocompatibilidade, Laboratory of Immunogenetics and Histocompatibility Curitiba – Paraná and the CECAS (Centro de Estudos de Clima e Ambientes Sustentáveis, Center for Climate Studies and Sustainable Environments) – USP (Universidade de São Paulo, São Paulo University) Study Centre, São Paulo (GBC, 2014).

In March 2018, there were 1285 records, 478 of which were certificates in Brazil, being that 43% of them were in commercial buildings and only 3% were in school buildings, with only 9 registered schools. The south-eastern region continues to be the one that invests the most, with the state of São Paulo having 682 properties registered (GBCBRASIL, 2014).

Another system used in Brazil is AQUA, which was created in 2007 by the Carlos Alberto Vanzolini Foundation together with the Escola Politécnica da USP (Polytechnic School of São Paulo), through the adaption of the French system HQE, and was incorporated in the norms of ABNT (Associação Brasileira de Normas Técnicas, Brazilian Association of Technical Standards). Nowadays, Brazil has 65 projects in process of certification or already certified using the AQUA system (Foundation Vanzolini, 2013). Table 2.6. and

Table 2.7 show the panorama of AQUA certification in Brazil.

Table 2.6. Certification AQUA Panorama / Brazil (Fundação Vanzolini, 2013)

REGION	AQUA		∑	LEVEL OF CERTIFICATION				
	QAE	SGE		Program	Conception	Execution	Operation	Use
North	0	1	1	1	0	0	0	0
Northeast	1	12	12	12	7	1	1	0
Midwest	1	6	6	6	3	1	1	1
Southeast	12	133	133	120	46	12	16	5
South	4	12	12	8	5	4	7	4
∑	18	164	164	147	61	18	25	10
Media	3,6	32,8	32,8					

Table 2.7. Versions of AQUA used in the building (Fundação Vanzolini, 2013)

Certification AQUA	REGION					
	North	Northeast	Midwest	Southeast	South	
Residential building	0	3	0	54	1	58
Office buildings and school	0	4	3	41	2	50
Commercial	1	4	2	17	7	31
Accommodation sports, events and culture	0	1	1	10	1	13
Neighbourhoods and lots	0	0	0	6	0	6
Industry and logistics	0	0	0	3	1	4
Reform and rehabilitation	0	0	0	2	0	2
Total						164

Note:

SGE- Sistema de Gestão do Empreendimento, Enterprise Management System

QAE - Qualidade Ambiental do Edifício - Building Environmental Quality

The high school Ilha de Juventude in Vila Brasilândia, São Paulo, Figure 2.5., was the first public school to be certified by AQUA, evaluated by Foundation Carlos Alberto Vanzolini (GBCBRASIL, 2014).

Figure 2.5. Ilha de Juventude school (EDITORIAS EDUCAÇÃO, 2012)

The first school project to be certificated by AQUA was the Conservação Ambiental e Sustentabilidade Superior (Environmental Conservation and Superior Sustainability, ESCAS) School (Figure 2.6.). It has about 12 000 m^2 and is located in Nazare Paulista (SP). The project sought to meet the requirements of a bioclimatic architecture, giving priority to natural light and cross ventilation systems, thereby reducing the use of air conditioners (GBCBRASIL, 2014).

Figure 2.6. Conservação Ambiental e Sustentabilidade Superior School (ESCAS)

Another system is the PROCEL Program, launched in 1985 by the Federal Government and that is currently being managed by an Executive Secretariat subordinated to Eletrobras (the major Brazilian electric utilities company). The objective of this program is to mobilize society, define strategies in order to reduce energy waste and increase environmental awareness, thus contributing to the preservation of natural areas. The main purpose of PROCEL Program is to decrease the energy consumption in constructions. Eletrobras created the Program PROCEL Build, which invests in professional and technological training and intends to create solutions to decrease energy waste, a problem associated with the Brazilian reality (ELETROBRÁS, 2014).

BREEAM has started to operate in the Brazilian market in 2012 and has eight buildings with this rating system. The reason for this low number is the fact that this certification is still relatively unknown in the country. In addition, it did not possess patterns suitable to the Brazilian reality. However, that situation is changing, since it is being prepared a new version of this methodology that can be adaptable to all different regions of Brazil (Edge Buildings, 2017). In March 2018, the Sebrae Sustainability Center (Centro de Sustentabilidade do Sebrae, CSS) in Cuiabá, Mato Grosso, received the 2018 BREEAM Awards: best sustainable building in the category of New Construction in Use in America (Eco Development, 2018).

The necessity to adapt a sustainability assessment methodology for high school buildings according to the Portuguese reality has been found after analysing the several BSA tools (BREEAM, LEED, AQUA, and SBTool, among others) and some examples of sustainability methodologies applied in schools (LEED for schools 2013 and BREEAM Education 2004). After the study and the analysis of all the previously described methodologies, the choice of the methodology on which this work would be based was made, as described in the next subchapter.

2.6. Selection of the BSA methodology to be adapted

As seen in the previous sections, there are already some methodologies specifically developed to be used in school buildings, such as LEED for schools 2013 and BREEAM Education 2004. Although being the most widely recognized sustainability methods and the most applied in the construction industry worldwide, they are not suitable for this work.

BREEAM methodology is not suitable in this work for many reasons, as for instance:

- The weights related to the thermal performance are inadequate as these do not consider the economic and social dimensions (Ferreira et al, 2014);
- There is little concern related to the assessment of the users' comfort;
- It applies only for the building itself and its deployment area, not taking into account the area of influence of the building under analysis;
- This tool is available only for qualified professionals (consultants and auditors);
- This tool can only be applied in the design and use phases.

LEED methodology is not suitable for this work as well, due to the following:

- It is only fully accessible for qualified professionals (consultants and auditors) and researchers;
- The result of this methodology is the overall performance of the building, which is the sum of scores of all dimensions, meaning that the building can achieve a good overall performance even if one of the categories does not reach the expected points;

- It was developed to suit the US market, therefore, it is dominated by ASHRAE standards, while BREEAM uses European and UK codes (Rezaallah et al., 2012).

Among the different possibilities, the SBTool methodology (Sustainable Building Tool) was the chosen methodology to be adapted to the Portuguese reality within this work because it demonstrates greater flexibility and allows a better adjustment of the parameters evaluated in each dimension taking into account the typology, location and function of the building. The SBTool methodology also reduces subjectivity, adjusting more easily to local conditions when compared to alternative methodologies that are much more rigid (Barbosa et al., 2013).

Other advantages of the SBTool methodology is that it considers the three sustainability dimensions: environment, economy and society, besides the possibility of being used in all stages of the construction process (Mateus, 2009). Furthermore, taking into consideration that the SBTool methodology has already been adapted to the reality of Portugal, in other buildings typologies, makes it the one that best suits the purpose of this work, thus eliminating the necessity of using methodologies elaborated for other countries, as LEED, U.S. and BREEAM, U.K. Therefore, this work was based on SBTool^{PT} and the SBTool^{PT} STP for Office Buildings (Barbosa, 2013). This last one was presented at the International Conference SB13 (2013) in Portugal. The indicators and categories used for the new methodology for school buildings are mainly based on the SBTool^{PT} STP for Office Buildings categories and indicators, since both are considered service buildings.

The methodology developed in this thesis adapts to the specific characteristics of school buildings, which leads to some differences, as practices of reference. It also leads to the addition or removal of indicators from the evaluation methods, as well as changes in their weights. The methods selected to be used in this work will be covered in more detail in the next subchapter, in order to help a better understanding of this subject.

2.7. International versions of SBTool, SBTool for K-12 Schools

This section discusses the International SBTool methodology, chosen as the base methodology in this study.

According to Addis (2010), SBTool was developed to be used as an international tool. This system pursues to provide a better scientific methodological basis. It takes into consideration some priorities such as regional traditions in the construction sector, local cultural values and technologies. It differs from other BSA tools since it is part of a new generation of evaluation systems (Silva et al., 2003).

This international involvement distinguishes SBTool from other methodologies. It was specifically projected to allow its users, after a reflection on the different priorities of each region, to adapt it according to social, cultural, economic and environmental structure, and to specific technological contexts (Mateus & Bragança, 2011).

The evaluation system BREEAM, in coordination with LEED and SBTool, provide a starting point for the elaboration of other methodologies of sustainability assessment certification. Indicators in SBTool have different weights according to weighting coefficients given in the different national levels. BREEAM and LEED, on the other hand, offer a general system of credits.

The SBTool methodology compares the building under evaluation with another building of the same type using numerical, interconnected data that evaluate the building and verify its impact on the sustainability indicators. This evaluation usually occurs in four hierarchical levels that are performance issues, categories, criteria, and sub-criteria. This system uses a performance scale established between -2 (minimum performance accepted) and +5 (maximum performance). The "0" of the scale corresponds to the reference performance.

SBTool reduces subjectivity of analysis by using numerical indicators in the evaluation criteria. This system has a more uniform distribution among the factors that form sustainable development (30% for social, 30% for economic and 40% for environmental), and its structure is composed of 53% of quantitative indicators and 47% of qualitative indicators. This methodology provides a numerical indicator that is converted to a qualitative indicator for each category (Mateus, 2009). Some countries have adapted national versions of this methodology, as SBTool CZ, Czech Republic; Verde, Spain; ITACA, Italy; and SBTool ^{PT}, Portugal.

The SBTool was designed to be flexible and to have characteristics that make it easy to adjust according to the region and the development of the process of application of this tool (Larsson et al., 2012). Some of the main characteristics of SBTool are the following:

- Covers a wide variety of points concerning sustainable buildings and may be rated from 6 to 120 points, according to the necessities of the buildings;
- Allows the users of the methodology to set different weights to a given criterion, according to the regional importance given to the criterion and to the type of construction that is being assessed;
- Provides specific indicators concerning location and construction;
- Takes into consideration specific criteria of evaluation for each region reviewed, according to the context;
- Provides specific criteria for each life cycle phase of the building;
- Allows the addition of new parameters when the building occupancy changes, and in accordance with that change, regardless the size of the building;
- Allows the possibility of being utilized both in small or large projects, commercial or residential, new buildings or renewals;
- Allows architects to specify main objectives and modify the weights of the indexes according to the defined objective.

The SBTool is a comparison between aspects of the building under evaluation and the national practice references – common and best practices, which have as main supports three aspects of sustainability: society, economy and environment. These are subdivided into categories, which are subdivided into several indicators (Barbosa et al., 2013). After analysing the key features of a variety of systems of sustainability assessment of buildings in different countries and studying the local context, the methodology SBTool has defined nine categories for its assessment tool. Each category is a global indicator that demonstrates the performance of a building according to a certain aspect of sustainability. Then, a category can be identified by one or more indicators.

Those nine categories are: i) energy efficiency, ii) health and comfort of users, iii) materials and waste management, iv) soil utilization and biodiversity, v) water efficiency, vi) climate change and air quality, vii) easy internal access, viii) education and consciousness of sustainability and ix) life-cycle costs (Mateus & Bragança, 2011).

In the next subchapter will be approached the main features, categories, and indicators of SBTool^{PT}-STP for Office Buildings that is the basis of the methodology being proposed in this work.

2.8. Portuguese SBTool^{PT} STP for Office Buildings

Methodologies for sustainability assessment use different indicators for the certification and evaluation of buildings, according to the economic, cultural, social, technological, and environmental features of the countries in which they are applied (Saraiva et al., 2019b). This research is based on the SBTool^{PT}-STP for Office Buildings, therefore, the comparison between the indicators used by the BREEAM Education, SBTool^{PT}-STP for Office Buildings, SBTool for Schools and LEED BD + C Schools, can be seen in Table 2.8.

Table 2.8. List of indicators used by SBTool^{PT} STP for Office Buildings and LEED BD+C Schools, SBTool for K-12 Schools and BREEAM Education

Dimension	Category	ID	SBTool ^{PT} STP for Office	LEED	SBTool	BREEAM
ENVIRON MENT	C1. Climate Change and outdoor air quality	I1	Life cycle environmental impacts	X	X	X
		I2	Heat island effects	X	X	
	C2. Biodiversity and land use	I3	Land use efficiency		X	
		I4	Sustainable location	X	X	X
		I5	Local biodiversity protection during construction	X		X
		I6	Certificated wooded materials	X		X
	C3. Energy	I7	Energy consumption	X	X	X
		I8	Renewable Energy	X		
		I9	Commissioning	X	X	X
	C4. Materials, solid residues and resources management	I10	Reuse of materials	X	X	X
		I11	Materials with recycled content	X		X
		I12	Construction and demolition wastes	X	X	X
		I13	Environmental management plan	X		X
		I14	Flexibility and adaptability	X	X	
	C5. Water	I15	Water consumption	X	X	X
		I16	Water treatment and Recycling	X	X	X
		I17	Storm water management	X	X	X
SOCTIEY	C6. User health and comfort	I18	Indoor air quality	X	X	X
		I19	Thermal Comfort	X	X	X
		I20	Visual Comfort	X	X	X
		I21	Acoustic Comfort	X	X	X
	C7. Accessibility	I22	Mobility plan	X	X	X
	C8. Security	I23	Occupants security		X	X
ECONOMY	C10. Life cycle costs	I24	Life cycle costs		X	X
C11: Sustainability of the area		I25	Accessibility to public transport		X	X

Subsequently, the categories (C) and indicators (I) of the SBTool^{PT} STP for Office Buildings methodology (Barbosa, 2013) will be briefly explained.

2.8.1. Environment Dimension

- Climate change and outdoor air quality (C1)

Climate change has been taking place over the years, and there is 90% chance of being caused by human activity, as a result of CO_2 emissions that cause global warming, according to the Intergovernmental Panel on Climate Change (IPCC, 2007). The greenhouse effect has severe consequences on the environment, such as temperature increase, climate change, biodiversity loss, desertification and reduction of the ice at the poles, thus leading to an increase in sea level. SBTool^{PT} STP for Office Buildings, in this category, analysed the *life cycle environmental impacts* (I1) and *heat island effects* (I2) of the building.

- Biodiversity and Land use (C2)

To minimize the negative effects of environmental impacts, the buildings should be constructed in areas that have already been occupied by other constructions or where the environment has changed, thereby reducing the use of virgin areas. If it is not possible, it should be applied measures of protection of the natural environment (iiSBE 2012). Maintaining biodiversity means maintain also the photosynthesis performed by plants and their efficient mechanism for carbon storage, consequently helping to reduce CO_2 emissions (EC, 2005). The SBTool^{PT} STP for Office Buildings, in this category, analyses the *land use efficiency* (I3), *sustainable location* (I2), *local biodiversity protection during construction* (I5) *and certificated wooded materials* (I6).

- Energy (C3)

Energy consumption can be pointed as the biggest responsible for global CO_2 emissions, making it one of the aspects with greater relevance to be analysed when dealing with the sustainable development (EC, 2011). Energy control, with the objective of decreasing environmental impacts, is of deep importance. In SBTool^{PT} STP for Office Buildings, this category, considers the energy *consumption* (I7), and also *renewable energy* (I8) and *commissioning* (I9).

- Materials, solid residues and resources management (C4)

Waste production occurs during the phases of construction, demolition and utilization by occupants, being the last one responsible for the production of solid urban waste. The flow of waste possesses a series of properties that difficult its management, namely the fact of being dangerous, having different dimensions, different types of material and different locations (Andrade, 2009). The construction industry is also one of the biggest consumers of raw materials, and, besides that, these ones need to be extracted, manufactured and transported to the construction site, which carries huge energy expenses (Mateus & Bragança 2006). SBTool^{PT} STP for Office Buildings considers this category through the analysis of *reuse of materials* (I10), *materials with recycled contents* (I11), *construction and demolition wastes* (I12). The *flexibility and adaptability* (I14) of the building are also analysed.

- Water (C5)

Water is one of the essential elements of the planet and it is vital to the human being, but it has been used in an excessive and inefficient way, causing high environmental and economic costs (UNESCO, 2014).

Water consumption should be decreased in the utilization phase of a construction since that is the phase when water consumption reaches the highest levels. It is also possible to reduce water consumption in the project phase through an educated choice of materials, choosing materials that utilize very little water in their production process and low amounts of incorporated water (UNESCO, 2014). In SBTool^{PT} STP for Office Buildings, this category analyses the *water consumption* (I15), *water treatment* and recycling (I16) and also the *storm water management* (I17).

2.8.2. Social Dimension

- Users' health and comfort (C6)

Sustainable construction aims to reduce environmental impacts, but also gives priority to the environmental comfort of the users of the buildings, looking to provide a suitable quality of indoor environment, through acoustic comfort, thermal comfort, indoor air quality and lighting (Frontczak & Wargocki, 2011). In SBTool^{PT} STP for Office Buildings, this category addresses the *indoor air quality* (I18), *thermal comfort* (I19), *visual comfort* (I20) and *acoustic comfort* (I21).

- Accessibility (C7)

The location of the buildings interferes with the routine of people who live or work there, so it is essential to give priority to easy access to public transport and also to the amenities (hospitals, schools, supermarkets), in order to reduce the necessity of using cars (Mateus, 2010). SBTool^{PT} STP for Office Buildings considers the *mobility plan* (I22) in this category. Despite the fact that these indicators interfere in the environmental sustainability of a building, they cannot be modified by a project (DGNB, 2009).

- Security and Safety (C8)

The category of security and safety is also part of other methodologies such as LEED, BREEAM and CASBEE. It is required to increase the security of a building and its surroundings, especially in what to the crime is concerned (Lenses, 2008). Safety at school is very important since it is mostly related to children's safety. In SBTool^{PT} STP for Office Buildings, this category exists, but refers only to *occupants' security* (I23). A school building should be designed or being subject to a retrofit while preserving the highest security for children. Security involves several features related to the security of the equipment, such as protection in case of a balcony and staircase accident, as well as in several other cases. Another aspect of security is to provide equipment for protection in case of fire and in case of need to use toxic materials or other that may offer any kind of danger.

2.8.3. Economic Dimension

- Life cycle cost (C9)

Sometimes, the methodologies for the assessment of sustainability do not analyse the *life cycle costs* (I24) of the building. It is important to mention that the benefits related to sustainability should not be evaluated only by following financial aspects, but by taking into account the cost as a balance between the economic, social and environmental benefits; a feature associated with the vast majority of sustainability criteria and that cannot be directly converted to cash (Ding, 2008). Despite a large number of studies made by academics demonstrating that the costs of sustainable construction are lower than those of traditional buildings, construction professionals still think sustainable constructions are very expensive, which makes it an obstacle to implement these methodologies in the market.

In this subchapter, the main categories and indicators in SBTool^{PT} STP for Office Buildings were analysed. Several of these indicators, some with adaptations, are used in the methodology developed in this thesis - SAHSB^{PT} methodology.

2.9. Concluding Remarks

This work, through the application of the presented methodologies to Portuguese high school buildings, seeks to define the level of sustainability in these schools, thus improving their usability.

This chapter presented a brief description of some Sustainability Assessment Methodologies adapted to school buildings and the characterization of Portuguese and Brazilian high schools. It also gave examples of the application of BSA tools in Portuguese and Brazilian school buildings, like the international version of SBTool and the Portuguese SBTool^{PT} STP for Office Buildings.

After that, were presented some examples of environmental methodologies applied in school buildings, namely BREEAM Education LEED BD+C Schools and International SBTool for school. A brief comparison of the categories and indicators used in these methodologies was made.

Since the main objectives of the thesis are the development of a methodology to assess the sustainability of Portuguese school buildings and to initiate the development of a similar methodology to be applied to Brazilian school buildings, a characterization of Portuguese and Brazilian schools was made, also showing the methods of sustainability assessment used in Portugal and Brazil.

The information presented in this chapter has also demonstrated why the SBTool methodology, and more specifically the SBTool^{PT} and SBTool^{PT} STP for Office Buildings were the chosen ones to serve as basis for the development of the SAHSB^{PT} methodology proposed in this work.

The bibliographical references presented in this chapter reported several methodologies specific to schools. They also showed that the SBTool methodology is the most flexible one and with greater potential to be adapted to different realities and contexts as well as different construction typologies. Besides its adaptation to other countries, in Portugal, SBTool has been already adapted to residences - SBTool^{PT} H (Mateus 2010), Offices - SBTool^{PT} STP for Offices Buildings (Barbosa, 2013), Hospitals - SBTool^{PT} Hospitals (Castro, 2017) and urban sites - SBTool^{PT} URBAN (Bragança, 2017). The methodology developed in this work, SAHSB^{PT}, specific for school buildings, is another contribution to this series of methodologies adapted to the Portuguese reality.

The following chapter shows the methodology followed in the elaboration of the SAHSB^{PT} methodology.

CHAPTER 3

Methodology followed in the Thesis

This chapter presents the methodology of the thesis and the methods used during all stages of this work, seeking to adapt the categories and indicators included in the methodology for Sustainability Assessment of High School Buildings in Portugal, SAHSB^{PT}, in accordance with the principles and concepts of the SBTool^{PT} methodology.

In chapter 1, the main objective of this thesis as well as three specific objectives were defined. The following subchapters will define the methodologies and tools used to achieve these objectives.

3.1. Analysis of building sustainability assessment (BSA) tools

One of the specific objectives of this thesis is the study of BSA tools that already incorporate parameters for school buildings, such as BREEAM, LEED and SBTool. In order to achieve this objective, exploratory research is used, which seeks to provide a greater familiarity with the problem through literature review.

The literature review is described in the second chapter, reporting on sustainability and sustainable construction, BREEAM Education, LEED BD + C for Schools and SBTool for K-12 Schools. In addition, the SBTool^{PT} STP for Office Buildings was also reported, since it is the methodology used as the basis of this work.

A review of the BSA used in Portugal and Brazil is also part of this chapter. Furthermore, the second chapter demonstrates the main characteristics of the high schools of Juiz de Fora, Brazil

(Cristo Redentor and Santa Catarina Schools), and the school refurbished by the *Parque Escolar,* Portugal (Escola Secundária Francisco de Holanda), since these are the schools where the methodology and the questionnaires used to define the new indictors proposed in this methodology were applied.

3.2. Adaptation of categories and indicators for the elaboration of SAHSB^{PT}

The main aim of this thesis is to adapt and define categories and indicators for the elaboration of a Sustainability Assessment of High School Buildings in Portugal (SAHSB^{PT}) methodology, in accordance with the international principles and concepts of the SBTool methodology.

The other specific objective is the intention of starting the sustainability assessment process in school buildings in Brazil, through the analysis of two schools in Juiz de Fora, MG and Macapá, Amapá, regarding only a few indicators, namely the comfort indicators and the sustainability awareness indicator.

In order to achieve those objectives, several procedures had to be performed, such as the analysis of the results of the questionnaires applied to the students in the schools in Portugal and Brazil related to the definition of the environmental comfort indicator (ANNEX 2) and related to the definition of the sustainability awareness indicator (ANNEX 3). The analysis of the results of the forms applied to specialists in sustainability issues had also to be performed (ANNEX 1) in order to better understand which indicators and categories should be considered in the proposed SAHSB^{PT} methodology.

The methodology used in the questionnaires and forms is the descriptive research, when the facts are observed, recorded, analysed, classified and interpreted, without the interference of the researcher, and using standard techniques of data collection. The research is also quantitative, as demonstrated by the number of opinions and information that are classified and analysed.

3.2.1. Questionnaires

Two questionnaires (ANNEXS 2 and 3) on comfort (indoor air quality, thermal, visual, acoustic and ergonomic comfort) and sustainability awareness indicators were applied to the students of the Francisco de Holanda High School, in Guimarães (Portugal) (Chapter 5), to the students of the schools Redentor and Santa Catarina, in Juiz de Fora (MG) (Chapter 8) and Gabriel Almeida Café School and the Tiradentes School (Chapter 9). The analyses of the process and the results of those questionnaires intent to support the definition of the weight of those specific indicators.

The questionnaire (multiple-choice answers) on the environmental comfort (ANNEX 2) was used to identify the Indoor Environmental Quality (IEQ) conditions in the school buildings. After that, a statistical analysis was performed to evaluate the performance of the answers. Through the analyses of the results, it was possible to understand which types of environmental comfort issues are most important to the students (Saraiva et al. 2018).

Regarding the sustainability awareness indicator, the questionnaire evaluates the level of environmental awareness of the students, the regularity with which environmental subjects are mentioned in school classes, and how often the students have acted to protect the environment during the day. Other issues address environmental practices in their homes and what students feel about how environmental issues should be addressed in high schools. Then, a statistical analysis was performed using the Microsoft Excel software ANOVA, with a level of probability equal to 0.05 to evaluate the performance of the responses (Saraiva et al., 2019a).

The analysis of variance (ANOVA) is a method used to test the equality of three or more averages from different groups. In mathematical terms, the value of F is calculated by the division among average squares of the model (Ftabulated) and the residual average squares (Fcalculated). If the groups' difference is a relevant value, their individual value would also differ. The between-group variability refers to differences between the distributions of individual groups as the values of each group are dissimilar. To calculate the between-group variability, it is necessary to find each squared deviation, weigh them by their group value, sum them, and divide by the degrees of freedom. The best result is achieved when F is high, demonstrating that the average squares of the model are higher than the residual average squares, indicating that there is a difference between these groups (Analyticsvidhya, 2018).

Microsoft Excel software ANOVA statistically verifies the effect of the influence of the level of consciousness factor related to sustainability awareness of the high schools in Juiz de Fora, Macapá and Guimarães (Figure 3.1.). It is verified that the value of the factor (Fcalculated) provided by the statistical analysis is greater than the factor (Ftabulated). The factor's effect was found to be significant (Saraiva et al., 2019a).

(BR)	(PT)	(BR)	(PT)	(BR)	(PT)	(BR)	(PT)	Anova: Single Factor						
29%	26%	49%	55%	16%	17%	6%	2%							
28%	32%	53%	51%	18%	16%	1%	1%	SUMMARY						
64%	63%	23%	25%	13%	10%	0%	2%	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
22%	32%	51%	55%	22%	7%	5%	6%	Column 1	9	435	48,33333	23,5		
75%	73%	21%	23%	3%	2%	1%	2%	Column 2	7	420	60	32,33333		
50%	55%	28%	39%	10%	6%	12%	0%	Column 3	9	393	43,66667	50,5		
38%	40%	8%	15%	5%	7%	55%	38%							
19%	38%	21%	11%	11%	7%	49%	44%							
								ANOVA						
								Source of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
								Between (	1085,84	2	542,92	15,19623	7,16E-05	3,443357
								Within Gr	786	22	35,72727			
								Total	1871,84	24				

Figure 3.1.Microsoft Excel software ANOVA

3.2.2. Sustainable level of indicators based on the opinion of experts

In the proposed SAHSB^{PT} methodology, the weight of each indicator was determined taking into account the result of the level of importance of each indicator selected by the specialists in the form that was applied to them (ANNEX 1). In this form, ten specialists in sustainability issues chose among all indicators from SBTool^{PT} STP for Office Buildings, LEED BD+C School, SBTool for K-12 Schools and BREEAM Education, which ones should be considered in the methodology specifically developed to schools.

The experts chose 30 indicators, with the final number of indicators for the SAHSB^{PT} methodology being 23. This selection and the number was defined based on the number of indicators used in other methodologies, namely the SBTool and its adaptations to the Portuguese reality, as the SBTool^{PT}H (25 indicators), SBTool^{PT} for Urban Planning (21 indicators) and SBTool^{PT} STP for Office Buildings (25 indicators).

In addition, the specialists determined the level of importance of each of the selected indicators. The level is among 0 and 10, as demonstrated in Figure 3.2., which helps to define the weight value assigned to each indicator through the arithmetic sum of all the defined indicators.

Figure 3.2. Weight value of each indicator

The experts who answered this questionnaire in Portugal are members of the iiSBE (International Initiative for Sustainable Built Environment), while those who answered it in Brazil are professors from the UFJF (Federal University of Juiz de Fora).

3.3. Application of SAHSB^{PT} Methodology to a Portuguese school

One of the specific objectives of this document is the application of the SAHSB^{PT} methodology in the Francisco de Holanda High School, Guimarães, as it would be useful to test the viability of the application of this method.

The SAHSB^{PT} methodology intents to benefit architects to design sustainable school buildings and also decrease errors in the evaluation process, allowing the evaluator to inform and guide the designer on how to achieve more sustainable projects and quantify the performance of the building at the level of each category and indicator, which results in the overall performance of the building (Sustainability Level).

At this stage of the thesis, the case study is used, as it involves the deep and exhaustive study of an object in a way that allows its ample and detailed knowledge. The case study in question is conducted at the Francisco de Holanda High School, Guimarães, where the main aspects related to the sustainability of this building are verified (Chapter 7).

The level of sustainability for each indicator and category is determined through specific calculations, demonstrated in chapter 5 of this thesis. This determines a quantitative research, since the values found demonstrate the information to be analysed.

The evaluation summarizes the performance level of the high school building at the indicator, by the qualitative scale consisting of six levels (from E to A+) that are used to demonstrate the result of the evaluation. The results of the 23 indicators, the 11 categories and the 3 dimensions of the SAHSB^{PT} methodology are defined, as demonstrated in chapter 7.

3.4. Concluding Remarks

In this research, the SAHSB^{PT} methodology was applied to confirm the suitability of the benchmarks and their practical applicability to the context of the Francisco de Holanda High School, Guimarães, Portugal.

In this chapter, the methods and the type of research were presented, considering the conclusion of all the objectives proposed in this thesis. One of the specific objectives of the thesis is the study and adaptation of the BSA tools that already incorporate specific parameters directed to school buildings, such as BREEAM, LEED and SBTool. In order to reach this objective, the exploratory methodology is used, which seeks to provide greater familiarity with the problem through literature review.

The literature review is described in the second chapter, as well as the reports on concepts of sustainability, BSA specific for school buildings, SBTool^{PT} STP for Office Buildings, the main features of the high schools in Brasil, Juiz de Fora (Cristo Redentor and Santa Catarina Schools), Macapá (Tiradentes School and the Gabriel Almeida Café School) and Portugal (Escola Secundária Francisco de Holanda). Chapter 4 is also related to the literature review, particularly with regard to recent research and the main key aspects of the indicators and categories included in the SAHSB^{PT} methodology.

To reach the main objective of the thesis, namely the elaboration of the SAHSB^{PT} methodology, questionnaires were applied to the students of the schools studied in both Portugal and Brazil; and forms were applied to specialists in the field of sustainability of buildings. In these questionnaires and forms, the methodology used was descriptive and quantitative, and for a better understanding of the results of the questionnaires, the ANOVA statistic tool was applied. The methodology used in the application of the SAHSB^{PT} methodology in the Francisco de Holanda High School, Guimarães was the case study, and it should be useful to test the viability of this methodology.

CHAPTER 4

System Structure and Content

In chapter two, some of the most widely used methodology for sustainability assessment in Portugal were analysed, having been observed that many of them do not respect the economic, socio-cultural and environmental contexts, local legislations, national traditions or technologies, which consequently makes them less efficient. The methodology developed in this work, based in SBTool, provides more objective results when compared with the other methodologies previously studied, therefore facilitating the understanding of those results and reducing errors.

This chapter presents the content and the structure of the support system for the design, evaluation and certification of the SAHSB^{PT} methodology. It also demonstrates the certification system used in this methodology.

4.1. Selection of indicators

The choice of the indicators to be used in the SAHSB^{PT} methodology was made through the application of some questionnaires (shown in ANNEX 1) to different experts on the topics under analysis. The experts chose, among all indicators from SBTool^{PT} STP for Office Buildings, BREEAM Education, LEED BD+C School and SBTool for K-12 Schools, those they considered to be the most appropriate, as shown in ANNEX 1 of this thesis.

4.2. Structure of the methodology

The assessment method used in the SAHSB^{PT} methodology follows the calculation procedures of the SBTool^{PT}-STP for Office Buildings, using indicators of economic, social, and environmental features and relating them with national practices (Saraiva et al., 2019b). The SAHSB^{PT} methodology has five parts:

- Part 1: Quantify each indicator (23 indicators);
- Part 2: Quantify each category (11 categories);
- Part 3: Quantify each dimensions of sustainable development (economic, social and environmental);
- Part 4: Quantify the sustainability level (SL);
- Part 5: Completion of the sustainability certificate.

Part 1: Quantify each indicator (23 indicators)

The evaluation of each indicator contains the following steps: quantification of the indicators and their standardization.

The standardization of the indicators establishes a dimensionless value that shows the performance of the building with respect to the benchmarks (Saraiva et al., 2019b). In this process, the Diaz-Baltero equation is applied (Díaz-Baltero, 2004).

$$\overline{\mathrm{P_I}} = \frac{\mathrm{P_I} - \mathrm{P}_{I*}}{\mathrm{P_I}* - \mathrm{P}_{I*}} \qquad (4.1)$$

where $\overline{\mathrm{P_I}}$ demonstrates the standardization value of the indicator; $\mathrm{P_I}$ demonstrates the result of the quantification of the indicator; $\mathrm{P_I} *$ demonstrates the value of the best practice; and $\mathrm{P_I} *$ demonstrates the value of the standard practice (Saraiva et al., 2019b).

The best practice is the value resultant to the data created by scientific work regarding the issue of each indicator, data made by designers who already have some reputation in the field of sustainable building, or data settled as a result of existing standards and policies. With the lack of references specifically applicable to Portugal, data from other countries was used (Mateus, 2010, Saraiva et al., 2019b).

The standard practice is the lowest acceptable value for a building to be considered sustainable. This value is based on the lowest levels set in the regulations and requests of the current building, or construction practices, of Portuguese school buildings (Mateus, 2010).

The standardization values (X) are transformed into a qualitative scale to simplify the comprehension of the results achieved. These results range from E (less sustainable) to A (more sustainable). In the qualitative scale presented, D corresponds to the standard practice, while level A corresponds to the best practice (Saraiva et al., 2019b), as shown in Table 4.1.

Table 4.1. General evaluation for dimension, categories and indicators, SAHSB^{PT}

Level	Conditions	Please check the level reached (✓)
A^{+}	$X > \mathbf{1.0}$	
A (Best Practice)	$\mathbf{0.7} < X \leq \mathbf{1.0}$	
B	$\mathbf{0.4} < X \leq \mathbf{0.7}$	
C	$\mathbf{0.1} < X \leq \mathbf{0.4}$	
D (Standard Practice)	$\mathbf{0.0} \leq X \leq \mathbf{0.1}$	
E	$X < \mathbf{0.0}$	

Part 2: Quantify the performance of each category (11 categories)

The quantification of the specific performance of each category is the arithmetic average of all indicators related to each one of the 11 categories considered in this work. The aggregations of the indicators are made according to the SBTool^{PT}-H methodology (Mateus, 2010).

Part 3: Quantify the dimensions of sustainable development

To quantify the dimensions of sustainable development, it is required to define the arithmetic average of the results achieved in the categories in order to quantify three dimensions: environment, social aspects, and economy of the area. In order to reach the conclusion of the evaluation for each dimension, it should be used Table 4.1, previously presented, in which "X" represents the result of each dimension. The values of these dimensions, in percentage, were determined by experts in the subject and are: environmental dimension (35%), social dimension (35%) and economic dimension (30%).

Part 4: Quantify the sustainability level

The global performance (Level of Sustainability) summarizes the performance of the dimensions into a single value. The best solution is the one that presents a balance between the various macro indicators. In order to reach the conclusion of the evaluation, it should be used Table 4.1. presented above, in which the "X" represents the result of the sustainability level.

The value of the global performance of a building should not be used alone to report its sustainability level, it must always be considered in conjunction with the results of the macro indicators. The value of each dimension should be presented to better understand each specific situation (Mateus, 2009). The weights of the indicators and categories are defined in chapter 5 of this thesis.

Part 5: Completion of the sustainability certificate.

At this phase, the certification of the construction, to which the application was submitted, is presented. This certificate demonstrated the value of the global performance as well as the value of each dimension (Mateus, 2009 and Saraiva et al., 2019b).

Several indicators of SBTool^{PT}-STP for Office Buildings were adapted from those of the SBTool^{PT}, which, in turn, were based on those of the international BREEAM, LEED and SBTool methodologies. Regarding the assessment of school buildings, some similar indicators were also used, and, in addition, some indicators of the SBTool^{PT}-STP for Office Buildings were maintained in the SAHSB^{PT}, since school buildings and office buildings share some similar features. Several characteristics justify the significance of these indicators in the SAHSB^{PT} methodology (Saraiva et al. 2019b).

The main aspects and categories present in the SBTool^{PT} STP for Office Buildings were also subject to analysis, and several of these categories, some of them having had adaptations, are used in the methodology developed in this work — the SAHSB^{PT} methodology (Saraiva et al., 2019b).

The indicators from the SBTool^{PT}-STP for Office Buildings that were kept in SAHSB^{PT} are the following: “life cycle” (I1); “heat island effects” (I2); “land use efficiency” (I3); “certificated materials” (I4); “commissioning” (I7); “environmental management plan” (I9); “flexibility and adaptability” (I10); “water consumption” (I11); “water treatment and recycling” (I12); “storm water management” (I13); “mobility plan” (I19); “accessibility to public transport” (I22); and “life cycle costs’ (I23).

Other indicators were changed for several motives, as explained below.

The indicators “energy consumption” (I5) and “renewable energy” (I6) had to be modified due to a change occurred in 2013 in the Portuguese legislation regarding energy. The SBTool^{PT}-STP for Office Buildings was developed based on the Regulation for Energy Systems and Air Conditioning in Buildings (RSECE) (Decreto-Lei, 79/2006) and on the Regulation of the

Thermal Performance of Buildings (RCCTE) (Decreto-Lei, 80/2006). These regulations were replaced in 2013 by the Regulation of the Energy Performance of Residential Buildings (REH) and the Energy Performance Regulation of Trade and Service Buildings (RECS) (Decreto-Lei, 118/2013) (Saraiva et al. 2019b).

The indicator "reuse and recycle of materials" (I8) is based on the indicators "reused materials" (I10) and "recyclable materials" (I11) present in the SBTool^{PT}-STP for Office Buildings. These indicators are intended to promote more frequent considerations regarding this subject, and, together with the fact that the choice of recycled or recyclable building materials is made at the same phase of the project, this helps to justify the junction of these two indicators.

With regard to the indicators concerning the comfort of the user, such as "indoor air quality" (I14), "thermal comfort" (I15), "visual comfort" (I16) and "acoustic comfort" (I17), the SBTool^{PT}-STP for Office Buildings was used as support for their choice. However, the scope of the indicators was modified, because the SAHSB^{PT} aims to meet the needs of children who remain confined for long periods in a learning environment, and for this reason, some comfort standards must be stricter (Saraiva et al., 2019b).

Throughout this century, changes in high school buildings are usually made through refurbishments, with very few new constructions. The indicators "sustainable location" (I4), "local biodiversity protection during construction" and "waste management indicator" (I12), which belong to the SBTool^{PT} STP for Office Buildings, are related to the construction phase and, consequently, were not included in the SAHSB^{PT} methodology.

Additionally, a new indicator was included: "ergonomic comfort" (I18). Through studies on ergonomic indicators, such as that of Grandjean (Kroemer, 1997), it has been observed that classroom desks of inadequate sizes and shapes cause pain. Therefore, the need to include this indicator in the SAHSB^{PT} methodology was determined (Saraiva et al., 2019b).

The indicator "occupants security" (I24) belonging to the SBTool^{PT} STP for Office Buildings is denominated "occupants security and safety" (I20) in the SAHSB^{PT} methodology. The issue concerning the safety of the occupants of the school environment can be evaluated under different aspects. In the SBTool^{PT}-STP for Office Buildings, this question is determined by aspects related to the guaranteed operating conditions of the main building services, such as water, energy and telecommunications, as well as the safety of users, including proper lighting and surveillance systems. These factors constitute a part of the methodology that still needs to be developed (Saraiva et al., 2019b).

Issues concerning accident prevention have also been addressed, and factors such as the presence of materials that can be dangerous in the school environment, the safety in the area dedicated to sports and recreation, and the safety on the stairs, among others, were analysed. Through studies on safety in high school buildings, including those of Jacob (Jacob, 2016) and Zwetsloot et al. (2017), it was realized that the major accidents occur in the area of sports and recreation or on the stairs, therefore, the need to include this indicator in the SAHSB^{PT} methodology was determined.

The indicator “sustainability awareness” (I21) was added to the methodology to be developed in the present work. It seeks to inform school students about how important sustainability is in today's world, since increasing awareness among students about the importance of sustainability helps to reduce the environmental impact of school buildings.

After the study and analysis of the indicators and categories used in other sustainability assessment methodologies specifically dedicated to school buildings, some conclusions were drawn regarding those that would be the most appropriate to the methodology elaborated in this work.

The parallel between the indicators used by the methodology adapted in this work – SAHSB^{PT} methodology – BREEAM Education, SBTool^{PT} STP for Office Buildings, LEED BD+C for Schools and SBTool for K12 Schools can be seen in Table 4.2.

Table 4.2. List of indicators (ID.) of SAHSB^{PT}, SBTool ^{PT} STP for Office Buildings, LEED BD+C Schools, SBTool for K12 School and BREEAM Education

Dimen sion	Category	ID	SAHSB^{PT}	SBTool^{PT} STP for Office Buildings	LEED BD+C School	SBTool For K12 Schools	BREEAM Education
Environ mental	C1. Climate change outdoor air quality	I1	Life cycle environmental impacts	X	X	X	X
		I2	Heat island effects	X	X	X	
	C2. Biodiversity and land use	I3	Land use efficiency	X		X	
		I4	Certificated materials	X	X		X
	C3. Energy	I5	Energy consumption	X	X	X	X
		I6	Renewable energy	X	X		
		I7	Commissioning	X	X	X	X
	C4. Materials, solid residues and resources managemet	I8	Materials reused and with recycled content	X	X	X	X
		I9	Environmental management plan	X	X		X
		I10	Flexibility and adaptability	X	X	X	
	C5. Water	I11	Water consumption	X	X	X	X
		I12	Water treatment and recycling	X	X	X	X
		I13	Collection and reuse of Rainwater	X	X	X	X
Social	C6. User health and comfort	I14	Indoor air quality	X	X	X	X
		I15	Thermal comfort	X	X	X	X
		I16	Visual comfort	X	X	X	X
		I17	Acoustic comfort	X	X	X	X
		I18	Ergonomic comfort				
	C7. Acces Sibility	I19	Mobility plan	X	X	X	X
	C8. Security and safety	I20	Occupants security and safety	X		X	X
	C9. Education sustainability awareness	I21	Sustainability awareness		X		X
	C10: Sustaina bility of area	I22	Accessibility to public transport	X		X	X
Econo-mic	C11. Life cycle costs	I23	Life cycle costs	X		X	X

4.3. Categories and indicators

In this subchapter, all indicators and categories included in the SAHSB^{PT} were defined. This chapter is used as a basis for Chapter 6 - Basis for the preparation of the evaluation guide for SAHSB^{PT}, which is used for the application of this methodology and therefore includes the calculation process for each indicator.

The main objective of these indicators is to simplify, quantify and communicate certain features of the constructions. The combination of several indicators originates a category. There are several variances among the indicators used in different methodologies aimed at assessing the sustainability of school buildings, which are originated by socio-cultural, environmental and economic differences, as well as by differences in the technologies available in each country (Mateus, 2010). The SBTool (Canada), BREEAM (UK) and LEED (US) methodologies were initially elaborated according to the realities of their countries of origin, and later, they were adapted to the reality of each country in which they were applied.

In this section, all the dimensions, indicators and categories used in SAHSB^{PT} methodology – are presented together with the justification of the reason they were selected and the comparison with related indicators belonging to other methodologies applicable to high schools, such as BREEAM Education, SBTool for K-12 Schools and LEED BD+C Schools. Through consultations with some experts in the field of sustainability of the built environment, it was recognized that some indicators should stay in the SAHSB^{PT} methodology. The indicators are presented in this chapter as follows:

- The introduction of the indicator;
- The justification for the permanence of this indicator in the SAHSB^{PT} methodology;
- The explanation of the aspects that are important to calculate these indicators;
- The reference to the indicator in the guidelines established by the EPE (Empresa Parque Escolar);
- The main bibliographical references that support and validate the options adopted for each indicator;
- The bibliographical references about the indicator related to the school environment.

C1. CLIMATE CHANGE AND OUTDOOR AIR QUALITY

Over the years, inordinate CO_2 emissions increase climate change. For that reason, it is necessary to pursue new proposals to decrease CO_2 emissions, in order to avoid or decrease the effect of this phenomenon. This category contains two indicators: "life cycle environmental impacts" (I1) and "heat island effect" (I2) (Saraiva et al., 2019b).

Indicator 1 - Life cycle environmental impacts

The reduction of life cycle environmental impacts in a building occur with the use of materials and construction processes that generate low environmental impact.

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, namely:

- Provides support to a specific construction to increase the quality of outdoor air and to mitigate climate change. It also decreases the environmental impact and improves the quality of life of users of high school buildings;
- The methodologies applicable to schools (Table 4.2.), as LEED BD+C Schools, SBTool for K-12 Schools and BREEAM Education, also include this indicator;
- This indicator is part of the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal, as well as of the SBTool^{PT} STP for Office Buildings.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator "life cycle environmental impacts" in the SAHSB^{PT} methodology.

It should be noticed that the materials covering the floor and the walls must be maintained, remodelled or modified in order to meet the requirements of the EPE standards. However, in the guidelines established by the EPE there is no determination concerning the life cycle environmental impacts related to materials of new construction and renovations.

To identify the environmental impacts regarding the life cycle of school buildings in the SAHSB^{PT} methodology, it is first necessary to identify the construction solutions implemented in the buildings, identify their LCA environmental impact values and their maintenance operations. Subsequently, it is necessary to multiply the value of each environmental impact by the amount of different elements present in the building.
Consequently, to facilitate the accounting of these environmental impacts related to the analysis of the life cycle of a construction, this methodology is using a specific method of calculation (Mateus, 2010). This method consists in comparing the building assessed with a building of reference, such as a building with the same dimensions and forms as the assessed building, but with construction solutions based on reference measures used in Portugal. The first step is to quantify the environmental impacts of the life cycle of the building, and then quantify these impacts in the reference building. Finally, it is made the standardization and aggregation of categories of environmental impacts.

It is calculated the value of several categories related to environmental impacts throughout the life cycle of a building, which will be weighted later, in order to achieve a final result (Barbosa, 2010). Some categories of environmental impact that are analysed in this indicator are:

Abiotic Depletion Potential (ADP): It is related to the preservation of the ecosystem and the health and comfort of the human being, seeking to assess the environmental problem of the depletion of natural resources, such as minerals and materials found in the sea, land or air. It is calculated in kilograms of antimony equivalents (Sb) per kilogram of extracted resource. It has a global repercussion.

Global Warming Potential (GWP): It is related to the preservation of ecosystems, human health and the performance of materials, seeking to assess the emission of greenhouse gases into the atmosphere. Based on the global warming potential for the next 100 years, carbon dioxide is expressed in kilograms. The scale of the effects extends until the removal of the substance from the atmosphere, with a global repercussion.

Ozone Depleting Potential (ODP): It refers to the balance of terrestrial and aquatic ecosystems and biogeochemical cycles, to human and animal health and to the performance and durability of materials, and is caused by the increase in the amount of UV-V radiation as a result of the depletion of the stratospheric ozone layer. This indicator is expressed in kilograms, and the range of effects is infinite and has a global repercussion.

Photochemical Ozone Creation Potential (POCP): The high level of tropospheric ozone causes damage to agriculture, materials and human health, besides changes in biodiversity. Photochemical oxidation is the formation of reactive chemical compounds, especially ozone. This indicator is expressed in kilograms. This emission has an effect for 5 days, having local and continental repercussions.

Acidification Potential (AP): The acidic substances can cause damage to natural and artificial materials, as well as to human health. This indicator is expressed in kilograms of equivalents of the compounds (SO2, NOX and NH3) per kilogram of emission into the atmosphere. The scale of time is infinite, with local and continental repercussions.

Eutrophication Potential (EP): The eutrophication is the result of all impacts caused by an excessive level of nutrients in the environment, which, in turn, is caused by emissions of nutrients to water, soil and air. This problem is associated with emissions of nitrogen (N) and phosphorus (P). This indicator is expressed in Kilograms, and the time scale is infinite, with local and continental repercussions.

Indicator 2 – Heat island effect

The heat island effect occurs when temperatures in urban areas are higher in comparison with rural areas or forests. This phenomenon occurs due to the removal of vegetation as a consequence of the construction of roads and buildings, which possess in their composition impermeable materials that store and release more heat (Mateus, 2010).

Different aspects explain the permanence of this indicator in the SAHSB^{PT} methodology, such as:

- Assists the use of materials in the composition of the façades and roofs that can decrease the heat island effect;
- The methodologies applicable to schools (Table 4.2.), namely LEED BD+C Schools and SBTool for K-12 Schools, also include this indicator;
- This indicator is part of SBTool^{PT} STP for Office Buildings, as well as SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator "heat island effect" in the SAHSB^{PT} methodology. This indicator is important for all types of buildings, since, currently, more than three billion people living in urban areas are directly exposed to the heat island effect. This is one of the main environmental problems that originates from an undesired result of industrialization and urbanization (Fernandez et al., 2014), thus justifying the importance and permanence of this indicator in the SAHSB^{PT}.

There are several reasons that explain the urban heat island effect. In a general way, the shortwave radiation is absorbed by the asphalt, concrete and buildings during the day, so the cooling process at night is very slow. Other reasons have to do with the lack of evapotranspiration in urban areas and the changes in the thermal properties of surface materials (Fernandez et al., 2014).

The heat phenomenon interferes with other features, such as the increased concentration of urban pollutants, the energy consumption of buildings in the summer seasons, human comfort and health and the increase in the carbon footprints derived from cities (Santamouris, 2007).

Several studies related to the heat island phenomenon have been conducted in recent years. The study by Giridharan et al. (2004) addresses the impact of design-related variables on the heat island effect. The most significant aspects of this microclimate were: the change and reduction of natural ventilation of the streets and, associated with this, the intensification of street temperature; the reduction in the daily temperature range; and a water budget whose value is different from that of rural areas (Giridharan et al., 2004).

The study by Okeil (2010) analysed sun exposure and the reduction of solar gains in the winter season, aiming to reduce the heat island effect. In this study, the concept of Residential Solar Block (RSB) was applied, showing that RSB favours strategies that help mitigate the urban heat island phenomenon, such as the use of green roofs, the increased air flow between buildings and the reduction in energy transport.

C2. BIODIVERSITY AND LAND USE

The growth of the areas used for agriculture, the destruction of forests and the enlargement of urban areas have been intensifying the negative environmental impacts. To decrease them, constructions should be built in areas that have already been occupied by other buildings (Mateus, 2010). This category contains two indicators: “land use efficiency” (I3) and “certificated materials” (I4) (Saraiva et al., 2019b).

Indicator 3 - Land use efficiency

This indicator intends to minimize the use of land for construction, leaving as much free space as possible, with the intent of preserving and protecting the environment (Larsson, 2012). Land use efficiency is related to the way buildings use the land, promoting the increase in building functionality and maximizing the use of the building on the land, according to the respective local legislation.

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, specifically:

- Encourages the reduction of area of land used for construction, with the intention of preserving the environment;
- The methodologies applicable to schools (Table 4.2.), as SBTool for K-12 Schools and LEED BD+C Schools include this indicator;
- This indicator is part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspect described before, it was decided to preserve the indicator "land use efficiency" in the SAHSB^{PT} methodology.

One of the objectives of the EPE is to open the school to the community, creating functional spaces so that in the after school hours, buildings can be used by the community for sports and cultural, social and leisure activities. The *Parque Escolar* also seeks the flexibility and adaptability of the entire school environment to maximize its use (Portal Parque Escolar, 2018).

Some definitions are important in order to understand the variables and indexes used in the assessments, as can be seen below (Barbosa et al., 2014):

- Net Floor Area (NFA): Area of all the compartments of the building, measured by the internal perimeter of the external walls, excluding ducts and internal walls;
- Functional Area (FA): Area of the compartments of the building, measured by the internal perimeter of the external walls, excluding internal ducts, walls, vestibules, interior corridors, bathrooms, closets in walls and storage areas;
- Gross Floor Area (GFA): Area of the total surface of the construction, measured by the external perimeter of the external walls, including balconies;
- Implantation Area or Deployment Area (IA): Area resulting from the vertical projection of the construction on a horizontal plan, measured by the external perimeter of the external walls, excluding porches, balconies, eaves, peaks, and parapets and including outbuildings and basements;
- Allotment Area (AA): Area of land resulting from an allotment process approved in accordance to the local legislation;
- Gross Floor Area Index (GFAI): ratio between GFA and AA; this index is usually limited with maximum values of local plans or rules (GFAIMAX);
- Development Density (DD): ratio between GFAI and GFAIMAX;

- Implantation Index (II): ratio between IA and AA;
- Spatial Efficiency Index (SE): ratio between FA and GFA.

The higher the Gross Floor Area Index (GFAI) is, the better is the use a construction will make of a certain area. If a building does not maximize its Gross Floor Area Index and Development Density (DD), it will increase the need of new constructions, leading to an urban sprawl and all its impacts (Feng & Li 2012).
Maximizing Spatial Efficiency (SE) also increases the sustainability of a building. Architects and engineers should find ways to reduce non-functional areas, such as internal circulations, to maximize functional areas (Kim & Elnimeiri, 2004), to optimize the organization of internal spaces in the building and to reduce the thickness of the building wall (Sev & Özgen, 2009). Arribas-Bel et al. (2010) address the number of users per land area to assess urban sprawl on a larger scale. According to "The Space Management Group", there are three elements to assess the efficiency in a building: the amount of space (floor area), the number of occupants and the total time the building is used (Alexi Marmot, 2006). The work of Alexi Marmot Associates (2006) found a solution for the refurbishment of several university buildings, increasing the occupation time by adding new functions to underused constructions.

According to Davis Iii and Nutter (2010), a better solution to optimize the occupancy of the university building is to open underused buildings so that they can be used with other functions, such as music and culture centres, open research centres, social centres, or others, during periods of low occupancy.

The same measures regarding the efficiency of land use that were mentioned for buildings in general should also be taken for schools, taking into account local regulations. The efficiency of school buildings must comply with current legislation for schools, using the shortest possible length for an area, always respecting the comfort of the users, and emphasizing its functionality.

Indicator 4- Certificated materials

The organic products originate from agriculture and forestry managed in a sustainable manner. The ecological certification given to those products (wood, paper, coal, cork, etc.) ensures that they are extracted from a forest in a proper way, in accordance with environmental, economic and social aspects. As a result, promoting the use of certified products in all types of construction contributes to reducing problems such as deforestation, illegal logging of trees, abusive exploitation of resources and loss of biodiversity (Mateus, 2010).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, namely:

- Contributes to the reduction of deforestation, as it supports the use of wood or organic products in building construction;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education and LEED BD+C Schools, include this indicator;
- This indicator is part of the SBTool^{PT} STP for Office Buildings, as well as SBTool^{PT} Homes, the first methodology the SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator "Certificated materials" in the SAHSB^{PT} methodology.

There are many international and Portuguese laws regarding certified materials, but no specification about certified materials for high school buildings in the documents of the EPE. This indicator is particularly important for the school buildings since, in addition to furniture, doors and windows, which are common in other types of buildings, there are also a large number of school desks, which are usually made of wood.

Deforestation is one of the most damaging human activities on the planet, causing damage to biodiversity, to the climate and to peoples' lives, also damaging ecosystems, and consequently causing the extinction of several species of animals and plants. Trees absorb carbon dioxide, a gas responsible for the greenhouse effect, therefore, deforestation will lead to an increase in global warming. Other consequences of this activity are the interference with river systems, increasing erosion and desertification as well as land degradation. The rapid loss of forests worldwide led to the creation of the first forest certification, in the late 1980s (World Bank, 2004).

In 1993, the Forest Stewardship Council (FSC) was created with the objective of promoting forest practices that do not harm the local economies or environment. After the launch of the FSC, wood producer groups and forest industry associations from different countries designed their own competing schemes and joined the Program for the Endorsement of Forest

Certification Schemes (PEFC). Both PEFC and FSC intend to control the trade in illegally logged wood products and promote sustainable forestry (Elliott, 2000).

The Manual of Forest Management System of Portugal was created through a combination of different organs, such as the Association for the Competitiveness of Industries of Forestry (AIFF), the Portuguese Cork Association (APCOR), the Association of Paper Industry (CELPA) and the Association for the Recovery of Pine Forest (PINUS Centre). Its main purpose is to contribute to the achievement of the FSC and PEFC certifications together with the organizations of forest producers (Manual of Forest Manager System, 2015).

The main agents of the Portuguese Forest Sector have created in 2007 the Association for Responsible Forest Management (AGFR), which aims to regulate the FSC certification scheme in Portugal. FSC International created the FSC National Office in Portugal in 2010 and, in 2014, the forest area certified by the FSC in Portugal reached about 350,000 hectares, 11% of the national forest area (Manual do Sistema de Gestão Florestal – Manual of Forest Manager System, 2015).

C3. ENERGY

Energy control, aiming to decrease environmental impacts, is essential in the proposed methodology. Energy consumption occurs through all phases of the life cycle of a construction, beginning with the production of materials and continuing in the use phase (Barbosa, 2013). This category contains three indicators: “energy consumption” (I5); “renewable energy” (I6); and “commissioning” (I7) (Saraiva et al., 2019b).

Indicator 5 – Energy consumption

Much of the energy used for human consumption comes from oil and coal, causing emissions into the atmosphere and, therefore, huge environmental impacts. One of the main factors responsible for climate change and global warming has to do with high energy consumption (IEA, 2013). This consumption has increased in order to meet the needs of global economic growth, however, the natural process to restore these energy sources is very slow (National Academy of Sciences and The Royal Society, 2014).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, specifically:

- Assists the decrease of energy consumption in constructions, through the use of passive solutions and efficient equipment;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education, SBTool for K-12 Schools and LEED BD+C Schools, include this indicator;
- This indicator is part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator “Energy consumption” in the SAHSB^{PT} methodology.

When the EPE executed the refurbishment work of the high school buildings, in the Portuguese legal system there was a set of instruments that encouraged and regulated an efficient energy management of existing buildings, such as: RECS (Regulamento de Desempenho Energético dos Edifícios de Comércio e Serviços– Energy Performance Regulation of Commerce and Services Buildings), according to the Decreto-Lei 118/2013 (Decree-Law 118/2013).

The three main aspects that affect the built environment are thermal comfort, indoor air quality and energy efficiency. The main costs in schools are related to ventilation, cooling and heating systems (Papadopoulos & Avgelis, 2003), therefore, appropriate design strategies and the selection of building elements are very important for the construction or refurbishment of a school building (Serghides & Georgakis, 2012).

As a result of the work of Katafygiotou and Serghides (2014), some conclusions were drawn, such as: the hot water system must only be provided by solar panels; north or south orientation seems to consume less energy; the cooling system must be limited to office spaces; the horizontal roof is more efficient than the sloping roof; the most energy efficient shape for school buildings is the rectangular shape; the central heating system should be upgraded and renewed at least every ten years; and ground floor buildings need less energy than the multi floor school buildings (Katafygiotou & Serghides, 2014).

Several important Portuguese decree-laws are Decree-Law No. 78/2006, SCE (Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior em Edifícios, National

Certification System for Energy and Indoor Air Quality in Buildings); Decree-Law No. 79/2006, RSECE (Regulamento dos Sistemas Energéticos de Climatização em Edifício, Regulation for Energy Systems and Air Conditioning of Buildings) and Decree-Law No. 80/2006, RCCTE (Regulamento das Características do Comportamento Térmico dos Edifícios, Regulation of Thermal Performance of Residential Buildings) (Torres, 2012).

According to those systems and regulations, every building should have the lowest possible energy consumption. Therefore, the choice of equipment and systems and their management should follow certain criteria aimed at ensuring energy efficiency. In the context of Energy Efficiency, Indoor Air Quality and Sustainability, the following measures were promoted depending on the type of building (RSECE, 2006).

In the first place, most laws that legislate on energy in Europe emerged as a response to EU directives, specifically the Energy Performance of Buildings Directive, EPBD 2002 (European Council, 2002). The energy policy EPBD 2002 started with energy labelling and the EPBD Recast (EU Parliament, 2010) has created specific requirements for measurements and control.

Through previous directives of the European Parliament, of the European Council and national Decree-Laws, the Portuguese State has gained experience in this area, thus improving the diagnosis of the practical application of energy efficiency concepts as well as the effectiveness of energy certification systems. The transposition into the Portuguese law of the Directive No. 2010/31/EU of the European Parliament and Council, related to the energy performance of buildings (EPBD-recast), led to the enactment of the Decree-Law No. 118/2013 (Portugal, 2013), whose application significantly contributed to the improvement in the performance of the buildings.

Both the definition of the requirements and the evaluation of the energy performance of service and trade buildings are based on the installation and maintenance of technical systems, being also taken into consideration whether the buildings are new, undergoing major intervention or already existing. Energy efficiency requirements evaluate the thermal quality, lighting systems, power management, water heating, air-conditioning and the use of renewable energy (Portugal, 2013).

Since the scope of this work is a school environment, almost entirely occupied by children who need a high level of concentration to study for at least five hours a day, it is necessary to give higher priority to thermal comfort, which directly interferes with the use of energy.

Indicator 6 – Renewable Energy

Renewable energy is the energy produced from non-fossil sources, such as hydrothermal, solar, biomass, biogas, wind, aerothermal and hydroeletric (Portugal, 2013).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, such as:

- Assists the use of energy from renewable sources, reducing the consumption of energy produced from fossil sources;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education, LEED BD+C Schools and SBTool for K-12 Schools include this indicator;
- This indicator is part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described before, it was decided to maintain the indicator "Energy consumption" in the SAHSB^{PT} methodology.

In regulatory terms, the construction or refurbishment works of high school buildings executed by the *Parque Escolar* (EPE) promoted some measures concerning the use of renewable energy (Solar Thermal and Solar Photovoltaic). Regarding solar energy, it is expected that the heating of water for the bathrooms will be done using a solar energy facility and other support systems (Portal Parque Escolar, 2018).

According to Alnaser et al. (2008), the economic and feasibility justification for the use of renewable energy systems for applicability in urban areas comes from the effects on maintenance and operating costs, from the effects on the costs of the initial construction and from the reduction of fossil fuel consumption (Alnaser et al., 2008). There are still some obstacles to the general use of renewable energy systems, as the high initial costs, the lack of government support, the lack of appropriate and affordable technologies, the lack of awareness and the lack of appropriate facilities and planning approaches (Yunus & Yang, 2011).

Currently, several types of renewable energy are used for different applications. The technologies used to convert natural energy into usable energy are wind turbines, ground source heat pumps, PV (Photovoltaic) modules, vacuumed solar, water heaters, and some other hybrid systems that are a combination of renewable technologies. The common renewable energy systems used for buildings are fuel cells, wind and geothermal energy, and passive and active solar energy (Heravi & Qaemi, 2014).

Renewable energy plays an important role regarding the energy conservation of the building. Research on hybrid energy systems demonstrates that there are two ways to achieve carbon reduction and energy conservation in a building: energy-saving building materials and the development of hybrid renewable energy (Ho et al., 2014).
A hybrid energy system is a combination of two or more options for generating electricity based on fossil fuels or renewable energy. Several configurations of hybrid energy systems can be used for power generation, such as wind–PV based installation, PV–wind–hydrogen/fuel cell hybrid energy systems, PV–wind–diesel systems, biomass–wind–PV installations and hydro–wind–PV based systems, among others (Sunanda & Chandel, 2014).

Hybrid energy systems have some advantages in comparison to systems based on a single source, some of these advantages being as follows: small energy storage, better efficiency and higher reliability. However, when a hybrid energy system is not properly planned, or when it is oversized, the installation cost becomes high. The economic and technical analyses of a hybrid system are very important for the efficient use of renewable energy resources (Sunanda & Chandel, 2014).

A school campus is an urban space that can provide a foundation for promoting the sustainable development of a city, and can serve as a promoter, pioneer and demonstrator. The refurbishment of a school building can promote the use of renewable energy, helping to reduce electricity consumption, serving as teaching materials and supporting renewable energy education in the school environment (Ho et al., 2014).

The Decree-Law No. 118/2013, published in 2013, included in a single diploma the REH, the RECS and the SCE. The RECS, which is specific to the energy performance of service and trade buildings, is based on the maintenance and installation of technical systems. The incentive for the use of renewable energy sources has thus been added to energy efficiency, focusing on methods to quantify their respective contribution (Portugal, 2013).

Regarding buildings in Portugal, priority is given to the use of solar resources, abundantly available in this country. By means of the maximum reduction in energy consumption achieved through the use of renewable energy sources, there is an intention to apply the concept of "new public buildings of nearly zero energy" to other buildings, from 2019 or 2021 (Portugal, 2013).

Indicator 7 – Commissioning

Project commissioning is the procedure of assuring that all systems and components of a building plant are installed, designed, maintained, and operated along with the operational requirements of the owner, and should be applied to new or existing projects (Djuric & Novakovic, 2007).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, as:

- Encourage the use of suitable management of all the mechanical systems of a construction over its life cycle, supporting the decrease of environmental impacts, energy and costs consumption, improving the functionality of the construction;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education, LEED BD+C Schools, and SBTool for K-12 Schools, include this indicator;
- This Indicator is not part of SBTool^{PT} STP for Office Buildings, as well as SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator "Commissioning" in the SAHSB^{PT} methodology.

Parque Escolar provides proper management of all mechanical systems in high school buildings. This company is responsible for refurbishments and construction of more than 74% of all existing school buildings in Portugal, therefore, the majority of the high school buildings in the country have a good commissioning plan. According to the guidelines established by the EPE, in all high school buildings there must be a person responsible for the maintenance of the

HVAC systems, who has control of all heating and cooling systems through a cell phone and a computer, being able to detect the problems that may occur with the equipment whenever they occur.

The commissioning process includes the integrated application of a set of engineering measures and techniques to check each operational component of the project, such as equipment and instruments (Fares et al., 2010). Therefore, commissioning tools and methods must guarantee that buildings operate with energy efficiency and reach their technical potential. It is also a process that ensures that all building facility systems are executed interactively in conformity with the design documentation, accepting different guidance, procedures and methods (Djuric & Novakovic, 2007).

The Commissioning Plan is the main tool that provides different actors with an understanding of what is meant by commissioning in a specific project, how much money and effort will be required, and how it will be managed (ANNEX 40, 2004). It detects how the commissioning process will be organized at all phases of the life cycle of the building, from the moment of design to the use of the building. Finally, this document also identifies all team members, their responsibilities and roles (Bulbul & Akin, 2006).

Continuous Commissioning is an ongoing process to identify retrofits, solve operational problems, optimize energy use and improve the comfort of both existing and new buildings. In this process, a comprehensive engineering evaluation is performed, followed by the identification of the optimal operational parameters created under measured conditions, and after that, new schedules are implemented. The commissioning process is called continuous because it should be reviewed periodically to identify operational problems and propose corrections (Tremblay & Zmeureanu, 2014).

From the beginning of the design of a building, the commissioning process should be concerned with verifying whether a program and the design are in accordance with the functionalities desired by the owner. In the course of the construction process, commissioning intends to ensure that the performance of the building meets the stated decision regarding the design specifications (Bulbul & Akin, 2006).

There are some obstacles that delay the use of commissioning, such as high costs, and lack of awareness and time. Therefore, consideration should be given to how new tools, methods and organizations can reduce costs, raise awareness and validate the benefits obtained from commissioning (ANNEX 40, 2004). Every building should adopt the use of commissioning; therefore, school buildings are included.

C4. MATERIALS, SOLID RESIDUES AND RESOURCES MANAGEMENT

The construction industry is one of the major generators of solid waste. The production of waste occurs during demolition, construction and use phase. This category includes three indicators: "reuse and recycle materials" (I8); "environmental management plan" (I9); and "flexibility and adaptability" (I10) (Saraiva et al., 2019b).

Indicator 8 - Materials reused and with recycled content

Reuse and Recycling can only be planned in the design phase, i.e., they refer to the construction material that goes into the production of a building. These practices include skilful techniques and different measures to minimize the volume of construction and demolition waste (CDW). This indicator includes the indicators "Reused materials" (I10) and "Recycled materials" (I11) from the SBTool^{PT}-STP for Office Buildings for a new function. "Recycling of materials" is related to the reuse in another construction of materials of a construction after the end of its life cycle and after a suitable treatment (Poon, 2007).

Some features justify the permanence and importance Several aspects justify the permanence of this indicator in the SAHSB^{PT} methodology, specifically:

- Encourages the use of recycled and reused materials in new constructions, consequently reducing the energy and the cost required to produce new materials;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education, SBTool for K-12 Schools, and LEED BD+C Schools include this indicator;
- This Indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator "reuse and recycle material" in the SAHSB^{PT} methodology.

According to the United States Environmental Protection Agency, reuse and recycling solutions have several benefits, since these practices help conserve energy, save money for consumers and businesses, reduce pollution, save natural resources and reduce the toxicity of the waste (US EPA, 2012).

The EPE standards define that floor and wall covering materials must be maintained, modified and remodelled according to the aspects of each school environment (Portal Parque Escolar, 2018).

According to Norby (2008), the last century was a period of inordinate innovations in building materials. There are currently about 100,000 types of these materials, and most of them are not appropriate for recycling and reuse. The recent concern about the environmental and economic impacts caused by the disposal of these materials has led to several countries drafting new legislation and taking further action to minimize these problems (Norby et al., 2008).

The internationally accepted guidelines for the practice of waste management follow the waste management hierarchy (Figure 4.1.), focusing on reducing waste at source. Reuse should be explored and, if waste cannot be reused, the option of recycling should be encouraged (US EPA, 2006).

Figure 4.1. Solid waste management hierarchies (EPA, 2006)

After reuse, recycling is the best alternative, as it can offer three benefits (Tam, 2008): reduce the demand for new resources; reduce energy production and transportation costs; use CDW rather than disposing it in landfill sites. Two major concerns about recycling are the acceptability of recycled materials and their economic viability, since the general public often expresses concern about the quality of reused or recycled materials (Tam & Tan, 2007). Reusing and recycling CDW reduces the use of energy incorporated in a new building that will eventually be built, either for the reason that the construction waste is not sent to the landfill or because less energy is required due to the use of existing building materials (Vefago & Avellaneda, 2013).

The reuse of building components is an alternative in the demolition and refurbishment of buildings, through the execution of building deconstruction, which enables the recovery of building parts as functional components, such as tiles, windows and bricks. The evaluation of the end-of-life stage should include the benefits and impacts regarding the reuse and recycling potential of the CDW. These benefits and impacts are particularly important for recyclable and reusable construction materials (CEN, 2012).

Indicator 9 - Environmental management plan

The increased attention and concern about the environmental impact of construction has led some organizations to look for ways to reduce exposure to environmental risks. Therefore, a large number of construction companies have invested in the implementation of an Environmental Management System. The establishment of an EMS provides many benefits, such as better use of staff and resources, better public reputation, better management of regulatory compliance and reduction of environmental risks (Tinsley & Pillai, 2006).

Some features justify the permanence of this indicator in the SAHSB^{PT} methodology, such as:

- Promotes the control and management of the entire property, solving problems in a more efficient and faster way, identifying possible malfunction in several sectors, avoiding environment and financial damages;
- The methodologies applicable to schools (Table 4.2.), as LEED BD+C Schools and BREEAM Education, include this indicator;
- This Indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described before, it was decided to maintain the indicator “environmental management plan” in the SAHSB^{PT} methodology.

Nowadays, energy and environmental management are becoming the key concerns in the construction sector, and these are supported by some international standards such as ISO 14001 or ISO 50001. The ISO 14001 – International Standard for Environmental Management, established in 1996 and based on the BS 7750, specifies the requirements for an environmental management system to enable a company to develop and implement an organizational policy, taking into account legal requirements. Some of the main objectives that must be addressed in an EMS are (NP EN ISO 14001:2004):

- choose cleaning products and detergents that are of the low environmental impact type;
- control and reduce hazardous air emissions;
- provide a monitoring system for water and energy consumption;
- offer proper management of solid waste produced in the use phase;
- supply equipment used in buildings, such as appliances and lamps;
- provide a User Manual.

Municipal solid waste management is a major problem of modern society, causing serious environmental problems. This requires complex solutions, such as adequate logistics of collection and disposal as well as efficient screening, aimed at achieving sustainability in environmental, economic, political, cultural and social aspects (Rada et al., 2013).

The energy efficiency of buildings relates to the presence and behaviour of occupants in the building, energy prices, operational characteristics of the building and installed systems and devices. Energy measurement helps reduce costs through the detection of inefficiencies, using internal and external benchmarking and improving the use of energy and load planning (Genet & Schubert, 2011).

Some appliances have energy efficiency labels that inform the class to which the equipment belongs. When choosing an appliance, the buyer should always consider its degree of efficiency to obtain an object that performs its functions with the lowest energy consumption (Ecosave, 2011). Another aspect that interferes with the energy consumption of a building is lighting, therefore, it is important to choose the most appropriate type of artificial lighting solutions for each situation (Saldo Positivo, 2016).

The user manual of a building should be developed in accordance with current rules and legislation, as an important instrument of the construction company to instruct users and other responsible persons about the use, maintenance and operation of building equipment in the correct manner, considering the particularities of its design. The management of a maintenance system should take into account the characteristics of the buildings, such as location, environmental implications, size, complexity, type and effective use of the building. A construction cannot be considered as a disposable product and should serve its users for many years (NBR 14037: 2011 Fixed: 2014).

Indicator 10- Flexibility and adaptability

Buildings that have technologies and designs that allow flexibility and adaptability bring several benefits. There is consensus in the literature on the concepts of "adaptability" and "flexibility" in construction, with adaptability being defined as the ability to change for different social uses, while flexibility is defined as the ability to change with different layouts (Groak, 1992).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, such as:

- Assists the decrease the need for repairs related to electrical and communication systems; plumbing and water system; and air conditioning and ventilation systems. It also decreases the need for main reforms related to alterations in the function of a specific environment through the modularity systems of compartments. Therefore, it reduces the necessity to use new construction materials, thereby decreasing environmental impacts and costs;
- The methodologies applicable to schools (Table 4.2.), as SBTool for K-12 Schools, BREEAM Education, and LEED BD+C Schools, include this indicator;
- This Indicator is part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator "flexibility and adaptability" in the SAHSB^{PT} methodology.

There are still few concerns about adaptability and flexibility in Portuguese school buildings. As this is a new theme, those schools built before the introduction of this theme in Portugal were not designed to be adaptable. One of the objectives of the EPE is “to ensure adaptability and flexibility of the learning and non-learning spaces, in order to maximize their use and minimize future investments” (Portal Parque Escolar, 2018).

With the economic and technological advances of the last decades, the time of use of a building, regarding its functionality, has been reduced (Schmidt III et al., 2010). Buildings usually have a useful lifetime that is longer than its function, and for this reason, buildings should be easily adaptable to new functions to extend their life cycle.

Flexibility is associated with requirements for the upgrade and maintenance of buildings throughout their life cycle, allowing for internal changes in high-turnover environments. Cost, effort and renovations will be reduced if buildings are designed to provide flexibility. Technological growth and rising consumer expectations (ageing population) increase the need for changes in the buildings (Slaughter, 2001).

Adaptability is the ability of the construction to “fit” a purpose (Ridder et al., 2008, etc.), by “changing its capacity, function or performance” (Douglas, 2006). It may occur before the building is occupied, through the initial choices in a project, or after building occupancy, through changes made by new users. It can occur through the understanding of physical and spatial differences between different uses, also with an interference of environmental, social, legal, technical, economic and political forces by designing architecture within a holistic context, with awareness of change and of time. Adaptability brings an understanding of time, with an emphasis on process, allowing the building to “learn” from users (Beadle et al., 2008).

For high schools to be planned in a flexible and adaptive way, versatility should be sought to accommodate the new requirements of the physical environment. It is needed to design high schools that can be adapted to new proper conceptions, or even to new non-educational functions.

C5. WATER

The select of appropriate equipment and materials in the design phase supports decrease water consumption. This should be decreased in the construction phase, but especially in the use phase of a construction. This category includes three indicators: “water consumption” (I11); “water treatment and recycling" (I12); and "collection and reuse of rainwater" (I13) (Saraiva et al., 2019b).

Indicator 11- Water consumption

Water is essential to human life. Currently, 97.5% of the world's water resources represent salty water, with only 2.5% representing fresh water (Rozin et al., 2015). Population increase, urbanization, changes in human lifestyle, climate change, environmental degradation and depletion of natural resources are related to the growing demand for water, causing serious consequences for human health (UNESCO, 2014). There have also been changes in lifestyle, such as the emergence of dishwashers and washing machines, as well as the use of modern showers and baths (Schleich, 2009), which have aggravated the imbalance between demand and availability of freshwater resources (Almeida et al., 2013).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, specifically:

- Encourages the reduction of water consumption inside buildings and in surrounding areas; consequently, it decreases the environmental impacts and the cost related to water consumption;
- The methodologies applicable to schools (Table 4.2.), as SBTool for K-12 Schools, BREEAM Education and LEED BD+C Schools, include this indicator;
- This indicator is part of the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal, as well as of the SBTool^{PT} STP for Office Buildings.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator "water consumption" in the SAHSB^{PT} methodology.

In the school environment, there should be concerns related to water saving, mainly in washbasins, toilets and showers. The determinations related to water consumption present in the guidelines elaborated by the EPE state that the faucets used in bathroom sinks, kitchens and showers, as well as water equipment used in toilets, should be rigorously selected in order to maximize water savings.

Many countries have invested in technological treatments, aiming to develop alternative sources of water to meet the demands for drinking water (NRC, 2012). Proper water management is a growing concern of governments, not only as a way to help ensure future water supplies, but also as a tool to reduce environmental impacts (Beal & Stewart, 2014). Currently, smart water meters have been used for washing machines, showers, faucets and toilets (Willis et al., 2013).

Another important aspect regarding the conservation of drinking water would be the use of water respecting and regulated by peak times. The peak in water demand varies throughout the day, being usually lower during late night and highest in the evening and in the morning. This peak of demand is variable, usually impelled by seasonal factors (Gurung et al., 2015).

The increase in tariffs is another factor that may also contribute to a more efficient use of water (Romano et al., 2014A). This has to do with the fact that wealthier consumers use more water than lower income consumers, existing, therefore, a correlation between income and water consumption. However, on the other hand, the increase in income may result in a reduction in water consumption as well, through the use of more efficient technologies and better maintenance of water distribution systems (Katz, 2015).

In buildings, water loss is very common and is usually caused by leaks in bathrooms and hydraulic equipment. These losses verified in water distribution systems are usually the result of incorrect maintenance procedures, bad habits of the users and errors of design (Gois et al., 2015), and they may reach between 10% and 70% of the distributed water (Xu et al., 2014).

The reduction of water consumption is also linked to energy saving, inside and outside the building, given that the reduction in water use for buildings purposes decreases the amount of energy required to remove the water (Fidar et al., 2016).

The interventions in water use systems in school buildings can cause large-scale changes, thus affecting all heterogeneous stakeholders with diverse interests. Therefore, it is necessary to have a systemic approach that incorporates operation rules, physical structure, system performance and the interaction with system components (Angelis-Dimakis et al., 2016).

Indicator 12- Water treatment and recycling

The successful establishment and implementation of new applications in existing or future water recycling systems depends on several factors, such as environmental impacts, health risks, social attitudes, economic status and technical concerns (Chen et al., 2013).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, such as:

- Assists the reuse of water inside buildings and in the surroundings using grey water, groundwater or recycling devices. Therefore, as the indicator “water consumption” (I14), it reduces the environmental impacts and the cost related to water consumption;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education, LEED BD+C Schools and SBTool for K12 Schools, include this indicator;
- This Indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator “water treatment and recycling” in the SAHSB^{PT} methodology.

There is no determination with regard to water treatment and recycling in the guidelines established by the EPE, regarding the refurbishment and construction of new schools (Portal Parque Escolar, 2018).

Population growth and climate change have greatly increased the demand for water, causing depletion of natural water resources (Chen et al., 2014). Water supply from traditional sources is not enough to meet the demands and, as a result, in recent decades, environmental concerns related to this issue have increased. Some solutions to these problems are the reduction in consumption, the use of non-traditional sources (sea water or rainwater) and the increase in the purification of traditional sources by wastewater recycling (Luckmann et al., 2016).

Current applications of recycled water are still quite limited, usually used for certain purposes that do not require drinking water, such as car washes, industrial uses, irrigation and toilet flushing. Advanced studies and experiments have greatly increased the chances of developing new uses for recycled water in both rural and urban areas that can contribute to the conservation of freshwater (Chen et al., 2014). Despite the apparent force of the recycled water issue, water reuse can be affected by a variety of factors, such as public acceptance, environmental concerns, costs and regulations on water rights (NRC, 2012).

The reuse of greywater (Figure 4.2.) involves the collection and treatment of water used inside the building. Several studies have reported potable water savings of between 25% and 50% when reusing greywater (Zhang et al., 2010).

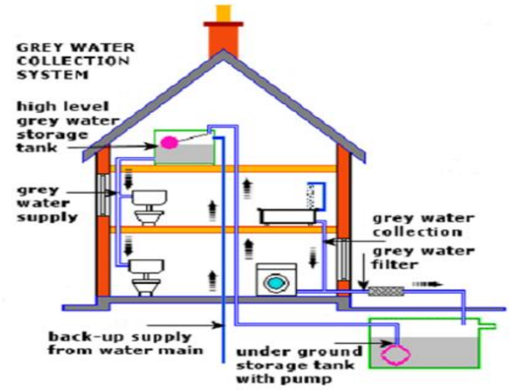

Figure 4.2. Greywater collection system (Baltasound Development, 2015)

The water from sinks, baths, washing machines and kitchen appliances, named greywater (GW), may contain soaps, fibres, oils, foods, detergents, nutrient salts, pathogenic micro-organisms, fats and hair particles. Therefore, it is necessary to be careful with the reuse of GW, thus avoiding any human contact, and it must also be properly managed because these contaminants can degrade the structure of the soil, or obstruct the flow of groundwater (Oron et al., 2014).

Several high schools around the world treat and recycle their greywater through different systems. It is not possible to identify the value of recycled GW, since it depends on the method utilized and the water needs of each region (Chen et al., 2013).

It is estimated that each inhabitant spends between 100-180 L / day of water in Portugal (Al-Jayyousi, 2003). The amount of the corresponding greywater emitted in a residence is between 50-80% of the total water used in a residence, and around 50% in a school, therefore, reuse represents great savings (Al-Jayyousi, 2003). Studies on the reuse of greywater show savings of 30% to 50% when greywater is reused for garden irrigation, floor washing and toilet flushing (Jeppesen, 1996).

Indicator 13- Collection and reuse of Rainwater

To properly reuse the Rainwater (RW), it is necessary to establish common definitions of performance as well as ways to compare the dual purpose of water supply and drainage capture (Gold et al., 2010).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, such as:

- Promotes the reuse of water inside and around buildings using aquifer recharge and collective tip flow in rainwater (RW) drainage systems. Therefore, as the indicator "water consumption" (I11) and the indicator "water treatment and recycling" (I12), it decreases the environmental impacts and the cost related to water consumption;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education, LEED BD+C Schools and SBTool for K-12 Schools, include this indicator;
- This Indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described before, it was decided to maintain the indicator "collection and reuse of rainwater" in the SAHSB^{PT} methodology.

There is no determination regarding the collection and reuse of rainwater in the guidelines established by the EPE referring to the reform and construction of new schools (Portal Parque Escolar, 2018).

Certain factors such as climate change, the significant growth of population and lifestyle changes generate high water demands and, consequently, increase water shortages in urban areas (Umapathi et al., 2013). Currently, one of the major concerns of businesses, industries and institutions is the large amount of freshwater used in their construction systems (Nunes, 2006). Water reuse and conservation creates several environmental benefits, such as the reduction of water consumption, wastewater discharges into natural water bodies and proliferation of the algae eutrophication (Anderson, 2003).

Extending water supply and reducing flow brings benefits to system management (Sample & Liu, 2014). New regulations and incentives for local, regional and national levels related to the use of rainwater are being developed around the world (Domenech & Saurí, 2011).

Some studies have been performed regarding rainwater tanks, such as the assessment of the economy (Hall, 2013), rating scale of their economies (Gurung & Sharma, 2014), water quality (Ahmed et al., 2014), tank optimization (Imteaz et al., 2012), energy efficiency (Umapathi et al., 2013) and monitoring system of community tanks of rainwater in a commercial building (Cook et al., 2014) and in a residential area (Cook et al., 2013).

In a study in Barcelona, it was found that Rainwater Harvesting (RWH) could meet the needs of external and domestic demand of a building, however, due to high capital expenditures, there was a very long payback period (Domenech & Saurí, 2010).

The components of a RWH system, as shown in Figure 4.3, generally include a filter to remove the initial portion of the roof drain; a pump, if necessary, to provide the system with rain water collected from the roof; and a storage tank (also known as cistern). Rainwater harvesting is a water conservation practice that assists in water quality as it reduces runoff (Sample & Liu, 2014).

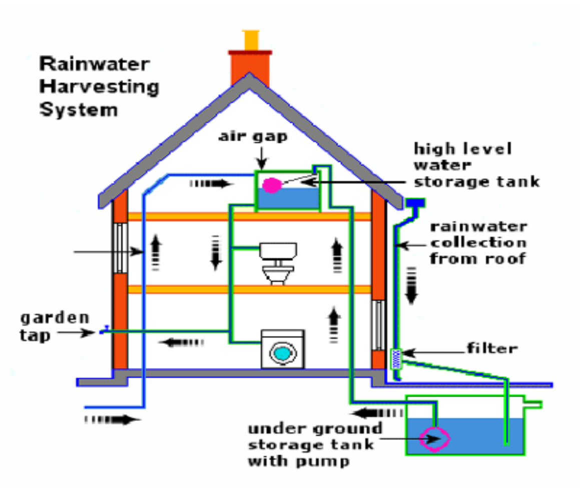

Figure 4.3. Rainwater Harvesting System (Baltasound Development, 2015)

C6. USER HEALTH AND COMFORT

The quality of life, health and productivity of building occupants are related to internal environmental quality. It is important to include and maintain comfort indicators in a sustainability assessment of school environments, since students spend long periods of time in the learning environment, and discomfort interferes with their health, concentration and learning [22]. This category includes five indicators: “indoor air quality” (I14); “thermal comfort” (I15); “visual comfort” (I16); “acoustic comfort” (I17); and “ergonomic comfort” (I18) (Saraiva et al., 2019b).

Indicator 14- Indoor air quality

Indoor air quality intents to support the proper level of indoor air quality. Indoor Air Quality (IAQ), which is the ability of the building to maintain the well-being and health of its users. Adequate humidity, air quality and temperature are essential for the health and comfort of the users of the building (Yang et al., 2015).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, as:

- Assists the suitable level of indoor air quality to maintain the health and the well-being of its users;
- The methodologies applicable to schools (Table 4.2.), as SBTool for K-12 Schools, LEED BD+C Schools and BREEAM Education, include this indicator;
- This indicator is part of the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal, as well as the SBTool^{PT} STP for Office Buildings.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator “Indoor air quality” in the SAHSB^{PT} methodology.

The objectives of the EPE include “improving living conditions and environmental comfort, with particular emphasis on hygrothermics, acoustics and air quality”.

Indoor environmental quality has a significant impact on modern life throughout the world. Nowadays, people spend more time inside buildings, resulting in increased exposure to the action of a wide range of pollutants. These pollutants are related to the materials used in the construction and maintenance of a building, the HVAC systems, and the quality of the outdoor air. Reduced IAQ can cause serious health problems, such as chronic skin and respiratory diseases, and may also influence the behavioural patterns of building users, which reflects on their productivity and well-being. According to the American Society of Heating Refrigeration Air Conditioning Engineers (ASHRAE), IAQ can be considered acceptable if the indoor air does not exhibit harmful concentrations of contaminants, or if more than 80% of people exposed to a particular indoor air have no dissatisfaction with the conditions of the IAQ (ADENE, 2007).

Three processes should be considered for proper management of the IAQ: emission source control, measurement of indoor air quality and verification of ventilation, and these three processes occur in different phases of the lifecycle of a building. Thus, emission source control happens through the choice of materials for the internal environment (Wei et al., 2015).
Indoor air quality is measured to verify if internal pollutant concentrations are within the limits established by local laws, and this measurement may occur before or after the occupation of a building. Several laws and regulations on the comfort of the indoor environment vary between countries due to different economic, environmental, historical and political contexts (Wei et al., 2015).

Natural ventilation is one of the most economical and simple ways to reach interior thermal comfort and is an effective tool for eliminating or reducing indoor pollutants emitted from internal sources, thereby improving IAQ. The purpose of ventilation is to provide suitable air renewal inside a building environment to achieve good indoor air quality. Artificial or natural ventilation can be used in accordance with the specific needs of each environment (Yang et al., 2015).

Regarding the physical parameters, the following should be considered: (i) the minimum new air flow, fixed according to the type of activity of the building; (ii) relative humidity; (iii) proper temperature and; (iv) air velocity. As for chemical parameters, the amount of chemical pollutants should be checked, as these can cause harm to human health. The most common pollutants that can be found in indoor building environments are (ADENE, 2007):

- Formaldehyde, which can cause irritation to the throat, nose, eyes and respiratory system, besides nausea, headache and fatigue;
- Carbon monoxide, which can prevent the inhalation of oxygen and, therefore, lead to death;
- Carbon dioxide, which can cause fatigue, eye and throat irritation, and headache;
- Tobacco smoke, which can cause numerous diseases;

- Ozone, which can cause chest tightness, cough, allergic reactions, eye irritation, dry mouth and throat, and headaches;
- Airborne particles, which may cause irritation to the skin and mucous membranes;
- Volatile organic compounds (VOCs), which can cause red eyes, dryness of the mucous membranes of the nose and throat, headaches and fatigue.

One of the most important environmental parameters that needs to be controlled is carbon dioxide, and that can only be achieved through proper ventilation (Ghita & Catalina, 2015). Education and communication are very important factors because if users and management operators are able to communicate and understand the causes and consequences of IAQ problems, they can work more effectively to prevent problems from occurring or solve them when necessary.

The IAQ in school buildings is one of the most important factors, as students spend about 25% of their daily time in classrooms, making it imperative that the indoor climate does not affect the intellectual performance, health and comfort of the students (Cartieaux et al., 2011). The comparison made between the effects caused by inefficient air quality in schools and the effects in office buildings has demonstrated the existence of a lower performance in children than in adults, which means that children are more susceptible to environmental conditions (Wargocki et al., 2012).

Inadequate IAQ conditions in classrooms can lead to a reduction in children's performance of up to 30%. High CO_2 concentrations are a result of poor ventilation and these low ventilation rates hinder teaching and learning by reducing the concentration and the memory of students (Bako-Biro et al., 2012).

Indicator 15 - Thermal Comfort

The environmental conditions required for comfort are not the same for everyone, since there are large variations from each person, making it hard to satisfy everyone. Therefore, "an environment must provide thermal conditions so that at least 80% of the occupants are satisfied with the thermal environment" (ASHRAE, 2004).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, namely:

- Supports the adequate level of thermal comfort to maintain well-being and health of its users;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education, LEED BD+C Schools and SBTool for K-12 Schools, include this indicator;
- Indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator “thermal comfort” in the SAHSB^{PT} methodology.
One of the objectives of the EPE, as mentioned in the previous indicator – Indoor air quality – is “to improve living conditions and environmental comfort, with particular emphasis on hygrothermics, acoustics and air quality”. According to the guidelines of *Parque Escolar*, temperatures should be kept stable; therefore, classrooms should always remain with the cooling or heating system operating to maintain the ideal temperature. The schools that have temperature control systems do not need to be evaluated by this indicator.

Human thermal comfort can be addressed through two approaches, the adaptive model and the classical model. The adaptive model relates acceptable temperature ranges or indoor design temperatures to external climatological or meteorological parameters (outdoor air temperature) (Udreaa et al. 2016).

Environmental comfort depends on the characteristics of each individual. Thermal comfort indices seek to represent in one parameter different environmental variables. There are about thirty indicators of thermal comfort, with several functions being used in the current environmental conditions. These indices can be classified as subjective, physiological and biophysical (Xavier, 2000).

Biophysical indices are the most common and are based on heat exchange between the body and the environment. Subjective indices are related to thermal perception in a group of people in field and laboratory experiments. Finally, physiological indices are based on metabolic reactions caused by variations in environmental conditions (air velocity and air humidity, average radiant temperature and dry air temperature) (Fernandes, 2009).

Another example of bioclimatic evaluation methods is the Bioclimatic Letters of Olgyay and Givoni, which are graphical representations of the relationship between climate and thermal comfort. This work aims to connect visual variables such as design strategies, physiological patterns of thermal comfort and weather conditions. Bioclimatic charts, which were the first thermal comfort diagrams, combined dry bulb temperature and relative humidity, determining comfort zones and showing how these areas can be transformed in the presence of sunlight and ventilation (Fernandes, 2009).

The bioclimatic chart developed by Givoni in 1969 (Figure 4.4.) was created to correct the limitations of the bioclimatic diagram designed by Olgyay. The main difference between these two systems is that the Olgyay diagram is drawn between two axes, while the work of Givoni is drawn over a standard psychometric chart (Givone, 1992).

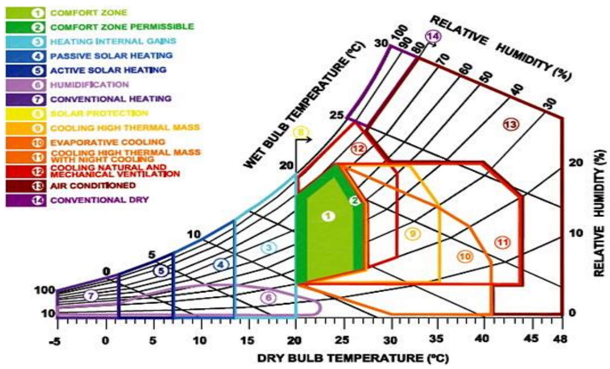

Figure 4.4. Bioclimatic chart developed by Givoni (Hosseini et al., 2016)

According to Barrett et al. (2015), thermal comfort is related to the learning progress, as students usually perform better in the classroom if the temperature is easy to control (Barrett et al., 2015).

Indicator 16- Visual Comfort

The visual comfort is the main aspect to be considered regarding the illumination needs of a construction. It is related to the set of artificial and natural light conditions, in a particular environment, under which human beings can improve their tasks with less works, with reduce risk of accidents, with less risk of eye damage, and with the maximum visual accuracy (Lamberts, 1997).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, specifically:

- Encourages the suitable level of visual comfort to maintain the well-being and health of its users;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education, LEED BD+C Schools and SBTool for K-12 Schools, include this indicator;
- Indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as of the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspect described above, it was decided to maintain the indicator “visual comfort” in the SAHSB^{PT} methodology.

According to the guidelines of *Parque Escolar*, as mentioned in the indicator “indoor air quality” (14), one of the objectives of the EPE is “to improve living conditions and environmental comfort”, however there is no specification related to visual comfort.

Visual comfort can also be defined as the adjustment of the relative and absolute brightness levels of objects related to the environmental activities, where the light sources are used to illuminate these objects. A person should be able to see, without suffering stress or injury to the eyes, the area and objects related to the activity performed, without the interference of what diverts attention from the task. Therefore, good lighting should provide no glare, should provide good colour definition and must be sufficiently intense (Schmid, 2005).

Light is an essential element in people's lives. Technologies involving lighting systems have been developed over the years and nowadays there is a wide variety of equipment available for various uses. Lighting quality is crucial in relation to the human well-being, to the performance of activities, also having influence on the human emotional side (PROCEL, 1993).

It should be checked the subjective perceptions and the preference of the users regarding the luminous comfort, according to the various activities that happen in an indoor environment. Thus, by integrating objective and subjective aspects, three fundamental aspects of learning spaces are achieved: efficiency, comfort and performance resulting from appropriate design (Monteoliva et al., 2015).

Daylight penetration into a building is important to ensure good performance and visual comfort for the occupants of the building. This comfort can be achieved by providing enough illumination levels and good daylight illumination, using efficient lighting to reduce electricity consumption and allowing occupants to control the lighting (Kamaruzzaman, 2016).

Due to the changes in natural lighting throughout the day and year, there must be a proper integration of daylight and artificial light in a building, so that problems related to energy consumption and change in light intensity are solved. Thus, interior spaces must have artificial lighting devices suitable to complement natural lighting wherever and whenever necessary. In Portugal, the luminous climate is characterized, in average, by the predominance of clear skies or light clouds, which favours the use of natural lighting (PROCEL, 1993).

Light has a fundamental impact on the learning progress when compared to other design parameters. Nevertheless, the size of the windows alone is not meaningfully correlated with the learning progress, only when there is concern about the risk of glare and disorientation, could students benefit from the optimum window size. Both the quality and quantity of electrical lighting have a significant relation with the students' learning progress (Barrett et al., 2015).

Indicator 17 - Acoustic Comfort

Acoustics is the area of physics that studies sound, sound insulation, spread, genesis and covering reception. Acoustic comfort is related to the convenience of hearing only what is necessary and not hearing what may cause distraction or stress, thus impairing the activity being performed (Schmid, 2005). Acoustic comfort depends on sound intelligibility, reverberation time and noise control.

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, such as:

- Assists the suitable level of acoustic comfort to maintain the well-being and health of its users;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education, LEED BD+C Schools and SBTool for K-12 Schools, include this indicator;

- This indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as of the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain this indicator in the SAHSB^{PT} methodology.
One of the objectives of the EPE, as mentioned in the Indicator 14 – Indoor air quality – is "to improve living conditions and environmental comfort, with particular emphasis on hygrothermics, acoustics and air quality".

Noise is a non-articulated sound that, according to its frequency and intensity, can cause discomfort and, in some cases, health affectations (Correa & Patino Osorio, 2011).

To evaluate the acoustic comfort of a building, the characteristics of human activities that influence or are influenced by noise, the envelope of the building and the internal and external sources of noise must be analyzed. The components of the built environment and their surfaces should also be evaluated, as they are responsible for the distribution of noise in the environment, reverberation time and intelligibility (Romero & Ornstein, 2003).

Noise prevention and control in school buildings begins at the time of project design, including the definition of use, land use and the choice of building materials appropriate for each environment. A project without major acoustic concerns causes difficulties in the teaching and learning process and may cause the need for repetition, interruption of the explanations and the raising of the natural level of the voice. Therefore, it is advisable to respect the noise level recommendations (Freire, 1996).

The reflections caused by the surfaces that compose the classroom environment produce secondary waves, which prolong the residual sound in the environment. If this reverberation time is long, it can degrade sound communication in the classroom. This phenomenon depends on the capacity of the absorption material and the volume of the room (Freire, 1996). Table 4.3. shows the sound levels in order to establish noise levels compatible with the acoustic comfort in school environments.

Table 4.3. Recommended noise levels

Local		**dB(A)**
Schools	School libraries, music rooms, drawing rooms	35 – 45
	Classrooms, laboratories	40 – 50
	Circulation	45 – 55
	Places to practice sports	45 – 60

Noise can be generated from the school environment, from the common areas or from within the classroom. The design should avoid openings directed to the roads and, as far as possible, reduce the number of windows and doors facing the main roads, so that they do not affect the requirements of thermal and visual comfort (Freire, 1996).

There is some evidence to support the relationship between some design strategies, such as carpet area and room shape, and the reverberation time. These factors were significantly correlated with the learning rate. In addition, external and internal noise have a substantial negative impact on performance. The factors that affect the noise level, such as busy areas adjacent to the classrooms and the distance from main traffic, show a correlation with the learning rate (Barrett et al., 2015).

There is a huge need to develop techniques that may provide adequate conditions of acoustic comfort for building users, as well as a need to raise awareness among architects and designers about the design and dimensioning of human space to create an adequate acoustic environment for their activities.

Indicator 18 - Ergonomic Comfort

Ergonomics is the study of the adaptation of work to humans, involving the organizational and physical environment aspects related to the activities performed on site. Ergonomics studies several aspects of human behaviour (IIDA, 1990).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, such as:

- Contributes with the suitable level of ergonomic comfort to maintain the health and well-being of its users,
- The methodologies applicable to schools (Table 4.2.), namely the LEED BD+C Schools, SBTool for K-12 School and BREEAM Education; and the SBTool^{PT} Homes SBTool^{PT} STP for Office Buildings do not include this indicator. The results obtained in the questionnaires (ANNEX 2) on comfort indicators applied in the high school in Portugal (Subchapter 5.2) demonstrate that only 27% of the students stated that they are comfortable with ergonomics. Therefore, there is a clear need to support the schools,

prioritizing ergonomic comfort related to the IEQ in the building of the Portuguese school.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator "ergonomic comfort" in the SAHSB^{PT} methodology.

There is no determination as to ergonomic comfort in the guidelines established by the EPE regarding both the refurbishment and the construction of new schools (Portal Parque Escolar, 2018).

In the 1950s, ergonomics began as a military concern, but in the 1960s it was widely applied in agriculture, industry and services. Then, in the 1970s, it started to have a greater influence in various sectors, including construction. To achieve its objectives, ergonomics uses tools such as anthropometry, which is the set of studies that relate the physical dimensions of people with their ability to occupy a space where activities are carried out, using furniture and equipment suitable for their performance (Taylor et al., 2000).

Every day, children and adolescents remain seated for many hours in their classrooms. School furniture determines the posture and comfort of users, its design demonstrates a close link between school desks, health problems and discipline in the classroom. The incorrect posture of the spine while students are sitting causes them pain in the back, especially in the lower back, gluteal and cervical regions. A major problem faced by many elementary schools is the increase in the student population, which has caused an increased risk of serious musculoskeletal injuries and postural stresses due to the long time students spend in the same sitting position (Mokdad & Al-Ansari, 2009).

Anthropometric measurements should be considered in the design of school furniture. For proper design of classroom furniture, it is necessary to collect some specific anthropometric measurements such as thigh height, popliteal height, lumbar and elbow support space. Moreover, the height of the lumbar support is required to determine the dimensions of the furniture, which are important for achieving a proper posture. Classroom furniture is used continuously, so it is important that the products are of good quality in order to withstand frequent use.

It is necessary to understand various educational subjects in order to define the relationship among ergonomic, furniture, pedagogical and technological criteria. The psychological and physical comfort of students interferes with learning achievements. Students have at their disposal different rooms, each suitable for certain social and educational purposes. Furniture varies depending on the activities in each of the highlighted environments (School Furniture, 1999). Students and teachers might make the necessary modifications for each activity and that may vary depending on the space, furniture and mobility of each situation.

The determination of anthropometric criteria for the height of the dimensions, seat and backrest of chairs and tables is essential. Different sizes of tables and chairs should be used to meet the basic requirements of students of different statures, assisting the implementation of several activities in the classroom (School Furniture, 1999).

C7. ACCESSIBILITY

It is required to prioritize access to public transport in order to decrease the need for car use and the resulting negative impacts caused by them (Van Dyck et al., 2013).. This category includes the indicator: “mobility plan” (I19) (Saraiva et al., 2019b).

Indicator 19 - Mobility plan

Currently, a sedentary lifestyle is adopted by most of the population, however, the growing global awareness related to the impacts caused by physical exercise on health aroused great interest (Van Dyck et al., 2013). In addition to improving the physical health conditions, physical activity can also benefit the emotional health and the quality of life (Ohmatsu et al., 2014), as well as increase sociability levels (Lee, 2011).

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, namely:

- Encourages the use of bicycles, encourages walking, and allows adequate mobility for people with some degree of mobility difficulty, increasing the quality of life of the employees and students of a school;
- The methodologies applicable to schools (Table 4.2.), as LEED BD+C Schools, SBTool for K-12 Schools and BREEAM Education , include this indicator;
- This indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

- Through a consultation made with some specialist in the field of sustainability of building constructions, it was recognized that this indicator should remain in the SAHSB^{PT} methodology.

Therefore, through the analysis of the aspects described before, it was decided to maintain the indicator “mobility plan” in the SAHSB^{PT} methodology.

There is no determination as to the mobility plan in the guidelines established by the EPE regarding both the refurbishment and the construction of new schools (Portal Parque Escolar, 2018).

Students who go to school by bike or on foot have better physical and psychological well-being and a lower incidence of chronic diseases (Martin et al., 2014), thus reducing obesity-related diseases (diabetes, cardiovascular disease) (Lubans et al., 2011).

In the United States, Australia and the United Kingdom, motorized transport is the most widely used, since the distances to school are generally longer than in most European countries (United States Environmental Protection Agency, 2008). In Portugal, the most common way to go to school is on foot (68.8%), while cycling is less frequent (14.4%). The routes from home to school, either on foot (96.7%) or by bike (92%), have distances of less than 2.0 km (Pizarro, 2014). Those activities have been proposed as a potential source of physical activity (PA) for children and adolescents, reaching almost 40% of the recommended physical activity per day (Klinker et al., 2014).

The results found in Portugal are within average compared to those found in European studies that reported walking from home to school as the main way to travel, with 44.8%, followed by cycling with 34.6% (Dessing et al., 2014). Schools in Portugal are built in order to maintain a distance from students’ homes of about 1.5 km or 30 minutes’ walk, with 2.2 km being the maximum distance considered (Department of Prospective Evaluation and Planning, 2000).

Another important factor that interferes with the choice of bicycle as a transport to go to school concerns the parking conditions found in the school environment. Bicycle parking should be easy to find, easy to access, well designed, functional and safe. Scheltema (2012) has developed a scheme for a bicycle parking space based on the satisfaction pyramids of Maslow and Van Hagen, comprising four layers:

- Attractiveness is important to maintain flexibility and bicycle parking. It can only be achieved if the following factors are met;
- Security is the fundamental precondition for all other elements, including the location of the access roads, the visibility, and the illumination of the site; bikes stored in supervised parks provide added security against vandalism and theft;
- Comfort must be considered to create a place that is suitable to the human structure, functional and pleasant to use in terms of ergonomics, lighting, air quality and sound;
- Directness consists of aspects regarding the bicycle path, such as fluency orientation, readability, continuity, linearity, right of way for cyclists and parking capacity for bicycles.

There are several types of bicycle parking with different aspects: access; level of affordability; accessibility (hours); fixing method, stored (by school officials, in person, by an automatic gate) or not (outdoors); and open or closed construction (Pucher et al., 2010). Cities are increasingly demanding the implementation of bicycle parking in new buildings to achieve sustainable certification systems such as LEED, BREEAM, CASBEE, SBTool and Green Star, among others. Already existing buildings may be adapted to add bicycle parking facilities (Pucher et al., 2010).

In order to promote the use of bicycles in high schools, it is necessary to meet some new external and internal requirements in the school buildings, as mentioned above. It would also be necessary to build specific facilities for the students who come on foot or by bicycle, such as showers and changing rooms near the bike racks (Furness, 2007).

C8. SECURITY AND SAFETY

A school building should be remodelled or designed in order to preserve the maximum safety for students. Safety involves several features related to the safety of the provision and equipment, for protection in case of fire. This category includes one indicator: "occupants' security and safety" (I20) (Saraiva et al., 2019b).

Indicator 20 - Occupants security and safety

The security and safety concerning occupant safety in a school buildings can be analysed under different features. In the SBTool^{PT} STP Office Buildings, this issue is determined by aspects related to the operating condition in the guarantee of the main building services, such as water, telecommunications and energy supply, and personal safety of users, specifically through the use of appropriate lighting and surveillance systems. These aspects remain part of this methodology.

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, such as:

- Assists the implementation of measures to ensure the safety and security of the occupants in different aspects;
- The methodologies applicable to schools (Table 4.2.), as SBTool for K-12 Schools and BREEAM Education, include this indicator, the construction materials from other buildings, located outside of the site;
- This indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to maintain the indicator “occupants security and safety” in the SAHSB^{PT} methodology. The users of this type of building are children and the school environment should promote the welfare and protection of children through a safe environment for all school activities.

One of the objectives of the EPE is to improve the security of the high school building, therefore, it demonstrates the concerns of the *Parque Escolar* related to the security of the users.

In the case of fire safety, there is a specific and effective legislation to be applied in schools in Portugal, namely the Decree-Law No. 414/98, which approves the Fire Safety Regulations in School Buildings. The components of security installations must comply with the requirements of these regulations, and therefore there is no need to include this aspect in this methodology. Since the focus is on the safety of children in school, issues pertaining to the prevention of accidents should also be addressed together with factors such as the absence of materials that may be hazardous in school environments, the safety in the sports and recreational environment and the banisters on stairs, among others.

One type of safety approach in general construction was created from the preparation of a discussion paper on the topic of Security Science (2013) through the publication of a set of empirical studies by several authors with new perspectives on the subject called Zero Accident Vision (ZAV). This new line of thought is based on the statement that all (major) accidents are preventable, so there is a commitment to avoid all accidents (Zwetsloot et al., 2017).

In the case of the power system, the effectiveness of the electrical system in the event of supply failures is analysed, such as the existence of a power generator and/or the division of this system by sections, so that a failure in one of the sectors will not interfere in the others. In the case of water systems, there must be a water supply tank and the distribution system must be designed divided into sections, therefore, there will be no lack of water in case of supply disruptions.

With regard to telecommunications systems, the existence of at least two different types of systems aimed at providing uninterrupted services should be assessed. Finally, for the security system, it is investigated the existence of lighting systems in critical areas, such as parking area, entrance and paths that connect the buildings. The relevance of having a safety technician present on site and/or in a monitoring system should also be pointed out.

Schools must promote the welfare and protection of children's health through a safe environment for school activities, they should be responsible for creating and maintaining safety and emergency procedure plans in order to reduce accidents, and also ensure a safe environment for recreational and school activities (Gomes et al., 2010).

The school environment should be free of woods, holes, barbed wire and abandoned building materials. Doors should always open outwards, thus facilitating the exit in panic situations, and there should also be devices used for a slower closing of the door, thus avoiding injuries. The protection of windows and physical barriers to prevent access to the stairs should be considered. Finally, furniture should be ergonomic, with rounded edges to reduce the risk of injury (Manual of accident prevention and first aid in schools, 2007).

Inspections and maintenance of the building must be made periodically, evaluating the condition of the painting, the state of the electrical wiring, cracks in the plaster, exposure to water leaks, wires or sewage, irregularities on the floors and children's access to unprotected emergency exits.

Regarding sports, it is important to promote safety in the environments where students play sports through the use of materials that absorb the impact of accidents related to falls, by reducing gaps or cracks in sports fields and protecting the architectural structures that can pose risks while using the site (Manual of accidents prevention and first aid in schools, 2007).

Informational posters on safety and accident prevention should be fixed in a prominent area (Manual of accidents prevention and first aid in schools, 2007). The occurrence of falls on stairs is often associated with serious injuries, which occur mainly with teenagers. It is important to meet the construction standards, always in accordance with the local laws, in the process of demarcating the dimensions of the stairs. Visual cues and lighting also appear to be relevant factors in preventing falls on the stairs that occur with young adults (Kamel, 2013). The existence of a handrail as well as its design features are key elements for the safety of the users. All these aspects, if applied properly, contribute to the reduction of accidents, making the environment safer (Jacob, 2016).

In the United States, 19% of injuries affecting children and young people occur at school (Elgie et al., 2005), and 54.9% of these injured are between 10 and 14 years old, followed by children between 5 and 9 years old (26.7%) and adolescents between 15 and 19 years old (18.4%). Such accidents usually happen for several reasons, such as falls and accidents in the classroom or at school parks (Josse et al., 2009).

Accidents involving children in schools are very common, with records showing an increase in such accidents in Portuguese schools. As seen in a study made by Josse (Josse et al., 2009), most accidents occur due to falls, especially when students are playing in poorly maintained school parks. Based on the results of this study, several procedures that help prevent students from falling were analysed for three specific locations: stairs, play areas and physical activity areas.

C9. EDUCATION FOR SUSTAINABILITY AWARENESS

The significance of sustainability awareness in schools has to do with encouraging students to have positive attitudes towards sustainability and educating citizens who will be more aware about sustainability. This category includes one indicator: “sustainability awareness” (I21) (Saraiva et al., 2019b).

Indicator 21 - Sustainability awareness

This indicator intents to promote awareness among children about the significance of sustainability in the current world. It is important to rise students’ awareness about the relevance of sustainability for the protection of local biodiversity of the site, and also to help them understand how and why students are supposed to use water and energy (lighting and ventilation) in a sustainable way.

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, namely:

- Assists the intensification in students’ awareness of sustainability, supporting them to follow sustainable practices in their routines and to identify how they can have a a critical view of sustainability matters (Repka et al.,2019);
- The methodologies applicable to schools (Table 4.2.), as LEED BD+C Schools and BREEAM Education, include this indicator;
- This indicator is not part of SBTool^{PT} STP for Office Buildings, as well as SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to include the indicator “Sustainability awareness” in the SAHSB^{PT} methodology.

There is no determination regarding sustainability awareness in the guidelines established by the EPE referring to the reform and construction of new schools (Portal Parque Escolar, 2018). The importance of fostering social awareness about the impacts of sustainability is undeniable. This indicator allows the use of schools as vehicles to disseminate the importance that the experience of sustainability has on people's lives, using students as tools since they can spread this idea both in their families and in society, naturally transforming them as part of their daily lives (Saraiva et al., 2019a).

There is still some strain regarding the adoption of a sustainable way of life, mainly due to the lack of specific education on the subject, so, therefore, the development of appropriate environmental programs in schools is necessary. These programs should target attitudes and cognitive abilities related to environmental practice, beliefs, values, intentions and action strategies (Ntanos et al., 2018).

The main objective of sustainable school is to promote sustainability, by assisting students to follow sustainable practices in their daily routine, teaching them how to make decisions, set goals, deal with information and identify how to think with a critical view on the issue of sustainability (Repka et al., 2012).

The study performed by Kim (2018), with 12,000 students from the University of Washington, analysed the influence of three types of sources related to awareness of and attitudes towards sustainability, specifically news sources; blogs and social media sources; and local sources of information. All sources of communication were successful in increasing awareness among participants, however, there was only a slight impact on their behaviours related to sustainability. To increase behavioural transformation, they should also provide opportunities for involvement and use participatory methods to encourage the involvement of the students (Kim et al, 2018).

The indicator related to education and sustainability awareness exists in specific methodologies such as the LEED for school and the BREEAM for education. The LEED for school methodology addresses this question through the innovation of indicators, Design 6, and through the use of the school as a teaching tool (LEED V4, 2013; Saraiva et al., 2019a).

BREEAM for education in 2008 reported on this subject with the MAN 10 indicator, addressing the importance of developing the indicator as a learning resource and aiming to recognize and encourage the use of the site and learning resources to demonstrate environmental consciousness by analysing sustainability factors (BREEAM Education, 2008). This indicator of the BREEAM methodology considers the building as an example of sustainability in order to teach the user. This differs from the indicator proposed and addressed in this article, whose function is to evaluate the level of sustainability awareness of the students of a given school (Saraiva et al., 2019a).

In the methodology SBTool for K-12 schools, there is no specific indicator related to environmental education, which is part of the category education for sustainability (Mateus, 2010). Therefore, it is perceived that there is no methodology that evaluates and promotes the level of education and awareness related to sustainability (Saraiva et al., 2019a).

The sustainability certification of the aforementioned methodologies is requested in order to determine whether they meet the prerequisites of the indicators contained in these methodologies. Therefore, the inclusion of the proposed indicator will promote sustainability awareness among students, using the school building as an example to be observed and promoting sustainable attitudes in students' daily lives. (Saraiva et al., 2019).

C10. SUSTAINABILITY OF THE AREA

The use of public transport, such as the bus and the train, to school decreases the use of private cars, and therefore decreases CO_2 emissions, producing less environmental impacts (Vasconcellos, 2014). This category includes one indicator: “accessibility to public transport” (I22) (Saraiva et al., 2019b).

Indicator 22 - Accessibility to public transport

The problems caused by transport systems are widely known. There is an urgent need to restructure these systems to make them more environmentally and socially sustainable (EC, 2011). Cycling, walking and public transport systems play important roles in sustainable projects related to urban transport (Pucher & Buehler, 2012).

Some features justify the permanence of this indicator in the SAHSB^{PT} methodology, such as:

- Encourages the use of public transportation by students, increasing the quality of life of the employees and students of a school and decreasing the pollution created by private vehicles;
- The methodologies applicable to schools (Table 4.2.), as BREEAM Education and SBTool for K-12 Schools, include this indicator;
- This indicator is not part of the SBTool^{PT} STP for Office Buildings, as well as the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described before, it was decided to include this indicator in the SAHSB^{PT} methodology.

In several parts of the world, cities have serious problems related to noise and air pollution and register a high number of traffic accidents and congestion as a result of the high use of motorized transport (Stanley et al., 2011). The undue use of private cars has resulted in a drop in demand for public transport, leading to a concomitant reduction in available road services (Vasconcellos, 2014).

Several factors affect the choice of public transport, such as security, flexibility and convenience. Some factors related to security are: the frequency of occurrence of problems related to theft and violence, as well as accidents resulting from the lack of security. Factors related to flexibility refer to flexible departure times and travel route, while convenience factors refer to the functional aspects of transport, such as frequent departures, distances to the departure points and punctuality.

There is a wide variety of studies on public transport, including the public transport accessibility level (PTAL), which was developed in the UK and measures the level of accessibility. The PTAL provides a rating scale with several levels of accessibility to public transport, including measures such as: frequency of service, waiting time and the access time to walk to the next bus stop or train station. The PTAL estimates the public transport accessibility level to the points of interest (Currie, 2010).

The existing accessibility measures can be classified into three groups: access to stops, journey times and the form of access to a specific destination by public transport (bus or train) (Lin et al., 2014). Most studies on the subject consider access at the physical level, with emphasis on proximity to public transport stops (Currie, 2010).

The damage caused by poorly planned transport systems can be summarized in three dimensions: space (quality of roads, accessibility), exposure (noise, risk of accident, odour, stress, climate change and pollutants) and time (time spent on the trip), as it can be seen below:

- The quality of roads. Actions taken by the public organs usually favour the use of private vehicles (Hutton, 2013);
- The term "accessibility" means the opportunity to reach a specific destination. The term involves considerable complexities about how cities can foster different modes of transport;
- Noise. It causes physiological stress reactions that affect health, such as anxiety, sleep disorders and chronic fatigue, mood swings, phobia and cardiovascular diseases (WHO, 2011). It produces psychological and physical stress;
- Traffic accident. It is estimated that there are 1.2 million deaths resulting from traffic accidents annually (WHO, 2013);
- Odour. There are few scientific studies on this subject. It is uncomfortable and causes health damage (Klæboe et al., 2000);
- Stress. Traffic causes suffering to the user of this mode of transport (Bissell, 2010);
- Climate change. It is a global problem, although different countries contribute in a different proportion. Transportation requires 27% of global energy end use (IPCC, 2014A), causing great impact on climate change (Gilbert & Perl, 2008);
- Harmful substances. It has short-term and long-term effects on health risks, such as asthma, bronchitis, cardiopulmonary disease and lung cancer (Pope et al., 2002);
- The time spent travelling is generally considered a waste, and transportation planners always try to reduce the travel time. The journey time is one of the traffic priorities and is considered an important aspect of transport policies (Wardrop, 1952).

C11. LIFE CYCLE COSTS

The cost of a school building should consider the value related to the building entire life cycle. This category includes one indicator: "life cycle costs" (I23) (Saraiva et al., 2019b).

Indicator 23 - Life cycle costs

Sustainability is the junction of three important aspects: social, environmental and economic aspects. There is no reason for a building that has had large environmental and social concerns to cost much more than expected.

Some features justify the permanence and importance of this indicator in the SAHSB^{PT} methodology, such as:

- Promotes the design of school buildings with low life cycle costs;
- The methodologies applicable to schools (Table 4.2.), such as SBTool for K-12 Schools, BREEAM Education, include this indicator;
- This indicator is not part of the SBTool^{PT} STP for Office Buildings, nor the SBTool^{PT} Homes, the first methodology SBTool adapted to Portugal.

Therefore, through the analysis of the aspects described above, it was decided to include the indicator "life cycle costs" in the SAHSB^{PT} methodology.

Even though there is no explicit concern on the part of the EPE about the cost of the school environment, every enterprise, state or private, has concerns about the financial side. It is no use having only social or sustainable concerns if the company does not sustain itself economically.

In this methodology, the social and environmental aspects of water use were addressed through the indicators "water consumption (I11), "water treatment and recycling" (I12) and "collection and reuse of rainwater" (I13). The social and environmental aspects of energy use were addressed through the indicators "energy consumption" (I5), "renewable energy" (I6), and also through the indicators responsible for the control and management of water and energy: "commissioning" (I7) and "environmental management plan" (I9).

A green building has many advantages if compared to traditional buildings in terms of energy, resource and water savings. Despite the fact that the term "green building" has been used for a long time, its meaning is not yet well known by people. It is still necessary to promote and disseminate several economic benefits related to the life cycle of a green building (Zhau et al., 2015).

The cost, along with the quality and function of a building, are factors that value or devalue a property. These factors are analysed as social and economic characteristics of the target audience (Construction Forum, 2012). Estimates of water and energy consumption made during the design stage of a project are usually well below the actual consumption. This is due to the difference in consumption during the seasons and the number of users and features of this consumption (Kern et al., 2016).

The additional cost of a sustainable construction is about 2% above the cost of a traditional building, however, this cost is four times exceeded by the direct benefits (energy and water saving, health, etc.) (Kats, 2010). Nowadays, it has been confirmed that buildings that receive sustainable certifications tend to have a lower cost of maintenance related to the consumption of energy and water, when compared to a traditional building (Agdas, 2015).

The technologies for environmental measurement and monitoring assist in the performance of energy efficiency measures and water consumption based on data, thus causing a reduction in consumption costs. The progress in building legislation and regulations related to the reduction of the use of energy and water in buildings encourages increased sub-level metering and automated control metering, especially in non-residential buildings (Genet & Schubert, 2011).

Buildings are the largest energy consumers in Europe and account for 40% of the total energy consumed (Grözinger et al., 2014). Energy expenditures on buildings can reach up to 50% of maintenance costs, as it happens in Finland, for example (KTI, 2013). In the schools studied by Sekki (2016), the average energy costs reached 45%. When the maintenance costs of schools are analysed, it becomes clear that the energy costs in the more recently constructed buildings are lower because there is no need for repairs in these new buildings (Sekki et al., 2016).

One of the main variables that impact the final consumption of energy is the degree of density of students attending school, which depends on the number of shifts in the school and the efficient use of space. In contrast, the age of the children and the type of construction do not greatly affect the final cost of energy (Sekki et al., 2016).

4.4. Sustainability Certificate

The commonly used to show a certificate of sustainability assessment of a building is through a graduated scale that reveals the performance of the building in relation to the benchmarks (LENSE, 2006). The performance should be demonstrated in a clear way, simplifying its interpretation by the users of the building, and be easily conceptualized by the evaluators.

The communication of sustainability through several indexes supports in the measurement, comparison and interpretation of the performance of the construction, thus assisting the location and identification of the problem and consequently, facilitating its solution. Therefore, the categorization of performance levels was performed through a six-level scale: from E (less sustainable) to A + (more sustainable), in which D corresponds to conventional practice and A to the best practice, according to the SBTool^{PT} H methodology (Figure 4.5).

A+	$\bar{P} > 1,00$
A	$0,70 < \bar{P} \leq 1,00$
B	$0,40 < \bar{P} \leq 0,70$
C	$0,10 < \bar{P} \leq 0,40$
D	$0,00 \leq \bar{P} \leq 0,10$
E	$0,00 < \bar{P}$

Figure 4.5. Performance levels of SAHSB^{PT} methodology (SBTOOL^{PT} for Sustainable Construction, 2011)

The sustainability certificate that shows the results achieved in the evaluation through the SAHSB^{PT} methodology is composed of three fields:

1. Identification of the School construction;
2. Sustainability label – sustainability level of the construction evaluated and its performance in the three dimensions of sustainable development;
3. Disaggregation of performance by each category – performance of the construction at the level of each of the eleven categories considered in the methodology.

4.5. Concluding Remarks

In this chapter, the relevance of each indicator, category and dimension of the SAHSB^{PT} methodology has been described. Also, a literature review of each indicator was carried out, addressing its main objectives and recent studies on the subject of each indicator.

The decisions made in this chapter on the indicators and categories that are part of the methodology support the decision on indicators, categories and dimensions, which are discussed in chapter 5.

CHAPTER 5

Identification of the weights of the indicators used in the SAHSB^{PT} methodology

In this chapter, the weight of each indicator and category of the SAHSB^{PT} methodology is determined through the analysis of different aspects. It is analysed the survey applied to sustainability specialists, the value of the weight attributed to the dimensions, the questionnaires related to the awareness about comfort and sustainability and the weights used in the methodology SBTool^{PT} STP for Office Buildings.

This chapter is taken from the articles "Environmental Comfort Indicators for School Buildings in Sustainability Assessment Tools" (https://doi.org/10.3390/su10061849) and "The inclusion of a sustainability awareness indicator in assessment tools for high school buildings" (https://doi.org/10.3390/su11020387), about high schools in Portugal, whose authors are also the author and the supervisors of this thesis.

5.1. Introduction

The weight of the indicators is reflected in the results. Even though some indicators have greater relevance, there is still no consensus regarding a methodology for defining the specific weight for each of these indicators (Mateus, 2010). The weight attributed to the indicators used in the methodology developed in this work was defined in accordance with the priorities of the school environment. The decision on the indicators, categories and weights attributed to the dimensions of the SAHSB^{PT} methodology was based on several aspects, namely:

1 – The survey developed and applied to specialists in sustainable buildings

Questions about the importance of each indicator (ANNEX 1) were applied to specialists in sustainability of the built environment, and subsequently the surveys were analysed. The main objective was to understand the opinion of these experts about the indicators to be selected in the SAHSB^{PT} methodology, as well as to define the weights to be attributed to them. This subject was explained in more detail in Chapter 3, section 3.2 of this thesis.

2 The weights attributed to the dimensions
The weight attributed to each of the dimensions of the SBtool^{PT}H and SBTool^{PT}STP for Office Buildings methodologies is as follows: Environmental Dimension with 40%, Social Dimension with 30% and Economic Dimension, with 30%. This subject was explained in more detail in Chapter 3, section 3.3. of this thesis.

However, it is important to note that the SAHSB^{PT} methodology is intended to be applied in schools, which are characterized by having an environment dedicated to the learning of children and adolescents, who need major comfort, accessibility and safety, as well as education on sustainability awareness. All these subjects concerning the indicators are related to the social concerns of users.

The result of the forms applied to the specialists, on the choice of the indicators and their respective weights, detected a greater weight for the indicators of inclusion in the social dimension. Therefore, the weights of each of the dimensions relating to the SAHSB^{PT} methodology are: Environmental Dimension, with 35%, Social Dimension, with 35%, and Economic Dimension, with 30%.

3 – The questionnaires about the indicators of comfort and sustainability awareness
The questionnaires about the two additional indicators proposed in this work – comfort (indoor air quality, thermal, visual, acoustic and ergonomic comfort) and sustainability awareness – were applied to the students of the Francisco de Holanda High School, in Guimarães, and were intended to help define the weight of those indicators, as it can be seen in the sections 5.2 and 5.3 of this chapter.

4 – Analyses of the weights attributed to the indicators and categories of the SBTool STP^{PT} for Office Buildings.

The weights of the indicators and categories of the SBTool^{PT} STP for Office Buildings are studied, analysed and compared, thus contributing to the decision on the weights to be allocated to the indicators and categories of the SAHSB^{PT} methodology.

5 – Analyses of the weights attributed to the indicators and categories of the SBTool for K-12 Schools, LEED BD+C for Schools and BREEAM Education.

The most popular assessment methods are LEED (US) and BREEAM (UK), representing the continents to which they belong. The weights of the indicators and categories of the SBTool for K-12 Schools, LEED BD+C for Schools and BREEAM Education are studied, analysed and compared, therefore contributing to the decision on the weights to be allocated to the indicators and categories of the SAHSB^{PT} methodology.

In the following paragraphs, there is a summary of the comparison between the indicators and categories of the SAHSB^{PT} methodology and those of the SBTool^{PT} STP for Office Buildings methodology, to clarify the changes:

The indicators that have been created and introduced in the SAHSB^{PT} methodology are:

- I18 – “Ergonomic comfort” (C6 – Category “Comfort and health of users”);
- I21 – “Sustainability awareness” (C9 – Category “Education Sustainability awareness”).

The indicators that have been modified in the SAHSB^{PT} methodology are:

- I8 – Indicator “materials reused and with recycled contents” (C4 – Category “materials, residues and resources management”) in the SAHSB^{PT} methodology, is a junction of I10 – Indicator “reuse of materials” and I11 – Indicator “materials with recycled content” (C4 – Category “materials, residues and resources management”) from the SBTool^{PT} STP for Office Buildings;
- I20 – Indicator “occupants security and safety” (C8 – Category “occupants security”) in the SAHSB^{PT} methodology is I22 – Indicator “occupants security” (C8 – Category “occupants security”) in the SBTool^{PT} STP for Office Buildings.

- I5 – Indicator "energy consumption" (C3 – Category "energy") in SBTool^{PT} STP for Office Buildings;
- I6 – Indicator "renewable energy" (C3 – Category "energy") in SBTool^{PT} STP for Office Buildings;
- I14– Indicator "indoor air quality" (C6 – Category " comfort and health of users") in SBTool^{PT} STP for Office Buildings;
- I15 – Indicator "thermal comfort" (C6 – Category "comfort and health of users") in SBTool^{PT} STP for Office Buildings;
- I16 – Indicator "visual comfort" (C6 – Category "comfort and health of users") in SBTool^{PT} STP for Office Buildings;
- I17 – Indicator "acoustic comfort" (C6 – Category " comfort and health of users") in SBTool^{PT} STP for Office Buildings;

The indicators that have been excluded in the SAHSB^{PT} methodology are:

- I4 – Indicator "sustainable location" (C2 – "biodiversity and land use") in SBTool^{PT} STP for Office Buildings;
- I5 – Indicator "local biodiversity protection during construction" (C2 – "biodiversity and land use") in SBTool^{PT} STP for Office Buildings;
- I11 – Indicator "materials with recycled content using during construction phase" (C4 – "Materials, solid residues/resources management") in SBTool^{PT} STP for Office Buildings;
- I27 – Indicator "accessibility for amenities" (C10 – Category "accessibility to public transport") in SBTool^{PT} STP for Office Buildings.

The indicators that remain in the SAHSB^{PT} methodology are:

- I1 – Indicator "life cycle environmental impacts" (C1 – Category "climate change and outdoor air quality) in SBTool^{PT} STP for Office Buildings;
- I2 – Indicator "heat island effects (C1 – Category "climate change and outdoor air quality") in SBTool^{PT} STP for Office Buildings;
- I3 – Indicator "land use efficiency" (C2 – Category "biodiversity and land use") in SBTool^{PT} STP for Office Buildings;
- I4 – Indicator "product with organic basis certificate (C2 - Category "biodiversity and land use") in SBTool^{PT} STP for Office Buildings;

- I7 – Indicator “commissioning” (C3 – Category “energy”) in SBTool^{PT} STP for Office Buildings;
- I9 – Indicator “environmental management plan (C4 – Category “materials, residues and resources management”) in SBTool^{PT} STP for Office Buildings;
- I10 – Indicator “flexibility and adaptability (C4 – Category “materials, residues and resources management”) in SBTool^{PT} STP for Office Buildings;
- I11 – Indicator “water consumption” (C5 – Category “water”) in SBTool^{PT} STP for Office Buildings;
- I12 – Indicator “water treatment and recycling” (C5 – Category “water”) in SBTool^{PT} STP for Office Buildings;
- I13 – Indicator “storm water management” (C5 – Category “water”) in SBTool^{PT} STP for Office Buildings; and Indicator “collection and reuse of rainwater” (C5 – Category “water”) in the SAHSB^{PT} methodology;
- I19 – Indicator “mobility plan” (C7 – Category “accessibility”) in SBTool^{PT} STP for Office Buildings;
- I25 – Indicator “accessibility to public transport” (C10 – Category “accessibility to public transport”) in SBTool^{PT} STP for Office Buildings;
- I26. Life cycle costs (C11 – Category “Life cycle cost”) in SBTool^{PT} STP for Office Buildings;

The SBTool^{PT} STP for Office Buildings, SBTool for K-12 Schools, LEED BD + C for Schools and BREEAM Education methodologies were used as the basis of this study.

The weight of each indicator was calculated based on the SBTool^{PT} STP for Office Buildings methodology (Table 5.7.in the end of this chapter), but with some adaptations regarding indicators that have been added or modified, and also based on the opinion of the experts consulted. The calculations of these weights are shown in this section. As a result of the use of new categories, and also considering that this methodology is adapted to a new environment (school buildings), there were some modifications related to the weights to be attributed to the indicators.

The indicator “sustainability awareness” is of great importance with regard to the school environment since it evaluates and encourages students to have sustainable attitudes. This indicator was included with the same weight given to the indicator “awareness and education for sustainability”, which is part of the SBTool^{PT} H methodology (Mateus, 2010), specifically 10% of the social dimension and 3% of the total value.

“Accessibility for amenities” is not part of this methodology. In an office building, where the users are adults, accessibility to amenities is required, however, in the high schools, where the users are mainly students, this requirement is not so evident, therefore there is no need for it in a school environment.

The following subchapters aim to determine the weight of the two new indicators proposed in this work that are related to “sustainability awareness” and to “environmental comfort”. This is done by analysing the results found in the questionnaires applied at the Francisco de Holanda high school, in Guimarães. These results support the definition of the weights to be attributed to the indicators of comfort and sustainability awareness in the SAHSB^{PT} methodology.

5.2. Environmental Comfort and sustainability awareness questionnaires

The indicators regarding environmental comfort have already been used in the first SBTool methodology adapted to the Portuguese reality, the SBTool^{PT}H for houses (Mateus, 2010) and the questionnaires used in the elaboration of the SAHSB^{PT} methodology are based on the questionnaires elaborated for the development of the SBTool^{PT}H methodology.

The indicator "sustainability awareness" is relevant for school constructions since it assists awareness of sustainability among students, encouraging sustainable attitudes in the students' quotidian. Another objective of the use of questionnaires on “sustainability awareness” is that this indicator was not used in other SBTool methodologies related to the Portuguese reality, as SBTool^{PT}H, SBTool^{PT}STP for Office Buildings and SBTool^{PT} for Urban Planning. For this reason, this subject deserves special attention.

5.3. Comfort indicators

This subchapter aims to show how to determine the weight, as a percentage, of each comfort indicator: thermal comfort, visual comfort, ergonomic comfort, acoustic comfort and indoor air quality. The weights were determined based on the questionnaires (ANNEX 2) applied at the Francisco de Holanda High School (FHHS), in the city of Guimarães, Portugal.

This city is considered the ninth city in quality of life in Portugal (out of a total of 338 cities) and has good education and health systems. The climate is warm and temperate, with an average annual temperature of 14 °C, an average annual air humidity of 81%, and annual precipitation above 1500 mm. The Francisco de Holanda High School, subject of this study, was built in 1864 and, in 2011, underwent a major renovation for modernization purposes, and currently holds the title of "standard school" in Portugal (Parque Escolar, 2018).

The multiple-choice answers of the questionnaires were sorted according to the level of importance to the students and to how they interfere in their well-being and learning process, ranging from comfort (very good) to extreme discomfort (insufficient). The complete survey is presented in the ANNEX 2 of this thesis and comprises six questions (Saraiva et al., 2018).

Francisco de Holanda High School (FHHS) was initially built to be an industrial school in 1864. In 1959, a major renovation took place with the building of its main construction with three floors. In 2011, there were new major renovations carried out by the *Parque Escolar* and the high school still uses a major part of the resources and equipment installed by the company. The school represents the current school construction standard in Portugal (Portal Parque Escolar, 2018) (Saraiva et al., 2018).

The Program for the Modernization of Schools for Secondary Education (PMEES) intents to place Portuguese education in a position of international reference. The PMEES includes interventions in 332 schools. This program sets standards for all high schools that are or will be reformed by the EPE. Table 5.1. shows several standards adopted by the PMEES regarding classroom comfort (Saraiva et al., 2018).

Table 5.1. Standards adopted by PMEES regarding classroom comfort. FHHS (Saraiva et al., 2018)

Dimensions	Normal classroom (50 m^2), small (20 to 40 m^2) and large (100 m^2) Minimum classroom height: 2.70 m
Air quality	Cross ventilation in all spaces of continuous occupation. Occupancy of room = 26 people; air renewal rate = 30 m3/h person
Thermal Comfort	Natural and / or Forced Ventilation + Passive Cooling Heat Recovery/Cooling Ventilation (Exchangers) Roof insulation (strong insulation) Double glasses in windows with heat treatment Exterior Wall Insulation Spaces without HVAC, dry bulb temperatures can be from 18 and 28 °C. Sun protection—allow the passage of 25–30% of the radiation.
Visual comfort	Recommended level: 500 lux, Fluorescent lamp, with a minimum of 99.99% purity
Acoustic Comfort	Ceiling with acoustic treatment Double glasses

The questionnaires were applied to high school students from 15 to 18 years old and the environmental comfort verified in this work takes as a base the classroom, where students spend most of their time. The research was done in nine classes, three of each grade, giving a total of 269 students. Table 5.2. shows the main aspects related to the interview and classroom characteristics, and Table 5.3. demonstrates the results of the survey, considering a total of 100% of the interviewed students, which reflects how satisfied students are or not with different types of environmental comfort issues (Saraiva et al., 2018). The students were properly instructed about the questionnaire. The survey reflects the feeling of comfort throughout the year.

Table 5.2. Main aspects related to the interview and classroom characteristics of FHHS (Saraiva et al.,2018)

Content	Description
Interview date	January 11, 2017
Number of students in the school	1400
Number of students that answered the questionnaires	269 (19.21% of total)
Outdoor temperature	11 °C to 15 °C
Air humidity	85%
Air quality	Ozonium, formaldehyde, bacteria, legionella, radon, carbon dioxide and carbon monoxide fungus, particles suspended in air with a diameter of less than 10 µm and volatile organic compounds presented low results according to Regulatory Compliance Statement for this construction.
Mechanical System	System of ventilation, aiding the entrance of new air, and air conditioners in every classroom, maintaining the same temperature.
Window size	Glasses are double and laminated, separated by a chamber of dehydrated air with 12 mm of thickness, helps to maintain the temperature with efficient energy.
Window material	Windows are large (2 windows, H = 1 m and L = 2 m), there are also skylights in darker places, favouring natural lighting.
Lamps	Fluorescent lamps or metal halide lamps are used, providing adequate illumination.
Cover Material	The floor is formic; the wall has bright white paint with glass windows.
Size of chairs and tables	Parque Escolar uses standard and fixed furniture, not adaptable to the biotype of each student.

Table 5.3. Result of the percentages related to the students' level of satisfaction with the different types of environmental comfort indicators at Francisco de Holanda High School, Portugal (Saraiva et al., 2018).

IEQ	Level 1 Comfortable	Level 2 Slightly Uncomfortable	Level 3 Uncomfortable	Level 4 Very Uncomfortable
Question 1 Thermal	61%	23%	10%	6%
Question 2 Visual	78%	18%	4%	0%
Question 3 Acoustic	54%	38%	6%	2%
Question 4 Air quality	72%	2%	26%	1%
Question 5 Ergonomic	27%	50%	19%	4%
Question 6 General	56%	31%	12%	1%

As explained in Chapter 3, section 3.2. and illustrated in Figure 3.1. of this thesis, the statistical analysis between groups was performed using Microsoft Excel regarding the IEQ results for Francisco de Holanda High School. It is verified that the Fcalculated = 14.17 > Ftabulated = 3.23 (probability of 0.05), i.e., there is significant variability between the data (Saraiva et al., 2018).

The students' satisfaction regarding thermal, lighting and air quality comfort was very high, but the satisfaction was somewhat lower regarding acoustic comfort and deficient regarding ergonomic comfort, as described below (Saraiva et al., 2018):

(i) 61% of the students stated that they are comfortable with the temperature inside the classroom, which is not a good result considering that this is one of the main problems found in Portuguese buildings and it is advisable that 80% of the people within the same environment should be comfortable.

(ii) 78% of the students stated that they are comfortable with the lighting inside the classroom, which is a good result. This result is within the expectations. Artificial lighting related to the students' level of comfort in this aspect seems to be quite adequate.

(iii) 54% of the students are comfortable with the noise level. It is a high value considering that it is a classroom. The students' dissatisfaction with the environment has a strong relationship with their productivity. The sounds come, mainly, from the inside.

(iv) 72% of the students stated that they are comfortable with the air quality inside the classroom.

(v) 27% of the students stated that they are comfortable with ergonomics. This low result related to the number of students who feel comfortable shows the need for greater concerns with this aspect and, therefore, the inclusion of an indicator related to the ergonomics of desks in the methodologies that evaluate and certify sustainability in school environments.

(vi) In general, 56% of the students are comfortable inside the classroom. This is not a good result, mainly due to the level of satisfaction of the students who answered the questionnaire regarding acoustic and ergonomic comfort.

Through the analysis of the information, it can be observed that there is a clear need to support the schools, prioritizing the ergonomic and to acoustic comfort related to IEQ in the Portuguese building school.

To create a percentage value to be associated with each environmental comfort indicator, the percentages related to questions 1 to 6 (Table 5.3.) considered just the uncomfortable situations of the students (levels 2, 3 and 4 in Table 5.4.). The three levels of discomfort for each indicator are added in order to indicate a total percentage of students dissatisfied with the different types of environmental comfort issues, thus helping to define the comfort indicator weights, as shown in Table 5.4.

Table 5.4. Result of the new percentages related to environmental comfort indicators as informed by students at the Francisco de Holanda High School, Guimarães

Comfort Indicators	Level 2	Level 3	Level 4	Total	Conversion to 100% scale
Thermal	23%	10%	6%	39%	19 %
Visual	18%	4%	0%	22%	11%
Acoustic	38%	6%	2%	46%	22%
Air quality	2%	26%	0%	28%	13%
Ergonomic	50%	19%	4%	73%	35%
Total	131%	65%	12%	208%	100%

Other sustainability assessment methodologies for schools buildings such as LEED BD + C Schools, SBTool for K-12 Schools and BREEAM Education consider these indicators, however with different weights, as shown in Table 5.5.

Table 5.5. Result of percentages of SAHSB^{PT}, SBTool^{PT}STP Office Buildings, SBTool for K-12 Schools, LEED BD+ C Schools and BREEAM Education, consider 100%

Indicator	SAHSB^{PT}	SBTool^{PT}STP Office Build.	SBTool for K12 Schools	LEED BD+C Schools	BREEAM Education	Sum
Thermal	19%	32%	35%	7%	13%	106
Visual	11%	25%	20%	30%	35%	121
Acoustic	22%	19%	25%	13%	22%	101
Air Quality	13%	24%	20%	50%	30%	137
Ergonomic	35%	0%	0%	0%	0%	35

$\sum$ 500%

As it can be seen in Table 5.5., none of the other methodologies has indicators of ergonomic comfort. However, as seen in the Table 5.4., the ergonomics referring to the dimensions of the chairs and tables is the most uncomfortable for students, thus demonstrating the need for the presence of this indicator in the methodologies for sustainability assessment of school buildings.

In order to define the weight of the category “comfort and health of users” (C6) in the SAHSB^{PT} methodology, these results were taken into account together with the results achieved from the analysis of the questionnaires applied to specialists in sustainable construction and of the weights of the categories used in other sustainability assessment methodologies for schools. It was also taken into account the inclusion of new categories in the “social dimension” like “education sustainability awareness” (C9) and “accessibility to public transport” (C10). Altogether, the value reached for category C6 was 70% (in opposition to 80% of SBTool^{PT} STP for Office Buildings).

The weight of the indicators of the category “comfort and health of users” (C6) was scaled according to the sum of the percentage of each indicator of SAHSB^{PT}, SBTool^{PT} STP Office Building, SBTool for K-12 Schools, LEED BD+ C Schools and BREEAM Education, according to Table 5.5. The “social dimension” corresponds to 35% of the total level of sustainability, therefore, the “category comfort and health of users” is 25% of a sustainability level. The calculations for each indicator of the Category 6 were executed as follows.

Calculations of Thermal Comfort Weight (TCW)

Table 5.5. shows the weights attributed to the indicator “thermal comfort” in 5 methodologies, which are as follows: SAHSB^{PT} (19%), SBTool^{PT}STP Office Build (32%), SBTool for K12 Schools (35%), LEED BD+C Schools (7%) and BREEAM Education (13%). The total weight of all “thermal comfort” indicators (Percentage of TCW) is 106%. The sum of the weights in all 5 methodologies mentioned above, 100% each methodology, is 500%. The “category comfort and health of users” is 25%. The specific percentage for the weight of the “thermal comfort” indicator is defined by the following calculation:

$$\frac{\text{Percent of TCW}}{\text{TCW}} = \frac{500\%}{25\%} \qquad (5.1)$$

$$\frac{106\%}{\text{TCW}} = \frac{500\%}{25\%} = 5.50\%$$

Thermal Comfort Weight = 5.50%

Calculations of Visual Comfort Weight (VCW)

Table 5.5. shows the weights attributed to the indicator "visual comfort" in 5 methodologies. The total weight of all "visual comfort" indicators (Percentage of VCW) is 121%. The specific percentage for the weight of the "visual comfort" indicator is defined by the following calculation:

$$\frac{\text{Percent of VCW}}{\text{VCW}} = \frac{500\%}{25\%} \tag{5.2}$$

$$\frac{120\%}{\text{VCW}} = \frac{500\%}{25\%} = 6.00\%$$

Visual Comfort Weight = 6.00 %

Calculations of Acoustic Comfort Weight (ACW)

Table 5.5. shows the weight attributed to the indicator "acoustic comfort" in 5 methodologies. The total weights of all "acoustic comfort" indicators (Percent of ACW) is 101%. The specific percentage for the weight of the "acoustic comfort" indicator is defined by the following calculation:

$$\frac{\text{Percent of ACW}}{\text{ACW}} = \frac{500\%}{25\%} \tag{5.3}$$

$$\frac{101\%}{\text{ACW}} = \frac{500\ \%}{25\%} = 5.00\%$$

Acoustic Comfort Weight = 5.00 %

Calculations of Air Quality Weight (AQW)

Table 5.5. shows the weight attributed to the indicator "air quality" in 5 methodologies. The total weights of all "air quality" indicators (Percent of AQW) is 137%. The specific percentage for the weight of the "air quality" indicator is defined by the following calculation:

$$\frac{\text{Percent of AQW}}{\text{AQW}} = \frac{500\%}{25\%} \tag{5.4}$$

$$\frac{137\%}{\text{AQW}} = \frac{500\ \%}{25\%} = 6.00\%$$

Air Quality Weight = 6.00 %

Calculations of Ergonomic Comfort Weight (ECW)

Table 5.5. shows the weight of the indicator “ergonomic comfort" in 5 methodologies. The total weights of all “ergonomic comfort” indicators (Percent of AQW) is 137%. The specific percentage for the weight of the “ergonomic comfort” indicator is defined by the following calculation:

$$\frac{\text{Percent of ECW}}{\text{ECW}} = \frac{500\%}{25\%} \tag{5.5}$$

$$\frac{35\%}{\text{ECW}} = \frac{500\ \%}{25\%} = 2.50\%$$

Ergonomic Comfort Weight = 2.5 %

5.4. Sustainability Awareness Indicators

Along with the questionnaires applied in high schools related to the comfort indicator, a questionnaire was applied with the objective of ascertaining the level of sustainability awareness in the Francisco de Holanda High School.

In this study, the adapted survey (multiple choice answers – ANNEX 3) was used in high school students to evaluate how students behave regarding sustainability awareness issues in those schools. The questionnaire was elaborated based on the opinion poll done by the Federal University of Uberlandia (UFU Sustentável, 2017), with the number of questions applied being reduced, in order not to disturb the progress of the classes. The number of students that answered those questionnaires was determined by using the sample calculator, and the choice of the high school students was random (Saraiva et al., 2019a).

This study aims to analyse the questionnaire applied at the school in Guimarães (Portugal) with the objective of verifying the students' level of sustainability awareness (Saraiva et al., 2019a). The application of this questionnaire was applied to high school students, from 15 to 18 years old. These questionnaires were applied in the classroom with the presence of the teacher. When applying these questionnaire, students were asked not to identify themselves, only by placing the age, grade and the school in which they studied. The reasons for the application of this questionnaire and the explanation on each question was clarified before its application (Saraiva et al., 2019a).

This questionnaire consists of eight questions related to attitudes and sustainable awareness, and Table 5.6. demonstrates the level of the students' awareness of each aspect of sustainability defined in the questions. With this data, through the ANOVA software, the analysis of variance is done verifying to what extent the average of each level is related to the global average (Saraiva et al., 2019a).

In 2016, the environmental education reference for sustainability was developed in Portugal, by the Directorate-General for Education (DGE), with the goal of supporting students in learning and the use of this knowledge, in order to critically assess the effects of human activities related to environmental impacts in the political, social and economic context (Saraiva et al., 2019a).

The survey answers were analysed with the objective of verifying the sustainability awareness level. The research was conducted in nine classes, three of each grade, with a total of 269 students. The results of the research are shown in Table 5.6. contemplating 100% of the interviewed students, reflecting on how students deal with the sustainability awareness (Saraiva et al., 2019a).

Table 5.6. Result of percentages (%) of students' sustainability awareness level in Portuguese high school

Questions	Level 1	Level 2	Level 3	Level 4
	Good	Average	Bad	Terrible
Question 1 – Environmental quality	26%	55%	17%	2%
Question 2 – Environmental issues	32%	51%	16%	1%
Question 3 – Environmental protection	63%	25%	10%	2%
Question 4 – Environmental practices	32%	55%	7%	6%
Question 5 – Water consumption	73%	23%	2%	2%
Question 6 – Energy consumption	55%	39%	6%	0%
Question 7 – Recyclable waste	40%	15%	7%	38%
Question 8 – Sustainable debate in class	38%	11%	7%	44

As explained in Chapter 3, section 3.2. and illustrated in Figure 3.1. of this thesis, the statistical analysis of sustainability awareness level observed in the questionnaire applied to the students of the school in Guimarães, according to Table 5.6., was performed in the Microsoft Excel software, analysis of variance (ANOVA), referring to the results of sustainability awareness for the Francisco de Holanda High school. It appeared that the Fcalculated = 14.17> Ftabulated = 3.23 (probability of 0.05 (reliability coefficient)), i.e., there is a significant variability among the data. Table 5.6 shows that the sustainability awareness levels of students in Portuguese schools is very high (good + average), namely (Saraiva et al., 2019a):

(i) 81% of the students stated that they are very or reasonably interested in issues related to environmental concerns (Question 1);

(ii) 84% of the students stated that they always, or with some frequency, mention subjects related to the environment in the classroom. In this aspect, the results seem to be quite adequate, since the global trend is to increase the concern about sustainability (Question 2);

(iii) 88% of the students stated that they always, or with some frequency, separate recyclable waste, save water and/or save electricity, and just 2% do nothing to protect the environment. Therefore, it is a good result, considering that most of the students are supporting the environment (Question 3);

(iv) 87% of the students stated that they always, or with some frequency, take environmental attitudes in their own homes and try to teach that to their family. The students take sustaining attitudes into the home, which are part of their quotidian (Question 4);

(v) 96% of the students stated that they always or with some frequency close the sink after use that. Just 2% declare that they do not close the sink. This low result related to the number of students who do not close the sink after use, is good, showing that most of the students are aware of the impact that the careless use of the water can cause (Question 5);

(vi) 94% of the students stated that they always or with some frequency turn off lights and fans when leaving a place. None of the students declares that they do not turn off the light. This low result related to the number of students who cares about the impact of irresponsible use of energy consumed by light demonstrate that most of students are aware of the impact that the irresponsible use of the water can cause (Question 6);

(vii) 55% of the students stated that they always or with some frequency do the selective collection of recyclable waste. This result shows that most of students are concerned about this aspect, but, still, it is necessary to do something to promote the students' attitudes about recycling (Question 7);

(viii) 49% of the students declare that the subjects related to the environment should be made through events and other academic projects, but, for 56%, this subject is supposed to be part of the high school grade (Question 8).

The students' sustainability awareness level in Francisco de Holanda High School is significant, since "Parque Escolar" promotes sustainable construction in all schools for which it is responsible. Furthermore, teachers motivate students to take sustainable attitudes supported by Environmental Education Reference for Sustainability, among other actions with the same objective (Saraiva et al., 2019a).

5.5. Weight of Indicators, categories and dimensions for the SAHSB^{PT} methodology

In the last two subchapters, the results of the questionnaires on comfort and sustainability awareness applied at the high school located in Guimarães, Portugal, were analysed. The results of these analyses aim to determine the weights of air quality, visual, thermal, acoustic and ergonomic comfort, as well as the indicators of sustainability awareness of the SAHSB^{PT} methodology.

After modifications to the indicators have been made (subchapter 5.1) and after analysing the results of the questionnaires about the comfort indicator (subchapter 5.3) and the sustainability awareness indicator (subchapter 5.4), the weights of all categories and indicators were recalculated, so that they would adapt to these changes while maintaining the weights of the three dimensions. This way, Table 5.7.shows the weights of the indicators, categories and dimensions adopted in the SAHSB^{PT} methodology in comparison with those used in the SBTool^{PT} STP Office Buildings methodology. In the global weight, the percentage of the sustainability level of 100% is considered, in the local weight the percentage of the category of 100% is considered.

Table 5.7. Weight of indicators, categories and dimensions - SBTool^{PT} STP Office Buildings and SAHSB^{PT}

ID	Indicators of SBTool^{PT} STP for Office building	Local W	Global W	Cate gory	Indicators of SAHSB^{PT}	Local W	Global W
ENVIRONMENTAL		100.0%	40.0%	ENVIRONMENTAL		100.0%	35.0%
C1.	Climate Change and outdoor air quality	18.0%	7.0%	C1	Climate Change and outdoor air quality	20.0%	7.0%
I1	Life cycle environmental impacts	60.0%	4.2%	I1	Life cycle environmental impacts	57.0%	4.0%
I2	Heat island effects	40.0%	2.8%	I2	Heat island effects	43.0%	3.0%
C2	C2. Biodiversity and land use	24.0%	9.0%	C2	Biodiversity and land use	14.%	5.0%
I3	Land use efficiency	44.0%	4.2%	I3	Land use efficiency	80.0%	4.0%
I4	Sustainable location	30.0%	2.8%				
I5	Local biodiversity protection	15.0%	1.4%				
I6	Product with organic basis certificate	11.0%	1.1%	I4	Product with organic basis certificate	20.0%	1.0%
C3	Energy	25%	10.0%	C3	C3. Energy	24.0%	11.0%
I7	Energy consumption	42.0%	4.2%	I5	Energy consumption	43.0%	5.0%
I8	Renewable energy	29.0%	2.8%	I6	Renewable Energy	28.50%	3.0%
I9	Commissioning	29.0%	2.8%	I7	Commissioning	28.50%	3.0%
C4	Materials, solid residues, resources management	18%	7%	C4	Materials, residues and resources management	14.00%	5.0%
I10	Reuse of materials	19.0%	1.4%	I8	Materials reused and with recycled contents	21.00%	1.5%
I11	Materials with recycled content	38.0%	2.8%				
I12	Construction and demolition wastes	10.0%	0.7%				
I13	Environmental management plan	19.0%	1.4%	I9	Environmental management plan	28.00%	2.0%
I14	Flexibility and adaptability	14.0%	1.1%	I10	Flexibility and adaptability	21.0%	1.5%
C5	Water	16.0%	6.00%	C5	Water	20.0%	7.0%
I15	Water consumption	44.0%	2.8%	I11	Water consumption	44.0%	3.0 %
I16	Water treatment and Recycling	44.0%	2.8%	I12	Water treatment and Recycling	44.0%	3.0%
I17	Storm water management	11.0%	0.7%	I13	Collection and reuse of Rainwater	12.0%	1.0%
SOCIAL		30.0%	30.0%	**SOCIAL**		100.0%	35.0%
C6.	Comfort and health of users	80.0%	24.0%	C6.	Comfort and health of users	70.0%	25.0%
I18	Indoor air quality	24.0%	6.0%	I14	Indoor air quality	24.0%	6.0%
I19	Thermal Comfort	32.0%	8.0%	I15	Thermal Comfort	22.0%	5.5%
I20	Visual Comfort	25.0%	6.0%	I16	Visual Comfort	24.0%	6.0%
I21	Acoustic Comfort	19.0%	5.0%	I17	Acoustic Comfort	20.0%	5.0%
	Ergonomic Comfort			I18	Ergonomic Comfort	10.0%	2.5%
C7	Accessibility	10.0%	3.0%	C7	Accessibility	2.0%	2.0%
I22	Mobility plan	100.0%	3.0%	I19	Mobility plan	100.0%	2.0%
C8	Occupants Security	10.0%	3.0%	C8	Occupants security	3.00%	3.0%

I23	Occupants Security	100.0%	3.0%	I20	Occupants Security and safety	100.0%	0%
				C9	Education Sustainability awareness	3.0%	3.0%
LOCAL SUSTAINABILITY				I21	Sustainability awareness	100.0%	3.0%
C10	Accessibility to public transport	100.0%	0%	C10	Accessibility to public transport	2.0%	2.0%
I25	Accessibility to public transport	50.0%	0%	I25	Accessibility to public transport	100.0%	2.0%
I26	Accessibility for amenities	50.0%	0%				
ECONOMIC		30.0%	30.0%	ECONÓMIC		30.0%	30.0%
C9	Life cycle costs	100.0%	30.0%	C11	Life cycle costs	100.0%	30.0%
I24	Life cycle costs		30.0%	I26	Life cycle costs	100.0%	30.0%

Table 5.7. Weight of indicators, categories and dimensions - SBTool^{PT} STP Office Buildings and SAHSB^{PT} (continuation)

5.6. Concluding remarks

At the beginning of this chapter, it was decided which indicators and categories belonging to the methodology SBTool^{PT} STP for Office Buildings would remain in the methodology elaborated in this work. It was also defined which indicators would not be used, the new indicators and categories proposed and the necessary adaptations for some indicators, specifically directed to school buildings.

Chapters 2, 3, 4 and 5 provide the necessary support for Chapter 6, which is the basis for the preparation of the Evaluation Guide of the SAHSB^{PT}.

CHAPTER 6

Basis for the preparation of the Evaluation Guide – Sustainability Assessment of High School Buildings in Portugal - SAHSB^{PT}

This chapter presents the preparation of the Evaluation Guide that is the basis of the evaluation process of sustainability of school buildings through the methodology adapted and elaborated in this work. The Evaluation Guide is presented in the Supplementary Material. This chapter is taken from the article "Adaptation of the SBTool for Sustainability Assessment of High School Buildings in Portugal—SAHSB^{PT}" (https://doi.org:10.3390/app9132664), whose authors are also the author and the supervisors of this thesis.

6.1. Introduction

The SAHSB^{PT} Evaluation Guide is primarily intended to assist in the development of better school building projects, mitigating errors in the assessment process, allowing the evaluator to measure the performance of the construction at the level of each dimension, category or indicator, resulting in the overall performance of the construction (Sustainability Level – SL).

The main purpose of these indicators is to measure, simplify, and show some features of the constructions. The combination of some indicators forms a category. There are great variances among the indicators used in different methodologies for assessing the sustainability of school constructions due to the socio-cultural, environmental and economic aspects and the existing technologies in each country (Bernardiet al., 2017, Saraiva et al., 2019b).

The SAHSB^{PT} methodology has 3 dimensions, 11 categories and 23 indicators which are listed below.

Environmental Dimension

- C1 Climate change and outdoor air quality
  - I1 Life cycle environmental impacts
  - I2 Heat island effects
- C2 Biodiversity and land use
  - I3 Land use efficiency
  - I4 Product with organic basis certificate
- C3. Energy
  - I5. Energy consumption
  - I6. Renewable Energy
  - I7. Commissioning
- C4 Materials, residues and resources management
  - I8. Materials reused and with recycled contents
  - I9. Environmental management plan
  - I10. Flexibility and adaptability
- C5 Water
  - I11. Water consumption
  - I12. Water treatment and Recycling
  - I13. Collection and reuse of rainwater

Social Dimension

- C6. Comfort and health of users
  - I14. Indoor air quality
  - I15. Thermal Comfort
  - I16. Visual Comfort
  - I17. Acoustic Comfort
  - I18. Ergonomic Comfort
- C7 Accessibility
  - I19. Mobility plan
- C8 Occupants security
  - I20. Occupants Security and safety
- C9 Education for sustainability awareness
  - I21. Sustainability awareness

- C10 Accessibility to public transport.
  I22. Accessibility to public transport

Economic Dimension

- C11 Life cycle cost
  I23. Life cycle costs

The Evaluation Guide is divided into four phases:

- Phase I - Evaluation of building performance at the level of each environmental indicator;
- Phase II - Evaluation of building performance at the level of each social indicator;
- Phase III - Evaluation of building performance at the level of each economic indicator;
- Phase IV - Combination of the performance of all indicators for the quantification of intermediate and overall building performance levels.

The indicators usually follow the subsequent structure in the Evaluation Guide (Saraiva et al., 2019b):

1. The main objective of the indicator;
2. Required elements for evaluation, in which the data for the assessment are found;
3. The life cycle phase to which the indicators apply.
4. Benchmarks of the indicators: best practice and standard practice;
5. Method of calculation: a report of the steps and procedures necessary to measure the performance of the construction;
6. Standardization to measure and normalize the performance level of the construction in the context of the indicators according to the previously defined benchmarks;
7. Assessment to summarize the performance level of the construction at the indicator level, using the qualitative scale consisting of six levels (A+–E), which is used to show the result of the assessment.

The decision about indicators, categories, methods of calculation and the reference practice about the Guide of SBTool^{PT} Sustainability Assessment adapted to High SchoolBuildings (SAHSB^{PT}) is presented on the following pages. In this subchapter, the first indicator will be explained in more detail in order to explain how the methodology will be performed. The new indicators included in this methodology are also described in detail in this chapter. The indicators already existing in previous SBTool methodologies, such as SBTool^{PT} (Mateus, 2010) and SBTool STP for Office Buildings (Barbosa, 2013) are summarized. The complete Guide of SBTool^{PT} Sustainability Assessment adapted to High School Buildings (SAHSB^{PT}) is presented as supplementary material of this thesis.

6.2. Environmental Dimension

CATEGORY CLIMATE CHANGE AND OUTDOOR AIR QUALITY - C1

INDICATOR LIFE CYCLE ENVIRONMENTAL IMPACTS (I1)

It was not possible to study all the constructive solutions used in high school buildings in Portugal, because it was not viable to carry out such an extensive investigation. The method of calculation used for this indicator is identical as that included in the SBTool^{PT}-H and SBTool^{PT}-STP for Office Buildings; consequently, this indicator is similar to those included in these former SBTool methodologies (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

The equivalent database, method of calculation and reference practice, were used in this study in order to preserve the standard of SBTool methodologies adapted to Portugal. Concerning with these methodologies, the environmental impacts of the life cycle of the building are calculated, and then, these impacts are measured according to the reference practice for construction (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

Objective:

This indicator promotes the construction procedures and the use of materials that generate a low environmental impact.

Required elements for the evaluation:

- Descriptive document of the building project of the evaluated high school building;
- Maps of quantities;
- Plants and elevations with the indication of construction details.

Project phase where indicator is applied:

This indicator can be used in the process of pre-design, design, construction or use. In the pre-design or design stages, only the solutions and the building materials planned for the building shall be used in the calculations, while in buildings under construction or in existing ones, only the solutions and building materials effectively applied to the building shall be considered. In the case of refurbishment, it shall not be considered the impact of the elements to be reused (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

Reference Practices

Standard Practice

The Standard Practice (SP) for this indicator is mentioned during the calculation method.

Best Practice

The Best Practice (BP) is one quarter of the Standard Practice (SP), the same value of SBTool^{PT} H and SBTool^{PT} STP for Office Buildings.

$$BP=\frac{SP\%}{4}$$

Calculation method

A database was developed on the quantification of the environmental impact categories associated with the life cycle of building materials and building elements in parallel with the Assessment Guide of Mateus (2010), which originated the SBTool^{PT}H and was also used in the SBTool^{PT} for Office Buildings.

This database includes renewable and non-renewable energy incorporated into the materials and constructive elements, accounting for environmental impact that are generally reported in Environmental Product Declarations (EPDs), such as: Global Warming Potential (GWP) Ozone Depletion (ODP); Potential Acidification (AP), Photochemical Oxidation Potential (POCP), Eutrophication Potential (EP) and Non-renewable Primary Energy (FFDP).

This same database is used in this thesis since it maintains the standard of the SBTool methodologies adapted to the reality of Portugal. The calculation method is divided into three sections (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b):

- A – Quantify the Life Cycle Environmental impacts of the building: quantify the environmental impacts of the construction's life cycle by multiplying the quantities (m^2 or m^3) of each element of the building by their respective unit environmental impacts;

- B – Quantify the environmental impacts of the life cycle of reference solutions (Benchmarks): multiply the environmental impacts concerning the reference solutions by the total area of each type of construction element;
- C – Normalization and aggregation of the environmental impact.

Section A: Quantify the Life Cycle Environmental impacts of the construction

- Through the architectural design, identify the construction elements of the building (floors, walls, structures and glazing) and put their measures (area and volume);
- Consult the Life Cycle Analyses (LCA) database to identify the LCA environmental impact value of the construction solution used and its maintenance operations;
- If the construction solution (standard) is not in the database, it should be used the value (square meter) of each construction material that constitutes the construction solution;
- Multiply the value of each environmental impact by the amount of the different elements of the building;
- Determine the building's life cycle.

There are several tables, as Table 6.1, that help calculating the LCA (cradle to gate, 50 years) for each construction material (concrete, masonry), in the different types of construction elements (internal and external walls). The numbers (1, 2, 3…) determine the type of construction material, and the symbols (A1, A2, A3…) represent the area of the construction material of each element (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

Table 6.1. Replica of the table of SBTool^{PT}STP Office Buildings: Description of building blocks used, their area and quantify the environmental impacts of building life cycle, Section A (Barbosa, 2013)

Solution Type	**Area (m^2)**	**Quantification of environmental impact categories (per m^2 of each type of support solution).**					
		GWP (Kg CO_2)	ODP (kg CFC_{-11})	AP (KgSO_2)	POCP (kg C_2H_4)	EP (kg PO_4)	FFDP (MJ)
Solution for Ground floor							
1							
Total surface (m^2)	(A1)	Solution of Maintenance for Ground floor					
Solution for High floors							
2							
Total surface (m^2)	(A2)	Solution of Maintenance for High floors					
Solution for Exterior walls							
3							
Total surface (m^2)	(A3)	Solution of Maintenance for Exterior walls					
Solution for Interior walls							
4							
Total surface (m^2)	(A4)	Solution of Maintenance for Interior walls					
Solution for Roofs							
5							
Total surface (m^2)	(A5)	Solution of Maintenance for Roofs					
Solution for Glazed areas							
6							
Total surface (m^2)	(A6)	Solution of Maintenance for Glazed openings					
Solution for Structure							
7							
Total surface (m^2)	(V1)						
Sum of Impacts							
Divide by Lifetime cycle							
Total impacts of life cycle m^2/year							

Section B. Quantification of the environmental impacts of the life cycle of reference solutions (Benchmarks):

- For each type of building element, it must be multiplied each environmental impact that corresponds to the reference solution by the total area of that element;
- For each type of constructed building, it should only be considered the values related to maintenance if they are taken into account.

In this section, it is presented the calculation procedure needed to help to quantify the categories of environmental impact for life cycle in reference buildings (standard practice and best practice). The quantification of these categories is carried out by completing Table 6.1. for the different building components: ground floor, high floors, exterior walls, interior walls, roofs, glazed areas and structure.

B.1. 1. Ground Floor

In Table 6.2 is made a sum of all environmental impacts of ground floor, multiplying by the respective area, and dividing the total value obtained for each category of environmental impact by the total area of ground floor, thus obtaining an average impact per unit of area.

Table 6.2. Replica of the table of SBTool^{PT}STP for Office Buildings Values corresponding to the standard practice for the ground floor (Barbosa, 2013).

					Ground floor	
	Quantification of environmental impact categories					
	GWP (Kg CO_2)	ODP (kg CFC_{-11})	AP (Kg SO_2)	POCP (kg.C_2H_4)	EP (kg PO_4)	FFDP (MJ)
Standard Practice	8.02E+01	4.33E-06	2.03E-01	7.53E-03	3.08E-02	5.88E+02
Maintenance						
Total						
			X			
Total area of element (m^2)			A1			
(P1.2) Impacts from standard practice						

1) The standard practice for the support solution is a lightweight slab of pre-stressed concrete beams and ceramic blocks, concrete compression layer, and a regularization layer of cement mortar (5 cm). To the floors, the standard practice consists of cement paste (1 cm) and ceramic tiles and for the ceilings it is considered the application of 1.5 cm of plaster, including painting (Barbosa, 2013).

2) For maintenance purposes it is considered that the ceramic coating is replaced one time every 20 years and that the ceiling is painted every 8 years, in a 50-year life cycle. Maintenance impacts must be considered in the calculation of the impacts of reference solutions if these impacts are calculated for the existing solution, in Part A of the calculation method.

B.1.2. High floors

In Table 6.3. is made a sum of all environmental impacts of high floor, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of high floor, thus obtaining an average impact per unit of area.

Table 6.3. Replica of the table of SBTool^{PT}STP for Office Buildings: Values corresponding to the standard practice for high floors (Barbosa, 2013)

					High Floor	
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP ($kgCFC_{-11}$)	AP ($KgSO_2$)	POCP ($kg.C_2H_4$)	EP (kg PO4)	FFDP (MJ)
Standard Practice	8.66E+01	5.22E-06	1.94E-01	9.01E-03	3.15E-02	6.57E+02
Maintenance						
Total						
			X			
Total Surface (m^2)	A2					
(P1.3) Impacts of standard practice						

1) The standard practice for the support solution is a lightweight slab of pre-stressed concrete beams and ceramic blocks, concrete compression layer, and a regularization layer of cement mortar (5 cm). To the floors, the standard practice consists of cement paste (1 cm) and ceramic tiles and for the ceilings it is considered the application of 1.5 cm of plaster, including painting (Barbosa, 2013).

2) For maintenance purposes it is considered that the ceramic coating is replaced one time every 20 years and that the ceiling is painted every 8 years, in a 50-year life cycle. Maintenance impacts must be considered in the calculation of the impacts of reference solutions if these impacts are calculated for the existing solution, in Part A of the calculation method.

B.1.3 Exterior Walls

In the Table 6.4. is made a sum of all environmental impacts of exterior walls, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of exterior walls, thus obtaining an average impact per unit of area.

Table 6.4. Replica of the table of SBTool^{PT}STP: Values corresponding to the standard practice for exterior walls (Barbosa, 2013)

					Exterior walls	
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP (kg CFC_{-11})	AP (Kg SO_2)	POCP ($Kg.C_2H_4$)	EP (kg PO_4)	FFDP (MJ)
Standard Practice	5.89E+01	3.91E-06	1.69E-01	1.72E-02	2.37E-02	6.32E+02
Maintenance						
Total						
			X			
Total surface (m^2)	A3					
(P1.4) Impacts from standard practice						

1) The standard practice for the external walls is a double wall brickwork (11 + 15 cm) with an air-box partially filled with extruded polystyrene (3 cm) and it is grouted from both sides with cement mortar (1.5 cm). Coating is considered if the walls are painted with two coats of acrylic paint.

2) For maintenance purposes, it is considered that the exterior walls are painted every 8 years in a life cycle of 50 years. The maintenance impacts should be considered in the calculation of the impacts of reference solutions if these impacts are calculated for the existing solution, in Part A of the calculation method.

B.1.4. Interior walls

In Table 6.5 the is made a sum of all environmental impacts of interior walls, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of interior walls, thus obtaining an average impact per unit of area.

Table 6.5. Replica of the table of SBTool^{PT}STP: Values corresponding to the standard practice for interior walls (Barbosa, 2013).

					Interior Walls	
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP ($KgCFC_{-11}$)	AP ($KgSO_2$)	POCP ($kg.C_2H_4$)	EP ($kg PO_4$)	FFDP (MJ)
Standard Practice	3.14E+01	2,17E-06	8.22E-02	4.54E-03	1.35E-02	2.82E+02
Maintenance						
Total						
	X					
Total area of the element (m^2)	A4					
(P1.5) Impacts from standard practice						

1) The standard practice solution for interior walls is a single wall of hollow brick masonry (11cm), plastered on both sides with cement mortar (1.5 cm). It is considered that the surfaces are painted with two layers of plastic paint.

2) For maintenance purposes it is considered that the surfaces are painted every 8 years in a life cycle of 50 years. Maintenance impacts must be considered in the calculation of the impacts of reference solutions if these impacts are calculated for the existing solution, in Part A of the calculation method.

B.1.5. Roofs

In theverage impact per unit of area.

Table 6.6. is made a sum of all environmental impacts of roof, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of the roof, thus obtaining an average impact per unit of area.

Table 6.6. Replica of the table of SBTool^{PT}STP: Values corresponding to the standard practice for roofs (Barbosa, 2013)

						Roofs
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP (kg CFC_{-11})	AP ($KgSO_2$)	POCP ($kg.C_2H_4$)	EP (kg PO_4)	FFDP (MJ)
Standard Practice	8.80E+01	4.75E-06	1.84E-01	9.66E-03	2.94E-02	6.15E+02
Maintenance						
Total						
	X					
Total Surface (m^2)	A5					
(P1.6) Impacts from standard practice						

1) The reference of support for construction solution is the lightweight slab of pre-stressed concrete beams and ceramic blocks with levelling floor cement mortar with an average thickness of 5cm. It is considered that the coating of the roof is made with ceramic tiles of the type "Lusa".

2) For maintenance purposes it is considered that the ceilings are painted every 8 years and that the ceramic tiles are replaced every 50 years. Maintenance impacts must be considered in the calculation of the impacts of reference solutions if these impacts are calculated for the existing solution, in Part A of the calculation method.

B.1.6. Glazed areas

In the Table 6.7. is made a sum of all environmental impacts of glazed openings, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of glazed areas, thus obtaining an average impact per unit of area.

Table 6.7. Replica of the table of SBTool^{PT}STP: Values corresponding to the standard practice for windows and glazed openings (Barbosa, 2013).

						Glazed areas
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP (kg CFC_{-11})	AP ($KgSO_2$)	POCP ($kg.C_2H_4$)	EP (kg PO_4)	FFDP (MJ)
Standard Practice l	8.31E+00	1,17E-06	1.16E-01	-.0.29E-03	8.18E-03	1.04E+03
Maintenance						
Total						
	X					
Total surface (m^2)	A6					
(P1.7) Impacts from standard practice						

1) For maintenance purposes, it is considered that the windows are replaced every 30 years in a life cycle of 50 years. Maintenance impacts must be considered in the calculation of the impacts of reference solutions if these impacts are calculated for the existing solution, in Part A of the calculation method.

B.1.7. Structures

In the Table 6.8. is made a sum of all environmental impacts of structure, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of structure, thus obtaining an average impact per unit of area.

Table 6.8. Replica of the table of SBTool^{PT}STP for Office Buildings: Values corresponding to the standard practice for the structure (Barbosa, 2013)

					Structure	
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP ($kgCFC_{-11}$)	AP ($KgSO_2$)	POCP ($kg.C_2H_4$)	EP ($kg PO_4$)	FFDP (MJ)
Standard Practice	3.70E+02	1.32E-5	5.71E-01	1.81E-02	1.37E-01	1.50E+03
	X					
Total volume (m^3) (2)	V1					
(P1.8) Impacts from standard practices						

1. The reference is a portico system of pillars and beams in reinforced concrete. The values of the environmental impacts presented consider the impacts associated with concrete and steel, assuming an average density for the reinforcement of concrete of 100kg/m^3. The environmental impact categories are presented *per m^3*.

2. Consider the total volume of reinforced concrete in a structure equivalent to the building structure under evaluation. In the absence of more accurate values, consider the approximate value of 0.34 m^3 of reinforced concrete per m^2 of gross floor area of the building. This average value was determined by the analysis of several building structures in which the structure is composed of reinforced concrete.

B.2. Benchmarks associated to the building's life cycle

Table 6.9. and Table 6.10. present the auxiliary calculation process required to quantify the life cycle environmental impact categories in reference buildings (standard and best practice).

Table 6.9. Replica of the table of SBTool^{PT}STP: Impacts of life cycle corresponding to the standard practice (Barbosa, 2013)

					Standard Practice	
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP ($kgCFC_{-11}$)	AP ($KgSO_2$)	POCP ($kg.C_2H_4$)	EP ($kg\ PO_4$)	FFDP (MJ)
Total impacts incorporated (P1.2+P1.3+P1.4+P1.5 +P1.6 +P1.7 + P1.8)						
	÷					
Duration of cycle life of reference (years)	50 years					
(P1.9) Impacts of the life cycle of standard practice						

Table 6.10. Replica of the table of SBTool^{PT}STP: Impacts of life cycle corresponding to the best practice (Barbosa, 2013)

					Best practice	
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP ($kgCFC_{-11}$)	AP ($KgSO_2$)	POCP ($kg.C_2H_4$)	EP ($kg\ PO_4$)	FFDP (MJ)
Total Impacts Incorporated $\frac{SP\ \%}{4}$						
	÷					
Duration of the life cycle of reference (years)	50 years					
(P1.10)Best practice life cycle impacts						

Section C. Normalization and aggregation of the environmental impact categories

By the filling of Table 6.11. it is possible to define the normalized value of each one of the environmental impact categories. The same table also presents the auxiliary calculation necessary to assist the aggregation of the different categories into a single indicator (PLCA) expressing the environmental impact of the solution assessed during its life cycle.

Table 6.11. Replica of the table of SBTool^{PT}STP: Standardization and assessment of the global environmental performance of the solution assessed (Barbosa, 2013)

Environmental impact Categories	**Life cycle impacts (per m^2 of useful area of pavement and year)**				Weight of the environmental impact category [B]	Weighted value =[A]x[B]
	Best practice [Pi*] = (P1.10)	Standard Practice [Pi*] = (P1.9)	Solution Assessed [Pi] = (P1.1)	Standard value (1) [A]		
GWP ($KgCO_2$)					40,7%	
ODP ($kgCFC_{-11}$)					8,4%	
AP ($KgSO_2$)					13,6%	
POCP($kg.C_2H_4$)					10,15%	
EP (kg PO4)					13,6%	
FFDP (MJ)					13,6%	
			(PLCA) (P1.24) Σ = Environmental performance of the solution			

1) The normalization is made through the following equation

$$\overline{P_i} = \frac{P_i - P_{i*}}{P_i^* - P_{i*}} \quad (6.1)$$

Pi Represents the result of the quantification of the indicator
P_i* Represents the value of the best practice
P_{i*} Represents the value of the standard practice

Table 6.12. Replica of the table of SBTool^{PT}STP: Assessment to summarize the performance level of the construction, Evaluation Table

Level	Condition	Please check the level reached (✓)
A^+	$\overline{P_{CCV}} > 1.0$	
A – Best Practices	$0.7 < \overline{P_{CCV}} \leq 1.0$	
B	$0.4 < \overline{P_{CCV}} \leq 0.7$	
C	$0.1 < \overline{P_{CCV}} \leq 0.4$	
D – Standard Practice	$0.0 \leq \overline{P_{CCV}} \leq 0.1$	
E	$\overline{P_{CCV}} < 0.0$	

INDICATOR HEAT ISLAND EFFECT (I2)

This indicator contributes to the use of materials with high reflectance and green areas set in the outer part of the construction and to the reduction of the heat island effect in urban areas.

Portugal has schools built in different historical phases; however, using a variety of constructive processes and materials, their roofs are frequently made with ceramic or metallic tiles and their façades are normally made to be white or light tones. These materials assist the reduction of heat island effect (Muscio, 2018).

Currently, the construction industry has use some parameters to analyse the thermal behaviour of materials used in facades subjected to solar radiation, through the interaction among different properties of the materials, using simple calculations, such as the Solar Reflectance Index (SRI) (Muscio, 2018). This is included in the SAHSB^{PT} methodology for its effective demonstration of the thermal performance of a built surface submitted to solar radiation.

This indicator is already included in the SBTool^{PT} and SBTool^{PT} STP for Office Buildings methodology, therefore, it is just reported in the Suplementary Material.

CATEGORY BIODIVERSITY AND LAND USE - C2

INDICATOR LAND USE EFFICIENCY (I3)

This indicator promotes mitigation of the impact caused by the development of urban areas by maximizing land occupation, where the construction of buildings is acceptable, making the best use of these built areas (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al, 2019c).

The calculation method and the references practices for this indicator are equal to those included in SBTool^{PT}-STP for Office Buildings. Consequently, this indicator is similar to those included in the SBTool^{PT}-STP for Office Buildings and SBTool^{PT}-H, therefore, it is just reported in the Suplementary Material.

This indicator in the SAHSB^{PT} methodology contemplates the total area of the construction, the area resulting from the vertical projection on the ground of constructions, the sum of the high school buildings' compartment areas, the number of classroom students and the land area in vertical projection to determine the normalized value of the Index of Territorial Efficiency Ratio Occupation of the school building (Saraiva et al., 2019b).

INDICATOR CERTIFICATED WOODEN MATERIALS (I4)

This indicator contributes to the use of organic products with environmental certification. There are many international and Portuguese laws concerning with certified materials. The calculation method and the reference practices for this indicator are the same as those included in the SBTool^{PT} for Office Buildings. Consequently, this indicator is similar to that included in the SBTool^{PT}-STP for Office Buildings.

This indicator in the SAHSB^{PT} methodology is concerned with the cost of organic materials or wood with environmental certification, such as footers, furniture, ceilings, walls floors, coatings, windows, doors, stairs and structural elements made of wood (Saraiva et al., 2019b).

This indicator is already part of the SBTool^{PT} and SBTool STP for Office Buildings methodology, therefore, it is just reported in the Suplementary Material.

CATEGORY ENERGY - C3

INDICATOR ENERGY CONSUMPTION (I5)

This indicator is based on Regulation of Energy Performance of Commercial Buildings and Services (RECS), according to the Decree Law 118/2013 procedures for energy consumption is concerned with values of the energy consumption per year related to gas (EG) and electricity (EE).

This indicator is already include in the SBTool^{PT} and SBTool STP for Office Buildings methodology, however, it was modified under the current legislation, RECS, as mentioned before. Therefore, it is just reported in the Suplementary Material.

Objectives

This indicator contributes to the mitigation of the energy consumption in school buildings through the use of passive solutions and efficient equipment.

Required elements for the evaluation

- Thermal Design or the Energy Performance Certificate and Indoor Air Quality Certificate.

Project phase where indicator is applied:

Design (predictive result), construction and use phase.

Reference Practices

This indicator is based on the RECS, according to Decree Law 118/2013.

Standard Practice and best practice are based on Calculation Sheet delivered to the Regulatory Entity and Energy Certificate. The reference practices have been defined as shown in the Table 6.13.

Table 6.13. Reference Practice of Energy.

Total Consume of Energy		
Electricity and gas	Standard Practice	310
	Best Practice	231

Standard Practice

Based on the Building Thermal Performance Project.

$$E_{C*} = IEE_{ref}$$

Best Practice

Based on the Building Thermal Performance Project.

$$E_C{}^* = 0{,}25 \times IEE_{ref} \quad (6.2)$$

Calculation method

The assessment is based on the procedures established by the RECS for the energy consumption of the building (E_C). Get the actual or estimated values of the energy consumption per year related to electricity (E_E) and gas (E_G) by consulting the consumption values of the building's Energy Certificate or the Thermal Engineering Project (design and construction phases) or the Calculation Sheet delivered to the Regulatory Entity in the immediately preceding calendar year (use phase).

If the Thermal Performance Project, the Energy Efficiency Indicator (Indicador de Eficiencia Energética –IEE_{ref}) should be calculated by the following equation:

$$\mathrm{IEE_{ref}} = \mathrm{IEE_{pr,S}} + \mathrm{IEE_{pr.T}} \quad (6.3)$$

$IEE_{pr,S}$ - represents the energy consumptions that are considered for calculating the energy rating of the building, as indoor and outdoor lighting, ventilation and pumping in air conditioning systems; heating and cooling (including; humidification and dehumidification); lifts; escalator; heating of sanitary waters and swimming pool;

$IEE_{pr.T}$ – represents the energy consumptions that are not considered for calculation purposes of the building's energy rating of the building,, as ventilation and pumping not associated with thermal load control; and all equipment and systems not included in $IEE_{pr,S}$.

If the Calculation Sheet delivered to the Regulatory Entity and Energy Certificate is consulted, it should be calculated by the following equation:

$$\mathbf{E_C} = \frac{\mathbf{E_E} + \mathbf{E_G}}{\sum \mathbf{A_{TC}}} \quad (6.4)$$

E_C= Total Energy Consumption of the building per m^2 per year;

E_E = The value of Electric Energy of the building;

E_G= The value of Gas Energy of the building;

$\sum A_{TC}$ - Total construction area is the sum of the building areas of all existing or planned buildings.

2. Calculate the normalized value of the intake energy of the building by the following equation:

$$\overline{\mathbf{E_C}} = \frac{\mathbf{E_C} - \mathbf{E_{C*}}}{\mathbf{E_C^*} - \mathbf{E_{C*}}} \quad (6.5)$$

INDICATOR RENEWABLE ENERGY (I6)

The assessment is based on the procedures established by the RECS. This indicator is already included in the SBTool^{PT} and SBTool STP for Office Buildings methodology, however, it has been modified under the current legislation, RECS, as mentioned before. Therefore, it is reported in this chapter.

Objectives

This indicator contributes to the mitigation of energy consumption in buildings using renewable energy.

Required elements for the evaluation

- Thermal Design or the Energy Performance and Indoor Air Quality Certificate.

Project phase where indicator is applied:

Design (predictive result), construction and use phase.

Reference Practices

The assessment is based on the procedures of the RECS for the renewable energy of the building (E_{REN}). No national data were found to allow the definition of the corresponding reference practice values, therefore, the reference practice is similar to SBTool^{PT} STP for Office Buildings.

Standard Practice

The value of standard Practice of renewable energy in the building($\mathbf{E_{REN*}}$) is 30% of the total energy spended by the building.

$$\mathbf{E_{REN*} = 30\%}$$

Best Practice

The value of best Practice of renewable energy in the building ($\mathbf{E_{REN}}^*$) is 60% of the total energy spended by the building.

$$\mathbf{E_{REN}}^* = \mathbf{60\%}$$

Calculation Method

Calculate the normalized value of renewable energy in the building (E_{REN}), using the following equation:

$$\overline{\mathbf{E_{REN}}} = \frac{\mathbf{E_{REN}} - \mathbf{E_{REN*}}}{\mathbf{E_{REN}}^* - \mathbf{E_{REN*}}} \tag{6.6}$$

$$\frac{\mathbf{E_{REN}} \ - \ \mathbf{30\%}}{\mathbf{60\%} - \mathbf{30\%}} \tag{6.7}$$

INDICATOR COMMISSIONING (I7)

This indicator contributes with the suitable management of mechanical systems throughout the building life cycle. The method of calculation and the best practice for this indicator are the same as those used in SBTool^{PT}-STP for Office Buildings, therefore, it is just reported in the Suplementary Material.

This indicator in the SAHSB^{PT} methodology uses a form that assesses the schedule that defines the important dates and milestones regarding water and energy consumption defined by the commission team, the plan for the management of mechanical systems, the documentation and the performance verification regarding the building and the energy system, and the purchase of energy generation for the building. (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

MATERIALS, SOLID RESIDUES, AND RESOURCES MANAGEMENT – C4

INDICATOR MATERIALS REUSED AND WITH RECYCLED CONTENTS (I8)

This indicator is the junction of the indicators of “reused materials” (I10) and “recyclable materials” (I11) included in the SBTool^{PT}-STP for Office Buildings. This indicator in the SAHSB^{PT} methodology concerns the value equivalent to the sum of the cost of the construction elements and materials from deconstructions located outside of the site that will be reused and elements or materials in the construction that are pre-existing in the building and will be reused (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

No national data were found that could allow the definition of the corresponding reference practice values. Although there is no reference in the objectives defined by Parque Escolar about the reuse and recycling of construction materials, floor and wall covering materials must be maintained, remodelled or modified in order to meet the requirements of the EPE standards.

The calculation method and reference practices for this indicator are the same as those included in in SBTool^{PT}-STP for Office Buildings (Saraiva et al., 2019b). Since this indicator is a junction of the indicator “reuse of materials” and the indicator “materials with recycled content” in the SBTool^{PT} STP for Office Buildings, this indicator is reported in this chapter.

Objectives

This indicator promotes the use of recycled and reused materials in the high school buildings.

Required elements for the evaluation

- Materials quantities plan;
- Budget plan;
- Technical documentation of the materials used;
- Budget plan of construction work;
- In the case of re-use of CDW from other works, submit a document that certify this reuse.

Project phase where indicator is applied:

- Design phase.

Reference Practices

Standard Practice

In Portugal, the practice of reuse of building materials in unusual. The value of standard practice is 0%.

$$\mathbf{P_{CREU*} = 0\%}$$

Best Practice

The value of best practice is 15% (International SBtool).

$$\mathbf{P_{CREU}^{*} = 15\%}$$

Calculation Method: Reuse Material

1. Determine the percentage of cost of materials and products used in the building that are reused (P_{CREU}), using the equation below:

C_{REU} - Cost of goods corresponding to the construction materials and elements that will be reused (C_{REU}). This value corresponds to the sum of the cost of the following items:

- Materials or elements at the construction that are pre-existing in the building and will be reused. If the budget does not include the value of these items, its cost of production should be assigned;
- Construction elements and materials from deconstructions located outside of the site.

C_{TOT} - Total amount of the budget of building materials.

$$P_{CREU} = \frac{C_{REU}}{C_{TOT}} \quad (6.8$$

4. Calculate the normalized value of percentage of cost of materials and products used in work that is reused P_{CREU}, using the equation below:

$$\overline{\mathbf{P_{CREU}}} = \frac{\mathbf{P_{CREU}} - \mathbf{P_{CREU*}}}{\mathbf{P_{CREU}}^{*} - \mathbf{P_{CREU*}}} \tag{6.9}$$

$$\frac{\mathbf{P_{CREU}} - \mathbf{0\%}}{\mathbf{15\%} - \mathbf{0\%}}$$

Calculation Method: Recycled Material

Determine the percentage in cost of materials with recycled content (P_{REC}) using the following equation:

$$\mathbf{P_{REC}} = \frac{\mathbf{C_{REC}}}{\mathbf{C_{TOT}}} \tag{6.10}$$

C_{REC} - Cost of materials with recycled content;

C_{TOT} - Total cost of the materials used on site.

2. Standard practice for the percentage cost of materials with recycled content ($\mathbf{P_{REC*}}$) is 0%.

$$\mathbf{P_{REC*}} = \mathbf{0\%}$$

3. Best practice for the percentage cost of materials with recycled content ($\mathbf{P_{REC}}^{*}$) is 10%.

$$\mathbf{P_{REC}}^{*} = \mathbf{10\%}$$

4. Calculate the normalized value of the percentage cost of materials with recycled content ($\overline{\mathbf{P_{REC}}}$) of the building by the following equation:

$$\overline{\mathbf{P_{REC}}} = \frac{\mathbf{P_{REC}} - \mathbf{P_{REC*}}}{\mathbf{P_{REC}}^{*} - \mathbf{P_{REC*}}} \tag{6.11}$$

$$\frac{\mathbf{P_{REC}} - \mathbf{0\%}}{\mathbf{10\%} - \mathbf{0\%}}$$

After finding the result of the material reused and the recycled material, one must add both and divide by two.

$$P_{REUC} = \frac{\overline{\mathbf{P_{CREU}}} + \overline{\mathbf{P_{REC}}}}{2} \tag{6.12}$$

INDICATOR ENVIRONMENTAL MANAGEMENT PLAN (I9)

This indicator encourages the suitable management of resources during the use phase of the building and/or the use of an Environmental Management System (EMS) (Mateus & Bragança, 2009, Barbosa et al., 2013). This indicator in the SAHSB^{PT} methodology is evaluated through a form that assesses the training of occupants, monitoring systems, and the environmental management system. This indicator is similar to those used in the SBTool^{PT}-STP for Office Buildings and SBTool^{PT}-H. (Saraiva et al., 2019b), therefore, it is not reported in this chapter.

One of the purposes of EPE is that all high schools reformed or built must have an environmental management system (EMS). Based on this information, the value of this indicator was defined. The reference practices and calculation method are the same of SBTool^{PT} STP for Office Buildings, therefore it is just reported in the Suplementary Material.

INDICATOR FLEXIBILITY AND ADAPTABILITY (I10)

This indicator contributes to the use of construction material and processes that assist the changing uses of the building in decommissioning and repair work. Adaptability Flexibility and are new issues that have not been used widely in the planning of high school building construction (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). Therefore, there is no information or research that can give accurate information about it. Even if that is a new theme and the older schools of Portugal were not designed to be adaptable, the reforms by *Parque Escolar* aim to ensure the adaptability and flexibility in school buildings.

This indicator in the SAHSB^{PT} methodology is measured using a form that assesses the electrical and communications system (duct location), modularity of compartments, water plumbing and system, air conditioning and ventilation systems (duct location and size of equipment). The reference practices and calculation method for this indicator are the same as those included in the SBTool^{PT}-STP for Office Buildings. This indicator is similar to those included in the SBTool^{PT}-STP for Office Buildings and SBTool^{PT}-H (Saraiva et al., 2019b), therefore, it is just reported in the Suplementary Material.

CATEGORY WATER - C5

INDICATOR WATER CONSUMPTION (I11)

This indicator contributes to the reduction of water consumption inside the high school buildings during the use phase, using efficient systems. In the school environment, the main concerns relate to water saving in toilets, lavatories, and showers (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

This indicator in the SAHSB^{PT} methodology is evaluated using a form that assesses the annual water used for irrigation, drinking water consumption and the average daily water consumption of each exterior and interior device. This indicator is similar to that included in the SBTool^{PT}-STP for Office Buildings (Saraiva et al., 2019b), therefore it is just reported in the Suplementary Material.

INDICATOR WATER TREATMENT AND RECYCLING (I12)

This indicator contributes to the reduction of water consumption inside buildings in the use phase, using recycling devices, reusing groundwater, rainwater and greywater. There is a lack of reference values regarding this issue, and it may increase with the updating of the methodology (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

This indicator in the SAHSB^{PT} methodology is regarding annual per capita (l/year) use of devices that drain into the recycling system. The reference practices and calculation method for this indicator are the same as those used in the SBTool^{PT}-STP for Office Buildings; therefore, this indicator is similar to that used in the SBTool^{PT}-STP for Office Buildings (Saraiva et al., 2019b), therefore it is just reported in the Suplementary Material.

INDICATOR COLLECTION AND REUSE OF RAINWATER (I13)

This indicator encourages the use of groundwater recharge and reduce the peak flow in rainwater drainage systems (Mateus & Bragança, 2009; Barbosa et al., 2013; Saraiva et al., 2019b).

This indicator in the SAHSB^{PT} methodology is concerning annual per capita (l/year) value of the construction potential for rainwater management. The reference practices and calculation method for this indicator are the same as those included in the SBTool^{PT}-STP for Office Buildings; consequently, this indicator is similar to those included in the SBTool^{PT}-STP for Office Buildings (Saraiva et al., 2019b), therefore it is just reported in the Suplementary Material.

6.3. Social Dimension

CATEGORY USER HEALTH AND COMFORT - C6

INDICATOR INDOOR AIR QUALITY (I14)

This indicator contributes to an adequate level of air quality inside the buildings (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). Portugal is the European country where students spend more time in classrooms for a total of 936 hours per year. The objectives of the EPE include "improve living conditions and environmental comfort, with particular emphasis on hygrothermics, acoustics and air quality". The reference practices and calculation method are the same of SBTool^{PT} STP for Office Buildings.

This indicator in the SAHSB^{PT} methodology is concerned with the finishing materials with low volatile organic compounds (VOC) content and the renewal rate of the air inside the building. The method of calculation for this indicator is the same as that in the SBTool^{PT}-STP for Office Buildings; however, the reference practices are different (Saraiva et al., 2019b), therefore, just the reference practices is reported in this chapter.

Reference Practices

Standard Practice for Ventilation

The value of standard practice for the air change rate $\mathbf{P_{ARR*}}$ is 70%.

$$\mathbf{P_{ARR*} = 70\%}$$

Best Practice for Ventilation

The value of best practice for the air change rate $\mathbf{P_{ARR}^{*}}$ is 90%.

$$\mathbf{P_{ARR}^{*} = 90\%}$$

Standard Practice for VOC

The value of standard practice for the weight percentage of finishing materials with a low content VOC $\mathbf{P_{voc*}}$ is 80%.

$$\mathbf{P_{VOC*} = 80\%}$$

Best Practice for VOC

The value of best practice for the percentage by weight of coating materials with a low content VOC $\mathbf{P_{voc}}^{*}$ is 40%.

$$\mathbf{P_{VOC}^{*} = 40\%}$$

INDICATOR THERMAL COMFORT (I15)

This indicator contributes to the existence of a comfortable thermal environment inside the building (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). This indicator has the classrooms as reference. The schools that have the control system over the temperatures do not need to be evaluated by this indicator.

According to the RECS, when a construction has permanent air conditioning, it should be considered an indoor temperature in the range of 20 °C to 25 °C, and, in the case of use of the hybrid or passive system, an indoor temperature within the range of 19 °C to 27 °C shall be considered. Therefore, the best practice values are considered, 20ºC (winter) and 25ºC (summer), and standard practice, 19ºC (winter) and 27ºC (summer). The schools that do not have this control system related to temperature should be analysed, according to the procedure described below.

This indicator in the SAHSB^{PT} methodology is concerned with the level of thermal comfort, especially during the winter and summer seasons (Mateus & Bragança, 2009, Barbosa et al., 2013). The calculation method is the same, however, the reference practices for this indicator are different than those includes in the SBTool^{PT}-STP for Office Buildings, therefore, just the reference practices is reported in this chapter. It is not required to assessed high schools that have a control system for temperature (Saraiva et al., 2019b).

Reference Practices

Standard Practice in the summer season

The value of standard practice is 27°

$$\mathbf{P_{s*} = 27°}$$

Best Practice in the summer season

The value of best practice is 25°.

$$\mathbf{P_s^* = 25°}$$

Standard Practice in the winter season

The value of standard practice is 19°.

$$\mathbf{P_{w*} = 19°}$$

Best Practice in the winter season

The value of best practice is 21°.

$$\mathbf{P_w^* = 21°}$$

INDICATOR VISUAL COMFORT (I16)

This indicator contributes to the adoption of procedures to increase the levels of visual comfort in the high school building (Mateus & Bragança, 2009, Barbosa et al., 2013). This indicator in the SAHSB^{PT} methodology considers the illumination levels provided by the illumination levels provided by natural lighting and artificial lighting in all areas of the building that are occupied by students. The reference practices are different, although, the calculation method for this indicator is similar to that used in the SBTool^{PT}-STP for Office Buildings (Saraiva et al., 2019b), therefore, just the reference practices for the illuminance of school compartment is reported in this chapter.

Reference Practices

The value of standard and best practice is demonstrated in the calculation method. For benchmarking purposes considered as standard practice value (P_{DII*}) and best practice (P_{DIL}*) for illuminance values shown in Table 6.14.

Table 6.14. Reference Practices for the illuminance of each compartment depending on its use

Type of compartment	Predominant use	PDIL* (lux)	PDIL* (lux)
School Classroom	Classroom	300 l	500
	Laboratories	500	750
	Technical drawing	750	1000
	Computer classroom	500	750
	Conference and meeting rooms	500	750
	Reception	300	500
	Libraries	200	300
Areas of traffic of people	Areas and corridors	100	150
	Stairs	150	200
	Ramps and areas of exchange of goods	150	200
Bath House	Bathrooms, sinks, showers,	200	300

INDICATOR ACOUSTIC COMFORT (I17)

This indicator assists the adoption of procedures that allow a high level of acoustic comfort for occupants (Mateus & Bragança, 2009, Barbosa et al., 2013). This indicator in the SAHSB^{PT} methodology is concerned with the reverberation time and the percussion sounds in classroom, and the level of acoustic comfort with airborne sounds between classrooms. The calculation method for this methodology is similar to SBTool^{PT}-STP for Office Buildings, however, the reference practices used for this indicator are different from those include in the SBTool^{PT}-STP for Office Buildings (Saraiva et al., 2019b), therefore, just the reference practices for the illuminance of school compartment is reported in this chapter.

Reference Practices

The value of standard and best practice is demonstrated in the Method of Calculation.

Level to airborne sounds between the outside and classrooms:

Best Practice: 36 (dB)

Standard Practice: 30 (dB)

Acoustic comfort level to the reverberation time in classrooms

Identify the acoustic project reverberation time

Best Practice: T * = 0,6s

Standard Practice: T∗ = 0.8s

Level of noise where are the places inside the building that require concentration and silence:

Best Practice: 40 dB(A)

Standard practice: 55 dB(A)

INDICATOR ERGONOMIC COMFORT (I18)

The ergonomic comfort indicator is a new subject, rarely used for planning a high school building. Therefore, there is no information or research that can give accurate information about it. The inclusion of this indicator serves to inform about it and its importance in planning new high school buildings. Consequently, it has low reference values, which may rise with the updating of this methodology, according to the disclosure and the knowledge of its importance by construction professionals.

The method of calculation involves the determination of the value of the building potential for the promotion of an adequate ergonomic comfort inside the classroom. The value of this indicator has to do with the adaptation of the desks to the specific physical characteristics of each student and the answers of the questionnaires (ANNEX 2), given by the majority of the students who participated in the inquiry. This indicator is already part of the SBTool^{PT} and SBTool STP for Office Buildings methodology, therefore, it is reported in this chapter.

Objective

This indicator contributes with the existence of ergonomic comfort inside the classroom.

Required elements for the evaluation

A questionnaire should be applied to students about the level of discomfort related to ergonomics, specifically about the proper sizing of the chair and table where they sit.

Project phase where indicator is applied:

Use phase.

Reference Practices

Standard Practice

The value of standard practice corresponds to a building potential for the promotion of an adequate ergonomic comfort for the student, equal to 10% of the total credits in the

Table 6.15.

$\mathbf{E_* = 10\%}$

Best Practice

The value of best practice corresponds to a building potential for the promotion of the best ergonomic comfort for the student, equal to is 20% of the total credits in the

Table 6.15.

$\mathbf{E^* = 80\%}$

Calculation Method

Determine the value of the building potential for the promotion of an adequate ergonomic comfort inside the classroom according to the

Table 6.15.

Table 6.15. Conditions of comfort considering only the level of ergonomic comfort offered by desks

Criteria	Description	√	Credits
1	There are school desks that are adaptable to the specific physical characteristics of each student, or		100
2	Consider, as an answer, the option given by the majority of the students who participated in the research (questionnaire, ANNEX 2)		
2.1	Neutral		100
2.2	A little uncomfortable		60
2.3	Uncomfortable		40
2.4	Very uncomfortable		0
			$\sum \bar{\mathbf{E}}$

Determining the value of ergonomic comfort level $\overline{(\mathbf{E})}$ of student inside the classroom, in accordance with the following equation:

$$\overline{\mathbf{E}} = \frac{\mathbf{E} - \mathbf{E}_*}{\mathbf{E}^* - \mathbf{E}_*} \tag{6.13}$$

$$\frac{\mathrm{E} \quad - \ 10\%}{80\% - \ 10\%}$$

CATEGORY ACCESSIBILITY - C7

INDICATOR MOBILITY PLAN (I19)

This indicator contributes with a sustainable mobility plan (Mateus & Bragança, 2009, Barbosa et al., 2013). The reference practices and calculation method for this indicator are the same of that indicator include in the SBTool^{PT}-SPT for Office Buildings. This indicator is already include in the SBTool^{PT} and SBTool STP for Office Buildings methodology, therefore it is just reported in the Suplementary Material.

This indicator in the SAHSB^{PT} methodology is assessed using a form that evaluates conditions for access to the building on foot or by bike, other sustainable transport, and access for disabled people (Saraiva et al., 2019b).

CATEGORY SECURITY - C8

INDICATOR OCCUPANTS SECURITY AND SAFETY (I20)

This indicator in the SAHSB^{PT} methodology is evaluated using a form that assesses the assurance of continued operation of the main building services (telecommunications, energy and water) and the security of the building users (stairs handrails, signalling stairs, security and lighting systems) (Mateus & Bragança, 2009, Barbosa et al., 2013).

The part of the form that relates to the main building services is the same as that include in the SBTool^{PT}-SPT for Office Buildings; however, the part of the form concerns with accident prevention was developed for this methodology. Therefore, this indicator is reported in this chapter.

This indicator aims to evaluate the potential to protect students inside the school, related to water, energy and telecommunication systems, and protecting students from being harmed.

Since there are no studies referring to these data, and it is of the utmost importance, the best and the standard practices have very high values.

Objectives

This indicator assists the implementation of measures to ensure the safety and security of the occupants.

Required elements for the evaluation

- Description document of the evaluated school building - Architectural Design plans;
- Electrical project;
- Water network Projects;
- Project of infrastructure of telecommunications in buildings;
- Security fire Project.

Project phase where indicator is applied:

Design, construction and use phase.

Reference Practices

Standard Practice

The standard practice for building potential to support a level of security appropriate to its occupants ($\mathbf{P_{SO*}}$) is 30% of the total credits in the Table 6.16.

$$\mathbf{P_{SO*} = 30\%}$$

Best Practice

The value of best practice to the building potential to support a level of security appropriate to its occupants ($\mathbf{P^*_{SO}}$) is 90% of the total credits in the Table 6.16.

$$\mathbf{P^*_{SO} = 90\%}$$

Calculation Method

1. Determine the value of the building potential for the promotion of a level of security appropriate to its occupants (P_{SO}) by accounting in Table 6.16. the criteria checked the building and the following equation. The $\sum$Total credits is the sum of all Credits.

$$P_{SO} = \frac{\sum C\text{redits obtained}}{\sum \text{Total credits}} (\%) \tag{6.14}$$

Table 6.16. Determination of the building's potential to promotion of a level of security appropriate to its occupants - Telecommunications

	Description	**Credits**	√
1	Operating continued assurance of the main building services		
1.1	**Energy**		
1.1.1	It is installed a power generator able to provide electricity:		
	At the main building systems, in case of natural disaster or failure in services;	5	
	The Entire building, in case of interruption of supply by the public services.	10	
1.1.2	The electrical system has been designed in sections, and the occurrence of a failure of the system does not prevent the proper operation of the remaining sections.	5	
1.2	**Water**		
1.2.1	The building has a water tank that can be used in case of the public system interruption.	10	
1.2.2	The water distribution system has been designed in sections, and the occurrence of a failure of the system does not stop the proper operation of the remaining sections.	5	
1.3	**Telecommunications**		
1.3.1	The building has at least two different media (e.g. Optical fibber, wireless, etc.).	10	
1.3.2	The telecommunications system has been designed in sections, and the occurrence of a failure of the system does not prevent the proper operation of the remaining sections.	5	
2.	Security of students – Fall		
2.1	The percentage of stairs that have handrails in a building is:		
	From 0 to 35%;	0	
	From 35% to 70%;	5	
	From 70% to 100%;	10	
2.2	The percentage of signalling stairs in a building is:		
	From 0 to 35%;	0	
	From 35% to 70%;	5	
	From 70% to 100%;	10	
2.3	The percentage of floors in areas for sports and recreation area with the use of materials that absorb the impact at the time of the falls is:		
	From 0 to 35%;	0	
	From 35% to 70%;	5	
	From 70% to 100%;	10	
2.4	The percentage of areas of floor for sports activities and recreation areas without any difference of levels is:		
	From 0 to 35%;	0	
	From 35 to 70%;	5	
	From 70% to 100%;	10	
2.5	The percentage of areas for sports activities and recreation area that are free of holes, piece of wood or metal, and other materials that can cause accidents is:		
	From 0 to 35%;	0	
	From 35% to 70%;	5	
	From 70% to 100%;	10	
2.6	The percentage of areas for sports activities and recreation area that have adequate protection of architectural structures that may pose a risk for use of the site is:		
	From 0 to 35%;	0	
	From 35% to 70%;	5	
	From 70% to 100%;	10	

6.16. Determination of the building's potential to promotion of a level of security appropriate to its occupants – Telecommunications (continuation)

3	Security of the building users		
3.1	Lighting		
3.1.1	Lighting system in parking areas (at least 5 lux).	5	
3.1.2	Lighting system in the footpaths and the main buildings' entrance arranged linearly along the pathways by setting alignments that assist in the routing of pedestrian accesses (at least 10 lux).	10	
3.2	Security System		
3.2.1	The building is protected by a security guards for 24 hours.	5	
3.2.2	The building is equipped with a surveillance system.	10	
		$\sum P_{SO} =$	

Calculate the normalized value of the building potential for the promotion of an adequate level of safety to its occupants, using the following equation:

$$\overline{P_{SO}} = \frac{P_{SO} - P_{SO*}}{P^{*}_{SO} - P_{SO*}} \qquad (6.15)$$

$$\frac{P_{SO} - 30\%}{90\% \ - 30\%}$$

EDUCATION FOR SUSTAINABILITY AWARENESS- C9

INDICATOR SUSTAINABILITY AWARENESS (I21)

There are several projects for teaching sustainability in high schools in Portugal. Some schools have already included this as part of their class activities, while other high schools are still in the process of its inclusion. Since there are no research mentioning these data, the best and the standard practices of sustainability awareness of students have high value.

The calculation method is made through the determination of the value of the students' level of awareness in a subjective way, through questionnaires (ANNEX 3), and if there are activities and materials provided by the school, which aim to inform, educate, and make students aware of sustainability.

The calculation method involves the determination of the value of the students' level of awareness about the potential of a building for the promotion of an adequate ergonomic comfort inside the classroom. This value concerns the students' level of awareness about the existence of Public Legislation, methodologies or manuals related to sustainability in the school environment, how the school addresses the theme of sustainability and the answers of the questionnaires (ANNEX 3), given by the majority of the students who participated in the research. This indicator in the SAHSB^{PT} methodology is evaluated using a form that assesses the level of the students' awareness regarding sustainability. The form estimates the level of environmental interest of the students, the frequency with which students do something to protect the environment in their daily lives and the frequency of environmental issues mentioned in class, and (Saraiva et al., 2019b).

Other concerns addressed refer to environmental practices in the homes of the students and how students consider that environmental issues should be addressed in high schools. This indicator supports awareness of sustainability among students and promotes positive attitudes towards sustainability in the students' quotidian (Saraiva et al., 2019a). This is a new indicator developed for the SAHSB^{PT} methodology (Saraiva et al., 2019b) therefore, it is reported in this chapter.

Objective

This indicator assists the high level of sustainability awareness of students in high school buildings.

Elements necessary for evaluation:

Questionnaire to be applied to the students, from the 10th to the 12th grade.

Project phase where indicator is applied:

Use phase.

Reference Practices

Standard Practice

The standard practice for building potential to support a level of sustainability awareness of students ($\mathbf{L_{SA*}}$) is 45% of the total credits in the Table 33, in the Suplementary Material.

$$\mathbf{L_{SA*} = 45\%}$$

Best Practice

The best practice value to the building potential to promote a level of security appropriate to its occupants ($\mathbf{L^{*}_{SA}}$) is 90 % of the total credits in the Table 6.17.

$$\mathbf{L^{*}_{SA} = 90\%}$$

Calculation Method

Determine the value of the students' level of awareness in a subjective way, through questionnaires (Table 6.17) and if there are activities and materials provided by the school, which aim to inform, educate, and make students aware of sustainability.

Table 6.17. Determination of the value of the potential of the building to promote an adequate level of sustainability awareness of students in a high school

	Description	Credits	√
1	Manuals for Sustainability at school		
1.1	Existence of Public Legislation, methodologies or manuals related to sustainability in the school environment used by the school.		
	Yes	10	
	No	0	
1.2.	If the school addresses the theme of sustainability by:		
	Matters required	15	
	Specific courses	10	
	Events, lectures and / or panels	5	
2.	Questionnaire applied to students (Annex 2)		
2.1	Highest percentage of answers to the question 1:	15	
	a. Answer A	10	
	b. Answer B	5	
	c. Answer C	0	
	d. Answer D		
2.2	Highest percentage of answers to the question 2	15	
	a. Answer A;	10	
	b. Answer B	5	
	c. Answer C	0	
	d. Answer D		
2.3	Highest percentage of answers to the question 3	5	
	a. Answer A	10	
	b. Answer B	15	
	c. Answer C		
2.4	Highest percentage of answers to the question 4		
	a. Answer A;	15	
	b. Answer B	10	
	c. Answer C	5	
	d. Answer D	0	
2.5	Highest percentage of answers to the question 5		
	a. Answer A;	0	
	b. Answer B	5	
	c. Answer C	10	
	d. Answer D	15	
2.6	Highest percentage of answers to the question 6		
	a. Answer A;	0	
	b. Answer B	5	
	c. Answer C	10	
	d. Answer D	15	

Table 6.17. Determination of the value of the potential of the building to promote an adequate level of sustainability awareness of students in a high school (continuation)

2.7	Highest percentage of answers to the question 7		
	a. Answer A	0	
	b. Answer B	5	
	c. Answer C	15	
2.8	Highest percentage of answers to the question 8		
	a. Answer A	15	
	b. Answer B	10	
	c. Answer C	10	
	d. Answer D	5	
	e. Answer E	5	

Calculate the normalized value of the building potential to promote an adequate level of awareness of its students ($\overline{\mathbf{L_{SA}}}$), using the following equation:

$$\overline{\mathbf{L_{SA}}} = \frac{\mathbf{L_{SA}} - \mathbf{L_{SA*}}}{\mathbf{L^{*}_{SA}} - \mathbf{L_{SA*}}} \quad (6.16)$$

$$\frac{\mathbf{L_{SA}} - \mathbf{45\%}}{\mathbf{90\%} - \mathbf{45\%}}$$

SUSTAINABILITY OF THE AREA – C10

INDICATOR ACCESSIBILITY TO PUBLIC TRANSPORT (I22)

This indicator assists the buildings that meet most of the travel requirements of the students through the public transport system (Saraiva et al., 2019b). The reference practices and method of calculation are the same of SBTool^{PT} STP for Office Buildings.

This indicator in the SAHSB^{PT} methodology considers the frequency of each public transport line close to the building entrance, the travel time to each public transport stop and the waiting time for each public transport line. The reference practices and calculation method used for this indicator are the same as those include in the SBTool^{PT}-STP for Office Buildings; consequently, this indicator is similar to that include in the SBTool^{PT}-STP for Office Buildings (Saraiva et al., 2019b), therefore it is just reported in the Suplementary Material.

6.4. Economic Dimension

CATEGORY LIFE CYCLE COSTS - C 11

INDICATOR LIFE CYCLE COSTS (I23)

This indicator encourages the decreases of the initial costs of the building and the mitigation of the life cycle costs for the maintenance of the high school buildings (water, energy) (Mateus &

Bragança, 2009, Barbosa et al., 2013, Saraiva et al, 2019b). The reference practices and calculation method are the same of SBTool^{PT} STP for Office Buildings.

This indicator in the SAHSB^{PT} methodology is concerned with building performance in terms of operating cost and initial costs (water and energy consumption). The reference practices and calculation method for this indicator are the same as those include in the SBTool^{PT}-STP for Office Buildings. This indicator is similar to that include in SBTool^{PT}-STP for Office Buildings, therefore, therefore it is just reported in the Suplementary Material.

6.5. Concluding remarks

The SAHSB^{PT} methodology was based on SBTool^{PT}STP for Office Building and SBTool^{PT}H. Some indicators are preserved, others are included and others are adapted. In the SAHSB^{PT} methodology, some calculations and baseline reference practices were maintained. The modifications made to the calculations and reference practices of each indicator are demonstrated in Table 6.18.

Table 6.18. Comparison between SBTool^{PT}SPT for Office Building and SAHSB^{PT} methodology,

SAHSBPT Indicators	Weights equal to SBTool^{PT} STP for Office Buildings	Calculation Methods equal to SBTool^{PT} STP for Office Buildings	Reference practices equal to SBTool^{PT} STP for Office Buildings
I1. Lifecycle environmental impacts	-	Preserved	Preserved
I2. Heat island effects	-	Preserved	Preserved
I3. Land use efficiency	-	-	Preserved
I4. Product with organic certificate	-	Preserved	Preserved
I5. Energy consumption	-	-	-
I6. Renewable Energy	-	-	-
I7. Commissioning	-	Preserved	Preserved
I8. Reuse and recycle of materials.	-	-	-
I9. Environmental management plan	-	Preserved	Preserved
I10. Flexibility and adaptability	-	Preserved	Preserved
I11. Water consumption	-	Preserved	Preserved
I12. Water treatment and Recycling	-	Preserved	Preserved
I13. Storm water management	-	Preserved	Preserved
I14. Indoor air quality	-	Preserved	-
I15. Thermal Comfort	-	Preserved	-
I16. Visual Comfort	-	Preserved	-
I17. Acoustic Comfort	-	Preserved	-
I18. Ergonomic Comfort	-	-	-
I19. Mobility plan	-	Preserved	Preserved
I20. Occupants security and safety	-	Preserved	-
I21. Sustainability awareness	-	-	-
122. Accessibility to public transport	-	Preserved	Preserved
I23. Life cycle costs	-	Preserved	Preserved

The next chapter describes the case study, the Francisco de Holanda High School, Guimarães, Portugal to which SAHSB^{PT} methodology was applied.

CHAPTER 7

Application of SAHSBT^{PT} methodology to a case study - Francisco da Holanda High School

This chapter presents the results of the application of SAHSB^{PT} methodology at the Francisco de Holanda High School (FHHS), aiming to analyse the suitability of the benchmarks and their applicability in practice to the context of school buildings in Portugal. This chapter is taken from the article "Application of the Portuguese Sustainability Assessment Tool of High School Buildings, SAHSB^{PT}, to the Francisco de Holanda High School, Guimarães" (https://doi.org/:10.3390/su11174559), whose authors are the author and supervisors of this thesis.

The application of the SAHSB^{PT} methodology was occurred at the FHHS located in Alameda Dr. Alfredo Pimenta, 4814, Azurém, Guimarães (Figure 7.1).

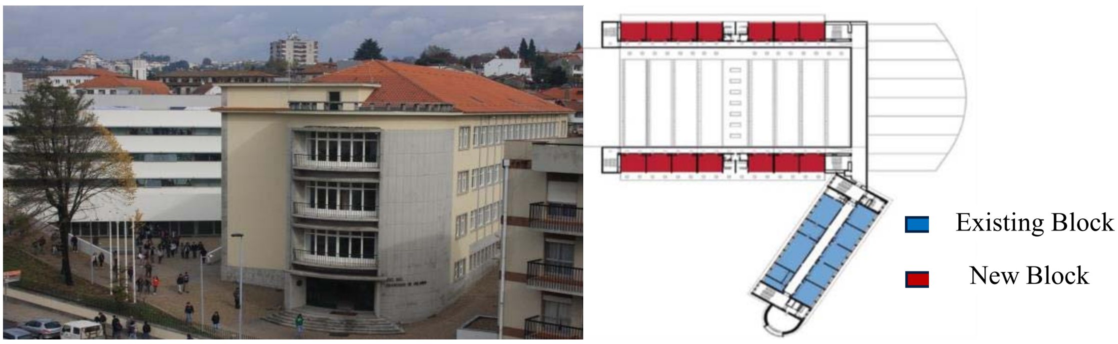

Figure 7.1. Francisco de Holanda High School localization. Source: Portal Parque Escolar

The renovation works of the FHHS happened through the maintenance of the structural and modification conditions. The main block was preserved in its formal identity, whereas the building where the new classrooms were located resulted in the addition of two new volumes located on the sides (red colour in Figure 7.1), and absorbed the area corresponding to the laboratories.

7.1. The result of the Application of the methodology SAHSB^{PT}

The application of the methodology SAHSB^{PT} to FHHS, followed the guide referred in chapter 6 of this thesis. The responses acquired by the application of the guide were always taken into consideration, with the application of the formula of Diaz Balteiro (Díaz-Balteiro & Romero, 2004), regarding the best and standard practices. The results of the dimensions, categories and indicators related to the application of the SAHSB^{PT} methodology are presented below. The calculations of all indicators, including the formularies, best and standard practices, as well as tables, are based on the Evaluation Guide SAHSB^{PT}, Supplementary Material and Chapter 6 of this thesis.

ENVIRONMENTAL DIMENSION

C1 **Category: Climate Change and outdoor air quality**

I1 Life cycle environmental impacts

To find the life cycle (LC) environmental impact of the high school building, according to SAHSB^{PT} methodology, it is required to recognize the construction materials of the building and their dimensions; recognise the life cycle environmental impact value of each construction procedure used and its maintenance operations. After that, it should multiply the value of each environmental impact by the amount of different measurements and elements of the building (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). The calculation is showed in ANNEX 4. Based on this calculation, the value given to the indicator "life cycle environmental impacts" is 0.92, or A, the best practice.

I2 Heat island effect

The reflectance resulting from the percentage of green spaces on the ground was analysed, as well as the colour and the type of material used in the façade (Mateus & Bragança, 2009, Saraiva et al., 2019b). The SAHSB^{PT} methodology uses Solar Reflectance Index (SRI) (Table 12 in the Supplementary Material of this Thesis) to calculate this indicator. Figure 7.1 demonstrates that the roofs are made of ceramic material and façades of the Francisco de Holanda High School are white or with light colours. These materials supports the reduction of heat island effects (Parque Escolar, 2018).

Calculation of indicator heat island effects (2)

A_{TOT} – Total land area in horizontal projection - m^2

A_{GS} – Area of green spaces of the building in horizontal projection - m^2

A_{REF} – Constructed area in horizontal projection (not covered outdoor decks and roofs) with reflectance equal to or greater than 60%

P_{REF} – Percentage of plan area with a reflectance lower than 60%

$\overline{P_{REF}}$ – Normalized value of the indicator Heat Island Effect

$$\overline{P_{REF}} = \frac{P_{REF} - P_{REF*}}{P_{REF}^{*} - P_{REF*}} \tag{7.1}$$

$$\overline{P_{REF}} = \frac{4178 + 5{,}557}{12{,}810} = 0{,}76$$

$$\frac{P_{REF} - 30}{90 - 30} = \frac{76 - 30}{90 - 30} = 0{,}77$$

Based on this calculus, the value set for the indicator “heat island effects” is 0.77 or A, the best practice.

Calculation of category climate change and outdoor air quality (1)

In Table 7.1., it is calculated the percentage of Category “climate change and outdoor air quality” (1), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.1. Calculation of the percentage of Category 1

CATEGORY	INDICATOR	Indicator Weight [B]	Indicator Evaluation [A]	Value [A]x[B]
C1 Climate Change and outdoor air quality	I1 Life cycle environmental impacts	4.00%	0.92	3.68%
	I2 Heat island effects	3.00%	0.77	2.31%
Sum		7.00%		∑ = 5.99%

$$\frac{\sum \text{Value [A]x [B]}}{\text{C1}} = \frac{\sum \text{Indicator Evaluation [A] of C1}}{1} \tag{7.2}$$

$$\frac{5.99}{C1} = \frac{7.00}{1}$$

C1 = 0.86

Based on this calculus, the value set for the category “climate change and outdoor air quality” is 0.76 or A, the best practice.

C2. Category: Biodiversity and land use

I3. Land use efficiency

Parque Escolar (EPE) intents to open the school to the community, producing functional environment to be used for cultural, social, leisure and sports activities. EPE also seeks the adaptability and flexibility of the entire high school environment to maximize its use (Parque Escolar, 2018). In this indicator, it is analysed the number of students of the school building, the area of the plot, the area of implantation, the gross area and the net usable area (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). In addition, FHHS is open to the community just for cultural activities. The values of the building areas were taken from the materials supplied by the *Parque Escolar*.

Calculation of indicator land use efficiency (3)

$$T_{ERO} = \frac{A_U x C_O}{A_E x A_I x A_P} \tag{7.3}$$

$$T_{ERO} = \frac{13{,}877 \text{ x } 2{,}874}{16{,}326\text{x}7{,}253\text{x}12{,}810} = 0.0000263$$

T_{ERO}- Efficiency Ratio on Territorial Occupation

A_E – Gross external area;

A_I – Area of implementation;

A_P – Plot area or lot area;

A_U – Net usable area;

C_O – Number of students;

$\overline{T_{ERO}}$ - Normalized value of the Indicator land use efficiency.

$$\overline{T_{ERO}} = \frac{T_{ERO} - T_{ERO*}}{T_{ERO}^{*} - T_{ERO*}} \tag{7.4}$$

$$\frac{0.0000263 \text{ c}/m^4 - 0.00002 \text{ c}/m^4}{0.00003 \text{ c}/m^4 - 0.00002 \text{ c}/m^4} = 0.63$$

Based on this calculus, the value set for the indicator land use efficiency is 0.63 or B, a reasonable result.

I4 Product with organic basis – Certificate

The indicator "product with organic basis" is related to the cost of wood or organic materials with environmental certification (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). Through the investigation of the materials elaborated by the *Parque Escolar* (EPE), it was perceived that there is no specific concern on this subject (Parque Escolar, 2018).

Therefore, there was no concern regarding organic certificates during the school construction and reforms. Based on this information, the value given to the indicator “product with organic basis” is 0 or D, the standard practice.

Calculation of category biodiversity and land use (2)

In the Table 7.2., it is calculated the percentage of Category “biodiversity and land use” (2), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.2. Calculation of the percentage of Category 2

CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATION OF IND. (%) [B]	VALUE [A]x[B]
C2. Biodiversity and land use	I3 Land use efficiency	4.00%	0.63 – B	2.52 %
	I4 Product with organic certificate	1.00%	0 – E	0 %
Sum		5.00%		2.52%

$$\frac{\sum \text{Value [A]x [B]}}{\text{C2}} = \frac{\sum \text{Indicator Evaluation [A] of C2}}{1} \tag{7.5}$$

$$\frac{2.52}{\text{C2}} = \frac{5.00}{1}$$

C2 = 0.50

Based on this calculus, the value set for the category “biodiversity and land use is 0.50 or B, a reasonable result.

C3. Category: Energy

I5 Energy consumption

The indicator “energy consumption” (5) has to do with the values of energy consumption per year related to gas (EG) and electricity (EE). It is based on the determinations of RECS for energy consumption. Energy efficiency is one of the main purposes of the *Parque Escolar*, seeking to “ensure the energy efficiency of buildings in order to reduce operating costs” (Parque Escolar, 2018). According to the Regulatory Compliance Statement (DCR TEMP 53947937) of this high school building, the total amount consumed on energy is 18.61 Kgp/m^2-year.

Calculation of indicator energy consumption (5)

$\overline{\mathbf{E_C}}$ - Normalized value of the Indicator Energy Consumption

$$\overline{E_C} = \frac{E_C - E_{C*}}{E_C^* - E_{C*}} \tag{7.6}$$

$$\overline{E_C} = \frac{186 - 310}{231 - 310} = 0.8$$

E_C= Total Energy Consumption of the building

E_E = The value of Electric Energy of the building

E_G= The value of Gas Energy of the building

Based on this calculus, the value set for the indicator "energy consumption" is 0.8 or A, the best practice.

I6 Renewable Energy

The indicator "renewable energy" refers to the values of renewable energy consumption per year related to Solar Panels and Photovoltaic, based on the determinations of RECS (Decreto Lei 118/2013). In the high school buildings refurbished or built by EPE, there is a concern with renewable energy, through solar collectors for heating water for the bathrooms and kitchen (Parque Escolar, 2018). The total energy originated by this system is 30421 kwh/year, according to the Regulatory Compliance Statement (DCR, TEMP 53947937).

Calculation of indicator renewable energy (6)

$$\overline{E_{REN}} = \frac{E_{REN} - E_{REN*}}{E_{REN}^{*} - E_{REN*}} \tag{7.7}$$

$$\frac{48\% - 30\%}{60\% - 30\%} = 0.6$$

Based on this calculus, the value set for the indicator "renewable energy" is 0.6 or B, a reasonable result.

I7 Commissioning

The indicator ‘commissioning“evaluates the management of mechanical systems throughout the building life cycle *Parque Escolar* offers suitable management of all mechanical systems in the high schools, being all of them controlled through a system provided by EPE (Parque Escolar, 2018). These systems are controlled through computers and the personal cell phone of the school administrator. The SAHSB^{PT} methodology uses a formulary (Table 14 in the Supplementary Material of this Thesis) to calculate this indicator.

Calculation of indicator commissioning (7)

$$\overline{M_{SM}} = \frac{M_{SM} - M_{SM*}}{M_{SM}^{*} - M_{SM*}} \tag{7.8}$$

$$\frac{100\% - 40\%}{100\% - 40\%} = 1.0$$

Based on this calculus, the value set for the indicator "commissioning" is 1.0 or A, the best practice.

Calculation of category energy (3)

In the Table 7.3. , it is calculated the percentage of Category "Energy" (3), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.3. Calculation of the percentage of Category 3

CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATI ON OF IND. (%) [B]	VALUE [A]x[B]
C3. Energy	I5 Energy consumption	5.00%	0.8 – A	4.00 %
	I6 Renewable Energy	3.00%	0.6 – B	1.80 %
	I7 Commissioning	3.00%	1. – A	3.00 %
Sum		11.00%		8.80 %

$$\frac{\sum \text{Value [A]x [B]}}{\text{C3}} = \frac{\sum \text{Indicator Evaluation [A] of C3}}{1} \qquad (7.9)$$

$$\frac{8.80}{\text{C3}} = \frac{11.00}{1}$$

C3 = 0.80

Based on this calculus, the value set for the category 'energy" is 0.80 or A, the best practice.

C4. Materials, solid residues, and resources management

I8 Materials reused and with recycled contents

There was no concern regarding the reuse of products or materials and the material with recycled content used in the construction of the Francisco de Holanda High School building. Based on this information, the value set for the indicator "reuse and recycle of materials" is 0 or D, the standard practice.

I9 Environmental management plan

This indicator "environmental management plan" is performed through a form that evaluates training of occupants, the environmental monitoring and management system (energy, water) (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). One of the purposes of EPE is "to create an efficient and effective system of building management. An Environmental Management System is used" (Parque Escolar, 2018). The SAHSB^{PT}

methodology uses a formulary (Table 15 in the Supplementary Material of this Thesis) to calculate this indicator.

Calculation of indicator environmental management plan (9)

$$\overline{P_{MS}} = \frac{P_{MS} - P_{MS*}}{P_{MS}^{*} - P_{MS*}} \qquad (7.10)$$

$$\frac{130\% - 30\%}{120\% - 30\%} = 1.1$$

Based on the calculus, the value set for the indicator "environmental management plan" is 1.1 or A+, excellent result.

I10 Flexibility and adaptability

The indicator "flexibility and adaptability" is performed through a form that assesses the electrical, air conditioning and communication systems, ventilation systems, water system and plumbing and the modularity of the compartments (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). One of the purposes of EPE is to "ensure adaptability and flexibility of school and non-school spaces in order to maximize their use and minimize future investments" (Parque Escolar, 2018). Despite the use of the Environmental Management System, the type of construction process still follows the traditional style, with few concerns regarding flexibility and adaptability of the building. The SAHSB^{PT} methodology uses a formulary (Table 16 in the Supplementary Material of this Thesis) to calculate this indicator.

Calculation of indicator flexibility and adaptability (10)

$\overline{P_{FA}}$ Normalized value of the Indicator Flexibility and Adaptability

$$\overline{P_{FA}} = \frac{P_{FA} - P_{FA*}}{P_{FA}^{*} - P_{FA*}} \qquad (7.11)$$

$$\frac{16\% - 11\%}{25\% - 11\%} = 0.34$$

Based on this calculus, the value set for the indicator "flexibility and adaptability" is 0.34 or C, an insufficient result.

Calculation of category materials, solid residues, and resources management (4)

In the Table 7.4. it is calculated the percentage of Category "materials, solid residues/resources management" (4), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.4 Calculation of the percentage of Category 4

CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATION OF IND. (%) [B]	VALUE [A]x[B]
C4. Materials, solid residues/resources management	Materials reused and with recycled contents	1.50%	0 – E	0 %
	Environmental management plan	2.00%	1.1 – A*	2.20 %
	Flexibility and adaptability	1.50%	0.34 - C	0.50 %
Sum		5.00%		2.70%

$$\frac{\sum \text{Value [A]x [B]}}{\text{C4}} = \frac{\sum \text{Indicator Evaluation [A] of C4}}{1} \quad (7.12)$$

$$\frac{2.70}{\text{C4}} = \frac{5.00}{1}$$

C4 = 0.54

Based on this calculus, the value set for the category "materials, solid residues/resources management" is 0,54 or B, a reasonable result.

C5. Category: Water

I11 Water consumption

The indicator "water consumption" is calculated through a form that evaluates the average water consumption of each exterior and interior device, consumption of water for irrigation and drinking (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). When the school was refurbished, Parque Escolar was very concerned about the use of showers, taps and toilets with the intention of decreasing consumption (Parque Escolar, 2018). The SAHSB^{PT} methodology uses a formulary (Table 17., Table 18., Table 19., Table 20., Table 21., Table 22. and Table 23. in the Supplementary Material of this Thesis) to calculate this indicator.

Calculation of indicator water consumption (11)

$\overline{P_{WC}}$ – Normalized value of the Indicator Water Consumption

$$\overline{P_{WC}} = \frac{P_{WC} - P_{WC*}}{P_{WC}^{*} - P_{WC*}} \quad (7.13)$$

$$\overline{P_{WC}} = \frac{9{,}919{,}000 - 19{,}551{,}550}{8{,}780{,}087 - 19{,}551{,}550} = 0.89$$

Based on this calculus, the value set for this indicator "water consumption" is 0.89.

I12 Water treatment and Recycling

The indicator "water treatment and recycling" is related to the annual per capita (l/year) use of measures related to the recycling system (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). Through the analysis of the materials elaborated by the EPE, it was observed that there is no specific concern about this issue (Parque Escolar, 2018). Therefore, there are no concerns related to the recycling or treatment related to water. Based on this information, the value set for the indicator "water treatment and recycling" is 0 or D, standard practice.

I13 Collection and reuse of Rainwater

The indicator "collection and reuse of rainwater" is related to the capacity of the building to manage the reuse of rainwater (l/year) (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). Through the analysis of the materials elaborated by the EPE, it was concluded that there is no concern about this subject (Parque Escolar, 2018). Therefore, there is no treatment related to rainwater management. Based on this information, the value set for the indicator "collection and reuse of rainwater" is 0 or D, standard practice.

Calculation of category water (5)

In Table 7.5., it is calculated the percentage of Category Water (5), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.5. Calculation of the percentage of Category 5

CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATIO N OF IND. (%) [B]	VALUE [A]x[B]
C. 5. Water	Water consumption	3.00%	0,89 - A	2.67 %
	Water treatment and Recycling	3.00%	0 – E	0 %
	Collection and reuse of rainwater	1.00%	0 – E	0 %
Sum		7.00%		2.67

$$\frac{\sum \text{Value [A]x [B]}}{\text{C5}} = \frac{\sum \text{Indicator Evaluation [A] of C5}}{1} \quad (7.14)$$

$$\frac{2.67}{\text{C5}} = \frac{7.00}{1}$$

C5 = 0.38

Based on this calculus, the value set for this category "water" is 0,38 or C, an insufficient result.

Calculation of Environmental Dimension

In the Table 7.6., it is calculated the percentage concerning the "environmental dimension", by the sum of the categories included in this dimension, and the percentage relative to the total value, 1.

Table 7.6. Calculation of the percentage of Environmental Dimension

DIMENSION	CATEGORY	WEIGHT OF CAT. (%) [A]	EVALUATION OF CAT. (%) [B]	VALUE [A]x[B]
ENVIRON MENTAL (40%)	C1. Climate Change and air quality	7.00%	0.86 – A	6.02%
	C2. Biodiversity and land use	5.00%	0.50 – B	2.50%
	C3. Energy	11.00%	0.80– A	8.80%
	C4. Materials, solid residues/resources management	5.00%	0.54 – C	2.70%
	C5. Water	7.00%	0.38 – C	2.66%
Sum		35.00%		22.68%

$$\frac{\sum \text{Value [A]x [B]}}{\text{ED}} = \frac{\sum \text{Indicator Evaluation [A] of ED}}{1} \quad (7.15)$$

$$\frac{22.68}{\text{ED}} = \frac{35.00}{1}$$

ED = 0.65

Based on this calculation, the value set for the indicator "environmental dimension" is 0.63 or B, an insufficient result.

Social Dimension

C6. Category: User health and comfort

I14 Indoor air quality

The indicator "indoor air quality" is related to the renewal rate of the air in the building and to the finishing materials with low VOC content, having also been calculated through a form that evaluates all the indicators of comfort.

One of the purposes of the EPE is "to improve living conditions and environmental comfort, with particular emphasis on hygrothermics, acoustics, and air quality" (Parque Escolar, 2018). Many of the information required for the analysis of air quality necessary by this methodology were not found, such as the air renewal rate expected for the construction, and the finishing materials with low Volatile Organic Compounds (VOC) content, according to the standards established by the RECS (Decreto Lei 118/2013).

The building evaluated has indoor air certification and energy. According to the information on the certificate, new airflow rates per space are much higher than required in all environments. The certificate concludes as follows: "Although the building in question is an existing building and a new building in annex, care was taken to try to comply with the minimum requirements stipulated in the current regulations Decree – Law 80/2006. However, there are interior spaces in contact with useful areas that do not comply with these requirements because it is an existing building and it is not possible to interfere in these areas." Since the Declaration of Regulatory Compliance do not include information about the concentrations of the pollutants, the value set for the indicator "indoor air quality" is 1.0% or A, the best practice.

I15 Thermal Comfort

The indicator "thermal comfort "is related with the level of thermal comfort during the summer and winter seasons and was also calculated through a form that evaluated all the comfort indicators (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). The temperature of all the environments of this school is controlled by heating systems or cooling; always maintaining the ideal temperature, from 21 to 25.5 degree Celsius. The value given to this indicator is 1.0. Based on this information, the value set for the indicator "thermal comfort" is 1.0 or A, the best practice.

I16 Visual Comfort

The indicator "visual comfort" is related to the illuminance levels provided by artificial or natural lighting in all compartments of the building. It also uses a formulary that assesses all comfort indicators (Mateus & Bragança, 2009, Saraiva et al., 2019b, Barbosa et al., 2013). The classrooms in FHHS are located mainly in the North and South facades, receiving natural light for most of the day. Circulation areas, support rooms and laboratories, which are less used, receive a smaller amount of sunlight. The SAHSB^{PT} methodology uses a form (Table 6.14., in the Chapter 6 of this Thesis) to calculate this indicator.

Calculation of indicator visual comfort (16)

$\overline{\mathbf{P_{DILi}}}$– Normalized value of the Indicator "visual comfort"

$$\overline{\mathbf{P_{DILi}}} = \frac{\mathbf{P_{DILi}} - \mathbf{P_{DILi*}}}{\mathbf{P_{DILi}}^{*} - \mathbf{P_{DILi*}}} \quad (7.16)$$

$$\overline{\mathbf{P_{DILi}}} = \frac{456-300}{500-300} = 0.78$$

Based on this information, the value set for the indicator "visual comfort" is 0.78 or A, the best practice.

I17 Acoustic Comfort

The indicator "acoustic comfort" refers to the comfort to airborne sounds among classrooms, the reverberation time and the level of acoustic over percussion sounds (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). It also uses a formulary that evaluates all the comfort indicators. In the context of the renovation of the high school, several procedures were done with the objective of solving existing acoustic issue and avoiding new problems, mainly related to the acoustic isolation between the internal and the external environments.

Calculation of indicator acoustic comfort (17)

$$\overline{D_{2m,nT,w}} = \frac{D_{2m,nT,w} - D_{2m,nT,w*}}{D_{2m,nT,w}^{*} - D_{2m,nT,w*}} \quad (7.17)$$

$$\frac{34.4\% - 30\%}{36\% - 30\%} = 0.73$$

Based on this calculus, the value set for the indicator "acoustic comfort" is 0.73 or A, the best practice.

I18 Ergonomic Comfort

The indicator "ergonomic comfort" deals with the comfort of the high school tables and chairs. It uses a form that evaluates all the comfort indicators related to ergonomics, specifically about the suitable sizing of the desks. Through the investigation of the materials elaborated by the *Parque Escolar*, it can be perceived that there is no concern about this issue (Parque Escolar, 2018). It is not possible to define specific physical features for high school students. Consequently, it is not possible to define a standard dimension for school desks. The SAHSB^{PT} methodology uses a formulary (Table 6.15. in the Chapther 6 of this Thesis) to calculate this indicator.

Calculation of indicator ergonomic comfort (18)

$\overline{E}$ – Normalized value of the indicator ergonomic comfort

$$E = \frac{\sum Credits\ obtained}{\sum Total\ credits} (\%) \quad (7.18)$$

$$\frac{60}{100} (\%) = 60\%$$

$$\overline{E} = \frac{E - E_*}{E^* - E_*} \tag{7.19}$$

$$\frac{60\% - 10\%}{20\% - 10\%} = 0{,}50$$

Based on this calculus, the value set for the indicator "ergonomic comfort" is 0.50 or B, a reasonable result.

Calculation of category user health and comfort (6)

In Table 7.7., it is calculated the percentage of Category "user health and comfort" (6), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.7. Calculation of the percentage of Category 6

CATEGORY	INDICATOR	WEIGHT OF IND.(%) [A]	EVALUATION OF IND. (%) [B]	VALUE [A]x[B]
C6. User health and comfort	Indoor air quality	6.00%	1.00- B	6.00 %
	Thermal Comfort	5.50%	1.00 - A	5.50 %
	Visual Comfort	6.00%	0.78 - A	4.68 %
	Acoustic Comfort	5.00%	0.73 - A	3.65 %
	Ergonomic Comfort	2.50%	0.50 - B	1.25 %
Sum		25.00%		21.08 %

$$\frac{\sum \text{Value [A]x [B]}}{\text{C6}} = \frac{\sum \text{Indicator Evaluation [A] of C6}}{1} \tag{7.20}$$

$$\frac{21.08}{\text{C6}} = \frac{25.00}{1}$$

C6 = 0.84

Based on this calculation, the value set for the category "user health and comfort" is 0, 84 or A, the best practice.

C7. Category: Accessibility

I19 Mobility plan

The indicator mobility plan is calculated through a form that evaluates the conditions of sustainable access to the high school building (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

Through the examination of the materials elaborated by the EPE, it was concluded that there is no concern about this issue (Parque Escolar, 2018). In this school, there is no area dedicated to cyclists, such as routes or parking, which makes the value of this indicator very low. Though, there is a large variety of public transport near the school. Several compartments of the building are designed to support the access of people with disabilities. The SAHSB^{PT} methodology uses a formulary (Table 30 in the Supplementary Material of this Thesis) to calculate this indicator.

Calculation of indicator mobility plan (19)

$\overline{\mathbf{P_M}}$ - Normalized value of the Indicator Mobility plan

$$\mathbf{P_M} = \frac{\sum Credits\ obtained}{\sum Total\ credits}(\%) \tag{7.21}$$

$$\frac{40}{100}(\%) = \mathbf{40}\%$$

$$\overline{P_M} = \frac{P_M - P_{M*}}{P_M^* - P_{M*}} \tag{7.22}$$

$$\frac{40\% - 10\%}{90\% - 10\%} = 0.37$$

Based on this calculus, the value set for the indicator "mobility plan" is 0.37, or C, an insufficient result.

Calculation of category accessibility (7)

In Table 7.8. it is calculated the percentage of category accessibility (7), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.8. Calculation of the percentage of Category 7

CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATIO N OF IND. (%) [B]	VALUE [A]x[B]
C7. Accessibility	I22 Mobility plan	2.00%	0.37 - C	0.74 %

$$\frac{\sum \text{Value [A]x [B]}}{\text{C7}} = \frac{\sum \text{Indicator Evaluation [A] of C7}}{1} \tag{7.23}$$

$$\frac{0.74}{C7} = \frac{2.00}{1}$$

C7 = 0.37

Based on this calculus, the value set for the category "accessibility" is 0,37 or C, an insufficient result.

C8. Category: Security

I20 Occupants security

The indicator "occupants security" is calculated through a form that evaluates the guarantee of the proper functioning of the main services of the building, such energy, water and telecommunications (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b), and the protection of students from being harmed. One of the intentions of the *Parque Escolar* is "to improve, security and accessibility" (Parque Escolar, 2018). Several procedures were taken regarding the safety of students in school buildings.

The SAHSB^{PT} methodology uses a formulary (Table 6.16. in the Chapther 6 of this Thesis) to calculate this indicator.Through the analysis of that formulary and the materials elaborated by the *Parque Escolar* (EPE).

Calculation of indicator occupants security (20)

$$P_{SO} = \frac{\sum Credits\ obtained}{\sum Total\ credits}(\%) \qquad (7.24)$$

$$\frac{100}{100}(\%) = 100\%$$

Normalized value of the Indicator Occupants Security and Safety.

$\overline{\mathbf{P_{SO}}}$ - Normalized value of the Indicator Occupants Security and Safety.

$$\overline{P_{SO}} = \frac{P_{SO} - P_{SO*}}{P^*_{SO} - P_{SO*}} \qquad (7.25)$$

$$\frac{100\% - 30\%}{90\% - 30\%} = 1.2$$

Based on this calculus, the value set for the indicator "occupants security" is 1.2 or A+, an excellent result.

Calculation of category security (8)

In Table 7.9., it is calculated the percentage of Category "security and safety" (8), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.9. Calculation of the percentage of Category 8

CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATION OF IND. (%) [B]	VALUE [A]x[B]
C8. Security and Safety	I23 Occupants security and safety	3.00%	1.20 – A*	3,60 %

$$\frac{\sum \text{Value [A]x [B]}}{\text{C8}} = \frac{\sum \text{Indicator Evaluation [A] of C8}}{1} \tag{7.26}$$

$$\frac{3.60}{\text{C8}} = \frac{3.00}{8}$$

C8 = 1.20

Based on this calculus, the value set for this category “security and safety” is 1.2 or A+, an excellent result.

C9. Category: Education for Sustainability awareness

I21 Sustainability awareness

This indicator is obtained through a form that evaluates the level of the students regarding sustainability awareness. Through the analysis of the materials elaborated by the *Parque Escolar,* it is concluded that there is no concern about this subject (Parque Escolar, 2018). The SAHSB^{PT} methodology uses a formulary (Table 6.17. in the Chapter 6 of this Thesis) to calculate this indicator.

Calculation of indicator sustainability awareness (21)

$\overline{\mathbf{L_{SA}}}$- Normalized value of the Indicator Sustainability Awareness

$$\text{L}_{\text{SA}} = \frac{\sum Credits\ obtained}{\sum Total\ credits} (\%) \tag{7.27}$$

$$\frac{97}{145} (\%) = 67\%$$

$$\overline{\text{L}_{\text{SA}}} = \frac{\text{L}_{\text{SA}} - \text{L}_{\text{SA*}}}{\text{L}^*_{\text{SA}} - \text{L}_{\text{SA*}}} \tag{7.28}$$

$$\frac{67\% - 10\%}{20\% - 10\%} = 0{,}57$$

The value set for the indicator “sustainability awareness” is 0.57 or B, a reasonable result.

Calculation of Category education for sustainability awareness (9)

In Table 7.10., it is calculated the percentage of Category education for sustainability awareness (9), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.10. Calculation of the percentage of Category 9

CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATIO N OF IND. (%) [B]	VALUE [A]x[B]
C9 Education for sustainability awareness	I21 Sustainability awareness	3.00%	0.57– B	1.71%

$$\frac{\sum \text{Value [A]x [B]}}{\text{C9}} = \frac{\sum \text{Indicator Evaluation [A] of C9}}{1} \tag{7.29}$$

$$\frac{1.71}{\text{C9}} = \frac{3.00}{1}$$

C9 = 0.57

Based on this calculus, the value set for the category "education for sustainability awareness" is 0.57 or B, a reasonable result.

C10. Category: Sustainability of the area

I22 Accessibility to public transport

This indicator is calculated through a form that assesses issues considering public transport (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b).

Through the analysis of the materials elaborated by the EPE, it was detected that there is no concern about this issue (Parque Escolar, 2018). There is a bus stop in front of this high school, where a major diversity of lines passes. The train station is 1 km from the school.

Calculation of Indicator accessibility to public transport (22)

$\overline{I_{ATP}}$ – Normalized value of the Indicator Sustainability of the area.

$I_{ATP} = 2.2 + 1.9 + 2.0 = 6.1$

Normalized value of the indicator "accessibility to public transport"

$$\overline{I_{ATP}} = \frac{I_{ATP} - I_{ATP*}}{I^{*}_{ATP} - I_{ATP*}} \tag{7.30}$$

$$\overline{I_{ATP}} = \frac{6.1 - 2}{7.5 - 2} = 0.75$$

Based on this calculus, the value set for the indicator "accessibility to public transport" is 0.75 or A, a best practice.

Calculation of category sustainability of the area (10)

In Table 7.11., it is calculated the percentage of category “sustainability of the area” (10), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.11. Calculation of the percentage of Category 10

CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATION OF IND. (%) [B]	VALUE [A]x[B]
C10 Sustainability of the area	I23. Accessibility to public transport	2.00%	0.75 – A	1.50 %

$$\frac{\sum \text{Value [A]x [B]}}{\text{C10}} = \frac{\sum \text{Indicator Evaluation [A] of C10}}{1} \quad (7.31)$$

$$\frac{5.31}{\text{C10}} = \frac{7.00}{10}$$

C10 = 0.75

Based on this calculus, the value set for category “sustainability of the area” is 0.75 or A, a best practice.

Calculation of Social Dimension

In the Table 7. 12. it is calculated the percentage of “social dimension”, by the sum of the category included in this dimension, and the percentage relative to the total value, 1.

Table 7. 12. Calculation of the percentage of Social Dimension

DIMENSION	CATEGORY	WEIGHT OF IND. (%) [A]	EVALUATION OF IND. (%) [B]	VALUE [A]x[B] (%)
SOCIETY 30%	C6. User health and comfort	25.00%	0.84- A	21.08 %
	C7. Accessibility	2.00%	0.37 – C	0.74%
	C8. Security and Safety	3.00%	1.20 – A*	3,60 %
	C9. Education for sustain. Awareness	3.00%	0.57 – B	1.71 %
	C10: Sustainability of the area	2.00%	0.75 – A	1.50%
Sum		35.00%		28.63

$$\frac{\sum \text{Value [A]x [B]}}{\text{SD}} = \frac{\sum \text{Indicator Evaluation [A] of SD}}{1} \quad (7.32)$$

$$\frac{28.63}{\text{SD}} = \frac{35.00}{1}$$

SD = 0.82

Based on this calculus, the value set for the “social dimension” is 0.82 or A, a best practice.

Economy Dimension

C11. Category: Life cycle costs

I23. Life cycle costs

Through the analysis of the materials elaborated by the EPE, it was perceived that there is no concern about this issue. Nevertheless, every school, private or public, has concerns about the financial part. Only sustainable or social concerns are not sustainable if the construction does not sustain itself economically. This indicator is related to the performance of the building related to initial and operating costs (energy and water consumption). For the evaluation of this indicator, the values of purchase and sale of the property are analysed (Mateus & Bragança, 2009, Barbosa et al., 2013, Saraiva et al., 2019b). As regards the specific case of the FHHS, it was not possible to assess the price of the sale, since this is a public school. Likewise, it was not possible to assess the value of the purchase, since the land was bought in the XIX century and the school began to be built in 1886, having been subject to further reforms in 1959 and in 2011 (Craveiro, 2015). (Craveiro, 2015).

In the case of FHHS, the cost paid by the government relative to the number of students, together with the monthly capital consumed with features such as water, gas and energy bills, among others, was analysed. These expenses must be made in a way that guarantees the well-being and health of the students in terms of water consumption, air quality, light, thermal comfort and others.

According to the research made by Saraiva et al. about the Francisco de Holanda high school (Saraiva et al., 2018), most of the students (88%) are comfortable or a little uncomfortable with regard to the environmental comfort. The analyses related to the categories 3 and 5 of this work show that energy and water consumption are suitable. After confirming this data, it was detected that the monthly budget used for all expenses of the Francisco de Holanda high school does not exceed the budget, and this meets the basic necessities for students' comfort. Based on this information, the value set for the indicator "life cycle costs" is 1.0, or A, the best practice.

According to question number seven of the questionnaire applied to the students, explained in the subchapter 5.2 of this thesis (ANNEX 2), the majority of students (58%) feel generally comfortable and 30% feel a little uncomfortable.

Calculation of category life cycle costs (11)

In Table 7.13. it is calculated the percentage of Category "life cycle costs" (11), by the sum of the indicators included in this category, and the percentage relative to the total value, 1.

Table 7.13. Calculation of the percentage of Category 11

CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATION OF IND. (%) [B]	VALUE [A]x[B]
C11 Life cycle costs	I26. Life cycle costs	30.00%	1.00 – A*	30.00 %

$$\frac{\sum \text{Value [A]x [B]}}{\text{C11}} = \frac{\sum \text{Indicator Evaluation [A] of C11}}{1} \quad (7.33)$$

$$\frac{30.00}{\text{C11}} = \frac{30.00}{1}$$

C11 = 1.00

Based on this calculus, the value given to the category "life cycle costs" is 1.0 or A, a best practice.

Calculation of Economic Dimension

In the Table 7.14. it is calculated the percentage of "economic dimension", by the sum of the category included in this dimension, and the percentage relative to the total value, 1.

Table 7.14. Calculation of the percentage of Economy Dimension

DIMENSION	CATEGORY	WEIGHT OF IND. (%) [A]	EVALUATION OF IND. (%) [B]	VALUE [A]x[B] (%)
ECONOMIC 30%	C11 Life cycle costs	30.00%	1.00 – A*	30.00%
Sum		30.00%		30.00%

$$\frac{\sum \text{Value [A]x [B]}}{\text{ED}} = \frac{\sum \text{Indicator Evaluation [A] of ED}}{1} \quad (7.34)$$

$$\frac{30.00}{\text{ED}} = \frac{30.00}{1}$$

ED = 1.00

Based on this calculus, the value set for the "economic dimension" is 1.0 or A, a best practice.

7.2. Analysis and demonstration of the results

Table 7.15. presents the results achieved in the evaluation of all sustainability indicators of SAHSB^{PT} methodology in the FHHS.

Table 7.15. Summary of the Analysis and demonstration of the results

DIMENSION	CATEGORY	INDICATOR	WEIGHT OF IND. (%) [A]	EVALUATION OF IND. (%) [B]	VALUE [A]x[B] (%)
ENVIRONMENT	**C1. Climate Change and air quality**	I1. Life cycle environmental impacts	4.00%	0.75 – A	3.00 %
		I2.Heat island effects	3.00%	0.77 – A	2.31 %
	C2. Biodiversity and land use	I3. Land use efficiency	4.00%	0.63 – B	2.52 %
		I4. Product with organic certificate	1.00%	0 – E	0 %
	C3. Energy	I5. Energy consumption	5.00%	0.8 - A	4.00 %
		I6. Renewable Energy	3.00%	0.6 - B	1.80 %
		I7. Commissioning	3.00%	1.00 – A	3.00 %
	C4. Materials, solid residues/resources management	I8. Materials reused and with recycled contents	1.50%	0 – E	0 %
		I9. Environmental management plan	2.00%	1.10– A*	2.20 %
		I10. Flexibility and adaptability	1.50%	0.34 - C	0.51 %
	C5. Water	I11. Water consumption	3.00%	0,89 - A	2.67 %
		I12. Water treatment and Recycling	3.00%	0 – E	0 %
		I13. Collection and reuse of rainwater	1.00%	0 – E	0 %
SOCIETY	**C6. User health and comfort**	I14. Indoor air quality	6.00%	1.00 - A	6.00%
		I15. Thermal Com	5.50%	1.00 - A	5.50 %
		I16. Visual Comfort	6.00%	0.78 - A	4.68 %
		I17. Acoustic Comfort	5.00%	0.73 - A	3.65 %
		I18. Ergonomic Comfort	2.50%	0.50 - B	1.25 %
	C7. Accessibility	I19. Mobility plan	2.00%	0.37 - C	0.74%
	C8. Security and Safety	I20. Occupants security and safety	3.00%	1.20 – A*	3,60 %
	C9. Education for sustain. awareness	I21. Sustainability awareness	3.00%	0.57 - B	1.71 %
	C10: Sustainability of the area	122. Accessibility to public transport	2.00%	0.75 - A	1.50%
ECONOMY	**C11.Life cycle costs**	I23. Life cycle costs	30.00%	1.00 - A	30.00%

The analysis of Table 7.15. shows that 24% achieved a level B and most of the indicators, 35%, achieved a level A. Just 13% achieved a level A+ and C and 15% of the indicators achieved a level E. These results show that more than 72% of the indicators reached a level B, A and A+. Therefore, this is an excellent result.

The summary of the high school performance level for the 11 categories and the dimensions of the SAHSB^{PT} methodology applied to FHHS are shown in Table 7.16.

Table 7.16 Level of performance of the building for each category

Dimension	Category	Quantity	Quality
ENVIRONMENTAL 35.00% (0.65) - B	C1. Climate Change and outdoor air quality	0.86	A
	C2. Biodiversity and land use	0.50	B
	C3. Energy	0.80	A
	C4. Materials, solid residues and resources management	0.54	B
	C5. Water	0.38	C
SOCIAL 35.00% (0.82) – A	C6. User health and comfort	0.84	A
	C7. Accessibility	0.37	C
	C8. Security and safety	1.20	A*
	C9. Education for sustain. Awareness	0.57	B
	C10. Sustainability of the area	0.75	A
ECONOMY 30% (1.00) – A	C11. Life cycle costs	1	A

The analysis of Table 7.176. shows that most of the categories (82%) was evaluated with A and with B, 18% with E, A+ and C. These results demonstrated that more than 80% of the categories are A and B, therefore, this is a good result.

The overall Sustainability Level (SL) of the FHHS and the weight considered for each environmental dimension is shown in Table 7.17.

Table 7.17. Dimensions and sustainability levels

Dimension	Quantitative	Qualitative
Environmental	22.68%	0.65 – B
Social	28.70 %	0.82 – A
Economic	30.00%	1 – A
Sustainability level	81.38%	0.81 – A

The analysis of Table 7.17. demonstrates that most of the dimension (66%) were evaluated with A and 34% with B, therefore, it is an outstanding result. The total value is 0.81, which corresponds to the qualitative level of sustainability "A". This classification is given to buildings that have an average performance level higher than that of a conventional building in the Portuguese context.

7.3. Concluding remarks

This chapter covered the application of the Evaluation Guide at the Francisco de Holanda High School, Portugal, as well as the analysis of the results of the indicators, categories and dimensions. The average performance of the FHHS is 81%, and most of the indicators, 65%, got an A or B grade. Since this is one of the high school buildings built by *Parque Escolar*, and taking into account that the EPE intends to reform 74% of the Portuguese high schools under the same rules, the majority of the high schools has good results.

Some of the indicators in this methodology are already part of the standard rules of the *Parque Escolar*, however, others are new subjects. These new subjects, such as security and occupant safety, sustainability awareness and ergonomic comfort, should be included in future projects, whether they relate to new high school buildings or to the rehabilitation of existing high school constructions. Architects and engineers should be alerted to the relevance of these new indicators.

CHAPTER 8

Exploratory study of the application of the methodology to Brazilian High Schools

High

In the previous chapters, the SBTool^{PT} methodology has been analysed and adapted to school buildings in Portugal. In this chapter, the purpose is to demonstrate how to begin the adaptation of this methodology to the Brazilian context. This chapter is taken from the articles “Environmental Comfort Indicators for School Buildings in Sustainability Assessment Tools” (https://doi.org/10.3390/su10061849) and “The inclusion of a sustainability awareness indicator in assessment tools for high school buildings” (https://doi.org/10.3390/su11020387), about Juiz de Fora high school, whose authors are the author and supervisors of this thesis.

Some indicators were added to the methodology elaborated in this work, the SAHSB^{PT} methodology, such as the ergonomics indicator and the awareness indicator. The comfort indicators are of great relevance, as the school environment is characterized by being a learning environment for children and adolescents. The indicator related to motivation on sustainability is also very important for students and, for this reason, the comfort indicators and the indicator related to motivation on sustainability were chosen as the subject of the questionnaire applied at the school in Portugal and also in the Brazilian schools.

The subchapters 8.2, 8.3 8.4, 8.5 describe the results obtained through the application of questionnaires to students from two high schools in the city of Juiz de Fora, based on the indicators of comfort and sustainability awareness in schools.

The indicators of environmental comfort and sustainability awareness were chosen as subjects for the questionnaires, as mention in the subchapter 5.2. The selection of the environmental comfort indicator, which includes air quality, thermal, visual, acoustic and ergonomic comfort, was selected because students spend several hours at school, and comfort interferes with the quality of learning. The “sustainability awareness” indicator was chosen because this indicator allows the use of schools as vehicles to spread the relevance of the sustainability experience on people's lives, using students as tools, since they can broadcast this idea in their families and in society (Saraiva et al., 2019).

While Portugal is a small country and, through the EPE, it tries to standardize the construction of the public schools, Brazil is a country of great proportions, with several differences related to culture, building materials, and climate, among others.

8.1. Comfort Indicators

This subchapter presents the results concerning questionnaires applied to the students of two high schools chosen in Juiz de Fora. These schools are two of the best and most traditional private schools in the city, both of which have been operating for more than 100 years. Colégio Santa Catarina was built in 1900 and Colégio Cristo Redentor was built in 1891 (jfminas, 2017).

The questionnaires were applied to high school students from 15 to 18 years old and the environmental comfort verified in this work takes as a base the classroom where students spend most of their time. The research was done in six classes, two of each grade and two of each school, reaching 269 students.

Table 8.1. shows the main aspects related to the interview and classroom characteristics and Table 8.2. shows the results of the survey, considering a total of 100% of interviewed students, reflecting how satisfied students are or not with different types of environmental comfort issues (Saraiva et al., 2018).

Table 8.1. Main aspects related to the interview and classroom characteristics in Juiz de Fora (Saraiva et al., 2018)

Interview Date	19 July 2017
Number of Students in the school	1980
Number of student that answered the questionnaires	269 (57% from Colégio Santa Catarina + 43% from Colégio Cristo Redentor)
Temperature in the City	11 °C to 14 °C
Air humidity	81%
Air quality	Ozonium, formaldehyde, bacteria, legionella, radon, carbon dioxide and carbon monoxide fungus, particles suspended in air with a diameter of less than 10 µm and volatile organic compounds presented low results according to Regulatory Compliance Statement for this construction.
Mechanical System	The classrooms of both schools do not have heating systems but they can maintain the internal temperature.
Window size	The windows are large, favouring natural lighting.
Window material	Windows are large (2 windows, H = 1 m and L = 2 m), there are also skylights in darker places, favouring natural lighting.
Lamps	Most of the lamps used are fluorescent, offering a good illumination.
Cover Material	The external walls are made of solid bricks, and the windows used are simple and without special sealing.
Size of chairs and tables	The schools use standard furniture, not adaptable to the biotype of each student.

The information about the two schools in Juiz de Fora is considered. Table 8.2 reflects how satisfied or not students are with the different aspects of the environmental comfort. The percentages related to the answers of the questionnaires applied in July 2017 to the students of the Juiz de Fora schools, reflect the students' perception of thermal comfort, air quality and lighting and show a good level of acceptance by the students. The biggest problems are related to acoustic comfort, for which the level of satisfaction in the questionnaire is only 38%. The ergonomic comfort of classroom furniture also shows a very low percentage of satisfaction, with just 29% of the students reporting a sense of comfort (Saraiva et al., 2018).

Table 8.2. Result of the percentages related to the students' level of satisfaction with the different types of environmental comfort indicators at High Schools in Juiz de Fora, Brazil

IEQ	Level 1 Comfortable (C)	Level 2 Slightly Uncomfortable (SU)	Level 3 Uncomfortable (U)	Level 4 Very Uncomfortable (VU)
Thermal	75%	14%	9%	2%
Lighting	80%	12%	6%	1%
Acoustic	38%	39%	13%	10%
Air quality	79%	1%	20%	1%
Ergonomic	29%	29%	28%	14%
General	58%	30%	11%	1%

Table 8.2. reflects how satisfied or not students are with the different aspects of environmental comfort at the Brazilian high schools. The statistical analysis between groups was done using Microsoft Excel (ANOVA) regarding the IEQ results for the Brazilian High Schools (the

software ANOVA was explained in subchapter 3.2. and illustrated in Figure 3.1. of this thesis). It is verified that the Fcalculated = 17.81 > Ftabulated = 3.09 (probability equal to 0.05), i.e., there is significant variability between the data. The students' satisfaction regarding thermal, lighting and air quality comfort was very high, but the satisfaction was somewhat lower regarding acoustic comfort and deficient regarding ergonomic comfort, as described below (Saraiva et al., 2018):

(i) 75% of the students stated that they are comfortable inside the classroom, which is a reasonable result considering it is advisable that 80% of the people within the same environment should be comfortable.

(ii) 80% of the students stated that they are comfortable with the lighting in the classroom, which is a good result. This result is within the expectations. Lighting related to the students' level of comfort in this aspect seems to be quite adequate.

(iii) 38% of the students are comfortable with the noise in the classroom. It is a high value considering that it is a classroom. The students' dissatisfaction with the environment has a strong relationship with their productivity. The reverberation time (0.86 s) and the sound levels (60 to 65 dB) are too high.

(iv) 79% of the students stated that they are comfortable with air quality in the classroom, which is a good result. This result is within the expectations.

(v) 29% of the students are feeling comfortable with ergonomics. This low result related to the number of students who feel comfortable is very close to the results found in Portugal (Table 5.3.), which show that 29% of the students are comfortable regarding ergonomics. That emphasizes the need of including the indicator related to ergonomics of desks in the methodologies that evaluate and certify sustainability in school environments.

(vi) 58% of the students feel comfortable with all the factors mentioned. This is not a good result mainly due to the level of satisfaction of the students who answered the questionnaire regarding the acoustic and ergonomic comfort.

Through the analysis of the information, there is a clear need to support the schools, giving priority to ergonomic and acoustic comfort without forgetting the other three indicators.

8.2. Sustainability Awareness Indicator

Along with the questionnaire applied to the students of the schools related to the comfort indicators, a questionnaire was applied with the objective of ascertaining the level of awareness in the same schools in Juiz de Fora. This questionnaire can be found in ANNEX 3.

The study aims to analyse the questionnaire applied in the Juiz de Fora schools with the objective of verifying the students' level of sustainability awareness. The schools analysed in this study are considered to be traditional in their respective cities and both were built in the 19th century (Saraiva et al., 2019a).

These questionnaires were applied in the classroom with the presence of the teacher. When applying these questionnaire students were asked not to identify themselves, only by placing the age, grade and the school in which they studied. The reasons for the application of this questionnaire and the explanation on each question was clarified before its application (Saraiva et al., 2019a).

The levels of sustainability awareness of students in Brazilian schools are good, as observed in the Table 8.3. Only the level relative to selective collection of recyclable waste is low, since Brazil is just starting to demonstrate some concern with the recycling of materials in schools. Therefore, there are just few places that collect recycled materials. In addition, students want to learn about sustainability without adding this as part of the school grade, showing the lack of commitment to the subject (Saraiva et al., 2019a).

Table 8.3. Percentages (%) of Students' sustainability awareness level in Brazilian high schools (Saraiva et al., 2019a)

Questions	Level 1	Level 2	Level 3	Level 4
	Good	Average	Bad	Terrible
Question 1 – Environmental quality	29%	49%	16%	6%
Question 2 – Environmental issues	28%	53%	18%	1%
Question 3 – Environmental protection	64%	23%	13%	0%
Question 4 – Environmental practices	22%	51%	22%	5%
Question 5 – Water consumption	75%	21%	3%	1%%
Question 6 – Energy consumption	50%	28%	10%	12%
Question 7 – Recyclable waste	38%	8%	5%	55%
Question8 – Sustainable debate in class	19%	21%	11%	49%

The questionnaire assesses the level of environmental interest of the students, the frequency of environmental issues mentioned in class, and the frequency with which they do something to protect the environment in their quotidian. Other issues address environmental practices in their homes and how students feel environmental issues should be addressed in high schools (Saraiva et al., 2019a). Then, a statistical analysis was performed using the Microsoft Excel software ANOVA, with a level of probability equal to 0.05, to evaluate the performance of the responses (Analyticsvidhya, 2018). The software ANOVA, as explained in subchapter 3.2. and illustrated in Figure 3.1. of this thesis, demonstrate how to use the software.

This questionnaire consists of eight questions related to attitudes and sustainable awareness, and Table 8.3. demonstrates the level of the students' awareness of each aspect of sustainability defined in the questions. With this data, through the ANOVA software, the analysis of variance is done verifying to what extent the average of each level is related to the global average (Saraiva et al., 2019a).

The statistical analysis of sustainability awareness level observed in the questionnaire applied to the students of the schools in Juiz de Fora, according to Table 8.3, referring to the results of sustainability awareness for high schools in Brazil. It was verified that Fcalculated = 15.43 > Ftabulated = 2.61 (probability equals to 0.05 (reliability coefficient), i.e., there is a significant variable among the data (Saraiva et al., 2019a).

Table 8.3 shows that the sustainability awareness level of students in Juiz de Fora schools are suitable (good + average), namely (Saraiva et al., 2019):

(i) 78% (29%+49%) of the students stated that they are very or reasonably interested in subjects related to environmental concerns (Question 1);

(ii) 81% of the students stated that they always, or with some frequency, mention subjects related to the environment in the classroom. In this aspect, the results seem quite appropriate, since the worldwide trend is to increase the concern with sustainability (Question 2);

(iii) 87% of the students stated that they always, or with some frequency, protect the environment in their daily lives. This is a good result, considering that the majority of students is involved in saving the environment (Question 3);

(iv) 73% of the students stated that they always, or with some frequency, take environmental attitudes in their own home and try to teach it to their family. The students adopt sustainable attitudes at home, so this is part of their daily lives (Question 4);

(v) 96% of the students stated that they always or with some frequency close the tap after use. Only one percent declares that they do not close it. This low result related to the number of students who do not close the tap after the use is good, which means that the majority of the students is aware of the impact that careless use of water can cause (Question 5);

(vi) 78% of the students stated that they always or with some frequency turn off the lights and fans when they leave the room. 12% of the students declare that they do not turn off the light. This elevated result related to the number of students who turn off the lights and fans to exit a place is good, therefore, the majority of the students are aware of the impact that the irresponsible use of electricity consumption can cause (Question 6);

(vii) 46% of the students always or with some frequency do the selective waste collection, and 55% of the students do not do that. In Brazil, only a short time ago, the concern with recycling began in schools. Therefore, there are still few recycling collection places (Question 7);

(viii) 40% of the students stated that the environmental issues should be made through events and other academic projects. Therefore, the students want to learn about sustainability, but only eventually, without including it as part of the school curriculum (Question 8).

8.3. Discussion of comparison among comfort indicators in Guimarães and Juiz de Fora high schools

Previously in this thesis, the results of the questionnaires related to the indicator of environmental comfort, applied at Francisco de Holanda High school, Guimarães, Portugal (subchaper 5.2) and at the Cristo Redentor and Santa Catarina schools, in Juiz de Fora, Brazil (Subchapter 8.2) were analysed. In this subchapter, the results of the questionnaires of the schools in Guimarães and Juiz de Fora are compared.

The results on acoustic comfort (see Table 8.4.) show that just 38% of Brazilian students and 54% of Portuguese students are comfortable. That was so because, at the Brazilian high schools, the sound level inside the class is around 54 to 71 dB and the reverberation time is 0.86 s, and at the Portuguese school the sound level is 49 to 65 dB and the reverberation time is 0.75 s. These values are higher than what is recommended by the European Comfort Standard EN 15251 (30 to 45 dB) and EN ISO 3382-2, (0.55 s to 0.60 s). These high values occur because the classroom's surface materials are smooth and hard, accentuating reverberation and the walls dividing one room from the other do not have adequate acoustic insulation treatment (Saraiva et al., 2018).

Table 8.4. and Figure 8.1. show the differences and similarities between the percentages of environmental comfort perceived by the students of the schools of Juiz de Fora (Brazil) and Guimarães (Saraiva et al., 2018).

Table 8.4**.** Comparison of the percentages of the answers given by students of the schools of Juiz de Fora (BR) and Guimarães (PT) regarding environmental comfort (Saraiva et al., 2018)

IEQ	**Level 1 Comfortable (C)**		**Level 2 Slightly Uncomfortable (SU)**		**Level 3 Uncomfortable (U)**		**Level 4 Very Uncomfortable (VU)**	
	(BR)	(PT)	(BR)	(PT)	(BR)	(PT)	(BR)	(PT)
Thermal	75%	61%	14%	23%	9%	10%	2%	6%
Lighting	80%	78%	12%	18%	6%	4%	1%	0%
Acoustic	38%	54%	39%	38%	13%	6%	10%	2%
Air quality	79%	72%	1%	2%	20%	26%	1%	0%
Ergonomic	29%	27%	29%	50%	28%	19%	14%	4%
General	58%	56%	30%	31%	11%	12%	1%	1%

The statistical analysis between groups (Table 8.4.) using Microsoft Excel (ANOVA) regarding the IEQ results for the Brazilian and Portuguese High Schools found that:

(i) For the countries: Fcalculated = 0.02 < Ftabulated = 2.60 (probability equal to 0.05), i.e., there is no significant variability between countries. The Brazilian students and Portuguese students have the same parameters in building school.

(ii) For the IEQ: Fcalculated = 9.68 < Ftabulated = 2.60 (probability equal to 0.05), i.e., there is significant variability of IEQ between the countries.

As can be seen in Table 8.4. and Figure 8.1, the general results of environmental comfort assessments are similar, since the cities of Juiz de Fora (Brazil) and Guimarães (Portugal) have similar characteristics, such as temperature and humidity (Saraiva et al., 2018).

The level of ergonomic comfort has low results (under 30%), in comparison with other IEQ values because there are standard desks in all schools, which can cause discomfort and muscle pain in the users. Considering that there are large differences in size among teenagers, adaptable portfolios that fit the biotype of each student should be used (Saraiva et al., 2018).

Finally, there is a need to consider the ergonomic comfort of school buildings in sustainability assessment tools because it is very important of environmental issues for the performance of human beings (Saraiva et al., 2018).

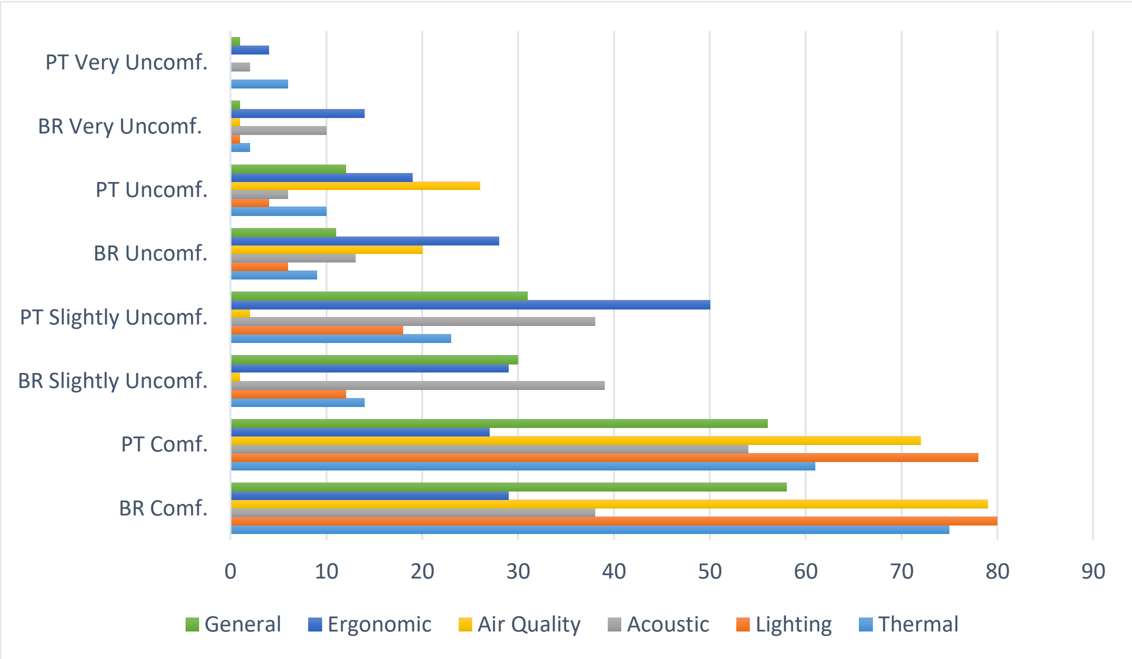

Figure 8.1. Results of the environmental comfort level in Brazilian and Portuguese high schools

This study made clear the importance of maintaining comfort indicators within a sustainable range, specifically for school environments, since students stay long periods inside the school and comfort interferes in the students' health, concentration and learning. It also aimed to determine the need of including the ergonomic comfort indicator in sustainability assessment tools for school buildings, for the sake of the welfare of the students, since most of the students, 73% in Portugal and 71% in Brazil, feels that the school desks are uncomfortable (Saraiva et al., 2018).

Another aspect observed through the results of the work is that, although there are common characteristics between the cities of Guimarães and Juiz de Fora (such as temperature, humidity and school characteristics), different results were found for most indicators studied. Therefore, there is a clear need of adaptation of this methodology to each location in each country. Brazil has a large territorial area, so several adaptations of the methodology will be necessary to adjust it to the specific needs of each region (Saraiva et al., 2018).

A good sustainability assessment tool interferes with the comfort of the building users and improve quality of life. Additionally, there is a great tendency of local legislation to follow the requests of the methodology applied to assess sustainability in school buildings, especially when it is widely used by the population, thus bringing great benefits (Saraiva et al., 2018).

The study carried out in Juiz de Fora serves to open precedents for new research in Brazil related to sustainability assessment methodologies specific for schools that may be adapted to different Brazilian regions. This kind of research is unprecedented, necessary considering that sustainability has growing demand around the world, and there is a huge demand for this subject in Brazil (Saraiva et al., 2018).

8.4. Discussion of the comparison between sustainability awareness indicators in the high schools of Guimarães and Juiz de Fora

Previously in this thesis, the results of the questionnaires related to the indicator of sustainability awareness, applied at the high school Francisco de Holanda, Guimarães, Portugal (subchapter 5.3) and at the Cristo Redentor and Santa Catarina schools, in Juiz de Fora, Brazil (Subchapter 8.3) were analysed. In this subchapter, the results of the questionnaires of the schools in Guimarães and Juiz de Fora are compared.

Table 8.5. and Figure 8.2., reveal the differences and similarities between the percentages of sustainability awareness among the students of Juiz de Fora (Brazil) and Guimarães (Portugal)

schools. The statistical analysis between groups using Microsoft Excel (ANOVA) regarding the sustainability awareness results for the Brazilian and Portuguese High Schools found that (Saraiva et al., 2019a):

(i) For the countries: Fcalculated = 0.001 < Ftabulated = 2.20 (probability equal to 0.05), i.e., there is no significant variability between countries. The Brazilian students and Portuguese students have the same parameters in building school.

(ii) For the IEQ: Fcalculated = 5.19 < Ftabulated = 2.20 (probability equal to 0.05), i.e., there is significant variability of sustainability awareness between the countries.

Through the results shown in Table 8.5., it is noticed that students do not perform activities related to sustainability in their homes very often, and do not have the concern of teaching this to their families, in Brazil only 22% and in Portugal, 32%. The level regarding selective collection of recyclable waste is low in both Brazil, 38% and Portugal, 40% (Saraiva et al., 2019a).

Table 8.5. Percentages (%) of students' sustainability awareness level in Brazilian and Portuguese high schools (Saraiva et al., 2019a)

Questions	**Level 1**		**Level 2**		**Level 3**		**Level 4**	
	(B)	**(PT)**	**(B)**	**(PT)**	**(B)**	**(PT)**	**(B)**	**(PT)**
Question 1 – Environmental quality	29%	26%	49%	55%	16%	17%	6%	2%
Question 2 – Environmental issues	28%	32%	53%	51%	18%	16%	1%	1%
Question 3 – Environmental protection	64%	63%	23%	25%	13%	10%	0%	2%
Question 4 – Environmental practices	22%	32%	51%	55%	22%	7%	5%	6%
Question 5 – Water consumption	75%	73%	21%	23%	3%	2%	1%	2%
Question 6 – Energy consumption	50%	55%	28%	39%	10%	6%	12%	0%
Question 7 – Recyclable waste	38%	40%	8%	15%	5%	7%	55%	38%
Question 8 – Sustainable debate in class	19%	38%	21%	11%	11%	7%	49%	44%

Another aspect perceived in both schools was that the students wanted to learn about sustainability without adding this to the part of the school grade (Brazil, 19% and Portugal, 38%), showing the lack of commitment to the subject (Saraiva et al., 2019).

Since these methodologies should be applied in several countries, including the countries under development where the simple concern of turning off a tap and switch off a light is not common, it is necessary to include an indicator of sustainability awareness in school environments in sustainability assessment tools, with the purpose of increasing the awareness level (Saraiva et al., 2019).

It is impossible to build a sustainable school if the students of this institution do not identify how and why to use the existing mechanisms properly and consciously.

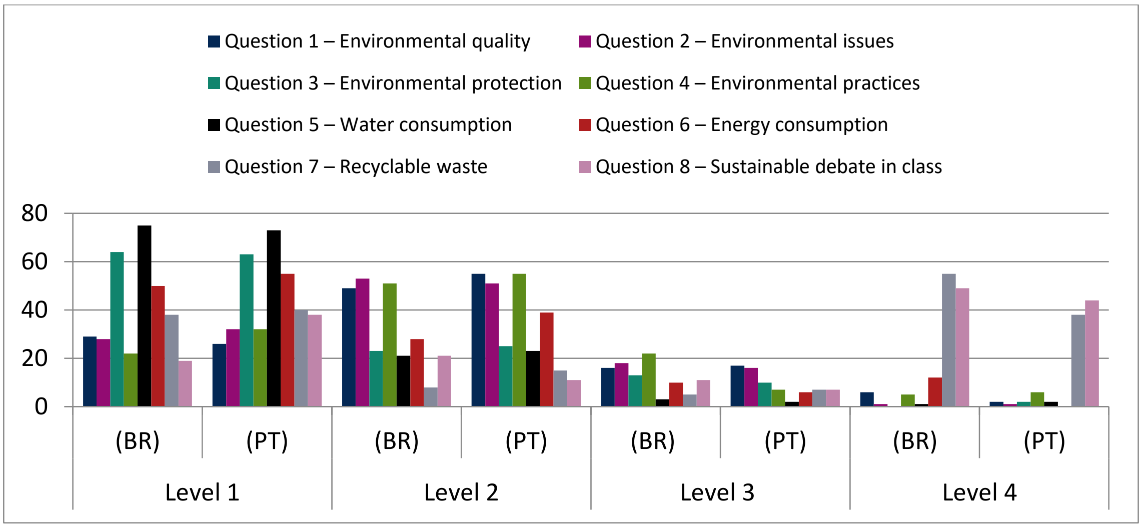

Figure 8.2. Results of sustainability awareness for Brazilian high school and Portuguese high school (Saraiva et al.,2019)

In Brazilian and Portuguese schools, the level of the students' sustainability awareness is suitable, as observed in Table 8.5. and in Figure 8.2. The results are well balanced, being that Portuguese schools show a slightly better level in most of the results. This can be attributed to the fact that the environmental education reference for sustainability was developed in Portugal, in 2016, by the DGE, with the goal of supporting students in learning this knowledge.

This happens since the concern with the motivation for sustainability in European countries is further encouraged and also because the *Parque Escolar* always has the concern of building schools with sustainable environments, using equipment that decreases energy and water consumption. Portugal also has environmental education incentives (Saraiva e al., 2019a).

In Brazil, the incentives started a little later, but the result was good because in this country, and especially in its schools, there is great motivation to activities related to the reduction of the environmental impact, in addition to the environmental education by means of lectures and teachers (Saraiva et al., 2019a).

It is necessary to perform according to environmental issues, thus, there is a need of practices of environmental awareness, since the interconnection regarding the level of sustainability and the awareness of the inhabitants of a region is remarkable. Therefore, there must be a motivation for learning and for sustainable attitudes in education through environmental education, to achieve the economic, environmental and social aspects of sustainability of a country (Saraiva et al., 2019a).

This work demonstrates the need to include the indicator of sustainability awareness in specific methodologies for sustainability assessment in the high school environment. The inclusion of this indicator in the methodologies of sustainability assessment for high school buildings promotes the awareness of sustainability among students, encouraging sustainable attitudes in the students' daily lives.

Therefore, future studies related to this subject should be made with the intension of the addition of sustainability awareness indicator in several assessment tools for school buildings.

8.6. Concluding Remarks

There should also be studies on the adaptation of methodologies for sustainability assessment for school buildings to each region, taking into account cultural, social, financial, political and educational aspects; specific to the region or country under analysis (Saraiva et al, 2018).

The results of the work demonstrated that, although there are common characteristics between the cities of Guimarães and Juiz de Fora (such as temperature, humidity and school characteristics), slightly different results were found for most indicators studied. Therefore, there is a clear need of adaptation of this methodology to each location in each country. Brazil has a large territorial area, so several adaptations of the methodology will be necessary to adjust it to the specific needs of each region (Saraiva et al., 2018).

CHAPTER 9

Comparative study of environmental comfort indicators in the Southeast and in the Amazon region in Brazil

In the last chapter, a comparison was made between schools in Guimaraes, Portugal, and Juiz de Fora, Brazil, in order to draw a parallel between the two countries. These two cities have similar characteristics regarding climatic (humidity, temperature) and cultural conditions, construction processes and teaching standards.

This chapter aims to initiate research on the adaptation of sustainable methodologies in Brazil, emphasizing the indicators of environmental comfort, and the results of the application of surveys to students from the previously evaluated city of Juiz de Fora (Saraiva et al., 2018), along with those from the city of Macapá, in the Amazon region, thus in a totally different context.

This chapter is taken from the article "Comparative study of Environmental Comfort Indicators for School Buildings in Sustainability Assessment Tools: schools in the Amazon region and in the Southeast region of Brazil" (https://doi.org/10.3390/su11195216), whose authors are also the author and the supervisors of this thesis. In the following section, the main aspects of the regions of Brazil are shown.

9.1. Overview of Brazilian regions

Brazil is a country with huge dimensions, with a significant diversity of cultures, economies and climates. It is the fifth biggest country in the world, with an area of 8.515.767 km². Brazil is divided into five regions: North, Northeast, Centre-West, Southeast and South. There are several types of climatic regions in Brazil, such as equatorial, tropical, subtropical, high altitude tropical, Atlantic tropical and semiarid.

The flora in Brazil has a great diversity, such as Tropical Semi Deciduous Forest, Grassland, Thorny Shrub, Savanna, Tropical Rain Forest and Periodically Wet Land. The GDP per capita differs for each region, with Brasilia having the largest, followed by Sao Paulo. The states with the lowest GDP per capita are in the north and northeast. All these characteristics interfere in the selection of construction practices and also in the types of constructions [Barbosa & Almeida, 2017). The maps of Brazilian regions, finance, flora, and climate can be seen in Figure 9.1.

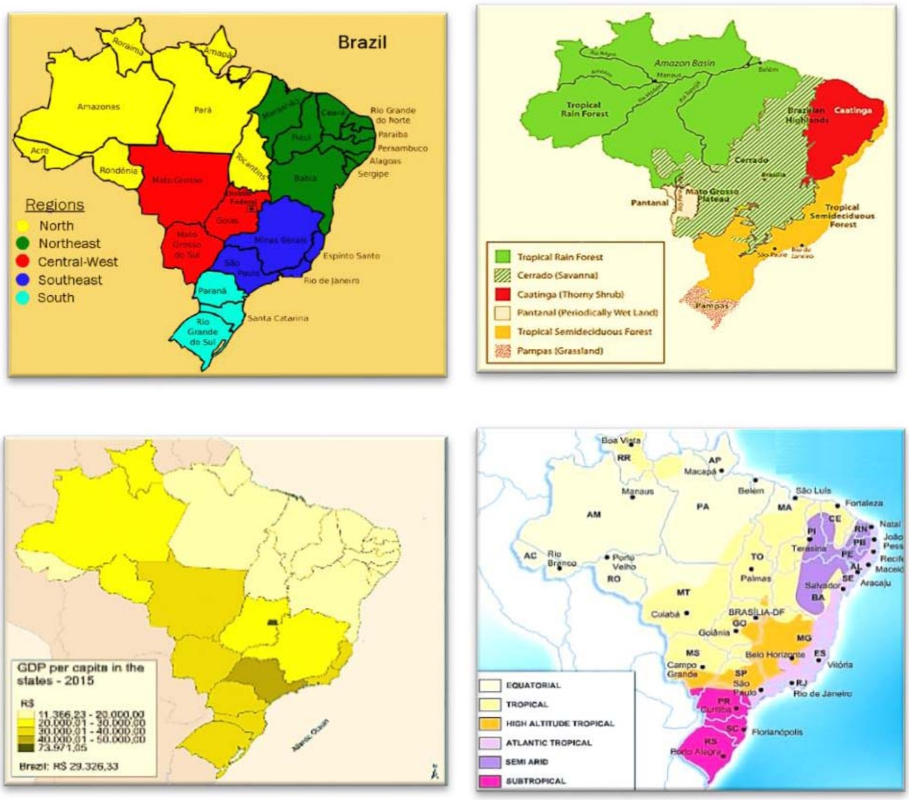

Figure 9.1. Maps of Brazil (regions, flora, finance and climate) (Matos et al., 2016)

The main features of the Brazilian regions are described in the following paragraphs (IBGE, 2015):

1. South Region:

- Formed by the States: Rio Grande do Sul, Santa Catarina and Paraná;
- Area: 576,774 km², about 7% of the total area, has a high population density (about 43.50 inhabitants/km2) and 14.36% of the Brazilian population (Matos et al., 2016);

• Socioeconomic aspects: high cultural, economic and social development, similar across all sectors (education, health, economy and others);

• Climate: lowest temperatures in the country, subtropical, with rains distributed regularly throughout the year and well-defined seasons of the year.

2. Southeast Region:

• Formed by the States: Minas Gerais, São Paulo, Espírito Santo and Rio de Janeiro;

• Area: 924,620 km2, being the second smallest region of the country, but it has the highest population density (about 85 inhabitants/km2), about 43% of the Brazilian population (Matos et al., 2016);

• Socioeconomic aspects: very urbanized (91% of the population lives in urban areas). The region is the best offer of basic health services, the most satisfactory water supply system in the country, has the highest GDP per capita and the second in quality of life. There are an important financial, commercial and industrial region of the country, using around 85% of the total electricity consumed in the country and employing 70% of the Brazilian workers;

• Climate: tropical, oscillating between hot and temperate, with great local differences and two well defined seasons, one dry (winter) and one rainy (summer).

3. Central-West Region:

• Formed by the States: Mato Grosso, Goiás, Mato Grosso do Sul and the Federal District, where the capital of the country, Brasília, is located;

• Area: 1,606,403 km2, 18.86% of the national territory, the second largest region of the country in territorial area, with the second lowest population density, with 7.36% of the total population of the country, showing large demographic gaps (Matos et al., 2016);

• Socioeconomic aspects: serious deficiencies in the water supply system in the rural area. This region is in a constant process of development, having numerous incentives and investments in transport infrastructures, which contributed to the modernization and growth of the region;

• Climate: tropical, rainy and hot, with dry winters and hot summer seasons.

4. Northeast Region:

• Formed by the States: Sergipe, Rio Grande do Norte, Pernambuco, Maranhão, Bahia, Piauí, Ceará, Paraíba and Alagoas;

- Area: 1,554,291 km², 18% of the national territory, with 27.83% of the Brazilian population (Matos et al., 2016);
- Socioeconomic aspects: it has varying levels of human development throughout its geographical zones, having the lowest average index in the country. The socioeconomic deficiencies in the development of this region are the lack of housing services, education and basic health;
- Climate: Tropical (Piauí, Ceará, Bahia and Maranhão) and Semi-arid (northeast of the interior of the region), due to the low average of annual rainfall.

5) North region:

- Formed by the States: Tocantins, Amazonas, Rondônia, Amapá, Roraima, Pará, and Acre;
- Area: 3,853,676 km2, 45.27% of the national territory, being the most extensive region of Brazil, and the least populated in the country, with a population density of only 4.77 inhabitants per km², corresponding to 8.32% of the population of the country (Matos et al., 2016);
- Socioeconomic aspects: many socio-environmental problems, such as provision of basic health services and severe deficiencies in access to water supply in urban areas, adequate housing, among others;
- Climate: The humid equatorial climate provides the region an elevated temperature throughout the year and with low thermal amplitude.

After the regions of Brazil have been described in the previous paragraphs, it is noticed that there are great differences between each region, in economic, social, political, cultural and climatic aspects.

9.2 Discussion of comparison among comfort indicators in Juiz de Fora and Macapá high schools

This chapter intended to analyse the level of the environmental comfort in high school buildings in the cities of Macapá (Amapa) and Juiz de Fora (Minas Gerais).

The multiple-choice questionnaire was used with high school students from Macapá and Juiz de Fora, with the objective of identifying the Indoor Environmental Quality (IEQ) conditions in these school buildings. As explained in subchapter 3.2. and illustrated in Figure 3.1. of this thesis, the performance of the responses gave by the students was made by a statistical analysis using Microsoft Excel, with a level of probability of 0.05 (reliability coefficient). The results determine the comfort level of the students inside the classroom of the analysed schools. The questionnaire has six questions (ANNEX 2), whose options range from high discomfort to comfort (Saraiva et al., 2018).

The surveys were applied in the winter, when the temperatures were 8–15 °C in Juiz de Fora and 25–33 °C in Macapá. Air humidity was high in both cities (about 80%). This questionnaire consists of six questions related to comfort environments. Through the results of the questionnaires, using the Microsoft Excel software ANOVA, it is prepared an analysis, verifying to what level the average of each measured variable is correlated to the global average (Analyticsvidhya, 2018).

It is possible to verify hypotheses about the differences between the means of a variable (response variable) in relation to treatment with two or more categorical levels through the statistical analysis realized by ANOVA. The ANOVA software statistically tested the effect of the impact of the level of satisfaction factor associated with the environmental comfort of high schools in Juiz de Fora and Macapá. It is tested if the value of the factor (Fcalculated) supplied by the statistical analysis is superior to the factor (Ftabulated).

High School in Juiz de Fora

The questionnaires (ANNEX 2) were applied in the two high schools in Juiz de Fora Table 9.1. demonstrates the level of satisfaction of the children concerning to comfort in the learning spaces, in the schools in Juiz de Fora.

Table 9.1. Results of the percentages of the answers given by the students of High Schools in Juiz de Fora, Minas Gerais concerning to environmental comfort (Saraiva et al., 2018)

IEQ	Level 1 Comfortable (C)	Level 2 Slightly Uncomfortable (SU)	Level 3 Uncomfortable (U)	Level 4 Very Uncomfortable (VU)
Thermal	75%	14%	9%	2%
Visual	80%	12%	6%	1%
Acoustic	38%	39%	13%	10%
Air quality	79%	1%	20%	1%
Ergonomic	29%	29%	28%	14%
General	58%	30%	11%	1%

The statistical analysis between groups was done, specifically, the Microsoft Excel (ANOVA) was used to make the statistical analysis among the comfort level, regarding the IEQ results. It has defined that the Fcalculated = 17.81 > Ftabulated = 3.09 (probability equal to 0.05), i.e., there is major variability between the data. The students' satisfaction about thermal, visual and air quality comfort was high, but the satisfaction was somewhat inferior regarding acoustic comfort and was deficient about ergonomic comfort (Saraiva et al., 2018).

High School in Macapá

The surveys on environmental comfort were conducted in two traditional schools in the city of Macapá (Amapá), namely the Gabriel Almeida Café School and the Tiradentes School, both of which were founded in the 1970s. The interviews were applied to 271 high school students in February 2019. This period in the city of Macapá is characterized as being winter, the humidity was 78% and the average temperatures ranged from 27 to 33 °C (Silva, 2019). The aspects related to environmental comfort in the classroom in the high schools in Macapá are demonstrated in 100% of the interviewed students (Table 8.2.). The results of the questionnaire (ANNEX 2) are shown in the Table 9.2, considering a total of 100% of the interviewed students.

Table 9.2.Aspects of the classrooms of the Tiradentes and Gabriel Almeida Café Schools, Macapá

Date of Interview	February 2019
Number of Students in the schools	1127
Number of Students that answered the questionnaires	271 (54% from Tiradentes School + 46% from Gabriel Almeida Café School)
Temperature in the City	27 °C to 33 °C
Air humidity	78%
Thermal Comfort	HVAC is usually on in every room every day. In several classrooms, the air conditioners or the windows are damaged; No natural ventilation at any time of day; except when the air conditioner is damaged; No roof insulation (strong insulation); Simple glasses in windows; Windows are not efficiently insulated; No insulation of external walls; Cover Material: The external walls are made of standard bricks, and the windows used are simple and without special sealing.
Visual comfort	One meter high glass windows throughout the exterior walls, but is not sufficient; Artificial lighting is produced by fluorescent lamps; The lamps are less than what would be necessary, with great distance between them; The artificial and natural lighting are not adequate.
Acoustic Comfort	No acoustic treatment; Simple glasses in windows; Proximity to automobile traffic lanes; Sound level outside: has interference in the learning places, and there is noise coming from the rooms close to the classrooms;
Air quality	There is little natural air circulation as the windows are always closed to preserve HVAC.
Ergonomic Comfort	The size of chairs and tables is not flexible, the schools use standard furniture, not ergonomically suited for all students.

Table 9.3. Results of the percentages of the answers given by the students of High Schools in Macapá concerning environmental comfort (Silva, 2019)

IEQ	Level 1 Comfortable (C)	Level 2 Slightly Uncomfortable (SU)	Level 3 Uncomfortable (U)	Level 4 Very Uncomfortable (VU)
Thermal	49%	18%	16%	17%
Visual	41%	18%	22%	19%
Acoustic	42%	34%	15%	9%
Air quality	84%	1%	14%	1%
Ergonomic	50%	26%	17%	8%
General	47%	32%	20%	1%

Tabe 9.3. demonstrates the level of satisfaction of the students regarding comfort in the learning places in the high schools in Macapá. The statistical analysis between groups was done using the Microsoft Excel (ANOVA). This software was used to make the statistical analysis among the comfort level, regarding the IEQ results. It has defined that the Fcalculated = 13.51 > Ftabulated = 3.28 (probability equal to 0.05), i.e., there is relevant variability between the data. The students' satisfaction concerning air quality comfort was very high, but the satisfaction was somewhat lower regarding visual, thermal and acoustic comfort, and was deficient regarding ergonomic comfort.

Through the analysis of the information, it can be concluded that there is a clear need to support the schools, giving priority to thermal, visual, acoustic and ergonomic comfort, without forgetting the air quality indicators.

9.3. Discussion and comparison

Table 9.3. and Figure 9.2. show the similarities and differences between the percentages of environmental comfort perceived by the students of the schools of Juiz de Fora (Minas Gerais) and Macapá (Amapá).

Table 9.3: Comparison of percentages of the answers given by the students of the schools of Macapá and Juiz de Fora regarding environmental comfort.

IEQ	Level 1 Comfortable (C)		Level 2 Slightly Uncomfortable (SU)		Level 3 Uncomfortable (U)		Level 4 Very Uncomfortable (VU)	
	(JF)	**(MA)**	**(JF)**	**(MA)**	**(JF)**	**(MA)**	**(JF)**	**(MA)**
Thermal	75%	49%	14%	18%	9%	16%	2%	17%
Visual	80%	41%	12%	18%	6%	22%	1%	19%
Acoustic	38%	42%	39%	34%	13%	15%	10%	9%
Air quality	79%	84%	1%	1%	20%	14%	1%	1%
Ergonomic	29%	50%	29%	26%	28%	17%	14%	8%
General	58%	47%	30%	32%	11%	20%	1%	1%

The statistical analysis between groups (Table 9.5.), using Microsoft Excel (ANOVA), regarding the IEQ results for the High Schools in Minas Gerais e Amapá, showed that:

(i)For the cities: Fcalculated = 0.003 < Ftabulated = 2.48 (probability equal to 0.05), i.e., there is a substantial variability among the cities. The students from Amapá (AP) and Juiz de Fora (MG) have different parameters regarding school buildings.

(ii) For the IEQ: Fcalculated = 13.41 < Ftabulated = 2.28 (probability equal to 0.05), i.e., there is significant variability of IEQ between the cities. Fifty-three percent of the students feel comfortable inside the learning spaces, which is an insufficient result.
As a result of the analysis of the data, it can be concluded that it is important to support the schools, giving priority to acoustic and ergonomic comfort, without forgetting the other indicators.

As can be seen in Table 9.3., the general results of environmental comfort assessments are completely different, since the cities of Juiz de Fora (Minas Gerais) and Macapá (Amapá) have distinct characteristics, such as flora, culture, climate and locations. The results regarding general comfort (seeTable 9.3.) show that just 58% of students from Minas Gerais and 47% of the students from Amapá are comfortable.

Only 38% of the students in the schools of Juiz de Fora (MG) and 42% in the schools of Macapá (AP) are satisfied regarding acoustics. These occur since the walls that divide one room from another do not have adequate acoustic insulation, and, furthermore, the treatment of the materials of the classroom surface is hard and smooth, accentuating reverberation.

The level of ergonomic comfort presents low results (29% and 50%), in comparison with other IEQ results, since there are standard chairs and tables in all schools, causing learning problems, discomfort and health problems in the students. Different sizes of furniture should be used among teenagers that may fit the biotype of each student.

Students from both schools are comfortable with the air quality (79% and 84%). The students of Juiz de Fora are comfortable with the thermal aspects (75%). Just 49% of the students from Macapá are satisfied with the thermal conditions, because sometimes the air conditioner is too cold or broken. Only 41% of the students from Macapá are comfortable with the lighting in the classroom, since the windows are not enough to let in adequate daylight, and the lamps are not of sufficient quality and efficiency.

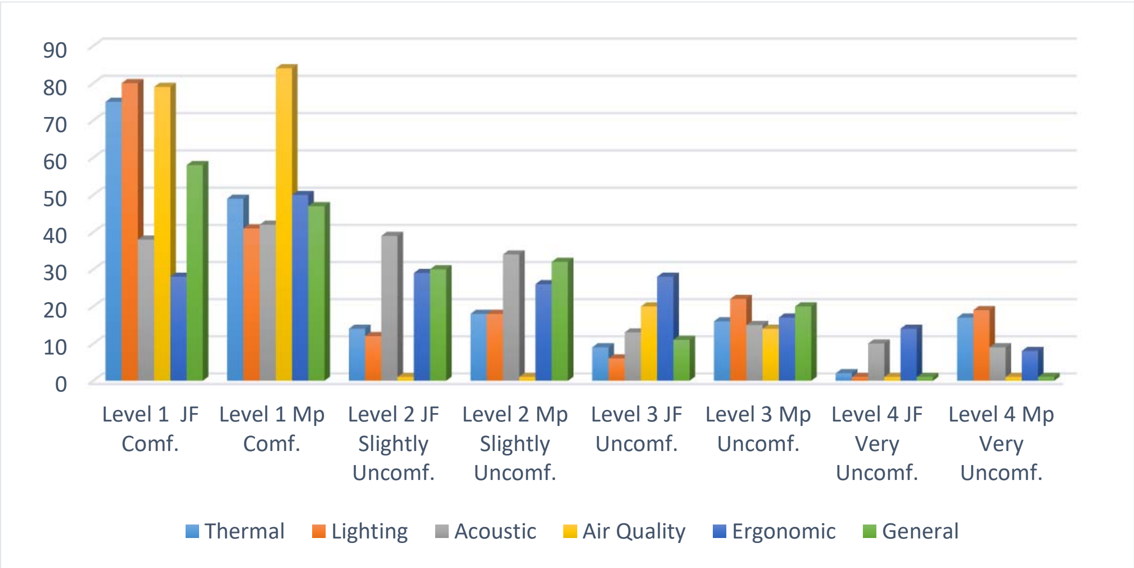

Figure 9.2. IEQ for the high schools of Macapá (Mp) and Juiz de Fora (JF)

9.4. Concluding Remarks

Brazil is a country with large dimensions, with a great cultural, economic and climatic diversity. Therefore, it would be necessary to have several specific sustainability assessments for each region.

This study highlights the significance of comfort indicators for sustainability assessment for school buildings, since students stay around 25% of their days inside the learning place and environmental comfort affects learning, health and concentration of students.

The research has shown that these differences are very large by analysing the levels of satisfaction of the students with regard to environmental comfort. Increasing environmental impacts and improving people's quality of life are increasingly being sought, and sustainable buildings help achieve these objectives.

This thesis is relevant, as sustainability has a growing demand in Brazil, with increasingly sustainable methodologies such as LEED, BREEAM, SBTool, AQUA methodologies being or intended to be applied in Brazil.

CHAPTER 10

Conclusions and Final considerations

In this chapter, a synopsis of each chapter of this work is presented. Nonetheless, at the beginning and end of each chapter of this thesis were introduced, respectively, the presentation and the conclusions of the chapters in question, therefore there may be some repetition of conclusions already described above.

In the first chapter of this thesis, the scope was discussed, along with the objectives and the organization of the thesis. In addition, the concerns about sustainability in buildings, the environmental impacts caused by construction and several methodologies for sustainability assessment for constructions were also reported. Finally, it was also mentioned that some of these methodologies were created specifically for school environments, as well as the reasons why they are relevant.

In the second chapter, several concepts related to sustainability were discussed. Besides, the main characteristics of the Francisco de Holanda High School (Guimarães, Portugal), the Academia school and the Santa Catarina school (Juiz de Fora, Brazil) and Tiradentes School and Professor Gabriel Almeida Café school (Macapá) were also described, as these were the schools in which the methodology and the questionnaires developed in the work performed in this thesis were applied.

Also discussed were the main aspects of Building Sustainability Assessment Methodologies, mainly the sustainability assessment methodologies adapted to schools, such as LEED BD+C Schools, BREEAM Education and SBTool for K-12 Schools.

After being made the study of these specific methodologies, examples of the application of the BSA tools in Brazilian and Portuguese schools were also reported. In Portugal, there is a variety of methodologies applied, and some schools have already been analysed by different methodologies, but none of them have been analysed by a methodology created specifically for the Portuguese context. For this reason, the importance and necessity of elaborating this methodology becomes evident.

Along with the analysis performed on these sustainability methodologies intended exclusively for school buildings, some studies on the SBTool, SBTool^{PT} and SBTool^{PT} STP for Office Buildings were mentioned, as these were the core methodologies used for the elaboration of this work. The information collected in this chapter helped to achieve the objectives of the thesis – the adaptation of the SBTool^{PT} methodology to school buildings taking into account the Portuguese reality.

Chapter 3 presents the Methodology of this thesis. Therefore, in this chapter are demonstrated the methodology and the tools used to achieve each objective of the thesis, as well as how they contribute to achieving the purposes of the thesis.

The fourth chapter presented the content and the structure of the support system to the design, assessment and certification of sustainability of school buildings. Moreover, in this chapter, it was analysed and decided which indicators and categories of the SBTool^{PT} STP for Office Buildings methodology should remain in the methodology elaborated in this work, as well as which indicators should not be used. The new indicators (Sustainability awareness and Ergonomic Comfort) and categories, and the adaptations of some indicators (Renewable Energy, Reuse and Recycle of materials, Environment Comfort, Occupants security) specifically for high school buildings, were also presented.

After the decision making and subsequent explanations regarding all indicators that are part of this new methodology, the concepts, the historical context, the characteristics and the studies of these indicators and categories were described.

Chapter 5 presents the methods by which the weights of the SAHSB^{PT} methodology were determined, together with their definition. Accordingly, in this chapter are discussed the process and the results regarding the indicators of environmental comfort and of sustainability awareness, as regards the high schools in Portugal, and the result aimed to define the weights of the indicators and categories.

Chapters 2, 3, 4 and 5 provided the necessary bases for the elaboration of the Evaluation Guide to the SAHSB^{PT} methodology.

Chapter 6 provides the basis for the preparation of the Evaluation Guide – Sustainability Assessment of High School Buildings, SAHSB^{PT}. The main purpose of this guide is to reduce errors in the evaluation process, allowing the evaluator to quantify the performance of the building at the level of each indicator, category or dimension, which will result in the overall performance of the building (Sustainability Level – NS). As a result, with this guide, it becomes possible to evaluate the level of sustainability in school buildings.

In chapter 7, the methodology developed was applied to a case study, the Francisco de Holanda high school, Guimarães, to verify the adequacy of the benchmarks and their practical applicability to the context of the school buildings in Portugal.

Parque Escolar has recently renovated the high school building studied in this thesis, specifically from 2011 to 2013. The Portuguese government intends to reform most of the Portuguese schools with the support of *Parque Escolar*, with a single standard. The EPE intervened in 477 of the 616 existing Portuguese high schools, representing 77.5% of the Portuguese high schools. Considering that the Francisco de Holanda High School has the standards determined by the *Parque Escolar*, it is possible to say that it represents the standard Portuguese school.

The results of the methodology applied in this school are good in most of the indicators and categories, being that the results of the indicators have demonstrated that more than 74% fall into levels A+, A or B. Since the school evaluated represents the standard Portuguese high schools, this represents a good result, demonstrating how they are improving in terms of sustainability.

These results also made it possible to learn that more than 82% of the categories reached a level of at least category "B", indicating that the *Parque Escolar* is achieving its objectives related to the conditions of habitability, environmental comfort (air and thermal quality) and accessibility, equipment modernization and safety, besides guaranteeing the energy efficiency, the flexibility and the adaptability of the school buildings. The results for the Social (0.80 – Best Practice) and Economic (1 – Best Practice) dimensions were "A", whereas for the Environmental Dimension (0.65) the grade was "B".

The grades "E" are attributed to the indicators in category 4 (Reuse and recycle of materials – I8), while the grades "C" are attributed to the indicators Life cycle environmental impacts (I1), Flexibility and adaptability (I10) and Mobility plan (I19). These were related to the design and execution phases of the work, so it is very difficult to be modified. The grades "E" have also been attributed to all indicators in the category Water (C5), so it would be advisable to make certain modifications for the installation of systems that assist in the reuse and reduction of water consumption.

In chapter 8 were represented the starting point of the adaptation of this methodology in the city of Juiz de Fora, thus initiating a study of a methodology adapted to Brazil. It presented studies related to the results of the questionnaires about the indicators of ergonomic, thermal, visual, acoustic and air quality comfort and the indicators of sustainability awareness in Juiz de Fora, Brazil.

In chapter 9 was demonstrated the differences between the characteristics of the various Brazilian regions, being therefore necessary to elaborate specific criteria for the sustainability assessment methodologies for schools in each region. It shows the comparison between the indicators of environmental comfort for the cities of Juiz de Fora, in the southeast region of Brazil, and Macapá, in the Amazon region.

As a result of the study of other methodologies for the evaluation of sustainability of school buildings, it was noticed that there are still large differences related to the diversity of indicators and categories, and their weights. This happens because these methodologies are created in different countries, and also because of the subjective characteristics of each indicator. For this reason, this methodology was developed for Portugal based on another Portuguese methodology, SBTool^{PT}-STP for Office Buildings, to attend Portuguese high schools, according to the reality of the country.

This study made clear the importance of maintaining comfort indicators within a sustainable range, specifically regarding school environments, since, on the one hand, students stay for long periods inside the school and, on the other hand, comfort interferes with the students' health, concentration and learning.

A good sustainability assessment tool, in addition to the environmental and economic concerns, positively interferes with the well-being of the building users, reducing impacts on their health and improving their quality of life. Moreover, there is a great tendency for local legislation to follow the requirements of the methodology applied to assess sustainability in school buildings, especially when it is widely used by the population, therefore bringing great benefits.

Future perspectives

The development of a methodology for school buildings specific to each country or region is necessary since the environments of high schools are very unique. In addition, sustainability in a school building improves the performance, safety and health of teachers, students and staff. Finally, increased attention to the construction, design and operational practices of schools contributes to the achievement of the national sustainability goals for the environment (Healthy Schools, 2013).

The study conducted in Juiz de Fora and in Macapá serves to set precedents for new research in Brazil related to sustainability assessment methodologies specific for schools that may be adapted to different Brazilian regions. This type of research is unprecedented and necessary, since sustainability has had a growing demand around the world, so there is also a great demand for this subject in Brazil.

This work assists in the implementation of sustainability in the area of construction, specifically in school buildings. Investigations under the SBTool methodology for schools in the city of Juiz de Fora have already started. Some proposals for future work can be as follows:

- The application of this methodology in other schools in Portugal;

- The preparation of evaluation guides for the 26 Brazilian states, respecting the regional characteristics of each locality;
- An investigation into the ergonomic comfort indicator related to the design of school desks, reducing the discomfort of students;
- Further studies on education and awareness of students about sustainability in the school environment.

Therefore, it is intended that the SAHSB^{PT} evaluation methodology elaborated/adapted in this work and its results help in the decision of the designers to create high school buildings that may offer comfort to the user, with low environmental impacts and with moderate costs.

References

References

Addis, A. 2010. *Reuso de materiais e elementos de construção;* translator Christina del Posso, São Paulo. Editora: Oficina de textos.

ADENE, Perguntas & Respostas –Versão 1.0 de 21/06/2007 *Regulamento dos Sistemas Energéticos de Climatização em Edifícios – Qualidade do Ar Interior/*

Agdas, D., Srinivasan, R.S., Forrest, K, F., Masters, J. 2015. Energy use assessment of educational buildings: Toward a campus-wide sustainable energy policy. Sustainable Cities and Society 17 (2015) 15-21

Ahmed, W., Brandes, H., Gyawali, P., Sidhu, J.P.S., Toze, S. 2014. Opportunistic pathogens in roof-captured rainwater samples, determined using quantitative PCR. *Water Res*. 53, 361e369.

Alegre, A. 2009. *The standardized study of Lyceums type. Modernization program of the Parque Escolar*. Lisbon: Universidade Tecnica de Lisboa, Instituto Superior Técnico. Doctoral Thesis.

Al-Jayyousi, O. Greywater reuse: Towards sustainable water management, August 2003. Desalination 156(1-3):181-192. http://doi.10.1016/S0011-9164(03)00340-0

Almeida, C.M.V.B., Bonilla, S.H., Giannetti, B.F., Huisingh, D. 2013. Cleaner production initiatives and challenges for a sustainable world: an introduction to this special volume. *Journal of Cleaner Production* 47, 1 e10.

Alnaser, N.W., Flanagan, R., Alnaser, W.E. 2008. Model for calculating the sustainable building index (SBI) in the kingdom of Bahrain, *Journal of Energy and Buildings* 40, 2037–2043.

Analytics Vidhya. 2018. *A Simple Introduction to ANOVA* (with applications in Excel. Available at https://www.analyticsvidhya.com/blog/2018/01/anova-analysis-of-variance/ [Accessed 9 July 2019]

Anderson, J. The environmental benefits of water recycling and reuse August 2003. *Water Science & Technology Water Supply* 3(4) http://doi.10.2166/ws.2003.0041

Andrade, J.B. 2009. Avaliação da sustentabilidade do edifício solar XXI=21 utilizando a metodologia SBTool – PT. *Sustainability assessment of solar building XXI = 21 using the SBTool - PT methodology.* Integrated Master Thesis. Environmental engineering. Engineering College. University of Porto, Department of Civil Engineering. Minho's university. 2009

Angelis-Dimakis, A., Arampatzis, G., Assimacopoulos D. 2016. Systemic eco-efficiency assessment of meso-level water use systems, *Journal of Cleaner Production,* 1 and 13.

ANNEX 40, 2004. IEA, International Energy Agency, ECBCS, *Commissioning tools for improved energy performance.* Avaliable at http://www.ecbcs.org/annexes/annex40.htm [accessed 13 june 2017]

Arribas-Bel, D., Nijkamp, P., Scholten, H. 2010. Multidimensional urban sprawl in Europe: A self-organizing map approach. *Computers, Environment and Urban Systems.* 35, 263-275.

ASSOHQE. HQE mode d'emploi. 2006. Avaliable at http://www.assohqe.org/docs/hqe_mode_d'emploi.doc [accessed 9 may 2014]

ASHRAE 55. 2004. American Society of Heating Refrigerating and Air Conditioning Engineers. *Thermal Environmental Conditions for Human Occupancy*. Atlanta.

Bako-Biro, Z., Clements-Croome, D., Kochhar, N, Awbi, H., Williams, M. Ventilation rates in schools and pupils'performance, *Building and Environment*. 48 (February) (2012) 215–223. 6

Barbosa, J.; Mateus, R.; Bragança, L. Development of a sustainability assessment tool for office buildings. In Sustainability of Constructions: Towards a Better Built Environment, *Proceedings of the Final Conference of the COST Action C25*; Department of Civil & Structural Engineering, Faculty for the Built Environment, University of Malta: Malta. 2011; pp. 205–214, ISBN 978-99957-816-0-6.

Barbosa, J.A., Mateus, R., Bragança, L. 2013. Adaptation of SBTool^{PT} for Office Buildings. International *Journal of Sustainable Building Technology and Urban Development,* 4, 89-97.

Barbosa, J.A., Mateus, R. Bragança, L. 2014. The assessment of land use efficiency in BSA Tools. Development of a new index. *Journal of Urban Planning and Development.* 12/2014; 5(4):1-9

Barbosa, M.T.G. & Almeida, M. Developing the methodology for determining the relative weight of dimensions employed in sustainable building assessment tools for Brazil. *Ecological Indicators* 73 (2017) 46–51.

Barrett, P., Davies, F., Zhang, Y., Barrett, L.2015. The impact of classroom design on pupils' learning: Final results of a holistic, multi-level analysis. *Building and Environment.* 89 (2015) 118 e133.

Beadle, K., Gibb, A., Austin, S., Fuster, A., and Madden, P. 2008. Adaptable futures: Setting the agenda. Proceedings of the *1st I3CON International Conference,* Loughborough University, Loughborough, UK, 14-16 Ma

Beal, C.D., Stewart, R.A., 2014. Identifying residential water end-uses underpinning peak day and peak hour demand. *Journal of Water Resources Planning and Management.* (ASCE)WR.1943-5452.0000357.

Bernardi, E.; Carlucci, S.; Cornaro, C.; Bohne, R.A. An Analysis of the Most Adopted Rating Systems for Assessing the Environmental Impact of Buildings. *Sustainability.* 2017, 9, 1226.

Bianchini F. 2012. How green are the green roofs? life cycle analysis of green roof materials *Building Environment*; 48:57–65.

Bragança, L. and Mateus, R. 2012. *Life-cycle amalysis of buildings, environmental impact of building elements.* September, 2012. Printed in Portugal by iiSBE Portugal, 1° Edition. ISBN: 978-989-96543-3-4.

Braganca, L., Vieira, S.M., and Andrade.B.J. 2014. Early Stage Design Decisions: The Way to Achieve Sustainable Buildings at Lower Costs. *The Scientific World Journal* 8.

BREEAM Education. 2008. Scheme Document. SD 5051. [internet] available at: http://ecoconsulting.net/www/breeamschools.pdf [accessed 8 january 2014].

BREEAM. 2012. New construction technical manual 2011, *BRE Global 2012* [internet] avaliable in: http://www.breeam.org [accessed 13 may 2014].

Building and Construction Authority. 2005. Green mark for buildings available at: http:// www.bca.gov.sg/greenmark/green_mark_buildings.html [accessed 12 july 2014].

Bulbul, T.T.M. and Akin, O.2006. Computational support for building evaluation: Embedded Commissioning Mode. *Automation in Construction.* 15 (2006) 438 – 44.

Cartieaux, E., Rzepka, M.A., Cuny, D. 2011. Qualite de l' air a l' interieur des ecoles, *Indoor Air* 18 (2011) 789–796.

CASBEE *for new construction, comprehensive assessment system for building environmental efficiency, technical manual* (2010 edition), Japan sustainable building consortium, Japan. [internet] avaliable in: http://www.ibec.or.jp/casbee/ english/index.htm [accessed 23 april 2014].

Castanheira, G.S. 2013. *Estratégias de intervenção para a regeneração urbana sustentável*. Dissertation of Master. University of Minho, Guimarães.

Castro, M.F. 2017. *Sustentabilidade no Edificado - método de apoio ao projeto de edifícios hospitalares.* Thesis of PHD. University of Minho. Guimaraes.

Cavaliéri, A.M.V. & Coelho, l.M. 2003. Para onde caminham os CIEPs? Uma análise após 15 anos. *Cadernos de Pesquisa,* n. 119, p. 147-174, julho/ 2003- UFRJ.

CEN. 2012. Sustainability of Construction Works e Environmental Product Declarations e Core Rules for the Product Category of Construction Products. EN 15804. *Comité Européen de Normalization*. Brussels, Belgium.

Chen, Z., Ngo, H.H., Guo W., Limb, R., Wang, X.C., O'Halloran, K., Listowski, A., Corby, N., Miechel, C.A. 2014. Comprehensive framework for the assessment of new end uses in recycled water schemes. *Science of the Total Environment*. 470–471, 44–52.

Coelho A., Debrito J., 2012. Influence of construction and demolition waste management on the environmental impact of buildings. *Wastemanage*. 32(3): 532–41.

Commission of the European Communities, 1994 COM (94) 533 Final, Brussels, 25.11.199 4. *Report to the European council on the application of the subsidiarity principle*, 1994.

Cook, S., Sharma, A., Chong, M., 2013. Performance analysis of a communal residential rainwater system for potable supply: a case study in Brisbane, Australia. *Water Resources. Manager*. 27 (14), 4865e4876.

Cook, S., Sharma, A.K., Gurung, T.R., 2014. Evaluation of alternative water sources for commercial buildings: a case study in Brisbane, Australia. *Resources, Conservation and. Recycling*. 89, 86e93.

Correa, S.F., Osorio, M.J.D.Y., Patiño, V.B. (2011), Valoración económica del ruido: una revisión analítica de estudios, en *Semestre Económico*, 4 (29), pp. 53-76.

Couto, H.A. 1995. *Ergonomia Aplicada ao Trabalho: Manual Técnico da Máquina Humana*. 1. Ed. Belo Horizonte: Ergo Editora.

Currie, G. 2010. Quantifying spatial gaps in public transport supply based on social needs. *Journal of Transport Geography*, 18, 31–41.

Davis III, J.A. & Nutter, D.W. (2010). Occupancy diversity factors for common university building types. *Energy and Buildings*. Volume 42 (2010), PP 1543–1551. Available: http://www.elsevier.com/locate/enbuild.

Decreto Lei N° 41/2007 *Resolution of the Council of Ministers number 41/2007 approved the Program of Modernization*, Decree-Law no. 41/2007.

Decreto-Lei n° 79/2006 de 4 Abril. Regulamento dos Sistemas Energéticos e de Climatização dos Edifícios (RSECE). Decree-law n° 79/2006. *Regulation of Energy Systems and Air Conditioning of Buildings.* 2006; pp. 2416–2468.

Decreto-Lei n°.80/2006 de 4 April. Regulamento das Características de Comportamento Térmico dos Edifícios (RCCTE). Decree-law n°.80/2006. *Regulation of the Characteristics of Thermal Behavior of the Buildings*. 2006, pp. 2468–2513.

Decreto Lei n° 118/2013. Regulamento do Desempenho Energético dos Edifícios de Comércio e Serviços, REH. Decree-law 118/2013. *Regulation of the Energy Performance of Residential Buildings and the Energy*. 2013, pp. 4988–5005.

Decreto Lei n° 118/2013. Regulamento do Desempenho Energético dos Edifícios de Comércio e Serviços, RECS, Decree-law n° 118/2013. *Regulation of the Energy Performance of Trade and Service Buildings*. 2013, pp. 4988–5005.

Departamento de Avaliação Prospectiva e Planeamento. 2000. *Critérios de Reordenamento da Rede Educativa.* Ministério da Educação, Lisboa.

Dessing, D., de Vries, S.I., Graham, J.M., Pierik, F.H. 2014. Active transport between home and school assessed with GPS: a cross-sectional study among Dutch elementar school children. *BMC Public Health*. 14, 227.

DGNB *Certification System* Barcelona October 10, 2011 [internet] avaliable at: http://www.eic.cat [access 29 april 2014].

Díaz-Balteiro, L, and Romero, C. 2004. In search of a natural systems sustainability index. *Ecological Economics*. 49(3), 401-405.

Ding, G. K. 2008. Sustainable construction—the role of environmental assessment tools. *Journal of Environmental Management*. 86(3): 451-464.

Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. *Official Journal.* L 001, 04/01/2003 P. 0065 - 0071.

Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. *Official Journal*. L 153, 18.6.2010, p. 13–35.

Djuric N, Frydenlund F, Novakovic V, Holst J. 2007. Preliminary step in collecting data for commissioning of existing buildings (characterization of buildings, systems and problems). In: *Proceedings of the Clima 200*, WellBeing Indoors, Helsinki, REHVA, 2007.

Domènech, L.; Saurí, D. A. Comparative Appraisal of the Use of Rainwater Harvesting in Single and Multifamily Buildings of the Metropolitan Area of Barcelona (Spain): social experience, drinking water savings and economic costs. *Journal of Cleaner Production*. v. 19, n. 6-7, p. 598-608, apr. /may 2011.

Douglas, J. 2006. *Building adaptation.* 2nd Ed., Publisher: Butterworth-Heinemann. ISBN-10: 0750666676, ISBN-13: 978-0750666671

EC (European Commission) [internet] White paper. 2011. Roadmap to a single European transport area towards a competitive and resource efficient transport system. Available at: http://ec.europa.eu/transport/themes/strategies/2011_white_paper_en.htm. [accessed 06 may 2016.

Ecosave (2011) [internet] avaliable http://www.ecosave.org.pt/ [accessed 28 April 2016].

Eco Desenvolvimento, 2018 Available at: http://www.ecodesenvolvimento.org/posts/2012 [accessed 18 June 2014].

Edge Buildings, 2017. Available at: https://www.edgebuildings.com/wp-content/uploads/2017/10/171003-Ch8-Approval-Protocol-EDGE-X-3.0-all-new-1.pdf [internet] [accessed 18 may 2018].

Elgie, R.; Sapien. R. E.; Fullerton-Gleason, L. 2005. The New Mexico School Nurse and Emergency Medical Services Emergency Preparedness Course: Program Description and Evaluation. *Journal of School Nursing. v. 21, n. 4, p. 218-223, 2005.*

*Eletrobrás. Siste*ma Eletrobrás. [internet] avaliable at: <http://www.eletrobras.com/elb/data/pages/lumis293e16c4ptbrie.htm> [accessed 6 april 2014.

Elliott, C., 2000. *Forest Certification: A Policy Perspective.* Publisher: Center for International Forestry Research (CIFOR). DOI: 10.17528/cifor/000825

Fares, F., Montenegro, B., Prates, A. 2010. Comissionamento de Projetos de Petróleo e Gás - Situação Atual, Evolução e Tendências. in: Rio Oil & Gas Rio de Janeiro, Brasil, set 2010.

Fernandes, J.T. 2009. *Código de obras e edifícios do DF: inserção de conceitos bioclimáticos, conforto térmico e eficiência energética.* Dissertação de mestrado. Departamento de Arquitetura e Urbanismo Universidade Federal de Brasília, Brasil.

Fernández, F.J., Alvarez-L.J.V., García, C.N., Martínez, A., Vázquez, M.E. 2015. Optimal location of green zones in metropolitan areas to control the urban heat island, *Journal of Computational and Applied Mathematics.*

Feng, L., and Li, H. 2012. Spatial Pattern Analysis of Urban Sprawl: Case Study of Jiangning, Nanjing, China. *Journal of Urban Planning and Development*. 138(3), 263-269.

Freericks, R. 2010. Freizeitwissenschaft. Handbuch für pädagogik, management und nachhaltige entwicklung. München: *Oldenbourg Wissenschaftsverlag*.

Fidar. A.M., Memon F.A., Butler, D. 2016. Performance evaluation of conventional and water saving taps. *Science of the Total Environment*. 541 (2016) 815 –824.

Foley, J.A. 2005. Global Consequences of Land Use. *Science*. 309, 570-574. DOI: 10.1126/science.1111772

Freire, M. R. *Iluminação Natural em Salas de Aula: o Caso das Escolas FAEC em Salvador.* 1996. Porto Alegre. Dissertação de Mestrado – PROPAR – UFRGS.

Frontczak, M. and Wargocki, P. 2011. Literature Survey on How Different Factors Influence Human Comfort in Indoor Environments. *Building and Environment*. 46, 922-937.

Fundação Vanzolini. 2007. *Referencial técnico de certificação "edifícios do setor de serviços - processo aqua: escritórios e edifícios escolares*. Versão 2007. São Paulo: Fundação Vanzolini. [internet] avaliable at <http://vanzolini.org.br/download [accessed 24 april 2014].

Furness, Z. 2007. Critical mass, urban space and velomobility. *Mobilities 2* (2), 301– 319. https://doi.org/10.1080/17450100701381607

GBC, *Green Building Council Brasil*. 2014. [internet] Available at http://www.gbcbrasil.org.br/ [accessed 18 may 2015].

Genet, J., Schubert, C. 2011. Designing a metering system for small and medium-sized buildings, *Technical Report*. SEMED310007EN, SE.

Gervásio, H. 2010. *Sustainable Design and Integral Life-Cycle Analysis of Bridges*. Philosophiæ Doctor in Civil Engineering, Departamento de Engenharia Civil Faculdade de Ciências e Tecnologia da Universidade de Coimbra.

Ghita, S.A. and Catalina, T. 2015. Energy efficiency versus indoor environmental quality in diferente Romanian countryside schools. *Energy and Buildings*. 92 (2015) 140-154.

Gilbert, R. and Perl, A. 2008 Transport Revolutions: Moving People and Freight Without Oil, *Canadian Journal of Urban Research*. Vol. 17, No. 2, pp. 144-146.

Giridharan R., Ganesan, S., Lau S.S.Y. 2004. Daytime urban heat island and effect in high- rise and high-density residential developments in Hong Kong. *Energy and Building*. 36:525–34.

Givoni, B. 1992. Comfort Climate Analysis and Building Design Guidelines. *Energy and Buildings*. v. 18, n. 1, p. 11-23, 1992.

Gois, E.H.B., Rios, C.A.S., Costanzi R.N. 2015. Evaluation of water conservation and reuse: a case study of a shopping mall in souther n Brazil. *Journal of Cleaner Production*. 96, 263e271

Gold, A.; Goo, R.; Hair L.; Arazan, N. Rainwater Harvesting: Policies, Programs, and Practices for Water Supply Sustainability April 2010 *Conference: Low Impact Development International Conference* (LID).

Gomes, I.B., Farias, G.M., Mineiro, F.H.G.R.; Barros, W.C.T.S; Ramos, C.S. 2010. *Acidentes em crianças no ambiente escolar: Estudo bibliográfico*. FIEP Bulletin - Volume 80 - Special Edition.

Grandjean, E. 1998. *Manual de ergonomia: adaptando o trabalho ao homem*.Trad. João Pedro Stein. Porto Alegre. Editora Bookman, 338 p. ISBN 8573073535, 9788573073539.

Groak, S. 1992. *The idea of building: thought and action in the design and production of buildings*. London: E&FN Spon ISBN 0-203-13378-1.

Grözinger, J., Boermans, T., John, A., Wehringer, F. Seehusen, J. 2014. Overview of Member States information on NZEBs: Background paper – final report. *ECOFYS GmbH*. Cologne, Germany.

Gu, Z., Wennersten, R. and Getachew A. G. 2006. Analysis of the most widely used building environmental assessment methods. *Environmental Sciences*. 3:3,175-19.

Gurung, T.R., Stewart, R.A., Beal, C.D, Ashok K. Sharma, A.K. 2015. Smart meter enabled water end-use demand data: platform for the enhanced infrastructure planning of contemporary urban water supply network. *Journal of Cleaner Production*. 87 (2015) 642-654.

Hall, M. 2013. Review of Rainwater Tank Cost Effectiveness in South East Queensland. *Urban Water Research Security Alliance,* Brisbane, QLD. Technical Report No. 105.

Hens l., Nath B. 2003. *The Johannesburg Conference*. Environment, development and sustainability, 5(numers 1-2), 7-39.

Healthy Schools. 2013: *Environmental Factors, Children's Health and Performance, and Sustainable Building Practies*. [internet] Available at http://epa.gov/ncer/rfa/2013/2013_star_healthy_schools.html [accessed 23 august 2014].

Heravi, G. and Qaemi, M. 2014. Energy performance of buildings: The evaluation of design and construction measures concerning building energy efficiency in Iran. *Energy and Buildings.* 75 (2014) 456–464. 457.

Hilgenberg, F.B., 2010. *Sistemas de certificação ambiental para edifícios. Estudo de caso: AQUA 2010.* Dissertação de Mestrado. Universidade Federal do Paraná, Brasil.

Ho, Y.F., Changa, C.C., Weia, C.C., Hsiao-Lin Wang, H.L. 2014. Multi-objective programming model for energy conservation and renewable energy structure of a low carbon campus. *Energy and Buildings.* 80 (2014) 461–468.

Hutton, B., 2013. *Planning Sustainable Transport.* Routledge, London. eBook ISBN 9780203436066.

IBGE. 2015. *Instituto Brasileiro de Geografia e Estatística*, Evolução da divisão territorial do Brasil 1872-2010. Source: [internet] available at: https://ww2.ibge.gov.br/home/geociencias/geografia/default_evolucao.shtm [accessed 02 July 2019].

IBGE, 2018. Instituto Brasileiro de Geografia e Estatística. Projeção da população do Brasil e das Unidades da Federação. Source: [internet] available at: https://www.ibge.gov.br/apps/populacao/projecao/ [accessed 10 July 2019].

IEA. 2013. CO2 Emissions from Fuel Combustion Highlights, Paris, France, *International Energy Agency*.

IIDA, I. 1990. Ergonomia Projeto e Produção. São Paulo: Edgard Blucher.

IiSBE. 2012. An overview of the GBC method and SBTool. *International initiative for sustainable built environment*. [internet] available at: http://www.iisbe.org/down/gbc 2005 [accessed 18 march 2014].

Imteaz, M.A., Rahman, A., Ahsan, A. 2012. Reliability analysis of rainwater tanks: a comparison between South-East and Central Melbourne. *Resources, Conservation and Recycling*. 66, 1e7.

IPCC. 2014a. Summary for policymakers. In: *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jacob, J.V. 2016. A review of stairway falls and stair negotiation: Lessons learned and future needs to reduce injury. *Gait & Posture* 49, 159–167.

Jeong, B.Y., Park, K.S. 1990. Sex differences in anthropometry for school furniture design. *Ergonomics.* 33 (12), 1511e1521.

JFminas. Source: [internet] available at: http: http://www.jfminas.com.br/portal/historia/colegios [accessed 10 June 2017].

Josse, J.M. 2009. School injury among Ottawa - area children: a population - based study. *Journal of School Health*, v. 79, n. 2, p.45-50, 2009.

Kamaruzzaman, S., N., Lou, E., C., W., Zainon, N., Zaid, N., S., M., Wong, P., F. 2016. Environmental assessment schemes for non-domestic building refurbishment in the Malaysian context, *Ecological Indicators* (2016) 69 548–558.

Kamel, M.H., Abdulmajeed, A.A., Ismail Sel, S. 2013 Risk factors of falls among elderly living in urban Suez–Egypt, *Pan African Medical Journal.* 14 (2013) 26.

Katafygiotou, M.C., Serghides, D.K. 2014. Analysis of structural elements and energy consumption of school building stock in Cyprus: Energy simulations and upgrade scenarios of a typical school. *Energy and Buildings*. 72 (2014) 8–16.

Kats, G., Perlman, J., Jamadagni, S. 2005. National review of green schools: costs, benefits, and implications for Massachusetts. U.S.A.: a capital e report. *A report for the Massachusetts Technology Collaborative.* [internet] from http://www.usgbc.org [accessed 15 December 2018].

Katz, D. 2015. Water use and economic growth: reconsidering the environmental Kuznets curve relationship. *Journal of Cleaner Production*. 88, 205-213.

Kern, A.P., Antoniolli, C.B., Wander, P.R., Mancio, M., Gonzaalez,M.A.S. 2016. Cost of water energy after LEED in Brasil Energy and water consumption during the post - occupancy phase and the users' perception of a commercial building certified by Leadership in Energy and Environmental Design (LEED) *Journal of Cleaner Production* 133 (2016) 826-834.

Kibert, C.J. 1994. Establishing principles and model for sustainable construction. *Proceedings of the first international conference of CIB TG 16*; Tampa, EUA.

Kibert, C.J., 2005. Sustainable construction: Green building design and delivery. *John Wiley & sons*, New York, EUA.

Kim, A.A., Sadatsafavi, H., Medal, L., & Ostergren, M.J. 2018. Impact of communication sources for achieving campus sustainability. *Resources, Conservation and Recycling*, 139, 366–376.

Klæboe, R., Kolbenstvedt, M., Clench-Aas, J., Bartonova, A. 2000. Oslo traffic study–part 1: An integrated approach to assess the combined effects of noise and air pollution on annoyance. *Atmospheric Environment.* 34 (27), 4727 –4736.

Klinker, C.D., Schipperijn, J., Christian, H., Kerr, J., Ersboll, A.K., Troelsen, J. 2014. Using accelerometers and global positioning system devices to assess gender and age differences in children's school, transport, leisure and home based physical activity. *International Journal of Behavioral Nutrition and Physica*. Act. 11, 8.

KTI. 2013. Property Information Ltd, Operational Cost Benchmarking.

Kroemer, K.H.E.; Grandjean, E. Fitting the Task to the Human: A Textbook of Occupational *Ergonomics*. 5th ed.; Taylor & Francis: London, UK, 1997; ISBN 0 7484 0665 4.

Lamberts, R. 2010. *Casa eficiente: Bioclimatologia e desempenho térmico*. v. 1. Florianópolis: UFSC/LabEEE. 2010.

Larsson, N. 2012. *SBTool 12 Generic: Sustainable Building Tool*. <http://www.iisbe.org/system/files/SBT12_Generic_DEV_3_Dsn_31Oct12.zip>.

Larsson, N., iiSBE and Macias, M. 2012. Assessment schemes. *Energy and Buildings*. 62, 403–413, Spain.

Lee, K.K. 2011. Active design guidelines: Promoting physical activity and health in design. NYC Panel, *Fit Nation Conference*. Washington DC, USA. February, 2011.

LEED *v4 for Building Design and Construction. 2013.* U.S. Green Building Council [internet] avaliable at: http://www.usgbc.org [accessed 19 may 2014].

Lee, W.l. 2013. A comprehensive review of metrics of building environmental overview of the sbtool assessment framework. *Energy and Buildings.* 62, 403 413.

LEnSE. 2008. *Methodology Development towards a Label for Environmental, Social and Economic Buildings.*

LiderA. 2005. Sistema de avaliação de \sustentabilidade. [internet] avaliable in http://www . Lidera.info [accessed: 22 may 2014].

Lin, T., Xia, J., Robinson, T.P., Goulias, K.G., Church, R.L., Olaru, D., Tapin, J., Han, R. 2014. Spatial analysis of access to and accessibility surrounding train stations: a case study of accessibility for the elderly in Perth, Western Australia. *Journal of Transport Geography.* 39, 111 –120.

Lubans, D.R., Boreham, C. a, Kelly, P., Foster, C.E. 2011. The relationship between active travel to school and health-related fitness in children and adolescents: a systematic review. *International Journal of Behavioral Nutrition and Physical*. Act. 8, 5.

Manual de prevenção de acidentes e primeiros socorros nas escolas. 2007. *Secretaria da Saúde. Coordenação de Desenvolvimento de Programas e Políticas de Saúde*. CODEPPS. São Paulo: SMS, 2007.

Manual of Forest Manager System. 2015. *Associação de Produtores Florestais de Coruche, Portugal.*

Marmot, A. 2006. Promoting Space Efficiency in Building Design. *Space Management Group, 107.*

Marques, F.M.A, 2007. *Importância dos materiais de construção para a sustentabilidade ambiental do edifício.* These (master in architecture) PROARQ/FAU/UFRJ.

Martek, I., Hosseini, M.R., Shrestha, A.; Zavadskas, E.K.; Seaton, S. 2018. The Sustainability Narrative in Contemporary Architecture: Falling Short of Building a Sustainable Future. *Sustainability.* 2018, 10, 981.

Mateus, R., Bragança, L. 2006. *Tecnologias construtivas para a sustentabilidade da construção.* Edições Ecopy, Porto, Portugal.

Mateus, R. 2010. *Avaliação da sustentabilidade da construção - Propostas para o desenvolvimento de edifícios sustentáveis*. Phd, University of Minho, Guimarães.

Mateus, R., Bragança, L. 2011. Sustainability assessment and rating of buildings: developing the methodology SBTool^{PT}-H. *Building and Environment.* 46, 1962-1971.

Matos, B.F. Barbosa, M.T., Almeida, M., Condorelli, C., Furtado, J., Braga, L. 2016. *Sustainable building: Assessment toolin Brazil. SBE16 Brazil & Portugal*. Sustainable Urban Communities towards a Nearly Zero Impact Built Environment. ISBN: 978-85-92631-00-0.

Miana, A.C. 2010. *Adensamento e forma urbana: inserção de parâmetros ambientais no processo de projeto.* Doutorado em Arquitetura e Urbanismo, tecnologia da arquitetura, Faculdade de Arquitetura e Urbanismo da Universidade de São Paulo, São Paulo, Brasil.

Mokdad, M., Al-Ansari, M. 2009. Anthropometrics for the design of Bahraini school furniture. International Journal of Industrial. September 2009. E*rgonomics*. 39 (5), 728 e735.

Monteoliva, J.M., Villalba, A, Pattini, C. 2015. Correlated color temperature of daylight: Dynamic analysis in sunlit indoors. *Informes de la Construction.* 2015, 67, e123,doi:10.3989/ic.14.146.

Murakami S., Iwamura, K., Sato M., ikaga t, endo J., 2002. Comprehensive assessment system for building Environmental efficiency (CASBEE), 2002. In: *Proceedings of the fifth international conference on Eco balance*, 6 – 7 November.

Muscio, A. 2018. The Solar Reflectance Index as a Tool to Forecast the Heat Released to the Urban Environment: Potentiality and Assessment Issues. *Climate Published*. 15 February 2018.

Myhrvold, A.N., Olsen, E. and Lauridsen, O. 1996. Indoor environment in schools - pupils health and performance in regard to CO_2 concentrations. Proceedings of *Indoor Air 96: The 7th International Conference on Indoor Air Quality and Climate*, Nagoya, Japan, July, 1996, Vol. 4. 369–374.

NABER. 2005. National Australian built environment rating system. [internet] available at: http://www.deh.gov.au/industry/construction/nabers [accessed 12 february 2014].

National Academy of Sciences & the Royal Society. 2014. Climate Change Evidence and Causes. Washington, DC: The National Academies Press. https://doi.org/10.17226/18730.

NBR 14037: 2011 Fixed: 2014 Norma Brasileira (Brasilian Law) *Guidelines for building use, operation and maintenance manual preparation*- Requirements for content preparation and presentation. [internet] available at: https://www.abntcatalogo.com.br/norma.aspx?ID=87859 [accessed 23 may 2016].

Neothemi, A. 2009. School Building. [internet] Available at http://neothemi.up.pt/temas/edif4.htm [accessed 29 June 2018].

Nordby, A. S., Berge, B., Hestnes, A. G. 2008. *Salvageability of building materials*. Department of Architectural Design, History and Technology, Norwegian University of SP. Anais.CD-*Science and Technology* (NTNU), Trondheim, Norway.

NP EN ISO 14001. 2004. *Environmental management systems-Requirements with guidance for use.* [internet] Available at. *https://www.iso.org/obp/ui/#iso:std:iso:14001:ed-2:v1:en* [accessed 20 may 2014].

NRC (National Research Council). 2012. *Water reuse: potential for expanding the nation's water supply through reuse of municipal wastewater*. Washington, DC: The National Academies Press.

Ntona, E., Arabatzis, G. and Kyriakopoulos, G. 2015. Energy saving: Views and attitudes of students in secondary education. *Renewable and Sustainable Energy Reviews* 46 (2015) 1–15. Available online: http://dx.doi.org/10.1016/j.rser.2015.02.033 (accessed November 12, 2018).

Nunes, F.P. 1985. Special education teacher's perception of the educational desk: A survey report. *International Journal of Instructional Media*. 12, 231-246

OECD Publishing. 2003. *Environmentally Sustainable Buildings* - Challenges and policies, Paris, France, OECD.

Ohmatsu, S., Nakano, H., Tominaga, T., Terakawa, Y., Murata, T., & Morioka, S. 2014. Activation of the serotonergic system by pedaling exercise changes anterior cingulate cortex activity and improves negative emotion. *Behavioural Brain Research*, 270, 112 – 117.

Okeil A. 2010. A holistic to energy efficient building forms. *Energy and Buildings*; 42:1437–44.

OPEN HOUSE. 2011. Open House Assessment Guideline, version 1.0.

O Povo de Guimaraes. 1985. News Paper *O Povo de Guimaraes,* 15 of dezember, 1985.

Oron, G., Adel, M., Agmon, V., Friedler, E., Halperin, R., Leshem, E., Weinberg, D. 2014. Greywater use in Israel and worldwide: Standards and prospects. *Water Research,* 58, 92 - 101

Papadopoulos, A., Avgelis, A. 2003. Indoor environmental quality in naturally ventilated office buildings and its impact on their energy performance, *International Journal of Ventilation* 2 (3) (2003) 203–212.

Pettersen T.D. 2000. *Ecoprofile for commercial buildings: simplistic environmental assessment method.* Reference document: Oslo. Norges bygg for sknings institutt, økoprofil and grip senter

Pinto, A.C. 1997. *Estaleiros e o Ambiente Internal Report*. Dissertação de Mestrado em Engenharia Municipal, Universidade do Minho, Portugal.

Pizarro, A.I.N. 2014. *Active living and built environment: Active transport to school in Portuguese adolescents*. Master in Porto University, Portugal.

Poon, C.S. 2007. Reducing construction waste. *Waste Management* 27, 1715–1716.

Pope III, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D. 2002. *Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA* 287 (9), 1132 –1141.

Pordata. 2018. [internet] Available at https://www.pordata.pt/[accessed 10 january 2019].

Portal da construção sustentável. 2018. *Domus Natura – Sistema de Certificação Ambiental* [internet] Portugal. Available at http: / / www.csustentavel.com [accessed 29 april 2018].

Portal Itambé. 2013. *Certificações verdes têm novos concorrentes no Brasi*l. In 19 de setembro de 2013. Available at: http://www.cimentoitambe.com.br/ [accessed 2 april 2018].

Portal Parque Escolar. 2018. [internet], Portugal. Available at: http://www.parque-escolar.pt [accessed 15 April 2018].

PROCEL. 1993. *Programa Nacional de Conservação de Energia Elétrica – Conservação de Energia Elétrica na Indústria* – Eletrobrás-CNI.

PromisE, 2013. Finnish Environmental Association and Classification system for building, Operated by VTT Technical Research Station. ISBN 978-951-38-8288-4 (online).

Pucher, J. and Buehler, R. 2012. *City Cycling.* MIT Press, Cambridge ISBN: 9780262517812.

Pucher, J., Dill, J., & Handy, S. 2010. Infrastructure, programs, and policies to increase bicycling: An international review. *Preventive Medicine.* 50, 106–125.

Rada, E.C., Ragazzi, M. e Fedrizzi, P. 2013. Web –GIS oriented systems viability for municipal solid waste selective collection optimization in developed and transient economies. *Waste Management*, v. 33, p. 785-792, 2013.

Reidel, J. 2010. E*rfolgreich oder ruinös? Transnationale unternehmen und nachhaltige entwicklung – kritische reflexion aus menschenrechtlicher perspektive.* Munique. Oekom Verlag GmbH. 2010. ISBN-13: 978-3-86581-179-0.

Repka, P. and Švecová, M. 2012. Environmental education in conditions of National Parks of Slovak Republic *Procedia, Social and Behavioral Sciences.* 55, 628–634.

Rezaallah, A., Bolognesi, C.R.A., Khoraskani, R.A. 2012. LEED and BREEAM; Comparison between policies, assessment criteria and calculation methods; BSA 2012, *Proceedings of the 1st International Conference on Building Sustainability Assessment*, Porto, Portugal, 05/2012.

Ridder, H., and Vrijhoef, R. 2008. *Developing a strategy for living buildings: Beyond cradle to cradle with living building concept.* Delft University of Technology, Faculty of Civil Engineering en Geosciences. Delft, The Netherlands.

Romano, G., Salvati and N., Guerrini, A., 2014a. Estimating the determinants of residential water demand in Italy. *Water* 6, 2929 - 2945.

Romero, M.A., Ornstein, S.W. 2003. Post-Occupational Assessment: Methods and Techniques applied to Social Housing. Porto Alegre: *ANTAC*, 2003. *Habitare Collection*. 294p.

Rozin, P., Haddad, B., Nemeroff, C., Slovic, 2015. Psychological aspects of the rejection of UNESCO. *Water and Energy.* United Nations World Water Development.

RSECE. 2006. Regulamento dos Sistemas Energéticos de Climatização nos Edifícios. *Diário da República*, I Série - A, Decreto-lei nº 79/2006, Abril, Lisboa, 2006.

Rydin, E., 2000. Potentially mobile phosphorus in Lake Erken sediment. *Water* res. 34: 2037–2042,

Santamouris, M.; Synnefa, A.; Karless, T.i Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions, *Solar Energy V*. 85 Issue 12 P 3085-3102. Publisher Pergamon.

Sample, D., J., and Liu, J. 2014. Optimizing rainwater harvesting systems for the du al purposes of water supply and runoff capture. *Journal of Cleaner Production*. 75, 174e194.

Santos, D.G., LIMA, D.M.F. 2007. Melhoria na produção em canteiro de obras através do gerenciamento de resíduos sólidos da construção civil: Resíduos Incorporados. *Simpósio Brasileiro de Gestão e Economia da Construção* – V SIBRAGEC. Campinas.

Santos, K.P. C.; Cunha, A., C.; Costa; A. C. L.; Souza, E. B. Índices de tendências climáticas associados à "ilha de calor" em Macapá-AP (1968-2010) *Revista Brasileira de Ciências Ambientais*, N. 23 – Março de 2012 ISSN Impresso 1808-4524 / 1 ISSN : 2176-9478

Saraiva, T., Almeida, M., Bragança, L., Barbosa, M.T. 2018. Environmental comfort indicators for school buildings in sustainability assessment tools. *Sustainability*. 1849; https://doi.org/10.3390/su10061849.

Saraiva, T., Almeida, M., Bragança, L., Barbosa, M.T. 2019a. The inclusion of a sustainability awareness indicator in assessment tools for high school buildings. *Sustainability*. 2019a, 11(2), 387; https://doi.org/10.3390/su11020387.

Saraiva, T., Almeida, M., Bragança, L. Adaptation of the SBTool for Sustainability Assessment of High School Buildings in Portugal—SAHSB^{PT}. *Applied Sciences*. 2019b, 9, 2664; https://doi:10.3390/app9132664.

Saraiva, T., Almeida, M., Bragança, L., Barbosa, M.T. 2019c. Application of the Portuguese Sustainability Assessment Tool of High School buildings, SAHSB^{PT}, to the Francisco de Holanda High School, Guimarães. *Sustainability*. 2019c.

SBTool^{PT}–STPU. *Evaluation Guide. Methodology of Urban Plan*. Consórcio: Ecochoice-iiSBE PT. Minho University, Physics and Methodology Laboratory, Guimarães, Portugal, 2014.

Scheltema, N. 2012. *Recycle city: Strengthening the bikeability from home to the Dutch Railway Station*. MSc Thesis NL: TU Delft.

Schleich, J. and Hillenbrand, T. 2009. Determinants of residential water demand in Germany. *Ecological Economics* 68, 1756 e1769.

Schmid, A.L. 2005. A idéia de conforto: reflexões sobre o ambiente construído. *Curitiba: Pacto Ambiental*, 2005. 338p.

Schmidt III,R., Eguchi, T., Austin,S., Gibb, A. 2010. What is the meaning of adaptability in the building industry? Loughborough University. United Kingdom. *Open and Sustainable Building*. ISBN 978-84-88734-06-8.

Sekki, I., Andelin, M., Airaksinen, M., Saari, A. 2016. Consideration of energy consumption, energy costs, and space occupancy in Finnish daycare centres and school buildings. *Energy and Buildings.* 129 (2016) 199–206.

Serghides, D.K. and Georgakis, C.G. 2012. The building envelope of Mediterranean houses: optimization of mass and insulation. *Journal of Building Physics*, 36 (1) (2012)83–98.

SEV, A. and ÖZGEN, A. 2009. Space Efficiency In High-Rise Office Buildings. METU *Journal of the Faculty Of Architecture*, 2009/2, 69-89.

Silva, E.M. 2019. Arquitetura e conforto ambiental: Avaliação Pós-Ocupação (APO) de duas escolas secundárias tradicionais do estado de Macapá. Monografia do curso de Arquitetura e Urbanismo, Centro de Ensino do Amapá CEAP, Brasil.

Silva, V.G. 2000. Avaliação do desempenho ambiental de edifícios. In: *Revista Qualidade na Construção*, São Paulo, n.25, p.14-2.

Slaughter, S.E. 2001. Design strategies to increase building flexibility. *Building Research & Information*. 29(3), 208-217.

Silva, V.G., 2003. *Avaliação da sustentabilidade de edifícios de escritórios brasileiros: diretrizes e base metodológica*. Tese de Doutorado, São Paulo. EPUSP. 210p.

Stanley, N.; Miller Pamela, M.; Foster Helen, R.F.; Thomson, G. A. 2011. Stop-Start Response: Social Services' Interventions with Children and Families Notified Following Domestic Violence Incidents. February 2011. *British Journal of Social Work.* 41(2):296-313. http://doi.10.1093/bjsw/bcq071.

Sunanda, S. and Chandel, S.S. 2014. Review of software tools for hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews.* 32 (2014) 192–205.

SUPERBUILDINGS, 2012. *Superbuildings - Sustainability and performance assessment and benchmarking of buildings* [internet]. Available at: http://cic.vtt.fi/superbuildings/ [accessed 12 may 2014].

Swarup, L., Korkmaz, S., Riley, D. 2011. Project delivery metrics for sustainable, high-performance buildings. *Journal of Construction Engineering and Management*. 2011, 137, 1043–1051.

Tam, V.W.Y. 2008. On the effectiveness in implementing a waste-management plan method in construction. *Waste Management* 28 (6), 1072–1080.

Tam, V.W.Y., Shen, L.Y., Tam, C.M. 2007. Assessing the levels of material wastage affected by sub-contracting relationships and projects types with their correlations. *Building and Environment* 42 (3), 1471–1477.

Taylor, R., Jones, I., Williams, S. and Goulding, A. 2000. Evaluation of waist circumference, waist-to-hip ratio, and the city index as screening tools for high trunk fat mass, as measured by dual-energy X-ray absorptiometry, in children aged 3–19 y. *American Journal of Clinical Nutrition* 72, 490–495.

Tinsley, S., Pillai, I., 2006. *Environmental Management Systems: Understanding Organizational Drivers and Barriers*. t published by Earthscan, London. ISBN-13: 978-1-85383-936-8.

Torgal, F.P.; Jalali, S. 2007. Construção sustentável: o caso dos materiais de construção. In: *Congresso Construção*, 3., 2007, Coimbra. Anais. Universidade de Coimbra.

Torres, F.M.C. 2012. *Análise técnico-económica das soluções construtivas utilizadas na reabilitação de escolas*. Dissertação de Mestrado, Faculdade de Engenharia, Universidade do Porto, Portugal.

Tremblay, V. and Zmeureanu, R. 2014. Benchmarking models for the ongoing commissioning of heat recovery process in a central heating and cooling plant. *Energy*. 70 (2014) 194 - 203.

Udreaa, I., Croitorub, C., Nastaseb,I., Crutescuc, R., Badescua, V. 2016. Thermal comfort in a Romanian Passive House. Preliminary results. *Energy Procedia* 85 (2016) 575 – 583.

UFU Sustentável. *Universidade Federal de Uberlândia*. Available online: http://www.sustentavel.ufu.br/node/74 [accessed June 10, 2017].

Umapathi, S., Chong, M.N., Sharma, A.K., 2013. Evaluation of plumbed rainwater tanks in households for sustainable water resource management: a real-time monitoring study. *Journal of Cleaner Production*, 42, 204e214.

UNESCO. 1999. *Educação para um futuro sustentável: uma visão transdisciplinar para uma ação compartilhada.*. Brasília: IBAMA. 1999.

UNEP – *United Nations Environment Program*. 2000. The Vienna convention for the protection of the ozone layer & the Montreal protocol on substances that deplete the ozone layer. [internet] kenya: unon. 54p available at: <http://www.unep.org/ozone/pdf/montreal-protocol 2000.pdf [accessed 25 march 2018].

U.S. *Department of Energy, Buildings Energy Data Book,* 2011. Internet]https://ieer.org/wp/wp-content/uploads/2012/03/DOE-2011-Buildings-Energy-DataBook-BEDB.pdf [Accessed: 20 August, 2014].

US EPA *United States Environmental Protection Agency*. 2008. Youth travel to school: community design relationships with mode choice. In: Torma, T. (Ed.), *Vehicle Emissions, and Healthy Body Weight*. United States Environmental Protection Agency.

US EPA *United States Environmental Protection Agency*. 2008. *Solid Waste Management Hierarchy.* Overviews & Factsheets, [internet] http://www.epa.gov/osw/nonhaz/municipal/hierarchy.htm [Accessed 25 August, 2015].

USGBC, 2013. *Annual Report.* [Internet] https://www.usgbc.org/annual-report/2018/ [accessed 15 April, 2018].

Van Dyck, D., Cerin, E., Conway, T.L., De Bourdeaudhuij, I., Owen, N., Kerr, J. 2013. Perceived neighborhood environmental attributes associated with adults' leisure time physical activity: Findings from Belgium, Australia and the USA. *Health & Place*, 19, 59 –68.

Vasconcellos, E.A., 2014. *Urban Transport Environment and Equity: The Case for Developing Countries*. Routledge, London 1st Edition, First Published, 2001, eBook Published May 2014.

Vefago, L.H.M. and Avellaneda J. 2013. Resources, Conservation and Recycling, Recycling concepts and the index of recyclability for building materials. *Resources, Conservation & Recycling* 2013;72:127–35.

Vogt, M. 2010. Maßstäbe einer nachhaltigen unternehmensführung aus der sicht christlicher sozialethik und wirtschaftsanthropologie. *Vortrag beim ersten deutschen eliteforum zur nachhaltigkeit der lmu*. Munique 28/10/2010.

Von Weizsäcker, E.U. 1992. *Erdpolitik. Ökologische realpolitik an der schwelle zum jahrhundert der umwelt*. Darmstadt: Darmstadt University Press.

Wardrop, J.G. 1952. Some theoretical aspects of road traffic research. *Road Engineering Division Meeting,* 24 January 1952 [internet]. Available at: http://dx.doi.org/10.1680/ipeds.1952.11259. [accessed 5 May 2016].

Wargocki, P. and Wyon, D. Providing better thermal and air quality conditions in school classrooms would be cost effective. *Building and Environment.* 2013, 59, 581–589, doi: 10.1016/j.buildenv.2012.10.007.

Wargocki, J., Sundell, W., Bischof, G., Brundrett, P., Fanger, F., Gyntelberg, S., Hanssen, P., Harrison, A., Pickering, O., Seppanen. P., Wouters, P. 2002. Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN), *Indoor Air* 12 (2) (2002) 113–128.

Warwick, E. 2008 School Building [internet]. Available at: http://www2.warwick.ac.uk/fac/soc/wie/eubuildit/educational/tipologias/[accessed 9 May 2018].

WCED. 1987. *Report of the World Commission on Environment and Development: Our common future; world commission on environment and development*; United Nations, 1987 Oxford University press.

Wei, W., Ramalho, O., Mandin, C. 2015. Indoor air quality requirements in green building certifi cátions. *Building and Environment*, 92, 2015, 10-19.

Willis, R.M., Stewart, R.A., Giurco, D.P., Talebpour, M.R., Mousavinejad, A. 2013. End use water consumption in households: impact of socio-demographic factors and efficient devices. *Journal of Cleaner Production*, 60, 107e115.

World Bank. 2004. *The Global Citizen Handbook: Facing Our World's Crisis and Challenges*, 1° Edition U.S.: Collins, 144 p. ISBN 978-0061243424.

WHO. World Health Organization. 2011. *Burden of disease from environmental noise*. [Internet] Available at: http://www.who.int/quantifying_ehimpacts/publications/e94888.pdf?ua=1 [accessed 5 May 2017].

Xavier, A.A.P. 2000. *Predição de conforto térmico em ambientes internos com atividades sedentárias – teoria física aliada a estudos de campo*. Tese de Doutorado. Departamento de Engenharia de Produção e Sistemas. Universidade Federal de Santa Catarina.

Xu, Q., Liu, R., Chen, Q., Li, R. 2014. Review on water leakage control in distribution networks and the associated environmental benefits. *Journal of Environment Science*. 26, 955 e961.

Yang, F., Kang, Y., Gao, Y., Zhong, K. 2015. Numerical simulations of the effect of out door pollutants on in door air quality of buildings next to a street canyon. *Building and Environment*, 87 (2-15) 10-22.

Yunus, R., Yang, J. 2011. Sustainability criteria for industrialized building systems (IBS)in Malaysia, The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction, *Procedia Engineering*, pp. 1590–1598, 14.

Zambrano, M. A. 2004. *A avaliação do desempenho ambiental da edificação: um instrumento de gestão ambiental.* Dissertação (Mestrado em Arquitetura) Faculdade de Arquitetura e Urbanismo, Universidade Federal do Rio de Janeiro, Brazil.

Zhang, Y., Grant A., Sharma A, Chen D, Chen L. 2.010 Alternative water resources for rural residential development in Western Australia. *Water Resources Management* 2010; 24:25–36.

Zhao, D.X., He, B.J., Johnson, C., Mou, B. 2015. Social problems of green buildings: From the humanistic needs to social acceptance. *Renewable and Sustainable Energy Reviews* 51 (2015) 1594–1609.

Zuo, J., Zhao, Z.Y. 2007. Green building research–current status and future agenda: a review, *Renewable and Sustainable Energy Reviews*, b, n 83, 29–38

Zwetsloot, G.J.M., Kines, P., Wybo, J.L., Ruotsala, R., Drupsteen, L., Bezemera, R.A. 2017. Zero Accident Vision based strategies in organisations: Innovative perspective. *Safety Science* 91 (2017) 260–268 https://doi.org/10.1016/j.ssci.2016.08.016

Annexes

In this part of the thesis, the attachments mentioned throughout the work are shown. It presents forms and questionnaires that helped to define the weights of the indicators of this methodology, and the demonstration of the first indicator of the thesis, applied at the Francisco de Holanda High School. The annexes are the following:

ANNEX 1 – Formulary applied to experts on sustainability;

ANNEX 2 – Questionnaires – Environmental comfort indicators;

ANNEX 3 – Questionnaires – Sustainability awareness indicator;

ANNEX 4 – Calculation of the indicator I1 – SAHSB^{PT}, applied at the FHHS

ANNEX 1: Formulary applied to sustainability specialists

In this Annex, a survey applied to 10 experts on sustainability buildings issues is shown. This survey aimed to determine the indicators and their weights included in the SAHSBPT methodology, developed under this doctoral thesis. This survey includes indicators and categories of the SBTool^{PT} STP for Office Buildings methodology and specific sustainability methodologies for schools.

Profession: ( ) Consultant / Specialist in Sustainable Construction ( ) Architect ( ) Civil Engineer ( ) Qualified appraiser of sustainable construction
Fill in the form below, Table A.1 giving grade from 1 to 10, according to the importance of each indicator:

Table A.1. Formulary applied to sustainability specialists

Category	Indicator	Grade
C1. Climate Change and outdoor air quality	Life cycle environmental impacts – I1	
	C2.1 Emissions of ozone-depleting substances during facility operations	
	Refrigerant GWP – Building Services	
	Preventing Refrigerant Leaks	
	Refrigerant GWP – Cold Storage	
	NOx emissions from heating source	
	Heat island effects - I2	
C2. Biodiversity and land use	Land use efficiency - I3	
	Sustainable location - I4	
	Local biodiversity protection during construction – I5	
	Certificated wooded materials – I6	
	Flood Risk	
	Minimising Watercourse Pollution	
	Land use and Ecology	
	Enhancing Site Ecology	
	Long Term Impact on Biodiversity	
	Local Wildlife Partnership	
	A1 Site Regeneration and Development	
	A1.5 Remediation of contaminated soil, groundwater or surface water	
	C4.4 Changes in biodiversity on the site	
	C4.5 Adverse wind conditions at grade around tall buildings	
	C5.5 Potential for project operations to contaminate nearby bodies of water.	
	C5.6 Cumulative (annual) thermal changes to lake water or sub-surface aquifer	
C3. Energy	Energy consumption – I7	
	Renewable Energy – I8	
	Commissioning - I9	
	Energy Efficient Fume Cupboards	
	Energy Efficient Laboratories	
	Energy Efficient IT Solutions	
	B2.1 Electrical peak demand for building operations	
C4. Materials, solid residues, resources management	Reuse of materials – I10	
	Materials with recycled content – I11	
	Construction and demolition wastes – I12	
	Environmental management plan – I13	
	Flexibility and adaptability – I14	
	Designing for Robustness	
	Publication of building information	
	Development as a learning resource	
	Shared facilities	
	Considerate Constructors	
	A1.9 Provision of public open space(s).	
	B3.3 Material efficiency of structural and building envelope components.	
	B3.4 Use of virgin non-renewable materials.	
	B3.5 Use of finishing materials.	
	E3.3 Degree of local control of lighting systems.	
	E2.5 Provision of exterior access and unloading facilities for freight or delivery	
	E2.6 Efficiency of vertical transportation system.	
	E5.6 Retention of as-built documentation	

	Prerequisite 1 Construction Activity Pollution Prevention	
	Credit 7 Site Master Plan (Schools)	
	Credit 8 Joint Use of facilities	
	Prerequisite 2 Environmental Site Assessment	
	Credit 3 Open Space	
C5. Water	Water consumption – I15	
	Water treatment and Recycling – I16	
	Storm water management - I17	
	A1.8 Reducing irrigation requirements through the use of native plantings	
	Credit 4 Cooling Tower Water Use	
C6. Comfort and health of users	Indoor air quality – I18	
	Thermal Comfort – I19	
	Visual Comfort -- I20	
	Acoustic Comfort – I21	
	Consultation with Students and Staff	
	Drinking Water	
	Specification of Laboratory Fume Cupboards	
	Thermal Zoning	
	View Out	
	Glare Control	
	High frequency lighting	
	Lighting zones and controls	
	-Reduction of Night Time Light Pollution	
	-Noise Attenuation	
	A1.6 Shading of building(s) by deciduous trees.	
	A1.7 Use of vegetation to provide ambient outdoor cooling	
	A1.10 Provision and quality of children's play area(s).	
	C5.1 Impact on access to daylight or solar energy potential of adjacent prosperity	
	C5.8 Degree of atmospheric light pollution caused by project exterior lighting system	
	D1.3 Mould concentration in indoor air.	
	D3.2 Control of glare from day lighting.	
	F1.3 Visual privacy in principal areas of dwelling units.	
	F1.4 Access to private open space from dwelling units.	
	F2.2 Impact of the design on existing streetscapes.	
	F2.3 Maintenance of the heritage value of the exterior of an existing facility	
	-F3.1 Impact of tall structure(s) on existing view corridors	
	F3.2 Quality of views from tall structures.	
	F3.3 Sway of tall buildings in high wind conditions.	
	Prerequisite 2 Environmental Tobacco Smoke (ETS) Control	
	Credit 3 Construction Indoor Air Quality Management Plan	
	Credit 8 Quality Views	
	Credit 6 Light Pollution Reduction	
C7. Accessibility	Mobility plan - I22	
	Maximum Car Parking Capacity	
	A3.13 Provision of on-site parking facilities for private vehicles	
	A3.15 Provision of access roads and facilities for freight or delivery.	
	Credit 7 Reduced Parking Footprint	
	Credit 8 Green Vehicles	
C8. Occupants Security	Occupants security - I23	
C9. Life cycle costs	Life cycle costs - I24	
	E5.3 Durability of key materials	
C10. Transport	Accessibility to public transport – I 25	
	Proximity to amenities	
	Travel Plan	
	Travel Information Point	
	Deliveries and Manoeuvring	
	A2.2 Reduce the need of commuting transport through provision of mixed uses	
	A3.14 Connectivity of roadways.	
	C5.3 Impact of building user population on peak load capacity of public transport system.	
	C5.4 Impact of private vehicles used by building population on peak load capacity of local road system.	
	G1.5 Affordability of residential rental or cost levels.	
	Credit 3 High Priority Site	
	Credit 4 Surrounding Density and Diverse Uses	

ANNEX 2 - Questionnaires - Environmental comfort indicators

The questionnaires about environmental comfort were applied to students in schools in Guimarães (Portugal), Juiz de Fora (Minas Gerais, Brazil) and Macapa (Amapa, Brazil). This questionnaires is about the environmental comfort of student during the year.
Its application in schools in Portugal aimed to assist in the calculation of the weights of the indicators related to environmental comfort for the SAHSB^{PT} methodology, whereas its application in the schools in Juiz de Fora occurred in order to make a parallel between the results of Portugal and Brazil.
Regarding the application in the schools in Macapá, it aimed to make a comparison with the schools of Juiz de Fora, demonstrating the need to make sustainability methodologies specific to each region of Brazil.

QUESTIONNAIRES - ENVIRONMENTAL COMFORT INDICATORS

Grade Date:

1. Check the feeling of comfort where you are considering only the temperature.
A) Comfortable B)Very cold C) Cold D) A little cold E)A little hot F) Hot G)Very hot

2. Check the feeling of comfort considering only the natural and artificial lighting.
A) Neutral B) A little uncomfortable with excessive lighting C) Uncomfortable with excessive lighting D) Very uncomfortable with excessive lighting E) A little uncomfortable with insufficient lighting F) Uncomfortable with insufficient lighting
G) Very uncomfortable with insufficient lighting

3. Check the feeling of comfort considering only the noise level
A) Neutral B) Slightly noisy C) Noisy D) Very noisy

4. Check the feeling of comfort considering only the level of air quality.
A) Fresh B) Muffled C) Odorless D) Smelly E) Neutral
F) A little polluted G) Polluted H) Very Polluted.

5. Check the feeling of comfort considering only the level of ergonomic comfort, that is, the comfort offered by desks and the movement of students in the classroom
A) Neutral B) A little uneasy C) Uncomfortable D) Very uncomfortable

6. Check the sense of comfort considering all the factors mentioned above.
A) Neutral B) Slightly uncomfortable C) Uncomfortable D) Very uncomfortable

Thank you very much for your attention

ANNEX 3 - Questionnaires - Sustainability Awareness indicator

The questionnaires about sustainability awareness were applied to students in the schools in Guimarães, (Portugal) and Juiz de Fora (Minas Gerais, Brazil).
Its application in the school in Portugal aimed to assist in the calculation of the weights of "sustainability awareness" indicator for the SAHSB^{PT} methodology. Its application in the schools in Juiz de Fora occurred in order to make a parallel between the results of Portugal and Brazil.

QUESTIONNAIRES – SUSTAINABILITY AWARENESS INDICATOR

Grade: Date:

1. Qualify your interest in matters related to the Environment?
A) Very interested B) Reasonably interested
C) Little interested D) No interest

2. How often are mention subjects related to the Environment in the classroom?
A) Always B) With some frequency C) Rarely D) Never

3 What do you do to protect the environment?
A) Saves water (Faucet, Sanitary Discharge) B) Saves electricity (Lamps, TV)
C) Separates recyclable waste (Pet Bottle, Paper, Cardboard, Glass)

4. Do you have environmental attitudes in your home or try to teach this to your family?
A) Always B) With some frequency C) Rarely D) Never

5. Do you close the sink tap when you finish to use? Why?
A) No B). Yes, because everyone does C) Yes, because it is expensive
D) Yes, because the planet goes through serious problems related to this subject

6. Do you turn off lights and fans when leaving an environment? Why?
A) No B) Yes, because everyone does C) Yes, because it is expensive
D) Yes, because the planet goes through serious problems related to this subject

7. Do you usually do the selective collection of recyclable waste? Why?
A) No B) Yes, because everyone does
C) Yes, because the planet goes through serious problems related to this subject

8. In schools, how should the subjects related to the environment be addressed?
A) In class B) As a mandatory subject C) As an optional subject
D) In specific courses E) At events and other academic projects

Thank you very much for your attention

ANNEX 4- Calculation of the indicator I1 - SAHSB^{PT}, applied in FHHS

Application of SAHSB^{PT} Methodology in Francisco de Holanda High School (FHHS) - Calculation of the indicator I1, Life cycle environmental impacts.

This indicator was the only one executed in detail since it is the most complex of all indicators, containing numerous tables. The values related to the type of materials used and the area of each of these materials were extracted from the materials provided by the *Parque Escolar*. The Life Cycle Analysis (LCA) database of the building elements was taken from the Life Cycle Analysis of Building (Bragança and Mateus, 2012).

I1 Life cycle environmental impacts

To find the life cycle environment impact of the high school building, according to the SAHSB^{PT} methodology, it is necessary to identify the construction elements of the building and their measures; identify the LCA environmental impact value of each construction solution used and its maintenance operations.

Then, multiply the value of each environmental impact by the amount of different elements measures of the building.

For maintenance purposes, it is considered that the exterior walls are painted every 8 years in a life cycle of 50 years. The maintenance impacts is not considered in the calculation of the impacts of reference solutions since the Francisco de Holanda High School was reformed in less than 8 years.

The buildings elements and the LCA database using in this indicator is according to Life –Cycle Analysis of Buildings (Bragança & Mateus, 2012), in the Annex 1, (Description of building elements) and the Annex II (LCA Database). The building elements using in the Francisco de Holanda High School are:

PExt 1: Single wall with support element in masonry of brick (22 cm). The insulation is in molded polystyrene plates with 6 cm thick. The outer shell is in reinforced plaster (2cm);

PExt 12: Double pane wall with an exterior pane in masonry of hollow brick (15 cm) and interior 11cm thick hollow brick pane. The panes are separated by a 4 cm thick air cavity, filled with a 2cm thick insulation layer, with plaster on both sides (1.5 cm).

PExt 16: Double wall with an exterior pane in stone masonry (12 cm) and interior pane in masonry of hollow brick (11cm). The pane is separated by an air cavity (4 cm). The interior panes is coated with traditional plaster (2 cm);

PExt 16: Double wall with an exterior pane in stone masonry (12 cm) and interior pane in masonry of hollow brick (11cm). The panes are separated by an air cavity (4 cm). The interior pane is coated with traditional plaster (2 cm);

PExt 15: Double wall with an exterior pane in mass brick of 11cm and an interior pane in masonry of brick (11cm). The pane is separated by an air cavity (4 cm), totally filled with insulation in plates, extruded explained polystyrene (4 cm) and fixed to the inner pane. The interior panes are coated with traditional plaster (2 cm);

Pint 7: Brick masonry single wall (11 cm). The panes, interior and exterior are coated with traditional plaster (1.5cm);

Pint 9: Brick masonry single wall (22 cm). The panes, interior and exterior are coated with traditional plaster (1.5cm);

Cob 1: Traditional flat roof coating in cobble, with 10cm thick and inner coating in traditional plaster of 2cm thick. The support is in solid slab with a thickness of 20cm, upon which rests: the layer of lightweight concrete form with 10cm thick, upon which rests, the PVC vapour barrier, the thermal insulation in plates of expanded polystyrene (EPS) with 8cm thick, the layer of waterproofing in PVC membranes, the blanket of geotextile, and finally, the ceramic mosaic;

Cob 12 Sloping roof with wooden structure (ripped with a section (5x3cm) and sticks (8x12cm) that serve as support to the outer coating in ceramic tile. Thermal insulation is in extruded expanded polystyrene (8cm). Under the thermal insulation, there is a vapour barrier in PVC membranes. The interior is in gypsum plasterboard (1.25);

Cob 22 It has a discontinuous structure in wood (5x3cm) and sticks (8x12cm) that serve as support to the exterior coating fiber cement sheet. The isolation, in rock wool (10cm), is laid on the horizontal belt. The belt is composed of support elements in wood (8x12cm) and the celling is covered with gypsum plasterboards. On the gypsum, plasterboards there is a vapour barrier in PVC membranes;

Pav 7 Pavement composed by alveolar panels (20cm) containing (4 cm) complementary concrete layer;

Pav 13 Discontinuous structure pavement, composed of wooden flooring (1.8cm) wooden beams (0.25x.30m) spaced by 0.65 and ceiling coated with plasterboards (1.25cm);

Env 5 It is composed by PVC window frame system with 5 chambers, has a sheet with a constructive (depth 79mm) and a ring (72mm). It is equipped with a double-glazing, composed by an outer glass (4mm), an air gap (16mm) and an inner glass (16mm);

Env 8 It is composed of a window frame system with solid or laminated wood profile, has a sheet with a constructive (68mm) and a ring (58mm). It is equipped with a double-glazing, composed by an outer glass (4mm), an air gap (6mm) and an inner glass (10mm).

Table A.2. shows the description of all solution types used in Francisco de Holanda High School building, their area and quantify the environmental impacts of building life cycle (Barbosa, 2013).

Table A.2. Solution types used in FHHS (Barbosa, 2013)

Solution Type	Area (m^2)	Quantification of environmental impact categories (per m^2 of each type of support solution).					
		GWP ($KgCO_2$)	ODP (kg CFC_{-11})	AP ($KgSO_2$)	POCP (kgC_2H_4)	EP (kg PO_4)	FFDP (MJ)
Solution for Ground and High floor							
1	15,042	58.9694	0.0000049911	0.19	0.01048	0.03928	861.0458
Solution for Exterior walls							
2	13,886.4	82.994	0.0000495	0.16797	0.01756	428.7344	495.78
Solution for Interior walls							
3	18,769	36.7907	0.0000043587	0.1585	0.00341	0.02590	690.6769
Solution for Roofs							
4	7,770	20.51	0.000004527	0.22769	0.009365	0.024	411.25825
Solution for Glazed areas							
5	649	68.0023	0.0000004083	0.65498	0.023234	466.0823	1,389.811205
Sum of Impacts	56,116.4	267.2664	0.0000637851	1.39914	0.064049	894.90588	3848.572155
Divide by Lifetime cycle							
Total impacts of life cycle m^2/year		4.76E-3	7.28E-12	0.25 E-4	0.11E-5	1.59E-2	6.86E-2

Section B. Quantification of the environmental impacts of the life cycle of reference solutions (Benchmarks):

- For each type of building element, it must be multiplied each environmental impact that corresponds to the reference solution by the total area of that element;
- For each type of constructed building, it should only be considered the values related to maintenance if they are taken into account.

In this section, it is presented the calculation procedure needed to help to quantify the categories of environmental impact for life cycle in reference buildings (standard practice and best practice). The quantification of these categories is carried out by completing Table A.2. for the different building components: ground floor, high floors, exterior walls, interior walls, roofs, glazed openings and structure.

B.1. 1.Ground and High Floor

In Table A.3. is made a sum of all environmental impacts of ground floor, multiplying by the respective area, and dividing the total value obtained for each category of environmental impact by the total area of ground floor, thus obtaining an average impact per unit of area.

Table A.3. Values corresponding to the standard practice for the ground floor of FHHS.

						Ground and High floor
	Quantification of environmental impact categories					
	GWP (Kg CO_2)	ODP (kg CFC_{-11})	AP (Kg SO_2)	POCP (kg.C_2H_4)	EP (kg PO_4)	FFDP (MJ)
Standard Practice	8.02E+01	4.33E-06	2.03E-01	7.53E-03	3.08E-02	5.88E+02
			X			
Total area of element (m^2)	A1: 15,042					
(P1.1) Impacts from standard practice	1,206,368.8	0.0651318	305,352.6	113.2662	463.2936	8844.696

B.1.2 Exterior Wallsk

In the Table A.4 is made a sum of all environmental impacts of exterior walls, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of exterior walls, thus obtaining an average impact per unit of area.

Table A.4. Values corresponding to the standard practice for exterior walls of FHHS

					Exterior walls	
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP (kg CFC_{-11})	AP (Kg SO_2)	POCP (Kg.C_2H_4)	EP (kg PO_4)	FFDP (MJ)
Standard Practice	5.89E+01	3.91E-06	1.69E-01	1.72E-02	2.37E-02	6.32E+02
			X			
Total surface. l (m^2)	A2: 13,886.4					
(P1.2) Impacts from standard practice	817,885.4	0.054295824	2346.8016	238.84608	329.10768	8776204.8

B.1.4. Interior walls

In the Table A.5. it is made a sum of all environmental impacts of interior walls, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of interior walls, thus obtaining an average impact per unit of area.

Table A.5. Values corresponding to the standard practice for interior walls of FHHS

					Interior Walls	
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP (Kg CFC_{-11})	AP ($KgSO_2$)	POCP (kg.C_2H_4)	EP (kg PO_4)	FFDP (MJ)
Standard Practice	3.14E+01	2,17E-06	8.22E-02	4.54E-03	1.35E-02	2.82E+02
			X			
Total area of element (m^2)	A3: 18,769					
(P1.3) Impacts from standard practice	589,346.6	0.04072873	1,542.8118	85.21126	253.3815	5292858

B.1.5. Roof

In the Table A.6. is made a sum of all environmental impacts of roof, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of the roof, thus obtaining an average impact per unit of area.

Table A.6. Values corresponding to the standard practice for roofs of FHHS

					Roofs	
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP (kg CFC_{-11})	AP ($KgSO_2$)	POCP (kg.C_2H_4)	EP (kg PO_4)	FFDP (MJ)
Standard Practice	8.80E+01	4.75E-06	1.84E-01	9.66E-03	2.94E-02	6.15E+02
			X			
Total Surface (m^2)	A4: 7,770					
(P1.4) Impacts from standard practices	683,760	0.0369075	1429.68	75.0582	228.438	4778550

B.1.6. Glazed areas

In the Table A.7. is made a sum of all environmental impacts of glazed openings, multiplying by the respective area, dividing the total value obtained for each category of environmental impact by the total area of glazed areas, thus obtaining an average impact per unit of area.

Table A.7. Values corresponding to the standard practice for windows and glazed openings of FHHS

						Glazed areas
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP (kg CFC_{-11})	AP ($KgSO_2$)	POCP ($kg.C_2H_4$)	EP (kg PO_4)	FFDP (MJ)
Standard Practice l	8.31E+00	1,17E-06	1.16E-01	-0.29E-03	8.18E-03	1.04E+03
			X			
Total surface (m^2):	A5=649					
(P1.5) Impacts from standard practices	5276.37	0.00075933	75.284	-0.18821	5.3088	0.67496

B.2. Benchmarks associated to the building's life cycle

The Table A.8 and Table A.9 present the auxiliary calculation process required to quantify the life cycle environmental impact categories in reference buildings (standard and best practice).

Table A.8. Impacts of life cycle corresponding to the standard practice of FHHS

						Standard Practice
	Quantification of environmental impact categories					
	GWP (KgCO2)	ODP (kgCFC-11)	AP (KgSO2)	POCP ($kg.C_2H4$)	EP (kg PO4)	FFDP (MJ)
Total impacts incorporated (P1.1+P1.2+P1.3+P1.4 +P1.5)	3,302,637.17	0.19782	310747.17	512.19353	1279.529	18,856458.2
			÷			
Duration of cycle life of reference (years)	50 years: 56,116.4					
(P1.6) Impacts of the life cycle of standard practices	58.8533	0.00000352	5.5375464	0.0091273	0.02280133	336.024018

Table A.9. Impacts of life cycle corresponding to the best practice of FHHS

						Best practice
	Quantification of environmental impact categories					
	GWP ($KgCO_2$)	ODP ($kgCFC_{-11}$)	AP ($KgSO_2$)	POCP ($kg.C_2H_4$)	EP (kg PO_4)	FFDP (MJ)
Total Impacts Incorporated $\frac{SP\ \%}{4}$	825,659.2925	0.09891	77,686.7925	128.0483825	319.8822	84.006
			÷			
Duration of the life cycle (years)	50 years					
(P1.7) Best practice of life cycle impacts	14.713325	0.00000088	1.3843866	0.0002281825	0.0057	4714114.55

Section C. Normalization and aggregation of the environmental impact categories

By the filling of Table A.10 it is possible to determine the normalized value of each one of the environmental impact categories. The same table also presents the auxiliary calculation necessary to assist the aggregation of the different categories into a single indicator expressing the environmental impact of the solution assessed during its life cycle.

1. The normalization is made through the following equation

$$\bar{P}_i = \frac{P_i - P_{i*}}{P_i^* - P_{i*}} \qquad (A.1)$$

Pi Represents the result of the quantification of the indicator;

P_{Ii}* Represents the value of the best practice;

P_{i*} Represents the value of the conventional practice.

GWP ($KgCO_2$)

$$\bar{P}_i = \frac{0.00476 - 58.8}{14.7 - 58.8} = 1.20$$

ODP (kgCFC-11)

$$\bar{P}_i = \frac{0.00000000000728 - 0.00000352}{0.00000088 - 0.00000352} = 1.33$$

AP ($KgSO_2$)

$$\bar{P}_i = \frac{0.000025 - 5.54}{1.38 - 5.54} = 1.33$$

POCP ($kg.C_2H_4$)

$$\bar{P}_i = \frac{0.0000011-0.00913}{0.000228-0.00913}=1.02$$

EP ($kg\ PO_4$)

$$\bar{P}_i = \frac{0.0159 - 0.0228}{0.0057 - 0.0228} = 0.403508$$

FFDP (MJ)

$$\bar{P}_i = \frac{0.0686 - 336}{4710114.55 - 336} = 0.000071$$

Table A.10. Standardization and assessment of the global environmental performance of the solution assessed of FHHS

Environmental impact categories	Life cycle impacts (per m² of useful area of pavement and year)				Weight of the environmental impact category [B]	Weighted value =[A]x[B]
	Best practice [Pi*] = (P1.7)	Standard Practice [Pi*] = (P1.6)	Solution Assessed [Pi] = (P1.1)	Standard zation value = (1) [A]		
GWP ($KgCO_2$)	1.47 E-1	5.88 E+1	4.76E-3	1.20	40.7%	0.48
ODP ($kgCFC_{-11}$)	0.88 E-6	3.52 E-6	7.28E-12	1.33	8.4%	0.11
AP ($KgSO_2$)	1.38 E0	5.54 E0	0.25 E-4	1.33	13.6%	0.18
POCP ($kg.C_2H_4$)	2.28 E-4	9.13 E-3	0.11E-5	1.02	10.1%	0.10
EP ($kg\ PO_4$)	0.57 E-2	2.28 E-2	1.59E-2	0.40	13.6%	0.054
FFDP (MJ)	4.71 E+2	3.36 E+2	6.86E-2	0.000071	13.6%	0.00001
			(P_{LCA}) (P1.24) Σ = Environmental performance of the solution			0.92

Based on this calculus, the value given to this indicator is 0.92– A.