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WEIGHTING FACTORS FOR THE CRITERIA OF A BUILDING SUSTAINABILITY ASSESSMENT TOOL (DGNB)

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ABSTRACT

This work relates to the Building Sustainability Assessment tools in particular to the weighting factors of criteria used on those tools.

The aim of this dissertation is to develop new weighting factors for the criteria considered in the assessment of new office and administrative buildings. For that purpose, ten different criteria were chosen, related to building physics, in which the study has focused.

With this objective, this work comprises of two main stages: (1) study of the criteria and definitions of the weighting factors for criteria and (2) implementation of the weighting factors for criteria on the DGNB system and analysis of the results with the new weighting factors.

Therefore, at the first stage a study was made of the different existing Building Sustainability Assessment tools and of the criteria considered through a realization of a questionnaire addressed at experts in different fields of building constructions, which made it possible to define the new weighting factors for the criteria. At the second stage, the implementation of the new weighting factors of criteria on the DGNB system was made, applying it to a specific case and then a comparison between it and the original results was made.

Keywords: criteria, weighting factors, DGNB, building sustainability

RESUMO

Este trabalho está relacionado com as ferramentas de avaliação de sustentabilidade de edifícios e particularmente com os fatores de ponderação de critérios utilizados nestas ferramentas.

O objetivo desta dissertação é o desenvolvimento de novos fatores de ponderação para os critérios utilizados na avaliação de novos edifícios administrativos e de escritório. Nesse sentido, foram escolhidos dez diferentes critérios, relacionados com a física das construções, nos quais este trabalho se foca.

Este trabalho compreende duas fases principais: (1) estudo dos critérios e definição dos fatores de ponderação para os critérios e (2) implementação dos novos fatores de ponderação dos critérios no sistema de certificação DGNB e análise dos resultados com estes novos fatores.

Portanto, na primeira fase foi feito um estudo das diferentes ferramentas de avaliação de sustentabilidade em edifícios existentes e dos critérios que estas consideram e através de um inquérito destinado a especialistas de diferentes campos da física das construções foi possível definir os novos fatores de ponderação.

Na segunda fase foi feita a implementação destes novos fatores de ponderação no sistema de certificação alemão DGNB, e a aplicação deste sistema a um caso específico bem como uma posterior análise comparativa entre os novos resultados e os originais.

PALAVRAS-CHAVE: Critérios, fatores de ponderação, DGNB, sustentabilidade na construção.

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LIST OF ACRONYMS

BMVBS - Federal Ministry of Transport, Building and Urban Affairs

BRE - Building Research Establishment

BREEAM – Building Research Establishment Environmental Assessment Method

BSA – Building Sustainability Assessment

CASBEE – Comprehensive Assessment System for Built Environment Efficiency

DGNB – German Sustainable Building Council

HQE – High Quality Environment standard

LEED – Leadership in Energy & Environmental Design

LIDERA – Lead for the Environment

SBTool – Sustainable Building Tool

iiSBE – (international initiative for the Sustainable Built Environment)

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INTRODUCTION

1.1. GENERAL CONSIDERATIONS

The development of society, at the level of population and quality of life, provided the uncontrolled rising consumption of resources and materials available in nature.

With the oil crisis in the 1970s, there began to be a rise in awareness about the environment and on saving energy. Thus, with awareness of the environment, the future of the planet and its resources, humanity began to take a greater role in our society.

The construction sector is one of the most responsible for the negative environmental impact that is felt on the planet, due to the large consumption of energy and materials, as well as pollutant emissions of building, throughout the life cycle of a building.

These concerns have warned for the need to introduce the concepts of sustainability and sustainable development in all sectors, particularly in the construction sector.

Thus arises, in this context, the concept of sustainable construction. Sustainable construction is a concept that relies on the need to find a balance between environment, economic and social aspects throughout a building's life-cycle. Thus, sustainable construction aims to reduce the environmental impact of a building from design, construction, operation, maintenance, renovation and deconstruction, optimizing the economic aspects and the building comfort.

To respond to the need to put into practice this concept, several systems have been developed and applied to evaluate the building's performance in respect to its sustainability, the building sustainability assessment (BSA) tools.

This work focuses on the study of the weighting factors of criteria used on the BSA tools, in which an approach to different BSA tools will be made as well as a study of some of the criteria present in those tools.

1.2. MOTIVATION AND OBJECTIVE

The aim of this work is the study of the existing building sustainability assessment tools and the criteria considered as well as a proposal for new weighting factors for the criteria of office buildings. Thus, this study will be focused on ten criteria related to building physics.

The study is also aimed at the implementation of new weighting factors, for the criteria, on the German BSA tool, DGNB, for a comparison between the original results and the results with the new weighting factors.

This study arises because the weighting factors of the criteria considered by the German certification system was decided by a restricted group of people and these weighting factors might not be the most appropriate, resulting in some distrust in them.

With this work, it is expected that the new weighting factors may be more reasonable and may more accurately transmit the weight of each criterion and thus the overall score of the office building will be closer to the reality.

1.3. STRUCTURE

In Chapter 1, an introduction and a first approach are made on the theme of this work. It describes the objectives and the proposed targets of achievement as well as the structure of this thesis.

In Chapter 2, concepts and principles of sustainable buildings are present, as well as the advantages and the importance of the assessment tools for sustainable buildings. Furthermore, a description of the most important existing building sustainability assessment tools are also made.

In Chapter 3 contains the development part of the thesis, with a description of each one of the ten criteria chosen to be studied and the methodology used. In this chapter, the questionnaire developed on this study and all the questions presented on the questionnaire are described.

In Chapter 4 the obtained results as well as the discussion on them are presented. Present in this chapter is also the proposal for the new weighting factors for the ten criteria studied as well as their implementation on a DGNB certification system's specific case and two hypothetical cases with a comparison between the new results and the original ones.

In Chapter 5 the conclusions of this research are presented. There are also some recommendations for further work and possible criticism of this project.

2

LITERATURE REVIEW

2.1. SUSTAINABLE CONSTRUCTION

2.1.1. EVOLUTION OF THE CONCEPT

With the environmental degradation and the concerns about the natural resources becoming increasingly important, international conferences on the environment started to be realized.

In 1972 the first conference with good results took place. It was the United Nations Conference on the Human Environment – the Stockholm Conference.

In 1987 the Brundtland Report arises [1], "Our common future: The world commission on environment and development". This report seeks to recapture the spirit of the Stockholm Conference in which the definition of sustainable development arose:

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

In this document measures to promote the sustainable development were defined, focusing mainly on energy and consumption of non-renewable resources [1].

Another conference that changed the perception about sustainable development was the Rio de Janeiro Conference, in 1992. At this conference, environmental degradation and the solutions for a sustainable development were discussed. It was at this conference that the "Agenda 21" arose, which was a plan to be applied at global, national and local level [2]. This document was intended to be a global action plan for sustainable development, containing recommendations and specific references with the objective of promoting the environmental regeneration and social development [3].

In 1996, the "Habitat Agenda II" arose, in the Istanbul conference. This document shows the concerns about the sustainability of population clusters and contains several sections devoted to the construction industry and how national governments should encourage industry towards sustainability [3] [4].

The sustainable development is a concept that is based on three main dimensions: economic, social and environmental (Figure 1). On the environmental dimension, the intent is to reduce the consumption of resources, the production of waste and to preserve the biodiversity. The social domain is about the understanding of social institutions and their role in development, as well as well-being, health and education. The economic dimension is about the impact that the economic growth has on society and the environment [3].

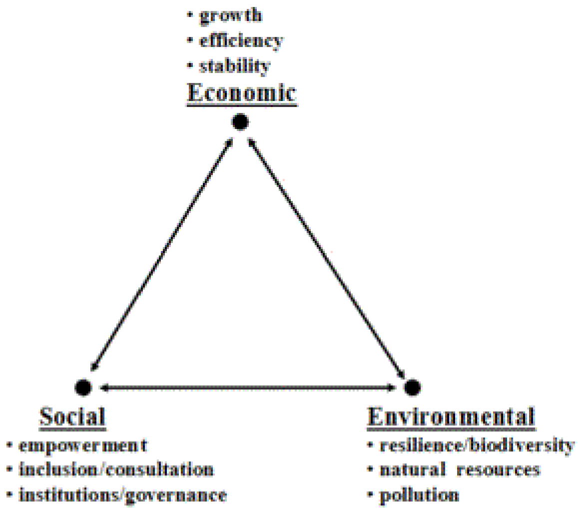

Figure 1- Sustainability Objectives

Nowadays, our planet faces an environmental challenge whose lack of resolution could result in the end of human civilization, as we know it.

The world population has been experiencing a strong growth since 1950. In 1950 the world population was 2.500 billion people, currently it is at over 7.000 billion people and it is expected that this number will rise to over 9.000 billion people by 2050.

This population growth, together with the satisfaction patterns of people ever higher, has led to an excessive consumption of the natural resources of our planet. These facts will cause serious consequences on the environment and also the development process of societies that aims to be sustainable.

The construction sector is one of the most responsible for the consumption of natural resources (water, energy, materials, etc.) and it is also a major producer of waste and pollutant emissions for the environment. Thus, it is of great importance to intervene in this sector.

2.1.2. Principles and Definitions

The term "sustainable construction" was defined for the first time in 1994, by Professor Charles Kibert to describe the responsibilities of the construction industry in the concept and objectives of sustainability [5]:

"Sustainable construction is the responsible development and management of a healthy built environment, based on the efficient use of the resources and on the ecological principles"

The sustainable construction concept is based on the development of economically viable models that enable the construction sector to propose solutions for the environmental problems of our time, without having to give up modern technologies and of the creation of buildings that respond to the needs of its users. In other words, sustainable construction aims to reduce the environmental impact of buildings over its lifetime, while optimizing the costs and the comfort of the users.

While the standard building practices are guided by concerns related to the short term economic aspects, in order to achieve maximum profit, the sustainable construction is based on practices that have as major importance long term aspects as the economic and environmental aspects as well as the user's comfort, the quality and efficiency of the building. Thus, the sustainable construction seeks to match the reduction of consumption of energy, water and the production of waste, with the user's comfort and needs and the life-cycle costs of the building.

Sustainable construction is based on a set of fundamental principles such as [6]:

Energy and water efficiency – minimize the use of energy, use renewable energies like solar, biomass and wind energy and increase the energetic efficiency of the building. Minimize the use of water and reuse and recycle used water;

Waste management – minimize the generation of waste and efficient management of the waste produced;

Indoor Comfort –the site and shape of the building are very important to benefit from favorable solar orientation, wind exposure and natural illumination and ventilation. It is also important to provide health and well-being indoor conditions to its occupants, as well as provide excellent thermo-acoustic conditions in order to improve life quality and comfort for the user;

Use of environmentally friendly materials - use eco-friendly and recyclable materials and non-toxic materials that support the protection and cooperation with natural systems.

Durability of buildings – use durable and flexible materials to allow the adjustment to different uses. Plan conservation and maintenance interventions on the building.

Costs – Reduce the costs for sustainable solutions otherwise the solution will not be competitive with the traditional buildings. Increase productivity and decrease the length of construction with simple constructive solutions.

By fulfilling all of these fundamental principles it is possible to achieve a sustainable construction [7].

Thus, the key elements of sustainable construction are: the reduction of energy and natural resources consumption, the conservation of the environment and biodiversity, the maintenance of the quality of the built environment and health management of the indoor environment.

2.1.3. Application Stages

2.1.3.1 Introductory note

To be considered a sustainable construction, the building has to be thought out to minimize the environmental impacts and its natural resources and to improve the building comfort, necessarily in all the phases of a building's life-cycle [4].

Thus, the fundamental principles of a sustainable construction must be present in the project, construction, operation, maintenance, renovation and deconstruction phases through the application of rigorous methods and constructive processes, the use of renewable materials and an efficient monitoring and evaluation [4] [5].

The sustainable building process requires a correct and constant monitoring of all stages of the building life-cycle in order for it to be possible to assess the efficiency of the choices made in the process, from the project to demolition and if necessary to correct the eventual deviations from the desired result levels [8].

The impacts generated by a construction occur from the construction phase, through to the use, maintenance and renovation phases to the demolition phase. All these stages, with different intensities, have environmental impacts and most of these impacts are determined at the project stage [9].

2.1.3.2. Project

On the project stage it is very important at first, to be aware of the characteristics of the location, as well as the sun and wind exposure, rainfall, climate, and surrounding noise in order for the best constructive solutions to be met in order to optimize the benefits of the natural conditions of the place [10].

After knowing the characteristics and conditions of the place, the constructive solutions to be adopted are defined, focusing on solutions with less impact on the environment [10].

Thus, the main activities on this stage are: location, solar and wind orientation, choice of eco-friendly materials, determination of the level of thermal efficiency of the building, natural ventilation; rainwater harvesting and reuse of water systems [9].

2.1.3.3. Construction

At this stage the strategies defined on the previous phase are implemented.

This process must be very controlled since it is a stage where there are many participants and higher probability of occurring errors. Some errors may compromise the efficiency of the building or some of its functionalities, so it is important to minimize them [10].

At this stage, a strong monitoring of the work process is important so that it is carried out as defined in the project in order to achieve the expected results.

The main measures to be taken at this stage are: strict control of the implementation and planning of the work; strict control of the technological process of construction; use of materials and equipment that reduce the production of waste and pollution [9].

2.1.3.4. Operation/Use

As this phase is the longest, its impacts also have greater durability in the consumption of resources, pollutant emissions and the accumulation of material level.

The strategies defined in the previous phases are now put into practice, like the efficient use of water, for example.

The elaboration of a manual of use for the adjustment of the protective solar systems, temperature regulation, etc., is a good measure to take [10].

2.1.3.5. Maintenance and Renovation

This is the stage that focuses on the procedures to be adopted in order to increase the durability and the efficiency level of the building and therefore its life-cycle.

It is at this stage that the maintenance manual is applied and defined in the project. Where the action, maintenance work and renewal is defined to be performed, as well as its periodicity [10].

2.1.3.6. Demolition

This is the last stage of the building life-cycle at which point the resulting materials should be ensured and waste is sent for recycling, in order to minimize their impact on the environment. Again, this process should be defined at the design stage.

2.1.4. Advantages and Disadvantages

The benefits of sustainable construction may be grouped in three different fronts: environmental, economic and social [11].

Environmental benefits:

- Pollutant emissions reduction;
- Water conservation and management;
- Waste reduction;
- Natural resources preservation.

Economic advantages:

- Energy and water savings;
- Increased property values;
- Increased employee productivity and satisfaction;
- Optimize the economic performance of the building life-cycle.

Social advantages:

- Improved air quality, thermal and acoustic comfort of the building;
- Improved comfort and health of the user;
- Healthier Lifestyles and Recreation.

The disadvantages of sustainable construction are mainly related with the initial costs of the construction. The lack of offer of eco-friendly materials makes them more expensive, which can cause the prices to be much higher than standard building materials [12].

Apart from the initial costs of the construction, finding a lender who offers loans for this kind of building may be difficult [12].

The availability of materials in more distant areas of production centers is directly associated with the high cost of products. The greater the distance, the higher the transportation cost of materials [12].

Time may also be a disadvantage, since eco-friendly materials may take extra-time to be found and the builder and/ or homeowner might have a deadline.

2.2. SUSTAINABLE CONSTRUCTION ASSESSMENT

Even countries that are believed to have the full domain about the sustainable construction had no means to check "how green" their buildings were. This was the first sign of the need to assess the environmental impact of a building [3].

Buildings projected to be sustainable buildings had most of the times higher energy consumption than standard buildings, as was proven years later.

The creation of sustainable construction assessment tools started with the agreement between governments and researchers about the performance classification combined with the certification systems [3].

This step on the environmental assessment development was instrumental in the formulation of guidelines and methods for sustainable construction, their quality criteria and methods for assessment and verification of those, leading to the creation of several models and systems for the assessment of sustainable construction [3].

Until 1990, little attempt had been made to simultaneously assess a broad range of environmental considerations, based on explicit criteria, and make an overall performance summary.

The sustainable construction field has experienced a remarkably quick growth since the introduction of the United Kingdom system - BREEAM – and in the past twenty years have witnessed a large increase in the number of assessment tools.

The use and development of building environmental assessment methods now represent a central focus for the building environmental design and performance debate [13].

The aim of sustainable construction assessment is the recognition and certification of buildings that adopt sustainable practices, i.e., buildings that take into account the economic, environmental and social aspects.

The assessment is made through the application of assessment systems that aim to guarantee the sustainability during the whole building's life-cycle.

These systems have contributed enormously to furthering the promotion of higher environmental expectations, given focus to green building practices and have directly and indirectly influenced the performance of buildings.

These systems play a valuable role by providing a clear declaration of the key environmental considerations and their relative priority, assisting in the design process, as well as enabling the building performance to be described comprehensively [13].

2.3. EXISTING BUILDING SUSTAINABILITY ASSESSMENT TOOLS

2.3.1 INTRODUCTORY NOTE

In the last years, sustainable construction is assuming great importance and therefore the assessment tools have known a great development and are an important challenge for the market. These tools, in addition to the assessment, also allow the certification of buildings, in regards to sustainability.

The building sustainability assessment tools have emerged in Europe and quickly spread through other countries, mainly Canada and the USA, and also in countries like Japan, Australia, among others, which also already have their own certification systems [14].

Among the main systems, the following stand out:

- DGNB Certification System (DGNB - German Sustainable Building Council) – Certification system developed in Germany;
- BREEAM (Building Research Establishment Environmental Assessment Method)- Certification system developed in the United Kingdom;
- LEED (Leadership in Energy & Environmental Design) – Certification system developed in the USA;
- CASBEE (Comprehensive Assessment System for Built Environment Efficiency) – Certification system developed in Japan;
- HQE (High Quality Environment standard) – Certification system developed in France;
- LIDERA (Lead for the Environment) – Certification system developed in Portugal;
- SBTool^{PT} (Sustainable Building Tool, Portugal) – Portuguese adaptation of the international system SBT (Sustainable Building Tool).

These systems work through the definition of a set of performance criteria of the building, grouped into different sets of criteria forming a logical structure, which allow a partial and global final evaluation of the building. Each one of these criteria has associated a weighting factor, according to their importance in terms of sustainability. The more important the criterion the greater will be its weighting factor [6].

The assessment is made through the attribution of a number of points to each criterion within a defined range, depending on the performance of the building. The overall score of the building is obtained through these points or scores of each of the criteria [6].

2.3.2. DGNB CERTIFICATION SYSTEM

2.3.2.1. Introduction

This system was developed by the German Sustainable Building Council (DGNB) together with the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) to be used as a tool for the planning and evaluation of buildings with a comprehensive perspective on quality [15].

The purpose of the DGNB was to create a second generation certification system, which emphasizes on an integrated view over the whole life-cycle of the building and with focus on the following main groups of criteria that affect the evaluation: ecology, economy, socio-cultural and functional topics, techniques, processes and location [7] [8].

The DGNB is a clearly arranged and easy to understand rating system, covering all the relevant topics of sustainable construction, and awards outstanding buildings in the categories with bronze, silver and gold [16].

This certification system was initially developed for new office and administration buildings, in 2008. This version emerged from the pilot phase of the system and the sustainability of office and administration buildings were evaluated based on 49 criteria [8]. The current version considers a total of 63 criteria but only uses 48, because the scientific principles for 15 criteria are currently being developed.

But the DGNB system is very flexible. Different buildings have different characteristics and requirements that need to be taken into account. It is for this reason that DGNB Certification System has developed several "schemes" depending on the type of building (Table 1) [17].

Table 1 - Overview of all schemes

Existing Buildings	New Buildings	New Districts
Office and administrative buildings, Retail Buildings, Industrial Buildings and Residential Buildings.	Educational facilities, Office and administrative buildings, Office and administrative buildings (with modernization measures), Retail Buildings, Hotels, Industrial buildings, Hospitals, Laboratory buildings, Tenant fit-out, Assembly buildings, Residential Buildings and small residential buildings.	Urban districts, Industrial estates and Trading estates.

2.3.2.2. Structure and Application

The DGNB scoring and rating system is based on the performance of six evaluation areas, the topics, with a fixed relative importance. These topics are weighted in the following way [7]:

- Ecological Quality: 22,5%;
- Economical Quality: 22,5%;
- Socio-cultural and functional Quality: 22,5%
- Technical Quality: 22,5%
- Quality of the Process: 10%
- Quality of the Location: this topic is not included in the final grade but presented separately.

Thus, the first five topics flow into a final and last grade, Quality of the Location that is evaluated separately. This topic is not included in the overall evaluation of the building so that each building might be evaluated independent of its location.

Each one of these topics contains several criteria. For each criterion, measurable target values are defined, and a maximum of ten points can be achieved. These measuring methods for each criterion are clearly defined [8].

At the same time each criterion has a weighting factor associated, this way, for instance, the indoor hygiene of an office building is of more importance than the acoustic comfort, so the first has a weighting factor that is higher than the second. The weighting factor can also be zero, if the criterion is not applicable to the specific case on study [8]. Each criteria flows into the overall result in a clearly differentiated way with the support of calculation software that displays the building's performance.

Depending on the degree of compliance, the evaluated buildings are awarded with the gold, silver or bronze certification (Figure 2).

ab 80%	**Gold**
65-79,9%	**Silver**
50-64,9%	**Bronze**

Figure 2 - Degree of compliance

The grades are given for overall performance of the building as well as for the individual topics [7] [8].

2.3.2.3. Criteria

As already mentioned, the DGNB certification system considers 6 topics. These topics contain a total of 63 individual criteria but the development of 15 criteria was postponed. This way, the certification for "New Construction Office and Administration" in the version of 2012 is based on 48 criteria, from which 6 are evaluated separately (Quality of Location). Therefore, 42 of these criteria are evaluated and flow of the overall score (Table 2).

Table 2- DGNB Certification System Criteria

Main Criteria Group	Criteria (No.)
Ecological Quality	(1) Global warming potential; (2) Ozone depletion potential; (3) Photochemical ozone creation potential; (4) Acidification potential; (5) Eutrophication potential; (6) Risks to the regional environment; (8) Other impacts on the global environment; (9) Microclimate; (10) Non-renewable primary energy demands; (11) Total primary energy demands and proportion of renewable primary energy; (14) Potable water consumption and sewage generation; (15) Surface area usage.
Economical Quality	(16) Building related life cycle costs; (17) Value stability.
Socio-cultural and Functional Quality	(18) Thermal Comfort in Winter; (19) Thermal comfort in the summer; (20) Indoor Hygiene; (21) Acoustical Comfort: (22) Visual comfort; (23) Influences by users; (24) Roof design; (25) Safety and risks of failure; (26) Barrier free accessibility; (27) Area efficiency; (28) Feasibility of conversion; (29) Accessibility; (30) Bicycle comfort; (31) Assurance of the quality of the design and for urban development for competition; (32) Art within Architecture.
Technical Quality	(33) Fire protection; (34) Noise protection; (35) Energetic and moisture proofing quality of the building's Shell; (40) Ease of Cleaning and Maintenance of the Structure; (42) Ease of deconstruction, recycling and dismantling.
Quality of the Process	(43) Quality of the project's preparation; (44) Integrated planning; (45) Optimization and complexity of the approach to planning; (46) Evidence of sustainability considerations during bid invitation and awarding; (47) Establishment of preconditions for optimized use and operation; (48) Construction site, construction phase; (49) Quality of executing companies, pre-qualifications; (50) Quality assurance of the construction activities; (51) Systematic commissioning.

2.3.2.4. International Application

The DGNB Certification System can easily be adapted to the climatic, constitutional, legal and cultural particular features of other countries. This is one of the strengths of this System since it allows that the DGNB system might be applied internationally [9].

The DGNB system takes two different approaches to international certification:

- Local application together with a partner organization;
- Direct application of the DGNB system.

On the first approach if a DGNB's suitable partner organization has been established in a country, the DGNB can work in tandem with it on the certification system, regarding the local requirements and the building culture, but always in accordance with the DGNB system [9].

The second approach takes on the cases where there is no DGNB partner organization. In these countries an international version of the DGNB Certification System is available based on the current European norms and standards. The criteria catalogue can be adapted to the local circumstances, by the DGNB GmbH [9].

In many countries the local sustainability experts receive further training and education. These efforts are done with the cooperation of the partner organizations, but also with Private Partnership Projects (PPP), e.g. in Brazil, China and Ukraine [9].

The international application of the DGNB Certification System has already been done in several countries, such as Austria, Denmark, Bulgaria, Switzerland, among others.

2.3.2.5. Advantages of the Certificate

The DGNB Certification System has a set of advantages, among them [8] [9] stand out:

- The certificate demonstrates the positive effects of a building on the environment and society;
- The certification provides, in an early stage, a high degree of certainty that the goals, in terms of the performance of the building, can be achieved at the time of completion.
- As the System is present in all stages of the construction, it leads to more transparency and well-defined processes, minimizing the risks during construction, operation, renovation and removal.
- The certificate supports owners and designers in a globally oriented way for the development of sustainable buildings.
- It is based on the life cycle of a building.
- The German certificate is not only about the ecological aspects but also the economic performance, as well as socio-cultural and functional aspects of buildings.
- The certificate system can flexibly be updated. It can easily be adapted to technical, social and international developments.

2.3.3. Other Existing Building Sustainability Assessment Tools

As already mentioned, there are many other Certification Systems. In this sub-chapter, a small description of some of them will be given.

2.3.3.1. BREEAM (Building Research Establishment Environmental Assessment Method)

The BREEAM Certification System was developed in the United Kingdom by BRE (Building Research Establishment) in partnership with the private sector and aimed at measuring and specifying the environmental performance of buildings. The development started in 1988 and it was launched in 1990. This system has several schemes, each one specifically designed to adapt to a particular kind of building. Examples of those schemes are the *BREEAM for offices* (designed for office buildings), the *EcoHomes* (designed for housing buildings) or the *Superstores* (designed for new trade buildings), among others [10] [6].

The assessment carried out by this system is done in a similar way to the one made by the DGNB Certification System. The system considers ten different categories: Management; Health and Wellbeing; Energy; Transport; Water; Materials; Waste; Land Use and Ecology; Pollution; Innovation [10].

Each one of these categories contains several criteria to which credits are awarded when certain requirements are checked. To each criterion a weighting factor is allocated according to the importance given by the system. The credits are added together to produce an overall score on the following scale [10] [6]:

- <30% = Unclassified
- ≥ 30% = Pass
- ≥ 45% = Good
- ≥ 55% = Very Good
- ≥ 70% = Excellent
- ≥ 85% = Outstanding (besides >= 85% percentage score, there are additional requirements for achieving a BREEAM *Outstanding* rating).

2.3.3.2. LEED (Leadership in Energy & Environmental Design)

The LEED Certification System was developed by USGBS (the U.S. Green Building Council) in the United States in 1999 and it was launched in 2000. This system is based on BREEAM and like the British system there are several schemes of LEED, designed for different uses, including the LEED-NC (new construction), or the LEED-EB (existing buildings), among others [6].

The sustainable buildings are rated from seven categories: Sustainable site, Water efficiency, Energy and atmosphere, Materials and resources, Indoor environmental quality, Innovation and Regional Priority. Like the other certification systems mentioned above, the assessment process of the LEED certification system is done with the attribution of credits to each criterion contained in these categories. Once again, each criterion has a weighting factor associated according to its importance. The total score achieved leads to the assignment of different types of certifications. The LEED considers the following scale [10] [18]:

- 40-49 points – Certified
- 50-59 points – Silver
- 60-79 points – Gold
- 80-110 points – Platinum

2.3.3.3. CASBEE (Comprehensive Assessment System for Built Environment Efficiency)

This certification system was presented by the Japanese Sustainability Building Consortium in 2002. The aim of CASBEE is to assess residential, office and school buildings and this tool is in constant adaptation and evolution [10].

This system can be divided on four different tools, each one directed to different users who assess the building at different stages of its life cycle. These four tools are divided in two categories [10]:

The first one focuses on new buildings: it contains a tool for the pre-design stage (directed at owners and designers) that intends to identify the basic context of the project and the other on the environmental project (directed at designers and constructors) that intends to improve the environmental efficiency of the building during the design stage.

The second focuses on existing buildings: it contains an environmental certification tool (for owners, designers and constructors) to classify the existing buildings in terms of environmental efficiency and a tool to assess after the project (directed at owners, designers and operators/ managers) and aims to collect information about how to improve the environmental efficiency of the building during the operation stage.

This system is composed of several categories (Energy Use/GHG emissions; Water Use; Material/Safety; Biodiversity/Land use; Indoor Environment) that contain different criteria. For each criteria a grade from 0-5 is attributed, according to the technical and social patterns of the building [13].

The final classification of the building has 5 levels: S, A, B+, B and C. The higher classification is S [18].

2.3.3.4. HQE (High Quality Environment standard)

The HQE system was developed in France and it was launched in 2005 and was integrated in the standard of the French Association for Standardization (AFNOR) [19].

This system considers four evaluation groups with a total of fourteen unweighted categories [10]:

- Eco-construction: Managing the impacts on the outdoor environment; Selection of the materials/Building elements; Sustainable construction site;
- Management: Energy; Water demand; Waste Management; Adaptability and durability of the building;
- Comfort: Hygrothermal comfort; Sound insulation; Optimization of natural and artificial light comfort; Reduction in sources of unpleasant odors/air pollutants;
- Health: Hygienic aspects; Indoor air quality; Drinking water quality.

The evaluation system has three performance degrees:

- B – Base (Basic: regulation level or normal performance);

- P – Performant (Good practice, better than basic);
- TP – Très performant (Best practice, better than basic).

The results of the categories do not flow to an overall score. To achieve the HQE certification, the building has to meet the following requirements:

- TP in at least three categories;
- P in at least four categories;
- B in seven categories (at most);
- P or TP in the category *Energy*.

2.3.3.5. LIDERA (Lead for the Environment)

The LIDERA is the Portuguese certification system and its first version was presented in 2005. This system can be applied to the different stages of the building process (project, construction, operation/use, maintenance and renovation and demolition) and it adopts six main principles [2] [6].

1. Valuing the local dynamics and promote the proper integration,
2. Boosting the resource consumption efficiency;
3. Reduce the impact loads (both in value and in toxicity);
4. Ensure the ambient air quality;
5. Promoting the socio-economic sustainable practices;
6. Ensure the best sustainable exploitation of the built environment, through environment management and innovation.

The LIDERA certification system considers six categories with different intervention areas: Site Integration (soil, ecosystems, landscape and heritage), Resources Consumption (energy, water, materials, food), Environmental Loads (air emissions, waste, outside noise, …), Environmental Comfort (air quality, thermal comfort, lighting and acoustics), Socio-economic Experience (access for all, life-cycle costs, economic diversity, social interaction, …) and Sustainable Use (environmental management and innovation) [6] [2].

To each criteria contained in the intervention areas its performance is assessed on the building and the score flows to the final score of the building [3].

To assess the sustainability of a building performance, degrees from G (less efficient) to A+++ (more efficient) were defined. The E class is the reference and represents the usual practices of the existing buildings in Portugal [2].

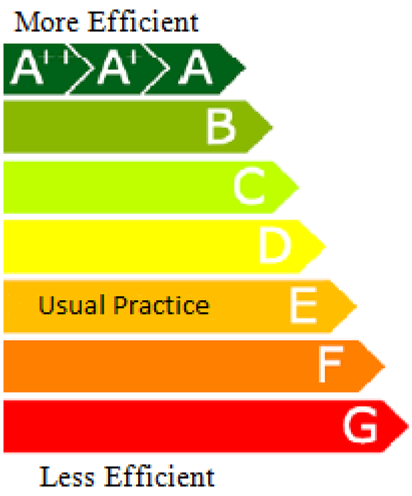

Figure 3- Global Performance Degrees of the LIDERA Certification System

A building is able to get the LIDERA certificate if its performance grade is at least C.

2.3.3.6. SBToolPT (Sustainable Building Tool, Portugal)

The structure of this tool is based on the international certification system SBTool, adapted to the Portuguese reality. The SBTool was developed by the non-profit association iiSBE (international initiative for the Sustainable Built Environment) with the collaboration of teams from more than 20 countries (Europe, Asia and America).

The Portuguese version was developed by the iiSBE Portugal with the collaboration of the University of Minho and the company Ecochoice. This system has specific modules for each type of building and it has 9 sustainability categories that contain several indicators/criteria and summarizes the building performance:

- Climate change and outdoor air quality;
- Land use and biodiversity;
- Energy efficiency;
- Materials and waste management;
- Waste efficiency;
- Occupant's health and comfort;
- Accessibilities;
- Awareness and education for sustainability;
- Life-cycle costs.

This system uses a different approach to weight the criteria, considering the reference value, the best practice value for each criterion and also the value achieved by that criterion.

The categories have also a weight that allows the calculation of the score of each category and of the overall performance of the building. The ranking scale is from A+ to E.

3

METHODOLOGY

3.1. INTRODUCTION

To achieve the aims of this thesis, the first step was to select the criteria of the study. This choice was made by taking into account the criteria present on the existing Building Sustainability Assessment tools but mainly the criteria considered by the DGNB Certification System. This decision was made because the final objective of this study is the implementation of the new weighting factors for the criteria, on the German certification system, thus all the ten criteria of study are also present on this certification system. Another important aspect of this choice was for all the criteria chosen to be related to the Building Physics. Thus, 10 criteria were selected and this list does not claim to be exhaustive.

After the selection of the criteria a questionnaire was developed with several questions about the ten criteria selected and also about the existing certification systems. This questionnaire was addressed to experts from all over the world and it was sent via e-mail. The objective of this chapter is to explain the methodology adopted in this thesis, since the choice of the criteria to be studied and their description of the development of the questionnaire and its content.

3.2. CRITERIA

As already mentioned, the 10 criteria selected for this study are present on the DGNB Certification System list of criteria. To avoid wrong interpretations or mistakes on the response phase of the questionnaire and make this study trustworthy, it was important to have a clear definition of each criterion present on this study. Thus, the definition of each criterion is in accordance with the definitions present on the DGNB Certification System for the respective criterion.

Thus, the criteria chosen to be part of this study are:

- Energy Demand;
- Thermal Comfort in Winter;
- Thermal Comfort in Summer;

- Indoor Air Quality;
- Acoustic Comfort;
- Visual Comfort;
- User Influence on Building Operation;
- Sound Insulation;
- Building Envelope Quality;
- Fire Protection.

3.2.1. Energy Demand

The DGNB certification system splits this criterion in two: *nonrenewable primary energy demand* and *total primary energy demand and share of renewable primary energy*. On this study it was decided to join those two into a criterion called Energy Demand.

The use of nonrenewable fossil energy sources should be minimized. The figure to be evaluated is the amount of nonrenewable primary energy needed for the construction, use, and dismantling of the building. Primary energy is energy from naturally occurring sources. This includes both nonrenewable and renewable energy. Black (bituminous) coal, brown coal (lignite), crude oil, natural gas, and uranium are nonrenewable energy sources; renewable energy includes solar energy, geothermal energy, hydropower, wind energy, and biomass [8]. The demand for nonrenewable primary energy is calculated throughout the building's lifecycle for construction, maintenance, operation, and dismantling [8].

The total demand for primary energy shall be minimized and the percentage of renewable energy shall be maximized during the life cycle of a property [8]. The total value of primary energy demands are evaluated, as well as the percentage of renewable energy demands, as compared to the total primary energy demands.

3.2.2. Thermal Comfort in Winter and Thermal Comfort in summer

The acceptance of the indoor climate is evaluated with focus on the factors: thermal comfort, air quality, noise and illumination. The thermal comfort of a person is closely linked to satisfaction at the work place. On the one hand it is defined by an overall comfort; on the other hand local uncomforting phenomenon can impact the thermal comfort. Thus, a person can feel thermal comfort but can be adversely affected by local draught on a body part. To assure thermal comfort all criteria have to be fulfilled [8].

For the evaluation of the thermal comfort, the following list of criteria are assessed:

- Operative temperature (quantitative);
- Draught (qualitative);
- Asymmetry of radiation temperature and flooring temperature (qualitative);
- Relative humidity (qualitative);
- Vertical thermal gradient.

Required records include documentation of the heating system design condition as well as documentation of the air conditioning plant and the characteristics of the air exhausts if applicable [8].

3.2.3. Indoor Air Quality

The goal is to assure the indoor hygiene and to avoid negative impacts on the user's state of health.

Through the choice of odorless and low-emission products the basis for low emission concentrations of fugitive and smell active substances can be established for interior spaces in the planning phase. The successful planning is ascertained by measuring the TVOC-concentration of the room air at the latest 4 weeks after completion of the building. The completion time point is defined when all stages that affect the quality of the interior air are terminated including building services and commissioning of the sanitary and ventilation plants but prior to furnishing by the user. With a checklist the following criteria are evaluated [8]:

- Indoor hygiene – fugitive organic substance (VOC);
- Indoor hygiene – felt air quality, unwanted odors;
- Indoor hygiene – microbiological situation, mould build-up.

3.2.4. Acoustic Comfort

The aim is to achieve a low level interference and background noise with speech intelligibility in all rooms to avoid affecting use, health and capability of the users. The lower the level of interference and background noises is, the less detraction and detriment to health and capability. High speech intelligibility in communication rooms and high absorbability of sound propagation to restrict the mutual interfering potential is of advantage [8].

For the evaluation of offices different acoustic input parameters are necessary:

- Average resulting overall noise pressure level LA,F,Ges in dB(A) as expression of the level of interferences;
- Reverberation period T in s, oriented on the values according to DIN 18041w (T/TDIN 18041);
- Absorption of sound propagation in multiple-person offices DA in dB/m.

Sound propagation is ascertained via calculation or measurement. Furnishing is only allowed to be taken into consideration if it is part of the architecture and building design.

3.2.5. Visual Comfort

Visual comfort shall be achieved by balanced illumination without appreciable interferences such as direct and reflected glare, a sufficient illumination level and the possibility to adjust illumination individually to the particular needs. Vitally important for the workplace contentment is the view that informs about time of day, location, weather conditions etc. Further criteria are nonglaring, light distribution and spectral colour in the room. The requirements are valid both for illumination by daylight and artificial light [8].

By an early and integral daylight and artificial light planning, a high quality of illumination can be created with low energy demands for illumination and cooling. Furthermore, a high degree of daylight use can enhance workplace capability and health and reduce the operational costs. In a checklist the visual comfort is evaluated:

- Daylight availability for the entire building (quantitative);
- Daylight availability for the permanent workplaces (quantitative);
- Visibility to the exterior (quantitative);
- Non-glaring – daylight (quantitative);
- Non-glaring – artificial light (quantitative);
- Light distribution – artificial light (quantitative);
- Color reproduction and spectral color (quantitative).

3.2.6. User Influence on Building Operation

Goal is the maximization of the user influence capabilities in the sectors ventilation, sun protection, visor, temperature as well as regulation of daylight and artificial light at the workplace.

Within an early and integral planning of measures that convey the users influence at the workplace, comfort can be conveyed. Advancement of comfort leads to increased satisfaction and achievement of users in office and administration buildings. A checklist of the possible influence by users is evaluated with the following criteria:

- Ventilation;
- Sun protection;
- Visor;
- Temperatures during the heating period;
- Temperatures outside the heating period;
- Regulation of daylight and artificial light.

3.2.7. Sound Insulation

Noise protection shall be improved. Minimum requirements of structural noise protection are defined in DIN 4109. This only addresses the unacceptable but not automatically all possible noise pollutants. Additional requirements to noise protection in office buildings are: avoiding loss of concentration, protection of privacy and confidentiality, and consideration for people with limited hearing.

Measures that exceed the minimum noise protection requirements lead to a better score. A pointless exceeding of the standards shall be avoided. The quality of noise protection of building parts is determined from the certificate of noise protection or the quality of the specified building parts. It is evaluated if the building parts comply with the regulations of DIN 4109 supplement 2 and where the regulations are exceeded:

- Airborne noise protection against surrounding noise;
- Airborne noise protection against other workplaces and against the own workplace;
- Impact-sound protection against other workplaces and against the own workplace;
- Structure-borne sound protection against other workplaces and against the own workplace.

3.2.8. Building Envelope Quality

The energy demand for the space conditioning shall be minimized, high thermal comfort shall be assured, and structural damages shall be avoided. The quality of heat insulation and moisture-proofing of the building's shell shall be optimized.

Basis of the requirements are the specifications of EnEV 2007, DIN 4108, and DIN EN 12207. A higher quality increases the score. Individual requirements for the parts of the building's shell are described.

The building's shell is evaluated with a checklist of the following criteria:

- Average heat transmission coefficient (qualitative);
- Consideration for thermal bridges (qualitative);
- Permeability of joints (qualitative);
- Formation of condensate (qualitative);
- Air change rate (quantitative).

3.2.9. Fire Protection

The quality of fire protection measures shall be increased. The main cause of death involving fire in buildings is toxic smoke. Measures that exceed the fire protection regulations can be rated positively. However, fire protection measures that exceed the legal regulations should also consider the total economic impact as well as additional emissions caused by the addition amounts of raw materials and supplies.

A checklist evaluates the following issues, as long as they exceed the minimum requirements set by the building authorities:

- Is the building equipped with an area-wide fire alarm and electro acoustic alarm system, so that a prompt response in a hazardous situation is possible?
- Is a sprinkler system present that delays the fire's expansion, and that enables the fire department to carry out effective fire fighting at an early stage?
- Can the ventilation system be used for smoke extraction in case of fire, and does the system prevent a re-circulation of the (smoke-filled) air during the smoke extraction? Do air duct systems have fire dampers to prevent the distribution of smoke during a fire?

- Is the spreading of smoke and fire avoided beyond the required amount by reducing the sizes of the fired compartments?
- Is spreading of smoke and fire avoided through structural measures beyond the required amount?

The necessary parameters for the calculation can be extracted from the state building code, the fire protection concept, and the announcement documents.

3.3. QUESTIONNAIRE

After the selection and clear definition of each criterion having been made, a questionnaire (Figure 4) was developed. With this questionnaire it was expected to find valuable data that would make the development of the weighting factors possible for the criteria.

This questionnaire was sent via e-mail to University professors, researchers and also to auditors and consultants of several existing Building Sustainability Assessment tools. All the people chosen to be part of this study have knowledge of building physics and sustainable constructions and/or have experience with the Certification Systems for sustainable constructions.

The questions present on this questionnaire were not mandatory. In order to make this study trustworthy a screening of the answers was done. At this screening, people who answered to less than 75% of the questions were eliminated from the data analysis.

A total of 229 answers has been collected but, after the screening was done, a total of 210 valid answers resulted. The statistical analysis made in this study is based on these 210 responses.

In this questionnaire several questions with respect to the 10 criteria were made, but also questions related to personal experiences with the Building Sustainability Assessment tools that each person was familiar with, as well as some personal questions to help in the analysis of the collected data.

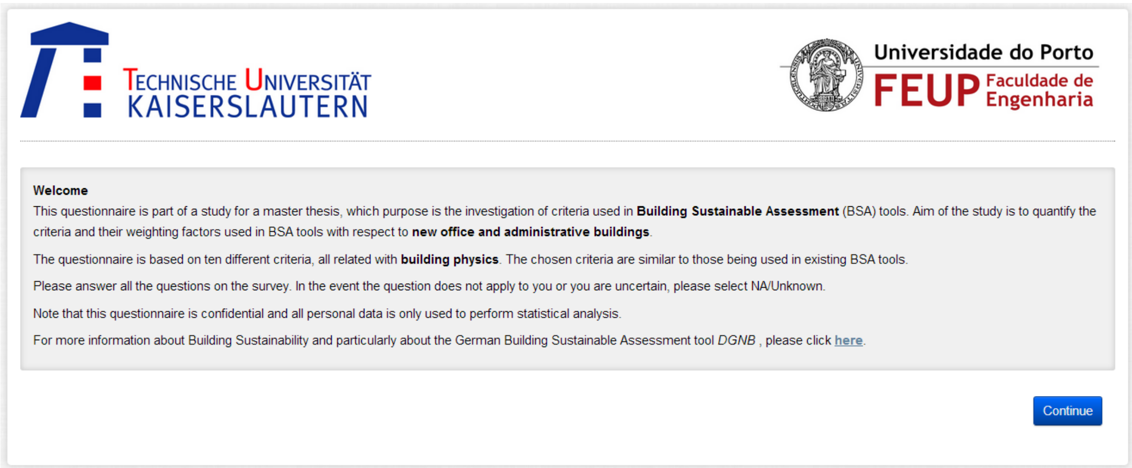

Figure 4 - Homepage of the questionnaire

On the following sub-chapter a description of the questionnaire developed will be made.

3.3.1. Description of the Questionnaire

Importance of the Criteria

One of the key questions on the questionnaire dealt with the importance in terms of sustainability of each of the criterion, on the list of 10 criteria, from the perspective of the people surveyed. The surveyed people were asked to "Rate each of the following criteria taking into account the importance in terms of sustainability". For the assessment, a scale from 1 to 6 was used, in which 1 indicates "very important" and 6 "very unimportant". An option "NA/Unknown" was also available to those people who did not want or did not know what to answer for each criterion (Figure 5). To avoid wrong interpretations by the people inquired, each criterion had a small description. All these descriptions are in accordance with the ones present on the DGNB Certification System.

Rate each of the following criteria taking into account the importance in terms of sustainability.

For more information about the criteria please click **here**.

	Very important 1	Important 2	Slightly important 3	Slightly unimportant 4	Unimportant 5	Very unimportant 6	NA/Unkown
Demand of Energy (Amount of primary energy needed for the construction, use and dismantling of the building)							
Thermal Comfort in Winter (Operative temperature, relative humidity, drafts, ...)							
Thermal Comfort in Summer (Operative temperature, relative humidity, drafts, ...)							
Indoor Air Quality (Indoor hygienic air quality principles that might affect users' wellbeing, ...)							
Acoustic Comfort (Level of interference and background noise with speech intelligibility in all rooms)							
Visual Comfort (Daylight availability for the entire building, artificial light distribution, ...)							
User Influence on Building Operation (Possibility to control temperature, ventilation, sun protection, ...)							
Sound Insulation (Improvement of the noise protection apart from the minimum required in regulations and standards)							
Building Envelope Quality (Improvements regarding to the standards in terms of thermal transmittance, air permeability, ...)							
Fire Protection (Measures that exceed the fire protection regulations)							

Figure 5 - First question of the questionnaire about the importance of the criteria

Frequency of the deficiencies

Another important question on this questionnaire was about the frequency of occurrence of deficiencies. With each one of the 10 criteria on study several deficiencies were associated (Table 3). Thus, it was asked "With which frequency do you think, the following deficiencies occur in buildings?". A scale from 1 to 6 was used, in which 1 corresponds to "always" and 6 to "never". Once again the people surveyed had the "NA/Unknown" option, in the cases of people who did not know or did not want to answer (Figure 6).

Table 3- List of the 10 Criteria on study and respective deficiencies associated

Criteria	Deficiency
Energy Demand	Excessive energy consumption
Thermal Comfort in Winter	Cold room temperature, cold walls.
Thermal Comfort in Summer	Overheating in Summer
Indoor Air Quality	Poor ventilation, presence of volatile organic compounds.
Acoustic Comfort	High background noise and reverberation time levels.
Visual Comfort	Deficient artificial light distribution, poor daylight availability.
User Influence on Building Operation	Impossibility to control ventilation, temperatures.
Sound Insulation	Pointless exceeding of the standards.
Building Envelope Quality	Poor air permeability class, condensation within structure.
Fire Protection	Absence of sprinkler system, automatic smoke detectors.

Again, this list of deficiencies is present on the DGNB Certification System.

With which frequency do you think, the following deficiencies occur in buildings?

	Always 1	Frequently 2	Occasionally 3	Rarely 4	Very Rarely 5	Never 6	NA/Unkown
Energy Demand (Excessive energy consumption, ...)							
Thermal Comfort in Winter (Cold room temperature, cold walls, ...)							
Thermal Comfort in Summer (Overheating in summer, ...)							
Indoor Air Quality (Poor ventilation, presence of volatile organic compounds, ...)							
Acoustic Comfort (High background noise and reverberation time levels, ...)							
Visual Comfort (Deficient artificial light distribution, poor daylight availability, ...)							
User Influence on Building Operation (Impossibility to control ventilation, temperatures, ...)							
Sound Insulation (Pointless exceeding of the standards, ...)							
Building Envelope Quality (Poor air permebility class, condensation within the structure, ...)							
Fire Protection (Absence of sprinkler system, automatic smoke detectors, ...)							

Figure 6- Extract of the questionnaire - Question about the frequency of occurrence of deficiencies on buildings

As it is possible to see on the Figure 6, to each criterion a description of the deficiency related with that criterion was associated.

Extent of deficiencies

Another question was made about the personal experience of the people surveyed with the deficiencies related to the ten criteria in the study.

It was asked, "To what extent have you personally suffered at your work or home from any of the deficiencies belonging to:". The deficiencies present on this question were the same as the ones that were asked about on the question about their frequency of occurrence and can be consulted on Table 3. For the assessment a scale from 1 to 6 was used, in which 1 indicates an "Extremely large extent" and 6 indicates an "Extremely small extent" and it was once again possible to answer "NA/Unknown" (Figure 7).

To what extent have you personally suffered at your work or home from any of the deficiencies belonging to:

	Extremely large extent 1	Very large extent 2	Large extent 3	Small extent 4	Very small extent 5	Extremely small extent 6	NA/Unkown
Energy Demand (Excessive energy consumption, ...)	○	○	○	○	○	○	○
Thermal Comfort in Winter (Cold room temperature, cold walls, ...)	○	○	○	○	○	○	○
Thermal Comfort in Summer (Overheating in summer, ...)	○	○	○	○	○	○	○
Indoor Air Quality (Poor ventilation, presence of volatile organic compounds, ...)	○	○	○	○	○	○	○
Acoustic Comfort (High background noise and reverberation time levels, ...)	○	○	○	○	○	○	○
Visual Comfort (Deficient artificial light distribution, poor daylight availability, ...)	○	○	○	○	○	○	○
User Influence on Building Operation (Impossibility to control ventilation, temperatures, ...)	○	○	○	○	○	○	○
Sound Insulation (Pointless exceeding of the standards, ...)	○	○	○	○	○	○	○
Building Envelope Quality (Poor air permebility class, condensation within the structure, ...)	○	○	○	○	○	○	○
Fire Protection (Absence of sprinkler system, automatic smoke detectors, ...)	○	○	○	○	○	○	○

Figure 7- Extract from the questionnaire- Extent of the deficiencies

With this question the intent is to find out whether the answers of the people surveyed were or not influenced by their personal experiences at their home and/or work.

Building Sustainability Assessment tools

After the questions about the ten criteria, some questions about the building sustainability assessment tools were made. At first, it was important to know if the people surveyed had or not any kind of experience with these certification systems. Thus, it was asked "Have you had experiences with Building Sustainability Assessment tools (DGNB, BREEAM, LEED, LIDERA, etc.)?". With this question it was already possible to divide the people surveyed into two groups, which could prove to be important later, in the data analysis: The people with experience with BSA tools and the people without experience with these tools.

At this stage of the questionnaire, the people who answered “No”, i.e. people who do not have experience with any existing Building Sustainability Assessment tool, were redirected to the last page of the questionnaire, where some personal questions were made. People who have experience with at least one BSA tool were redirected to some more questions about this experience.

Thus, to the people surveyed who had experience with BSA tools it was asked, “Which Building Sustainability Assessment system(s) have you already had experience with?”. On this question possible answers were given, namely the BSA tools already introduced in Chapter 2 (DGNB, LEED, BREEAM, LIDERA, HQE and CASBEE), and also the option “Other” with the possibility to type in the name of that BSA tool.

There are many possible kinds of experiences with the existing certification systems. In order to understand how well the people inquired knew the certification systems it was asked “What kind of experience have you had with the Building Sustainability Assessment System?”. This question is important because the weighting factors are a very specific subject on the BSA tools. The possible answers for this question were: “I have been involved in its development”, “I am involved with its application (as an auditor or consultant, for example)”, “I used it “as a client” and once again the option “Other” was available with the possibility of typing in that kind of experience.

The following question was about the failures that the people surveyed thought each certification system they knew had. Thus, it was asked “Which failures would you identify as failures of the BSA Systems?”. Thus, for each BSA system several possible answers were available. Those answers were: “Extensive list of criteria”, “Restricted list of criteria”, “Inappropriate attribution of the weighting factors of criteria”, “Other”, “None” and “Don’t know”. For the people surveyed who answered “Other” a box to fill in with the specification of that failure was available. It is important to note that the people surveyed only had access to the BSA tools that they had experience with, so they only pointed out the failures of the certification systems they knew and had enough experience with which to do it.

Personal Questions

After the questions about the BSA tools, some personal questions were made. These questions were made to help in the statistical analysis, enabling the data analysis as per country, age, gender… On these questions we can highlight the last one in which it was asked “In which specific field(s) do you consider yourself an expert?”. The answer options were “Acoustics”, “Fire Protection”, “Energy and Heat”, “Rehabilitation”, “Ventilation”, “Indoor Environment Quality”, “Other” and “None”. With this question it is possible to make different comparative analysis. For example, it is possible to compare the answers of the experts on Fire Protection and the experts on Energy and Heat about the importance of the criteria. This kind of analysis might prove to be important.

Finally, on the last page of the questionnaire a box was available to people surveyed to fill in with any comments or suggestions about the questionnaire.

4

NEW WEIGHTING FACTORS

4.1. ANALYSIS OF THE RESULTS

4.1.1. DATA COLLECTION AND SIMPLE ANALYSIS

Data were collected using the functionalities of the online survey tool, Unipark. When the questionnaire was deactivated all the data collected was imported to the SPSS statistical software to proceed with the data analysis.

Thus, with the support of the SPSS statistical software, the data of the questionnaire was analyzed.

As already mentioned this questionnaire was sent via email all over the world and 210 answers were received. From those 210 people surveyed, almost 70% were males and 30% were females (Figure 8). The age distribution is represented in Figure 9 and it is possible to see that the biggest group of ages of the people surveyed is 25 to 35 followed by a group of 36 to 45 years of age. Another relevant fact is that only 1% of the people had less than 25 years old.

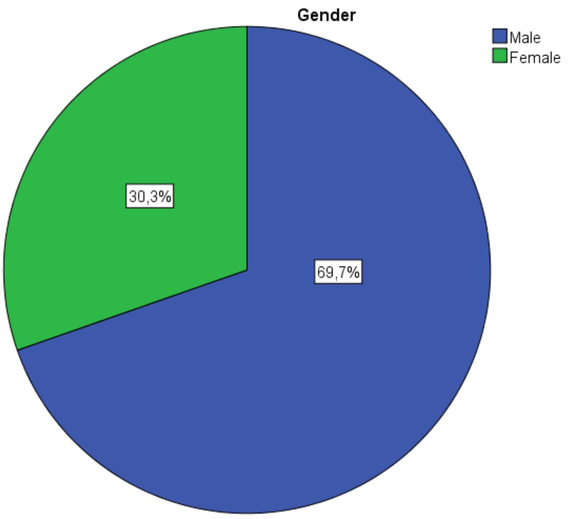

Figure 8- Gender distribution of the people surveyed

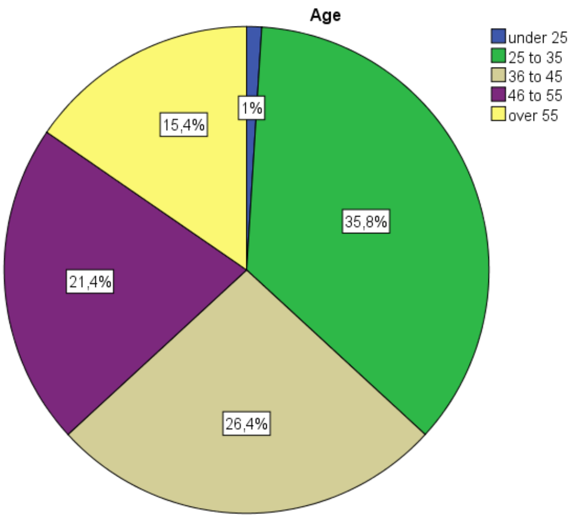

Figure 9- Age distribution of the people surveyed

The answers collected from this questionnaire came from at least 38 different countries. It is possible to verify that the majority of the answers came from Germany with the participation of almost 60 people. The second country with more answers provided on this questionnaire was Portugal followed by France and Italy, but there is a big difference between the number of answers from these countries and the number of answers that came from Germany. In this Figure, it is also possible to see that the second set of answers with greater number is “Other”. This happens because the group “Other” gathers several countries less represented with only a few answers per country. The group “NA” gathers the answers of people who did not want to specify their nationality.

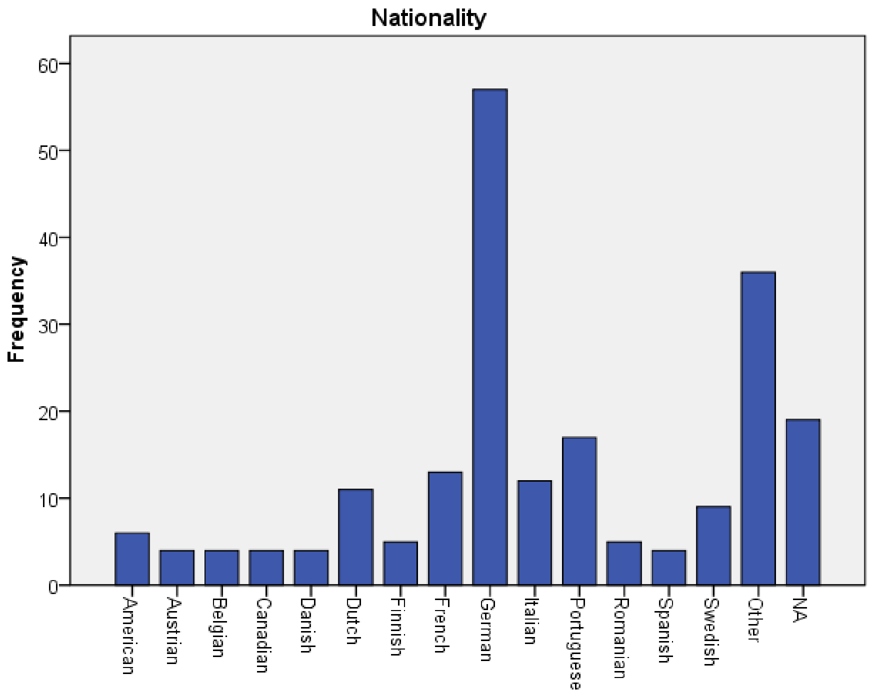

Figure 10- Nationalities of the people inquired

As already mentioned in Chapter 3 of this thesis, one of the questions present in the questionnaire developed was about the field of specialization of the people who answered it.

Figure 11 represents the distribution of the fields of specializations. In this question each person was able to choose more than one answer. The Energy and Heat specialization was the one with more number of answers, 130. It is followed by “Other” specializations and by Indoor Environment Quality. The specializations less chosen were Acoustics and Fire Protection and only 12 people did not consider themselves as experts in one of the specific fields of the building constructions.

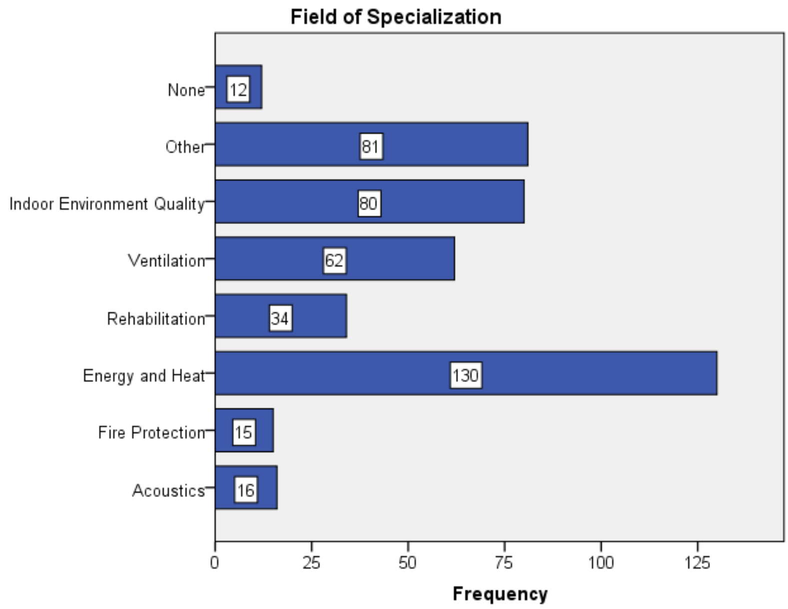

Figure 11- Fields of specialization of the people surveyed

From all the 210 answers received, more than 71% of the people already had experience with at least one Building Sustainability Assessment system (Figure 12).

The BSA tool with which there is more people surveyed with experience is the American, LEED, followed by the British certification system, BREEAM. In the third place is the German certification system, DGNB, with more than 60 people. The Portuguese, LIDERA is the one that people surveyed have less knowledge about, possibly because this system is very recent.

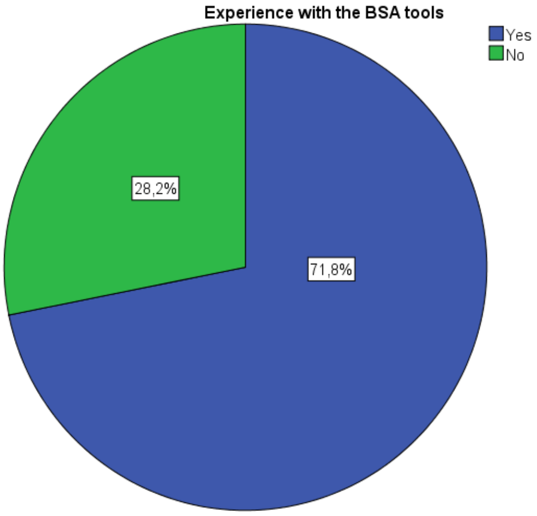

Figure 13- Experience with the BSA tools

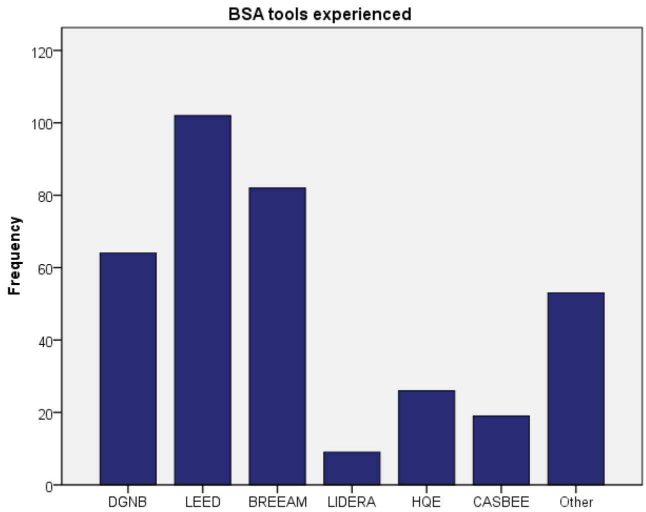

Figure 12- BSA tools experienced

People that are involved in the application of the existing BSA tools (like auditors or consultants), represent 50% of the people that answered the questionnaire (Figure 14). The third most common type of experience is from people that were involved in the development of these certification systems. One quarter of the people had another type of experience with the BSA tools (mostly academic researches). This means that the great majority of the people inquired had a really good knowledge about the BSA tools.

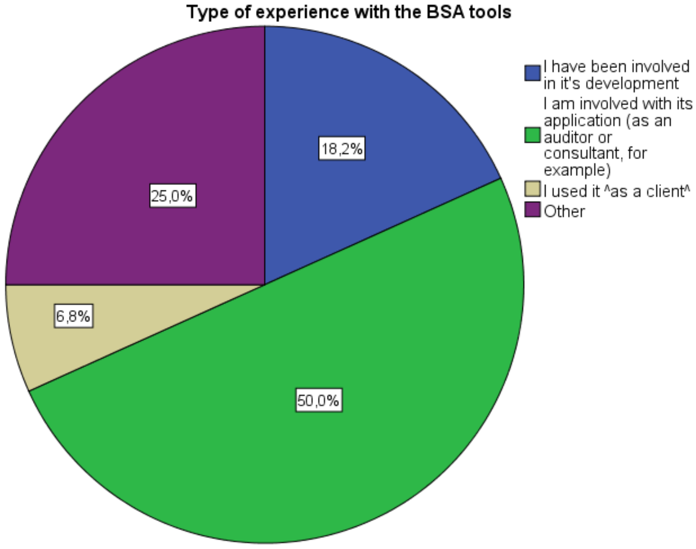

Figure 14- Type of experience with the BSA tools

In Figure 15 the failures that the people surveyed think each BSA tool has are represented, from the systems that they have experience with.

It is possible to see that in all the BSA tools the most common failure, from the opinion of the people surveyed, is the inappropriate attribution of the weighting factors of criteria. It is notable that for BREEAM and LEED people that think that the weighting factors are not the most correct is the double of the number of the ones that chose each of the other possible failures. For the DGNB certification system, this number is balanced with the failure "Extensive list of Criteria", but it is still the biggest.

It is noteworthy that the certification systems BREEAM and LEED are the ones that have associated a larger number of failures, on the opinion of the people inquired. This happens because only people with knowledge with each one of the systems could point out their respective failures and those two systems are the most known by the people who answered the questionnaire.

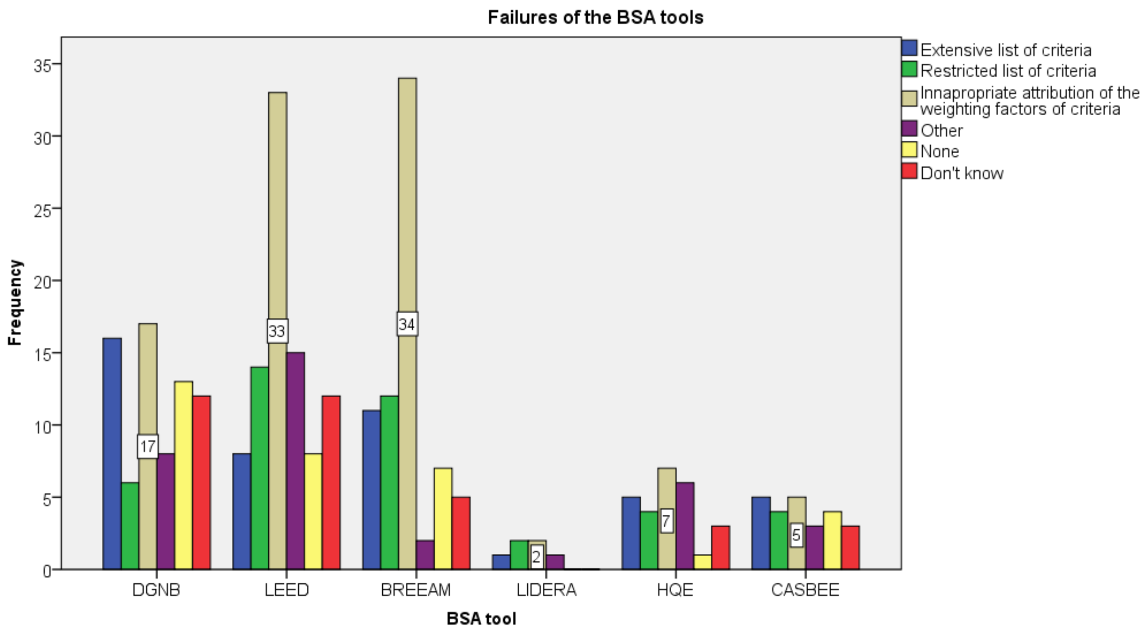

Figure 15- Failures of the BSA tools

4.1.2. Criteria Analysis

4.1.2.1 Introductory note

For the study of the criteria and its weighting factors, several approaches have been made.

At first, an overall analysis of the answers about the criteria of the people surveyed was made, considering the 210 valid answers. Then, different analyses were made, considering more restricted groups among those 210 people. Examples of those groups are: people from Germany, North European Countries and South European Countries, people with experience with the DGNB certification system and people with experience with another BSA tool, analysis per field of specialization, among others. Thus, it is possible to compare the results between the different groups and the data analysis will be more complete.

The analysis made consist on the ranking of the 10 criteria based on the average answers of each group of people. Thus, the results are presented in the same scale from the one used on the questionnaire, from 1 to 6.

4.1.2.1. Overall

The overall analysis considers all the valid answers given by the people surveyed.

Figure 16 represents the importance of each criterion, in terms of sustainability, on the perspective of all the people who answered the questionnaire. In this figure, the red dots represent the averages and the standard deviation is shown as a line.

The results clearly show that the Demand of Energy is the most important, with an average score of 1, 45. This criterion is immediately followed by the Indoor Air Quality, Thermal Comfort in Winter and Thermal Comfort in Summer. On the other side, Fire Protection is considered the least important criterion among the 10 criteria, but its average score is considerable. Besides being the criterion with the lowest average score, it is considered important.

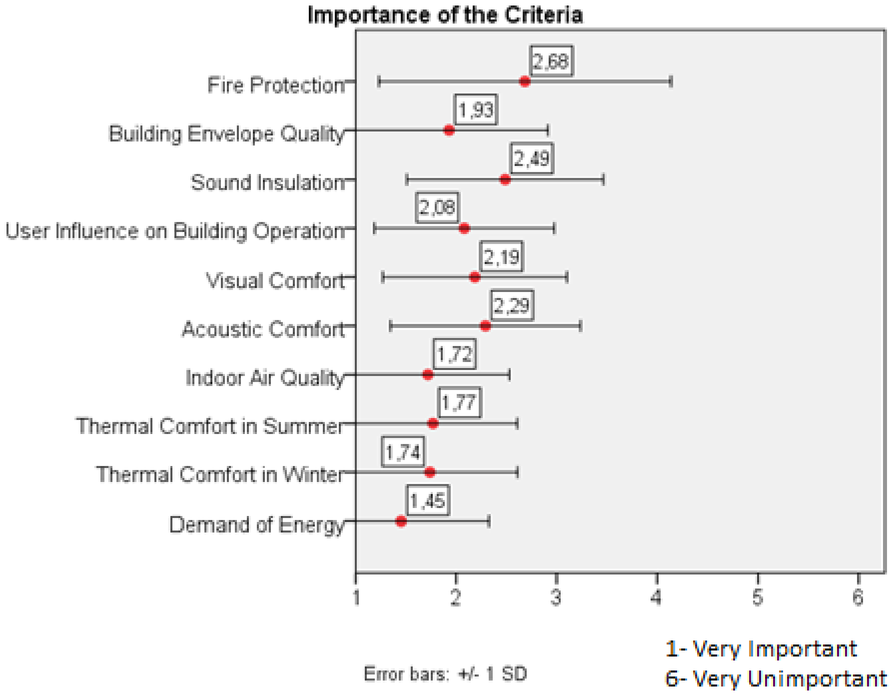

Figure 16- Importance of the Criteria – Overall

The same analysis was made for the frequency that deficiencies occur on buildings, in the opinion of the 210 people (Figure 17). Problems related with the Energy Demand, like excessive consumption of energy are of the opinion of the people inquired the most frequent deficiencies. Deficiencies on buildings related with the Indoor Air Quality, Thermal Comfort in Winter and Summer and the User Influence on Building Operation follow the ones related with the Energy Demand in this ranking and are considered frequent. The deficiencies related with the Fire Protection are at the bottom of this ranking, but the answers were very variable, as shown by a large standard deviation.

In Figure 18, it is possible to see the similar analysis made for the extent of suffering on their home or work from the deficiencies related with the 10 criteria. The ranking of the majority of the deficiencies associated with the 10 criteria is situated in the middle of the scale, between the large and the small extent. However, problems related with the criteria Thermal Comfort in Summer, Thermal Comfort in Winter and Energy Demand assume a larger extent than the others. The deficiencies on buildings related with the Fire Protection have almost a ranking matching the very small extent.

The results of the frequency of occurrence of deficiencies on buildings are in accordance with the results of the extent of suffering with those deficiencies. The deficiencies associated with the criteria Energy Demand, Thermal Comfort in Summer, Thermal Comfort in Winter and User Influence Building on Building Operation have the highest scores and on the other side, the ones related with the Fire Protection and Sound Insulation have the lowest scores.

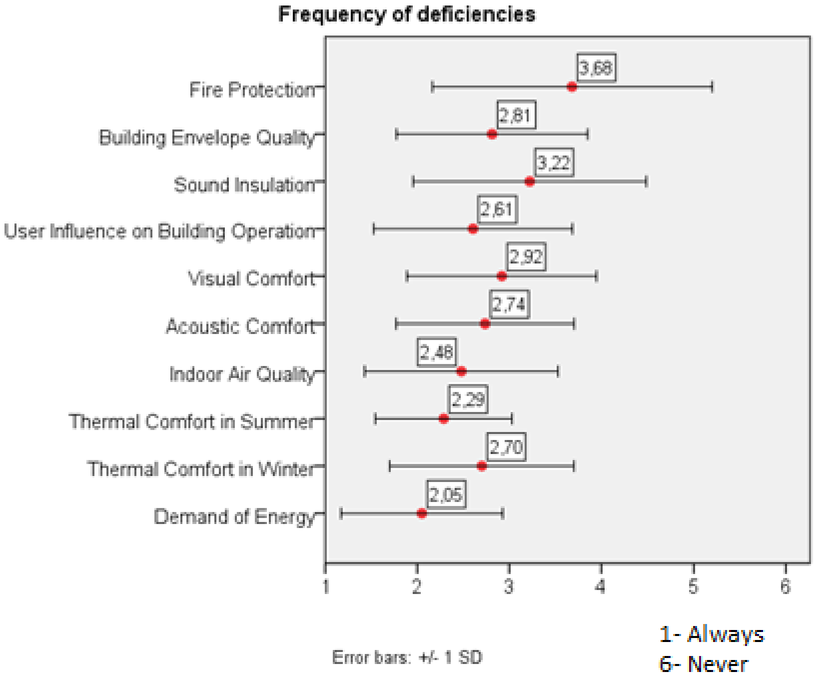

Figure 17- Frequency of deficiencies - Overall

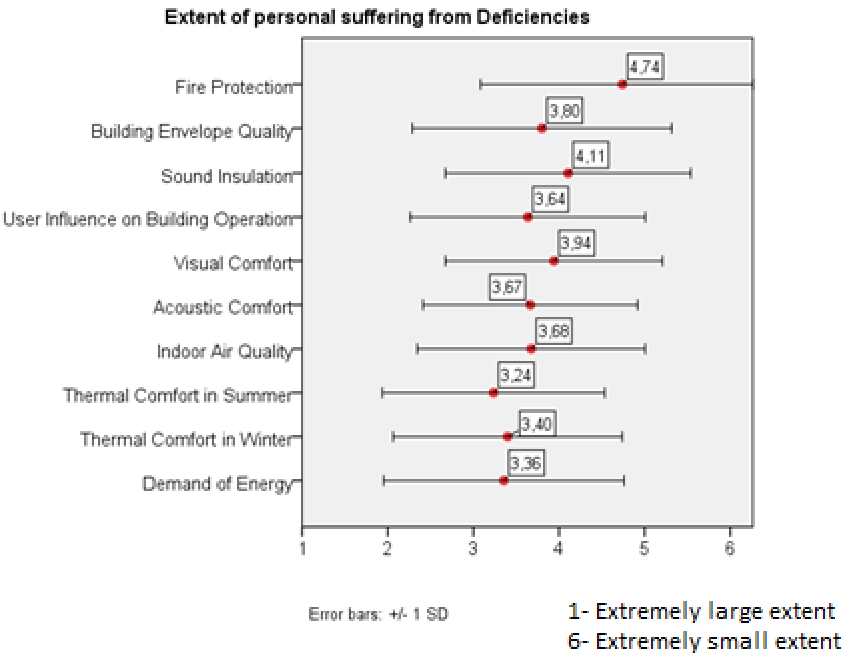

Figure 18- Extent of personal suffering with the deficiencies – Overall

After these analysis a correlation analysis to assess the relationships between the three variables of relevance of criteria was made: importance of the criteria, frequency of the deficiencies and extent of personal suffering from the deficiency (Table 4).

A linear correlation between each two variables was assumed and therefore applied the calculation of Pearson's correlation coefficient (r) on this analysis. The correlation coefficient can take values between -1 and +1, where r = -1 means an absolute negative correlation with linear dependence and r = +1 means an absolute positive correlation with linear dependence.

Table 4- Correlations between variables – Overall analysis

Criteria	Importance Vs Frequency of Deficiencies r	Importance Vs Extent of the Deficiency r	Frequency of Deficiencies Vs Extent of the Deficiency r
Energy Demand	0.117	0.078	0.261**
Thermal Comfort in Winter	0.169*	0.165*	0.440**
Thermal Comfort in Summer	0.175*	0.210*	0.296**
Indoor Air Quality	0.112	0.100	0.204**
Acoustic Comfort	0.281**	0.056	0.324**
Visual Comfort	0.246**	0.171*	0.485**
User Influence on Building Operation	0.065	0.007	0.446**
Sound Insulation	0.327**	0.150*	0.433**
Building Envelope Quality	0.184**	0.212**	0.467**
Fire Protection	0.306**	0.181*	0.467**

From these correlations it is possible to take the following conclusions:

- Importance Vs Frequency of Deficiencies – There are no significant correlations between the importance attributed to a criteria and the frequency of deficiencies related with these criteria. All the values are too close to zero to be considerable.

- Importance Vs Extent of the Deficiency – Once again there is no correlation between the importance assigned to each criterion and the fact that the respondent has or not been in their home or work some of the deficiencies identified. This might mean that the answers given about the importance of the criteria were not affected by personal experience but based on the real opinion of the respondent.
- Frequency of Deficiencies Vs Extent of the Deficiency - There are some correlations between these two variables but not very strong, something already expected. Respondents associate the frequency of occurrence of disabilities in residential or office to their personal experience, ie, the lived experiences in terms of the existence of defects in their own home or workplace. They export their lived experiences, from a personal to a general plan.

4.1.2.2. Analysis per experience with the BSA tools

One of the approaches taken on the data analyses was to analyze the data taking into account the experience with the BSA tools. Thus, first the data was analyzed considering only the answers of people with experience with at least one BSA tool, which means considering 148 answers.

The results, in terms of importance of the 10 criteria are presented on the Figure 19.

It is possible to see that the criterion Energy Demand is considered of greater importance. This criterion is followed by Thermal Comfort in Winter, Thermal Comfort in Summer and Indoor Air Quality. Fire Protection is the least important criterion of the 10 studied, in the opinion of people with experience with BSA tools that answered the questionnaire.

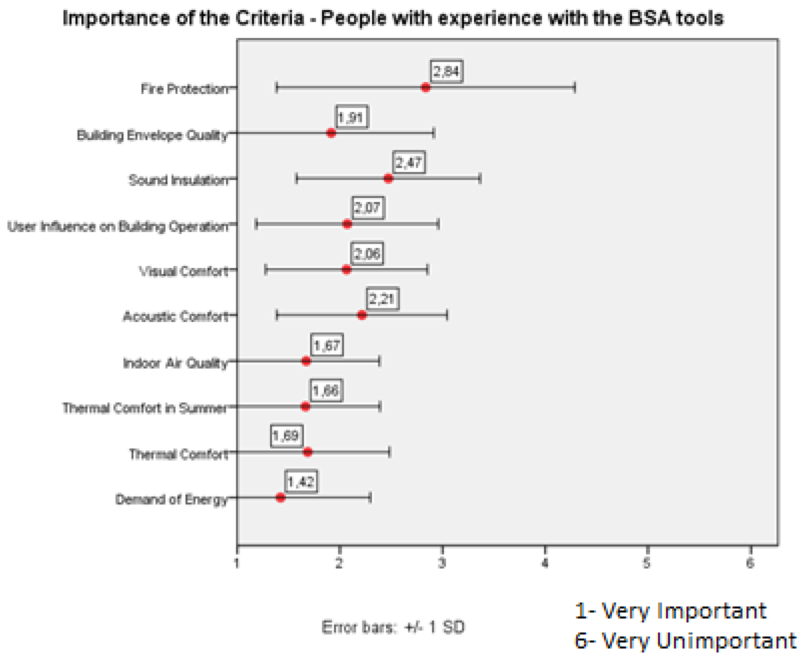

Figure 19- Importance of the Criteria - People with experience with the BSA tools

In Figure 20 the average frequency of occurrence of deficiencies related with the 10 criteria is represented, on the perspective of people with experience with the BSA tools.

In this case, problems related with the energy demand are the most common, as well as problems related with the thermal comfort in summer. Once again the problems with fire protection are considered less frequent.

People who belong to this group have suffered in a larger extent from problems related to thermal comfort in summer at their homes or work, as it is possible to see in Figure 21. The deficiencies on buildings related with the Fire Protection almost have a ranking matching the very small extent.

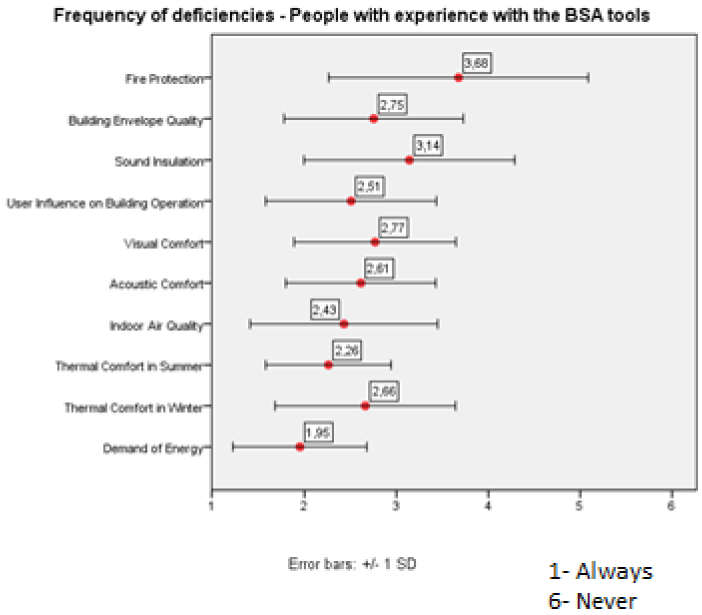

Figure 20- Frequency of deficiencies - People with experience with the BSA tools

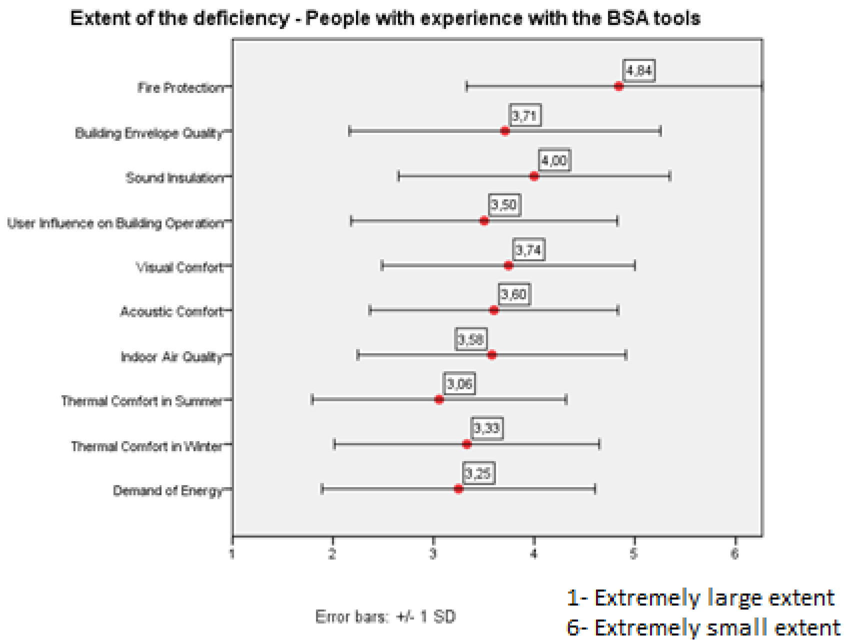

Figure 21- Extent of personal suffering with the deficiencies - People with experience with the BSA tools

On table 5 a similar analysis to the one made on table 4 for the overall is made. But this time the analysis is focused only on people with experience with the BSA tools.

Table 5- Correlations between variables – People with experience with the BSA tools

Criteria	Importance Vs Frequency of Deficiencies r	Importance Vs Extent of the Deficiency r	Frequency of Deficiencies Vs Extent of the Deficiency r
Energy Demand	0.265**	0.060	0.401**
Thermal Comfort in Winter	0.228**	0.317**	0.393**
Thermal Comfort in Summer	0.167*	0.229**	0.322**
Indoor Air Quality	0.156	0.172*	0.198*
Acoustic Comfort	0.286**	0.113	0.213*
Visual Comfort	0.291**	0.224**	0.484**
User Influence on Building Operation	0.054	0.032	0.441**
Sound Insulation	0.462	0.207*	0.360**
Building Envelope Quality	0.199*	0.260**	0.440**
Fire Protection	0.408**	0.347**	0.561**

The results of this table are very close to the ones reached in table 4.

As it is possible to see, the strongest correlation existing is between the variables frequency of deficiencies and the extent of deficiencies. As on the overall analysis, this might mean that people associate their personal suffering from a construction problem at their home or work to a general plan. The correlations between the other variables are not significant.

Then, the same analysis was made, but considering only the people with experience with the DGNB certification system. The total of people with knowledge on DGNB system is 64.

Figure 22 represents the average importance attributed by the people with experience with DGNB. Energy Demand is once again considered very important, like the Thermal Comfort in Winter and Summer. Fire Protection is considered important, however it is the criterion with the worst importance score of the 10 studied.

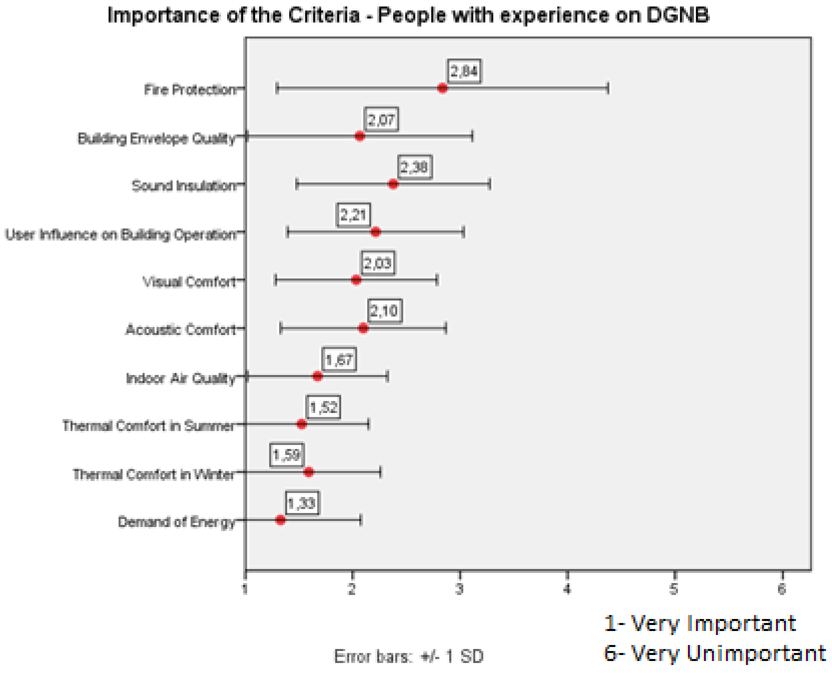

Figure 22- Importance of the Criteria - People with experience with the DGNB system

Then, the average frequency of occurrence of deficiencies related with the 10 criteria was studied. The results are very similar to those already shown for the overall and people with experience with BSA tools analyses. Problems like the excessive consumption of energy lead this ranking and on the other side problems related with Fire Protection are considered less frequent (Figure 23).

The extent of the deficiencies are represented on Figure 24 and it is possible to see that the deficiencies related with Thermal Comfort in Summer have the highest score, followed by Energy Demand, and Thermal Comfort in Winter. People with experience with the German system consider suffering at a very small extent from problems related with Fire Protection.

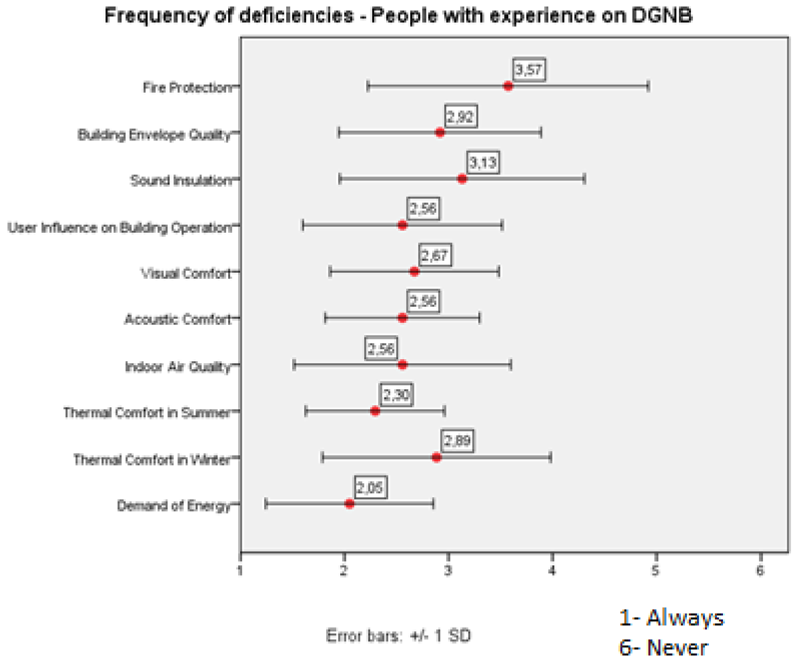

Figure 23- Frequency of the deficiency – People with experience with DGNB

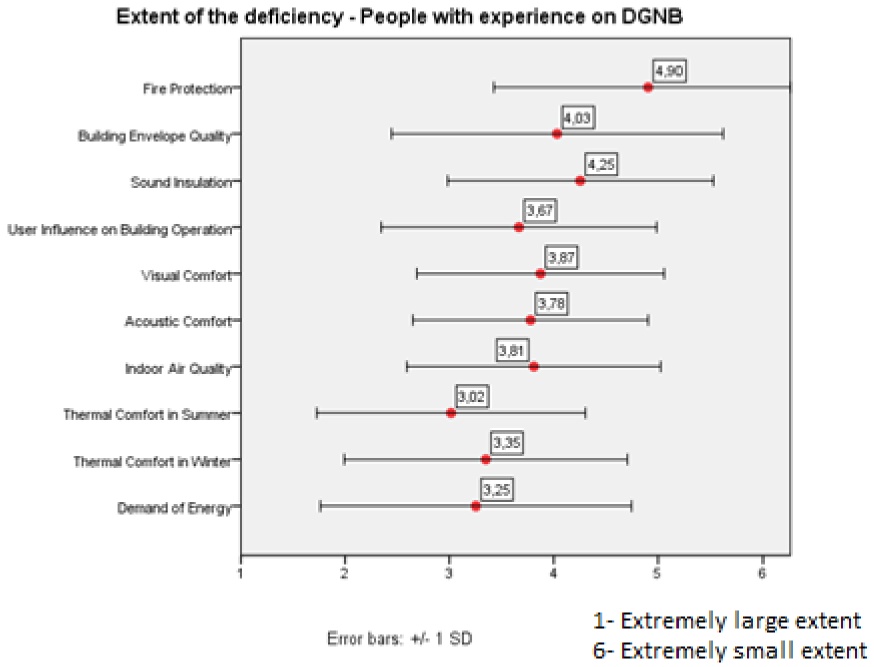

Figure 24- Extent of personal suffering with the deficiencies - People with experience with the DGNB system

For this analysis a test of the correlations between variables was also made (Table 6).

Table 6- Correlations between variables – People with experience with the DGNB system

Criteria	Importance Vs Frequency of Deficiencies r	Importance Vs Extent of the Deficiency r	Frequency of Deficiencies Vs Extent of the Deficiency r
Energy Demand	0.206	-0.052	0.297*
Thermal Comfort in winter	0.154	0.083	0.349**
Thermal Comfort in Summer	0.268*	0.092	0.410**
Indoor Air Quality	0.125	0.023	0.033
Acoustic Comfort	0.349**	0.169	0.330**
Visual Comfort	0.270*	0.129	0.527**
User Influence on Building Operation	0.096	0.071	0.454**
Sound Insulation	0.486**	0.207	0.303*
Building Envelope Quality	0.246	0.238	0.445**
Fire Protection	0.437**	0.307*	0.533**

The correlations are once again almost inexistent. Only the variables Frequency of Deficiencies and Extent of deficiencies have some correlations, but they are not strong.

These results are very similar to those already presented in this thesis.

On the next subchapter more similar analyses are presented, but considering different target groups. On those analyses only the average results for the importance of the criteria will be presented because the results are very close to those already presented. Further analyses might be found on the appendices of this thesis.

4.1.2.3. Analysis per Region

Another of the approaches taken on the data analyses was to separate the value answers per region.

As the answers came from different parts of the world and mainly from countries of Europe, while in most of the cases it was a few answers per country, the division of the data on 3 groups was decided: Germany, North European Countries and South European Countries. These 3 groups make up a total of 115 people, which means more than half of the sample. After the separation of the data per region, a similar analysis to the one made for the Overall sample was taken.

Thus, in Figure 25 the average ranking of importance of the 10 criteria is represented. The criterion Demand of Energy is considered as high importance, with an average score of 1,38. It is followed by the criteria Thermal Comfort in Summer, Thermal Comfort in Winter and Indoor Air Quality. Fire Protection is considered the least important of the 10, but still with a good average score in terms of importance, 2,58.

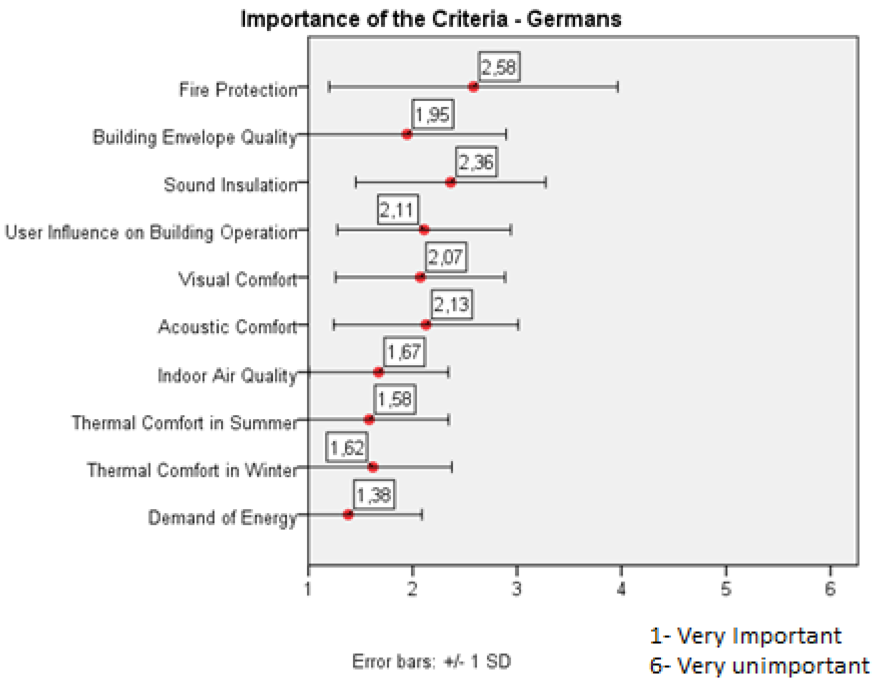

Figure 25- Importance of the criteria - Germany

Figure 26 represents the average importance of the 10 criteria on the perspective of people from the North European Countries. This group has a total of 22 people and it is composed of the following countries: Denmark, Sweden, Norway, Finland, Lithuania, Estonia and Latvia.

In the opinion of people from Northern Europe, the criterion with less importance is the Fire Protection, with an average score of 3,20. Indoor Air quality is, for this target group the most important criterion, with a score of 1,40. Demand of Energy, Thermal Comfort in Winter and Thermal comfort in Summer, follows the Indoor air Quality criterion, as the ones of most importance.

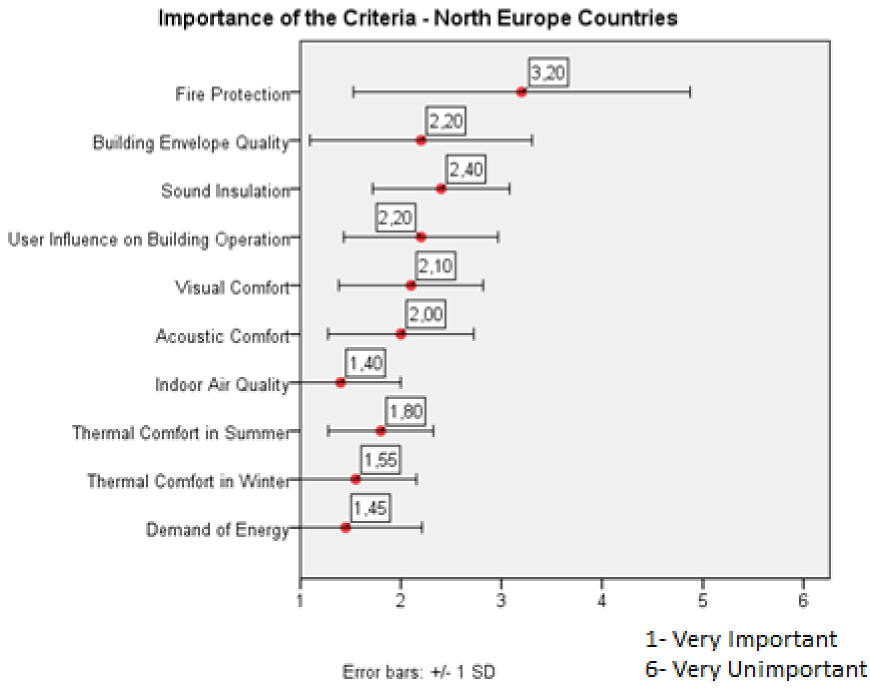

Figure 26- Importance of the Criteria - North Europe Countries

Then, the same analysis was made but considering the people from Southern Europe. The people who belong to that group are from: Portugal, Spain, Italy and Turkey. This group has a total of 36 people (Figure 27).

The criterion Fire Protection is once again considered of less importance, with an average score of 2,74. However, people from the South of Europe think that this criterion has more importance than people from Northern Europe, as it shows the average scores: 2,74 against 3,20.

The Demand of Energy assumes the leadership in terms of average importance, with an average score of 1,40. This value is really close to the one considered by people from Northern Europe for the same criterion, 1,45. Thermal Comfort in Summer and Indoor Air Quality follow this list as the most important.

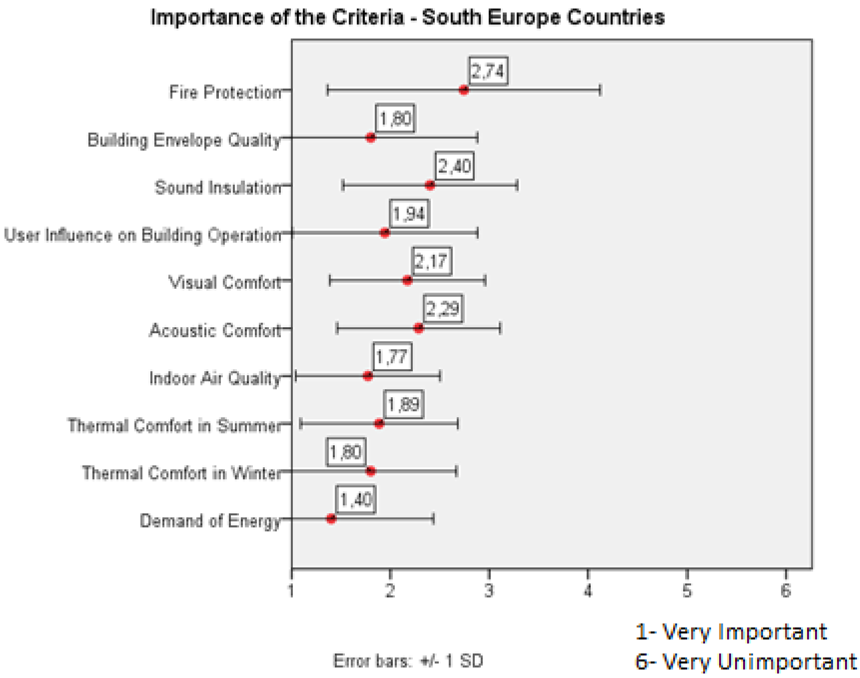

Figure 27- Importance of the Criteria- South Europe Countries

4.1.3. Overall View of the Results

As it possible to see so far, the results are very similar to each other, apart from the country, experience with BSA tools or field of specialization (the last analysis is present in the appendix). The values achieved in the different analysis made for the importance of the criteria, frequency of occurrence of deficiencies related with the criteria and extent of suffering with those deficiencies are very similar.

In Figure 28 it is possible to see a general analysis of the results. This Figure represents the average importance of all the 10 criteria as a function of the age, gender, experience, or not, with the BSA tools, country and field of specialization.

This figure, confirms the analyses presented before. As it is possible to see, the average importance given by the different target groups is very close. The maximum average importance of the ten criteria is given by the group of less than 25 years old and it is 2,15. On the other side, the minimum is given by the group of people that considers themselves as experts on indoor environmental quality and the score is 1,89. Thus, the difference is only of 0,26, which is a very small difference.

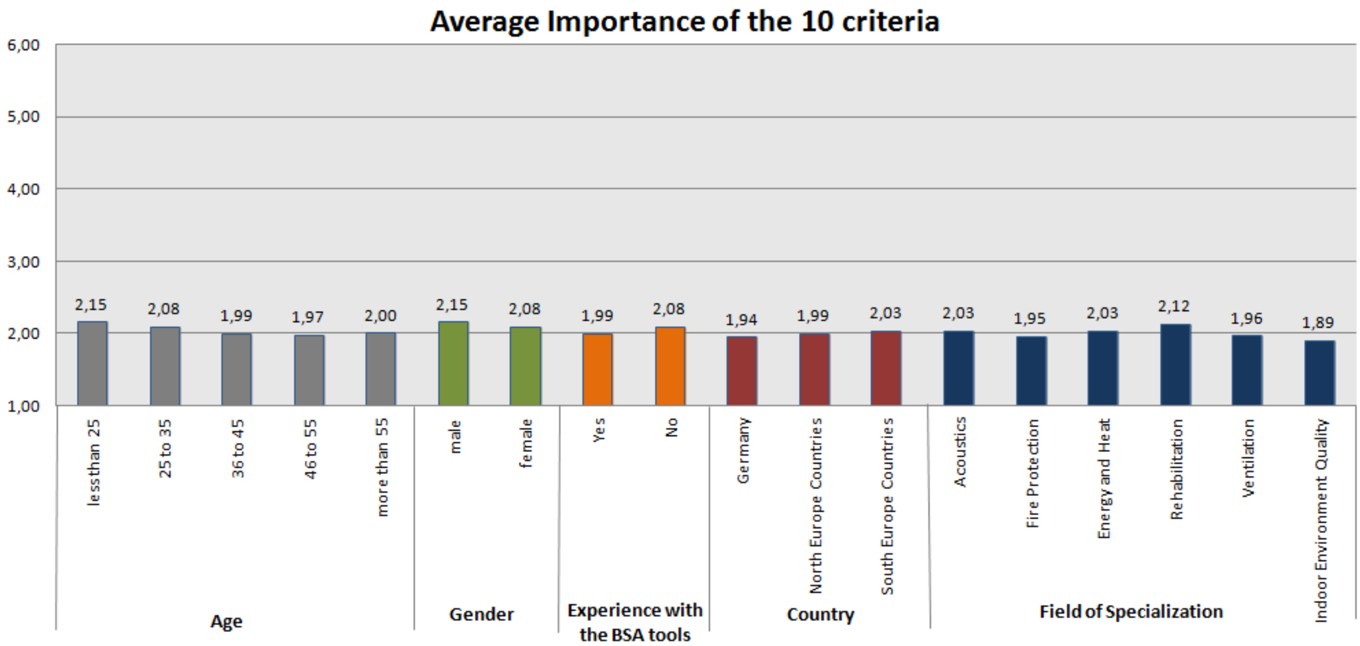

Figure 28- Average importance of the 10 criteria

In the appendix of this work there is a table with all the different analyses in terms of importance of the criteria, on the perspective of the different target groups. This table summarizes the analyses made and it is also possible to see that the differences between the results are not significant.

Thus, in the calculation of the weighing factors, done on the next subchapter, only the overall results will be included, i.e., considering all the 210 valid answers.

4.2. Proposal for the New Weighting Factors

The SPSS analyses evidenced that the results of the different target groups are very similar and that there are no correlations between the importance of the criteria, the frequency of the deficiencies and the extent of those deficiencies. Thus, for the development of the new weighting factors the results of the overall analysis are used, shown in Figure 16.

Table 7 shows, once again, the results of the importance of the 10 criteria studied based on the opinion of the 210 people that answered the questionnaire.

Table 7- Importance of the Criteria - Overall Analysis

Criteria	Importance of the criteria
Energy Demand	1,45
Thermal Comfort in winter	1,74
Thermal Comfort in Summer	1,77
Indoor Air Quality	1,72
Acoustic Comfort	2,29
Visual Comfort	2,19
User Influence on Building Operation	2,08
Sound Insulation	2,49
Building Envelope Quality	1,93
Fire Protection	2,68

These results are on the questionnaire scale, 1 to 6, in which 1 means very important and 6 means very unimportant. Thus, it is necessary to transform these values into the DGNB certification System scale for the weighting factors, 1 to 3 in which 1 is less important and 3 being the most important. To do so, it was necessary to make interpolations between the values of Table 7 and these two scales mentioned.

After these interpolations the results of the importance attributed by the 210 people to the 10 criteria are presented on Table 8.

Table 8- New weighting factors of the 10 criteria

Criteria	New weighting factors
Energy Demand	2,8
Thermal Comfort in winter	2,7
Thermal Comfort in Summer	2,7
Indoor Air Quality	2,7
Acoustic Comfort	2,5
Visual Comfort	2,5
User Influence on Building Operation	2,6
Sound Insulation	2,4
Building Envelope Quality	2,6
Fire Protection	2,3

These values, present in Table 8 are a proposal for the new weighting factors of the 10 criteria studied. If they are compared with the DGNB Certification System weighting factors for the correspondent criteria it is possible to see that there are some differences (Table 9).

Table 9- Comparison between the new weighting factors and the ones present on the DGNB Certification System

Criteria	New weighting factors	DGNB system weighting factors
Energy Demand	2,8 *(3)*	3/2
Thermal Comfort in winter	2,7 *(3)*	2
Thermal Comfort in Summer	2,7 *(3)*	3
Indoor Air Quality	2,7 *(3)*	3
Acoustic Comfort	2,5 *(3)*	1
Visual Comfort	2,5 *(3)*	3
User Influence on Building Operation	2,6 *(3)*	2
Sound Insulation	2,4 *(2)*	2
Building Envelope Quality	2,6 *(3)*	2
Fire Protection	2,3 *(2)*	2

On the column of the New Weighting Factors there are values in brackets which represent the new weighting factors without decimal numbers, that is because the DGNB system considers its weighting factors without decimal numbers and it is easier to compare them this way.

On the first criteria it is possible to see two values for the Energy Demand criterion of the DGNB system but only one for the New Weighting Factors. This happens because the DGNB Certification System divides the Energy Demand criterion in two: “Non-renewable primary energy demands” with a weighting factor of 3 and “Total primary energy demands on proportion of renewable primary energy” with weighting factor of 2. In this study, those two criteria are compiled into one: Energy Demand.

The biggest difference between the two types of weighting factors is on the Acoustic Comfort criterion. The DGNB system considers a weighting factor of 1 but, according to the 210 people, this criterion is a lot more important and should have a weighting factor of 2,5 (3).

The criteria Thermal Comfort in Winter, User Influence on Building Operation and Building Envelope Quality are the other criteria with differences in the weighting factors when compared the new weighting factors and the ones considered on the DGNB certification system.

4.3. IMPLEMENTATION OF THE NEW WEIGHTING FACTORS ON THE DGNB CERTIFICATION SYSTEM

After concluding the definition of the new weighting factors, it is time to start the second main objective of this work, the implementation of the new weighting factors on the DGNB Certification System.

The aim of this stage is to apply the new weighting factors in a real case and watch what kind of performance that building has and in the end the comparison of these results with the original results of the building with the DGNB system weighting factors.

The DGNB Certification System services provided an Excel file with an Assessment Matrix for the New Office and Administrative Buildings, Version 2010. It is with this assessment matrix that buildings are assessed by the DGNB Certification System. They also provided a brochure of *New Construction Office and Administration, Version 2009.* This brochure contains an evaluation matrix applied to a real case (Figure 29).

The weighting factors used in those two versions are the same that are currently used on the latest version of the German Certificate.

As already mentioned in this thesis, all the criteria descriptions present on the questionnaire and in this thesis were taken from the documents provided by the DGNB services because only this way can the criteria in study be integrated in a DGNB evaluation matrix already existing.

Thus, using the excel file with the assessment matrix, replacing the weighting factors of the 10 criteria studied by the new weighting factors developed and the scores of each criterion of the real case available in the 2009 version, is it possible to calculate the new score of the building.

The assessment matrix also enables the calculation of a score per group of criteria.

ACCURATE AND CLEAR. THE ASSESSMENT MATRIX OF THE DGNB CERTIFICATE.

EVALUATION AREA	CRITERIA GROUP	CRITERIA	CRITERIA POINTS ACHIEVED	CRITERIA POINTS MAX. POSSIBLE	WEIGHTING FACTOR	WEIGHTED POINTS ACHIEVED	WEIGHTED POINTS MAX. POSSIBLE	GROUP POINTS ACHIEVED	GROUP POINTS MAX. POSSIBLE	GROUP PERFORMANCE INDEX	GROUP WEIGHT	TOTAL PERFORMANCE INDEX
ENVIRONMENTAL QUALITY	LIFE CYCLE ANALYSIS	Global Warming Potential	10.0	10.0	3	30.0	30.0	178.5	200.0	89.3%	22.5%	86.3% (Gold)
		Ozone Depletion Potential	10.0	10.0	1	10.0	10.0					
		Photochemical Ozone Creation Potential	10.0	10.0	1	10.0	10.0					
		Acidification Potential	10.0	10.0	1	10.0	10.0					
		Eutrophication Potential	7.1	10.0	1	7.1	10.0					
	GLOBAL AND LOCAL ENVIRONMENTAL IMPACT	Local Environmental Impact	8.2	10.0	3	24.6	30.0					
		Sustainable Use of Resources / Wood	10.0	10.0	1	10.0	10.0					
	RESSOURCE CONSUMPTION AND WASTE GENERATION	Nonrenewable Primary Energy Demand	10.0	10.0	3	30.0	30.0					
		Total Primary Energy Demand and Proportion of Renewable Primary Energy	8.4	10.0	2	16.8	20.0					
		Drinking Water Demand and Volume of Waste Water	5.0	10.0	2	10.0	20.0					
		Land Use	10.0	10.0	2	20.0	20.0					
ECONOMIC QUALITY	LIFE CYCLE COSTS	Building-Related Life Cycle Costs	9.0	10.0	3	27.0	30.0	47.0	50.0	94.0%	22.5%	
	ECONOMIC PERFORMANCE	Suitability for Third-Party Use	10.0	10.0	2	20.0	20.0					
SOCIOCULTURAL AND FUNCTIONAL QUALITY	HEALTH, COMFORT AND USER FRIENDLINESS	Thermal Comfort in Winter	10.0	10.0	2	20.0	20.0	251.1	280.0	89.7%	22.5%	
		Thermal Comfort in Summer	10.0	10.0	3	30.0	30.0					
		Indoor Air Quality	10.0	10.0	3	30.0	30.0					
		Acoustic Comfort	10.0	10.0	1	10.0	10.0					
		Visual Comfort	8.5	10.0	3	25.5	30.0					
		User Influence on Building Operation	6.7	10.0	2	13.4	20.0					
		Quality of Outdoor Spaces	9.0	10.0	1	9.0	10.0					
		Safety and Security	8.0	10.0	1	8.0	10.0					
	FUNCTIONALITY	Accessibility	8.0	10.0	2	16.0	20.0					
		Efficient Use of Floor Area	5.0	10.0	1	5.0	10.0					
		Suitability for Conversion	7.1	10.0	2	14.2	20.0					
		Public Access	10.0	10.0	2	20.0	20.0					
		Cycling Convenience	10.0	10.0	1	10.0	10.0					
	AESTHETIC QUALITY	Design and Urban Planning Quality through Competition	10.0	10.0	3	30.0	30.0					
		Integration of Public Art	10.0	10.0	1	10.0	10.0					
TECHNICAL QUALITY	TECHNICAL QUALITY OF BUILDING DESIGN AND SYSTEMS	Fire Prevention	8.0	10.0	2	16.0	20.0	74.0	100.0	74.0%	22.5%	
		Indoor Acoustics and Sound Insulation	5.0	10.0	2	10.0	20.0					
		Building Envelope Quality	7.7	10.0	2	15.4	20.0					
		Ease of Cleaning and Maintenance	7.1	10.0	2	14.2	20.0					
		Ease of Dismantling and Recycling	9.2	10.0	2	18.4	20.0					
PROCESS QUALITY	QUALITY OF THE PLANNING PROCESS	Comprehensive Project Definition	8.3	10.0	3	24.9	30.0	188.6	230.0	82.0%	10.0%	
		Integrated Planning	10.0	10.0	3	30.0	30.0					
		Comprehensive Building Design	8.6	10.0	3	25.8	30.0					
		Sustainable Aspects in Tender Phase	10.0	10.0	2	20.0	20.0					
		Documentation for Facility Management	5.0	10.0	2	10.0	20.0					
		Environmental Impact of Construction Site / Construction Process	7.7	10.0	2	15.4	20.0					
		Prequalification of Contractors	5.0	10.0	2	10.0	20.0					
	CONSTRUCTION QUALITY	Construction Quality Assurance	10.0	10.0	3	30.0	30.0					
		Systematic Commissioning	7.5	10.0	3	22.5	30.0					
SITE QUALITY	SITE QUALITY	Site Location Risks	7.0	10.0	2	14.0	20.0	93.3	130.0	71.8%		
		Site Location Conditions	7.1	10.0	2	14.2	20.0					
		Public Image and Social Conditions	1.0	10.0	2	2.0	20.0					
		Access to Transportation	8.3	10.0	3	24.9	30.0					
		Access to Specific Use Facilities	9.7	10.0	2	19.4	20.0					
		Connection to Utilities	9.4	10.0	2	18.8	20.0					

Example of an assessment matrix of a DGNB gold certified building,
occupancy profile "New Office and Administrative Buildings, version 2009"

Figure 29- Evaluation Matrix of the DGNB system for New Office and Administrative Buildings, version 2009

As we can see in Figure 29, the total performance index of the building assessed with all the DGNB weighting factors is 86,26%, which corresponds to a Gold classification.

After the implementation of the 10 weighting factors on the DGNB system the total performance index of the building is a little bit higher, 86,32% (Table 10). The building classification remains the same, Gold.

Table 10- Real case assessment - Original results Vs. Results with the new weighting factors

		Results with original scores achieved			
Evaluation area	**Criteria group**	**Original weighting factors**		**New weighting factors**	
Environmental Quality	Life Cycle Analysis	95,9%	89,3%	95,9%	89,0%
	Global and Local Environmental Impact	86,5%		86,5%	
	Resource Consumption and Waste Generation	85,3%		85,2%	
Economic Quality	Life Cycle Costs	90,0%	94,0%	90%	94,0%
	Economic Performance	100%		100%	
Socio-cultural and Functional Quality	Health Comfort and User Friendliness	91,2%	89,7%	91,3%	89,9%
	Functionality	81,5%		81,5%	
	Aesthetic Quality	100%		100%	
Technical Quality	Technical Quality of Buildings Design and Systems	74,0%	74,0%	74,3%	74,3%
Process Quality	Quality of the Planning Process	80,1%	82,0%	80,1%	82,0%
	Construction Quality	87,5%		87,5%	
TOTAL		**86,26%**		**86,32%**	

This difference was already expected not to be very big because the building assessment is based on 42 criteria and only 11 criteria (Energy Demand was compiled in two criteria) had their weighting factors changed. The fact that the new weighting factors are not very distant from the original ones also contributed for this small difference in the final score.

Thus, the differences end up to dilute in the middle of the other criteria and are not very perceptible on the final score of the building.

The technical quality was the evaluation area with a higher percentage of criteria studied. It contains 5 criteria and 3 of them were part of this study (Fire Protection, Building Envelope Quality and Acoustic Comfort). Besides, only the criteria Building Envelope Quality had its weighting factor different from the original one (the original was 2 and the new one is 3), the evaluation area score was 74% and now is 74,3%.

The differences between the original results and the new ones, on the rest of the evaluation areas, are also not very big because these groups consider a larger number of criteria and this way at the end the differences in the scores is not very perceptible. The evaluation areas Economical Quality and Process Quality, did not suffered any changes on its group performance index because those groups do not contain any of the criteria studied.

As the results with the new weighting factors are not very different it was decided to implement the new weighting factors on the same example of the evaluation matrix, but this time with different scores achieved by the criteria in study. Thus, a comparison between the results with the original and with the new weighting factors for two hypothetical cases was made, at first for a maximum score possible (10) of the 11 criteria and then for the minimum score possible (0).

Table 11 represents the comparison of results with the original and with the new weighting factors when the scores of the 11 criteria on study are the maximum possible, 10.

Table 11- Hypothetical case 1 - Original results Vs. Results with the new weighting factors – Results with the maximum scores achieved (10) by the 11 criteria studied

		Results with max scores achieved (10)			
Evaluation area	**Criteria group**	**Original weighting factors**		**New weighting factors**	
Environmental Quality	Life Cycle Analysis	95,9%	90,9%	95,9%	91,3%
	Global and Local Environmental Impact	86,5%		86,5%	
	Resource Consumption and Waste Generation	88,9%		90,0%	
Economic Quality	Life Cycle Costs	90,0%	94,0%	90,0%	94,0%
	Economic Performance	100%		100%	
Socio-cultural and Functional Quality	Health Comfort and User Friendliness	98,1%	93,6%	98,4%	94,3%
	Functionality	81,5%		81,5%	
	Aesthetic Quality	100%		100%	
Technical Quality	Technical Quality of Buildings Design and Systems	92,6%	92,6%	93,3%	93,3%
Process Quality	Quality of the Planning Process	80,1%	82,0%	80,1%	82,0%
	Construction Quality	87,5%		87,5%	
TOTAL		**91,70%**		**92,08%**	

As it is possible to see in this table the differences between the results with the original and with the new weighting factors are still not significant. The final score of the building with the original weighting factors is 91,70% and with the new weighting factors it is 92,08%. However, the biggest difference is on the criteria groups' classification. For example, the Resource Consumption and Waste Generation had a classification of 88,9% and after the new weighting factors were implemented, its classification is 90,0%, which corresponds to a difference of 1,10%. Also the criteria group Technical Quality of Buildings Design and Systems had a classification of 92,6% and after the new weighting factors were implemented its classification is 93,3%, which represents a difference of 0,7%. In this case, those classifications are also the classifications of the evaluation area Technical Quality because it only has one criteria group. In the other criteria group affected by the new weighting factors, Health Comfort and User Friendliness, the classification goes from 98,1% to 98,4% when the new weighting factors are implemented.

Then, the same analysis was made but with the scores of the 11 criteria on study equal to the minimum possible, 0. These results are represented on table 12.

Table 12- Hypothetical case 2 - Original results Vs. Results with the new weighting factors – Results with the minimum scores achieved (0) by the 11 criteria studied

		Results with min scores achieved (0)			
Evaluation area	**Criteria group**	**Original weighting factors**		**New weighting factors**	
Environmental Quality	Life Cycle Analysis	95,9%	65,9%	95,9%	62,7%
	Global and Local Environmental Impact	86,5%		86,5%	
	Resource Consumption and Waste Generation	33,3%		30,0%	
Economic Quality	Life Cycle Costs	90,0%	94,0%	90,0%	94,0%
	Economic Performance	100%		100%	
Socio-cultural and Functional Quality	Health Comfort and User Friendliness	10,6%	43,6%	8,9%	39,4%
	Functionality	81,5%		81,5%	
	Aesthetic Quality	100%		100%	
Technical Quality	Technical Quality of Buildings Design and Systems	32,6%	32,6%	29,6%	29,6%
Process Quality	Quality of the Planning Process	80,1%	82,0%	80,1%	82,0%
	Construction Quality	87,5%		87,5%	
TOTAL		**61,32%**		**59,00%**	

As it is possible to see, this situation is the one that reflects the biggest differences between the results with the original and the new weighting factors. The total performance index of the building went from 61,32% to 59,00%.

The Socio-cultural and Functional Quality evaluation area is where the differences are higher. The performance index of this evaluation area, with the original weighting factors, was 43,6% and after the implementation of the new weighting factors it is 39,4%, which represents a difference of 4,2%.

On the Environmental Quality, the difference is 3,2%. The result of the performance of this evaluation area when the original weighting factors were adopted was 65,9% and when they were substituted by the new weighting factors the result is 62,7%.

The other evaluation area, Technical Quality, also experienced significant differences. The results of this group performance went from 32,6% to 29,6% , which constitutes a difference of 3%.

On the criteria group Resource Consumption and Waste Generation the performance score goes from 33,3% to 30,0% after the implementation of the new weighting factors. Also the criteria group Health Comfort and User Friendliness performance suffers a difference from 10,6% to 8,9%.

Thus, after the evaluation of the two hypothetical cases it is possible to see that the differences are not very significant. The fact that the scale used by the DGNB certification system is too tight, from 1 to 3, and that only 11 criteria out of 48 were part of this study have a big contribution on this result.

5

CONCLUSIONS

After the study of the main building sustainability assessment tools, with special attention on the German certification system, a questionnaire, addressed to experts from the different fields of the building physics, was developed, as well as several approaches on the analysis of the results of this questionnaire. The results of this analysis have enabled the development of the new weighting factors and their subsequent implementation on the DGNB certification system. Thus, the main conclusions of this work are:

- The results of the importance in terms of the sustainability of the 10 criteria studied are very similar independently of the age, gender, region, field of specialization and experience with the BSA tools;
- Energy Demand was considered by almost all the different target groups as the most important criterion, in terms of sustainability, by achieving the highest average score of importance;
- Fire Protection was considered the least important, in terms of sustainability ,criterion by the different target groups, achieving the lowest average score of importance;
- The correlations between the variables importance of the criteria, frequency of occurrence of deficiencies and extent of suffering from the deficiencies almost do not exist;
- On the calculation of the new weighting factors, it was achieved 5 differences from the original ones, considered by the DGNB certification System. The new weighting factors developed for the criteria Energy Demand, Thermal Comfort in winter, Acoustic Comfort, User Influence on Building Operation and Building Envelope Quality are different from the original ones. The new weighting factors developed for the criteria of Energy Demand, Thermal Comfort in Summer, Indoor Air Quality, Visual Comfort, Sound Insulation and Fire Protection are equal to those already existing;
- The implementation of the new weighting factors for the criteria on the DGNB system into a real case, did not produce large differences from the original results because the new values end up diluted among the other criteria;
- The original total performance index was 86,26% and with the new weighting factors it was 86,32% on the real case studied, with all the original criteria scores;
- When the scores of the 11 criteria studied were changed, first to the maximum possible (10) and then to the minimum possible (0), it produced bigger differences of the results

of the building performance, but still not very significant. On the hypothetical case 1, when the scores of all the 11 criteria were changed to 10, the total index performance of the building was 91,70% with the original weighting factors and 92,08% with the new weighting factors. When the scores of all the 11 criteria were changed to 0, on the hypothetical case 2, the total index performance of the building was 61,32% and after the implementation of the new weighting factors it is 59,00%. The most significant differences of results were achieved on the second hypothetical case, where the 11 criteria had the minimum scores, 0.

- The fact that the only 5 weighting factors of criteria, out of 11, are different from the original ones, plus the fact that the scale used by the DGNB certification system is too tight, from 1 to 3, and the fact that only 11 criteria, and their weighting factors, out of 48 were part of this study had a major contribution for the small differences registered between the results with the original and with the new weighting factors.

As further work, it would be interesting to make a similar analysis to the one presented on this study for the remaining criteria. Thereby the real impact of the new weighting factors on the DGNB certification system could be evaluated.

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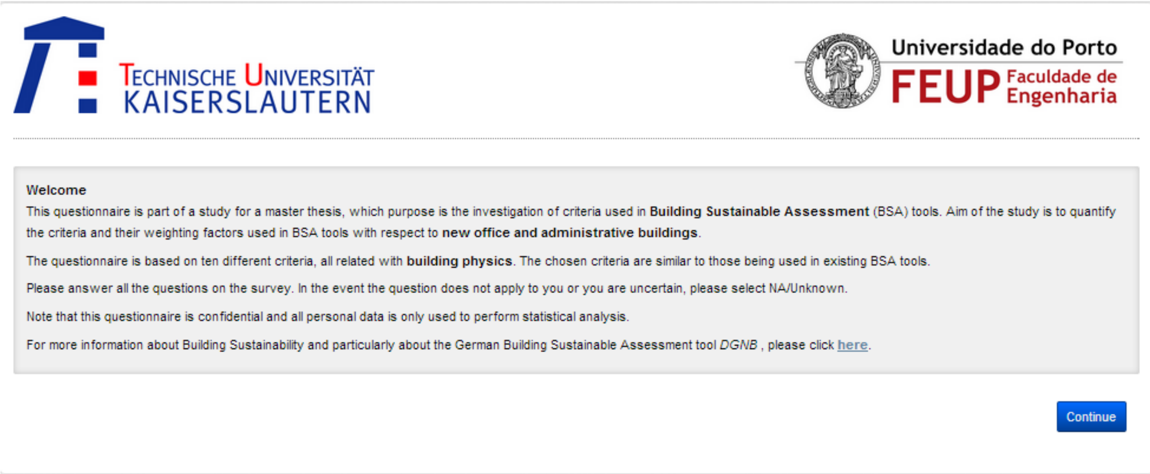
APPENDICES

1- QUESTIONNAIRE



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Welcome

This questionnaire is part of a study for a master thesis, which purpose is the investigation of criteria used in **Building Sustainable Assessment** (BSA) tools. Aim of the study is to quantify the criteria and their weighting factors used in BSA tools with respect to **new office and administrative buildings**.

The questionnaire is based on ten different criteria, all related with **building physics**. The chosen criteria are similar to those being used in existing BSA tools.

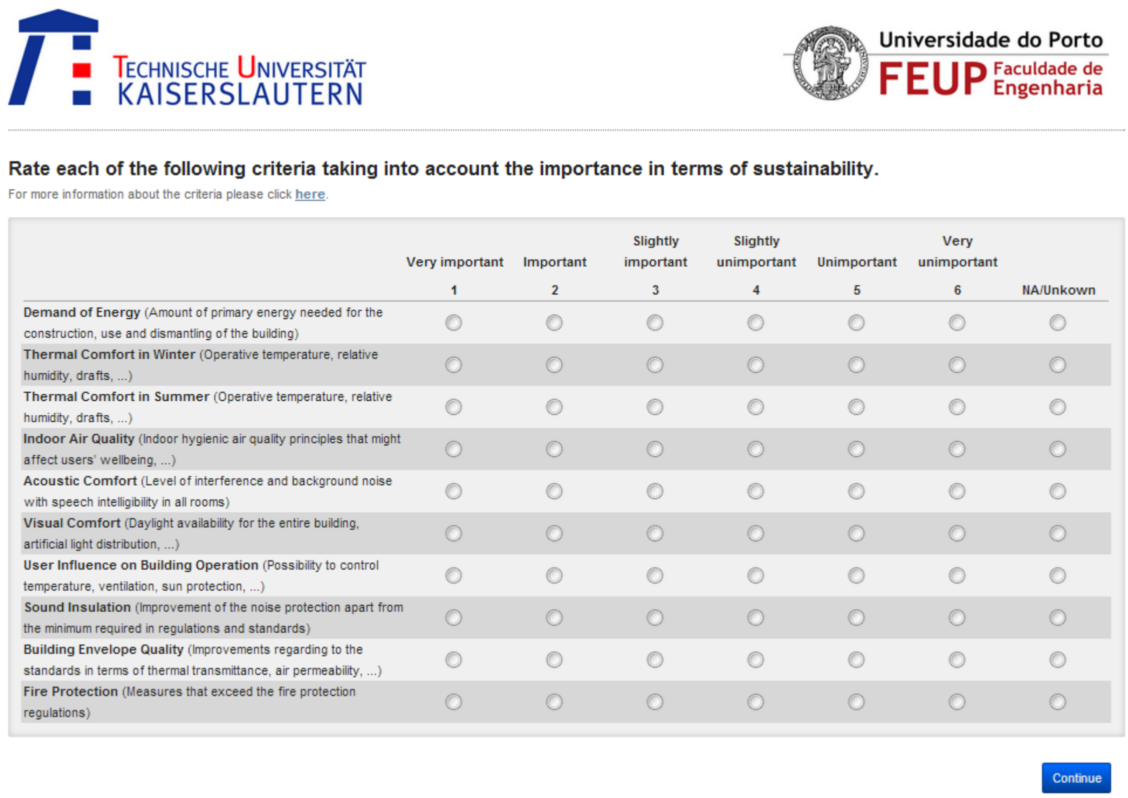
Please answer all the questions on the survey. In the event the question does not apply to you or you are uncertain, please select NA/Unknown.

Note that this questionnaire is confidential and all personal data is only used to perform statistical analysis.

For more information about Building Sustainability and particularly about the German Building Sustainable Assessment tool *DGNB* , please click here.

Continue

Figure 30- Questionnaire- page 1



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Rate each of the following criteria taking into account the importance in terms of sustainability.

For more information about the criteria please click here.

	Very important 1	Important 2	Slightly important 3	Slightly unimportant 4	Unimportant 5	Very unimportant 6	NA/Unkown
Demand of Energy (Amount of primary energy needed for the construction, use and dismantling of the building)							
Thermal Comfort in Winter (Operative temperature, relative humidity, drafts, ...)							
Thermal Comfort in Summer (Operative temperature, relative humidity, drafts, ...)							
Indoor Air Quality (Indoor hygienic air quality principles that might affect users' wellbeing, ...)							
Acoustic Comfort (Level of interference and background noise with speech intelligibility in all rooms)							
Visual Comfort (Daylight availability for the entire building, artificial light distribution, ...)							
User Influence on Building Operation (Possibility to control temperature, ventilation, sun protection, ...)							
Sound Insulation (Improvement of the noise protection apart from the minimum required in regulations and standards)							
Building Envelope Quality (Improvements regarding to the standards in terms of thermal transmittance, air permeability, ...)							
Fire Protection (Measures that exceed the fire protection regulations)							

Continue

Figure 31- Questionnaire- Page 2

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With which frequency do you think, the following deficiencies occur in buildings?

	Always 1	Frequently 2	Occasionally 3	Rarely 4	Very Rarely 5	Never 6	NA/Unkown
Energy Demand (Excessive energy consumption, ...)	○	○	○	○	○	○	○
Thermal Comfort in Winter (Cold room temperature, cold walls, ...)	○	○	○	○	○	○	○
Thermal Comfort in Summer (Overheating in summer, ...)	○	○	○	○	○	○	○
Indoor Air Quality (Poor ventilation, presence of volatile organic compounds, ...)	○	○	○	○	○	○	○
Acoustic Comfort (High background noise and reverberation time levels, ...)	○	○	○	○	○	○	○
Visual Comfort (Deficient artificial light distribution, poor daylight availability, ...)	○	○	○	○	○	○	○
User Influence on Building Operation (Impossibility to control ventilation, temperatures, ...)	○	○	○	○	○	○	○
Sound Insulation (Pointless exceeding of the standards, ...)	○	○	○	○	○	○	○
Building Envelope Quality (Poor air permebility class, condensation within the structure, ...)	○	○	○	○	○	○	○
Fire Protection (Absence of sprinkler system, automatic smoke detectors, ...)	○	○	○	○	○	○	○

Figure 32- Questionnaire- Page 3

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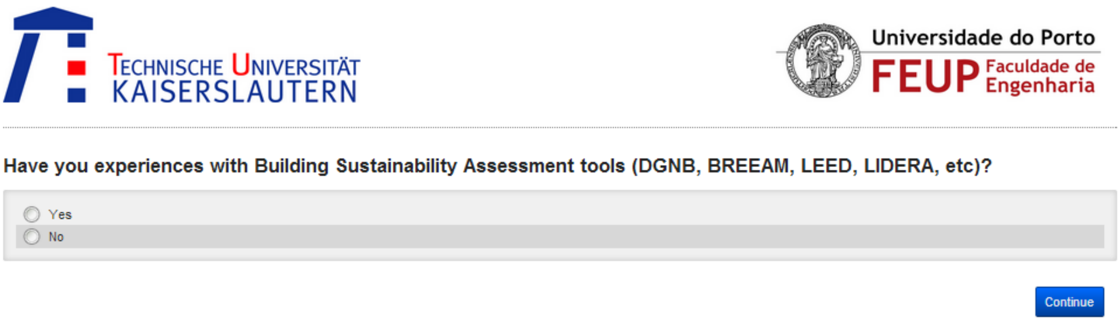
To what extent have you personally suffered at your work or home from any of the deficiencies belonging to:

	Extremely large extent 1	Very large extent 2	Large extent 3	Small extent 4	Very small extent 5	Extremely small extent 6	NA/Unkown
Energy Demand (Excessive energy consumption, ...)	○	○	○	○	○	○	○
Thermal Comfort in Winter (Cold room temperature, cold walls, ...)	○	○	○	○	○	○	○
Thermal Comfort in Summer (Overheating in summer, ...)	○	○	○	○	○	○	○
Indoor Air Quality (Poor ventilation, presence of volatile organic compounds, ...)	○	○	○	○	○	○	○
Acoustic Comfort (High background noise and reverberation time levels, ...)	○	○	○	○	○	○	○
Visual Comfort (Deficient artificial light distribution, poor daylight availability, ...)	○	○	○	○	○	○	○
User Influence on Building Operation (Impossibility to control ventilation, temperatures, ...)	○	○	○	○	○	○	○
Sound Insulation (Pointless exceeding of the standards, ...)	○	○	○	○	○	○	○
Building Envelope Quality (Poor air permebility class, condensation within the structure, ...)	○	○	○	○	○	○	○
Fire Protection (Absence of sprinkler system, automatic smoke detectors, ...)	○	○	○	○	○	○	○

Figure 3330- Questionnaire - Page 4

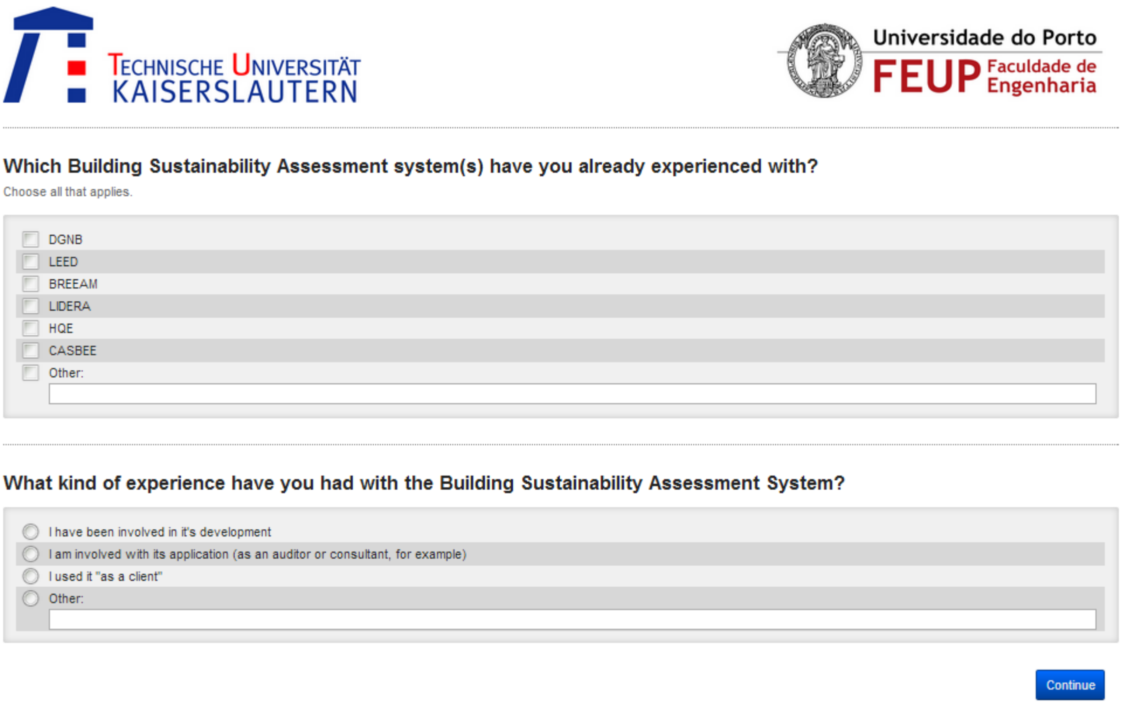


Have you experiences with Building Sustainability Assessment tools (DGNB, BREEAM, LEED, LIDERA, etc)?

- Yes
- No

Continue

Figure 34- Questionnaire - Page 5



Which Building Sustainability Assessment system(s) have you already experienced with?

Choose all that applies.

- DGNB
- LEED
- BREEAM
- LIDERA
- HQE
- CASBEE
- Other:

What kind of experience have you had with the Building Sustainability Assessment System?

- I have been involved in it's development
- I am involved with its application (as an auditor or consultant, for example)
- I used it "as a client"
- Other:

Continue

Figure 35- Questionnaire - Page 6

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Which points would you identify as failures of the BSA Systems?

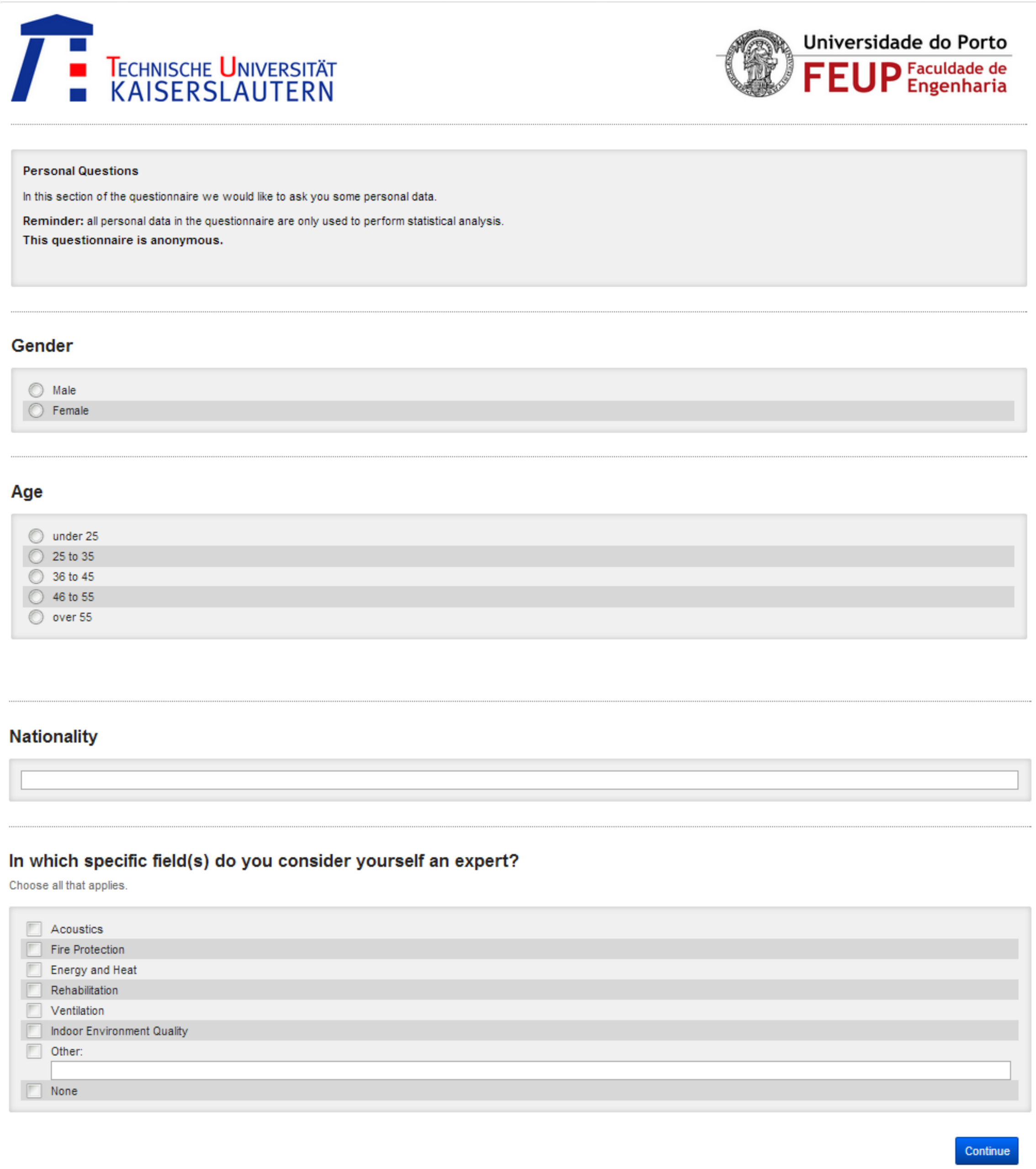
Check all that applies

	Extensive list of criteria	Restricted list of criteria	Innapropriate attribution of the weighting factors of criteria	Other	None	Don't know
DGNB						
LEED						
BREEAM						
LIDERA						
HQE						
CASBEE						

If you answered "Other" on the last question, please specify which failure(s):

Continue

Figure 36- Questionnaire - Page 7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Personal Questions

In this section of the questionnaire we would like to ask you some personal data.

Reminder: all personal data in the questionnaire are only used to perform statistical analysis.

This questionnaire is anonymous.

Gender

- Male
- Female

Age

- under 25
- 25 to 35
- 36 to 45
- 46 to 55
- over 55

Nationality

In which specific field(s) do you consider yourself an expert?

Choose all that applies.

- Acoustics
- Fire Protection
- Energy and Heat
- Rehabilitation
- Ventilation
- Indoor Environment Quality
- Other:
- None

Continue

Figure 3731- Questionnaire - Page 8

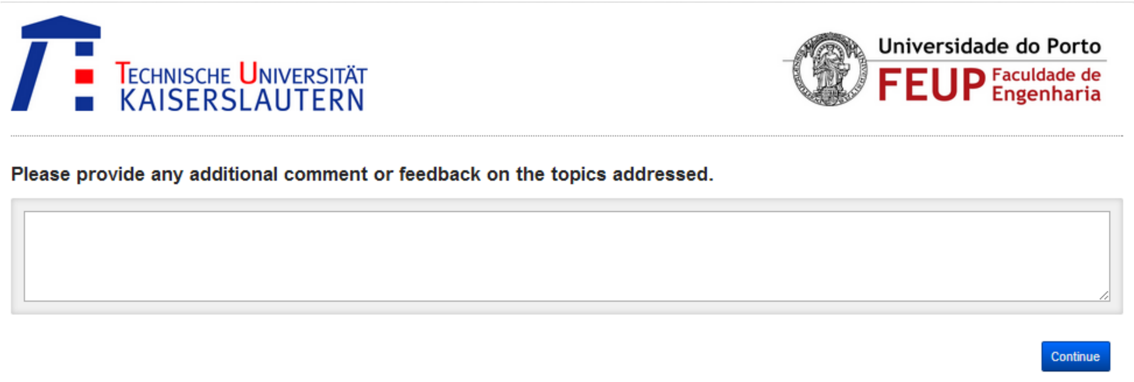

Figure 38- Questionnaire - Page 9

Figure 39- Questionnaire - Page 10

2- OTHER ANALYSES

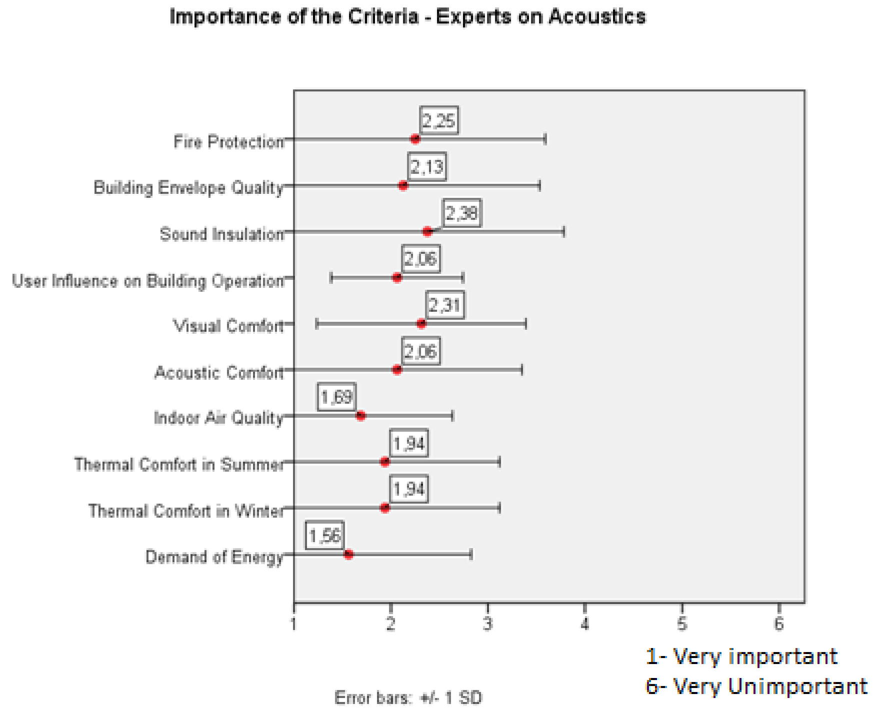

Figure 40- Importance of the criteria- Experts on acoustics

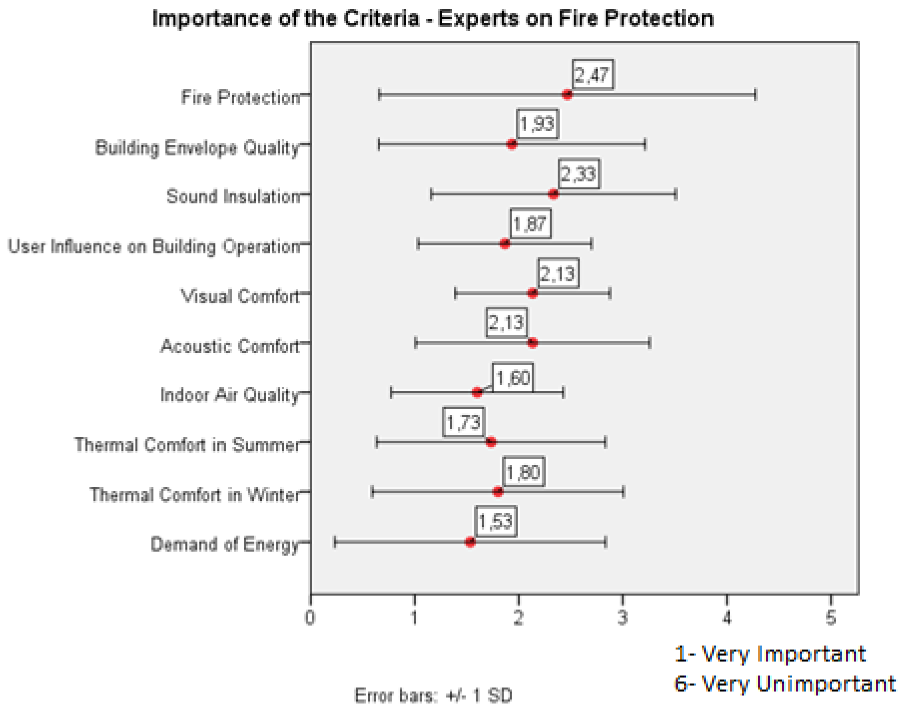

Figure 41- Importance of the criteria- Experts on fire protection

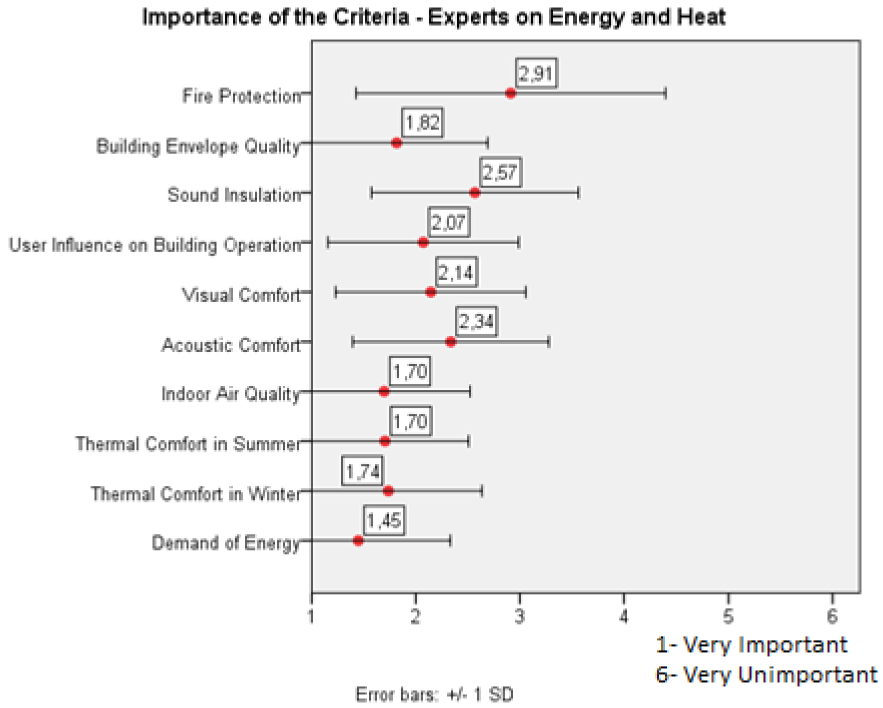

Figure 4232- Importance of the criteria- Experts on energy and heat

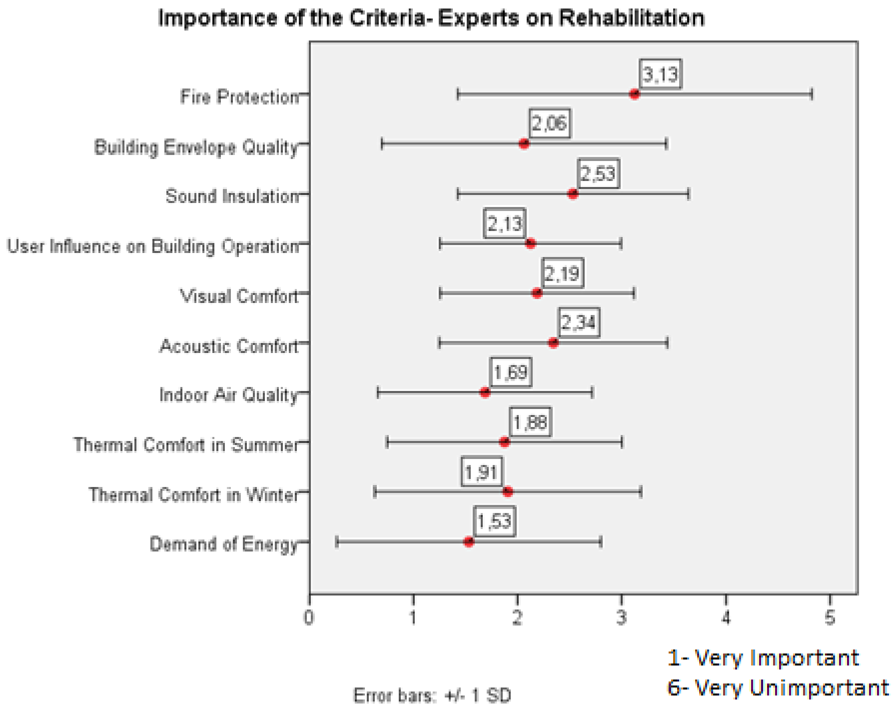

Figure 43- Importance of the criteria- Experts on rehabilitation

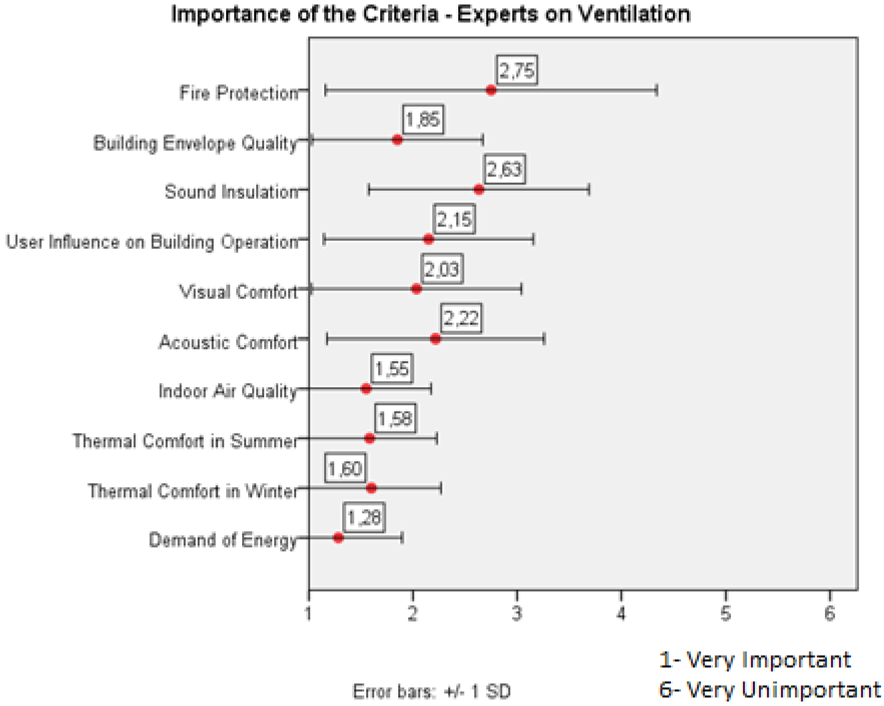

Figure 44- Importance of the criteria- Experts on ventilation

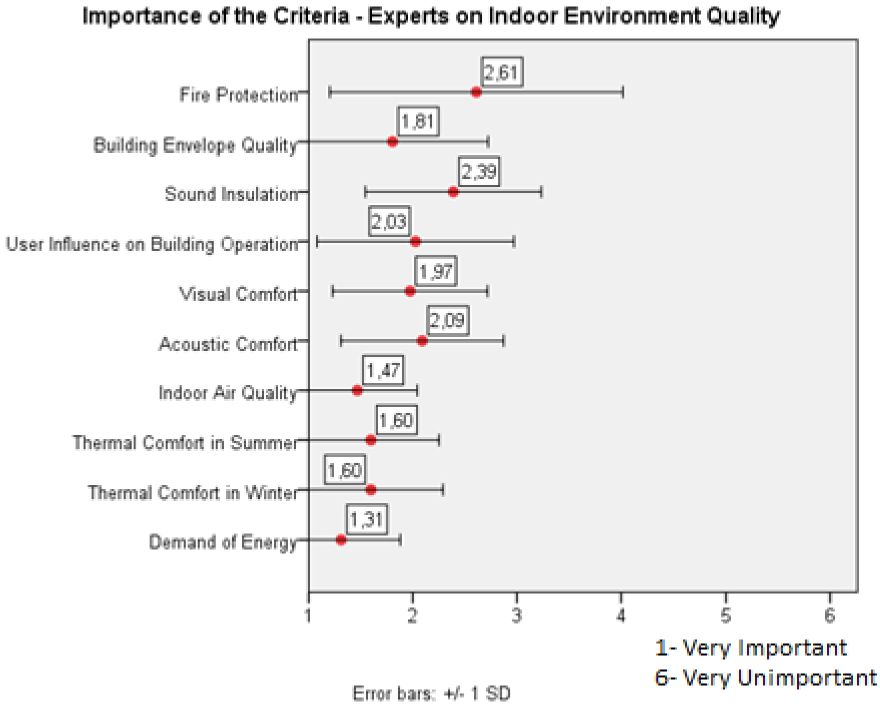

Figure 45- Importance of the criteria- Experts on indoor environmental quality

Table 13- Importance of the criteria – Summary table

Importance of the Criteria (scale from 1 to 6; 1= very importante; 6 = very unimportant)														
		Experience		Countries			Field of Specialization							
Criteria	Overall	Experience with DGNB	Experience with at least 1 of the BSA tools	Germans	North Europe Coutries	South Europe Countries	Experts on Acoustics	Experts on Fire Protection	Experts on Energy and Heat	Experts on Rehabilitation	Experts on Ventilation	Experts on Indoor Environment Quality	Minimum	Maximum
Energy Demand	1,45	1,33	1,42	1,38	1,45	1,4	1,56	1,53	1,45	1,53	1,28	1,31	1,28	1,56
Thermal Comfort in winter	1,74	1,59	1,69	1,62	1,55	1,8	1,94	1,8	1,74	1,91	1,6	1,6	1,55	1,94
Thermal Comfort in Summer	1,77	1,52	1,66	1,58	1,8	1,89	1,94	1,73	1,7	1,88	1,58	1,6	1,52	1,94
Indoor Air Quality	1,72	1,67	1,67	1,67	1,4	1,77	1,69	1,6	1,7	1,69	1,55	1,47	1,4	1,77
Acoustic Comfort	2,29	2,1	2,21	2,13	2	2,29	2,06	2,13	2,34	2,34	2,22	2,09	2	2,34
Visual Comfort	2,19	2,03	2,06	2,07	2,1	2,17	2,31	2,13	2,14	2,19	2,03	1,97	1,97	2,31
User Influence on Building Operation	2,08	2,21	2,07	2,11	2,2	1,94	2,06	1,87	2,07	2,13	2,15	2,03	1,87	2,21
Sound Insulation	2,49	2,38	2,47	2,36	2,4	2,4	2,38	2,33	2,57	2,53	2,63	2,39	2,33	2,63
Building Envelope Quality	1,93	2,07	1,91	1,95	2,2	1,8	2,13	1,93	1,82	2,06	1,85	1,81	1,8	2,2
Fire Protection	2,68	2,84	2,84	2,58	3,2	2,74	2,25	2,47	2,91	3,13	2,75	2,61	2,25	3,2

3- Summary of the Results

Table 14- Summary table of the results

		RESULTS WITH ORIGINAL SCORES ACHIEVED				HYPOTHETICAL CASE 1 - MAX SCORES (10)				HYPOTHETICAL CASE 2 - MIN SCORES (0)			
Evaluation area	**Group of criteria**	ORIGINAL WEIGHTING FACTORS		NEW WEIGHTING FACTORS		ORIGINAL WEIGHTING FACTORS		NEW WEIGHTING FACTORS		ORIGINAL WEIGHTING FACTORS		NEW WEIGHTING FACTORS	
ENVIRONMENTAL QUALITY	**Life Cycle Analisys**	95,9	89,3	95,9	89	95,9	90,9	95,9	91,3	95,9	65,9	95,9	62,7
	Global and Local Environmental Impact	86,5		86,5		86,5		87		86,5		86,5	
	Resource Consumption and Waste Generation	85,3		85,2		88,9		90,0		33,3		30,0	
ECONOMIC QUALITY	**Life Cycle Costs**	90	94	90	94	90	94	90	94	90	94	90	94
	Economic Performance	100		100		100		100		100		100	
SOCIOCULTURAL AND FUNCTIONAL QUALITY	**Health Comfort and User Friendliness**	91,2	89,7	91,3	89,9	98,1	93,6	98,4	94,3	10,6	43,6	8,9	39,4
	Funtionality	81,5		81,5		81,5		82		81,5		81,5	
	Aesthetic Quality	100		100		100		100		100		100	
TECHNICAL QUALITY	**Technical Quality of Buildings Design and Systems**	74	74	74,3	74,3	92,6	92,6	93,3	93,3	32,6	32,6	29,6	29,6
PROCESS QUALITY	**Quality of the Planning Process**	80,1	82	80,1	82	80,1	82	80	82	80,1	82	80,1	82
	Construction Quality	87,5		87,5		87,5		88		87,5		87,5	
TOTAL		86,26		86,32		91,70		92,08		61,32		59,00	