THE INFLUENCE OF ENERGY BALANCE OF BUILDINGS ON THE SBTOOLCZ ASSESSMENT METHODOLOGY – STATISTICAL EVALUATION OF STUDENT PROJECTS

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Summary

This article deals with issue the energy performance of buildings in terms of comprehensive assessment of the building for the whole its life cycle. Methodology for building certification SBToolCZ has among other things, to promote the improvement of energy performance of buildings and mitigation of buildings on the environment throughout the life cycle of the building. And this methodology was used in the evaluation of student work set 173 residential buildings of various types. Energy performance building operation and energy intensity of production materials used in the methodology SBToolCZ manifested in four criteria on which this paper focuses. Results of the statistical evaluation of this set of buildings can be used to understand the basic context and the idea of impact of the current Czech residential buildings on the environment.

Keywords: energy, performance, sustainability, SBToolCZ

1 Introduction

Energy is one of the key commodities needed for satisfying the needs of the modern society. Due to the increasing trend of construction of buildings with lower energy requirements, needs of the energy efficiency of other phases of the life cycle are also increasing. Therefore, it is necessary to comprehensively assess the environmental impacts of the whole life cycle of buildings. Moreover, it is necessary to assess other energy-related impacts, such as global warming, acidification, eutrophication, etc. All these indicators are part of the national certification methodology SBToolCZ [1]. One of its goals is to promote the reduction of energy consumption of buildings and mitigate the buildings impacts on the environment throughout its whole life cycle.

The aim of this paper is to highlight the increasing importance of a complex approach to the evaluation of energy balance of buildings and present a set of results of student work in this area. These works can be used for outlining the fundamental aspects and concepts of current environmental impacts of residential buildings in the Czech Republic.

2 SBToolCZ for residential buildings

SBToolCZ methodology is based on a multi-criteria assessment. Criteria range varies according to the type of building and the stages of the life cycle which are taken into account during the assessment. This paper deals only with residential buildings, therefore, by the SBToolCZ abbreviation is meant only assessment scheme for family houses and apartment buildings [4]. Scheme for the design phase of residential buildings assesses 33 criteria in four groups. This paper discusses in detail only four of these criteria, in the group of Environmental criteria. A more detailed description of the methodology is available in [1], [4] or [5].

Note: At the beginning of 2013 will be available newly revised version of SBToolCZ for residential buildings, which will include separate methodologies for assessment of apartment buildings and family houses (in the 2010 version [4] these types of residential buildings are assessed with use of identical methodology).

Energy consumption of the production of used building materials and energy consumption of building's operation have impact on several criteria in the SBToolCZ methodology – these criteria are listed in Tab. 1.

Tab. 1 *The criteria that are directly influenced by the energy performance of a building in SBToolCZ methodology (in design and operation phases of the buildings lifecycle)*

Criterion	**Indicator**
E.01 Global Warming Potential (GWP)	Equivalent carbon dioxide emissions
E.02 Acidification Potential (AP)	Equivalent sulfur dioxide emissions
E.03 Eutrophication potential (EP)	Emissions of nitrogen oxides
E.09 Non-renewable primary energy consumption	MJ

Weight proportions of these monitored criteria on the overall assessment of the building are shown in Tab. 2.

Tab. 2 *Weight proportions of monitored criteria on the overall assessment [4]*

Criterion	**Weight**
E.01 Global Warming Potential (GWP)	7,5 %
E.02 Acidification Potential (AP)	3,0 %
E.03 Eutrophication potential (EP)	1,0 %
E.09 Non-renewable primary energy consumption	10,5 %

Tab. 2 shows that the energy performance of the buildings operation and chosen structural and material design of the building (which relates to the environmental impact of the material production phase and construction phase) can affect the criteria which have 22% weight in the overall assessment. Such a great impact on the overall level of building's quality has no other assessed parameter of the building.

Most of the monitored criteria evaluate two phases of the life cycle of the building – construction and operation of buildings (see Tab. 3). Durability of the structures is also taken into account during the calculations. Construction phase also includes the phase of production of building materials.

Tab. 3 *Structure of the assessment of monitored criteria*

Criterion	**Phase**	
	Construction	**Operation**
E.01 Global Warming Potential (GWP)	Assessed	Assessed
E.02 Acidification Potential (AP)	Assessed	Assessed
E.03 Eutrophication potential (EP)	Not assessed	Assessed
E.09 Non-renewable primary energy consumption	Assessed	Assessed

For the evaluation of these criteria it is necessary to have calculations of the energy balance of the building (Certificate of energy performance of the building) – a set of information on energy-carriers of partial energy consumption and bills of quantities of the used materials.

In the construction phase are assessed primary energy consumption and emissions created during production of needed materials, related to one year of service life of the material in the construction (methodology considers 50 years operation life of the building). For determination of the environmental properties of materials the SBToolCZ uses catalogue of building structures [6] and Envimat database [2].

In the operational phase are assessed primary energy consumption and emissions created by production of this energy, during the service life of the building. For the conversion of final energy consumption to primary energy in the criterion E.09 are used conversion factors taken from the linear balance models taken from GEMIS software (using Czech databases) [3]. For the assessment of equivalent emissions criteria E.01, E.02 and E.03 are used so called emission factors, which are also taken from the GEMIS software and database.

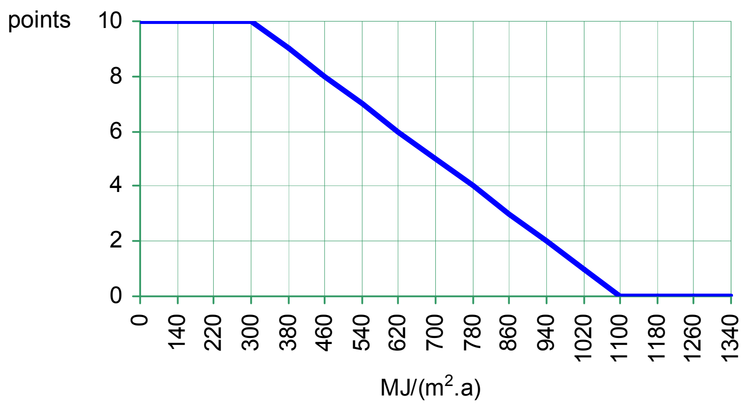

Fig. 1 *Normalization curve for criterion E.09 Non-renewable primary energy consumption [4]*

Where both phases (construction and operation) are assessed, the resulting values of both phases are summarized and subsequently recalculated to the unit of usable floor space – the methodology uses comparative assessment, thus it works with the functional unit of 1 m^2 of usable floor space. The goal of evaluation of each criterion is so called normalization. The normalization converts value of each criterion indicator through the normalization curve (Fig. 1), defined by criteria limits (Tab. 4), to points in a scale from 0 to 10 (10 = best result).

Tab. 4 *Criteria limits of monitored criteria [4] – the intermediate values are linearly interpolated.*

Criterion	**Unit**	**0 points**	**10 points**
E.01 Global Warming Potential (GWP)	kg $CO_{2,ekv}/(m^2.a)$	≥ 65	≤ 15
E.02 Acidification Potential (AP)	kg $SO_{2,ekv}/(m^2.a)$	≥ 0,120	≤ 0,040
E.03 Eutrophication potential (EP)	kg $NO_x/(m^2.a)$	≥ 0,100	≤ 0,015
E.09 Non-renewable primary energy consumption	$MJ/(m^2.a)$	≥ 1100	≤ 300

3 Description of the assessed group of buildings

As part of the study course "CH09 – Sustainable construction" at the Faculty of Civil Engineering of the Brno University of Technology and the subject of “Integrated building design” at the Faculty of Civil Engineering of the Czech Technical University in Prague each student evaluated his or her design for the construction of a residential building (family house or apartment building). The assessed set of buildings comprised mainly bachelor thesis’, the CTU students added also several realized projects. Some criteria had been simplified, because for the limited range of the study courses – primarily some criteria from groups “Social criteria” and “Economics and Management”. Despite the fact that these criteria are not more closely described in this paper, they have an impact on the final rating of the building. This influence is not particularly significant, given that environmental criteria, which represent 50 % of the results, were not simplified and in group Social criteria, only 2 to 3 of 11 criteria were simplified (weight of social criteria is 35 %).

Tab. 5 *Number of assessed works by year and place of origin*

Number of Assessed Buildings	**School Year**	**University**
71	2010/2011	CTU Prague
50	2011/2012	CTU Prague
52	2011/2012	Brno University of Technology

It should be noted that the results presented here are affected by some errors made by the authors of the assessment – the students, who were using with the methodology for the first time during their studies. However, the student works presented here were regularly consulted and most of the errors were corrected. In addition, the conclusions of this article are supported by other experiences – such as real building certification and case studies conducted so far by SBToolCZ development team at the Faculty of Civil Engineering, Czech Technical University in Prague.

4 Analysis of results from assessed buildings

Total number of 173 buildings was assessed. Of these, the highest ranking – Gold certificate – received only one building. There were 26 Silver and 115 Bronze certificates. 31 buildings received Basic certificate (See Fig. 2). Table 6 presents the scores in the monitored criteria for building which received Gold certificate and the mean (arithmetic average) and the median of all assessed works.

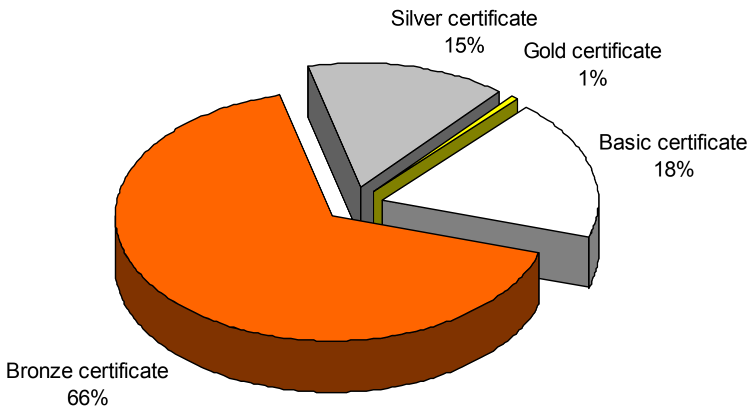

Fig. 2 *The frequency of individual certificates in the evaluated set of buildings*

Tab. 6 *Number of assessed works by year and place of origin*

Criterion	Gold certificate	Mean value	Median
E.01 Global Warming Potential (GWP)	9,2	3,4	3,0
E.02 Acidification Potential (AP)	9,1	3,5	3,9
E.03 Eutrophication potential (EP)	9,2	4,7	5
E.09 Non-renewable primary energy consumption	10	4,7	4,9

Interpretation of the results is shown in a number of charts that are showing the links between stages of buildings construction and buildings operation, in the context of the indicator values and the resulting certificate. In most figures, not all assessed buildings are shown for better clarity of the charts.

Presentation of results in charts, where the horizontal axis is the value of the monitored parameter in the construction phase (the tied values) and the vertical axis the value of the operational phase has a reason. Lower impact in the operation phase may require higher impact in the construction phase. E.g. passive house consumes more insulation than the standard house, which is certainly reflected in the increased energy consumption for the manufacture of used insulation. However, when taking into account the building as a whole (which is the case of presented assessments), it can be stated that the following do not always apply. Moreover, these types of charts can also serve for better understanding of the ratio between impacts during the construction phase and operation phase of the buildings life cycle. The current "standard" buildings can be seen that operation phase is predominant. For buildings that are energetically at a very low level the ratio between the operation phase and construction phase is balanced.

Firstly, Fig. 3 once more shows the principle of evaluation criteria E.09 Non--renewable primary energy consumption. The resulting value of the indicator is the sum of primary energy from the construction phase and operation phase. This figure is de facto a more detailed presentation of criteria limits specified in Fig. 1. Individual colored fields of the chart show how many points will a building get in its current state for its energy consumption. It could be seen that for the optimization of the design in order to achieve the highest ranking, it is still the best to reduce energy consumption during use of the building, rather than try to reduce energy consumption during the construction of the building.

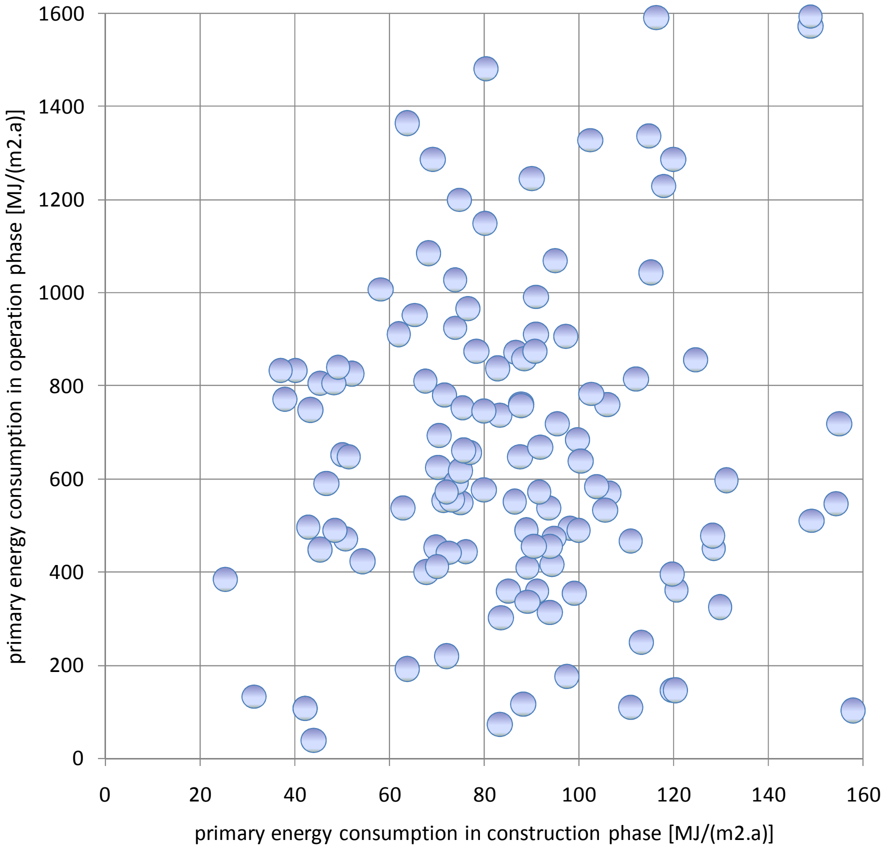

***Fig. 3** Energy consumption of assessed set of buildings according to E.09 criterion.*

When analyzing E.01 criteria that assess the equivalent amount of carbon dioxide emissions, we can see that most of the projects of residential buildings has specific annual production of carbon dioxide equivalent in the range between 20 to 70 kg/(m^2.a) at specific annual embodied production 2–13 kg $CO_{2,eq}$/(m^2.a). It can also be seen that, if the building has a specific annual carbon emissions greater than 50 kg $CO_{2,eq}$/(m^2.a), it couldn't got better than Bronze certificate. On the other hand, all buildings with Silver certificate are showing annual production below 40 kg $CO_{2,eq}$/(m^2.a).

For example house at coordinates [6,3; 13,2 kg $CO_{2,eq}$/(m^2.a)] in Fig. 4 is a family house in the energy class B, with a pellet boiler as a source of heat. These emission values correspond with gain of 9,1 points in the criterion E.01. Used solution is good for the assessment of the environmental criteria. Nevertheless the house got only the Bronze certificate of quality. This is due to failure to comply with other criteria (e.g. some social and economic criteria). This principle is valid in general and is also partial conclusion of this study. This statement can be shown on the building with a gold certificate. It was given to an apartment building, which got 9,2 points (only 0,1 more) in E.01 criterion. The apartment house has a main load bearing frame made of reinforced concrete walls, its energy performance corresponds with class A, and the energy need for heating and water boiling is covered mainly by a central boiler for natural gas. Photothermic and photovoltaic panels are also used for covering of a portion of energy needs of the building.

The median sample confirms the fact already stated above. We see that the production of $CO_{2,eq}$ during the operation of building is 5 to 6 times higher than during its construction. On the contrary, in the case of the building with the Gold certificate this ratio is much smaller – operation emissions are only 1,8 times higher than those originating in the construction phase.

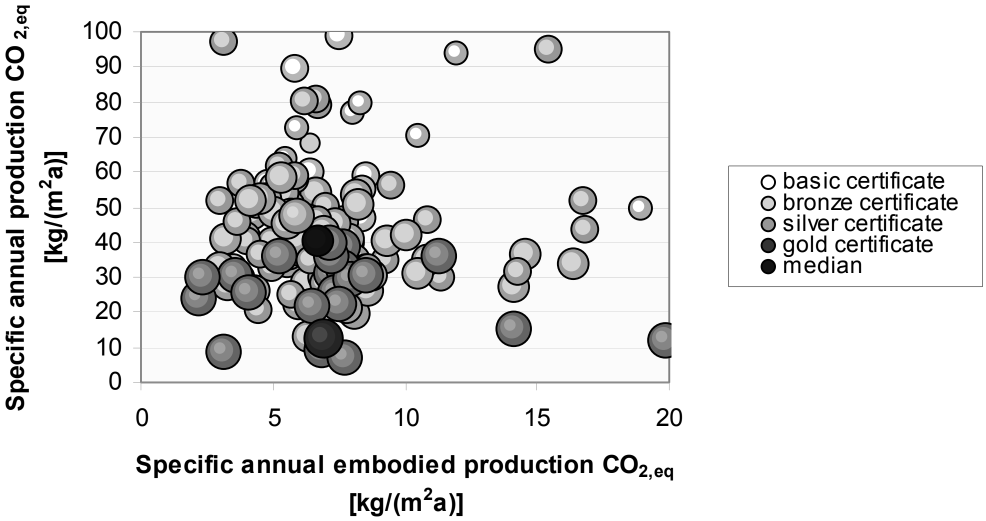

Fig. 4 *Values of $CO_{2,eq}$ emissions*

Interesting, but not surprising is fact, that buildings that received the Basic certificate showed small point gain in the E.01 criterion. Buildings with Bronze certificate achieved varying point gains, buildings with Silver certificates have received only higher point gains and Gold certificate means that the building has minimal environmental impact, thus the result of evaluation using this criterion are very well – see Fig. 5.

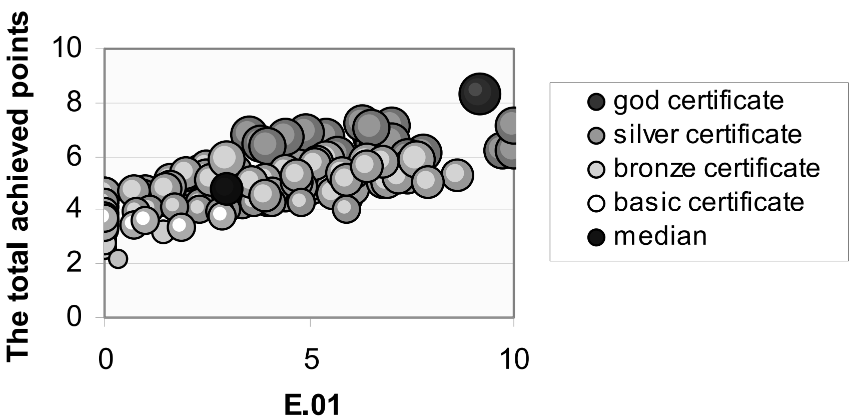

Fig. 5 *Dependence of the final certification on the results of criterion E.01 Global Warming Potential*

Application of the links and principles mentioned above on the E.02 and E.09 criteria is shown in Figure 6 and 7.

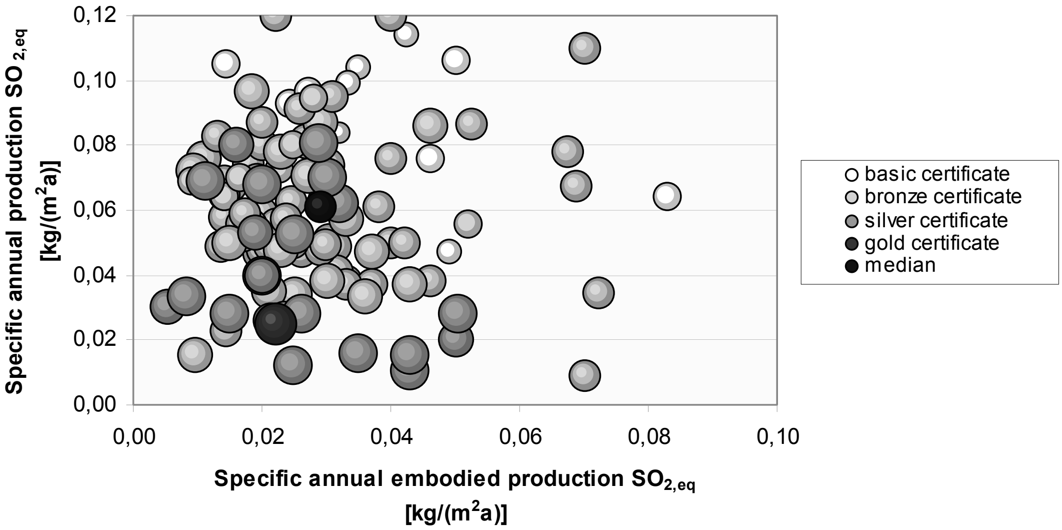

Fig. 6 *Values of $SO_{2,eq}$ production.*

For example, one of the best buildings in the environmental impact category of acidification – the building shown in Figure 6 on the coordinates [0,01; 0,015 kg $SO_{2,eq}/(m^2.a)$] – won Bronze certificate. This house has external walls made of expanded polystyrene permanent formwork and internal walls made of sand lime blocks. For heating and hot water boiling it uses natural gas boiler. The buildings energy performance category is A. In order to achieve higher certificate, the author of the design should focus on the criteria from "Economy and Management" group – for example improve the thermal stability of the structure and its spatial flexibility.

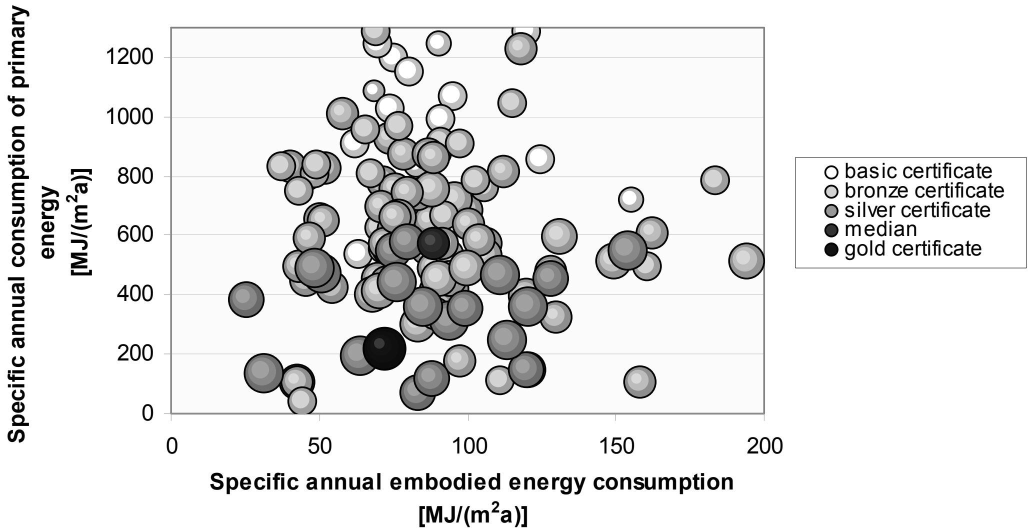

Fig. 7 *Dependence between specific annual consumption of primary energy and specific annual embodied energy consumption*

Based on Fig. 8 it can be assumed that larger buildings (measured by usable floor area) have lower variance in bound energy consumption, because of a similar material and design solutions that are most common in design of these buildings. In contrast, buildings with smaller floor area (detached family houses) have larger variety of energy consumption values, because they are built using much wider range of material and design. Generally, the higher bound energy values of family houses are caused by a known fact that smaller buildings consume more materials (for their construction) per unit of floor area than the larger buildings.

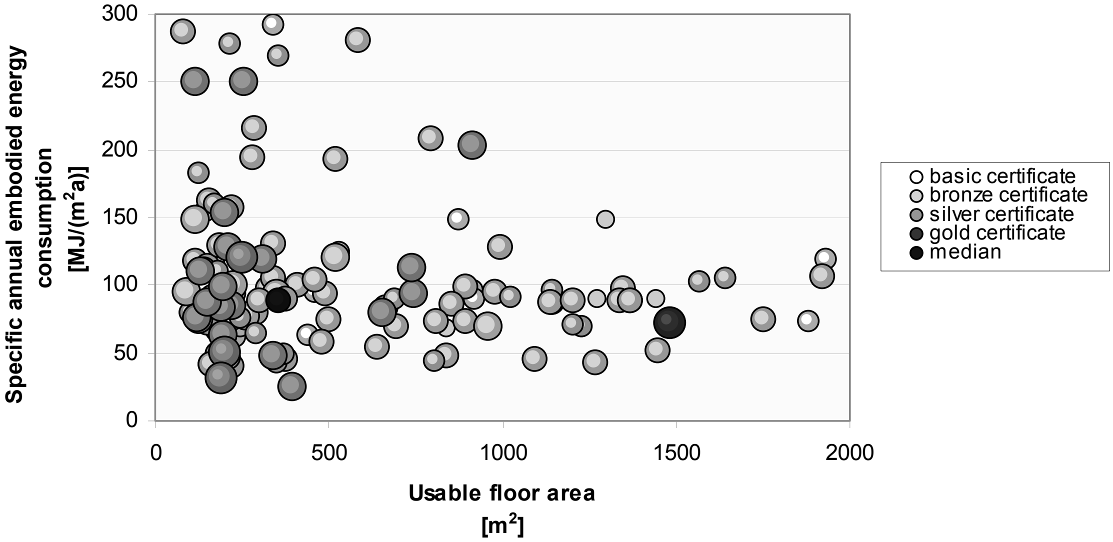

Fig. 8 *Dependence of specific annual embodied energy consumption on usable floor area*

An example: House at coordinates [190 m^2; 14 MJ/(m^2.a)] in Fig. 8 is designed as a two-story brick building from aerated-concrete blocks. It uses natural gas boiler for heating and hot water boiling. The house was evaluated to be in A category according to its energy performance. A building at coordinates [392 m^2; 25 MJ/(m^2.a)] is also a two-storey brick house. Ceramic tiles were chosen as main load bearing material. This house also uses natural gas as a source of energy for heating and water boiling. Like the previous house, its energy performance category is A. Reason why the first house got only Bronze certificate, while the second one got Silver certificate is, that the second house uses rainwater, solves treatment of waste created by the operation of the house, a greater proportion of recycled, recyclable and renewable materials was used for its construction, and shows higher thermal comfort during both summer and winter.

5 Conclusions

Several conclusions can be drawn from assessment of this set of 173 student work and generally the experience of other so far certified projects.

Students assessed not only their own designs, but also already built ones. This does not mean that the current construction is already of this high standard. The experience learned during the evaluation shows that standard project that can be defined as be in the energy performance category C which neither use renewable energy sources nor is built with accordance of principles of the sustainable construction, cannot get even Bronze certificate. However, just a few design changes cause that the building can receive Bronze certificate with little or none additional cost. Silver certificate is quiet difficult to obtain and to receive Gold certificate, the building has to fulfill most of the requirements SBToolCZ methodology. This difficulty level is confirmed by conducted study, where only one from the set of 173 assessed buildings got Gold certificate. At the time this paper was published first already built building aspires for the Gold certificate from the total of 19 already certified buildings – for actual information see the web SBToolCZ [1] – Issued certificates.

Important (partial) conclusion is that the energy consumption affects the overall score quiet much, but to achieve a high complex quality other criteria should be evenly matched too. This is precisely the difference that the current practice is still not fully aware of.

Criterion E.09 Non-renewable primary energy consumption, which has the greatest influence on the results of the assessment from all monitored criteria shows, that there is still a large percentage of the building designs that has significantly higher annual primary energy consumption value compared to the bound energy value. When analyzing the results of this criterion it was also confirmed that the higher specific annual consumption of primary energy the building has, the higher the production of $CO_{2,eq}$.

Based on this paper and in general the experience of already realized certifications we can say that for achieving a high level of complex quality (sustainability), we should not only reduce the energy performance of the building, but also use more renewable energy sources. An integral part of this effort must be also design of the building in accordance with other parameters of sustainable construction – for example, with the comfort of usage of the building, quality of the internal environment, thermal, acoustic and visual comfort, etc.

In other words, by addressing the energy consumption we should not forget that the building has to be practical, safe, and has to provide a healthy indoor environment and sufficient comfort for living.

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