THESIS ON CIVIL ENGINEERING F51

Quantification of Environmental and Economic Impacts in Building Sustainability Assessment

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

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ERKKI SEINRE

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List of publications

Paper I: Seinre, E., Voll, H. Energy Efficiency Regulations Taking Action in Estonia. *Selected Topics in Energy Environment, Sustainable Development and Landscaping: 6th International Conference on Energy, Ecosystems and Sustainable Development (EESD'10)*, WSEAS, 2010, 211-215.

Paper II: Seinre, E., Voll, H. Using LEED to Evaluate a Built Apartment Building in Estonia. *BSA 2012 Proceedings of The 1 st International Conference on Building Sustainability Assessment: The 1 st International Conference on Building Sustainability Assessment*, Green Lines Institute for Sustainable Development, 2012, 331-341.

Paper III: Seinre, E., Kurnitski, J., Voll, H. Quantification of environmental and economic impacts for main categories of building labeling schemes. – *Energy and Buildings*, 2014, 70, 145-158.

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Author's Contribution

Paper	Original idea	Study design and methods	Data collection and handling	Contribution to result interpretation and manuscript preparation	Responsible for result interpretation and manuscript preparation
I		x	x	x	x
II	x	x	x	x	x
III		x	x	x	x
IV		x	x	x	x

Introduction

A generally accepted fact is that the building sector of a country contributes about 40% of the CO_2 emissions of the total emissions load. That is why the energy consumption and the related CO_2 emissions have been a focal point since Kyoto protocol (the aim to reduce greenhouse gas emissions) back in 1997. Several successive directives and other formal documents have followed. One of which is the Energy Performance of Buildings Directive (EPBD) [1] by the European Union (EU). This directive is compulsory for each member state to implement.

The aim of current doctoral thesis is to go a step further. If we consider the energy efficiency as a green building concept (green buildings have been considered mostly as energy efficient buildings, though sometimes misinterpreted for sustainable buildings), then this thesis wants to uncover the sustainable building concept: in addition to the energy also the social and the economic impacts are included as stated by several researchers, including Cole [2], Haapio and Viitaniemi [3] and Zuo and Zhao [4].

Instead of concentrating only on the energy performance, sustainable buildings account much broader list of parameters to rank a building. Accounted issues start from indicators directly affecting the environment and ending with impacts on the building users: regulating waste collection, building site ecology and used refrigerants to internal pollution source control, lighting levels and VOC emissions, respectively. To put it in other words, sustainable buildings are much more considerate towards the environment, than energy labeling of buildings. A good overview of the most established sustainable building schemes and energy certification systems in the world is given by a publication from Swegon Air Academy in Simply Green [5]. This is a good reference for novice acquaintances of *sustainable/green* building schemes, who might still be mistaking latter with energy certification systems. The book offers a good coverage of the differences of the schemes and clearly distinguishes one from the other.

The movement towards sustainable buildings concept has been a step following the energy performance aspirations. While it is clear that energy is an important indicator, it is also evident that high quality buildings are not only energy efficient. Not at least according to today's level of expectation. When the energy would be the only indicator to define high quality buildings then we could only concentrate our attention to energy performance and forget the rest. This, on the other hand, could pave the way for superb buildings in the energy performance point of view, while providing dismal indoor environmental living conditions. Obviously nobody is fond of living or working in such a building. This is just one example of what should be covered by high quality buildings. The concept of sustainable buildings is fulfilling the requirements of what is expected by high quality buildings. Besides the environmental impact, also the social and the economic consideration should be included. These three are the foundation of the current sustainable building paradigm.

Unlike the energy efficiency policies, the sustainable buildings have not been made mandatory for EU member states to implement. To current date, this cannot be envisaged to change. Some studies, e.g. Haapio and Viitaniemi [3] have suggested, that the building sustainability assessment should be compulsory; the trend still is to use it on a voluntary base. Though the concern posed by Haapio and Viitaniemi - that only high quality buildings will be assessed and low quality ones neglected - the innovative front end is generally based on voluntarism. If developers are aiming for a high quality building and want a warrant on that, they can acquire a certificate. As I see it, the term '*sustainable building*' defines a building outperforming standard requirement levels, and as long as it surpasses the standards it cannot be made compulsory. What would otherwise be the reasoning of the standards which are not followed? Another supporting idea for voluntary certification is the limited knowledge: as long as the sustainable building concept is new and innovative, with limited knowledge in the society, it is reasonable to keep it as a voluntary measure.

In my studies I did consider the building sustainability assessment schemes as introduced in Simply Green [5] in the form of, e.g. LEED, BREEAM, DGNB, HQE etc., a predefined prerequisite. In other words, the thesis aimed to find the best solution for Estonia from already established concepts. This is reasonable, considering how well the respective schemes have been accepted and to what extent these have penetrated into the building sector. Thus, the thesis did not aim to propose a new concept, rather than to use the most relevant from the existing schemes to devise a solution for Estonia.

A concern, noted by several researchers related to the sustainable buildings, is the vast amount of schemes. A country establishing a scheme generally produces a new scheme specific for that country. Even more, several countries in Europe have more than one scheme per country: DGNB and BREEAM DE in Germany, Miljbyggnad and BREEAM SE in Sweden, LEED and BREEAM ES in Spain etc. While considering local context is reasonable, as the climatic conditions, local resources and economic development levels differ, the situation is peculiar when there are several schemes in a country. This might be the outcome of two or more competing institutions or organizations. It might not be a peculiarity when there is one developed country-specific scheme and the others are introduced as modifications of some already existing international schemes; for instance Germany, with its' DGNB and BREEAM DE, respectively, is a good example. The main concern is the missing link between different schemes: there are no clear or fixed correlations between the certifications. Considering the number of schemes, it is hard to expect such as well. As the scope of the schemes differs it complicates the comparison even more.

All previous provides a good initiative to search for a solution. As such, some researchers have proposed a standardized and a general scheme for building sustainability assessment. Dirlich [6] proposes a standardized scheme based on German DGNB [7] scheme due to its' holistic approach and flexibility. For standardization, the *Green Building Challenge* (GBC) has also provided a reference scheme for countries to exploit for developing their own scheme as reported by Todd et al. [8]. Lützkendorf and Lorenz [9] propose standardized minimum list of indicators to be included in a scheme, allowing direct comparison of different schemes. While the local context could be considered by different weighting factors and target limits for the indicators.

Objectives of the thesis

As the previous paragraphs demonstrated, there are mixed feelings and different proposals for the building sustainability assessment. It is a complex field to find a best solution as factors influencing the decision process can be limitless. My thesis explores the different approaches proposed and aims to find a suitable solution for Estonia. That is, when Estonian building sector reaches a stage where the need for expanding the scope of building quality evaluation is acknowledged.

Even though there are tens of sustainable building assessment schemes in the world, they all seem to follow a common concern - the difficulty of assigning the importance to different indicators and categories. It is clear that several indicators should be included in a scheme, but how to rank them against each other? Is it even necessary or could we consider all with the same importance? This has been generally resolved by including different stakeholders of the building sector in the decision making process to present their preferences. While this process is more reasonable than leaving the weighting (importance) allocation to be decided by an individual, it still lacks objectivity. The '*expert panel*' members vote according to their subjective understanding of the importance of different indicators. Thus, depending on the mix of the stakeholders, the outcome can be significantly varying. This has left building sustainability assessment field with a question: are the weightings of the indicators appropriate? Is there a possibility to define objective weightings for the indicators?

This thesis aims to solve the concern associated with the subjective allocation of weightings of the categories of the building sustainability assessment. The main purpose of the thesis is to rank the categories in an objective manner. The objective allocation in this thesis is generally made based on the impacts of operational phase of buildings, with the exception of materials. The materials impact considers the impacts of the construction phase caused by the use of alternative structural materials.

As an extension to the main research question - to objectively define the importance of the categories of building sustainability assessment schemes - we propose a possible scheme for Estonia. This follows the results of our studies as well as the idea of using the best (highly influencing) indicators of the existing schemes in the categories relevant in the Estonian context.

In conclusion, the main objectives of the thesis were:

- to identify the current situation of building sector and the need for sustainable building assessments;
- to explore the scope of the sustainable building concept;
- to identify objectively the importance of the sustainable building categories in Estonian context;
- an analysis and comparison of five contemporary office buildings in relation to sustainable building assessment schemes;
- to identify the relation of the Estonian regulations against LEED and BREEAM indicators;

- to propose a relevant and manageable building sustainability assessment scheme for Estonia.

While most of the objectives are reasonably straightforward, I do need to elaborate on the third objective. To establish the order of importance we used minimum acceptable and best possible design options for an indicator representing a category. This helped identifying the impact range of the design solutions, both on the environment and in economic terms. Also an absolute environmental impact of the categories was identified. Generally this was considered as an average value of the two ends of design options. The impacts on the environment were considered as CO_2 emissions as well as kWh; converting the two into Euros gave an economic impact. These numeric values allowed ranking the importance objectively.

Outline of the thesis

The literature review section firstly defines the sustainable building. Then gives an overview of the field, introduces several results of studies in the past and describes the current situation. Most interest is related to the costs and benefits of the sustainable buildings, with some studies destroying prejudice related with the expenses, while the others demonstrate varying span of benefits related to sustainable buildings.

The first article, presented at a conference, covers the building sector situation overview at the start of my PhD-studies. This was a time when building energy efficiency regulations were taking first steps in Estonia. The article gives an overview of the process of implementing the regulation, shows serious concerns in reality and specifies a couple of essential shortcomings.

The second conference article can be considered as an introductory article to sustainable building assessment schemes. With an example of LEED I assessed a recently built apartment building in Tallinn. Besides the final result showing the classification of the case-study building in LEED scheme also the contents of a sustainable building assessment scheme with its indicators is uncovered.

The third article quantifies the environmental and economic impacts of the main categories of a sustainable assessment scheme. The impacts of five categories were assessed with an example of an office building. To limit the study at a reasonable scope we used one indicator from each category to represent the impact of the category. I determined the environmental impact of the categories in relative and absolute scale. The relative impact was considered as a range of the minimum acceptable and the best solution according to Estonian regulations and sustainable assessment scheme requirements. The environmental impact was considered in CO_2 emissions and in kWh. Conversion of these impacts into Euros, showed the economic impact of the design solutions. The absolute impact on the environment was determined as an average of the minimum and best design solution impacts. The category weightings were determined as an average of the three impacts: the relative environmental, the absolute environmental and the economic. The results show significantly differentiating weightings of the categories when compared with the two most well-known assessment schemes.

From the category weighting identification, the fourth article moves towards specifying an Estonian building sustainability assessment scheme. Here we used the results of our previous studies, with the attention turned to three important categories for the Estonian context. I performed a comparison with the Estonian regulations and LEED/BREEAM requirements. The differences and gaps of the requirements were identified. Additionally, I ranked five case-study office buildings in LEED and BREEAM scale by comparing the projects documentation with LEED and BREEAM requirements for the indoor climate and the energy categories. Based on the results of the study we propose an Estonian scheme with its three certification levels and the indicators within the three categories.

Chapter 1

Literature review

One of the most comprehensive reviews of the sustainable building status is given by Zuo and Zhao [4] covering in their work close to 150 scientific references. They conclude that most of the studies related to *green/sustainable buildings* cover three matters:

1. the definition and scope;
2. benefits and costs and
3. the ways to achieve green buildings.

As they say, the term green building has been generally considered as environmentally sound building focusing on the environmental impact (energy use, water demand, materials environmental impact etc.) of a building.

In the current thesis I define *sustainable building assessment* as a term which besides the environmental impact also considers the social and economic impacts. Thus,

The sustainable building = 'green building' + social impact + economic impact

The latter is in good accordance with the current paradigm of the term '*sustainable building assessment*' as pointed out by several researchers, e.g. Forsberg and von Malmborg [10], Haapio and Viitaniemi [3] and Ding [11]. Thus, within the limits of current work I follow the paradigm and when writing about sustainable building I do consider the three pillars: environmental, social and economic impacts. While the environmental impact is quite clear, the social impact considers the benefits on the users of the building or the local community. The starting point of which is the indoor climate conditions of the proposed development ending with the impact to the surrounding community, e.g. by the additional amenities made available or the enhanced ecology of the site. The economic impact considers the costs of the development as well as the increased value of a building and its' surroundings.

An economic indicator is the cost/benefit of a sustainable building construction and certification. This matter is not unambiguously defined: there are mixed results of the outcome by different studies. To claim that *all* sustainable buildings are better performing than the ones without sustainable building certification is not true. Though one would expect a certified building to perform better, there are several projects where certified buildings are outperformed by conventional (without certification) buildings. A good example are the results by Newsham et al. [12] which showed that generally sustainable buildings perform better. In average they do, but still there are buildings which fail to supersede conventional buildings. Scofield [13] criticized Newsham et al. [14] earlier study methods, by showing the performance of LEED certified buildings in more comparable (methodically correct) way. Latter decreased considerably the positive performance of certified buildings in comparison with conventional buildings.

Studies have also compared the initial costs of sustainable and conventional buildings. This is because the stakeholders tend to perceive sustainable buildings as more expensive than the conventional ones. When thinking of potential higher quality, it is a reasonable assumption. At the same time, the results of studies have shown different reality: sustainable buildings are not considerably more expensive to construct. Bartlett and Howard [15] argue the misconception - that energy efficient buildings cost 5-15% more - of the quantity surveyors in the UK is not backed up. They state that this is clearly overestimated (real values are in the range of 1% increased costs), while at the same time the surveyors do underestimate the cost savings during the life cycle. Langdon [16] conducted a similar study over LEED certified buildings in the US. He concluded:

> 'there is no significant difference in average costs for green buildings as compared to non-green buildings'.

Sustainable buildings can be built with little or no added costs in comparison with conventional buildings. Thus, to claim that the sustainable buildings are more expensive is not entirely true. Anyway, it is clear that the design process of sustainable buildings is more complete and thorough thanks to the design process concept: assembling an integrated design team at early stages of project development with sustainable building features in focus. Even though latter means more effort, and probably also initial costs, the outcome is well-planned design solution with fewer modifications in the later stages of the development. This, on the other hand, is where besides environmental impact, also the economic impact for the developer can be reduced.

Certifications of the sustainable buildings are not just assigned; they come with the process to work through relevant indicators to achieve them. The certification process itself enquires for costs. First of all the certification itself costs, the process of interpreting the requirements and collecting the documentation costs. This is informatively introduced by Saunders [17] and Sleeuw [18]. Generally fee is payable to the governing body managing the scheme. Also at least an individual has to be hired to manage the certification process and explain the requirements to the design team and to keep track of the progress. The certification procurement process was analyzed by Northbridge Environmental Management Consultants [19]. They stated that the '*greening*' of the project (upgrading systems to meet the requirements, using specific materials etc.) cost around 3-8% of the construction costs. The costs of the design process, documentation collection, commissioning and fees were estimated to be in the range of 1-5% of the construction costs. Thus, the reluctance from the main contractor or even from the developer is no surprise, when the potential benefits are not introduced.

Developers and owners of buildings are foremost interested in benefits they get from the building - the financial income. Thus, being in the position of a developer one is most interested in increased continuous income and being in the position of a building owner one is interested in increased value of the asset (the building itself). There have been some studies evaluating the impact of certification on the rental price and the value of the building. One thing is clear: there is an increase of value, but the extent seems to vary considerably. Eichholtz et al. [20] conducted a market survey over LEED and EnergyStar certified buildings in the US. From the statistical analysis they determined that buildings with a certificate have a rental price 3% higher than identical commercial building without. The increased selling price according to the results of their study was as high as 16%. RICS report [21] states that the rental price of a certified building in UK is about 22% higher than a regular commercial building (without a '*green*' certificate). The same study reported that buildings with sustainability certificate were sold 26% higher price on average. Chegut et al. [22] also reported the sustainable building selling price increase of 26% and rental price increase of 21% in comparison with non-sustainable buildings based on the Londons office market. Miller et al. [23] reports that the selling price of LEED certified building in US was 10% higher than conventional similar building. We can conclude that there is a positive effect from a sustainable building certificate on the value of a building, but the rate can vary considerably. An article from Kamelgarn and Hovorka [24] gives estimation on the benefit of sustainable buildings (based on several studies), that the market value generally increases about 10% and the rental price 6%.

Saari et al. [25] conducted an interesting study on office building layout renovation solutions. The basis of the study was an existing office building from 1980's with a centralized mechanical air handling unit (AHU) without cooling. The study aimed to identify the effects of different renovation solutions on the costs. The variables were following: the efficiency of the space (floor area per employee), the indoor climate quality, the ventilation flow rates, the indoor temperatures and the salary of the employees. Results showed clearly the importance of considering all the costs when considering alternatives. That is, besides the investment, operational and maintenance (O&M) costs, also the effect on the health and productivity should be considered. When latter consideration is made then it is evident that the improvement of indoor climate quality is cost effective. Of course it depends on the reference level of the indoor climate quality and is more distinctive when the baseline is low. The study concluded with a note that should be remembered:

> 'The importance of good ventilation and air conditioning with a more efficient (densely populated) use of space, especially in conjunction with high-value work.'

A study conducted in California by Kats et al. [26] also demonstrated the feasibility of building sustainable buildings. First of all, it demolished a popular misbelieve of considerably higher investment costs of sustainable buildings - these were less than 2% of the construction costs. This is clearly lower than generally perceived to be at least in the order of 1/10 of construction costs. At the same time the claim is closely correlating with the outcome of the study results by Bartlett and Howard [15]. Secondly, the study aimed to put monetary values on different matters related to sustainable buildings. The following matters related to financial benefits were considered: energy, water, waste disposal, environmental and emissions, O&M costs and savings from increased health and productivity. The outcome of the study showed more than 10 times higher financial benefit than the initial investment costs. Most of the benefits are associated with better health and higher productivity constituting around 70% of the total benefits for lower level LEED certified buildings. The share would be even higher for higher LEED certified buildings with estimated higher indoor climate quality and the related increased health and productivity. Savings from energy (11%) and O&M costs (16%) were also in considerable order constituting altogether 27%. Cost savings from wastes, water and emissions were negligible, constituting 0, 1 and 2 %, respectively. The importance of the indoor climate is clearly visible. As the study emphasizes these estimations for productivity benefits are conservative and thus, could be even higher, while the other benefits are reasonably well fixed and exact.

To conclude, I can say that there are studies showing both the positive and negative effects of the sustainable building assessments and certification. Depending on the context and the methodical approach the results can be contradicting. At the same time, when considering the big picture (not just environmental impacts) the studies show clear positive impact of sustainable buildings. For instance when including the increased productivity of employees. Of course one has to keep in mind that sustainable assessment schemes allow certification while not applying for all the indicators. This means, that some buildings can perform at lower level than non-certified buildings at some indicators. When a specific indicator was considered in the certification, then certified buildings outperform the conventional counterparts. Thus, the more complete a certified building design and assessment is, the higher the probability for positive impact.

Chapter 2

Methods

In this section I will describe complete round of methods used to compile the thesis. Starting with the analysis of the building sector development stage and ending with determining the importance of building sustainability assessment scheme categories for the Estonian context and proposing an Estonian building sustainability assessment scheme.

2.1 Methods for the investigation of the EPBD implementation progress

The first aim was to position the Estonian building sector in its' development stage. At the beginning of my PhD studies in 2009 the term *sustainable building* was practically unknown in Estonia. The only quality related issue was the energy performance certificate (EPC), which had just recently been made compulsory for new and major refurbishment buildings applying building permit. Thus, the best way to identify the development level of the building sector was to use the results of a study on the progress of implementing the energy efficiency regulations in the form of Governmental Decree no. 258 '*The Minimum Requirements for Energy Performance*' [27].

The aim of the study was to assess the EPC values obtained by the designers of the buildings and compare them with the results obtained by the study group. The study group consisted of MSc and PhD students with sufficient level of expertise in building energy simulations. As required by the regulation, we used the design documentation defining the building layout, constructions and function areas of the buildings as the input for the simulations. Reasonably expecting that also the design teams applying for building permits used the same values; allowing us to perform compliance checks. Altogether 13 projects of non-domestic buildings were included in the study for check calculations. The study group performed the check calculations with IDA-ICE [28] and BSim [29] simulation software programs. The discrepancies of EPC values obtained by the design teams and the study group were identified. Furthermore, we evaluated the results compliance in a more detailed level to identify the mismatches between the results.

2.2 Methods to assess an apartment building

To introduce the scope of a sustainable building assessment scheme I performed an unofficial retrospective assessment of a recently built building in the center of Tallinn. An 8-storey apartment building was built in 2002. Above grade gross floor area and apartment area constitute 3000 and 2310 m^2, respectively. A view of the building can be seen in Figure 2.1. Additionally to the main purpose, this study showed where a building constructed in accordance with recent construction practice would classify in a building sustainability scale.

LEED New Construction (NC) 2009 Reference guide [30] was used as a guiding tool for LEED assessment. The LEED reference guide is an extensive manual for LEED assessors to use as guidance. The document comprises over 600 pages covering all categories and indicators within each. Furthermore, it specifies the intent of each criterion, the requirements to meet LEED levels, explanation why a criterion is included and its' impact

Figure 2.1: The view on the East facade of the assessed apartment building.

on the environment. To help an assessor, there is guidance on how to calculate the compliance, what is expected as a proof and further references to relevant sources that can help to understand the calculation procedures. The manual is suitable to assess three building types:

1. new constructions,
2. schools, and
3. core & shell projects.

The case study building was regarded as a new construction even though the building was already erected. The intent of each applicable indicator was studied, requirements for compliance checked and the documentation collected.

I used detailed phase project design documentation, site inspections, official buildings register database and communication with the main constructor to assess the building. Where a specific proof was unidentifiable, estimation of whether the intent of the criterion was met, was made by the author of the thesis.

2.3 Methods to quantify the relevance of the categories

Having introduced a building sustainability assessment scheme, with an example of LEED, we saw that there are plenty of indicators within the scope of such a scheme. While it is reasonable to include indicators from various fields, to reflect the complete quality (*sustainability*) of a building, it requires a lot of effort for a certification application. We wondered whether it is possible to keep a scheme at manageable scope; e.g. starting from the compulsory energy efficiency requirements and building up on that with additional requirements. We had already noticed that building sustainability assessment schemes tend to refer to so-called '*expert panels*' when determining the importance of the categories or indicators. We were looking for more objective methods.

Instead of calling for an '*expert panel*' (which is always a subjective opinion), we wondered if it is possible to evaluate the importance of the categories in an objective manner. We assumed it should be possible to rank the main categories of an assessment scheme objectively. It is clear, that it is difficult to quantify every indicator to make it comparable, but even so, it is justified to make an effort to quantify as much as possible. This will ensure that the comparison of the indicators is fair and unbiased from someone's opinion.

The quantification of the building sustainability assessment schemes' category impacts is what our article '*Quantification of environmental and* *economic impacts for main categories of building labeling schemes'* [31] published in Energy and Buildings journal is dealing with. In this study a step toward making a scientifically based decision of the relevance of the categories was made. The aim of analysis was to evaluate the importance of different categories on the building sustainability in Estonian context. For that reason each category was described by one representative performance indicator and its impact on the economic and environmental values were calculated. The impact band was determined by:

- firstly, using minimum acceptable level requirements, and
- secondly, using the best expected level in each category.

Altogether five categories were included. The categories were the following: the indoor environment, energy, water, materials and transport. The results allowed evaluation of the weighting factors of the categories (their importance) on scientific bases.

Even though the second paper assessed an apartment building, we shifted our attention. We decided to limit our research to office buildings. This is the sector of where the demand for sustainable buildings has been the greatest and the schemes have been developed in the first order (with other building types following) as stated, for instance, by Ding [11].

A sound justification for this is the distribution of the annual costs in an office building shown in Figure 2.2. This shows that although the construction costs (capital costs) are considered large and important from the investment point of view, the annual wages of the employees dominate the total costs. Meaning that even though the capital costs are most tangible at the investment decision stage, emphasize should be on the wages. Even the building running costs are negligible when compared to wages. As the wages form the largest share of the costs, it is essential to guarantee good indoor climate conditions. In other words, it is justified to increase the running costs on the heating and the electricity to ensure better working conditions for the employees, as long as their productivity will be increased.

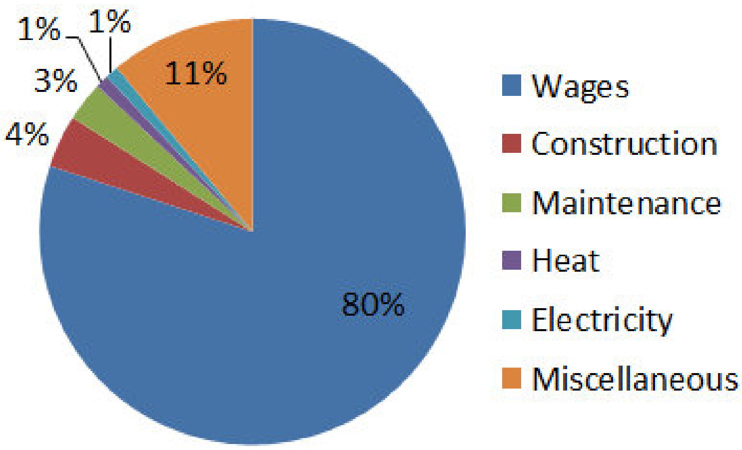

Figure 2.2: Distribution of annual costs in an office building. Derived from Figure 10 in REHVA GuideBook No. 6 [34].

The benefit from higher productivity outweighs the increased running costs.

We considered an office employee to be more expensive workforce than an average employee, thus we used two times the Estonian national average wage as the salary. For dynamic simulations I used IES [32] simulation software. The gross building area was 3830 m^2. Net floor height was 3.3 m, with the exception of the ground floor with 4.8 m height. Figure 2.3 shows a 3D-model of the six-story office building used in the simulations. Used construction types and other input values for the simulation were taken from Table 2 in '*Cost optimal and nearly zero energy performance requirements for buildings in Estonia*' [33] for "*BAU*" (business as usual) for an office building. Latter article specified the cost optimal technical solutions for office buildings in Estonia. Different occupancy densities were used to see the impact on the results due to the assumptions made. After validating the model, modifications were performed to answer the questions posed in the study.

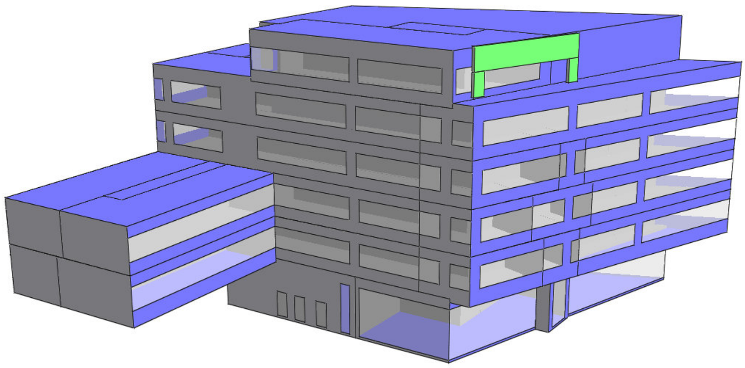

Figure 2.3: A 3D building model from IES simulation software used in the study.

The aim was to quantify the impact in numeric values. To do that we converted all impacts of the evaluated indicators into the following metrics:

1. for energy use and impact on resource consumption to kWh/(m^2 a);
2. for the cost/benefit impact to €/(m^2 a); and
3. for the environmental impact to CO_2/(m^2 a).

This allowed us to directly compare impacts of the indicators and to determine the indicators with the highest impact on specific reference unit.

2.3.1 Quantifying the indoor climate quality

Here we used valuable reference in our study, namely REHVA Guidebook No 6 '*Indoor climate and productivity in offices*' [34]. This is a compilation of the results from earlier studies showing the importance of the indoor climate on building occupants perception of the building and its quality.

REHVA Guidebook No 6 distinguished three indicators affecting office employees' work:

1. Ventilation rate - productivity,
2. Ventilation rate - short-term sick leave, and
3. Indoor temperature - productivity.

The correlation between ventilation flow rate and the productivity was originally covered by Seppänen et al. [35] analyzing the effect on productivity depending on different ventilation flow rates. We used the graphical representation of the results of Seppänens study by deriving the equations to calculate the effect of the ventilation flow rate (l/(s person)) on relative performance (productivity). Two equations were derived for two different occupancy density conditions.

Considering the ventilation flow rate impact on sick leave we used the results of the study conducted by Milton et al. [36]. Milton conducted a study on office employees looking at the ventilation flow rate and the sick leave correlation. We used a derived equation from the graphical presentation of the results of Miltons study presented by Fisk et al. [37]. The equation related sick leave prevalence depending on air change rate.

To consider the effect of the indoor temperature on productivity we used the results of a study conducted by Seppänen et al. [38]. That study derived an equation to calculate the relative performance of an employee depending on the room temperature analyzing statistically the results of some earlier studies.

Using these three correlations, together with the assumed average salary of an employee, I quantified the effect of the indoor climate quality on employees work output (productivity).

2.3.2 Quantifying the energy performance

The energy use is one of the most apparent categories included in the sustainable assessment schemes. First of all, the running costs of a building are reminded to the owners/renters on monthly bases - each time when bills for the electricity and heat have to be paid. Secondly, most stakeholders try to decrease the operating costs. That is why it is not surprising that this category is generally the most important (highest weighted or with the largest allocation of points).

Generally the energy performance compliance is proved by a dynamic building (energy) simulation. For that a suitable software needs to be available, the calculation methodology fixed and the competency to perform the simulations are required.

I used IES [32] simulation software that is widely used amongst engineers all over Europe. For the calculation methodology I used the legislation regulating the minimum requirements of the energy performance of buildings in Estonia [39] and [40], which superseded the first version of '*The Minimum Requirements for Energy Performance*'. I used these to define internal loads, the ventilation flow rates, system efficiencies and the occupancy patterns. As the reference building was not meeting the latest minimum requirements I used a modified situation. That meant modifying different energy users (e.g. lighting, equipment etc.) share on the overall energy demand. For that I used the results from Table 12 in '*Madal- ja liginullenergia hooned. Büroohoonete põhilahendused eskiis- ja eelprojetkis*' [41] (in Estonian) ('*Low and nZEB. Design solutions for office buildings in schematic and preliminary design phase*') modifying the reference building energy use to meet exactly the minimum requirements. This was used as a reference building or the base level for the energy category.

While the first version of '*The Minimum Requirements for Energy Performance*' [27] did set only minimum requirements for building EPC values, the updated version [39], launched at the beginning of 2013, defined also low (class B) and nearly-zero (class A) energy efficiency building requirements (with minimum requirements corresponding to class C). New version has also considerably more stringent values for the minimum requirements, which are also pointed out by Kurnitski et al. [42] comparing the status of nZEB definition status in the EU.

For the best solution we improved the building by improving the constructions, system efficiencies and adding PV-panels to increase the buildings energy efficiency to nZEB level. This was finalized by adjusting the shares of different energy users according to Table 23 in [41]. Largest adjustment concerned the internal lighting energy use, which was lowered by accounting energy efficient lighting systems.

To convert the delivered energy to CO_2 emissions I used a specific emissions factor for district heating in Tallinn (for heat) and the average emissions from the production of electricity in Estonia (for electricity).

The simulation results of the reference building just meeting the minimum energy efficiency requirements and the results of the nZEB configuration allowed determining the impact span of the energy category in economic and environmental values.

2.3.3 Quantifying the water efficiency

The scarcity of potable (drinking) water in some countries, especially in dry climates, is a generally known fact. A good example is Jordan, where the water scarcity is a serious concern hindering the country's development [43]. That is why the general inclusion of water category in a sustainability assessment scheme is no surprise.

For reference I used LEED indicator '*Water use reduction*' in [30]. According to this indicator, the maximum number of points is achieved when a building can demonstrate 40% reduction of potable water use in comparison with the baseline water use. The baseline potable water use was determined according to '*Hoonete energiatõhususe arvutamise metoodika*' [40] (in Estonian) (Methodology for calculating the energy performance of buildings), which specifies domestic hot water (DHW) consumption per floor area annually. In the study we assumed that DHW constitutes 40% of total water use. Converting the two water use values - the baseline and the -40% case - in to monetary (Euros), energetic (kWh) and environmental (CO_2 emissions) values, I quantified the impact of water efficiency.

2.3.4 Quantifying the materials impact

The building sustainability assessment schemes generally include materials category. The impact of materials can be assessed in various ways: according to the LCA assessment, CO_2 emissions, reuse of the available structures, recycled content of a product, the source of a material etc.

In this study we limited the investigation of the materials impact to main structural materials. That means three different solutions where considered: steel, concrete and timber structures. We assumed that the core of the building could be constructed out of one of these materials and did not go in depth of specification of the materials. The input values to rate different construction materials impact were taken from a study conducted by Buchanan and Honey [44] that specifies CO_2 emission according to material type for an office building. The emissions values specified in that study were divided for a 20-year period following the guidance of European Commission regulation No. 244/2012 [45]. Different CO_2 emissions of the materials allowed direct comparison on the environmental impact, while for economic impact, the emissions were converted into Euros considering a projected CO_2 quota price.

2.3.5 Quantifying the impact from transport

The location of a building can have a significant impact on the environment. A building sited in a well-developed area with close proximity to amenities offers its' users several benefits. First of all, the site generally has a good public transport connection. Thus, there are alternative options for private vehicle use. Secondly, the services that building users might want to use are close by, thus avoiding the need to travel long distances.

In this study I used the public transport access criterion as a representative for the transport category. This criterion in LEED [30] referred to *The Center of Clean Air Policy* (US) that had found out a pattern: increasing 1% of transit service increases 0.5% the public transport use. Based on that LEED awards extra point for the public transport connectivity if the service is increased four times the baseline limit, thus increasing the usage twice.

We assumed the reference public transport users share to 35% of the buildings' workforce. In an improved situation 70% of the buildings' employees were considered to be using public transport. To identify the sensitivity of the distance to work, we considered two average distances to work: 8 and 12 km (one way). Private vehicle CO_2 emissions were were 245 g/km, taken from EPA report [46].

2.4 Methods used to compare Estonian regulations against LEED and BREEAM

After identifying the important categories for Estonia, I investigated the requirements of building sustainability assessment scheme indicators in these categories. I compared five office buildings in three categories. The buildings were compared against indicators within the respective categories of LEED and BREEAM. Differences between the indoor climate and the energy performance indicator levels of the Estonian regulations against LEED and BREEAM respective indicators were quantified. I identified potential certification levels for the buildings, helping the stakeholders of the construction sector to understand the sustainability aspects of buildings. Based on a comparative evaluation of the indicators, we propose sustainable assessment scheme indicators for Estonia.

In the study I used five Estonian case-study office buildings. Images of the buildings are shown in Figure 2.4. Buildings #1-4 are in Tallinn, building #5 is in Rakvere, 100 km East from Tallinn. Buildings #1-3 are in the city center, building #4 is outside of the center of Tallinn. Building #2 has been occupied since 2009. Building #3 construction ended at the beginning of 2014 and has since been occupied. Building #4 was completed at the end of 2014. Buildings #1 and #5 are at the design stage. With the exception of building #2, all buildings set energy efficiency as a target, with building #5 being the most energy efficient according to energy performance certificate (EPC) class. Notably buildings #3 and #4 aimed for LEED '*Gold*' and GreenBuilding certificate, respectively. While LEED is a well-known sustainable building certification label, the GreenBuilding is an initiative by European Commission to reduce the energy demand of buildings.

The technical design phase project documentation of the buildings was used to compare the Estonian regulations with LEED and BREEAM requirements.

Three indoor climate and energy indicator levels of the current regulations were compared against LEED and BREEAM respective indicator levels. Then LEED and BREEAM transport indicators were evaluated to determine the relevant indicators for the Estonian context. The case study buildings and the three certification levels of the proposed scheme were classified against LEED and BREEAM certification levels. This allowed to make a proposal for the Estonian building sustainability assessment scheme for which equivalence against LEED and BREEAM is known.

Figure 2.4: Case study buildings. The building numbers correspond to the referred building numbers in the article by Seinre et al. [47] and in the thesis.

2.4.1 Indoor climate category indicators

The indoor climate category is one of the most important categories of sustainable assessments schemes. This category has one of the largest shares of the total weighting of the categories in several schemes. It is the third highest weighted category both in LEED [30] and BREEAM [48] for new office buildings. In the following the most important indicators of LEED and BREEAM, directly affecting the wellbeing of the users, were identified. I only considered the indicators affecting the design of a building. Indicators related to the use of the building and its systems were omitted from the consideration, as these can be implemented at the later stages of a building life cycle. For instance, the user training is carried out after the completion of building construction and it is not essential indicator for the design stage.

The indicators covered by the indoor climate category include the following:

1. ventilation flow rate,
2. indoor operative temperature,
3. air speed,
4. internal lighting levels,
5. sound levels,
6. emissions from materials,
7. daylight factor (DF),
8. view to outside,
9. building flush-out (extensive ventilation before occupancy),
10. user satisfaction (at post-construction stage).

The first two of the listed indicators have been considered in scientific studies by Seppänen et al. in [35] and in [38]. The results show an important impact on the productivity of an office employee.

The ventilation flow rate in LEED is regulated by ASHRAE standard 62.1 [49] setting the minimum acceptable flow rate. The flow rate according to ASHRAE 62.1 consists of two parts:

1. the flow rate per person, and
2. the flow rate per floor area.

BREEAM refers to EN 13779 [50] that sets flow rates per person for three quality classes. EN 13779 is used in Estonia as well. Besides that EN 15251 [51] is more widely used. Like EN 13779 the EN 15251 classifies ventilation flow rates into classes. Like ASHRAE 62.1 also EN 15251 classifies flow rates per person and per floor area (latter depending on the emissions from the materials installed as interior finishing).

The indoor temperature and draft rate in LEED is regulated by ASHRAE standard 55 [52], setting the minimum acceptable limits and no quality classes. BREEAM refers to class B (or higher) of ISO 7730 [53] for the temperature and draft rate limits. In Estonia both ISO 7730 and EN 15251 are used to specify the indoor temperature class. New buildings are generally constructed following the requirements of class II of EN 15251, which is equivalent to class B of ISO 7730. For draft rate specification EVS 916 [54] is used.

In the following I cover the rest of the indicators, regulated by various standards. First of all, electrical lighting quality (from users' perception) is not regulated by LEED. That means LEED sets no requirements to the electrical lighting illuminance levels, glare or color rendering. For internal electrical lighting design BREEAM refers to European standard EN 12464-1 [55] that is also used in Estonia.

LEED does not regulate internal noise level from building services in an office environment. BREEAM sets requirements in Table 15 in BREEAM manual [48]. The noise level in Estonia is regulated by Table E.1 in EN 15251. When comparing the BREEAM requirements for noise level against the Estonian requirements I can say that the Estonian regulations are more onerous.

Considering the emissions then here is the largest discrepancy between the regulations of LEED, BREEAM and the Estonian regulations. LEED refers to several local legislative acts that should be followed for compliance. The main idea of these acts is to regulate volatile organic compounds

(VOC) emissions from different products and to avoid specifying finishing wood products that contain formaldehyde resigns. BREEAM uses quite a similar approach: interior finishing materials have to be tested against VOC emissions according to several European standards (specific testing standard for a specific material group). Furthermore, BREEAM appreciates the post construction VOC concentration measurements according to appropriate standards as well. The Estonian regulation according to Appendix C of EN 15251 classifies materials emissions of a building into three classes:

1. '*not low*',
2. '*low*', and
3. '*very low*'.

The classification is made based on the total volatile organic compounds (TVOC), formaldehyde, ammonia and carcinogenic emissions rate and the emitted odor.

The following indicators of the indoor climate category are included in the sustainable assessment schemes, but are not covered by standards or legislative acts in Estonia. These were covered to keep the integrity of the study and the category with its indicators.

The daylight factor (DF) in office buildings in Estonia is regulated by a general guidance in EVS 894 [56] by assuring the average daylight factor of 2%. DF is not regulated by LEED, but instead daylight illuminance level is, which can be considered as an alternative to DF. LEED requirement is to ensure a daylight illuminance level of 269 to 5380 lx (25 to 500 footcandles (fc)) in a clear sky condition on September 21 at 9 and at 15 for 75% of regularly occupied areas. BREEAM, on the other hand, requires an average daylight factor of 2.1% for the Estonian latitude. Thus, following the Estonian guidance will be just short of the BREEAM requirement.

The Estonian standard EVS 894 also regulates the view to outside. At the same time, the regulation is quite vague with a statement of '*guaranteeing the view from working rooms*'. Also no requirement is set on what share of the floor area has to have the view. BREEAM specifies that all positions or alternatively at least 95% of the net floor area within relevant building areas must have a view out. Furthermore, window share of the surrounding wall for a certain room depth to guarantee the view is specified. The specified percentage values of the windows are the same as specified in EVS 894. Thus the BREEAM compliance can be expected. As for LEED, the requirement is to ensure direct line of sight to outdoors through glazing for 90% of regularly occupied areas. Thus, BREEAM requirement is more onerous than LEEDs'.

The extensive building ventilation before occupancy, the flush-out, is a specific indicator in LEED, while it is only a part of an indoor air quality (IAQ) plan requirement in BREEAM. Not used in the current construction practice in Estonia. Even so, it is considered applicable: when made aware of the requirement the only concern would be the cost of running the ventilation systems before the occupancy to ventilate the building.

Considering the post occupancy user satisfaction, both, LEED and BREEAM award one credit for conducting a user survey. This means that after a certain amount of time (about 1-2 years) after occupation, a survey of the satisfaction amongst the building users is carried out. Based on the results, the building performance could be enhanced when the users are not satisfied and the building is not performing according to the preferences of the users. Estonian regulations do not require conducting a survey. The implementation of such would be a minor concern for LEED and BREEAM compliance.

2.4.2 Energy category indicators

The energy category is the most important category in LEED and BREEAM, with the highest share of weighting and the number of possible points. Furthermore, the importance of the energy use is evident due to the fact that this sector is one of the most regulated in the European Union (EU). There is a lot of fuzz around the energy use, energy sources and the eventual environmental impact. Considering building related issues (e.g. the categories included in the sustainable assessment schemes) it is clearly the most regulated one. Legislative acts stemming from EPBD and imposed in the member states of EU is a very clear example of which. Although our earlier studies did not rank the energy category as the most important one, it still was a relevant category.

In this section I look more in depth into the indicators assessed in the energy category by sustainability assessment schemes. We decided to limit our consideration to indicators which have direct impact on the energy use, while leaving out some of the indicators generally included in the category. For example, we left out the environmental impact of the refrigerants, the external lighting and the efficient office equipment indicators. The reasoning behind was the following: does not affect energy use, is outside of the scope of the current consideration defined as building envelope and is a decision made by the user of a building, respectively. Besides the predicted energy use, the movement towards decreased energy use is promoted by installing monitoring systems for the energy use, by commissioning and by personnel training.

In LEED the main indicator in the category the energy use is regulated by ASHRAE standard 90.1 [57]. The main idea of using this standard is to show that proposed development energy performance is better (lower energy use and costs) when compared against a baseline building, which is defined by ASHRAE 90.1 depending on the location (climate conditions) of a building. The improved performance was converted to energy costs by using appropriate heat and electricity prices. BREEAM does not consider the costs. Instead BREEAM refers to national calculation methodology (NCM), which has to be followed to perform energy simulations. For Estonia it means using Decree no. 68 [39] to define the reference building (a minimum requirement building). The energy efficiency of a building in BREEAM is assessed by the energy performance ratio (EPR), which includes three impacts:

1. the energy demand reduction,

2. the systems and the distribution efficiency, and

3. the CO2 emission reduction.

The three impacts are weighted according to their importance in the following way: 23, 38 and 39%, respectively. The reduced CO_2 emissions were obtained when converting heating and electricity demand values into CO_2 emissions using local emissions rates.

In the current situation in Estonia, the energy performance is regulated by EPBD, which was the guideline document to develop Decree No. 68 '*Energiatõhususe miinimumnõuded*' [39] (in Estonian). A proposed building (new or major renovation) has to be in compliance with the minimum requirements of the energy performance specified in that document. As an evolution process from the Decree No. 258 to the Decree No. 68 (the Decree No. 68 superseded the Decree No. 258 from January 2013) the calculation methodology is now separated from the main document. Detailed guidance document how to calculate the energy performance is collected under the Decree No. 63 '*Hoonete energiatõhususe arvutamise metoodika*' [40] (in Estonian). The final outcome of the building energy performance simulation, an energy performance certificate (EPC), also considers the environmental impact of the primary energy source. This is done via weighting factors of the fuels with which the net energy demand is multiplied (e.g. 0.75 for wood-based fuels, 0.9 for district heating, 2.0 for electricity). A building is ranked according to its EPC (kWh/(m^2 a)) value:

- class C with EPC $\leq$160 (minimum requirement for a new office building),
- class B with EPC $\leq$130 (considered as low-energy building), and
- class A with EPC $\leq$100 (considered as nearly zero energy building (nZEB)).

To position current energy classes of the energy efficiency of buildings according in LEED and BREEAM, I created a generic office floor model and simulated it in IES simulation software. The aim was to determine the difference of the baseline building performance between both schemes and the points achievable with three energy performance classes of the Estonian regulations. The top floor was simulated; reasonably considering that middle floors are using less energy than the upper floor.

To establish the baseline building I followed the instructions of LEED and BREEAM:

1. LEED requires the compliance with ASHRAE 90.1,
2. BREEAM allows local building regulations (that follow EPBD directive) to be used.

Thus the minimum acceptable values of respective standards were used to construct the baseline building for both sustainable assessment schemes.

While the energy performance of a building is the most important indicator under the category there are others which influence the final energy use. While system efficiencies, like building services systems, are incorporated into simulations, there are systems which are not. A good example is lifts: their efficiency is not regulated by the Decree No. 68, but are considered in LEED and BREEAM. LEED sets limits to the lift lighting and ventilation efficiencies and the switching to a stand-by mode. BREEAM even considers energy efficiency of drive motors and regenerative drives.

While the initial testing is generally one-time testing soon after construction activities completion, the performance checking can, and should, be extended over 1-3 years. This ensures that the conformity of the systems performance with the design is not a fluke and helps to ensure proper performance under various conditions. Addressing commissioning in the project will ensure appropriate performance of the systems. Furthermore it allows making adjustments at the initial stages of the building life cycle and thus, avoid more than expected energy use over 50-60 years of building lifetime. Most of the major energy consuming systems that need to be commissioned by the Estonian regulations cover the ones specified in LEED and BREEAM. Although lighting systems are not and renewable systems commissioning can be considered covered under HVAC systems. For more detailed information of what is covered by Estonian regulations see Section 2.3 and Table 5 in Seinre et al. [47].

One thing is to predict the energy use by the simulations; the other is to measure it at use. To be able to measure the actual performance of a building, measuring equipment is installed. The measuring and monitoring is generally divided according to different building energy consuming systems, e.g. heating, ventilation and lighting are separately considered. The more detailed the monitoring, the easier it is to identify discrepancies from the predicted values. This helps to pin-point the systems where energy use is larger than predicted and correct their performance. While the benefits are obvious the economic impact has to be considered as well - the more detailed the monitoring, the more expensive it is to install. While LEED regulates monitoring with a general term ('*all energy flows*'), BREEAM and the Estonian regulations specify systems that need to be covered.

Finally, besides the great work of the design team, the users of a building need to know how the building works. The design intensions have to be passed on to the users, ensuring they use the building as intended. To cover that concern, the user training for users and maintenance personnel is advised. Each installed systems' working principle should be explained to the users as well as giving advice on how to manipulate their performance to meet users preferences. To consider user behavior on a longer time span, it is also reasonable to include user manuals for installed systems. To conclude, it is reasonable to require user training and user manuals to ensure proper building use, and that is why it is also requested by all three schemes (LEED, BREEAM and the Estonian regulations).

2.4.3 Transport category indicators

Our earlier study (Seinre et al. [31]) showed a significant impact private vehicle use can have on the environment. That is why every attempt to decrease private vehicle use should be supported. Generally buildings with good access with various transport options are located in developed areas. This means already developed infrastructure and local community with necessary services available. In such situations, a proposed development user has amenities in the close vicinity of the site and can generally reach the services by foot.

Current practice in Estonia does not regulate transportation in a way it is done by sustainability assessment schemes. That is why I compared and evaluated the importance of LEED and BREEAM respective indicators. In both schemes the public transport accessibility is the most relevant. That is how easily and frequently a building can be reached with public transport service. Also the vicinity to amenities is important according to the schemes. The third most important indicator is the alternative means of transportation, which covers bicycle access and parking conditions, car sharing (multiple riders instead of just a driver) and electric recharging stations to support the use of vehicles that use alternative fuels.

The sustainable assessment of buildings generally includes limitations to the car parking capacity, setting the maximum number of spaces allowed. Limiting the parking capacity does not fulfill the intensions of reducing private vehicle use in Estonia. In situations with limited parking capacity, a building is considered inaccessible and clients prefer other locations with better parking conditions. Furthermore, even if the parking is limited there is a pattern that nearby streets are filled with parked cars, hindering the traffic and ruining the aesthetics of the street. That is why, for the time being, limiting the parking capacity is not a solution for Estonia and it is not included in the proposed Estonian scheme.

Chapter 3

Results

This section of the thesis covers the results obtained from the studies performed during my PhD-studies. The results presented move from general background studies to specific sustainable building related studies.

3.1 Results of the check calculations

Only two projects out of the selected thirteen of check calculation analysis were done according to the methodology specified in '*The Minimum Requirements for Energy Performance*'.Thus, excluding the remaining projects from further analysis. The results of the two buildings are covered next.

Retail center in Narva

The building was built in 2009, with heated floor area of 12 733 m^2 and net floor area of 13 287 m^2. According to the design documentation the EPC value for the building was 291 kWh/(m^2 a). With check calculations we obtained a value of 247 kWh/(m^2 a). That is about a 15% difference. Looking at the detailed level of the results showed a larger discrepancy. For instance, the gap between two simulations for the heating energy consumption was 47%; with the values of 42.7 and 79.2 kWh/(m^2 a) according to the design and check calculation simulations, respectively. Furthermore, the ventilation equipment electrical energy use was about five times greater in the check calculations than in the design documents. The electricity use of the rest of the equipment is 20% less in the check calculations. The cooling energy use in the design calculations was 69.8 and in the check calculations 3.7 kWh/(m^2 a).

Office building in Tallinn

The building was built in 2009, with heated floor area of 964 m^2 and net floor area of 1 094 m^2. The EPC value was 169 and 147 kWh/(m^2 a) according to the project documentation and the check calculations, respectively. The discrepancy in the results is 13%. Heating energy consumption according to the check calculations was 47.8 kWh/(m^2 a) which is 18% larger than according to design documentation. The ventilation equipment and the rest of the equipment energy use are matching well between the two calculations with the difference being around 5%. The cooling energy demand for the building according to the design documentations was 7.8 and according to the check calculations 4.2 kWh/(m^2 a), constituting a 46% difference between the two.

3.2 Apartment building LEED assessment

In the following a summarizing results of a LEED assessment of the case-study apartment building is covered. The results are grouped into LEED categories giving an overall picture of each category and the extent of points achieved. A more detailed level of the results is available in the second paper [58].

3.2.1 Building site performance

The first category in LEED is '*sustainable sites*' evaluating the building site. New construction buildings are evaluated by fifteen indicators. One is a compulsory, the rest allocate 1 to 6 points depending on the indicator. The aim of this category is to evaluate the building site and its' appropriateness for a new construction development.

The assessed building scored 13 points out of possible 26 available for new buildings. Majority of the points scored are from two criteria:

1. available amenities in the vicinity, and
2. public transport connectivity.

As the building is situated in the close vicinity of the city center surrounded by well-developed community it was easy to find 10 different services within an 800m radius from the building. Maximum 5 points were gained. Furthermore, the public transport connectivity for the building site is of high quality: there are several bus stops within 400m walking distance with a number of service lines running through. The connectivity indicator scored an extra point as an innovation point due to around 800 rides per day. Thus 6 + 1 points were scored for the superb public transport connection.

One point was scored due to site selection, which was previously developed and was not included to any (biodiversity) conservation list nor was close to water bodies or had a flooding threat. Placing over 50% of parking spaces underground helped to gain one point.

To conclude this category, I can say that the number of points scored was reasonably high for a building which did not follow LEED requirements in the design nor construction process. I must still emphasize that most of the points scored were from two indicators while altogether the intension of four indicators out of fifteen were met.

3.2.2 Water efficiency performance

New construction buildings under this category are assessed by four indicators; one is compulsory, the rest are optional. The number of points available per indicator ranges from 2 to 4 points. The aim of the category is to decrease potable water consumption by sanitary systems (taps, toilets, irrigation). The compulsory indicator requires reducing potable water consumption by sanitary equipment -20% in comparison with the baseline building. The rest of the indicators deal with the following:

- innovative wastewater technologies,
- irrigation, and
- further reduction of potable water use.

The case study building scored maximum four points for not using irrigation system to water plantings. The rest of the indicators were not met. The information of the installed sanitary equipment was unknown. Also, no innovative wastewater technologies were installed.

Conclusion of the category: one indicator met, three unmet. Four points out of possible ten were scored.

3.2.3 Energy performance

There are nine indicators that are applicable for new construction LEED assessment under the energy category; three are compulsory, six optional. The number of points available for an indicator range from 1 to 19. The aim of the category is to decrease energy consumption of a building and ensure that building services systems perform as intended.

The building did not use CFC-refrigerants in HVAC systems and with that met the one of the compulsory requirements. Other two compulsory requirements: 1) commissioning requirements and 2) at least 10% energy performance improvement in comparison with the baseline building were not met.

Out of the optional indicators none was met. The energy performance improvement and the enhanced commissioning were not met. There was no on-site renewable energy production. Also no green electricity was purchased. Refrigerants used in the HVAC systems did not meet the limits set by LEED. No *post-occupancy evaluation* (POE) of the building was conducted.

There is a lot to improve: no points while there were thirty five points available! Only one out of nine requirements was met.

3.2.4 Materials category performance

For a new construction assessment the category consists of nine indicators; one compulsory, eight optional. The number of points available for an indicator range from 1 to 3. The aim of the category is to evaluate the impact of the building from the perspective of specified materials and generated wastes.

The compulsory requirement of collecting certain recyclable materials separately was met. Two points were scored from the use of regional materials and another point was gained by the use of Forest Stewardship Council (FSC) certified wood products.

The rest of the indicators were not met. Specifically the following matters were not considered: maintaining existing structural elements (walls, roofs, floors) and internal non-structural (partitions) elements; reusing materials; using recycled materials; rapidly renewable materials. Construction waste management plan was applied (as required by local legislation) and would have met the LEED requirements, but the plan was not fulfilled: more waste ended up in a landfill than planned and allowed.

Three points from available fourteen were scored. The compulsory requirement was met. Four indicators were considered, three were met and the rest were not covered in the project.

3.2.5 Indoor climate performance

The indoor environment quality category consists of seventeen indicators to be evaluated by the assessment of new constructions: two are compulsory and fifteen optional. Each optional indicator can score a point. The aim of the category is to ensure comfortable conditions for the building occupants.

The compulsory requirement of the minimum ventilation flow rates was met as these were higher than required. The compulsory requirement for tobacco smoke control was not met, as the smoking was allowed in the building.

The ventilation flow rates for the apartments were high enough to gain points for the '*increased ventilation flow rates*', but as these were not high enough for *each* individual room, the point was withheld. The installed AHUs did not incorporate fresh air monitoring sensors, and thus the point for this was not achieved. The project did not include an indoor air quality (IAQ) plan for construction phase nor was the flush-out used. Furthermore, no special attention was placed on VOC emissions from materials, but even so the requirement was met for paints and sealants. Indoor pollutant control was not met, as the ventilation flow rates from garage were below the expected limit and the filtration media used in AHUs was less efficient than required. The control over thermal comfort and electrical lighting was met.

The thermal comfort was in compliance with the requirements. The visual comfort indicator of daylight level was not within the acceptable limits. The view from the windows to outside environment was met.

To conclude the indoor climate quality category the following was achieved: one compulsory requirement from two was met and five points, from fifteen available, were scored.

3.2.6 The innovation section

This category can be considered as an addition to the main categories where additional points can be achieved. The assessed apartment building gained an extra innovation point for an outstanding public transport connection.

3.2.7 Total LEED score

The summarized results of the categories are shown in Table 3.1. The overall conclusion of the case study was the following: the building scored altogether 26 points. The possible number of points was 106 including six additional points available for innovation. This leaved the building uncertified in LEED scale, with its' 40 points being the minimum requirement for lowest certification level.

3.3 The relevance of the categories

This section covers the resulting impact of each of the five categories considered. The impact was evaluated on the energy use, the CO_2 emissions and the costs. To quantify the extreme ends of impact range two design solutions were considered: the baseline level and the best solution. The indoor climate category considers different design solutions (modifying room temperatures and ventilation flow rates) and identifies the extremes. The en-

Table 3.1: LEED category results for the case study building.

LEED category	Points/ max points	% of points
Sustainable sites	13/26	50%
Water efficiency	4/10	40%
Energy and atmosphere	0/35	0%
Materials and resources	3/14	21%
Indoor environmental quality	5/15	33%
Innovation in design	1/6	17%
Total	26/106	25%

ergy category shows the impact considering reference, minimum and nZEB building energy demand. Water category shows the impact of considerably reduced water consumption. Materials show the impact of different materials. Transport results show the extent of potential impact due to public transport use.

3.3.1 Indoor climate results

For ventilation flow rates two sources were used:

1. the Governmental decree No 68 [39], and
2. EN 15251 [51].

The first sets the minimum requirements for the energy efficiency of buildings (also fixing the default ventilation flow rates). The second is a European standard for indoor environmental quality, specifying ventilation flow rates for three quality classes. The flow rates set by the Decree No 68 equal or even surpass the class I flow rates according to EN 15251 depending on the occupancy density.

As mentioned earlier in section 2.3.1 two different occupancy densities were used. For the ventilation flow rate and the productivity correlation the productivity level of 1.0 was exactly the flow rate for class III (15 m^2/person considered as landscape offices according to EN 15251) or about the same for class III in the configuration where 10 m^2/person (considered as private offices according to EN 15251) were used. The positive impact of class I ventilation flow rate in comparison with class III ventilation flow rate resulted in an increase of productivity of 26.5 and 53.8 €/(m^2 a) for office type #1 (15 m^2/person) and #2 (10 m^2/person), respectively.

The impact of the ventilation flow rate on the short term sick leave was identified by comparing the class III (as baseline) flow rates (converted into air change rate per hour (ACH)), used in a specified equation, against class I (as the best solution) flow rates according to EN 15251. This was considered for both occupancy densities. The increased benefit, when converted to Euros, was up to 11.6 and 13.6 €/(m^2 a), for office configuration #1 and #2, respectively.

The effect of the room temperature on the performance of an office employee was identified with IES simulation software. Various room conditions were simulated, which were summarized in Table 1 in the article by Seinre et al. [31]. Main modified parameters were ventilation flow rates and cooling set-points. Also a set-up without mechanical cooling and night cooling with operable window were simulated.

To identify the effect of the temperature, one degree temperature ranges in the office areas and their corresponding hours were multiplied. This allowed considering the weighting of each temperature range. The relative productivity value of the lower end of the one degree temperature range was multiplied by the respective temperature range hours and ultimately added together to identify the impact. Based on the number of total occupants and their salary, the effect of the temperature on the productivity was converted into monetary units. The results are shown in Figure 4 in [31].

3.3.2 Energy performance results

The same indoor climate quality configurations as were used in the simulations for the indoor climate analysis were used in the energy analysis. A distinctive pattern according to the energy analysis results is: the more stringent the indoor environment condition, the more energy is used. This was anticipated, as it is evident that higher ventilation flow rates and lower cooling set-point temperatures demand more energy for running the fans and the chillers.

The impact of an energy category on the energy use and the cost is clearly visible in Figures 8 and 11 in [31], respectively. The case-study reference building uses 3.7 and 5.5 kWh/(m^2 a) more heat and electricity than the minimum requirement building. Latter uses 27.1 and 17.6 kWh/(m^2 a) more of respective energy sources in comparison with the nZEB. These results are obtained when building occupancy density was 17 m^2/ person according to the Governmental decree No 63 [40].

In economic values the reference building uses 0.8 € /(m^2 a) than the building meeting the minimum requirements. At the same time, nZEB allows savings up to 4.4 € per m^2 annually in comparison with the minimum requirement building.

3.3.3 Water efficiency results

The water efficiency band was determined as the baseline value according to the Governmental decree No 63 [40] (DHW was 40% of the total water use) and as the best value of 40% reduced water use. The impact on the energy use, CO_2 emissions and Euros can be seen in Figures 8, 9 and 11 in the article by Seinre et al. [31], respectively. A similarity in all of the referred figures is the low impact of the water category.

3.3.4 Materials impact results

The impact of the core construction materials was evaluated on CO_2 emissions and the costs derived from the projected CO_2 quota price per ton, which was considered as high as 40 € /ton which should be the level for meaningful initiative for CO_2 quota market and to support the investments in alternative energy sources as stated by Larson and Lönnroth [59]. The impact band margins in the materials category are formed by steel and timber structures, with lower CO_2 emissions assigned with timber. The concrete structures lie in between the two, closer to the steel emissions levels.

3.3.5 Transport results

The minimum effect on CO_2 emissions due to increased public transport use is 22.8 $kgCO_2/(m^2\ a)$ (occupancy density 15 m^2/person, one-way distance 8 km). In the case of 70% of building employees using public transport, in an office with occupancy density 10 m^2/person and the one-way distance of 12 km, the maximum effect of the public transport use on CO_2 emissions can be as high as 51.5 $kgCO_2/(m^2\ a)$ in comparison with the baseline case (35% of public transport users).

Converting the CO_2 emissions into Euros by multiplying the emissions change with CO_2 quota price shows significantly decreased impact. That is why in Figure 11 in the article by Seinre et al. [31] only the maximum impact is shown.

The impact on the energy use (kWh) was obtained by using following inputs: the reduced private vehicle distance covered was as high as 804 300 km (for the office occupancy density of 10 m^2/person and one-way distance of 12 km) annually; fuel consumption of private vehicle 8 l/100 km; calorific value and the density of gasoline were 44.4 MJ/kg and 737 kg/m^3. This resulted in an energetic impact of 152.7 kWh/m^2 annually.

3.3.6 Summarized results of the categories

The impacts on delivered energy use can be seen in Figure 3.1. Increased energy use in the productivity category is caused due to higher ventilation flow rates and increased cooling energy demand. The energy and the water use category show a possible reduction in energy use. Decreased energy use comes with better building constructions and improved system efficiencies and in water category from decreased water consumption and the need to treat and heat. The location category shows the effect of reduced petrol use by private vehicles. The effect for office configuration #1 (15 m^2/person) with an 8 km distance is 67.8 kWh/(m^2 a) indicating the lowest impact due to increased public transport use.

The effect on the CO_2 emissions is shown in Figure 3.2. The values were obtained by converting kWh values into CO_2 emissions using a value of 225 and 1180 gCO_2/kWh for the district heating and the electricity, respectively. The increased CO_2 emissions due to higher quality indoor climate resulted increased emissions in the order of 5.2 and 9.4 kgCO_2/(m^2 a) for heating and electricity, respectively. A nZEB resulted to decreased emissions: -26.9 and -34.1 kgCO_2/(m^2 a) altogether (including heat and electricity) in comparison with minimum and reference building, respectively. The impact due to reduced water use was 0.63 kgCO_2/(m^2 a) (including heat and electricity) comparing the baseline and the -40% reduction. The CO_2 emissions of the materials category resulted in a span of 4.57 kgCO_2/(m^2 a) between steel and timber structures derived according to the methods specified in Section 2.3.4. Considering CO_2 emissions from fuel consumption, the impact of transport resulted in a maximum impact (office #2 (10 m^2/person) and 12 km distance to work) of 51.5 kgCO_2/(m^2 a) of reduced CO_2 emissions. Minimum impact (office #1 and 8 km distance) from decreased private vehicle use resulted a reduction of 22.8 kgCO_2/(m^2 a).

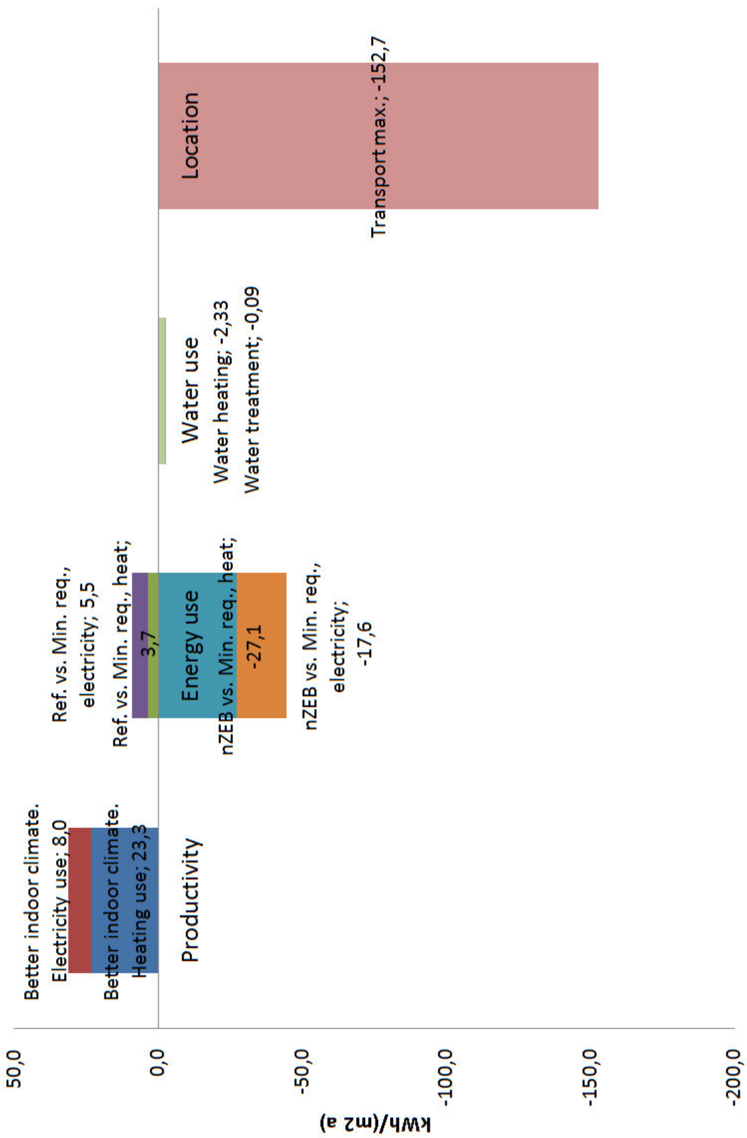

Figure 3.1: Categories impact on the energy use.

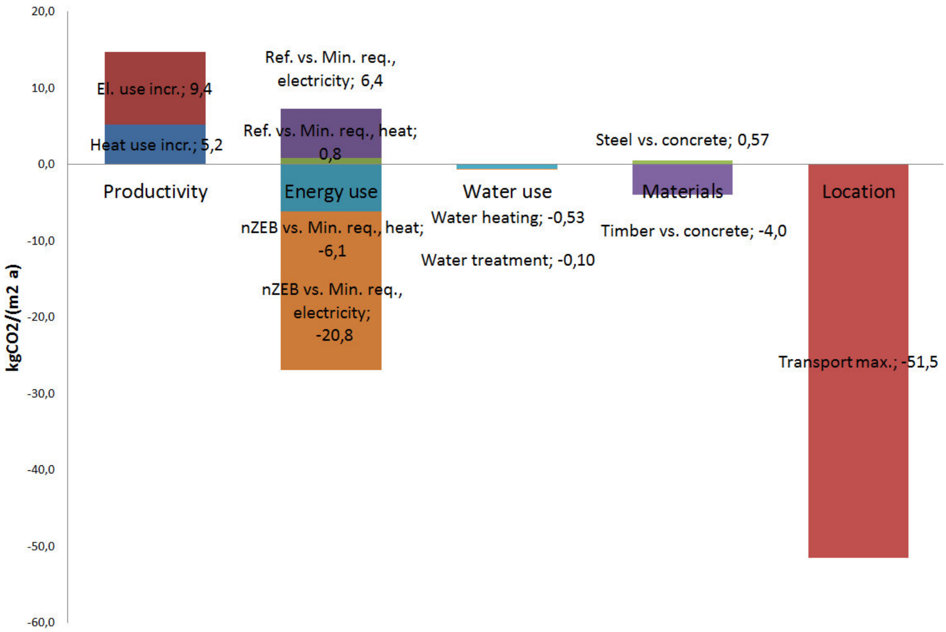

Figure 3.2: The impact band of CO_2 emissions due to two ends of the studied cases within each category.

Besides the impact band of CO_2 emissions, also the absolute impact was considered. This is shown in Figure 3.3. Energy use average in Figure 3.3 was determined as reference and nZEB building energy use average. Water use average emissions were based on average value of baseline case in Estonia and the 40% reduced water use situation. Concrete emissions rate was used for materials emissions rate as the most common construction material for office buildings. For steel and timber structures the emissions rates were 6.32 and 1.80 $kgCO_2/(m^2\ a)$, respectively. The average impact on emissions for location was determined as office configuration #1 emissions in a case where the distance to work is 8 km and there were 70% of public transport users against office configuration #2 with 12 km and 35% of users.

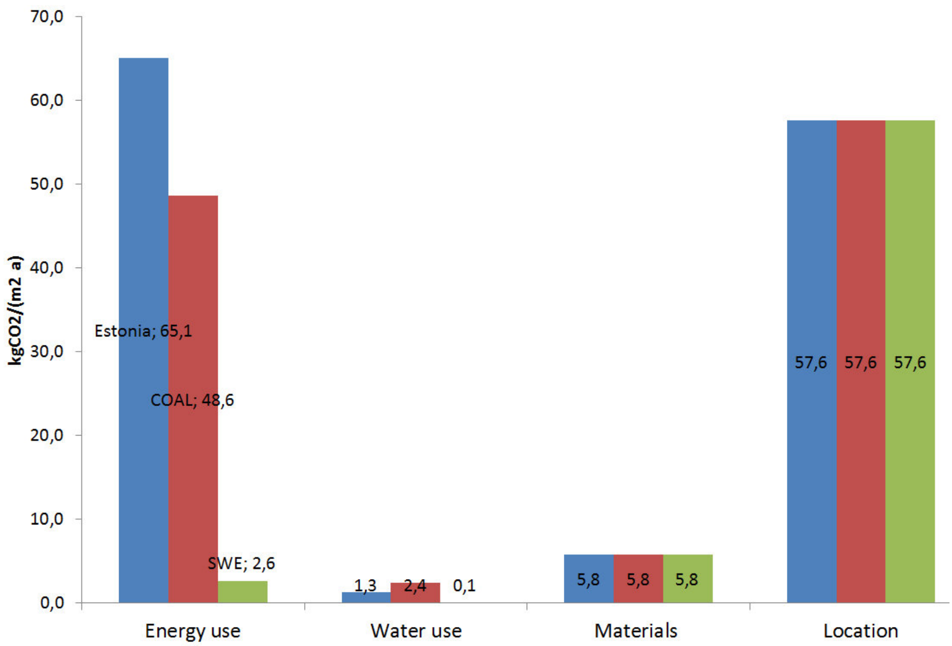

Figure 3.3: Average absolute CO_2 emissions of the categories. Average was determined from minimum and maximum values of each category. Materials emissions shown were concrete emissions. To emphasize the importance of energy sources, a comparison between Estonian energy sources, coal and Sweden emissions are shown.

The summarized economic impact is shown in Figure 3.4. This shows higher impact on the productivity due to temperature savings when compared to the original Figure 11 in Seinre et al. [31]. Latter had a mistake and included only the temperature effect due to class I against class III ventilation flow rate (due higher flow rate, the number of hours above certain limit was decreased). To also consider the effect of cooling set point at 23 ℃, the increased benefit is 16.7 €/(m^2 a).

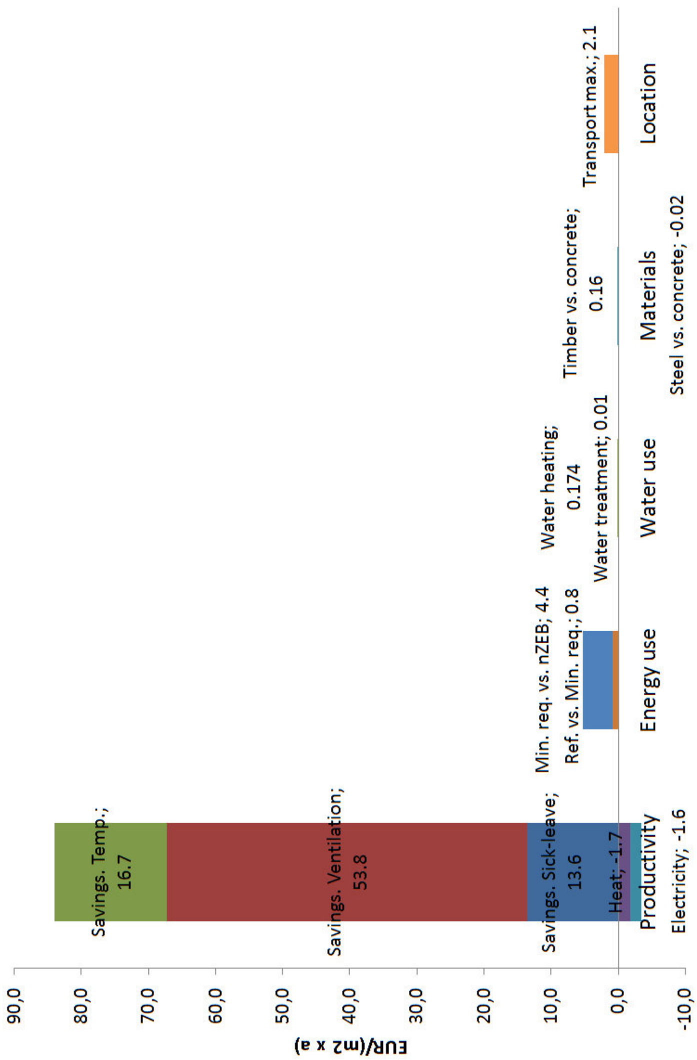

Figure 3.4: The economic impact of two ends of the studied cases within each category. Positive values represent savings, negative increased costs. The values represent the situation for office configuration #2 (10 m^2/person).

The productivity has the largest impact due to higher productivity of the employees in order of 84.1 €/(m^2 a). Extra running costs to achieve the specified level on increased productivity are negligible, only 3.3 €/(m^2 a). Thus, a clear conclusion is that the increased costs are well worth the investment - the increased benefits exceed the costs over 20 times. The energy and the water use categories results show that better construction standard and decreased water use will result in savings, when considering the respective energy prices. For the materials and the location categories we used similar approach to determine the economic effect: suggested CO_2 quota price is multiplied with the difference in CO_2 emissions between two extreme options. For materials the difference between steel and timber structures constitute the band; for transport the difference in the public transport users of 35 and 70% for office configuration #2 and 12 km distance is shown.

The impacts of different categories on the economic and the environmental indicators are summed up in Table 3.2. Productivity, energy and location had impacts across all indicator groups, whereas materials and water had insignificant shares. Productivity values in Table 3.2 for kWh and CO_2 indicators have reversed logic compared to other values, because more energy and CO_2 is needed to provide better IEQ. The lower the value means that relatively low impact is caused to the environment due to higher productivity levels. Some reservation toward the importance of location should be held, as the highest impact comes from kWh indicator which was determined according to assumptions made in Section 3.5 in Seinre et al. [31]. Besides that, the influence on the increased use of the public transport and its impact on the environment were not taken into account in the study.

3.4 Results of the comparative evaluation study

In the following I present the results of our study which compared Estonian requirements against LEED and BREEAM requirements in two categories.

Table 3.2: The impact on the environmental and the economic indicators. The values represent the impact of different design options (minimum acceptable and the best practice). Larger shared categories are more important.

Category	**kWh/(m^2 a)**	**kgCO$_2$/(m^2 a)**	**€/(m^2 a)**
Productivity	31.3 (13%)	14.6 (14%)	84.1 (91.6%)
Energy	53.9 (22%)	34.1 (32%)	5.2 (5.7%)
Location	152.7 (64%)	51.5 (49%)	2.1 (2.3%)
Water	2.4 (1%)	0.6 (0.6%)	0.2 (0.2%)
Materials	na	4.6 (4.4%)	0.2 (0.2%)

The points scored in both schemes, while meeting specific Estonian requirements, are shown. Also the outcome of comparative analysis of LEED and BREEAM transport category is given. Based on the latter a proposal for the transport category indicators for the Estonian scheme is given. Five case study buildings are classified in LEED and BREEAM certification scales using the results of the indoor climate quality and the energy category indicators.

3.4.1 Comparison of the indoor climate category indicators

In the building sustainability assessment schemes several indicators under the indoor climate quality category are assessed. Starting from the most obvious ones like the ventilation flow rate and the thermal quality and ending with the visual comfort and the acoustics. A detailed level comparative evaluation of the indoor climate indicators regulated by the sustainable assessment schemes is presented in Table 6 in Seinre et al. [47]. This table excludes ventilation flow rate, temperatures and draft rate (DR) which are grouped in Table 7 in Seinre et al. [47] along with noise level, internal lighting and materials emissions requirements. First table gives an implication of the gap between the Estonian standards and the requirements set by the sustainable assessment schemes. The second table shows the number of points achievable in LEED and BREEAM when a building is designed with different ventilation and thermal comfort classes. Also the potential number of points for the internal lighting and noise level and the materials emissions are shown.

Looking at Table 6 in Seinre et al. [47] one can conclude that even the two most well-known sustainability assessment schemes have variations. For instance, LEED does not set any requirements for the electrical lighting indicators or to the daylight factor (DF), while BREEAM does. Though LEED regulates minimum daylight illuminance level, which is comparable with the DF. At the same time, Estonian regulations follow the same standards as BREEAM for some indicators (e.g. electrical lighting), while do not regulate some of the indicators at all (e.g. post occupancy evaluation, flush-out). Thus, the comparison of the category including all the indicators is cumbersome. Comparing the indicators regulated in Estonia will give an idea of the differences of the requirements. Leaving out the indicators included in the building sustainability assessment schemes and not regulated by Estonian regulations. This is reasonable, as the latter would not score any points, while implementing these when being aware of their inclusion in the schemes might not be a difficult task for a design team.

In Table 7 in Seinre et al. [47] the points scored in LEED and BREEAM with three quality classes according to the Estonian regulations are presented. Only indicators with specified values in the Estonian regulations are included. A class III ventilation flow rate is below the point thresholds of LEED and BREEAM. A class II - a standard practice level for new constructions in Estonia - scores the point available for the both schemes under the ventilation flow rate. A class I (best practice) flow rate is of equal value as standard practice and no extra points are allocated.

Thermal comfort includes a combined assessment of the operative temperature and the draft rate in LEED and BREEAM. As introduced in Section 2.4.1 LEED sets minimum requirements for compliance, while BREE-

AM requires accordance with at least class B of ISO 7730. While the operative temperature limits set by the Estonian standard thermal comfort class III meet LEED operative temperature limits, building will not score the point in either scheme as the DR limit is exceeded. Class II and class I will meet the requirements of LEED and BREEAM, scoring one point (maximum) in both schemes. Class I thermal comfort would also score 1 point.

Lighting quality in an office space is a vital indicator to ensure proper working conditions of the employees. LEED does not set requirements for internal electrical lighting illuminance levels. BREEAM and Estonian practice refer to the same standard to design internal electrical lighting. Thus, following Estonian requirements will ensure the compliance with BREEAM.

Besides not regulating electrical lighting levels, LEED does not regulate noise levels in office spaces. Meeting the Estonian regulation levels set by EN 15251 for office spaces will ensure compliance with BREEAM requirements as well, as the latter sets less rigorous values.

Considering the way the materials emissions are regulated by LEED, BREEAM and the Estonian current practice then this is one of the most difficult indicators to compare. The reason is that all three limit the emissions in different units which are not directly comparable. LEED limits the VOC emissions [g/L] (not including water) per specific product range, with default value generally being at 50 g/L. BREEAM sets requirements for the producer to test their products against specific ISO or EN standards depending on the product type. Furthermore, for post construction phase, BREEAM expects emissions testing (concentration in the room air, $\mu g/m^3$) of finished rooms according to ISO or EN standards. The Estonian regulations (EN 15251) limit the emission as emissions over time from an area ($mg/(h\ m^2)$). As direct comparison is not possible, we made a rough assumption that '*very low*' and '*low*' emission materials score maximum and half of the points available for the indicator, respectively.

To conclude this section I must reiterate that the number of indicators under this category is larger than covered in the previous paragraphs. I covered only indicators that are regulated by the Estonian regulations or standards. With indicators regulated in Estonia altogether 6 points are attainable in both schemes. The total number of points available in the respective category in both schemes is 15, leaving more than half of the points outside of the scope of the consideration.

3.4.2 Comparative results of the energy category indicators

As mentioned in Section 2.4.2 LEED and BREEAM use different energy calculation methods. LEED refers to Appendix G in ASHRAE Standard 90.1 [57] to construct simulation models for baseline and design solutions. In LEED a proposed building has to yield at least -12% energy costs (not energy demand!) in comparison with the baseline building to earn a point. This has to be verified by a whole building energy simulation with appropriate simulation software and following the guidance of Appendix G. Further reductions in the energy costs will produce an increasing number of points: up to 19 points with the energy costs decreased -48%.

For the energy simulations BREEAM refers to local regulations or standards. If these are not available then Appendix G of ASHRAE 90.1 or National Calculation Methodology (NCM) [60] should be used. Estonia has its' own calculation methodology appropriate for the simulations. An EPR value has to be at least 0.06 to earn a BREEAM point for the energy efficiency indicator. With the EPR step of 0.06 up to 15 credits can be collected. Maximum 15 points are available only with zero net carbon buildings.

I simulated the top floor as the worst case floor and also to include the roof construction quality (U-value). Table 8 in Seinre et al. [47] presents the results of simulations for the generic office floor. Case #1 represents the results for LEED reference building according to the requirements set by Appendix G in ASHRAE 90.1. Case #2 just meets the minimum requirements set by Decree no. 68. This is also used as a baseline building for BREEAM ranking. In simulations for LEED I used the same flow rates and a VAV system as in case #1 changing constructions and the system efficiencies according to explanations. For instance, for the case #2 for LEED uses '*Min. Requirement*' column in Table 4 (excluding air flow rate, which is the same as in case #1) in [47]. The case #3 is just within '*low-energy* building class (class B) according to Decree no. 68. In this case the building envelope is improved: U-values for the external wall, roof and windows are 0.1, 0.08 and 0.6 W/(m^2 K), respectively. G-value for the windows is 0.26 and the internal lighting load is 8 W/m^2. A further improvement for the case #4, in comparison with case #3, is covering 80% of the annual heat demand with a ground-source heat pump. The rest is covered by the district heat. To conclude the energy efficiency requirements I can say that current regulations in Estonia set reasonably high demands. That is especially evident with class B and A energy efficiency buildings which score high number of points in LEED and BREEAM schemes.

The comparison of the rest of the indicators included in the energy category was given in Section 2.4.2. The differences between LEED, BREEAM and the Estonian requirements were limited as the concept of all the schemes is generally the same.

3.4.3 Outcome of the transport category indicators

As mentioned earlier, there are no regulations covering the transport category indicators in Estonia. That is why I compared LEED and BREEAM respective categories and identified the most important indicators with the largest impact on the environment. To keep the category at a reasonable scope for the Estonian scheme we only compared the three most relevant indicators: the public transport, the amenities and transport alternatives. The comparison is shown in Table 9 in Seinre et al. [47]. A general conclusion of the comparison of these three indicators is that they are very similar. Though, the specific numbers do vary between the schemes (e.g. the allowable distance to amenities or to a bus stop) and the specific indicators might be different (e.g. number of rides in LEED and accessibility index (AI) index in BREEAM), but the idea remains. Thus, we chose the most applicable option that could be implemented in Estonia.

LEED sets more stringent requirements for the amenities than BREEAM. The number of amenities that need to be available is larger - 10. BREEAM requirement for an office building can be met with three or five amenities. Furthermore, LEED allocates up to 5 points for the compliance, but does not clearly state how the points are allocated. In BREEAM this is more concrete. Due to obvious clarity in BREEAM and due to the consideration of the need for services we followed BREEAM pattern - lower number of amenities, but with more frequent need, are required. That is why we proposed only three amenities:

- a dining place, for people to have a lunch,
- a grocery shop, as an alternative for the first option and with an everyday need for most of the people, and
- an ATM/bank, to take out cash.

For the alternative means of transportation we suggest only bicycle parking capacity and showering and changing facilities. Additionally we deem electric vehicle recharging stations also relevant, as the state is supporting the purchase and use of electric vehicles. In conclusion we can say that the alternatives resemble more with BREEAM and actually follow BREEAM values for the specific percentage limits.

3.4.4 Classification of the case study buildings

The most anticipated results of the comparison study will be revealed next - the case study buildings classified in LEED and BREEAM. Figure 3.5

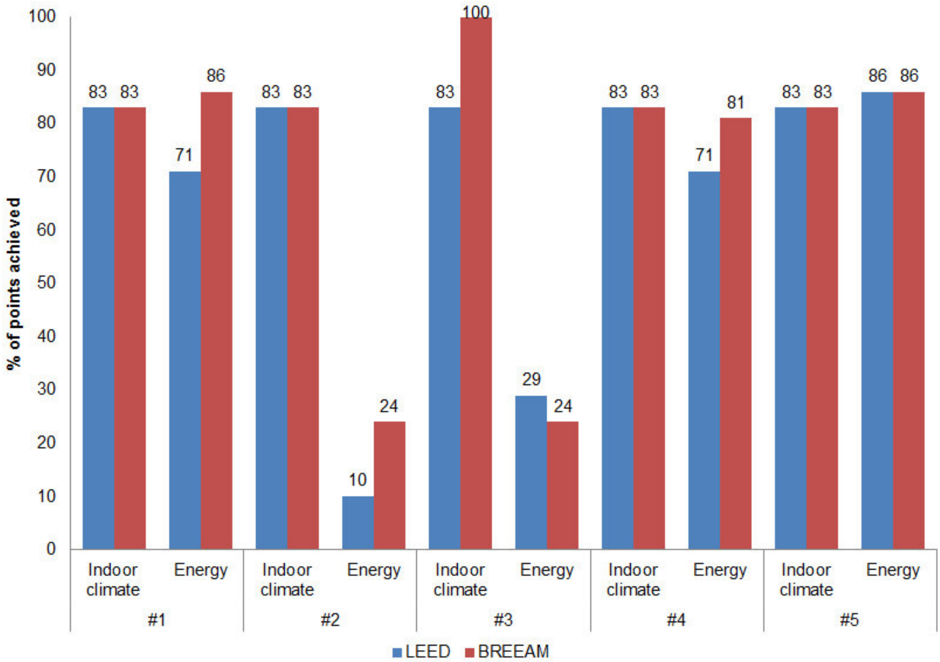

Figure 3.5: LEED and BREEAM score shares for the analyzed buildings based on the indoor climate and the energy categories. Only indicators regulated in Estonia were assessed against LEED and BREEAM respective levels. Assessed indoor climate indicators are shown in Table 7, energy indicators in Table 5 and 8 (excluding the '*system efficiencies*') in Seinre et al. [47].

shows the percentage of points achieved in the indoor climate and the energy category of the five buildings. The percentages are calculated on the bases of indicators regulated in Estonia, leaving out the ones which are not. The percentage share in the indoor climate category is high - over 80% - across all buildings. The shortcomings from the highest result were due to the VOC emissions indicator as most of the buildings specified materials with '*low*' instead of '*very low*' emission rate.

The energy category had a larger variation in the results. Here the shortcomings were related to the low energy efficiency; especially for buildings #2 and #3 which were class D and C buildings, respectively. Furthermore, for BREEAM, the level of detail for the energy monitoring was less than expected (BREEAM rewards an additional point for sub-metering). The other indicators covered in the energy category and regulated in Estonia were consistent with LEED and BREEAM requirements.

To keep the consideration of LEED and BREEAM comparison fair, in the following I list the indicators not covered by the current practice in the Estonian requirements. For full compliance with the LEED indoor climate category the following should be covered: the daylight factor; the lighting and heating controls; the views; the user satisfaction questionnaire; the flush-out; and the indoor climate quality during construction process. Respective additional indicators in BREEAM are: the daylight factor and the glare control; the views; water quality; safe access and natural hazards. One can notice, that some of the indicators do match, while the others do not. Thus, even the two most well-established schemes do have differences and are not exactly comparable.

The energy category for the sustainable assessment in LEED is completed by the following indicators: purchased green power; on site renewable energy and refrigerants environmental impact. Latter two are covered by BREEAM as well. Additionally BREEAM indicators include the energy efficiency of the external lighting, the energy efficiency of transportation systems (lifts and escalators) and the energy efficient office equipment.

I calculated the overall scores for the schemes as an average value of the energy and indoor climate category results shown in Figure 3.5. LEED and BREEAM scores for the assessed buildings are shown in Figure 3.6. Also top three certification levels are shown. Achieved scores are projected to the entire scale of the respective schemes. We considered that the regulated indicators give a reasonable estimation of the final score. Thus, if all the indicators covered by sustainable assessment schemes would be regulated, a similar result can be achieved. The buildings follow the same pattern

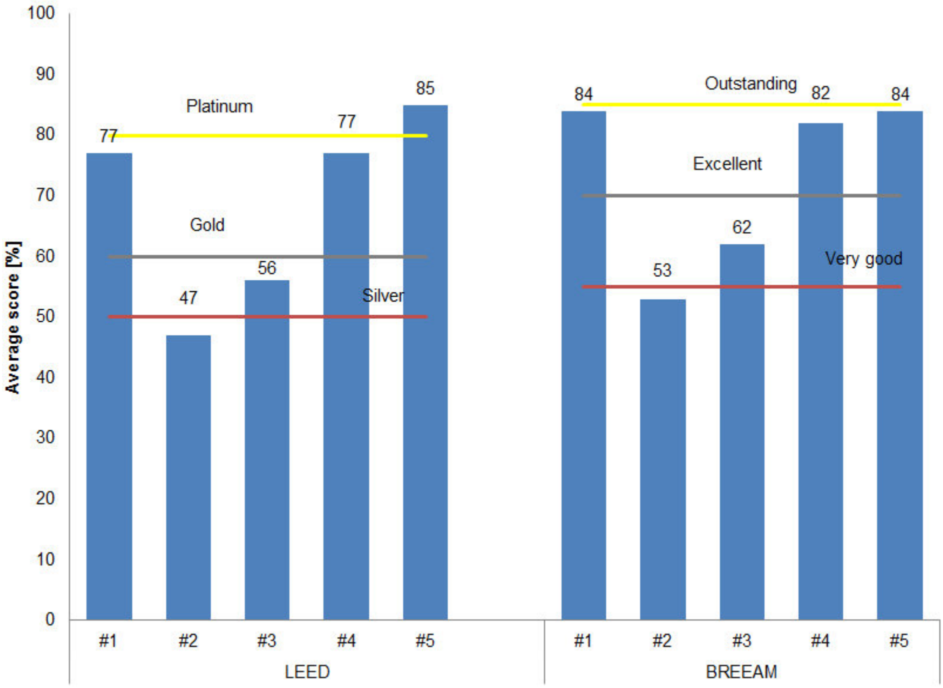

Figure 3.6: LEED and BREEAM scores for the assessed buildings. Scores are calculated as an average of the two category scores from Figure 3.5 for each building. Horizontal lines indicate top three certification levels of the schemes.

in both schemes: higher energy performance class buildings score higher number of points. Building #2 is just below the third certification level; building #3 above the third level; other three achieve the second highest certification. Building #5 is very close to the highest certification level in BREEAM and even surpasses it in LEED.

Chapter 4

Discussion

This section will give an overall interpretation of the studies performed. Analysing the results obtained, reasoning the topic development and evaluating the validitity of the study results.

4.1 Status of EPBD implementation in Estonia

The results of the study showed serious shortcomings in the implementation of the minimum requirements of the energy efficiency regulations of buildings in Estonia. Only two projects from 13 qualified for the check calculations. Others mainly failed to match the methodology required by '*The Minimum Requirements for Energy Performance*' [27]. The study deemed supporting trainings for software use and simplified explanation of the methodology of the regulation necessary. This will ensure that the individuals performing the simulations are more aware of the peculiarities of the software and the regulation. Resulting more accurate simulations that are comparable with the real consumption values, meeting the intent of the regulation.

Due to slow implementation of the regulation an option is to evaluate overall building quality; to evaluate a building according to a sustainable building assessment scheme. Latter is a comprehensive collection of indicators to evaluate the quality of a building and its impact on the environment. This guarantees that the classification of buildings is made based on more considerate assessment.

It must be still remembered that '*The Minimum Requirements for Energy Performance*' [27] (superseded by [39] and [40]) is a compulsory legislation directed by the governing bodies of the EU. Thus, even though the implementation has been difficult, it cannot just be neglected or changed to other solutions. Building sustainability assessment can be considered as an elaboration of the energy efficiency regulation, where latter would form just a part of the classification.

It was clear that some changes were necessary. While I was not convinced that building sustainability methods will be implemented, I still considered the latter concept worth further studying. While I did recognize the importance of energy efficiency, I was also convinced that high quality buildings should be ranked in more comprehensive manner. For that I considered sustainability assessment as a viable option, which in the years to come will also be introduced in Estonia.

4.2 Applicability of building sustainability

As a next step for a proposal to improve the situation in Estonian building sector I turned my attention towards sustainable buildings concept. For that I carried out an apartment building assessment according to LEED assessment scheme. This allowed covering two focal points in one study: to give an implication where similar buildings would classify in such a scheme and uncover the scope of building sustainability assessment scheme.

According to the results obtained for a case study apartment building LEED assessment it looked like the construction sector in Estonia was way behind the levels set by sustainable assessment schemes. The total number of points of the assessed building was clearly below the lowest certification level.

Still there are a couple of aspects to consider. Firstly, the assessment was done *after* the completion of the building. Secondly, the building was designed and constructed according to the local construction practice at the beginning of 2000's in Estonia. Thirdly, the awareness of the building sustainability concept was non-existing.

The aspiration of the sustainable buildings is to surpass standard levels. Considering the aforementioned justifications I think it was reasonable to expect that the building would not position as sustainable. Rather the number of points scored was surprisingly high.

Looking into more detailed level of the results we can see that the '*Sustainable sites*' category stands out. Half of the points of the total score were gained with this category. 13 points out of 26 available in the category, is a decent result. The rest of the categories, on the other hand, did not perform that well. Thus, it was expected that the certification of the case study building was at unattainable reach.

Although the assessed building complied very well with few indicators of sustainable building concept, in general the situation was not prosperous. The number of indicators included in sustainable building assessment schemes overwhelms the issues covered in a typical building project in Estonia. Even the excellent results for the amenities and the transport connectivity were a result of an arbitrary site selection rather than conscious consideration of different site options. Some of the other indicators meeting the requirements seem to have had the same characteristics.

While it is understandable that a quality building has to conform to several indicators, it is also clear that the list of indicators cannot be infinite. Large number of indicators would make a scheme difficult to manage and also require a lot of additional documentation from design teams. At the same time, all important indicators with the largest impact on the environment should be included. Even though sustainable building concept builds on the environmental impact, the economic impact, as the indicator generally used by decision makers, should be included as well. That is why our next studies aimed to identify the most important categories for the Estonian context, considering their environmental and economic impacts.

4.3 Outcome of the quantification study

To use scientific approach in defining the importance of the categories of sustainable building assessment schemes we aimed to compare them in numeric values as opposed to personal preferences. As the approach was unique we wanted to keep the study at a manageable scope. Limits were also set by the consideration of which indicators can be converted into numeric values to evaluate environmental and economic impact. That is why we used only one indicator per category to determine the weightings.

Most obvious way to determine weightings of the main categories is to use €/m^2 percentage shares of Table 3.2. This would result in the productivity impact of 91%. This also means that the productivity effects are not enough recognized in current codes and standards, and more rigorous IEQ would decrease the importance of productivity. To decrease the impact of productivity a comparison was suggested between class II and class I ventilation flow rates according to EN 15251. In such case the positive effect of class I ventilation flow rates for office configuration #2 would result in savings worth 19.3, 1.7 and 16.7 €/(m^2 a) for productivity, sick-leave and temperature, respectively. Thus altogether 37.7 instead of 84.1 €/(m^2 a). For office configuration #1 the respective values are 11.6, 2.8 and 11.1 (25.2 €/(m^2 a) altogether).

Even when the reference level was class II ventilation flow rate the share

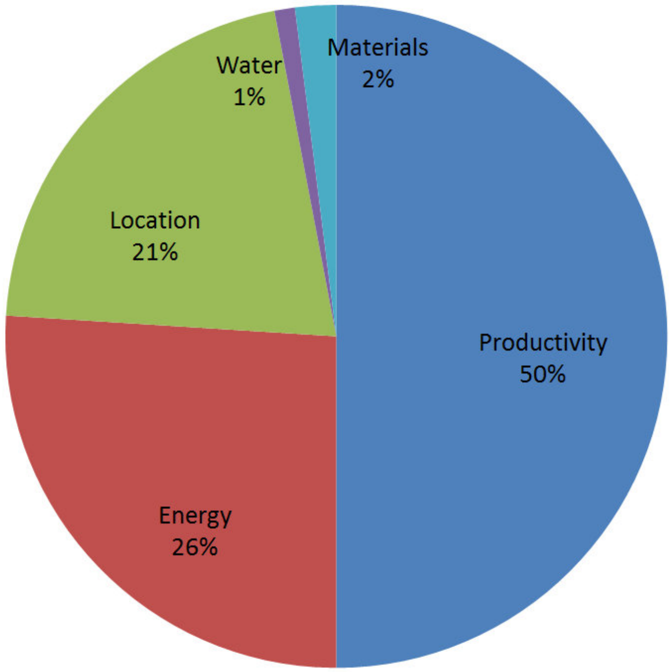

Figure 4.1: The weighting factors of the main categories for building sustainability assessment scheme in Estonia.

of productivity remains high - 83% of the total share. For that reason we suggested to limit the maximum weight of a category to 50% and to allocate the remaining 50% share amongst the other categories. The final outcome of the weights of the categories is shown in Figure 4.1. This was obtained by determining the average percentage share of each category (excluding productivity) across three impact groups (absolute CO_2, CO_2 band and Euros) and allocating the remaining 50% share between the categories depending on their average impact share.

When comparing weightings in LEED and BREEAM against the proposed weighting for Estonia in Figure 4.1, a clear discrepancy can be noticed. First of all, in Estonia only three categories had substantial importance; water and materials with their 1 and 2% share, had negligible effect. Secondly, the productivity prevailed. The importance of productivity cost savings has also been emphasized before, e.g., by Issa et al. [61]. Knowing the large share of wages in annual costs of an office building (shown in Figure 2.2) justifies the results of the current study. The most important category in LEED and BREEAM - energy - was ranked second. The building location was third highest weighted according to our study. Reiterating local contexts' relevance and suggesting that a universal scheme is not a solution. All this supports the idea of an Estonian own sustainability assessment scheme.

Furthermore, the methodology used in this study can be used to solve the concern related to all of the building sustainability assessment schemes - the weightings. As pointed out by Ding [11], there is neither consensus-based approach nor a satisfactory method to guide the assignment of weightings. The approach used in our study can be a signpost to guide the determination of weighting factors of the categories in scientifically acceptable manner. Thus, an objective method helping to overcome subjective approaches to determine category weightings.

4.4 Proposed Estonian scheme

Having fixed the important categories for the Estonian context, compared five case study office buildings' projects against the indoor climate and the energy category indicators of LEED and BREEAM, we developed a building sustainability assessment scheme for Estonia.

The proposed Estonian scheme is mostly based on existing regulations and standards for the indoor climate quality and the energy category. The transport category includes most important indicators from LEED and BREEAM affecting private vehicle use adjusted to the Estonian context.

Each category has three classification levels. Even though our previous study identified the weightings of the categories, we suggest keeping the system simple. The proposed scheme is exempt from the consideration of weighting factors and points allocation for the indicators.

To sense the rigorousness of the proposed Estonian scheme I compared the three classes of the scheme with LEED and BREEAM. Only the indicators covered by the Estonian scheme were assessed. The percentage scores for the both schemes for the categories and the three classes are shown in Figure 4.2.

Figure 4.2 shows clearly higher columns in BREEAM than in LEED, indicating that the proposed scheme has a better match with BREEAM. While the indoor quality and the energy category score high number of points with the highest class in both schemes, the transport category is rather modest.

To compare the Estonian scheme in the total scope of LEED and BREEAM schemes I considered all indicators within the two schemes; including also indicators not regulated within the three categories of the Estonian scheme. The indicators excluded from the Estonian scheme were evaluated individually considering their applicability in Estonia. As these were independent from the proposed scheme classes, the same values were used for all classes. The results for three Estonian sustainability classes are shown in Figure 4.3. The leftmost column in Figure 4.3 for both schemes shows the possible maximum number of points available per category.

A look at Figure 4.3 gives an implication that BREEAM results are higher and might give a feeling that BREEAM is less onerous. In order not to misinterpret the results it is important to emphasize that BREEAM certification levels are not easy to achieve. What is important to notice is the share of the energy, the indoor climate and the transport categories constitute in LEED - that is 70%! Respective share in BREEAM is 42%. Low performance in these categories makes it difficult to attain a good cer-

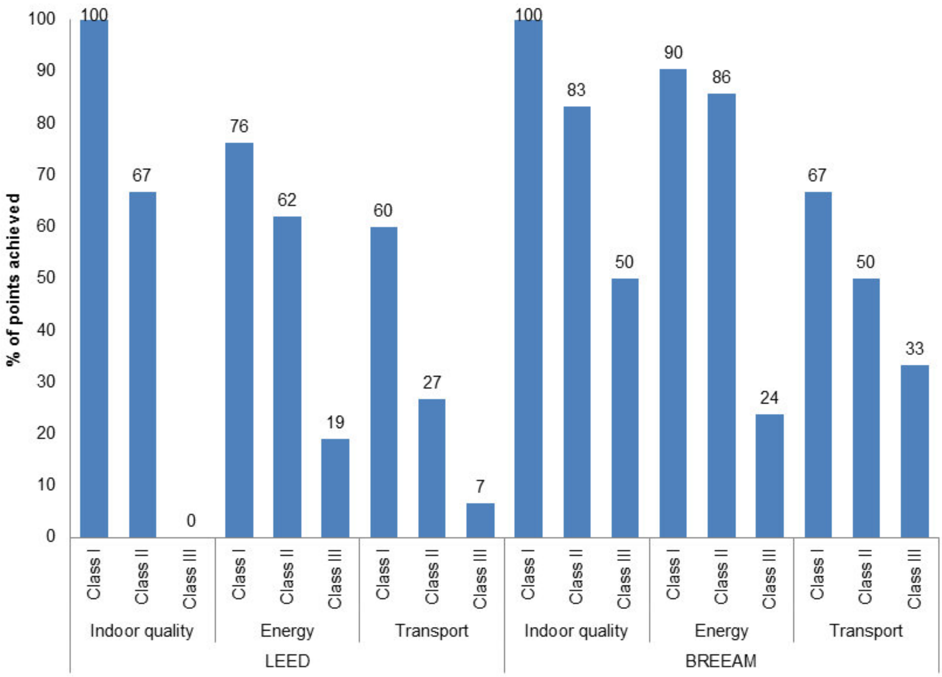

Figure 4.2: Comparative evaluation results of the proposed Estonian building sustainability assessment scheme levels with LEED and BREEAM. The classes represent the classification of a building according to the proposed scheme. Only three categories forming the Estonian scheme are shown.

tification level in LEED. Furthermore, the '*Sustainable sites*' category in LEED includes indicators not related to transport. As a result, the tansport related points achieved form a minority of the total category points. BREEAM, with its' higher number of categories, keeps the scope within a category concentrated. Also I must admit that the current standards and the proposed transport indicators follow more BREEAM than LEED.

A conclusion over the rigorousness of the Estonian scheme is that class I is serious contender for high level certification sustainable building. Es-

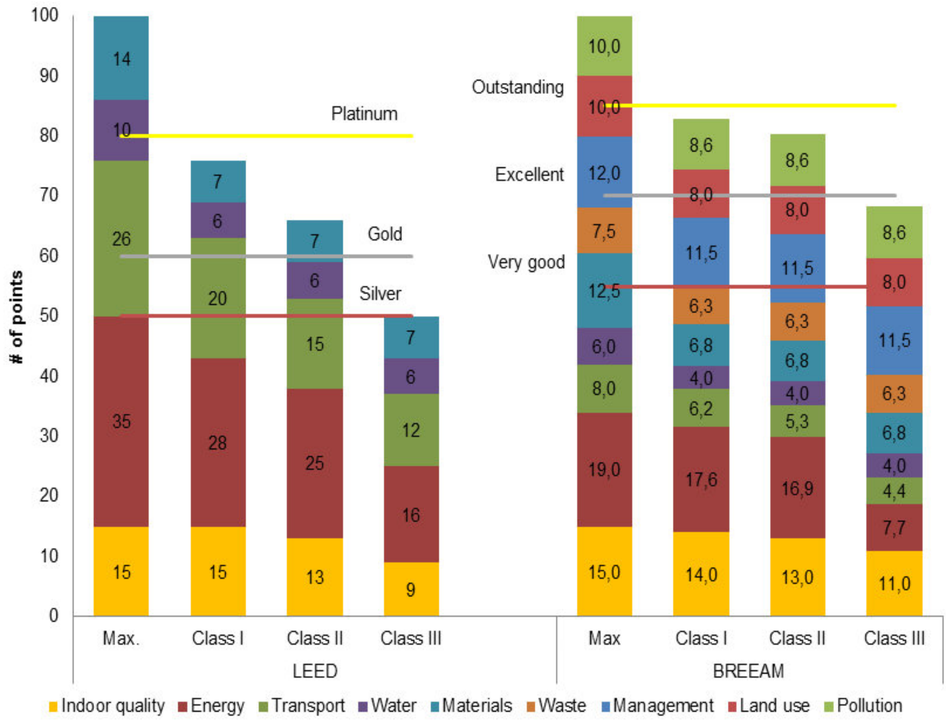

Figure 4.3: Three sustainable class levels in LEED and BREEAM scale. All except bottom three categories have the same values in each class. Horizontal lines indicate top three certification levels of the respective schemes.

pecially the indoor climate is following high requirement levels, but also the energy category is of considerable quality as shown in Figure 4.2. The transport category is modest, due to limits set considering local context and applicability. Knowing the non-compliance indicators within the three categories I can say that the highest certification levels in LEED and BREEAM could be achieved. Increasing the renewable energy share and improving transport access and the number of amenities in LEED. For the highest certification in BREEAM the energy monitoring level and the transport access of the Estonian scheme need improvement.

4.5 Validity of the results

The large discrepancy between the simulation results obtained by the study group and the design teams must be related to the used simulation software and the experience of performing simulations. I expect that the MSc and PhD students, forming the study group, are proficient in building energy simulations with their years of experience. Thus, with reasonably high certainty I consider the results obtained by the study group to be more accurate than design documentations were showing. Irrespective of the simulation results the study revealed serious shortcomings in the EPBD implementation process in Estonia.

Considering the sustainability assessment scheme scope and its' suitability to Estonia, I am convinced that buildings built at the beginning of 2000's would have scored similar amount of sustainability related points as the case-study building. Depending on the building project documentation rigorousness and the building site (city center or not), the overall score might have varied to some extent. Having followed the instructions of LEED manual [30] assessing the case-study apartment building, I am confident in the obtained score and the positioning in the sustainability scale. To conclude, it is evident that at that time the Estonian building sector was not ready for sustainable building assessments which included many indicators out of the scope of regular building projects.

The category quantification study is the one with the most uncertainty over the validity of the study results. Definitely the results might vary when using other indicators as a representative of the categories. In our studies we used specific indicators for which we could use inputs in numeric values studies by other authors. This might be even more so if one aims to quantify all the indicators of sustainable building assessment scheme.

Furthermore, the outcome of the study might show different proportions for the importance of the categories, if other figures to evaluate the impacts would be used. The economic impact figures used to evaluate the importance of categories can be considered reasonable and straightforward. At the same time, the environmental impact consideration can have larger choice. Environmental impact assessments usually cover, e.g., acidification, ozone depletion, global warming, eutrophication etc., that are included in life cycle assessment (LCA) tools. Thus, several figures that can have quantifiable values to assess the impact. We used CO_2 emissions as a representative figure to determine the environmental impacts. That has to be acknowledged when interpreting the results obtained.

The indoor climate category with productivity and sick-leave impact used in our study used scientifically proven conformance from other researches. Validated IES simulation models used to simulate different design solutions gave highly reliable energy demand values. Thus, the impact on the productivity and the energy use related with it, is realistic with high confidence. The same is true for the energy category weighting determination. The importance of indoor climate and related productivity was pointed out also by Issa et al. [61] where the discrepancy of points allocation in LEED scheme and the potential savings was well depicted. Their study also revealed the difference of energy and water category points share and the potential savings.

Water and materials category importance quantification used simple methods quantifying the effect. Knowing the amount of water use, the effect was easily quantifiable. The water treatment energy use values were obtained from local drinking water provider. Water heating demand was easily calculated, knowing the temperature difference and heat source. Environmental impact in CO_2 emissions was derived considering local energy source emissions; economic impact using the energy prices. For materials impact the CO_2 emissions values used were obtained from an earlier study comparing different office building construction materials CO_2 emissions. From materials no effect on the energy use was considered. Economic impact used highly overestimated CO_2-quota price related with the specific emissions of the materials. Thus, the economic impact in reality is even smaller than shown in Figure 3.4.

Transport category impact was considered in quite simple and straightforward way. Due to missing statistical information over the average distance to work and the percentage of users of public transport, we made assumptions over these values. While the distance assumptions were reasonable, we did overestimate the public transport use. Real value of latter is around 25% instead of 35% used in the study. Other input values, e.g. the CO_2 emissions per km, average fuel consumption etc. were taken from other reports. The method used to determine the energetic value of public transport use is a very simple calculation and probably is not the most precise way to determine the effect. The economic impact was calculated based on total CO_2 emissions from private vehicle use multiplied with the CO_2-quota price. Estimating the validity of our results suggests, that some reservations should be taken due to assumptions made and simple methods used. Latter means, that the effect and the importance of the transport category should be lower than identified in the study. Also, we did not consider the increasing emissions load from increased public transport services.

The comparative evaluation study used straightforward method comparing the Estonian requirements against corresponding requirements of LEED and BREEAM. Classifying the case-study buildings based on the percentage of points achieved in the energy and indoor climate category will, of course, not guarantee the certification levels shown in the study. Still the outcome of the study shows onerous requirements of local regulations for specific indicators. The comparison of the proposed Estonian scheme, which is mainly based on local regulations, shows good compliance with LEED and BREEAM respective indicators. The certification levels of the three classes of the Estonian building sustainability assessment scheme considering the entire scope of LEED and BREEAM were evaluations rather than proven compliance. Compliances of indicators not covered in the Estonian scheme, should be considered with reservations as these are not regulated and can be in accordance if a design team is aiming for compliance.

The overall conclusion is that, even though for some issues there is some concern over the validity of the results, the results in general can be considered validated within the scope of study methods used.

4.6 Future research

The quantification of the category importance in economic and environmental loads was the most important and distinctive result of my studies. This showed that placing numeric values behind the indicators will result clearly different category weightings in comparison with other schemes. The study's results clearly showed the need to consider local context when developing building sustainability assessment scheme. As a result the thesis proposes an Estonian building sustainability assessment scheme, with considerably concentrated scope while at the same time including the most important categories and indicators.

I must reiterate that the results of the studies were obtained with the assumptions and methodology specified in the thesis. The most important of which is clearly the use of representative indicator for the categories to identify the effect (environmental and economic) of the categories. Obviously, the validity of the research could be extended with more thorough consideration of the impacts. Whether including all the indicators of LEED and BREEAM or extending the scope of the environmental impact to quantify the importance of the categories and even the individual indicators. While the used indicators and values for Estonia produce the results covered here, the use of other representative indicators or context might lead to a different outcome. Irrespective of the chosen indicators, the methodology used proves the difference of category weightings from '*expert panel*' opinion that generally forms the bases of building sustainability assessment schemes.

Future research directions could build up on the work I have done. For instance, using the outcome of my research as an input for the same '*expert panel*' (various stakeholders) group for consideration for implementation as an official scheme in Estonia. As the study concentrated on the use phase of office buildings, with the exeption of the materials impact, the results obtained are valid when considering this specific stage of buildings. For more thorough consideration the scope of the studies could be extended to whole life cycle of buildings. The methodology could be used by the others to identify the category importances for new scheme developments or to check the importance of the categories of existing schemes. Furthermore, the same methodology could be applied specifically to indicators to identify the most important ones (irrespective from the category importance). Finally, if the scheme proposed prevails as viable and the proposed scheme indicator levels become common practice in the future, the importance of the categories could be re-assessed. Also the scope of the scheme could then be extended by adding gradually additional categories that prove important to thrive the building quality of sustainable buildings into higher excellence.

Chapter 5

Conclusion

This thesis studied the best solution for Estonia if the country evolves to stage where building quality is to be evaluated according to sustainable building concept. As stated in the introduction there were mixed feelings over the idea of how or where should building sustainability assessment schemes develop. Being acquainted with several countries' experience and the proposals of researchers, I wanted to determine the most suitable solution for Estonia. That is why my studies followed several stages starting from identifying the building sector current status at the beginning of my studies. Followed by the uncovering the scope of sustainable building assessment scheme. Then, instead of using expert panel to fix the importance of the categories included in a sustainable building assessment concept, I wanted to evaluate the importance in an objective manner. Finally, to conclude the studies I hoped to propose a sustainable building assessment scheme for Estonia.

To position my studies in the Estonian building sector I firstly used the results of a study conducted in TUT [62]. Latter investigated the implementation of EPBD legislation in Estonia and the market acceptance on the energy simulations requirements. Comparing building design energy simulation documentation with the results of study group energy simulations showed serious shortcomings, both in the implementation process as well as appropriate use of computer simulations. The reasoning behind was the sophisticated level of the regulation, which caused interpretation problems. Further concerns were the lack of qualified specialists as well as support in the process. Altogether leaving a lot to improve in the field.

The scope of a building sustainability assessment scheme was uncovered, as an example of LEED, with a case-study apartment building assessment. A post construction assessment was performed with the help of LEED manual [30] using project design documentation, site inspections, the buildings register database and communication with the main contractor. Overall score of the assessment resulted in 26 points from available 106. The lowest certification level was at 40 points level. The building scored reasonably well in the '*sustainable sites*' category scoring 50% of the available points of the category. Other categories were met with less success. The main reason for low score was that most of LEED indicators requirements were not covered in project documentation. Thus, the final score, not meeting the lowest LEED certification level, was expected. Introducing and assessing each of LEED indicators gave an implication of the scope of building sustainability assessment scheme; helping novice stakeholders to understand the contents of such a scheme.

As the previous study showed there are a lot of indicators within the scope of sustainable building assessment scheme. The findings also showed that several of these are not covered in building project documentations in Estonia. At the introduction part also the aspiration to classify the importance of categories objectively was stated. For that we used an indicator in each of the analyzed categories that could be quantified in environmental and economic values, allowing objective ranking of the categories. Using the results from other researchers as input in our study, validated computer simulations, reasonably straightforward and simple methods to identify environmental and economic impacts guaranteed high confidence in obtained results. Study showed that productivity (indoor climate) was the most important, followed by the energy and the transport category.

When all impacts were transferred to Euros through energy and carbon prices and productivity costs, the productivity category received the highest weighting, 91 or 83 % share of the total impact with indoor climate reference class III and class II, respectively. This indicates that the productivity effects are not enough recognized in current codes and standards. It was necessary to use the indoor climate reference level in between class I and class II to limit the share of productivity to 50%, which was used to assign meaningful weightings for other categories.

The final weightings obtained with Estonian input data were 50% for productivity, 26% for energy, 21% for location, 2% for building materials and 1% for water efficiency.

The results conflicted distinctively with the weightings of LEED and BREEAM, two of the most well-known sustainability assessment schemes. The materials and water category representative indicators had negligible effect in the Estonian context. Emphasizing that local context and using scientific methods to determine the importance of the categories are significant.

In the final part of my thesis I investigated the current practice indoor climate and energy related indicators against LEED and BREEAM respective indicator requirements. The third significant category, transport, was not regulated in Estonia.

There are several indicators in the indoor climate category of sustainable assessment schemes which are not considered by Estonian regulations. The ones that are form an acceptable comparison with LEED and BREEAM requirements. New buildings designed according to class II or I indoor climate quality requirements of the Estonian regulations will ensure related points in LEED and BREEAM. The most difficult comparison is concerned with emissions of finishing materials due to the different concepts used by the schemes. The inclusion of the indicators which are not currently regulated in Estonia is a minor concern due to their limited rigorousness, as long as design teams are made aware of their consideration need.

The energy category indicators are well regulated with current Estonian regulations. High number of points are achieved with EPC class B and A energy efficiency buildings. Also other indicators in sustainable building assessment schemes energy category are regulated in Estonia with comparable rigorousness of LEED and BREEAM. Only lifts' energy efficiency is not regulated in Estonia.

Furthermore, I assessed five office buildings technical design project documentation against respective sustainability assessment schemes. In transport category I compared the two schemes against each other to identify the indicators with the largest impact. High indoor climate scores were achieved across all buildings. Class A energy efficiency building showed close to the highest possible result in energy category. I can conclude that Estonian regulations highest levels set solid bases for sustainable buildings. Considering only the two regulated categories and the indicators regulated in Estonia, the certification levels in LEED and BREEAM are close to the top.

Based on three categories, out of which the indoor climate and the energy category were built up on current regulations and their quality classes, we proposed an Estonian building sustainability assessment scheme. The transport category indicators were suggested after comparison between LEED and BREEAM and identification of those with the highest impact. The proposed scheme had three certification levels for each category, which was generally true for the indicators as well. The evaluation of the proposed Estonian scheme against LEED and BREEAM revealed that a Class I and II buildings can achieve second highest certification levels in LEED and BREEAM. Study results showed also that the Estonian scheme will mean relatively small additional effort from design teams following current best practice, as the most demanding indicators are already regulated.

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Thanks to all my friends, fellow students and colleagues home and abroad, and my family. All of you have had an impact on me, and without YOU I would not be who I am now.

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■ *This thesis is dedicated to the memory of* LEIDA SEINRE. ■

Abstract

More than 20 years have produced large amount of building sustainability assessment schemes. The pattern seems to be, that each country has its own scheme. This has risen a concern that the scheme-based certifications of buildings are not comparable to each other. At the same time several researchers have proposed to use a standardized scheme to be applicable worldwide, while allowing minor local modifications to reflect local conditions. Thus far this proposal has not prevailed and still different schemes are being used and new ones developed. When deciding to implement building sustainability assessment which path should Estonia follow? To develop a new or adopt an existing scheme?

The main purpose of the thesis was to define the importance of the main categories of building sustainability assessment schemes objectively. Furthermore, to propose a viable assessment scheme for Estonia and to identify the relation of the Estonian regulations against two of the most well-known schemes.

The first step was to identify the development level of building sector. For that we investigated the progress of implementation of EPBD regulations in Estonia. The study group performed energy simulations with IDA-ICE and BSim simulation software's according to local regulations and compared the outcome with the project documentation. Altogether 13 projects were included in the study.

Secondly I uncovered the scope of building sustainability assessment scheme with an example of LEED. I assessed a recently built apartment building with LEED new construction requirements. The intent of each applicable LEED indicator and the requirements were uncovered. Detailed design phase project documentation of the building was the main source of information.

To define the importance of the categories objectively we needed numeric values. To keep the study at reasonable scope I used one indicator representing a category. Altogether five categories were evaluated. I identified categories impact on the environment and in economic terms. Relative impact was determined as a range of minimum acceptable and best design solution according to local regulations and sustainable assessment schemes. Absolute impact was considered as an average of the minimum acceptable and the best design solution. Materials absolute impact was taken as concrete emissions. The numeric values were represented in the following units: kWh for energy use, CO_2 emissions for environmental and Euros for economic impact.

To quantify the effect of indoor climate I used the ventilation flow rate and temperature impact on the productivity as well as the flow rate impact on sick-leave. The energy category effect was determined by comparing the loads of the reference office building, the one meeting the minimum requirements and a nZEB. I performed building simulations with IES simulation software. In simulations adjustments in ventilation flow rates, cooling setpoints, internal lighting loads and envelope constructions were made.

Water use effect was determined as a comparative impact of default water use in Estonia against considerably reduced water use. The change in water processing (electricity use) to guarantee water quality and hot water production (heat use) was quantified. The environmental impact in CO_2 emissions was determined by using specific emissions rate for Estonian electricity and Tallinn district heating. The effect in Euros was determined using electricity and heat price for water processing and heating.

In the materials category we considered main structural materials: timber, concrete and steel. The comparison was based on CO_2 emissions associated with respective materials. Emissions were obtained from an earlier study. The transport category importance was determined by the usage of public transport. We estimated the default share of public transport users. In best scenario the ridership was considered double and the reduced emissions form private vehicles was determined. The impact in Euros for materials and transport categories was determined by multiplying the CO_2 emissions with projected CO_2 quota price.

After identifying the most relevant categories for the Estonian context we wanted to compare the local regulations rigorousness. I identified the gap between sustainable building requirements and the Estonian regulations. I compared the requirements of LEED and BREEAM and the Estonian regulations covering indoor climate and energy indicators. Furthermore, to give an overview of the building quality status in Estonia, I assessed five case-study office buildings technical design documentations in the indoor climate and the energy categories of LEED and BREEAM. Case-study office buildings were whether recently built or in the design phase. The buildings were ranked in LEED and BREEAM scale based on the results obtained in the indoor climate and the energy category. I also compared transport category indicators of LEED and BREEAM identifying the ones with the largest impact on the environment.

The studies showed serious shortcomings in the implementation process of EPBD regulations. Only two projects qualified for the final check calculations. The results obtained by design teams and the study group differentiated considerably, indicating the need for change.

A possible solution in the form of the building sustainability assessment was proposed. The scope of such was uncovered with a post construction apartment building LEED assessment. While performing well in certain aspects, the overall results were far from lowest certification level. The main reason of low score was that the indicators required by LEED were not covered in the building project.

The category importance ranking process revealed some interesting results. After quantifying the environmental and economic effects in an objective manner, only three categories prevailed as important in the Estonian context. These were indoor climate, energy and transport, with the first being clearly the most important. The materials and water use had negligible importance. The results contradicted clearly with LEED and BREEAM category weightings. This emphasized the importance of considering local context and the difference between scientifically determined weightings and '*expert panel*' decisions.

Comparing the indicators regulated by Estonian regulations showed good compliance with LEED and BREEAM respective indicators. Class II and I indoor climate quality buildings ensured related points in LEED and BREEAM. Also energy category indicators in Estonia are regulated with comparable rigorousness of LEED and BREEAM. All five case-study buildings scored high-end values in the indoor climate category. Overall conclusion of the case-study buildings is that high quality buildings, that have at least class B energy efficiency rating and class II indoor climate quality, can meet the second highest certification level of LEED and BREEAM. That is, when considering only indicators that are regulated in Estonia.

Based on the results we proposed an Estonian building sustainability assessment scheme with indicators in three categories. Furthermore, a comparative evaluation of the Estonian scheme certification classes with potential LEED and BREEAM points share were shown. The study showed that Estonian scheme will need relatively small additional effort from design teams following current best practice, as the most demanding indicators are already regulated. Finally, a complete ranking in LEED and BREEAM certification classes for the three Estonian building sustainability classes was given.

Kokkuvõte

Viimased enam kui 20 aastat on toonud turule suurel hulgal hoonete jätkusuutlikkuse hindamise meetodeid. Muster näib olevat, et iga riik töötab välja oma meetodi. See on omakorda tõstatanud mure hoonete sertifikaatide omavahelise võrreldavuse raskuses. Selle lahenduseks on mitmed teadlased välja pakkunud ülemaailmselt rakendatavaid standardiseeritud meetodeid, mis võimaldavad mõningast kohandamist, arvestamaks kohalikke olusid. Senini pole see ettepanek selget poolehoidu leidnud ja seetõttu kasutatakse ikka erinevaid meetodeid ning luuakse ka uusi. Kui Eesti otsustab kunagi hoonete jätkusuutlikkuse hindamise meetodi rakendamise kasuks, siis millist teekonda peaks Eesti järgima? Kas arendada uus või võtta üle olemasolev?

Antud väitekirja põhiline eemärk oli määratleda objektiivselt hoonete jätkusuutlikkuse hindamise meetodite põhikategooriate olulisus. Lisaks sellele pakkuda välja elujõuline hindamise meetod Eestile ning tuvastada vastavussuhe Eestis kehtivate regulatsioonide ja kahe maailmas enim tuntud hindamismeetodi vahel.

Esimeseks sammuks oli tuvastada Eesti ehitussektori arengutase doktoriõpingute alguses. Selleks uurisime EPBD regulatsioonide rakendamise protsessi edukust Eestis. Uurimisgrupp võrdles kohalike regulatsioonide kohaselt teostatud IDA-ICE ja BSim energiasimulatsioonide tulemusi ehituslubade taotlusel esitatud dokumentatsiooni tulemustega. Kokku oli uuringusse kaasatud 13 projekti.

Järgnevalt tutvustasin LEED hindamismeetodi näitel hoonete jätkusuutliku hindamise meetodi sisu. Selleks hindasin hiljuti ehitatud korruselamut LEED uute hoonete meetodi nõudmiste kohaselt. Iga rakendatava kriteeriumi eesmärk ja nõudmised sai avaldatud. Põhiline informatsiooniallikas hoonest oli põhiprojekti staadiumi projektdokumentatsioon.

Määratlemaks kategooriate olulisust objektiivselt, vajasime numbrilisi väärtusi. Hoidmaks uuringut mõistlikes piirides, kasutasin ühte indikaatorit igast kategooriast. Kokku hindasime viite kategooriat. Hindasin kategooriate mõju nii keskkonnale kui rahalises vääringus. Suhteline mõju oli tuvastatud kui vahemik minimaalselt nõutud ja parimast võimalikust lahendusest vastavalt kohalikele regulatsioonidele ja jätkusuutlikkuse hindamise meetoditele. Absoluutse mõju arvestuseks kasutasime minimaalselt nõutu ja parima võimaliku lahenduse mõju keskmist. Erandina oli materjalide absoluutne mõju leitud betooni näitel. Uuringus kasutatud numbrilised väärtused olid esitatud järgnevates ühikutes: kWh energiakasutuse, CO_2 emissioon keskkonna ja euro majanduslike mõjude näitajatena.

Sisekliima mõju kvantifitseerimiseks kasutasin ventilatsiooniõhu vooluhulga ja ruumiõhu temperatuuri mõju tööviljakusele ning õhuvooluhulga mõju haiguspäevadele. Energia kategooria mõju tuvastasin võrreldes võrdlushoone, miinimumnõuetele vastava ja ligi-nullenergia hoone energiatarvet. Simulatsioonide teostamisel kasutasin IES simulatsioonitarkvara. Simulatsioonides kohandasin ventilatsiooni õhuvooluhulkasid, jahutuse seadetemperatuure, sisevalgustuse koormusi ja välispiirete konstruktsioone.

Veekasutuse mõju tuvastasin Eestis kasutatava vaikimisi veekasutuse väärtuse ja sellest märgatavalt väiksema veekasutuse võrdluses. Kvantifitseerisin muutuse vee töötlemiseks ja sooja vee valmistamiseks. Keskkondliku mõju CO_2 emissioonides määrasin, kasutades Eesti elektrienergia ja Tallinna kaugkütte emissioonitegureid. Rahalise mõju eurodes tuvastasin, kasutades elektri ja soojuse hinda vastavalt vee töötlemise ja soojendamise arvestusel.

Materjalide kategooria puhul arvestasime põhikonstruktsioonimaterjale: puitu, betooni ja terast. Võrdlus baseerus materjalidega seotud CO_2 emissioonidel. Vastavad emissioonid olid võetud varasemast uuringust. Transpordi kategooria olulisus sai määratletud ühistranspordi kasutajate arvu alusel. Selleks eeldasime vaikimisi ühistranspordi kasutajate osakaalu kogu hoone töötajaskonnast. Parima lahenduse korral arvestasime ühistranspordi kasutajate osakaaluks kahekordset vaikeväärtust ja tuvastasime vähenenud emissiooni individuaalsõidukite kasutamisest. Materjalide ja transpordi kategooria rahalise mõju eurodes leidsime, korrutades CO_2 emissioonid projetseeritud CO_2-kvoodi hinnaga.

Olles tuvastanud kõige olulisemad kategooriad Eesti tingimustes, tahtsime võrrelda kohalike regulatsioonide rangust. Selleks tuvastasin erinevused hoonete jätkusuutlikuse hindamise meetodi nõudmiste ja kohalike regulatsioonide vahel. Võrdlesin LEED ja BREEAM sisekliima ja energia kategooria kriteeriumite nõudmisi Eesti regulatsioonidega. Andmaks hinnangut Eestis kavandatavate hoonete kvaliteedile, hindasin viie kontorihoone põhiprojekti dokumentatsiooni LEED ja BREEAM sisekliima ja energia kategoorias. Kaasatud hooned olid kas hiljuti ehitatud või alles projekteerimise järgus. Baseerudes sisekliima ja energia kategooria tulemustele, järjestasin hooned LEED ja BREEAM skaalas. Võrdlesin ka LEED ja BREEAM meetodi transpordi kategooriaid, tuvastades neist suurima keskkonnamõjuga kriteeriumid.

Uuringud näitasid olulisi puudujääke EPBD regulatsioonide rakendamise protsessis. Ainult kaks projekti kvalifitseerusid lõplikuks võrdlusarvutuseks. Tulemused, mis saadi uurimisgrupi poolt ja mida oli kasutatud ehitusloa taotlusel, erinesid märgatavalt. Seega, uuringu tulemused viitasid muutuste vajadusele.

Võimalikuks lahenduseks eelnevale probleemile pakkusin välja hoonete jätkusuutliku hindamise meetodi rakendamise. Viimase sisu ja ulatus sai avatud, viies läbi kortermaja ehitusjärgse LEED hindamise. Kuigi hoone saavutas häid tulemusi osades aspektides, oli kogutulem kaugel madalaimast sertifitseerimise tasemest. Peamine põhjus tagasihoidlikus tulemuses oli see, et LEED-iga nõutud kriteeriumid ei olnud hoone projektis käsitletud.

Kategooriate olulisuse järjestamise uuring näitas huvitavaid tulemusi. Olles objektiivselt kvantifitseerinud keskkondlikud ja majanduslikud mõjud, eristusid kolm, mis olid Eesti tingimustes olulised. Need olid sisekliima, energia ja transport. Materjalid ja veekasutuse vähendamine omasid olematut tähtsust. Antud tulemused olid selges vastuolus LEED ja BREEAM kategooriate kaalumistegurite osakaaludega. See omakorda rõhutas kohalike olude arvestamise tähtsust ja erinevust, mida annavad teaduslikult määratletud kaalumistegurid ja '*ekspertkomisjoni*' otsused.

Eesti regulatsioonidega reguleeritud kriteeriumite võrdlus näitas head kooskõla LEED ja BREEAM kriteeriumitega. Sisekliima kvaliteedi klass II ja I hooned kindlustasid punktid LEED ja BREEAM kriteeriumite eest. Ka energia kategooria kriteeriumid on Eestis reguleeritud LEED ja BREEAM meetoditega võrreldava rangusega. Kõik viis uuringusse kaasatud hoonet saavutasid kõrgeid tulemusi sisekliima kategoorias. Kokkuvõtvalt võib viie uuringusse kaasatud hoone kohta öelda, et kõrge kvaliteediga hooned, millel on vähemalt energiatõhususe klass B ja sisekliima klass II, võivad saavutada paremuselt teise sertifikaadi LEED ja BREEAM skaalal. Seda olukorras, kui käsitleda ainult kriteeriume, mis on Eestis reguleeritud.

Uuringu tulemustele baseeruvalt pakkusime välja Eesti hoonete jätkusuutlikkuse hindamise meetodi kriteeriumitega kolmes kategoorias. Tõime välja Eesti meetodi kohase sertifikatsiooni tasemete paiknemise LEED ja BREEAM punktide osakaalu skaalas. Uuring näitas, et Eesti meetodi rakendamine nõuab suhteliselt väikest lisapingutust projekteerijatelt, kes järgivad kehtivat parimat praktikat, kuna enim nõudlikud kriteeriumid on juba reguleeritud. Lõpetuseks on välja toodud ka Eesti hoonete jätkusuutliku hindamise meetodi kolme klassi potentsiaalne paiknemine LEED ja BREEAM meetodite terviklikul skaalal.

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Curriculum vitae

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Tallinn University of Technology	2009	Environmental Engineering, Master of Science
Tallinn 32. Secondary School	2003	Secondary education

4. Language skills

Language	**Level**
Estonian	Native language
English	Fluent
Finnish	Average
Russian	Basic
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5. Special courses

Period	**Educational or other organisation**
02.-05.2012	*Introduction to building performance simulation for integrated solutions; and State of the art in building performance simulation for integrated solutions*, Eindhoven University of Technology
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17.-18.02.2010	*Solar Energy Systems*, Tallinn University of Technology

6. Professional employment

Period	Organisation	Position
2013- ...	BuildingLabel OÜ	BREEAM International assessor
2009- ...	Tallinn University of Technology	Teaching assistant
2009-2010	IB Aksiaal OÜ	HVAC Engineer
2007-2008	IB Aksiaal OÜ	HVAC Engineer
2007	AS Clik	Ventilation locksmith
2006-2007	Uponor Eesti OÜ	Technical consultant assistant
2005	RAP Arhitektid OÜ	Technician-draftsman

7. Research activity

Main research activity is related to sustainable buildings and sustainable building assessment schemes. Also building HVAC simulations is of interest, as it is closely related to the main activity.

Thesis supervised:

- **Erika Müller**, MSc. *Energy Efficiency analysis of Tallinn Liivaku kindergarten.* 2014.
- **Ülli-Kaisa Karro**, MSc. *Indoor climate and energy consumption analysis of kindergarten Pallipõnn.* 2014.
- **Mikk Tasa**, MSc. *Building sustainability assessment applicability in Estonia with an example of BREEAM.* 2013.

- **Helen Milva**, MSc. *BREEAM assessment of an apartment building and comparison with regulation no. 258 regulations with an example of Kaupmehe 6*. 2012.

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Õppeasutus	Lõpetamise aeg	Haridus (eriala/kraad)
Tallinna Tehnikaülikool	2009	Keskkonnatehnika, tehnikateaduste magister
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4. Keelteoskus

Keel	**Tase**
Eesti keel	emakeel
Inglise keel	kõrgtase
Soome keel	kesktase
Vene keel	algtase
Hollandi keel	algtase

5. Täiendõpe

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02.-05.2012	*Introduction to building performance simulation for integrated solutions; and State of the art in building performance simulation for integrated solutions*, Eindhoveni Tehnikaülikool
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13.-16.12.2010	*Net-zero-energy-buildings (NZEB) and on-site renewable energy*, Aalto Ülikool
17.-18.02.2010	*Solar Energy Systems*, Tallinna Tehnikaülikool

6. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
2013- ...	BuildingLabel OÜ	BREEAM International hindaja
2009- ...	Tallinna Tehnikaülikool	Assistent
2009-2010	IB Aksiaal OÜ	KVJ insener
2007-2008	IB Aksiaal OÜ	KVJ insener
2007	AS Clik	Ventilatsioonitööde lukksepp
2006-2007	Uponor Eesti OÜ	Tehnilise konsultandi assistent
2005	RAP Arhitektid OÜ	Tehnik-joonestaja

7. Teadustegevus

Peamine teadustöö on seotud jätkusuutlike hoonete ja nende hindamisega. Huvipakkuv valdkond on ka energiasimulatsioonide teostamine, kuna see on tihedalt seotud peamise uurimisvaldkonnaga.

Juhendatud lõputööd:

- **Erika Müller**, MSc. *Tallinna Liivaku lasteaia energiatõhususe analüüs.* 2014.
- **Ülli-Kaisa Karro**, MSc. *Lasteaia Pallipõnn sisekliima ja energiatarbe analüüs.* 2014.
- **Mikk Tasa**, MSc. *Hoone jätkusuutlikkuse hindamisstandardi rakendatavus Eestis BREEAMi näitel.* 2013.

- **Helen Milva**, MSc. *BREEAM hinnang korterelamule ja võrdlus määruse nr. 258 tulemustega Kaupmehe 6 näitel.* 2012.

PAPER I

Seinre, E., Voll, H. Energy Efficiency Regulations Taking Action in Estonia. *Selected Topics in Energy Environment, Sustainable Development and Landscaping: 6th International Conference on Energy, Ecosystems and Sustainable Development (EESD'10)*, WSEAS, 2010, 211-215.

Energy Efficiency Regulations Taking Action in Estonia

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Abstract: Since July 2009 it is compulsory for a new or major renovation building project to meet the requirements set by Estonian Government decree nr. 258 „The Minimum Requirements for Energy Efficiency". This article reports on analysis of evaluation carried out in Tallinn University of Technology how the implementation has taken effect. There are severe problems with application of this decree, concerning the decree itself, as well as the shortage of knowledge amongst people applying it. Due to difficulties of establishment of the decree an alternative building evaluating schemes that could be implemented in Estonia are introduced, with their merits and drawbacks stated.

Keywords: Energy efficiency regulations, BREEAM, LEED

1. Introduction

The following is an evaluation on the situation of construction market in Estonia. Main proportions of this article are based on the survey carried out during several months in Tallinn University of Technology (TUT) [1]. This work was requested and financed by Estonian Heating and Ventilation Association (EKVÜ) and by private partner Kliimakonsult OÜ. The project was carried through by lecturers from TUT, PhD and MSc students. Also a helping hand from private partners and State Technical Supervision Authority has to be mentioned.

Being a member of European Union (EU) Estonia has to adopt to legislation put forward in higher rankings in EU. Among those is the aim to decrease energy consumption of member countries [2]. Estonia has set a target to decrease energy consumption by 9% in the next following 9 years to come, compared with the average energy consumption during the years 2000 to 2005. As building sector energy consumption is above 40% of overall energy consumption, of which around 63% is dedicated to apartment and public buildings, there lies a great potential to decrease energy consumption.

Due to great potential and also to thrive to more sustainable future, by building more energy efficient buildings, a new legislation law was accepted in Estonia in 2009. This means that starting from 1st of July, 2009 all new buildings and major renovations must comply with Estonian government decree nr. 258 „The Minimum Requirements for Energy Efficiency" [3].

Shortly said this decree nr. 258 sets requirements to 2 main parameters:

1. Energy-Efficiency Value, which characterises building specific overall energy usage
2. summer operative temperature, which characterises indoor climate during summer months

Those 2 requirements are supplemented by usual requirements to building envelope, building service systems and energy supply.

The Energy-Efficiency Value (EEV) includes whole building overall energy use, including energy necessary to guarantee acceptable indoor climate, hot domestic water and miscellaneous equipment.

The calculation of overall energy consumption is based on net energy need for HVAC systems, lighting and other equipment not covered by previous terms. The heat loss of (heating/electrical) energy production and in transmission is considered.

Overall energy use gives a good reference value to evaluate building energy use and environmental impact. The implementation of „The Minimum Requirements for Energy Efficiency" and comparison of buildings energy efficiency assumes that overall annual energy use is given per m^2. As building energy consumption is dependent on internal loads and usage profiles, the overall energy use is calculated according to standard profile. This allows an energy-efficiency comparison of same type of buildings on objective basis. Government decree nr. 258 has standard profiles for most common building types. Having certain standard profiles to use, will determine most input values in a energy usage calculation. The values that are not determined with decree nr. 258 are acquired from project documentation.

Setting energy-efficiency value as a target is based on Building Energy Efficiency directive [4] which emphasizes the importance of primary energy and CO_2 emissions, the economic efficiency and good indoor climate.

Decree nr 258 has different maximum allowable energy-efficiency values for several types of buildings. These also differ depending whether it is a new construction or renovation under consideration, allowing renovations to have somewhat higher values.

The second point in „The Minimum Requirements for

Energy Efficiency" sets limits to operative temperature. This means that it is allowed to have up to 100 or 150 degree-hours(°C·h) over cooling set-point temperature during summer months depending on building type. To evaluate the meeting of this requirement it is assumed that a computer simulation is carried out for a sample room. Dwellings are allowed to be checked with simplified way by using specific graphs. There are other parameters that should be considered when evaluating indoor climate that are as important to give definite evaluation over indoor quality. That is why, in later part of this article alternative building grading programs are considered.

2. Problem Description

According to decree nr. 258 it is necessary for new and major renovation construction to prove that energy consumption requirements are met. To do that, means to have knowledge of methodology and the ability to use calculation programs. Concluding from first results on applying the decree in correct manner shows that there is a high probability to obtain incorrect final values by designers. Main reason behind that is low user experience with simulation software, but also incorrect input values, unclear calculations and wrong assumptions of the complicated methodology. At the same time local authorities do not have knowledge capacity to check the results. This has induced a situation where building permit is given to a project that according to energy label is acceptable, but in reality consumes considerably more energy. Altogether, there is a threat that the decree is not fulfilling its purpose – to prevent constructing houses that consume excessive amount of energy.

Current article is focused on the evaluation of how decree nr. 258 is taking effect and introducing main concern points.

2.1 Current Situation

In co-operation with State Technical Supervision Authority altogether 13 non-residential buildings were selected. Enquiry showed that only 3 project`s energy consumption calculations where done with suitable simulation software. Furthermore, 1 project calculation out of the 3 was not done according to decree, using project based input values and not standard profiles according to the decree. Thus, energy calculation check analysis was carried out only for 2 projects..

The reason behind using inappropriate simulation program was the user friendliness of the program BV2 with its easy-to-understand Estonian manual, good examples and quick response from developers in the case of questions. Also it is the only available simulation software without any fee. At the same time, the appropriate simulation programs where considered very sophisticated and difficult to understand with their foreign (English) language manual.

2.2 Check of Energy Calculation Results

2 project calculations that qualified for calculation check analysis where checked by MSc and PhD students. The check calculations where carried out with IDA-ICE and/or BSim simulation software. Both softwares do comply with IEA BESTEST methodology [5,6]. One of the projects is a retail centre in Narva, second is an office building in Tallinn.

1. Retail Centre in Narva

Building year:2009

Heated floor area: 12 733 m^2

Net floor area: 13 287 m^2

Results.

Energy Efficiency Value: In design documents a value of 291 obtained compared to 247 kWh/(m^2 x yr) in check calculations. This constitutes about 15% difference.

Looking at building service systems and their energy consumption shows even larger discrepancy. For instance, heating energy consumption is 42,7 in design documents while it is 79,2 kWh/(m^2 x yr) in check calculations showing about 47% difference. At the same time ventilation equipment electrical energy consumption is about 5 times larger in check calculations, while other electrical equipment energy consumption is over 20% less in the same calculations. Concerning cooling, the difference is immense, with 69,8 in design documents and 3,7 kWh/(m^2 x yr) in control calculations, constituting close to 20 times difference!

Evaluation of the results.

There are several possible considerations that constitute to results difference.

- different calculation software
- difference in EEV is probably caused by special equipment used in retail centre about which there were missing input values for check calculation.
- the reason for large difference in ventilation electrical energy consumption could lie behind SFP (specific fan power) value as design calculation software does not allow to input this value. Using simplified calculation with the same air flow rate and simple usage profile gives a result of 43,7 kWh/(m^2 x yr) being close to check calculation result.
- with more precise evaluation of results the main concern is associated with refrigeration equipment used in retail centres and how to consider these in energy calculations. That is not regulated in decree nr 258.

2. Office building in Tallinn

Building year: 2009

Heated floor area: 964,4 m^2

Net floor area: 1 094,2 m^2

Results.

EEV is 168,5 compared to 146,6 kWh/(m^2 x yr) in design calculations and in check calculations respectively. This constitutes around 13% difference. Heating energy consumption is around 18% lower for design calculation, with values of 39,1 and 47,8 kWh/(m^2 x yr) respectively. Ventilation electrical energy consumption is almost the same for both cases, with 14,9 kWh/(m^2 x yr) for design case and 14,7 kWh/(m^2 x yr) for check calculation. Furthermore, equipment energy consumption is matching well also, with 52,1 in design case compared to 49,4 kWh/(m^2 x yr) in check calculation. But there is a larger cap between cooling energy demand, around 2 times, with 7,8 kWh/(m^2 x yr) in design case and 4,2 kWh/(m^2 x yr) in check calculation.

Evaluation of results.

As there are occasional mismatches among the results, there are few possible considerations that constitute to these differences:

- different calculation software
- mismatch of floor areas
- It is unclear which part of building is considered unheated.
- Check calculations used profiles according to decree nr 258, which are not matching with design case.
- Difficult to understand such high cooling energy need in design calculations
- There is also a large, 3,5 times difference, in ventilation air heating demand. The reason behind it is the supply air temperature difference being +21 °C in design case while in check calculations it is +18 °C. It is also partly due to heat recovery temperature efficiency value difference, being 0,8 for control calculation according to decree, while it is 0,76 in design calculation (probably based on project documents).

2.3 Summary of Energy Calculation Results Check

The investigation showed that there are severe deficiencies in application of Estonian governments decree nr. 258 „The Minimum Requirements for Energy Efficiency“ and set targets are not met. Only 2 project energy calculations out of 13 where done in accordance with decree nr. 258. Investigation also showed that most calculations where incomplete, done with inappropriate calculation software or just missing.

Reasoning behind application difficulties lie behind sophisticated level of the decree, but also problems concerning appropriate simulation software usage. There have not been institution(s) to educate enough specialists in acceptable simulation software. Furthermore, acceptable software is available in foreign language, expects high level of knowledge in the field of building energy consumption and large work experience. Often the calculation process is not easily assessable and this makes energy calculation result checks complicated.

3. Future Alternatives

As the situation with current Estonian government decree nr. 258 „The Minimum Requirements for Energy Efficiency“ is not good there is room for improvement. Implementation of it has been made compulsory, but at the same time it seems Estonia is just not ready for that. All this is clearly visible by looking at implementation. There is only few projects granted building permit and most of them are based on wrong values due to the inappropriate use of the decree. To resolve this problem, there should be more supporting education in how to implement the decree and further guidance for the users.

Second alternative to evaluate building projects could be using more thorough building rating system. The latter would consider much more parameters than just annual specific energy use and indoor temperature during summer months. What supports this idea, is the fact that current regulative decree has not been enforced in full extent, meaning it is not fulfilling it`s purpose and it is not used in a right manner. Thus, there is room to implement a new grading system which is more complete to evaluate proposed building projects.

There are few established grading systems available in the world, which this new building project evaluation system should follow. The two most complete ones are LEED in US and BREEAM in UK.

The first one is LEED (Leadership in Energy and Environmental Design) Green Building Rating System developed by U.S. Green Building Council (USGBC) [7]. Latest edition is from 2009. BREEAM (Building Research Establishment`s Environmental Rating System) [8] is developed by BRE in UK current last edition is published in 2008.

Both of these rating systems are acknowledged all over the world. Both of them are consistently being improved by respective institutions.

Furthermore, as there can be several building project types (e.g. residential, retail, school, office etc. buildings) there are different grading scales for specific project type. BREEAM, for instance, has editions covering Courts, Education, Industrial, Healthcare, Offices, Retail, Prisons, Multi-residential projects. There are several

options for LEED as well, consisting of New Constructions or Major Renovations of Commercial and School buildings, Homes, Retail, Core&Shell and Commercial Interiors. There is a small difference between division by both organisations, but the idea stays the same – to use appropriate grading systems for specific building project types. Though there are several grading scales, the most urgent ones for Estonia are Office and Multi-residential by BREEAM or the edition for New constructions and Major Renovations of Commercial buildings.
These two grading systems are well composed covering matters in a wide range. They are not only about energy consumption and indoor temperature, but rather cover much broader range. For instance in LEED there are 5 main evaluation topics plus additional 2 topics, latter consisting of Innovation in Design and Regional Priority. Main topics are Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality. All of these main topics consist of several sub-themes making up an extensive scale to evaluate building projects. Each main topic has 1 to 3 requirements which a project has to pass to receive recognition from USGBC.
BREEAM is almost the same, at least the topics covered are in large part the same.
As BREEAM and LEED grading schemes are aiming not just to pass a project by meeting minimum requirements, but rather aiming for the best possible solution, there are levels to pass according to those standards. Taking LEED, for instance, it is possible to have 110 point maximum, including points from innovation and regional priority. But it is also enough to pass if a project achieves over 40 points. 40 point level is just passing according to LEED, but there are further levels at over 50, 60 and 80 points threshold. Developed project, having higher level certification from USGBC, is of course attracting more attention. Client can compare project only based on the level allocated, making it easy for client and the developer alike. Having world known grading scheme acknowledging your effort, is what each developer in the future will want and need to make their projects marketable.
The thing that should be considered is the volume of LEED and BREEAM. As these are considering a lot of parameters when evaluating a building project, it may turn out that it is too comprehensive and difficult to follow. There would surely be shortage of expertise personnel in the field. That is why both these grading schemes have certified personnel who are accredited to offer consultation and conduct evaluation of proposed building projects. To become one, one has to pass an exam conducted by relevant organisations, namely USGBC or BRE. Thus, the possibility to become recognised assessor is available to all.
This means that even though there would be shortage of qualified personnel in the first years after establishing BREEAM or LEED, it can change in the future.
To overcome the problem of too many points under consideration for evaluating a project, there could be made some modifications.
It might be reasonable to take LEED, BREAAM or a combination of both as a basic reference to compose custom Estonian building grading scale. It bares of course some threats, main of which would be that it would not surely be bearing the approved certification stamp from USGBC or BRE.
Another thing is that someone has to make a choice of what to include to the modified Estonian grading scale and what to leave out. This should be rather done by an institution, e.g. Tallinn University of Technology, or if BRE and USGBC would be interested, in co-operation with them. It is hard to expect interest from US and UK standard organisation to help working out standards for Estonia, thus the latter idea could be crossed out. BRE and USGBC would rather just see their standards directly taken over in Estonia as it is recognised all over the world as this would seem most reasonable choice to all.
TUT, on the other hand, could be very suitable institution to work it out. They have a well-known high level reputation in Estonia, and should have capacity also. As TUT is currently looking for further improvements of current decree nr. 258 considering building sustainability and energy efficiency as a PhD thesis the work towards more suitable solution for building rating in Estonia is in progress.
Besides working out most suitable solution for evaluating buildings we aim to become the organisation educating future assessors and becoming a consulting organisation considering buildings not just in Estonia but at least in Baltic countries.

4. Conclusion

To become more acquainted with BREEAM and LEED our next objectives are to evaluate some future building projects in Tallinn, and see where would these fit in BREEAM and LEED grading scales. These will show the current level of our standards necessary to pass for building permit. If the scores will be low, it will definitely show shortcomings in our regulations. The probable reasons behind those can be two kinds: 1) the points considered in BREEAM and LEED are not considered in Estonian regulations, thus can not be evaluated. 2) the parameter thresholds might be too low compared to levels in UK and US.
Based on the future evaluations it will be clear whether the best solution is to take LEED or BREEAM directly in use, to modify these to fit with Estonian situation or to make extensive additions to current decree nr. 258. All this will be future work in next 2-3 years to come ended by a PhD thesis and defence on the final results and solutions.

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PAPER II

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Using LEED to evaluate a built apartment building in Estonia

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ABSTRACT: The idea of using energy labeling is good way to restrict wasteful energy use in buildings. But energy consumption can be decreased in the expense of other indicators e.g. indoor air quality. To take the next step we must distinguish the need for more thorough evaluation scheme and thrive towards sustainable buildings. All this makes building assessment more complex. At the same time it is more comprehensive than just an energy label based on building simulation. Recently methods for evaluating buildings and their impact to the environment are worked out by several international organizations. The question is which of those would be the one to use in Estonia? In this article as an example one 8-storey apartment building is tested retrospectively with LEED NC requirements. The outcome shows where it would fit in the scale and comments about shortcomings are presented.

1 INTRODUCTION

There are several previous studies (Lee, 2011; Ali & Al Nsairat, 2009) which have compared different evaluation schemes available in the world. Being acquainted with current status of green building evaluation schemes it can be concluded that the most well-known in Europe are BREEAM (UK) (BREEAM) and LEED (US). In this article LEED was used to evaluate retrospectively already constructed apartment building.

2 QUICK OVERVIEW OF LEED

LEED, which stands for Leadership in Energy and Environmental Design, is a green building certification program established by U.S. Green Building Council (USGBC). The aim is to guide building designers in right direction in planning process and latter stages in a way that the final design would be environmental friendly and sustainable. Important part is also the comparative evaluation of the outcome with the design intensions.

There are various evaluation schemes in LEED, depending on the building type and project scopes. LEED evaluation scheme consist of 5 main categories: sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor environmental quality (IEQ). Besides these there are two additional categories out of which innovation in design (ID) deals with innovation and matters not covered in the main categories. Regional priority (RP) turns its attention to local conditions (eligible only for projects in US).

Each category consists of several criteria which turn attention to specific matters to be considered. These include prerequisites which have to be fulfilled to become LEED certified.

To differentiate between projects and their level of sustainability, there are 4 distinct levels that a project can achieve: Certified, Silver, Gold and Platinum. These enable interested parties to group projects in a quick and easy manner and only when necessary investigate deep into the credits.

3 CURRENT SITUATION IN ESTONIA

At the moment it is compulsory for new buildings to prove that their energy consumption is in accordance with minimum energy requirements depending on building type. This needs a simple building simulation beforehand a building permit is allocated. Although a few more requirements are stated in the Minimum Requirements for Energy Performance (Estonian Government, 2007) concerning construction U-values, ventilation rates etc., the decision is based on energy consumption value.

We must note that Minimum Requirements for Energy Performance was made compulsory for new buildings applying for building permit since July 1st 2009 and can be considered quite new. Estonia has to follow Energy Performance of Buildings Directive (EPBD, 2002) to achieve 2020 goals (Decision No 406/2009/EC, 2009). As a previous study (Seinre & Voll, 2010) has shown, the energy labeling in Estonia is not fulfilling the intended purpose due to several reasons.

Currently not many developers in Estonia are aware of different sustainable evaluation schemes and their benefits. Reluctance to implementation can be sensed. Explanation and introductions to the stakeholders is necessary to raise the awareness.

As a first step towards latter a post-construction evaluation on a recently built apartment building is covered in this article. This will give implications how such scheme would fit in Estonian context and where the main drawbacks are. Based on this analysis it can be evaluated how much work is there to be done to achieve levels expected by LEED evaluation scheme on documentation and the level of details in it.

4 OVERVIEW OF THE BUILDING

The building is a situated in Tallinn in the vicinity of city centre. The building is 8-storey apartment building, with below grade parking garage. The building can be seen in Figure 1.

Figure 1. Evaluated building situated in Tallinn.

Gross above grade building area for considered building is 3000 m^2 out of which apartments constitute 2310 m^2. The building was built in 2002. Although in this article one building is evaluated, the development on current site included three buildings of the same height and minor differences in floor plan outlay.

4.1 *Sustainable Sites*

LEED gives a comprehensive evaluation over building site selection. For that reason there are 15 categories under sustainable sites category to be evaluated when considering new constructions (NC). These include 1 mandatory prerequisite and 14 categories for which points can be awarded.

The prerequisite considers construction activity pollution prevention. The aim of it is to avoid pollution in the form of dust, soil erosion and also sedimentation due stormwater runoff to neighboring building sites. To comply with the credit there should be an action plan to avoid such threats. United States Environmental Protection Agency (EPA) (EPA) in US has developed a guidance material, National Pollutant Discharge Elimination System (NPDES) (NPDES), which should be followed or used as a reference to guarantee desired outcome. This was not covered in project documentation. The criterion would be difficult to meet even if considered in design phase, because there are no such regulations set in Estonia.

Site selection is a criterion for which it is possible to achieve 1 point. Matters considered here include the condition of the site, distance from water bodies, chance of floods, endangered flora and fauna species. Considering those indicators none were violated and credit compliance was assured.

Under development density and community connectivity, 5 points, an evaluation is given based on development density and the services offered in the vicinity of the project site.

Project matched with the requirements having a total development density 14 510 m^2/ha, when at least 13 800 m^2/ha is required. Furthermore, the number of services offered was met as there are more than 10 available in 800 m walking distance from main entrance. Maximum number of points were awarded.

Brownfield redevelopment, 1 point, values effort in converting contaminated sites into used sites. As the project was developed on previously developed, but not contaminated site, point was not awarded.

Public transportation access, 6 points, requires a bus stop within 400 m walking distance for 2 different bus lines and the number of rides has to be at least 50 per day. As the worst case scenario 796 rides per Sunday were provided. There were 4 bus stations within limit offering opportunity to take a ride towards the centre or to suburbs. A site plan denoting considered bus stops can be seen in Figure 2. Altogether there were 16 different public transport lines in the form of trolleybuses, trams and buses. Maximum credits and an extra for exemplary performance were awarded. For latter at least 200 rides per day must be assured.

When considering bicycle storage and changing rooms, 1 point, residential projects are expected to assign covered storage facilities for bikes to at least 15% of building occupants. There were no designated bicycle storage facilities in project. The credit intention was not met. Local standards are more stringent than LEED requirements. Following them would meet also this criterion.

Low-emitting and fuel-efficient vehicles criterion, 3 credits, has several opportunities for compliance. Options include preferred parking, fuel-station, allocating fuel-efficient vehicles or fuel-efficient vehicle sharing. As none of these matters were dealt within current project further elaboration is not given. Matters are not regulated in Estonian building regulations.

Parking capacity, 2 points, advises to size lot number exactly according to local requirements or not providing new parking spaces. Project parking capacity is 131 parking lots, while 62 were required. No compliance with criterion.

Protect or restore habitat, 1 point is awarded for previously developed sites that comply with percentage of site area that has to be covered with native or adapted vegetation. According to measurements from site plan there was vegetation cover on 1049, whereas necessary limit is at least 2344 m^2. Credit requirements were not met.

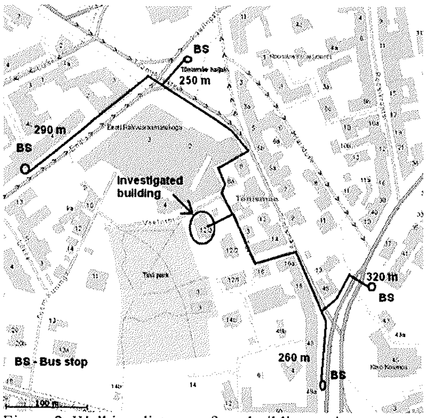

Figure 2. Walking distances from building main entrance to bus stops.

Maximize open space, 1 point, evaluates percentage of open space area from total site area, depending on whether there are local zoning requirements on open space or not. As there were no such requirements in Estonia the project should have had an open space area at least 20% of total site area. In reality vegetated site area constituted to 17 % of total site area.

Stormwater quantity control, 1 point. Stormwater management plan which can decrease stormwater runoff by 25 %, on sites that have existing imperviousness grater than 50 %, as is the case with current project, has to be implemented. A local standard on rain intensity was used to check compliance with current criterion. As there was limited information about site condition before development the calculations were not exact. Based on that, the stormwater runoff rate before development was 23.16 l/s. Post-development runoff rate was 41.02 l/s due to considerable increase in impervious cover.

Stormwater quality control, 1 point, evaluates whether means are applied to capture and treat stormwater runoff. Such measures were not considered in this project, which is common in Estonia as there are no regulations concerning these matters.

Heat island effect – nonroof, 1 point, evaluates building site hardscape influence on heat island effect. Under this credit the option to place at least 50% of parking spaces under cover was met. There are altogether 93 parking lots under cover in underground garage and building ground floors, which constitute 71% of total parking capacity.

For roof surfaces, 1 point, limits on solar reflectance index (SRI) are given, depending on the roof slope angle. As roofs in current project were low-sloped their SRI had to be at least 78. This was not met. Not regulated in Estonia and if to be used in design phase still difficulties to meet the requirements would be expected.

Light pollution reduction, 1 point, sets limits to interior and exterior lighting intensities during night hours. The interior lighting limits do not concern dwelling units. Limits to exterior lighting depend on the zone building is situated. Current project can be considered to be in zone 2 with allowed illumination limit at the boundary of site being 1 lux in horizontal and vertical direction and no more than 0.1 lux in horizontal direction 3 meters from boundary. Measurements showed that criterion is not met. The values on the boundary varied in the range of 3-26 in horizontal and 2-17 lux in vertical direction.

Total score from sustainable sites category was 13 points out of 26. This can be considered good, considering that no effort was made to score the points. It must be noted, that compulsory requirement was not met.

4.2 *Water Efficiency*

This category consists of 1 prerequisite and 4 criteria to evaluate how efficiently potable water is used.

Water use reduction is the only compulsory requirement under this category. The aim is to use 20 % less water compared to baseline building. Values for calculating baseline building are given in LEED manual. As there is no available information about water fixtures it is not possible to evaluate current building with baseline. Considering typical practice in Estonia it can be expected that fixtures are the cheapest ones and water consumption is not considered. If to be used in design phase difficulties to meet requirement can be expected.

Water efficient landscaping, 2-4 points, aims to reduce potable water consumption on irrigation. As there was no irrigation system in project it met with the requirement and scored maximum number of points.

Innovative wastewater technologies, 2 points, aim to reduce potable water use for sewage conveyance by at least 50 % or to treat 50% of wastewater on site to certain standards. These are not covered in project documentation. Even when used in design phase would probably not be economically feasible in Estonia.

Water use reduction, 2-4 points, is an elaborated version of compulsory prerequisite under this category: points are awarded if 30, 35 or 40 % water consumption reduction can be demonstrated. No information on fixtures was available, no points were awarded.

Total score under water efficiency category was 4 points from not using potable water for irrigation. 10 points were available. The points scored were rather accidental than a result of thoughtful planning process.

4.3 *Energy and Atmosphere*

This category consists of 3 compulsory prerequisites accompanied with 6 criteria for NC buildings.

Fundamental commissioning of building energy systems aims to guarantee that energy consuming systems (HVAC, DHW, lighting and daylighting) are working as they were intended. Tasks to be covered by commissioning authority (CxA) resemble very much construction supervisor that is used in Estonia's construction sector practice. However, energy consuming systems may not be at his responsibility list, and although supervisor was used in current project starting from construction process, complete compliance with requirements can not be assured. If to be used in design phase would not be a problem to meet the requirements.

Minimum energy performance assesses whether building is consuming energy according to allowable limits using baseline building as a reference. For that a whole building energy simulation has to be performed according to ASHRAE Standard 90.1 (ASHRAE, 2010) and at least 10% improvement against baseline has to be demonstrated. As simulations were neither common nor compulsory when the building was constructed, there were no simulation results available. By now energy simulations are compulsory and if used in design phase it is evaluated that no problems with -10% requirement would be expected.

Fundamental refrigerant management restricts the use of CFC-based refrigerants in HVAC and fire suppression systems. Fire suppression system was water-based sprinkler system and designed air handling units (AHUs) with cooling did not use CFC-refrigerants.

Optimize energy performance, 1-19 points, is elaborated version of prerequisite 2 awarding points when showing energy consumption reduction compared with baseline building by whole building energy simulation. No points were awarded as no simulations were performed.

On-site renewable energy, 1-7 points, criterion appreciates the effort of using on site renewable energy sources to cover building energy consumption. There were no renewable energy sources designed for the building, thus no points were received.

Enhanced commissioning, 2 points, elaborates on first prerequisite under this category by adding more responsibilities to CxA: more design document reviews during different stages of design, developing a system manual for users, verifying that operating personnel is trained and reviewing building operation within 10 months after substantial completion. None of these were covered in project documentation. No points were awarded.

Enhanced refrigerant management, 2 points, evaluates the impact of refrigerants on global warming and ozone layer. For that reason there is an equation for calculation and a table for various refrigerants in LEED manual (USGBC, 2009) with their potential on these matters. There are 4 AHU which use R-404a, having 0.6 kg of refrigerant each. Calculation gave a result 151, while it should be below 100 to be in accordance with credit requirements. If used in design phase and knowing the requirements with proper refrigerants the requirements would be met.

Compliance with measurement and verification (M&V), 3 points, requires whether Option B or D from International Performance Measurement & Verification Protocol (IPMVP) Volume III to be followed. This means that a measurement or a simulation on system level to be performed which would cover at least 1 year post-construction occupancy, respectively. There was no M&V plan in project documentation. When to be used in design phase the chances of meeting the requirements would be higher.

Green power, 2 points, awards projects which purchase for at least a 2-year period in the amount of at least 35% of buildings annual electricity demand from renewable resources. No green energy was purchased in this building.

Under energy and atmosphere category project earned 0 points out of possible 35. This is mostly because assessable credits whether are not covered in Estonia's construction industry practice or are just not specified in project documentation. One prerequisite was fulfilled. The biggest drawback comes from not performing any simulations which could account for more than half of the points available under this category.

4.4 *Materials and resources*

Category includes one prerequisite and 8 credits for new construction buildings to be evaluated.

The compulsory category, storage and collection of recyclables, requires for compliance that paper, cardboard, plastic, glass and metals to be collected separately in a designated room with easy access both to building occupants and service provider. There is a dedicated room for the purpose on the ground floor. Separately collected recyclables are paper, bio and general waste, which is compulsory in Estonia. Plastic and glass bottles are returned to grocery shops where they are refundable, other plastic and glass materials can be taken to designated containers, which are situated 600 m walking distance from building main entrance. With minor reservations criterion was considered fulfilled.

Maintain existing walls, floors and roof, 1-3 points, requires for compliance to maintain existing building structure in the form of aforementioned structures in the following percentage levels: 55, 75 or 95 %. There was an old sportcenter before development. No old constructions were used in new building.

Maintain interior nonstructural elements, 1 point, requires for compliance to use at least 50 % of existing non-structural elements by area in new building interior. Nothing from old building was re-used.

Even if requirements covered in last 2 paragraphs would be considered in design phase they would be difficult to be met in Estonian construction practice.

Construction waste management, 1-2 points, aims to avoid construction debris to end up in landfills or incineration facilities. For that reason a project should collect construction and demolition debris to re-use 50 or 75 % by weight or volume. The project had a plan to avoid debris ending up in landfills, but when compared to later documents from landfill manager, it showed that construction and demolition debris ended up in landfills.

Materials reuse, 1-2 points, criterion aims to reduce effect on environment by avoiding usage of virgin materials by using 5 or 10 % reused materials of total construction materials value. This is not current practice in Estonia's construction practice. There was no reference to reused materials in project documentation.

Recycled content, 1-2 points, evaluates whether materials with recycled content are used. The levels to meet the criterion are 10 or 20 % of total construction materials value. This is new matter gaining more attention by construction industry stakeholders, but is still innovative in Estonia. The criterion was not fulfilled in this project.

Regional materials, 1-2 points, favor the usage of local materials. To meet the requirement 10 or 20 % of building materials by cost have to be acquired-manufactured-extracted within 800 km radius from the project site. There was no documentation in project that explicitly identifies the origin of materials, but confirmation from project manager was given that concrete is from Estonia. As were windows. Parquet was from Sweden. All these made up quite large share of total building materials cost. It was assumed that materials used, but not mentioned were mostly from Estonia or at least within allowed limit. Even though there were no documentation verifying the requirements 2 points were awarded.

Rapidly renewable materials awards a point if at least 2.5 % of total value of building materials based on cost are used in the project. Rapidly renewable products are made of plants that can be harvested in 10-years. No such materials were used in the project.

Certified wood, 1 point, evaluates the wood products used in the project. For compliance at least 50 % of wood-based materials and products have to be in accordance with Forest Stewardship Council's (FSC) principles. According to project manager the largest share of wood products was parquet from Sweden. The producer of the product was AB Gustav Kährs, which holds current FSC certificate from 2008. It was assumed that they followed FSC criteria also before. Point was conditionally awarded.

3 points out of 14 were awarded in this category. Prerequisite was met. The awarded points are without verifying documents. Most criteria covered in this category are not considered in Estonia's construction sector practice. Required reuse percentage levels are high, whereas reuse and recycled materials and products are not common in Estonia even today. When the awareness of stakeholders is increased, surely more credits can be met in future projects.

4.5 *Indoor environmental quality*

This category consists of 2 prerequisites and 14 credits in the frame of NC.

Minimum Indoor air quality performance requires for compliance that ASHRAE Standard 62.1 (ASHRAE, 2007) section 4 to 7 minimum requirements to be followed when allocating ventilation rates by using ventilation rate procedure. Balanced mechanical ventilation was designed for the building, with each apartment having its own AHU. This is not common in Estonia as most apartment buildings are built with mechanical exhaust ventilation. Local standards were used when designing the ventilation for the building. When comparing the latter with Standard 62.1 ventilation flow rates necessary for apartments, used values are larger than required by Standard 62.1. This prerequisite was fulfilled.

Environmental tobacco smoke (ETS) control aims to avoid building users to be exposed to tobacco smoke and the health effects associated. For compliance there are several opportunities, starting from prohibiting smoking in the building and ending with special rooms where smoking is allowed with strict requirements to avoid smoke distribution in the building. This was not covered in project documentation. If to be used in design phase no problems to meet the requirements would be expected.

Outdoor air delivery monitoring, 1 point, requires for non-densely occupied zones, which apartments can be considered, to monitor permanently minimum outdoor air intake flow rates and generate an alarm when the deviation is larger than 10 % of the design value. The automation system of AHU probably ensured the design working conditions for the systems, but there were no specific means to measure outdoor air flow and its fluctuations. No point was awarded.

Increased ventilation, 1 point, appreciates projects that increase their ventilation flow rates +30 % compared to the requirements set by Standard 62.1 in each occupied space for mechanically ventilated spaces. Although in each apartment the ventilation flow rates constituted in total flow rate +30 % or more it was not fulfilled in each occupied room. No points were awarded.

Construction indoor air quality (IAQ) management plan during construction, 1 point, sets requirements to be met during construction phase, including storage of materials, filtration media efficiency in AHU, and control measures in Chapter 3 in (SMACNA, 2007). There was no documentation covering the matter. Considering current practice it is hard to believe that requirements would be met even if used in design phase.

IAQ management plan before occupancy, 1 point, requires whether a flush-out, in the form of supplying outdoor air in the order of 4270 m^3/m^2, or air testing by measurements to be carried out prior occupancy. Neither of these was performed. If to be used in design phase, probability to meet the requirements would be higher.

Low-emitting materials – adhesives and sealants, 1 point, requires that materials from this group are in accordance with relevant standards setting limits to various volatile organic compounds (VOC). Required US standards are not followed. All the products used have Estonian Health Protection Inspectorate (EHPI) certificates to assure their quality. After enquiry it was confirmed that EHPI certificates consider VOC concentrations among other things when issuing certificates. Point was allocated conditionally.

Paints and coatings, 1 point, evaluates VOC concentrations in used paints and coatings. As with previous category, there are EHPI certificates for all paints used. It was noted that for water-based paints, the limits in EHPI were more stringent than in US standards, while solvent paints were in similar order. Requirements are met and point was awarded.

Flooring systems, 1 point, under current project scope sets requirements for concrete and wooden floors. Compliance can be proved with FloorScore standard (RFCI). Also tile setting adhesives are rated. Overall purpose again is to limit VOC emissions from used materials. Used parquet was from FSC certified wood and no adhesives were used to install it, concrete floor was not evaluated. Although flooring probably is in accordance with requirements, no proof was identified. No point was awarded.

Composite wood and agrifiber products, 1 point, prohibit using materials containing urea-formaldehyde resins under this product group. Flooring in most rooms in apartments was parquet, but as there was no information about formaldehyde no point was awarded. Probably hard to meet even if used in design phase.

Indoor chemical and pollutant source control, 1 point, sets requirements on building entrance systems and ventilation rates in possibly contaminated areas, also on filter efficiency and on containment for contaminants. Building entrances had about 1,5 m long grille system, followed by over 4 m long mat. This complied with the requirements. Exhaust from garage and filter efficiencies used were not in accordance with requirements in Standard 62.1. Point was not awarded.

Controllability of lighting systems awards 1 point if at least 90 % of building occupants can make adjustments according to their preferences to lighting levels. As considered building was an apartment building it was considered that the requirements are met.

Thermal comfort awards a point if at least 50 % of occupants have the possibility to adjust room thermal conditions. All radiators were equipped with thermostatic valves allowing users to adjust room temperature during heating season. As each occupied room had operable windows, during summer period users could adjust their comfort zone by opening these.

Thermal comfort design, 1 point. Compliance requires that building HVAC systems and envelope are designed according to ASHRAE Standard 55 (ASHRAE, 2004). In Estonia the same content was covered by our own standard. As the project used latter in design process, compliance with the criterion was assured.

Daylighting, 1 point, requires for compliance that at least 75 % of regularly occupied zones are daylight. There are 4 options to prove compliance: simulation, prescriptive, measurement and combination. A prescriptive option was used by the authors to check compliance as no simulation software was available nor was it reasonable to conduct measurements. For compliance following equation was used:

$$0{,}150 < VLT \times WFR < 0{,}180 \qquad (1),$$

where

VLT – visible light transmittance

WFR – window-to-floor area ratio

The results for one apartment on the second floor are shown in Table 1. As can be seen from it, no room was within acceptable limits. None of the rooms on the 2nd floor were in accordance. The same was assumed for other floors.

Tabel 1. Calculation results for prescriptive path.

Room	Area m²	Window area m²	VLTxWFR
Living room	24,1	14,79	0,23
Bedroom	10,6	3,29	0,11
Bedroom	11,4	3,98	0,13
Bedroom	15,6	3,29	0,08

Views criterion awards 1 point for buildings in where at least 90 % of regularly occupied area has a direct view outside. Glazing that contributes to point achievement, must be 0.75-2.3 m from floor level. By analyzing typical floor plans it was concluded that almost 99 % of occupied area had direct sight to outdoor environment. An example of floor plan is given in Figure 3.

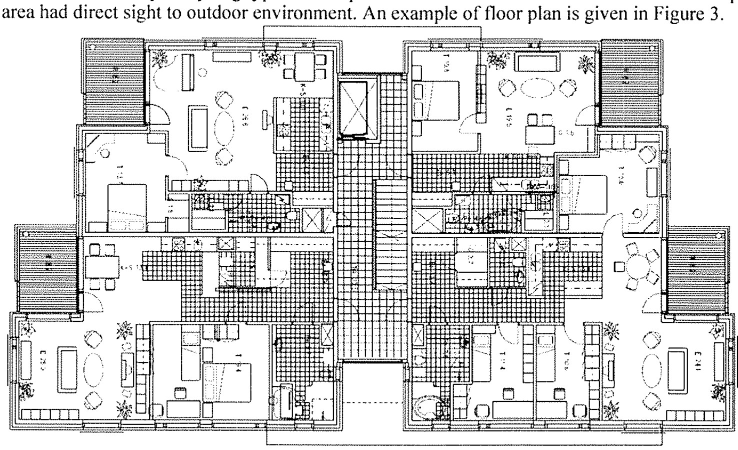

Figure 3. An example of typical floor plan.

This category gave 1 fulfilled prerequisite out of 2 and 5 points out of 14 applicable for residential projects. It still has to be noted that none of the criterion was explicitly considered in the design process and some points were awarded conditionally.

4.6 *Innovation in design*

This category can be considered as an addition to basic evaluation criteria. This means that further points can be achieved if matters that that are not considered in previous categories are covered. Maximum number of available points is 5. Three, if exemplary performance path is used. Exemplary performance is awarded if a previously covered criterion is met on larger extent than necessary for specific criterion. Also using LEED Accredited Professional (AP) can contribute with 1 point.

Current project fulfilled exemplary performance under public transportation access by providing close to 800 rides per day in the vicinity of the project.

5 CONCLUSION

Total score of the building was 26 points. For certified level at least 40 points were required in LEED 2009 for new construction. Considering that in the design phase most of the criteria covered by LEED were not even thought of the points achieved are quite reasonable. It is considerably easier to meet with LEED requirements when using it during design phase, while after completion of the building there is nothing that can be revised for compliance.

Most shortcomings in this building assessment can be allocated to the current building practice in Estonia. There were several criteria that were not met by requirements because these are not covered in construction documents. Another reason for not scoring points were too strict LEED requirements for some criteria.

It is clear that one building will not cover the Estonian construction market and further building types and even similar types of buildings need to be assessed. It would be much more illustrative if a building at its design phase would be included to LEED evaluation, thus considering necessary requirements already in early phases. This would ease a project considerably to achieve higher scores. At time being this is a thing for the future, but fortunately there can be noticed some interest growth from various stakeholders.

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PAPER III

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Quantification of environmental and economic impacts for main categories of building labeling schemes

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ABSTRACT

This study evaluated the weighting factors of five building sustainability assessment scheme categories – productivity, energy, water, materials and transport – to be used in Estonia. The method was based on environmental and economic assessment of available design options relevant for each category and transferring all impacts to euros through energy and carbon prices and productivity costs. The productivity category received the highest weighting, 89 or 70% share of the total impact with indoor climate reference class III and class II, respectively. This shows that the productivity effects are not enough recognized in current codes. To assign meaningful weightings for other categories the share of productivity was limited to 50%. The final weightings obtained with Estonian input data were 50% for productivity, 26% for energy, 21% for location, 2% for building materials and 1% for water efficiency. Obtained weighting factors for Estonia conflict quite remarkably with the weights of most well-known building sustainability assessment schemes, BREEAM and LEED, showing the importance of local conditions. Results denote that specific CO_2 emissions of energy sources change the importance of categories in a considerable manner. All findings in this study show that local context should be considered when designing a building sustainability assessment scheme.

1. Introduction

Sustainable building labeling is typically built on three pillars (environmental, social and economic) described with performance criteria which are assessed in the design or operation of a building. This means that in addition to environmental performance, which could be considered as the foundation of the sustainable assessment, also the impact on people and their well-being is considered. This type of quality indicators represents the social category. It is evidently important that environmental performance measured for example as CO_2 emissions from building project during its' life cycle, cannot come with the expense of the building users satisfaction. Third matter included is the costs. Generally life-cycle costs (LCC) of the building are considered. This will put the price on the environmental impact, helping investors to a choice that meets their needs. Such comprehensive assessment will ensure that a sustainable building has to be environmentally friendly (low CO_2 emission rate), economically feasible (low LCC), and healthy and comfortable to the users.

Introduction of green or sustainable building assessment schemes can be dated back to early nineties in last century. This was when BREEAM made its first steps in to the market where others followed in the coming years. Though the concept ideas of 'green building' existed before, the birth of assessment schemes can still be assigned to the beginning of 1990s [1,2].

Since then the market has expanded in considerable manner. There are several resources denoting the sustainable building market and its expansion [3,4]. The use of building labeling is continuously increasing ongoing process [5–7]. It is not surprising when considering construction market share in overall energy and resource consumption. Furthermore, to include the number of people it affects, e.g. employees working in offices, habitants in residential buildings etc. it is even more obvious. Labeled buildings are generally perceived as more energy efficient, with better indoor quality and possess quality impression [8,9]. All that makes these buildings more attractive and more valuable. It must be noted, that studies [10] have shown that certified buildings are not always more energy efficient.

To put monetary value on certified buildings several studies [5,11,12] have analyzed the effect of green building label on the value of property and also the impact on rental value. General conclusion that can be made is that market value of the property is about 10–25% higher (depending on the study) while rental value premium can be considered at about 6%.

Concern that possible clients have with green building labeling is associated with the costs. As green buildings are perceived better in quality [13] than conventional buildings then these are expected to be more expensive to build as well. It is true that designing and

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constructing a green building is a bit more demanding for the design team, but it has been proven in earlier studies [14,15] that the initial costs are just only about 1–2% higher.

A matter which has not seen a lot of coverage in scientific studies is the positive effect of labeled buildings. While there are clear social and environmental effects (productivity, CO_2 emission), these are not directly comparable to other costs and benefits expressed in monetary values (energy and water use). One known exception is [15] which is a study report conducted in U.S. placing monetary values on different categories evaluated in sustainable building schemes. The outcome of the study identified at least 10 times higher financial benefit (in present value) against higher construction cost for green building.

Current article quantifies the weighting factors for main environmental categories of sustainable building labeling schemes in Estonian context. The reasoning behind it is well supported by [16] which appreciates the effect of EPBD and suggests elaboration of topics to be regulated by European Commission (EC). The relevance of weighting factors has been emphasized in earlier articles [2,17]. As stated in [2] weightings are mostly based on 'expert group' opinion rather than scientifically based decisions. There are indeed usually some environmental or other studies behind the labeling schemes, but very often the ratings are based on the mix of descriptive design issues and performance based metrics. Ratings result may easily become not transparent, because being rather based on collecting of points instead of quantitative performance calculation/measurement. For example, LEED [18] refers to environmental impact categories and argues that these impact categories are compared with one another, but does not open what criteria (environmental, monetary, wellbeing, etc.) has considered in this comparison. As such a 700 page documentation of LEED remains somewhat black box for the users.

Several countries are developing their own sustainability assessment scheme, as also noted in [19]. From one point of view this is clearly understandable – an evaluation scheme has to consider local context with its benchmarks as emphasized by Todd et al. [2]. This is well illustrated in [13,20] where the relevance of materials and water category, respectively, were highlighted. Reasoning behind were the low emission rates of CO_2 from energy source in Sweden and shortage of water in Jordan, respectively.

On the other hand, looking more broadly, there is an interest to compare buildings and their environmental performance even with different scheme ratings. Thus, a unified (reference) scheme would be preferred. Aspirations can be seen in recent developments, where Green Building Challenge (GBC) initiated GBTool (by now SBTool) and BREEAM have been used to design country specific schemes [2,3,6,17].

Besides specific country schemes also differences in the scope of schemes has been pointed out in previous studies [2,3,21]. All that makes it more difficult to compare labels of different schemes. A question of standardization of building assessment has been risen before, e.g. in [4]. This article argues the question of setting minimum number of core indicators, which could be further elaborated to reflect local particularities.

As long as there is no universal/standardized scheme established, it is expected that new schemes will be continuously developed. That has taken Estonia in to situation where Estonia is looking to establish its building sustainability assessment scheme as well, providing a strong motivation for this study. Due to the plethora of available schemes decision makers are at crossroads in deciding which scheme is the most appropriate to use. Two distinctive opportunities seem possible: (1) to apply one of the existing well-established schemes in Estonia as a default scheme or (2) to work out a specific national scheme for Estonia. There are advantages to support both options. Overtaking a scheme will be less costly to manage and it will bring also a 'quality stamp' with it. On the other hand, it will not support consideration of local context, what could be the main advantage of Estonia's own scheme. A compromise could be something in between of these two options.

In this study a step toward making a scientifically based decision for the two alternatives was made. Authors analyzed the impacts of main categories in sustainable assessment schemes. The aim of analysis was to evaluate the importance of different categories on building sustainability in Estonian context. For that reason each category was described by one representative performance indicator and its economic impact (EUR/year) and environmental impact (CO_2 and kWh annually) were calculated. The band of impact was determined by firstly using minimum acceptable level and then improving it to the best expected level in each category: indoor environment, energy, water, materials and transport. Based on the results the appropriate weighting factors for the categories can be discussed on scientific bases.

2. Materials and methods

Authors limited the research to commercial (office) type building as a sector where the demand for sustainable building labeling has been the greatest. A distribution of annual costs in an office building can provide some explanation for the popularity of labeling as can be seen in Fig. 1.

Average annual wage in Estonia according to Statistics Estonia [23] in 2011 was 839 (average wages for 2012 were not yet available). Two times national average was used as the salary of office employees. This made 79.9 daily per person.

A 6-storey office building, the reference building of Estonian Cost Optimal analyses, situated in Tallinn was used as a reference in simulations (see Fig. 2).

Two different occupancy densities were used: 10 m^2/person and 15 m^2/person. Energy regulation [24,25] uses 17 m^2/person for office occupancy density (relevant to understand the differences in energy simulations results). Gross area of the simulation model was 3830 m^2. Net floor height was 3.3 m, with the exception of 4.8 m Ground floor height. Used construction types and other input values for simulation were taken from Table 2 in [26], in which the cost optimal technical solutions for office buildings in Estonia were defined, for "BAU" (business as usual) for office building. IES [27] simulation software was used for thermal simulations. The validity

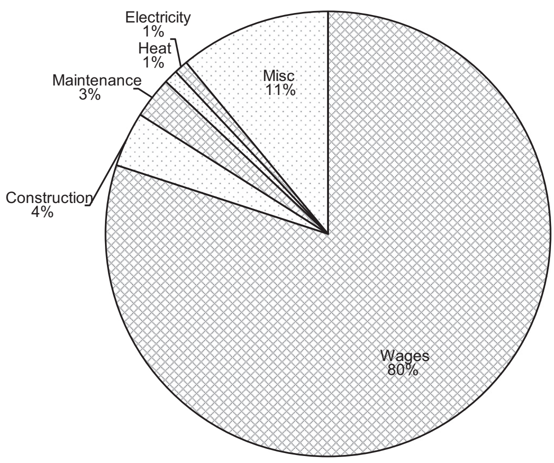

Fig. 1. Distribution of annual costs in office building. Derived from [22] Fig. 10.

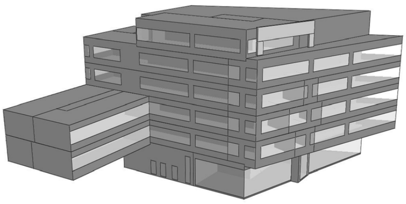

Fig. 2. A 3D building model from IES used in current study for indoor environmental quality and energy use simulations.

of IES model was confirmed by closely matching results with simulation results in [26]. After validating the model, modifications to IES model were performed to answer the questions posed in the study.

This study aimed to identify the importance of typical environmental categories in the form of weighting factors based on quantifiable values. Representative indicator from specific categories was used. The following main categories were included:

(1) indoor climate quality;
(2) energy;
(3) water use;
(4) material impact;
(5) project site.

The aim was to quantify the impact of representative indicators covered in building sustainability assessment methods into comparable numeric values. For that reason authors converted all impacts of evaluated indicators into the following metrics: (1) for energy use and impact on resource consumption to kWh/(m^2 a), (2) for the cost/benefit of the impact to /(m^2 a) or (3) for environmental impact to CO_2/(m^2 a). This allowed directly to compare the impact of indicators which usually are not comparable and to determine indicators with the highest impact on specific reference unit.

In the following the methods used in the quantification for selected categories are reported.

2.1. Indoor climate quality

Firstly the attention was given to indoor environmental quality. That was the topic most closely exposed to building users. Quantitative relations from REHVA Guidebook No 6 “Indoor Climate and Productivity in Offices” [22] were used. This reference is a compilation of results from earlier studies showing the importance of indoor climate on building occupiers perception of the building and its quality.

There could be distinguished 3 clear indicators affecting employees work: (1) ventilation rate – productivity; (2) ventilation rate – short-term sick leave and (3) indoor temperature – productivity. All these matters have been widely studied before and the correlations based on meta-analyses are reported in [22].

Ventilation rate – productivity effect was covered in [28] as referenced in [22]. Ref. [28] analyzed the effect of different ventilation rates on work productivity. Graphical representation of results in [28] was also the basis used in current study to take into account the ventilation rate effect on office employee productivity. Equations derived from graphical presentation of Seppänen’s results are the following (P stands for relative performance [–], L is ventilation flow rate [l/(s person)]):

$$P = -0.00002L^2 + 0.002L + 0.9823 \quad (1)$$

$$P = -0.00005L^2 + 0.0033L + 0.9807 \quad (2)$$

Eq. (1) was used for office type one (Off.#1) (15 m^2/person) and Eq. (2) was used for office type two (Off.#2) (10 m^2/person) to determine the effect of ventilation rate on relative performance.

Ventilation rate – sick leave study was conducted by Fisk et al. and is reported in [29]. This study refers to a couple of earlier studies out of which the graphical representation of research results from Milton et al. [30] were used in the current study. Milton conducted a study on office workers with ventilation flow rate and sick leave correlation. While there were more studies covered in [29], the results from [30] were the most appropriate for current study, as other studies covered different building types. Approximate equation derived from Milton’s study graphical representation used in current study is:

$$\mathrm{SL} = 0.2429\,\mathrm{ACH}^2 - 0.8757\,\mathrm{ACH} + 0.9874 \quad (3)$$

In Eq. (3) SL stands for sick leave prevalence relative to prevalence with no ventilation [–] and ACH stands for ventilation rate [1/h].

The effect of temperature on productivity was covered by Seppänen et al. in [31], which determined the effect based on statistical analysis of earlier studies. The equation to calculate relative performance depending on room temperature obtained in Seppänen’s study is:

$$P = 0.1647524T - 0.0058274T^2 + 0.0000623T^3 - 0.4685328 \quad (4)$$

In Eq. (4) P is productivity relative to maximum value [–] and T is room temperature [$^\circ$C].

The same equation was used in current study to determine the effect on productivity caused by room temperature.

2.2. Energy performance

Energy use is another basic category covered in sustainable building assessment. Usually it is also the category with highest weighting factor. As energy use directly influences the operational costs which bills are received monthly then occupants, users and owners are regularly reminded by the costs. Most stakeholders try to minimize operational costs. In current study energy use for reference building was determined using inputs from [24,25] for internal loads, ventilation rates, efficiencies and occupancy. The same constructions as in [26] for building as usual for offices were used. As reference building was not meeting the latest minimum requirements set in [24] for offices, a modified situation was derived according to percentage share for different energy users in Table 12 in [32] that exactly met the requirements. In [32] general design suggestions for low and nZEB design for office buildings at schematic design phase are discussed. Table 12 shows the effect of window-to-wall share on energy use. A version meeting nZEB requirements was derived with percentage share of different energy users like in Table 23, which represents the impact of PV-panels in attempt to design nZEB, in [32] with the renewable energy addition in the form of electricity produced by PV-panels. Largest adjustment in comparison with minimum requirement building was in the lighting load which is matching well with sensitivity analysis results in [33] as being one of the two most important parameters influencing non-residential building energy use. In [33] a sensitivity analysis on energy use was conducted with simulation software BE06 among 21 control and design parameters. All that helped to determine the possible gap in energy use and related costs between “minimum-requirement” and nZEB building.

In the conversion from delivered energy to CO_2 emissions a specific emission factor 225 gCO_2/kWh from district heating in Tallinn [34] and 1180 gCO_2/kWh as an average emissions from production of electricity in Estonia [35] were used.

Table 1
Indoor climate simulation set-up configurations for indoor climate analysis on the productivity of the employees according to [24,25] and [44]. Night-time ventilative cooling was active when outdoor temperature exceeded 12 °C and internal temperature exceeded outdoor temperature. The same set-up names are used in the following figures.

Set-up	Ventilation rate (l/(s m^2))	ACH (1/h)	Cooling set-point (°C)
Min. req., cooling 25 °C	2.00	2.2	25
Min. req., cooling 23 °C	2.00	2.2	23
Min. req., no cooling	2.00	2.2	–
Min. req., night cooling	2.00	2.2	25
EN 15251 class I Off.#2	2.00	2.2	25
EN 15251 class II Off.#2	1.40	1.5	25
EN 15251 class III Off.#2	0.80	0.9	25
EN 15251 class I Off.#1	1.67	1.8	25
EN 15251 class II Off.#1	1.17	1.3	25
EN 15251 class III Off.#1	0.67	0.7	25

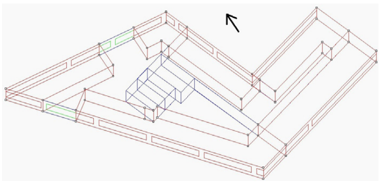

Fig. 3. Second floor representation of the reference building. Spaces in red were considered as office space where the indoor environment conditions were considered. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

2.3. Water use

Efficient water use is also a category included in numerous sustainability assessment schemes. A base for consideration was taken from LEED credit “Water use reduction” [18] according to which reduction of potable water consumption is praised. In current study the effect of water use reduction at a level that scores maximum number of credits was compared to baseline case in Estonia according to [25] in terms of CO_2 emissions, euros and kWh annually.

2.4. Material efficiency

Used materials in building construction are also evaluated in several assessment schemes, e.g. in BREEAM [6], LEED [36], OPENHOUSE [37], DGNB [38] and SBTool [39], whether in the form of LCA or directly as CO_2 emissions per project. In current study the authors limited the investigation of the impact of materials to main structural materials. That means 3 different solutions where considered: steel, concrete and timber structures. It was assumed that the core of the building could be constructed out of one of these materials and did not include more detailed level of specification of materials. Input values to rate different construction material impact were taken from [40] which specifies CO_2 emission according to material type for office building. These emissions are for New Zealand, but results from [41] show similar difference between concrete and timber construction in Finnish context. The values are divided for a 20-year period following guidance of [42].

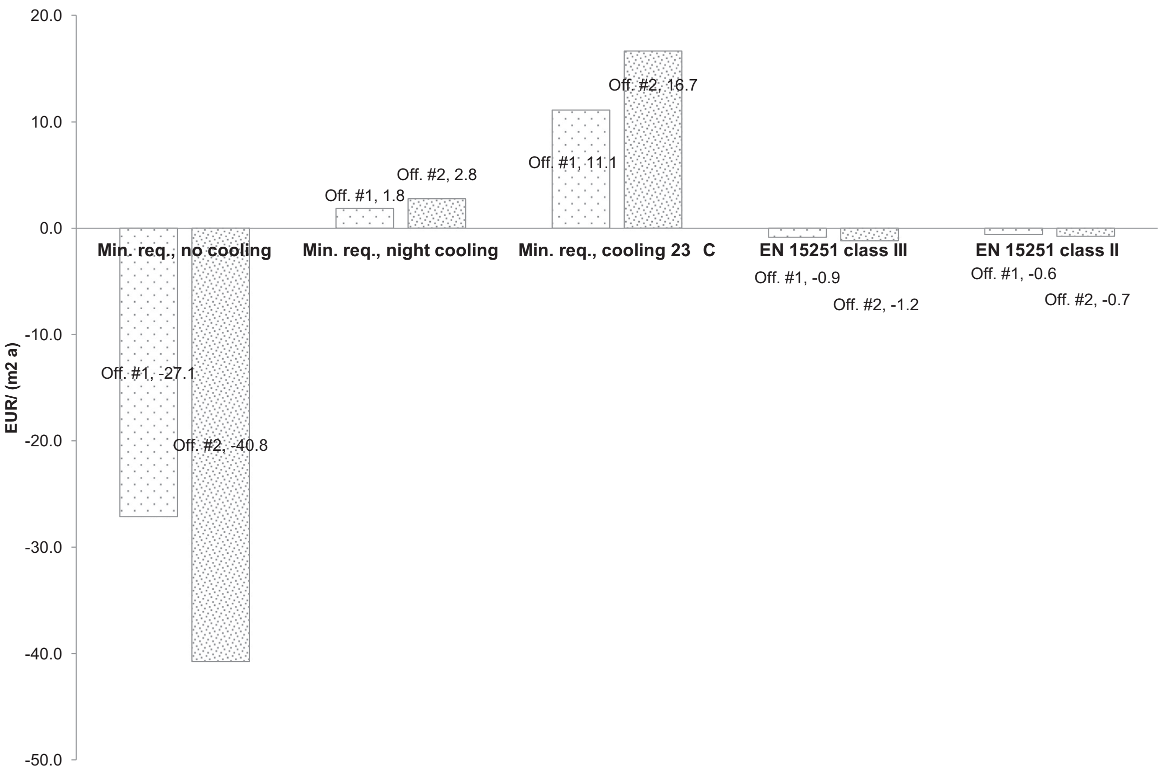

Fig. 4. Change in productivity due to temperature conditions in comparison with EN 15251 class I ventilation flow rate and cooling set point 25 °C. Negative values represent the performance decrement (caused by smaller ventilation rates or higher temperatures) and positive values performance increment.

2.5. Transport

Transport or location is a category that is rated in building sustainability assessment schemes, but is different from previous, because it is not related to specific building but rather to the building site. Numerous schemes promote developing sites that have been previously used, are close to amenities and in well-developed environment. All that provides prerequisite for the option to use alternative means of transportation instead of private vehicles. In current study the effect of availability of public transportation was analyzed. LEED "Public transport access" credit, see [18], was used as a bases for this consideration. This refers to Centre for Clean Air Policy which has found out that quadrupling the number of rides will increase twice the ridership. Furthermore, the effect on CO_2 emissions was evaluated, which was also converted into euros using projected CO_2 price per ton for EU's Emissions Trading Scheme (ETS) as stated in [43]. This is well over current price, thus showing larger impact than currently realistic.

3. Results

In the following the bands of impacts in terms of energy, CO_2 and costs are calculated for all categories studied. First, the solutions corresponding to minimum requirements or BAU construction are studied to quantify basic level of impacts. Then the solutions with improved environmental and social quality are studied to determine the band for each category.

3.1. Indoor climate

Considering ventilation rate then two reference sources were used. Firstly, minimum requirements from [24] for ventilation airflow rates were used. Secondly, [44] European indoor environmental quality standard and its ventilation classes were used. The ventilation rates according to [24] were in the reference office building close to class I ventilation flow rates in [44] or even higher depending on density of occupants.

Depending on occupant density the reference value for productivity level of 1.0 was exactly the same (Off.#1) or about the same (Off.#2) for ventilation class III according to [44]. In this study the positive effect on productivity due to class I ventilation in comparison with class III ventilation flow rate was determined using Eqs. (1) and (2). This resulted in an increased productivity equal to 26.5 or 53.8 /(m^2 a) for Office type #1 or #2, respectively.

Short-term sick leave was considered to be 2% of total working hours with 250 working days annually and with ventilation rate of 0.45 1/h as in [29]. This constitutes to a 400 loss per employee annually.

Air flow rates for 3 ventilation classes according to [44] for two different office occupancy density types were converted into ACH (air changes per hour) and entered into Eq. (3). Depending on air change rate relative difference between default short-term sick leave and the one possible to achieve with modified ventilation rate was determined. The increased benefit for Office type #1 due to class I ventilation flow rate on decreased sick-leave was 11.6 and

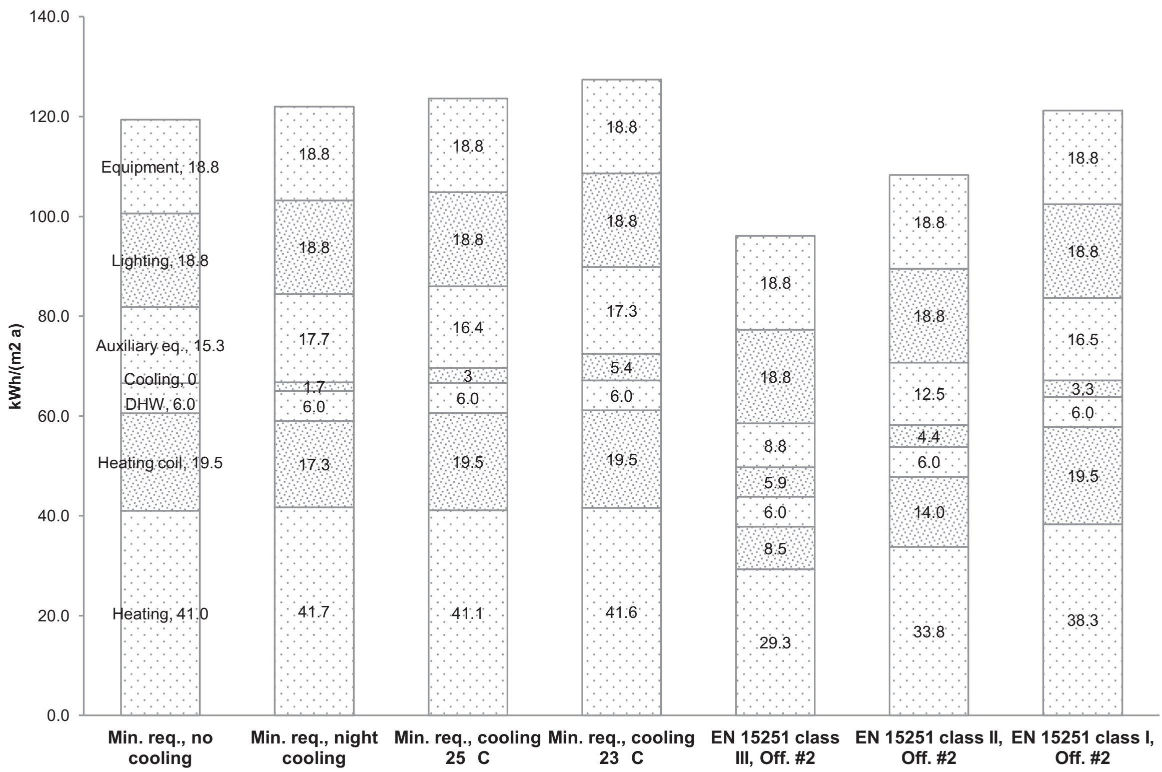

Fig. 5. Delivered energy use for indoor environment quality scenarios studied. The components from bottom to up are: space heating (heating), supply air heating in air handling unit (heating coil), domestic hot water (DHW), space and supply air cooling (cooling), fans and pumps (auxiliary), electric lighting and user and other appliances (equipment).

for Off.#2 up to 13.6 /(m^2 a) in comparison to class III ventilation flow rates.

To consider temperature effect on the performance of employee thermal simulations with IES simulation software were performed. Set-up configurations are summarized in Table 1. Temperature ranges and corresponding hours in the office areas of the building were summarized. Only staircases, lifts, corridors and technical rooms were excluded. See Fig. 3 as an example of zones layout.

Using Eq. (4) the relative performance of employees was determined. Based on the number of total occupants and their salary, the effect of temperature on productivity was converted into monetary units. The results are shown in Fig. 4.

Left column for each scenario represents Off.#1 (15 m^2/person), right column Off.#2 (10 m^2/person). Ventilation flow rates according to [44] class I are practically the same as for minimum requirements in [24], thus the differences shown in Fig. 4 are in comparison against these two.

Clear band for temperature–productivity relation can be seen. While cooling set point 23 °C increased the benefit for employer by 16.7 /m^2 annually and not using mechanical cooling was as costly as 40.8 /m^2 annually when comparing with minimum requirements with cooling set point at 25 °C (the effect caused by higher indoor air temperatures). Obviously class II and class III scenarios decrease the profit of employer due to lower ventilation rates and higher temperatures. Also the positive effect of night-time ventilative cooling can be seen.

3.2. Energy use

The breakdown of delivered energy use for scenarios studied can be seen in Fig. 5.

Lower 3 bars (DHW – domestic hot water) for each scenario are provided by heating system, the rest by electricity. General pattern is that more stringent indoor environment quality (e.g. "Min. req., cooling 23 °C" and "EN 15251 class I, Off.#2") requires more energy. This holds for Off.#1 as well. The same pattern can be seen in Fig. 6 showing the conversion to CO_2 emission rates caused by the use of district heat and electricity annually for the same scenarios. As expected with Estonian specific emission factors, electricity is dominating the CO_2 emissions.

Looking at operational costs, see Fig. 7, shows that electricity use causes larger share of costs for each scenario (from 54 to 64%). These values were obtained with Estonian tariffs. The price of electricity used was 0.009336 /kWh plus additional rate of 0.902 /(m^2 a) [45]. The price of heat used in the study was 0.07453 /kWh according to [46].

The effect on energy use and costs can be seen in Figs. 8 and 11, respectively. It can be seen that reference building uses 3.7 and 5.5 kWh/(m^2 a) more district heat and electricity, respectively. At the same time, minimum requirement building uses 27.1 and 17.6 kWh/(m^2 a) more district heat and electricity, respectively, than nearly zero energy building. Financial gain shown in Fig. 11 is clearly more moderate.

3.3. Water use

Water use reduction is considered as −40% consumption reduction in comparison with baseline situation. Treatment of potable water consumes 0.48 and treatment of wastewater 0.40 kWh/m^3 of electricity according to local water service provider Tallinna Vesi. Offices use 100 l/(m^2 a) of DHW according to [25]. It was assumed that DHW is 40% of total water use. Temperature difference in DHW

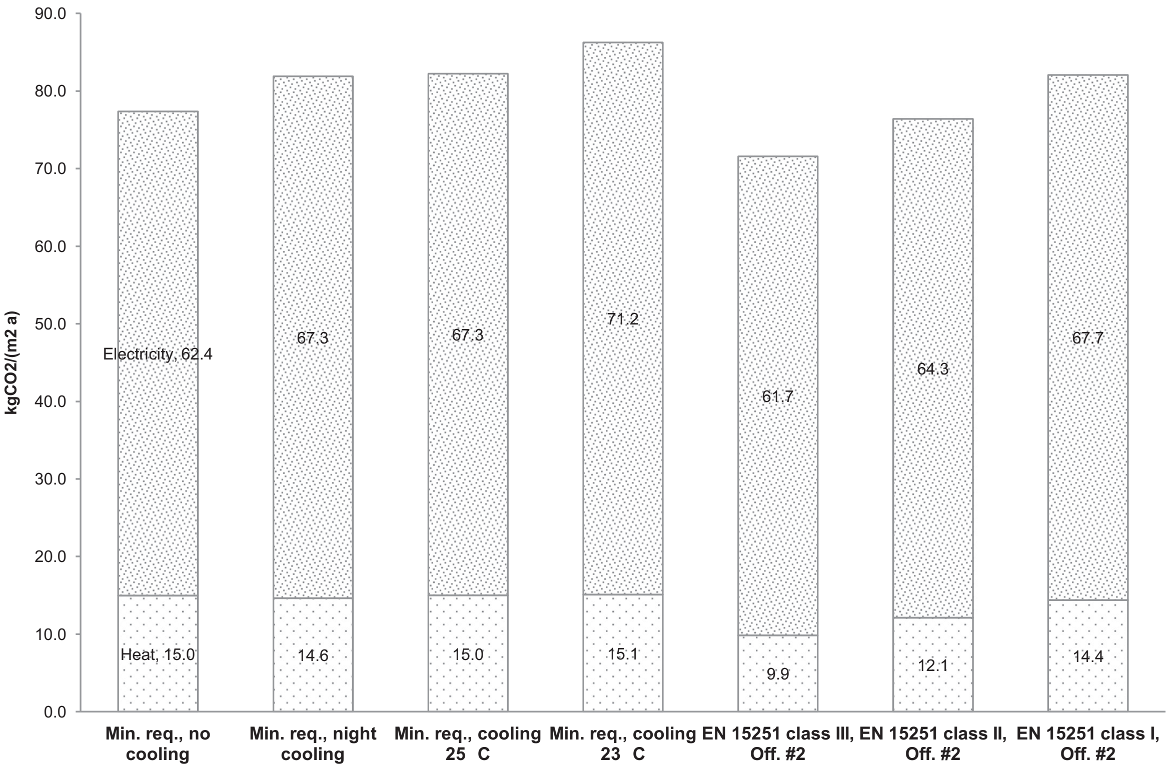

Fig. 6. CO_2 emissions from the delivered district heat and electricity for different indoor environment quality scenarios based on the delivered energy values shown in Fig. 5.

production was taken 50 °C [25]. The impact of reduced water use on delivered energy and CO_2 emissions can be seen in Figs. 8 and 9, respectively.

To put reduced water use in monetary values, the rates for heat and electricity given in Section 3.2 were used to multiply the difference in kWh and the results are shown in Fig. 11.

From all figures (Figs. 8–11) the low environmental and economic impact of reduced water use can be seen.

3.4. Materials impact

The impact of core construction materials was evaluated on CO_2 emissions and the costs derived from the projected CO_2 price per ton, which was considered as high as 40 /ton [43]. From Fig. 9 it can be seen that steel frame and structures resulted in slightly higher CO_2 emissions than concrete structures while timber is clearly the least detrimental. Fig. 11 shows the same pattern in monetary terms if one should be responsible for the costs associated with CO_2 emissions from building materials.

3.5. Vicinity to public transport

The effect to prefer public transportation in lieu of private vehicle, depends mostly on the availability of opportunity and the quality of service. In current study several assumptions were made to determine the environmental and economic impact. 35% of building users were assumed to be using public transportation in baseline scenario. Two average distances from home to work were considered: 8 and 12 km (one way). Fuel consumption was assumed to be 8 l/100 km using rounded average for year 2008 in [47]. CO_2 emissions from private vehicle were taken 245 g/km [48].

In improved scenario the number of building users that use public transportation was as optimistic as 70%. Reduction in CO_2 emissions from increased public transport use was determined for both distances. Results are shown in Fig. 9. Only 'Transport max' is shown on figure which represents reduction of CO_2 emissions if it would be Off.#2 (10 m^2/person) with 12 km distance to work. In such case the reduction would be 51.5 $kgCO_2/(m^2\,a)$ (−54% in comparison with baseline scenario). Minimum reduction of CO_2 emissions from larger share of public transport use would be 22.8 $kgCO_2/(m^2\,a)$ for Off.#1 (15 m^2/person) with 8 km distance (also −54% in comparison with baseline scenario).

The financial effect of decreased private vehicle use is shown in Fig. 11. Only the maximum possible gain is shown as 'Transport max' which corresponds to the scenario with a 51.5 $kgCO_2$ emissions reduction. The value in Fig. 11 was obtained multiplying the emissions reduction with the CO_2 price reported in Section 3.4.

The impact in kWh was determined using the following input values. The reduction of private vehicle distance covered for 'Transport max.' was 804 300 km (for Off.#2, home-to-work distance 12 km). Fuel consumption was 8 l/100 km. Gasoline density was taken 737 kg/m^3 and calorific value 44.4 MJ/kg [49]. The result is shown in Fig. 8. Thus, the total impact from reduced private vehicle use can be as high as 153 $kWh/(m^2\,a)$ in scenario with Off.#2 and one-way distance 12 km.

These results show highest impact from transportation on energy use (largest across all categories considered) as well as on

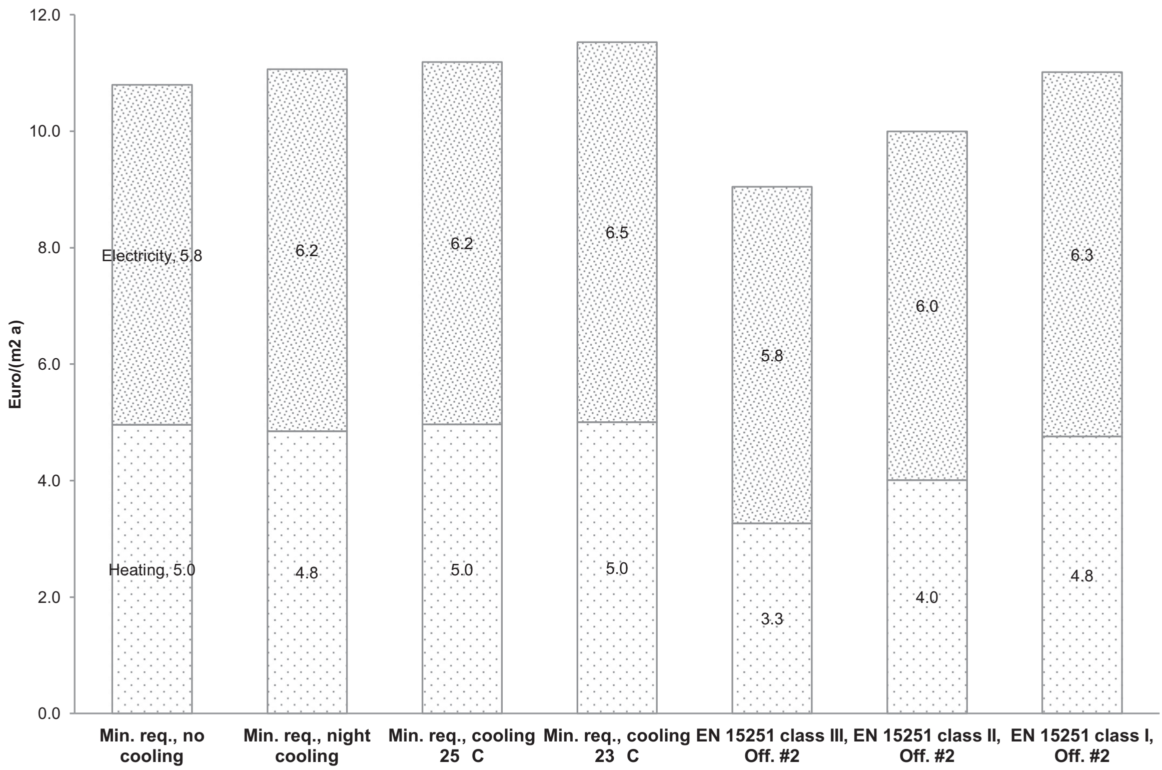

Fig. 7. Breakdown of operational costs on district heat and electricity for different indoor environment quality scenarios based on the end delivered energy use values shown in Fig. 5.

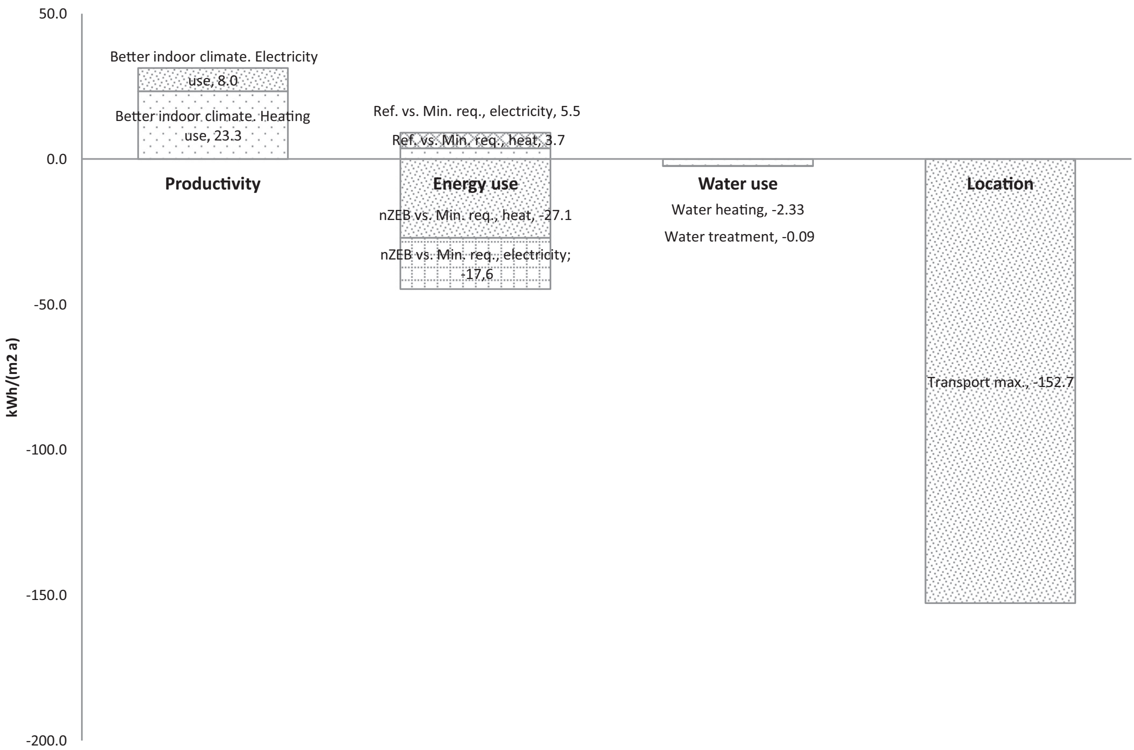

Fig. 8. The impact on energy use (in kWh) of the categories evaluated in this study. Better IEQ increases energy use, nZEB, water saving and public transport provide energy savings.

CO_2 emissions, while less significant when converted to monetary values.

3.6. Summarized results of five categories

Summarized impacts on delivered energy use can be seen in Fig. 8. Increased energy use in productivity category is due to effects of higher ventilation flow rates (class I) and increased cooling (cooling set point at 23 °C) in comparison with class III ventilation flow rates and cooling set point at 25 °C. Energy and water use categories show the possible reduction. Decreased energy use comes with better building constructions and lower water consumption. Location category shows the effect of reduced petrol use of cars. The same effect, for the lowest impact, for Off.#1 is −67.8 kWh/(m^2 a) for 8 km distance.

Energy use impacts are converted into CO_2 emissions in Fig. 9. These conversions are made based on CO_2 emissions from district heat and electricity production for energy uses in productivity, energy and water use categories. Materials category CO_2 emissions are following the procedure stated in Section 2.4 and location category emissions were taken according to Section 3.5.

The summarized economic impacts of five categories for office type #2 are shown in Fig. 11 (office type #1 showed similar pattern). Positive values on this figure represent lower costs or savings. Productivity category has the largest positive impact due to employees higher productivity (68.6 /(m^2 a)). To achieve this effect, more energy was used by building technical systems providing better indoor climate (about 3.3 /(m^2 a)). The difference between those two values show the positive effect of better indoor climate conditions. Similar results have been obtained earlier, e.g. in [50], which analyzed space efficiency in the view of indoor climate and productivity.

Energy and water use categories results show that better construction standard and lower water use rate will result in corresponding savings, calculated with energy price (CO_2 quota price not added).

Materials and transportation categories use similar approach to determine the economic effect: suggested CO_2 quota price is multiplied with difference in CO_2 emissions.

Absolute CO_2 values calculated as average of min and max values of each category are shown in Fig. 10. Figs. 9 and 10 should be considered together, first of which shows the range that can be affected by design and latter the average absolute value of emissions caused. Productivity category average emissions were determined from class III ventilation flow rate and cooling set point at 25 °C against class I ventilation flow rate and cooling set point at 23 °C resulting to an average of 78.9 kgCO_2/(m^2 a) due to the energy use to secure described set-up conditions. Energy use average is determined as reference and nZEB building energy use average. Only emissions caused by energy use category are shown. Water use average emissions are based on average value of baseline case in Estonia and a 40% reduced water use emissions. Concrete emissions rate is used for materials emissions rate as the most common construction material for office buildings. For steel and timber structures the emissions rates are 6.32 and 1.80 kgCO_2/(m^2 a), respectively. Average impact on emissions for location is determined as Off.#1 emissions in a case where the distance to work is 8 km and there are 70% public transport users against Off.#2 with 12 km and 35%, respectively.

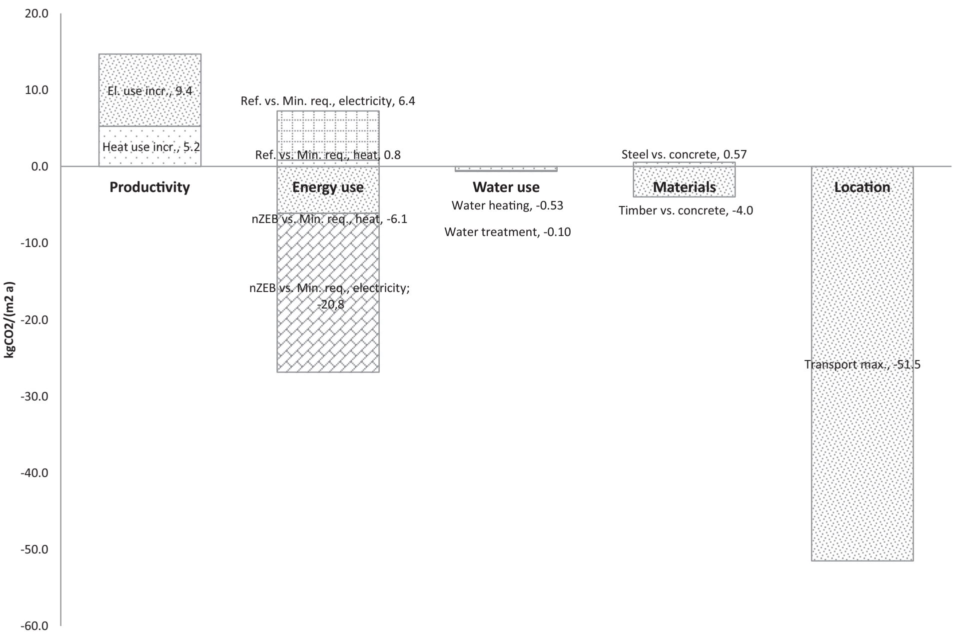

Fig. 9. The impact band in $kgCO_2/(m^2\ a)$ between the two ends of studied cases described in Sections 3.1–3.5 for all studied categories. Better IEQ increases CO_2 emissions, nZEB, water saving, wooden materials and use of public transport decrease CO_2 emissions.

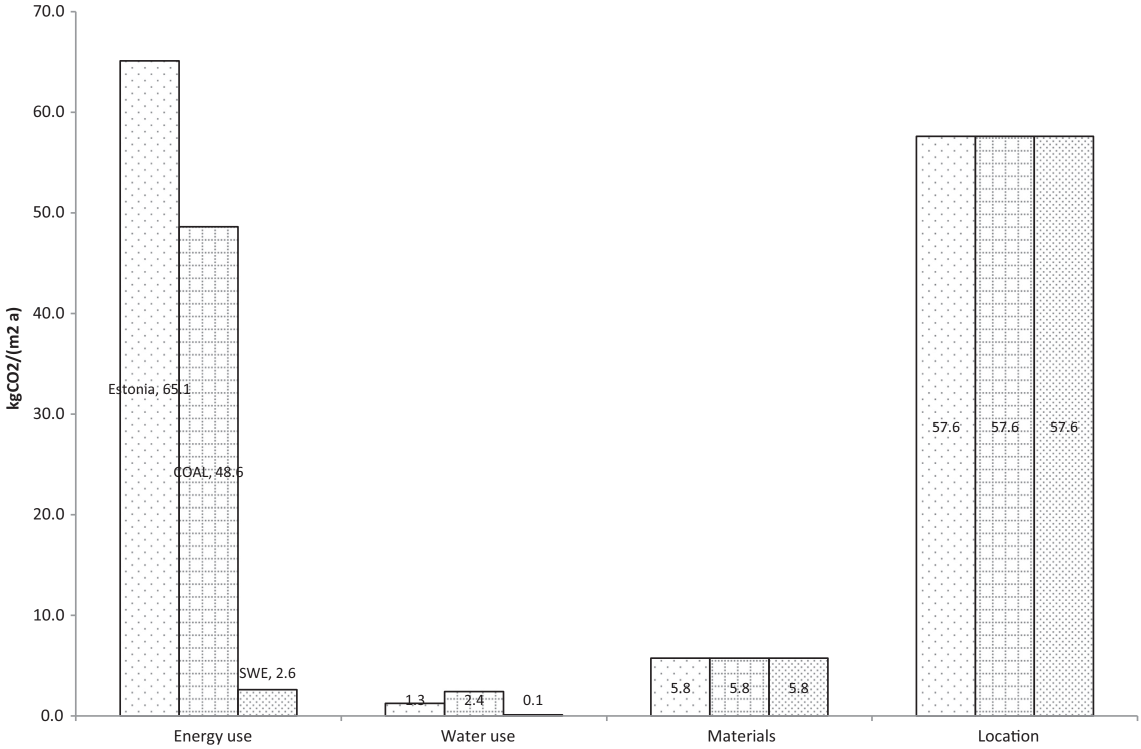

Fig. 10. Average absolute CO_2 emissions from the studied categories. Average is determined from minimum and maximum allowable values of each category. Materials emissions are according to emissions from concrete structures. The impact difference from Estonia energy sources is shown as coal and Sweden (Gävle) energy source emissions based on emissions rate in [20].

Table 2
Percentage share of impact of categories on environmental and economic indicators. All values are delta values, i.e. caused by the differences of available design options.

Category	kWh/(m^2 a)	$kgCO_2$/(m^2 a)	EUR/(m^2 a)
Productivity	31.3 (13%)	14.6 (14%)	65.3 (89.4%)
Energy	53.9 (22%)	34.1 (32%)	5.2 (7.1%)
Location	152.7 (64%)	51.5 (49%)	2.1 (2.9%)
Water	2.4 (1%)	0.6 (0.6%)	0.2 (0.3%)
Materials	na	4.6 (4.4%)	0.2 (0.3%)

Based on summarized results, a suggestion on weighting factors may be calculated as percentage share of each category. The impacts of different categories on economic and environmental indicators are summed up in Table 2. Productivity, energy and location showed major impacts across all indicator groups, whereas materials and water had insignificant shares.

Productivity values in Table 2 for kWh and CO_2 indicators have reversed logic compared to other values, because more energy or CO_2 is needed to provide better IEQ, i.e. the lower the value the more stressed the importance of productivity, meaning that with relatively low impact on the environment higher productivity levels are achievable. Some reservation toward the importance of location should be held, as the highest impact comes from kWh indicator which is determined according to assumptions made in Section 3.5. This is not what is generally considered when talking about transportation. Furthermore, the increased use of public transport and its impact on the environment is not taken into account in current study.

4. Discussion

Straightforward way to determine weighting factors of the main categories is to use /m^2 percentage shares of Table 2 resulting in the productivity impact of 89%. The importance of productivity is evident, but it is easy to argue that more weight than 11% should be put to environmental measures. In other words the productivity effects are not enough recognized in current codes and standards, and if stricter IEQ would be required this would correspondingly decrease the impact of productivity. To decrease the impact of productivity a comparison band is suggested between class II and class I ventilation flow rates according to [44], i.e. the reference level previously used of class III is changed to class II. This is well supported by good construction practice (in Estonia) as new nonresidential buildings are mostly built according to class II ventilation flow rates rather than class III. In such case the positive effect of class I ventilation flow rates would result in savings worth 19.3, 1.7 and 0.7 /(m^2 a) for ventilation flow rate-productivity, sick-leave and temperature conditions, respectively, for office type #2. Thus altogether 21.7 instead of 68.6 /(m^2 a) as show in Fig. 11. For office type #1 the respective values are 11.6, 2.8 and 0.6 (15.0 /(m^2 a) altogether).

These values with class II ventilation flow rate as a reference value will result in the following shares of categories: productivity ~70, energy ~20, location ~10 and materials and water both ~1%. This result assigns still too much weight to productivity. To increase the impact of other categories authors suggest to allow maximum 50% of weight for one category (productivity) and to weight the other categories between themselves for the rest of 50%.

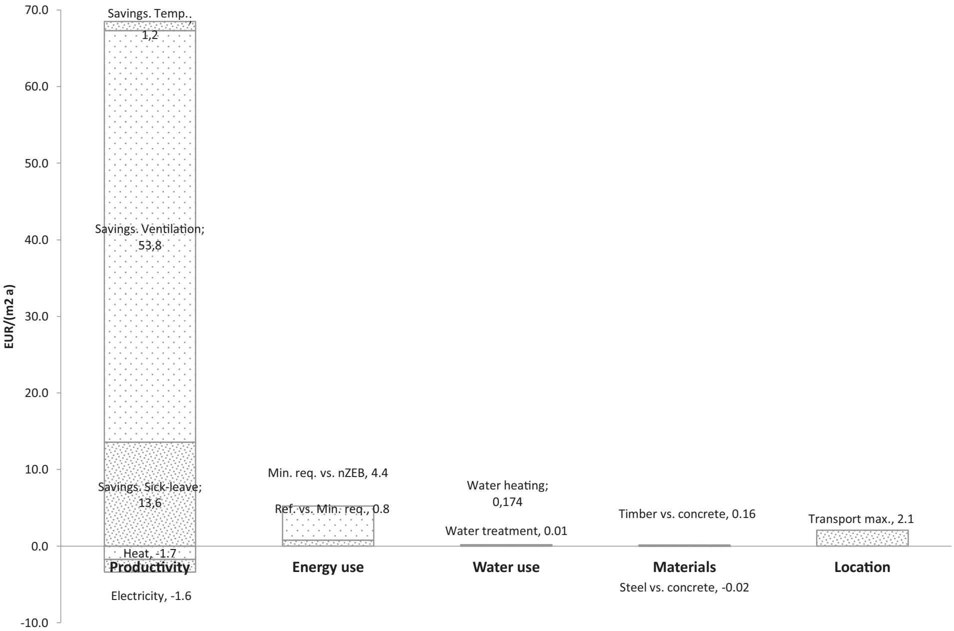

Fig. 11. The economic savings in /(m^2 a) between the two ends of the studied cases described in Sections 3.1–3.5 for all studied categories.

Table 3
The environmental and economic impact of four categories and their share on each impact factor.

Category	Abs. $kgCO_2/(m^2\ a)$	$kgCO_2/(m^2\ a)$	$EUR/(m^2\ a)$
Energy	65.1 (50.2%)	34.1 (37.6%)	5.2 (68.0%)
Location	57.6 (44.3%)	51.5 (56.7%)	2.1 (27.4%)
Water	1.3 (1.0%)	0.6 (0.7%)	0.18 (2.3%)
Materials	5.8 (4.5%)	4.6 (5.0%)	0.18 (2.3%)

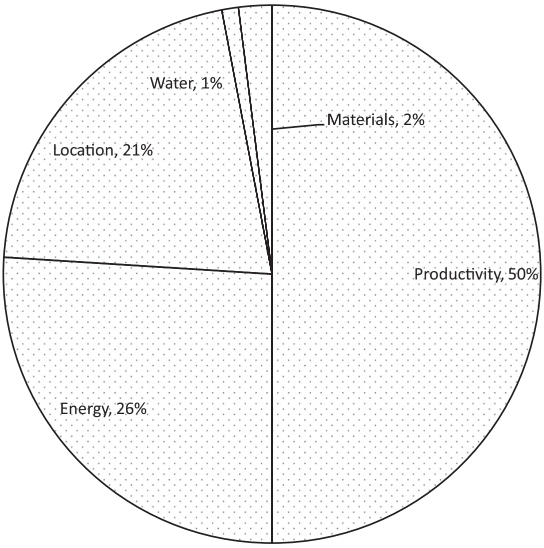

Fig. 12. Suggested weighting factors (for Estonia) for building sustainability assessment categories based on the results of current study.

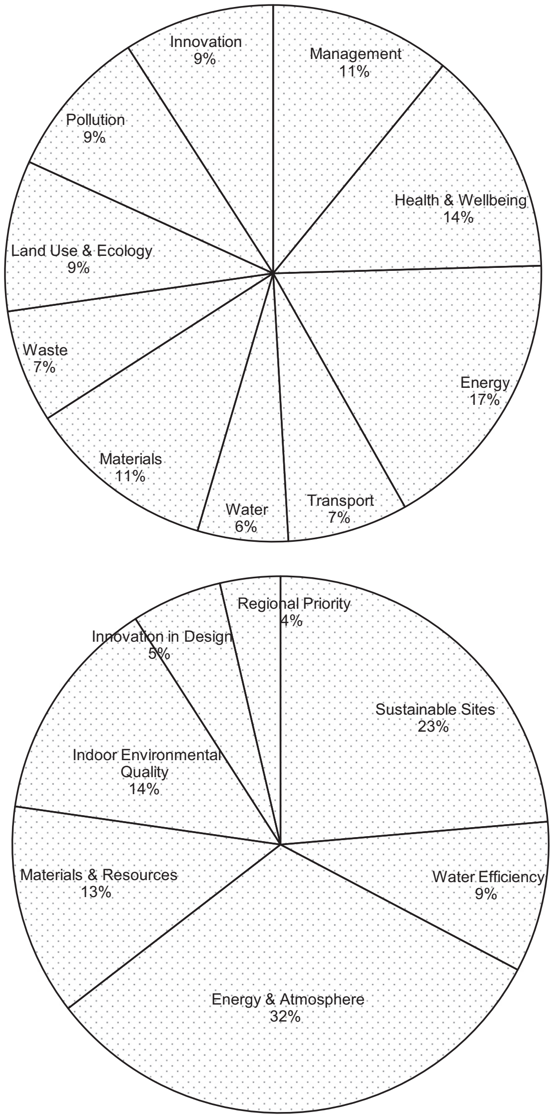

Fig. 13. BREEAM (left) and LEED (right) percentage shares of categories.

Authors identified that the reference ventilation flow rates must be about 1.7–1.8 $l/(s\,m^2)$ to reduce the economic impact of productivity to the level of 50% of total economic impact due to better indoor climate conditions for class I ventilation flow rates according to EN 15251 [44]. To determine the weights for the rest of 50%, the impacts of categories in absolute CO_2 emissions (from Fig. 10), CO_2 emissions band (between best and minimum levels) and in (both from Table 2) were summarized in Table 3.

Combining average percentage shares of categories across three impact groups shown in Table 3 and adding the additional proportion of 50% of productivity category will result in weightings shown in Fig. 12.

To answer to the question posed in introduction findings of current study support the idea of Estonian own sustainability assessment scheme as opposed to just taking over one of the well-known existing ones. When looking at weightings (as a percentage share of total number of credits available for categories) in Fig. 13 and comparing it with the outcome of current study (Fig. 12) clear distinctions can be seen.

Current study evaluates productivity (ventilation rate, temperature) as the most important category while it is second most important in LEED (indoor environmental quality) and in BREEAM (health and wellbeing). The importance of productivity cost savings was clearly emphasized in Table 3 in [51]. Keeping in mind Fig. 1 justifies the results of current study. The most important category in BREEAM and LEED (energy) is ranked 2nd in current study. Location (transport in BREEAM and sustainable sites in LEED) is 3rd highest weighted category based on current study. Water and materials have negligible impact in Estonian context according to the results of current study. This shows that suggestions of earlier studies [2,13] to include local context are highly relevant and at the same time the aspiration of universal scheme might not be realistic.

One thing that should be kept in mind is the high specific CO_2 emissions rate from electricity production in Estonia (see Section 2.2). This causes higher level of importance of categories connected with electricity use than would be in the case with very low specific CO_2 emissions for which Swedish CO_2 data was used. This is well illustrated in Fig. 10 where environmental impact ($kgCO_2/(m^2\ a)$) is presented using average absolute CO_2 emissions from four categories. The importance of energy source is evident when looking at energy use and water use categories for different energy mixes. Scenarios “Coal” and “SWE” are using inputs from

[20] with coal emissions rate of 503.5, district heating in Gävle of 21.6 and Swedish electricity mix of 33.4 gCO_2/kWh. Coal scenario uses coal emissions for both heat and electricity production, SWE uses Gävle district heating emissions for heating and Swedish electricity mix for electricity. It is clearly evident from Fig. 10 that energy category share on CO_2 emissions can be as high as 50% for the case of Estonia, while it constitutes only 4% of total emissions for Swedish energy sources. With Swedish energy sources the weighting factors of Fig. 12 will be (if calculated from absolute CO_2 values of Fig. 10): productivity 50%, location 43.5%, materials 4.4%, energy 2% and water 0.1%.

Methods used in current study can be considered as a step toward the ideas proposed in [2,13,17] which suggest that weighting factors should be based on scientific research.

5. Conclusions

This study aimed to determine the relevance of building sustainability assessment scheme main categories for Estonia. Five main categories with one quantitative indicator representing each category were evaluated in economic (/(m^2 a)) and environmental (kWh/(m^2 a) and CO_2/(m^2 a)) values based on available design options assessed for the reference office building situated in Tallinn. Minimum acceptable levels and best practice solutions helped to determine the band of possible variation within each category, summarized in Table 2. The main conclusions are:

- When all impacts were transferred to euros through energy and carbon prices and productivity costs, the productivity category received the highest weighting, 89 or 70% share of the total impact with indoor climate reference class III and class II, respectively. This indicates that the productivity effects are not enough recognized in current codes and standards, because stringent indoor climate requirements would decrease the impact of productivity. It was necessary to use the indoor climate reference level in between class I and class II to limit the share of productivity to 50%, which was used to assign meaningful weightings for other categories.
- The final weightings obtained with Estonian input data were 50% for productivity, 26% for energy, 21% for location, 2% for building materials and 1% for water efficiency.
- To demonstrate the importance of local input data, the weightings were recalculated with Swedish low emission energy sources. With Swedish energy, the productivity was still 50%, but energy was 2%, location 44%, materials 4% and water 0%.
- Estonian weighting factors conflict quite remarkably with the weights of the two of the most well-known building sustainability assessment schemes (see Fig. 13) showing the importance of local conditions. It can be also suspected that the weighting factors calculated with scientific methods differ from ones based on expert group assessment.
- Findings of this study show that the sustainability assessment must be done considering local conditions and global categories or weighting factors cannot be used, as some common categories were not at all meaningful in this study. However, the method used can be applied globally with relevant local input data and categories.

Acknowledgments

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PAPER IV

Seinre, E., Kurnitski, J., Voll, H. Building sustainability objective assessment in Estonian context and a comparative evaluation with LEED and BREEAM. – *Building and Environment*, 2014, 82, 110-120.

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Building sustainability objective assessment in Estonian context and a comparative evaluation with LEED and BREEAM

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ABSTRACT

Common practice building regulations are not that far reaching as are required by sustainable building assessment schemes. At the same time, regulations over a number of indicators can be onerous even without sustainable considerations. We compared indicators and their levels from Estonian regulations against LEED and BREEAM requirements. The differences and gaps between the best practice requirements were shown with the focus on the indoor climate, energy and transport categories of the sustainability assessment schemes. Five best practice buildings were positioned in LEED and BREEAM certification levels. The results show that the current regulations of indoor climate and energy indicators in Estonia form a solid base for high scores in these schemes. Indoor climate class I and class A energy performance achieved at least the second highest certification level in LEED and BREEAM. Thus, the gap between the current best practice and the highest score of a sustainable building scheme was not large. To make the comparison possible in a systematic way the Estonian building sustainability assessment scheme indicators were proposed and their compliance with LEED and BREEAM was quantified.

1. Introduction

The sustainable building is a further development from a simple building labeling – the energy performance based certificate – to more complete consideration of buildings and their impact on the environment. Many sustainability assessment schemes have been developed and new ones can be expected. The current paradigm considers sustainable building to stand on three pillars: an environmental, a social and an economic impact according to Cole [1] and Zuo and Zhao [2]. These three topics cover a wide range of indicators evaluated when assessing a building.

Haapio and Viitaniemi [3] report a move from green (reduced energy demand) to sustainable buildings. Although the aspiration for a standardized scheme would be preferable as stated by Lützkendorf and Lorenz [4], in reality this is not the case. Thus far the local context has proven to be important. Ding [5] also argues that one 'fit-for-all' scheme is hardly realistic as there are geographical, social, cultural and economic issues to consider. General frameworks, like 'green building challenge' (GBC) (Todd et al. [6]), can be used only as a reference for developing an assessment tool.

The outcome of GBC – the SB-Tool – has been used to develop several building sustainability assessment schemes. For example, Mateus and Braganca [7] introduced a scheme for residential buildings in Portugal that is based on the SB-Tool. Also El shenawy and Zmeureanu [8] used SB-Tool to develop their version of sustainability assessment scheme. Latter scheme is contrasting with the majority of the schemes by evaluating sustainability indicators in a single quantitative value – exergy; helping to overcome the subjective indicator weighting concern bound with other schemes.

Earlier studies by Lee and Burnett [9], Ali and Al Nsairat [10], Wallhagen et al. [11] and Alyami et al. [12] showed also the need to consider the local context. Depending on the country's geographical and economic situation various parameters prevailed as the most important.

The stakeholders of the building sector in Estonia feel concerned about the future: the awareness of the building sustainability is growing, while there has not been established a scheme. The need for an appropriate scheme, taking into account the Estonian context, is evident. The stakeholders agree that the scheme does not have to be new in the sense of categories included, but rather use the best of the existing schemes. The proposed scheme should be appropriately scoped: the number of indicators reasonably limited to keep the management of the scheme prudent. The need to keep a scheme at reasonable scope was also stated by Mateus and Braganca [7] and by

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0360-1323/

Ding [5]. Thus, the starting point was to analyze existing schemes and to identify the relevant categories for Estonia.

Building sustainability assessment schemes generally comprise a number of categories and several indicators. Generally, the indicators are determined based on the expert group opinion on their relevance on the impact of sustainability as stated by Cole [1] and by Todd et al. [6].

Current study is a next step following the study by Seinre et al. [13]. Latter allocated weights for building sustainability assessment scheme categories for Estonia. This was done by objectively assessing the effect of five categories with a representative indicator of each on the energy use, the environmental impact and the costs. The effect was evaluated as kWh, CO_2 emissions and Euros per m^2 annually, respectively. Results showed that the indoor climate, energy and transportation categories are important in Estonian context. Out of these three the productivity (indoor climate) prevailed, meaning that the most important is to ensure high indoor climate quality in office buildings. Second most important category was the energy use. Water and materials were less important due to the minor impact on the environment and the costs. The study also showed a significant difference of the weightings of the categories from the two most well-known schemes, LEED and BREEAM, emphasizing the importance of the local context.

In this study we compare five office buildings in three categories. The current best practice Estonian buildings were compared with indicators within the relevant categories of LEED and BREEAM. Differences between the indoor climate and the energy performance indicator levels of the Estonian regulations against LEED and BREEAM respective indicators were quantified. We identified potential certification levels for the buildings, helping the stakeholders of the construction sector to understand sustainability aspects of buildings. Based on a comparative evaluation of the indicators, we propose sustainable assessment scheme indicators for Estonia.

2. Material and methods

In this study we used five Estonian case-study buildings. Three indoor climate and energy indicator levels of the current regulations were compared against LEED and BREEAM respective indicator levels. Then LEED and BREEAM transport indicators were evaluated to determine relevant indicators for the Estonian context. The case study buildings and three certification levels of the proposed scheme were classified against LEED and BREEAM certification levels. This allowed to make a proposal for the Estonian building sustainability assessment scheme of which equivalence against LEED and BREEAM is known.

2.1. Case study buildings

An overview of the buildings used in the study is shown in Table 1. First four buildings are in Tallinn; three first ones in city center; building #4 is outside of the center and #5 is in Rakvere – 100 km East from Tallinn. Buildings #1 and #5 are at the design phase. Building #2 has been occupied since 2009. Building #3 construction ended at the beginning of 2014 and has since been occupied. Building #4 is at the construction phase and will be completed in 2014. With the exception of building #2, all buildings set energy efficiency as a target. Notably, buildings #3 and #4 aimed for LEED Gold and GreenBuilding certificate, respectively. While LEED is a well-known sustainable building certification label, the GreenBuilding is an initiative by European Commission [14] to reduce the energy demand of buildings.

The technical design phase project documentation of the buildings was used to compare the current practice with LEED and BREEAM requirements.

2.2. Indoor climate category indicators

An important category of the building sustainability assessment scheme is the indoor climate quality. This category has one of the largest shares of the total weighting of the categories in schemes. It is in LEED [15] and BREEAM [16] the third highest weighted category for new office buildings. In the following the most important indicators of LEED and BREEAM, directly affecting the wellbeing of the users, are identified. Only the indicators affecting the design of the building are covered. The indicators related to the use of the

Table 1
An overview of the buildings assessed.

Building no.	#1	#2	#3	#4	#5
Net area, m^2	22,462	8477	8691	2730	3689
Volume, m^3	105,578	28,800	40,802	12,378	14,434
Stories	2 + 14	1 + 10	1 + 6	4	1 + 3
U-values, W/(m2 K):					
Wall/roof	0.15/0.12	0.20/0.18	0.25/0.15	0.14/0.13	0.07/0.08
Floor/window	0.15/0.64	0.14/1.1, 1.4	0.34/0.5–0.6	0.13/1.1	0.14/0.80
Window g-value	0.16/0.26	0.41/0.56	0.12–0.24	<0.3	0.4
HVAC:					
Ventilation	MHRV	MHRV	MHRV	MHRV	MHRV
Cooling	Chiller	Chiller	Chiller	GSHP	Open well
Heating	District heating	Gas Boiler	District heating	GSHP	District heating
EPC class, kWh/(m^2 a)	"B", 125	"D", 177	"C", 156	"B", 111	"A", 98
Ventilation class	II	I	I	II	I
Office space ventilation flow rate, l/(s m^2)	2.0	2.0	1.5	1.5/1.7	2.0
Temperature limit, °C winter/summer	21/24	22/24	21/26	21/26	21/25
Velocity limit, m/s winter/summer	-/0.2	-/0.2	-/0.2	0.18/0.22	-/0.2
Illuminance on work plane, lux	500	500	500	500	500

MHRV stands for mechanical heat recovery ventilation, GSHP is ground source heat pump.

building and its' systems are omitted from the consideration, as these can be implemented at the later stages of the building life. For instance, the user training is carried out after the building completion and it is not essential for the design.

There are studies showing the impact of the indoor climate on the occupants' performance in a quantifiable manner. Seppänen [17] showed the effect of the ventilation flow rate on the productivity. Using a salary of an office worker the different design solutions (ventilation flow rate) impact on the productivity can be quantified in a monetary value.

LEED uses ASHRAE Standard 62.1 [18] to determine ventilation flow rates. ASHRAE standard sets minimum flow rate and does not define quality classes. The ventilation flow rate consists of two parts: 1) the flow rate per person and 2) the flow rate per floor area. If not specified by the design, the default occupant density by ASHRAE 62.1 [18] is 20 m^2/person. Ventilation flow rates in BREEAM are determined by EN 13779 [19] that sets the flow rate per person for three quality classes (I, II and III).

Estonia follows the guidance of the European standardization body: new standards are taken over as direct copies of the European standards or with minor adjustments to match local conditions. That is why EN 13779 is also used in Estonia. The European standard EN 15251 [20] is even more widely used. EN 15251 classifies flow rates into three classes depending on the materials emissions rate ('not low', 'low' or 'very low') and the flow rate per person. The materials emissions functions as the flow rate per floor area in ASHRAE 62.1 and flow rate per person is the same in both standards. There is a clear difference between the requirements of the ASHRAE 62.1 and EN 15251, with the latter being more onerous. Another difference lies in the default occupant density: for single offices it is 10 m^2/person according to EN 15251. The comparative results of the three standards are summed in Table 2.

Besides ventilation flow rate, also the thermal quality of indoor space is an important matter that affects person's perception of the working environment. Seppänen [21] quantified the effects of the room temperature on the office work productivity, concluding that temperature levels are important. The optimum temperature is around 22 °C with the productivity decreasing above and below this value. LEED refers to ASHRAE Standard 55 [22] for design values for the indoor temperatures. For BREEAM compliance, a class B temperature limits according to ISO 7730 [23] have to be met. Both ISO 7730 and EN 15251 are used in Estonia. New buildings in Estonia are constructed following the requirements of class II of EN 15251, which is equivalent to class B in ISO 7730. Table 3 shows a comparison between the standards and their operative temperature limits.

The rest of the indoor climate category indicators were grouped into two (within the boundaries of the current study): 1) the ones that have regulations in Estonia and 2) the ones without (including general design guidance's). In the first group there are indicators evaluating the air speed (draft rate), the internal lighting and sound level and the materials emissions.

LEED refers to ASHRAE 55 [22] for acceptable draft rate (DR) specifying acceptable percentage of people dissatisfied due draft.

Table 3
The operative temperature [°C] and draft rate (DR) [%] limits for an office. First number stands for the minimum temperature for the heating season, second, the maximum temperature for the summer. The draft rating limits the percentage of people dissatisfied due to air movement. ASHRAE 55 sets minimum requirements, others set quality classes.

Class	ASHRAE 55	ISO 7730	EN 15251/EVS 916 [24] (CR 1752 [25])
Operative temperature			
I		21/25.5	21/25.5
II		20/26	20/26
III	19/28	19/27	19/27
Draft rate (DR)			
I		<10	<15
II	<20	<20	<20
III		<30	<25

BREEAM specifies the limits in Table A.1 of ISO 7730 [23]. Estonian standard EVS 916 [20], that is a national annex to EN 15251 [20], is used to determine the air speed limits for the draft rate. Comparison of the requirements is shown in Table 3. Here we can see, that the 20% level of dissatisfied due to air movement is the same for all three standards. Class I and III do differ from each other for ISO 7730 and EVS 916, with latter being less onerous for class I, but more onerous for class III.

LEED does not set requirements for electrical lighting from the indoor quality point of view. That means that LEED sets no requirements to the electrical lighting illuminance levels, glare or color rendering, but does consider the daylighting illuminance level. For electrical lighting quality BREEAM refers to the European standard EN 12464-1 [26] that is also used in Estonia for the design of the internal electrical lighting.

The noise level from building services systems in an office environment is not regulated in LEED. BREEAM sets requirements in Table 15 in BREEAM Manual [16]. The current practice in Estonia is regulated by Table E.1 in EN 15251 [20]. Comparison of the latter two shows that EN 15251 sets more onerous requirements than BREEAM.

The materials emissions are regulated by Appendix C in EN 15251 [20], classifying buildings into three: 1) not low, 2) low and 3) very low materials emissions building. Depending on materials TVOC, formaldehyde, ammonia and cencerogenic substance emission levels and odor during their usage a material is classified as stated in Appendix C in EN 15251.

The second group of indicators (no or general guidance in Estonian) includes the following: daylight factor, view to outside, building flush-out and the user satisfaction. For the completeness of the study scope a short coverage of the probable impact is given in the following.

The daylight factor in office buildings in Estonia is regulated by a general guidance of meeting the average daylight factor of 2% by EVS 894 [27]. Not regulated by LEED, thus not affecting the LEED compliance. BREEAM, on the other hand, requires an average daylight factor of 2.1% for the Estonian latitude. Thus, meeting the Estonian guidance will be just short of the BREEAM requirement.

Table 2
Ventilation flow rates [l/(s person)] for a single occupancy office. Low and very low stand for materials emissions according to appendix C in EN 15251 (with low being the default level for new buildings). Default occupant density in ASHRAE 62.1 is 20 and in EN 15251 10 m^2/person. BREEAM (EN 13779) defines flow rates per occupant. EN 15251* shows flow rates per person when occupant density is 20 m^2/person. The first number in brackets shows the share of flow rate per person and the second per floor area.

Class	ASHREAE 62.1	EN 13779	EN 15251		EN 15251*	
			Low	Very low	Low	Very low
I		20	20 (10 + 10)	15 (10 + 5)	30 (10 + 20)	20 (10 + 10)
II		12.5	14 (7 + 7)	10.5 (7 + 3.5)	21 (7 + 14)	14 (7 + 7)
III	8.5 (2.5 + 6)	8	8 (4 + 4)	7 (4 + 3)	12 (4 + 8)	10 (4 + 6)

View to outside is regulated in Estonia by a general recommendation of 'guaranteeing the view from working rooms' according to EVS 894 [27]. Though the percentage of area required to meet the view criterion is not specified, the table with the recommended size of a window depending on the distance of a work space from the window is the same as specified in BREEAM [16]. Thus the view criterion is probably met even without a specific regulation.

The flush-out of a building is a specific criterion in LEED, while it is only a part of the indoor air quality (IAQ) plan in BREEAM. The aim is to take out the impurities emitted by the new internal finishing's when the emissions are the highest. Though, not used in the current construction practice, it is considered applicable. When made aware of the requirement the only concern is the cost of running ventilation systems before the occupancy to ventilate a building.

Both LEED and BREEAM award one credit for conducting a user survey. This means that after a certain amount of time (about 1–2 years) after occupation, a survey of the satisfaction amongst the building users is carried out. Based on the results, the building performance could be enhanced when it is not performing according to the preferences of the users. Estonian regulations do not require conducting a survey. The implementation of such would be a minor concern for LEED and BREEAM compliance.

2.3. Energy use category indicators

EU legislation is disseminating the energy efficiency of buildings with EPBD [28] for each member state to implement. Furthermore, the requirement to build nearly zero energy buildings (nZEB) is not that far future ahead as set in EPBD recast [29]. In this section we consider indicators from the energy category with direct impact on the energy use, excluding the environmental impact of refrigerants (not affecting energy use), external lighting (outside of the boundaries of current consideration defined as a building envelope), efficient office equipment (as a concern of the user). Besides the predicted energy use (simulations and renewable energy sources), the movement towards lower energy use is supported by installing energy use monitoring systems, by commissioning and by personnel training.

The main indicator in the current category is regulated in LEED by ASHRAE Standard 90.1 [30]. The energy cost performance of a designed building has to be improved in comparison with the baseline building. The improved energy performance is converted into decreased energy costs. The cost of electricity and heat in the current study is 0.1167 €/kWh (including stock price, tax, excise duty, network and renewable energy charge) + 525 €/annually (amperage charge) and 0.07285 €/kWh according to respective service providers Eesti Energia [31] and Tallinna Kute [32].

BREEAM refers to a national calculation methodology (NCM), which in Estonia means using Decree no. 68 [33] to define the reference building. BREEAM ranks the energy efficiency according to the energy performance ratio (EPR) allocating weightings for the energy demand reduction (23%), the systems and the distribution efficiency (38%) and the CO_2 emissions reduction (39%). CO_2 emissions in current study from district heating and electricity are 225 and 1180 g/kWh, respectively.

A new building in Estonia has to be in compliance with the minimum requirements for the energy performance of buildings according to Decree no. 68 [33]. This is the result of the implementation of the EPBD in Estonia. Furthermore, it is supplemented with a detailed methodology, Decree no. 63 [34], to calculate the energy performance. The energy performance certificate (EPC) takes into account the primary energy demand multiplied with the weighting factors (2.0 for the electricity, 0.9 for the district heat) of the energy sources to reflect the environmental impact. Depending on the simulated EPC (kWh/(m^2 a)) a new building can be ranked as a minimum requirement (class C) (EPC≤160), a low-energy (class B) (EPC≤130) or a nearly-zero (class A) (EPC≤100) building.

To position current minimum requirements for the energy efficiency of buildings according to Decree no. 68 [33] in LEED and BREEAM, a generic office floor model was created and simulated in IES-VE [35]. Fig. 1 shows the model layout. External wall is 370, partitions 100 mm thick. The aim was to determine the difference of the reference building performance between both schemes and the points achievable with three energy performance classes of the Estonian regulations. The top floor, as the worst case scenario, was simulated; reasonably considering that middle floors are using less energy than the upper floor. Furthermore, the top floor has besides external walls and windows also the roof construction for which requirements are set.

Input values used in simulations to determine the reference buildings are shown in Table 4. District heating with radiators was used (system efficiency of 0.97). Ventilation system was a mechanical supply and exhaust heat recovery ventilation (MHRV). A CAV system (with SFP = 1.7 kW/(m^3/s)) was used in the minimum requirement compliance simulation. A VAV system was used for LEED reference building. VAV was allowed to increase the flow rate up to 4 times the minimum requirement for the fresh air ('air flow rate' in Table 4). A central and a room based cooling were provided. Working hours were from 7 to 18 on weekdays (from 6 to 19 for the ventilation systems). No temperature set-back was simulated outside the working hours. The usage factor for the internal loads was 0.55. The Estonian test reference year meteorological data was used as a climate file to simulate hourly variations.

There are further indicators influencing the building energy use; Table 5 specifies the rest of them. While system efficiencies are included in the simulations to some extent, the rest of the

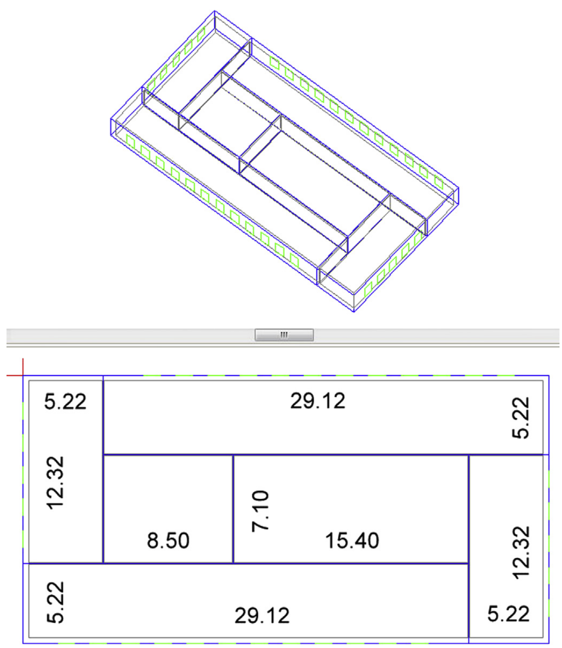

Fig. 1. A 3-D view and a plan of the simulated office floor. External dimensions of the zones in meters are shown. North is in the longitudinal direction. All zones are office spaces.

Table 4
Input data defining the reference building for the current practice and LEED. A CAV system is used in the Min. Requirement case, a VAV system in the LEED case.

	Min. requirement	LEED	Unit
U-values			
Wall	0.25	0.365	W/(m^2 K)
Roof	0.18	0.273	W/(m^2 K)
Window	1.1	1.99	W/(m^2 K)
Windows			
Dimensions	1.1 × 1.8	1.1 × 1.8	m
g-value	0.61	0.4	–
Frame ratio	15	15	%
Internal loads			
People	5	5	W/m^2
Equipment	12	12	W/m^2
Lighting	12	12	W/m^2
Air flow rate	2.0	0.43	l/(s m^2)
Heat recovery ratio	80	50	%
Heating setpoint	21	21	°C
Cooling setpoint	25	25	°C
Cooling COP	3.5	2.9	–

indicators specified in Table 5 are not. The efficiency of lifts is not covered by the calculation of EPC according to Decrees no. 68 [33] and no. 63 [34] while LEED and BREEAM regulate the efficiency of lifts. LEED sets limits to the lift lighting and ventilation efficiencies and the switching to a stand-by mode. BREEAM goes a step further by requesting to consider an energy efficient drive motor and a regenerative drive.

The energy monitoring helps to identify gaps between the predicted and the actual energy use. Thus, the more systems covered by the monitoring, the easier it is to check conformity. While the benefits are obvious, the economic impact has to be considered as well – the more detailed the monitoring, the more expensive it is. Table 5 shows that LEED regulates the monitoring with a general term to monitor ‘all energy flows’. BREEAM and Estonian regulations specify systems that are required to be monitored.

Also commissioning helps to identify discrepancies from the designed values. This is done after the system completion and at the initial stage of use. Including commissioning requirements in the project will ensure the appropriate performance of the systems and allows making corrections in the initial stages of the building use. Estonian standards do not specify the commissioning of the lighting and the renewable systems. While the lighting is clearly not covered by the Estonian regulations, the renewable systems can be covered within the HVAC commissioning. Other major energy using systems are included for commissioning for all three schemes.

Finally, to ensure a proper use of a building, the users and the maintenance personnel need a training of the installed building services. Besides that, also the user manuals are helping especially in the later stages of the building use, e.g. to search a solution to a specific concern. As Table 5 shows, all three schemes have the requirements for the user training and the user manuals.

2.4. Transport indicators

There are no regulations in Estonia for transport. The relevant indicators were identified based on the indicators of BREEAM and LEED. In both schemes the public transport accessibility is the most relevant, followed by the vicinity to amenities and the alternative means of transportation (bicycle access and parking, car sharing, electric recharging stations). The vicinity of public transport stops and the frequency of the rides determine the perceived accessibility of a building. A building in a remote area (far from bus stops or infrequent number of rides) is considered inconvenient to be accessed by the public transport and thus, considered only accessible with a private vehicle. Seinre et al. [13] showed the substantial effect of the public transport use on the environment. Effort made to decrease private vehicle use has a scientifically proven positive effect on the environment. Supporting alternative modes of transportation helps to perceive a building as an environmentally aware: offering for the users a choice of means of transport to access the building. Thus, a building design should incorporate at least bicycle parking and electric re-charging stations for electric vehicles.

A building in a developed area has another positive impact besides the accessibility – services. Generally there are various organizations meeting the needs of the locals. Starting from everyday services, e.g. restaurants and grocery shops, and ending with a dentist, a gym and a pharmacy. Vicinity to services also reduces the need for commuting by offering the opportunity to access a service by walking or by cycling.

Sustainable assessment of buildings generally includes limitations to the car parking capacity, setting the maximum number of spaces allowed. Limiting the parking capacity does not fulfill the intensions of reducing private vehicle use in Estonia. In situations with limited parking capacity, a building is considered inaccessible and clients prefer other locations with better parking conditions. Furthermore, even if the parking is limited (or with enough capacity, but for a fee) there is a pattern that nearby streets are filled with parked cars, hindering the traffic and ruining the aesthetics of the street. For the time being, limiting the parking capacity is not a solution for Estonia and it is not included in the proposed Estonian scheme.

3. Results

In this section the three performance levels of the current regulations in Estonia are evaluated against BREEAM and LEED indicators. Also LEED and BREEAM points scored while meeting specific Estonian requirements are shown. Secondly, considering

Table 5
A comparison of indicators covered under the energy use category, between LEED, BREEAM and the current practice.

Indicator	LEED	BREEAM	Estonian standards
Energy monitoring			
Systems included:	All energy flows	Heating, DHW, cooling, humidification, fans, lighting, small power, OMEC	Heating, ventilation, DHW, cooling, external lighting
System efficiencies	HVAC, lifts, lighting control (DF and time-switch)	HVAC, lifts, external lighting efficacy, lighting controls (DF or time-switch)	HVAC, external lighting controls (DF and time-switch)
Systems to commission	HVAC, lighting, daylighting controls, DHW, renewable energy systems	HVAC, lighting, water distribution, automatic controls, cold storage, refrigeration	HVAC, water, sewage, gas systems, refrigeration, fire suppression, automatics
Use and maintenance			
Training requirement	Yes	Yes	Yes
Manuals	Yes	Yes	Yes

OMEC stands for ’other major energy consuming items’, DF for ‘daylight factor’, DHW for ‘domestic hot water’.

Table 6
Specific requirement levels for various indoor climate category indicators.

Indicator	LEED	BREEAM	Estonian standards
Electrical lighting			
Work plane illuminance level, E	N/A	500 lx	500 lx
Unified glare index, UGR	N/A	≤19	≤19
Color rendering index, Ra	N/A	≥80	≥80
Noise			
Max. level	N/A	40–50 dB(A)	35–40 dB(A)
Daylight			
Minimum average illuminance	N/A	200 lx	N/A
Minimum illuminance	270 lx	60 lx	N/A
DF	N/A	2.1%	2–5%
View outdoors			
Floor area	90% of regularly occupied area	95% of NFA or all working positions	N/A
Building flush-out	4270 m^3/m^2	Suggested	N/A
Internal emissions			
TVOC	Varies (50 g/L default)	300 $\mu g/m^3$ (8 h)	0.2 mg/(m^2 h)
Formaldehyde	No resigns	100 $\mu g/m^3$ (30 min)	0.05 mg/(m^2 h)
Measurement requirement	No	Yes	No
Post occupancy evaluation	Yes	Yes	N/A

NFA stands for net floor area, N/A denotes 'not applicable'.

LEED and BREEAM transport category indicators and their suitability into Estonian context, a proposal for the Estonian transport category indicators is given. Following that, the case study buildings are classified in LEED and BREEAM certification scales using the results of the regulated indoor climate and energy indicators.

3.1. Comparison of the indoor climate indicators

In building sustainability assessment schemes several indicators under indoor climate quality are assessed. A detailed level comparative evaluation of the indoor climate indicators (excl. ventilation flow rate, temperatures and DR which are grouped in Table 7) is presented in Table 6. This helps to perceive the gap between the Estonian standards and the requirements set by the sustainable assessment schemes.

Table 6 clearly shows that even the two most well-known sustainability assessment schemes have variations. For instance, LEED [15] does not set any requirements for electrical lighting indicators or to DF, while BREEAM [16] does. At the same time, Estonian regulations follow the same standards as BREEAM for some indicators, while do not regulate some of the indicators at all. Thus, the comparison of the category including all the indicators is complicated. Using indicators regulated in Estonia, will give an overall impression of the extent of the differences.

In Table 7 the points scored in LEED and BREEAM with three quality classes according to the Estonian regulations are presented. Only indicators with specified values in the Estonian regulations are included. The ventilation flow rate is classified into three classes as introduced in Table 2. A class III ventilation flow rate is below the point thresholds of LEED and BREEAM. A class II is a standard practice level for new constructions in Estonia, scoring the point available for both schemes under the ventilation flow rate. A class I (best practice) flow rate is of equal value as standard practice and no extra points are allocated.

Thermal comfort includes a combined assessment of the operative temperature and the draft rate in LEED and BREEAM. As introduced in Sc. 2.2 LEED sets minimum requirements for compliance, while BREEAM requires accordance with at least class B in ISO 7730 [23]. Estonian standard thermal comfort class III building will not score the point in either scheme; class II and class I will meet the requirements of LEED and BREEAM, scoring 1 point (maximum) in both schemes. No reward is allocated due to higher quality of the class I thermal comfort.

Internal electrical lighting level is regulated by the same standard in BREEAM and in Estonia. The limits are shown in Table 6; accordance with them ensures the BREEAM point available. LEED [15] sets no requirements for internal electrical lighting levels.

The noise level of an office building is not regulated in LEED. Compliance with Estonian standards will ensure the BREEAM point, as BREEAM requirement is less onerous (as shown in Table 6).

The materials emissions indicator is not easily comparable between the Estonian regulation and the two schemes: schemes limit the materials emissions in different units that are not directly convertible. LEED uses g/L per product; BREEAM limits product testing standards and pre-occupancy measured concentrations in the indoor air. The current regulations limit emissions from the materials as overall. Thus, here a rough estimation is made considering 'very low' and 'low' emissions of EN 15251 [20] to score maximum and half of the points available, respectively.

Table 7
Indoor climate indicators regulated by the current practice and their relation with LEED and BREEAM points for the respective indicators. Temperature and DR combined award a point for the thermal comfort (not separately, as the rest).

Indicator	Estonian standards	LEED points	BREEAM points
Ventilation flow rate, low materials emission, [l/(s person)]	20.0 (I class)	1/1 (IEQc2)	1/1 (Hea 02)
	14.0 (II class)	1/1 (IEQc2)	1/1 (Hea 02)
	8.0 (III class)	0/1 (IEQc2)	0/1 (Hea 02)
Thermal comfort:			
1) Operative temperature limits, winter/summer, [°C]	21/25.5 (I class)	1/1 (IEQc7.1)	1/1 (Hea 03)
	20/26 (II class)	1/1 (IEQc7.1)	1/1 (Hea 03)
	19/27 (III class)	1/1 (IEQc7.1)	0/1 (Hea 03)
2) Draft rate, [%]	<15 (I class)	1/1 (IEQc7.1)	1/1 (Hea 03)
	<20 (II class)	1/1 (IEQc7.1)	1/1 (Hea 03)
	<25 (III class)	0/1 (IEQc7.1)	0/1 (Hea 03)
Internal lighting	EN 12464-1 (see Table 6)	N/A	1/1 (Hea 01)
Noise level, [dB(A)]	35–40 dB(A)	N/A	1/1 (Hea 05a)
Materials emissions, [mg/m^2 h]	very low (TVOC 0.1; formaldehyde 0.02)	4[a]/4 (IEQc4.1–4.4)	2[a]/2 (Hea 02)
	low (TVOC 0.2; formaldehyde 0.05)	2[a]/4 (IEQc4.1–4.4)	1[a]/2 (Hea 02)
	not-low	0/4 (IEQc4.1–4.4)	0/2 (Hea 02)

Abbreviations in brackets refer to a specific credit.
[a] denotes points that are awarded on an assumed compliance of the current practice.

The number of indicators assessed with the sustainable building schemes is larger than shown in Table 7. According to Table 7 the maximum score for both schemes is 6 points. Altogether 15 points under the indoor climate category are available for new office buildings in LEED and BREEAM. As the rest are not regulated by Estonian regulations, these are not included in Table 7.

3.2. Comparison of the energy indicators

As mentioned in Section 2.3 LEED and BREEAM use different energy calculation methods. In LEED a proposed building has to yield at least −12% energy costs in comparison with the reference building to earn a point. This has to be verified by a whole building energy simulation. Further reductions will produce an increasing number of points: up to 19 points with the energy costs reduced −48%. An EPR value has to be at least 0.06 to earn a BREEAM point for the energy efficiency indicator. With the EPR step of 0.06 up to 15 credits can be collected.

Table 8 presents the results of simulations for the generic office floor. The simulation results are for the top floor considering also the roof and simulating a floor with higher (worst) energy use than middle floors. Case #1 represents the results for LEED reference building (using values from Table 4). Case #2 just meets the minimum requirements set by Decree no. 68 [33] (Table 4). This is used as a reference building for BREEAM. In simulations for LEED we use the same flow rates and a VAV system as in case #1 changing constructions and the system efficiencies according to explanations. For instance, case #2 for LEED uses 'Min. Requirement' column in Table 4 (excluding air flow rate, which is the same as in case #1). Case #3 is just within 'low-energy' building class according to Decree no. 68 [33]. In this case the building envelope is improved: U-values for the external wall, roof and windows are 0.1, 0.08 and 0.6 W/(m^2 K), respectively. G-value for the windows is 0.26 and the internal lighting load is 8 W/m^2. A further improvement for the case #4 (comparing with case #3) is covering 80% of the annual heat demand with a ground-source heat pump (20% covered by district heat).

3.3. Identification of transport indicators

A comparison of LEED and BREEAM transport category indicators is shown in Table 9. Only three indicators (the public transport, the amenities and the alternative means of transport) of the category are included; to keep the category at a reasonable scope for the proposed Estonian scheme.

As a result of comparison of the indicators in Table 9 a suggestion for transport category for a scheme in Estonia was proposed. Table 10 illustrates the classification. First of all, a requirement for the frequency of the rides of public transport was proposed. This is an important matter: bus stop vicinity without a frequent connection is ineffective. Although LEED and BREEAM distinguish between different means of the public transport, all modes of the public transport are acceptable for the proposed Estonian scheme. Even though all modes are suitable, it generally means buses: train is not a common mode of transport within an Estonian city and trams and trolleys are only available in the capital. Requirement for the distance to a bus stop is derived from BREEAM (rounding it to a more stringent value). Only one bus stop requirement is set (being enough as long as there is a service provided). More important is the frequency of the provided public transport service; that is why class I requires more rides than class II (which itself requires more service lines than class III). More than one service line will ensure independence from a specific line that might cross with an obstacle

Table 8
The energy simulation results to position Decree no. 68 [33] classes against LEED and BREEAM energy efficiency points.

Situation	Primary energy	Current practice	LEED		BREEAM	
	Heat/Electricity [kWh/(m^2 a)]	Class/EPC	Reduced costs	Points	EPR	Points
Case#1	N/A (77.3/50.8)	N/A	0%[a]	N/A	N/A	N/A
Case#2	53.2/56.0 (42.3/51.7)	"C"/160[a]	19.6%	4/19	0[a]	0/15
Case#3	34.5/48.5 (23.1/44.0)	"B"/128	37.9%	13/19	0.8271	13/15
Case#4	6.9/50.8 (4.6/44.0)	"A"/100	43.3%	16/19	0.8753	14/15

Values in brackets are the simulation results for LEED air flow rates and VAV systems.
[a] denotes the minimum requirement level for the specific scheme.

Table 9
LEED and BREEAM transport category indicators comparison.

	LEED	BREEAM
Public transport		
Walking distance to rail station	≤804 m	≤1000 m
Walking distance to bus stop	≤402 m	≤650 m
# of stops required	≥1	not specified
# of service lines required	≥2	not specified
# of rides required	50 per day	Accessibility index (AI) ≥2
Vicinity to amenities		
Distance	≤804 m radius	≤500 m or ≤1000 m
# of possible amenities	22 (not conclusive)	10
Alternative modes of transport		
# of bicycle storage spaces	≥5% of all users	10% of building users (up to 500) + 7% for 501–1000 + 5% for over 1000 users
Shower facilities	≥0.5% of FTE occupants	1 per 10 bicycle storage space
Distance to bicycle parking	≤180 m	≤100 m
Parking capacity	Not exceeding minimum local zoning requirements	1 per 3–6 building users (depending on AI)
Recharging possibility	3% of parking capacity	≥3% of parking capacity

stands for 'a number'. FTE stands for 'full-time equivalent'.

Table 10
Estonian building sustainability assessment scheme proposed indicators and classes for the transportation category.

Class	Compliance requirement
Public transport	
I	≥1 stop ≤600 m from the main entrance of a building. ≥4 rides per hour during 8–19. ≥6 rides per hour during 8–9 and 17–18. ≥2 public transport lines.
II	≥1 stop ≤600 m from the main entrance of a building. ≥4 rides per hour during 8–19. ≥2 public transport lines.
III	≥1 stop ≤600 m from the main entrance of a building. ≥4 rides per hour during 8–19.
Vicinity to amenities	
I	All 3 services ≤500 m from the main entrance of a building.
II	All 3 services ≤1000 m from the main entrance of a building
III	Up to 2 services ≤1000 m from the main entrance of a building.
Alternative modes of transport	
I	Bicycle parking spaces >10% of building users, ≤50 m from the main entrance of a building. ≥1 shower/10 bicycle racks, changing facilities. ≥3% of parking capacity recharging stations.
II	Bicycle parking racks >10% of building users, ≤100 m from the main entrance of a building. ≥2 showers. ≥1 recharging station.
III	Bicycle parking racks >5% of building users.

hindering the provision of the service. For class I we suggest more frequent rides during rush hours, as the time when most of the employees travel to and from offices.

While LEED requires ten services to be at the vicinity, BREEAM credits can be met with only three services. Proposed scheme follows BREEAM approach: less services, but with more frequent need. For amenities only three options were included: 1) a dining place, 2) a grocery shop and 3) an ATM/bank. People generally eat at least three times per day; there is a daily need for groceries (or alternative meal) and for cash. Other services, e.g. a pharmacy, a gym, a public administration office etc. are not needed that frequently. The vicinity to services is defined as in BREEAM: allowing the walking distance from the main entrance of a building to be whether 500 or 1000 m.

Alternative modes of transport follow BREEAM logic. Firstly, the requirement for appropriate amount of bicycle parking spaces is proposed; secondly, the opportunity to recharge an electric vehicle. The percentage threshold set for class III can be expected to be met easily; while for class II and I BREEAM thresholds were used.

All three groups can be classified into 3 levels depending on the extent of the indicators met. A building can be considered a class I building only if all three transport indicators fulfill class I requirements.

3.4. Classification of buildings

The best practice Estonian buildings were assessed with sustainable building schemes. Fig. 2 shows the percentage of points achieved in the energy and the indoor climate category of five buildings. According to the project's documentation (partially presented in Table 1) and the assessment against the limits set in Tables 6 and 7: the thermal and the visual comfort, the ventilation flow rate and the acoustic performance were well met. The shortcomings from highest result were due to the VOC emissions indicator from Table 7, as the buildings specifying the acceptable materials, specified materials with 'low' emissions according to EN 15251 [20].

Energy efficiency points of the buildings were determined based on the energy efficiency class and the corresponding points from Table 8. Here the shortcomings in the results were caused by the low energy efficiency performance and the non-compliance with the energy monitoring requirements (the level of detail for the monitoring was less than required by LEED and BREEAM). The current practice commissioning, user training and user guide requirements are consistent with the requirements set by LEED and BREEAM.

For full compliance with the LEED indoor climate category also the daylight factor, lighting and heating controls, views, the occupant satisfaction questionnaire, the flush-out and the indoor climate quality during the construction work should be included. Respective additional requirements of BREEAM were the daylight factor and the glare control, views, the water quality, safe access to a building and natural hazards indicators.

LEED additional indicators in the energy category cover the following: purchased green power, on-site renewable energy and refrigerants. Latter two are covered by BREEAM as well. Further indicators in BREEAM include the efficiency of the external lighting, lifts/escalators and the office equipment.

LEED and BREEAM scores for the assessed buildings are shown in Fig. 3. The scores are calculated as an average value of the energy and indoor climate category results shown in Fig. 2. Achieved scores are projected to the entire scale of the respective schemes. We consider that the regulated indicators give a reasonable estimation of the final score. Thus, if all the indicators covered by sustainable assessment schemes would be regulated, a similar result can be achieved. Fig. 3 shows also top three certification levels. The buildings follow the same pattern in both schemes: higher energy performance class buildings score higher number of points. Building #2 is just below the third certification level; building #3 above the third level; and other three achieve second highest certification. Even more, building #5 is very close to the highest certification level in both schemes and even surpasses it in LEED.

4. Discussion

Where would buildings certified with the Estonian sustainability scheme classify in LEED and BREEAM? The proposed Estonian scheme, mostly based on the existing regulations and

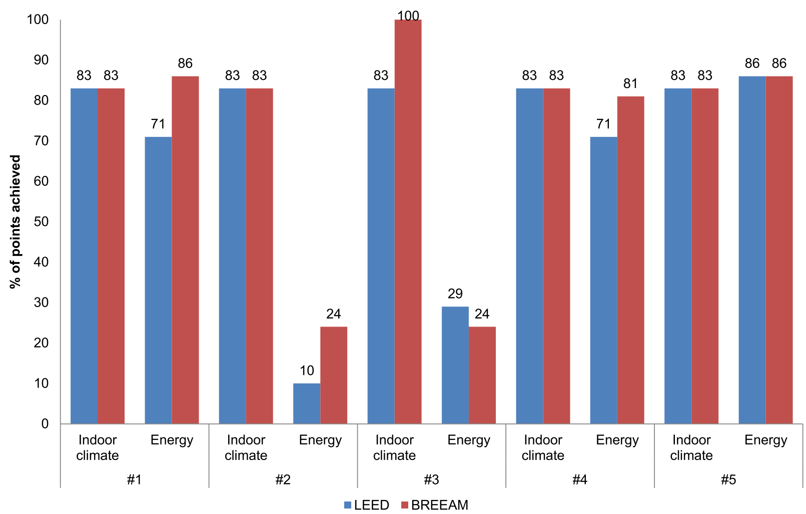

Fig. 2. LEED and BREEAM score shares for the analyzed buildings based on the indoor climate and the energy categories. Only indicators regulated in Estonia were assessed against LEED and BREEAM levels. Assessed indoor climate indicators are shown in Table 7, energy indicators in Tables 8 and 5 (excluding the 'system efficiencies').

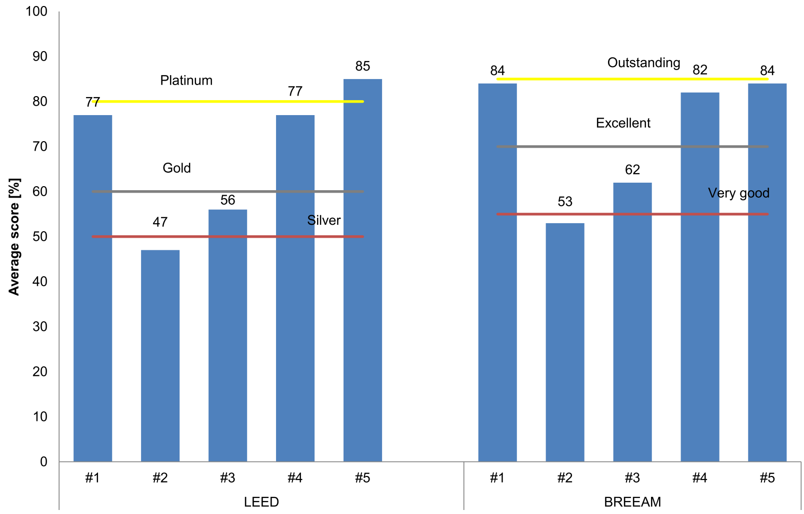

Fig. 3. LEED and BREEAM scores for the assessed buildings. Scores are calculated as an average of the two category scores from Fig. 2 for each building. Horizontal lines indicate top three certification levels of the schemes.

standards, assesses three categories. Inclusion of transportation category is well reasoned with the results of an earlier study by Seinre et al. [13]. We advise that a building can be qualified a class I building only if all 3 categories classify as class I. Thus, a class I sustainable building needs to have class I in indoor climate, has to obtain a class A energy certificate and meet all the class I requirements for transport. We conducted a comparative evaluation of the three classes of the Estonian scheme with LEED and BREEAM. This was done for the Estonian scheme categories and levels extended to the total of LEED and BREEAM scores.

Fig. 4 shows the results of the proposed Estonian scheme against LEED and BREEAM. Criteria levels for 3 classes are specified in Tables 5, 7, 8 and 10. Where classes in the tables are specified, the class level considered corresponds to the sustainability class of the Estonian scheme. When classes are not specified, all three sustainability classes have the same specification. The assessment considers only the indicators that are regulated by the Estonian scheme. A better match with BREEAM can be seen. Proposed transport category (see Table 10) is rather modest when comparing with the two schemes: class I scoring close to 60 and 67% of the maximum available in LEED and BREEAM, respectively.

Fig. 5 shows LEED and BREEAM scores of the classes for the proposed Estonian scheme. Indicators not specifically emphasized (also from the three considered categories) in the Estonian scheme

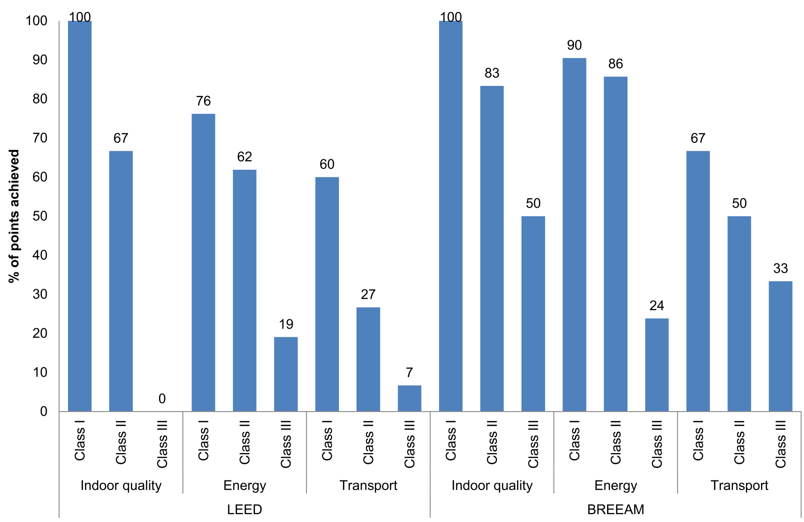

Fig. 4. Comparative evaluation results of the proposed Estonian building sustainability assessment scheme levels with LEED and BREEAM. The classes represent the classification of a building according to the proposed scheme. Only three categories forming the Estonian scheme are shown.

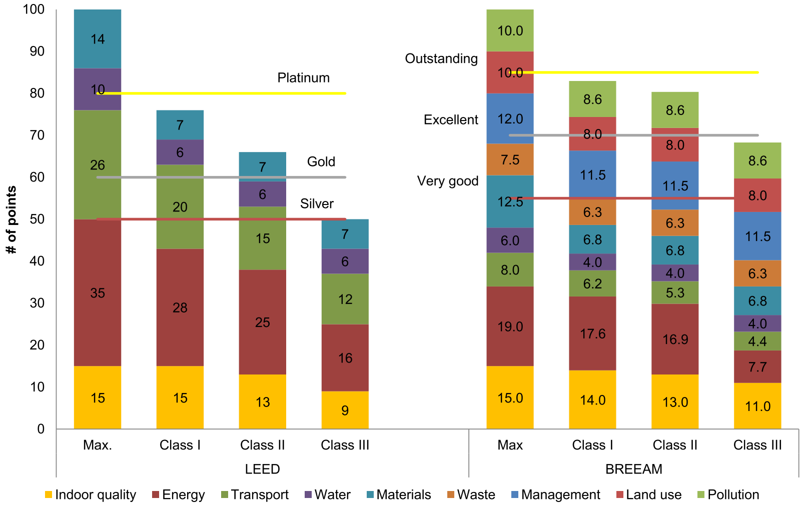

Fig. 5. Three sustainable class levels in LEED and BREEAM scale. All except bottom three categories have the same values in each class. Horizontal lines indicate top three certification levels of the respective schemes.

were evaluated individually according to the good construction practice following the local regulations: whether or not the intent of an indicator is covered with the good practice or not. As these are independent from the proposed scheme (not ranked into classes, thus not affecting sustainability class), the same values are used for all classes.

In order not to misinterpret the results in Fig. 5, it is important to emphasize that BREEAM certification levels are not easy to achieve. LEED energy, indoor climate and transport categories altogether constitute more than 70% of the total points available. Respective share in BREEAM is 42 percent. Not performing well in these categories makes it difficult to attain a good certification level in LEED, while it leaves more of a chance in BREEAM. Furthermore, the 'Sustainable Sites' category in LEED includes several indicators not specifically linked to transportation. At the same time, the latter is not covered by Estonian regulations. As a result, credits achieved with the transport indicators form a minority of the category points. Finally, the current common practice and the suggested transport indicators follow more closely BREEAM than LEED.

Considering that there are currently no further improvement opportunities for a class A energy certificate building, there can be seen only a couple of improvement opportunities to achieve the highest certification. In LEED, on-site renewable energy production needs to be increased to 13%. At the current estimation the percentage of renewable energy is considered to be 5% of the total energy costs. Another option would be improving transport access and the amount of amenities in the vicinity. For BREEAM both, the monitoring level of the energy consumption and the public transport connectivity needs to be improved to earn the highest certification.

5. Conclusions

The aim of the current study was to classify Estonian best practice buildings and regulations against sustainable building schemes. For that we assessed 5 recently built office buildings technical design project documentation against LEED and BREEAM. The categories considered included the energy and the indoor climate indicators.

Regulated indoor climate and energy indicators set high levels relative to LEED and BREEAM. High indoor climate scores were achieved across all buildings evaluated (Fig. 2). Furthermore, a class A energy performance building (#5) showed close to the highest possible result in the energy category as well. Thus, the current Estonian regulation highest levels form solid bases for sustainable buildings.

Evaluated high performance buildings achieved the second highest certification level in LEED and BREEAM. The class A energy performance building with high indoor climate quality achieved the highest certification level in LEED.

In conclusion, the second highest certification level was achieved with the regulated best practice values (nZEB and indoor climate category class I) in Estonia. Improvement possibilities for the indoor climate indicators are the emissions from materials. Specifying very low emissivity materials and measuring the concentrations after the construction, will help to earn maximum points in both schemes. In the energy category, LEED results can be improved by further improving energy performance beyond current EPC class A level (by increasing the renewable energy share). Maximum points in BREEAM energy category can be earned if the occupant level energy monitoring will be implemented (not just systems based) and a building will be net zero carbon.

A building sustainability assessment scheme for Estonia was proposed based on the indoor climate, energy and transport categories that were identified as relevant in a previous study by Seinre et al. [13]. Now we suggested specific indicators for these three categories: EPC classes A, B and C for the energy; indoor climate classes I, II and III for the indoor climate category; and the three classes according to Table 10 for the transport. It is advised that a building should be classified to a lowest level achieved in a single category.

The comparative evaluation revealed that a Class I and II buildings can achieve second highest certification levels in LEED and BREEAM. Class III achieved third highest level in both schemes. To achieve the highest certification in LEED a larger share of on-site renewable energy production is necessary or alternatively, an improved public transport access and the number of available amenities is needed. In BREEAM enhanced performance in the energy monitoring and the public transport access is required.

As an overall conclusion, the proposed scheme will mean only relatively small additional efforts in the current best practice design, as the most demanding indicators are already regulated. Latter allow achieving high scores in BREEAM and LEED.

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