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# A Holistic Holistic Approach to Building Performance: A Case Study of an Office Building in Sweden

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## **Abstract**

*With the increase of building certification systems worldwide, the evaluation of building performance has been standardized. These certifications provide some points for indoor air quality and thermal comfort in reference to standards like ASHRAE 55 and ISO 7730. However, the assessment is performed taking into account whether the design fulfils the requirements of the standards, in addition to measurements and a survey of the occupants' thermal comfort (Miljöbyggnad Gold). In fact, this only ensures that the requirements are met at the time of the inspection and little is known about the building's performance after the inspection.*

*In order to analyze the thermal comfort of occupants, a lot of studies have been done applying either the rational or adaptive approach. The rational approach is based on a heat balance model of the human body, while the adaptive approach concentrates on what happens outside controlled environments taking into account the humans' interaction with their surroundings.*

*This paper presents a new methodology to assess building performance in a holistic manner. The key parameters that are considered include the energy use, the occupants' thermal comfort, the environmental impact and the corresponding cost. An office building located in Stockholm, Sweden is used as a case study. The energy use is measured through installed energy meters, whereas the thermal comfort is assessed using the degree hours criteria, described in standard EN 15251 (2007).*

*The results allow a better understanding of the correlation between the amount of used energy (kWh per square meter) and the quality of the delivered service. Moreover a long term monitoring of the building leads to a better understanding of how the building should be operated and in some instances to energy savings without compromising on the quality.*

**Keywords – thermal comfort, energy consumption, building certifications**

## **1. Introduction**

In Sweden, in specific, and the European Union (EU), in general, the energy used in buildings amounts to almost 40 % of the total energy use [1, 2], most of which is utilized by heating, ventilation and air-conditioning (HVAC) systems. In order to reduce the impact of buildings on the

environment, the European Parliament issued a directive in 2010, [1], which states that by 2020 the total energy use and CO<sub>2</sub> emissions should be decreased by 20 %, in addition to increasing the share of energy used from renewable resources up to 20 %. Also, under this directive, all new buildings are to be nearly zero energy buildings. And although the directive affirms that the indoor environment should be taken into consideration while reducing the building energy use, an indication of the quality of the service provided to tenants is not a part of the proposed energy performance certification scheme, which leaves a margin of freedom for each state to add what they deem necessary. Most states including Austria, Cyprus, England, Flanders, France, Ireland, Portugal, and Wales incorporated both the energy use (kWh/m<sup>2</sup>.year) and the environmental impact (kg CO<sub>2</sub>/m<sup>2</sup>.year) [3], leaving behind any indication to the quality of the indoor environment. Besides these national certification schemes, there is a wide range of commercially available building assessment methods, among which are LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), and Miljöbyggnad. While the first two are internationally used, the third is only applied in Sweden. The users can apply these methods to almost the same types of projects, except in the case of miljöbyggnad, which does not include neighborhood development or renovation in its latest version. A more thorough discussion about each of the international certification systems is presented in [7], in which it is concluded that a user survey is needed to understand more the motives behind choosing a certain tool and how the corresponding results were used. Moreover, not only do LEED and BREEAM both address similar issues as shown in Table 1 [5,6,8,9], but also assessors evaluate each criteria based on a credit system with the total number of credits landing in one of the levels of each scheme; certified, silver, gold, and platinum in the case of LEED and acceptable, pass, good,

Table 1. General headlines of issues considered in LEED, BREEAM and Miljöbyggnad

<b>Certification scheme</b>	<b>Issues addressed</b>
LEED	location and transportation, sustainable sites, water efficiency, energy and atmosphere, material and resources, indoor environmental quality, innovation, and regional priority
BREEAM	energy, land use, innovation, land use, materials, management, pollution, transport, waste, and water
Miljöbyggnad	energy, required heating power, solar heat load, energy sources, acoustics, radon, ventilation, CO <sub>2</sub> , moisture prevention, thermal comfort in winter, thermal comfort in summer, day lighting, legionella, documentation of materials, materials

very good, excellent and outstanding in the case of BREEAM. On the other hand, Miljöbyggnad is a compliance-based assessment with different levels of constraints depending on the specific rating level. This is why knowing that a building is certified under Miljöbyggnad Bronze, for example, directly indicates that the indoor thermal comfort complies with category II of the standard EN15251 [10], while knowing that a building is certified under BREEAM Good or LEED Silver has no direct significance to the quality of the indoor environment.

The purpose of this paper is not to compare the available commercial building assessment tools, but rather to point out key parameters that have been either left out from existing certification systems or given minimum importance, in addition to identifying another problem in the building performance assessment approach that is evaluating the performance of buildings at a point in time or over a short period, which gives little information about the performance at other periods of time. Moreover, assessors should adopt a holistic approach while considering building performance, including not only energy use and emissions but also other parameters that reflect the quality of the service provided to the occupants. There is a great need for such an approach in order to convey specific information to the right people and to detect potential problems that might go unnoticed while considering a single variable approach. A holistic approach to refurbishment and to systems assessment is presented in [12] and [11], respectively. The former includes energy, cost and several indoor environment quality indicators, while the latter includes thermal comfort, energy and energy efficiency defined as the ratio of thermal energy to primary energy. In what follows, we explain a methodology for a holistic building performance, present results from a case study of an office building located in Sweden and discuss the implications of the use of such an approach.

## **2. Methods**

### **2.1. The Approach**

With buildings becoming smarter and more connected, building performance assessment is not something that has to be lumped up over annual values any more but higher resolutions are possible. For example, it can be done on a quarterly basis, which gives a good idea how the systems are performing in reference to the varying outdoor conditions. A bad building performance during winter for example might indicate problems in the heating systems while during summer signify faulty cooling systems. These faults are not possible to detect were the building performance assessment done once a year. By building performance here, we mean

operational building performance as opposed to that consisting of the construction aspect of the lifecycle of a building. We consider building performance as a multi-variable problem that includes cost of energy (SEK), net CO<sub>2</sub> emissions due to the energy use per square meter (g CO<sub>2</sub>/m<sup>2</sup>), energy intensity (kWh/m<sup>2</sup>), in addition to quality parameters. Quality parameters include thermal comfort, indoor CO<sub>2</sub> levels, acoustic satisfaction and day lighting, however incorporating those parameters depends on what sensors are available in each building. The unit of the energy intensity has been discussed in [4], where it was mentioned whether a unit of kWh/inhabitant might be more reasonable than kWh/m<sup>2</sup> in that it includes the social aspect of sustainability. However due to the huge difference in occupancy levels per square meter between building types and due to the challenges to accurately estimate the real occupancy in a building, we chose the one that is most often used, kWh/m<sup>2</sup>, in addition to a qualitative parameter, the building type. Another factor that might cause confusion while comparing buildings' energy use is the climate zone. For that adding a final qualitative parameter to the set of the previously mentioned parameters, the corresponding climate zone, becomes important. After that, any of the newly developed multivariate benchmarking techniques can be used to rank a pool of buildings [13,14,15].

## **2.2. The Building**

An office building located in Stockholm, Sweden was used as a case study and the building is to be certified under Miljöbyggnad Gold. The rented area is 39,930 m<sup>2</sup> and includes a garage (13 %), gym and changing rooms (3 %), technical rooms (9 %), storage rooms (2 %), restaurant and café (7 %), offices and meeting rooms (44 %), auditorium (1 %) and other (21 %), which includes common areas, corridors and atriums. The ventilation and cooling system consists of 6 air-handling units and 6 circulation units, with the heating coil fed by district heating and the cooling coil by cooling towers, chillers, bore holes, or free cooling depending on the outdoor conditions. The heating system includes water-based radiators installed along the building envelope.

The energy used for services, i.e. heating, cooling and domestic hot water (DHW) is shown in Fig. 1. It is noticed how the heating demand falls drastically after March and that the only significant change in DHW use is in July when most occupants are on vacation. The average thermal comfort in percentage of work hours is shown in Fig. 2, and as can be seen, on average, there are no hours in the unacceptable zone.

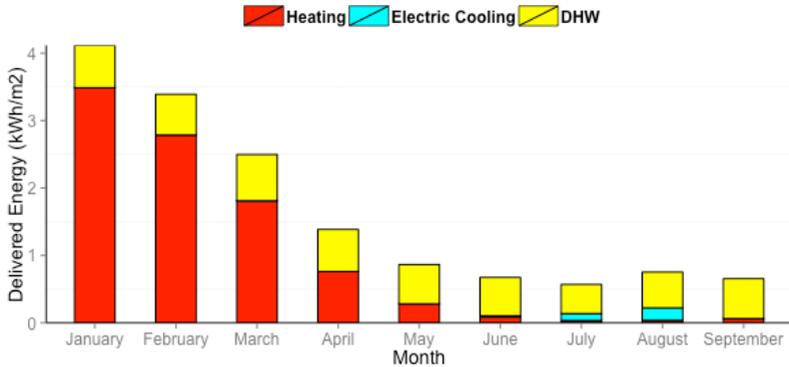


Fig. 1 Building energy profile for services throughout 2015



Fig. 2 Average thermal comfort as per standard EN 15251 [10]

The building is equipped with energy meters including DHW, district heating, and cooling. The cost is calculated using conversion factors for district heating and electricity presented in [2], however while applying this method, actual prices should be taken into account. Those prices might be constant according to long term contracts with district heating and electric power suppliers. As for the CO<sub>2</sub> emissions, conversion factors available from [16] and relevant to the Swedish context were used. Moreover, we chose thermal comfort as a quality indicator for this study due to the limitation in equipment and preinstalled sensors. The initial idea was to capture the actual mean vote (AMV) and percentage of people dissatisfied (PPD) via an automated questionnaire that pops up on the occupants' computers. However, security restrictions denied the possibility of pursuing this approach thus resorting to the degree-hours criteria for "long-term evaluation of the general thermal comfort conditions" described in Annex F of the standard EN 15251 [10]. Room temperature data stored by the building automation system were averaged throughout the building and an average performance was calculated. An example is presented in Fig. 3, where the upper limit for category I is breached and the area between the temperature profile and the upper limit is calculated resulting in a weighted unmet hours value.

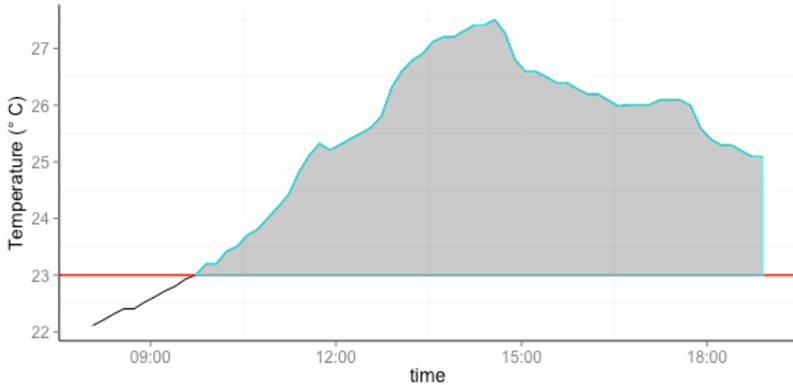


Fig. 3 Temperature profile with level I constraint for heating

### 3. Results and Discussion

The daily delivered energy for services is presented in Fig. 4 in addition to the unmet hours, according to category I constraints, used as the fill. Days with less than one hour that does not meet the requirements are colored yellow, those with five to six hours are colored in cyan, while those with eight to nine hours are colored red. It can be noticed that although the same amount of energy is used on the 6<sup>th</sup> and 10<sup>th</sup> of April, the number of unmet hours is much higher during the former. From a mathematical perspective, this can be explained by either higher deviations or longer periods; however, from a systems perspective, the outdoor temperature could have been much lower on the 6<sup>th</sup> or there was something wrong with operation on that particular day. Such information is highly useful to building operation managers in that it helps them identify possible problems that might arise under certain circumstances or detect reduced performance of the systems especially as buildings become older. Moreover, if this can be noticed while comparing a building with itself, how much difference will it make to compare buildings based on not only energy per square meter but also based on quality parameters.

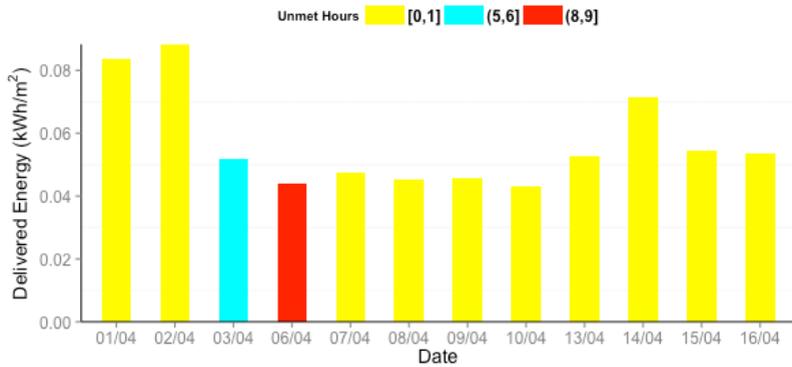


Fig. 4 Daily delivered energy for services masked by unmet hours (2015)

Fig. 5 and fig. 6 show the daily CO<sub>2</sub> emissions and cost due to energy use, respectively. Both parameters are directly proportional to the energy use and follow a similar trend. Such plots are important for decision makers who are interested in the financial aspect of running the building in addition to using the emissions plot promote a green image of the company renting the building.

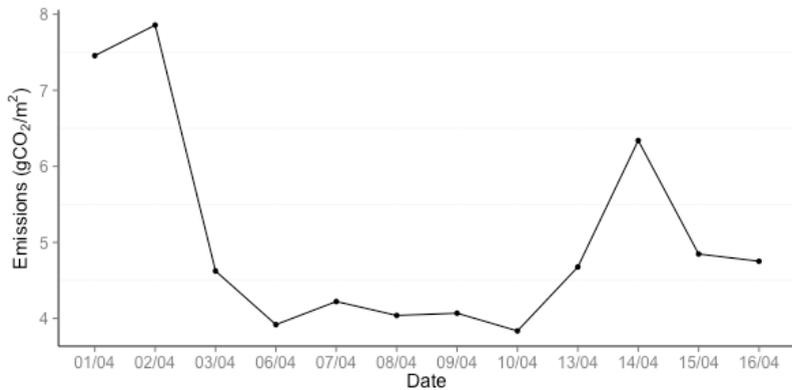


Fig. 5 Daily CO<sub>2</sub> emissions (2015)

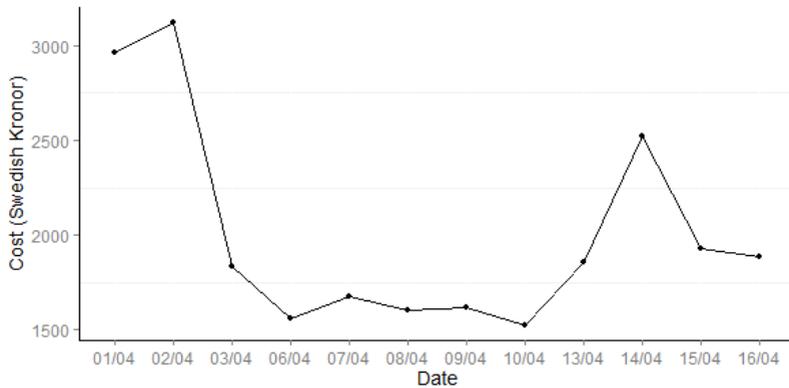


Fig. 6 Daily cost of delivered energy for systems (2015)

#### 4. Conclusion

There is still a lot to be done in the field of building performance assessment, especially in the field of performance certificates. National and international assessment schemes have to incorporate more parameters that represent the quality of service that is being provided to the occupants, after all they are the most valuable asset in the building since unhealthy conditions might lead to sickness and reduced productivity. Moreover, using a subjective assessment of key parameters like thermal comfort, acoustic satisfaction, indoor air quality, and day lighting could help capture the perceived quality of the indoor environment directly from the response of the users. This way there are no models that might result in discrepancies from building to building are used.

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