Energy Efficiency Assessment of Existing Buildings Based on Measurements of HVAC Systems Electric Energy Consumption: A Case Study

Gorazd Krese[1], Janez Mandelj, Matjaž Prek, Vincenc Butala

University of Ljubljana, Faculty of Mechanical Engineering
Aškerčeva 6, 1000 Ljubljana, Slovenia

[1]gorazd.krese@fs.uni-lj.si

Abstract
Since the building sector represents 30-40% of primary energy consumption in developed countries, reducing the energy consumption of buildings is crucial for achieving national and international goals for reducing both energy use and greenhouse gas (GHG) emissions. One of the most effective measures for reducing building energy consumption is the assessment of building energy efficiency.
In this paper energy efficiencies of five existing commercial buildings in Slovenia, of which three are office buildings and two are retail buildings, are assessed using various energy performance indicators (EPI) which are calculated based on measured electric energy consumption of installed heating, ventilation, and air conditioning (HVAC) systems. Rankings of buildings based on selected performance indicators are analyzed and compared with one another.

Keywords – energy performance indicators; air-conditioning energy efficiency; building energy efficiency; electric energy consumption

1. Introduction

Heating, ventilation, and air conditioning (HVAC) systems are the most energy intensive building services accounting for about 10–20% of final energy use in developed countries [1]. Furthermore, the energy consumption they account for is expected to rise at a higher rate than expected from the potential temperature rise due to an increasing demand for building services and comfort levels (i.e. expansion of conditioned area) along with the population growth.

Despite the above mentioned facts and rising energy prices, the interest in increasing energy efficiency in the field of air conditioning buildings is still quite limited, mostly due to a lack of information. This is especially troublesome since improvements in energy efficiency can be achieved, in addition to adopting more efficient technologies, with an increase in the knowledge among consumers as shown in [2]. For this reason various energy certification schemes for buildings arose. For instance, different possible approaches for certification are clarified in the European standard EN 15217 [3].

In this article a comparison of conventional energy performance indicators and new ones based on the rankings of five existing commercial buildings is presented.

2. Methods

Energy Performance Indicators

Since energy consumption due to air conditioning is the most often incorrectly used energy end-use in buildings [4], we focused only on performance indicators for highlighting excessive air-conditioning electric power consumption.

Two widely used demand indicators were selected for this study, namely HVAC system energy consumption per unit of conditioned area EI_a and per unit of conditioned volume EI_v:

$$EI_a = \frac{E_{AC}}{A_c \cdot t} \text{ [W/m}^2\text{]}, \qquad (1)$$

$$EI_v = \frac{E_{AC}}{V_c \cdot t} \text{ [W/m}^3\text{]}. \qquad (2)$$

where E_{AC} is the HVAC system electric energy consumption due to air-conditioning in the observed time period in watt-hours, t is the HVAC system runtime in the considered period in hours, A_c is the floor area conditioned in square meters and V_c is the volume served by the HVAC system in cubic meters. These two indices were chosen because they are unambiguous, can be easily converted into energy consumption and, most importantly, are measurable on-site.

In order to identify buildings with poor architectural design, we used an index called the coefficient of temperature-sensitivity K_θ (3) which we defined in another work [5] to quantify the temperature-sensitivity of air conditioning systems energy consumption.

$$K_\theta = \frac{\Delta E_C / V_C}{\Delta \theta} \text{ [Wh/m}^3\text{K]} \qquad (3)$$

where ΔE_c is the change in electric energy consumption of the HVAC system's cold generator/s over the observed time period in watt-hours, $\Delta\theta$ is outdoor dry-bulb temperature change over the same period in kelvins and V_c is the conditioned volume of the building in cubic meters.

It must be stressed that this indicator must be determined at certain operating conditions, i.e. when cooling load is removed solely by the use of the HVAC system's cold generator/s without the use of any cold storage system/unit, in order to correctly assess the quality of the building design in terms of energy efficient air-conditioning. For additional information regarding the determination of this coefficient, the reader is referred to the previously mentioned work.

Because retail and office buildings are classified among the most energy intensive buildings, e.g. annual energy use in European office buildings varies from 100 to 1000 kilowatt-hour per square meter of conditioned area [6], we defined a new indicator called the peak load impact factor (f_{PL}) to highlight the use of cold storage systems in these typologies:

$$f_{PL} = \frac{E_{AC}/A_c}{E_{el}/A_f} \; [/]. \tag{4}$$

where E_{el} is the building total electricity consumption for the considered time interval in kilowatt-hours, A_f is the building's floor area in square meters, E_{AC} is the HVAC system electric energy consumption due to air-conditioning in kilowatt-hours for the same time period as E_{el} and A_c is the conditioned area in square meters: If the floor and conditioned area coincide, (4) becomes:

$$f_{PL} = \frac{E_{AC}}{E_{el}} \; [/]. \tag{5}$$

It should be emphasized that buildings equipped with cold storage are not generally more energy efficient than buildings without thermal storage systems since they consume approximately the same amount of final energy (depending on the efficiency of the cold storage system and the heat rejection conditions during the cold storage process). However, buildings with thermal storage systems have a lower carbon footprint because the load is shifted to off-peak periods (i.e. when electricity is cheaper).

Case Study

A sample of five tertiary sector buildings, for which the HVAC energy consumption data was collected within the IEE project ISERVcmb, was selected as a case study. The HVAC systems of the buildings are comparable because they provide the same thermal comfort service, i.e. cooling and ventilation while humidity is allowed to free float, and are all served by one or multiple vapor-compression liquid chillers. Ventilation in all buildings is provided by single duct (SD) constant air volume (CAV) air handling units which also remove the cooling load. In case of buildings A, C, D and E the cooling load is removed in combination with fan coil units (FCUs). Additional information about the selected buildings and the installed HVAC systems is listed in Table 1.

Table 1. Building and HVAC system description

Building	A	B	C	D	E
Location	Ljubljana, Slovenia				
Building type	retail	retail	office	office	office
Area conditioned [m^2]	2604	25377	1438	19494	7171
Volume conditioned [m^3]	13143	89556	3664	60098	20080
HVAC system	SD CAV AHU + FCUs	6 SD CAV AHUs	SD CAV AHU + FCUs	7 SD CAV AHUs + FCUs	6 SD CAV AHUs + FCUs
Cooling capacity [kW]	346	714,5	122,2	537/537/401,2	120/120/182
EER	3,1	2,93	2,8	5,25/5,25/3,88	3,58/3,58/3,67
Heat rejection media	air	air	air	water	air
Cold storage system	no	yes	no	yes	no

3. Results

First the two demand indicators (EI_a and EI_v) were determined. For this the energy consumption data gathered for the period between July 1st and September 30th, 2012 was chosen, whereby only the working day data, i.e. without weekends and holidays, was considered. The results are listed in Table 2.

Table 2. Demand indicators results

Building	t [h]	EI_a [W/m^2]	EI_v [W/m^3]
A	1476	14,55	2,88
B	1262	7,71	2,19
C	1284	6,80	2,67
D	1528	14,62	4,74
E	1442	4,59	1,64

As can be seen from Fig. 1-2 building E has the lowest energy-intensity according to both demand indicators, while building D has the highest energy-intensity. One results especially stands out, namely building A. Its energy consumption per conditioned area EI_a is significantly higher in comparison to the other buildings than its energy use per conditioned volume EI_v. The reason for this lies in the height the air-conditioned spaces. In building A the spaces are considerably higher than in the other building, i.e. 5,6 meters compared to 2,5-3,6 meters. Hence the EI_a indicator is more suitable for compering residential buildings, where the height differs little from building to building, while EI_v is more generally applicable.

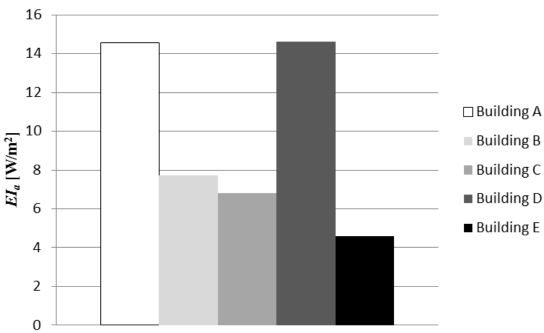

Fig. 1 EI_a raiting

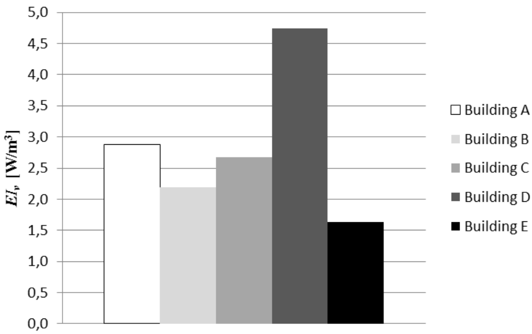

Fig. 2 EI_v raiting

The results for the coefficient of temperature-sensitivity K_θ were taken from our previously mentioned work [5], namely the coefficients determined at 9-10 a.m. Central European Time (CET) with 60-minute values of chiller electric energy consumption and dry-bulb outdoor temperature (Table 3). It should be noted that for building D only two chillers were considered, because the rooms being served by the excluded chiller (cooling capacity 401,2 kilowatt) were not exposed directly to the outdoor climate due to their location (i.e. core of the building).

Table 3. Coefficients of temperature-sensitivity

Building	K_θ [Wh/m^{3}K]
A	0,236
B	0,177
C	0,364
D	0,245
E	0,360

Compared to the EI_v rating the results for the temperature-sensitivity coefficient are quite surprising (Fig. 3). While building E has the lowest value of EI_v, its K_θ value is one of the highest. The situation with buildings C and E is exactly the opposite. This is the consequence of internal loads. Since building D has high internal loads, it has energy-intensive air conditioning which is at the same time less temperature sensitive because internal loads represent a high portion of the total cooling loads (vice versa for buildings C and E). Therefore the K_θ coefficient can be used together with the EI_v index to identify buildings with high or low internal cooling loads.

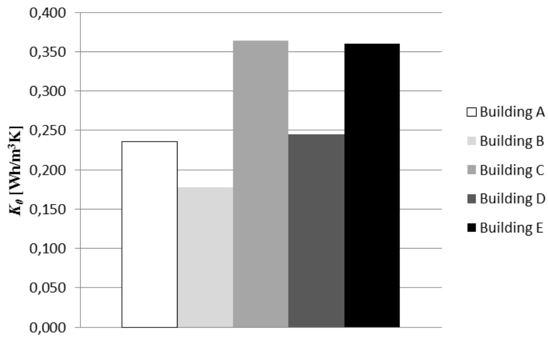

Fig. 3 K_θ raiting

Because the total electric energy consumption was obtained only for three buildings the peak load impact factor f_{PL} is calculated only for buildings B, C and D. The f_{PL} factor was calculated for the same period as the demand indices (July to September 2012), whereby only the working day data from 8 a.m. to 4 p.m. was considered since all the buildings were occupied during this interval as we found out in [7]. The results are summarized in Table 4 and shown in Fig. 4.

Table 4. Peak load impact factor

Building	f_{PL}
B	0,221
C	0,409
D	0,329

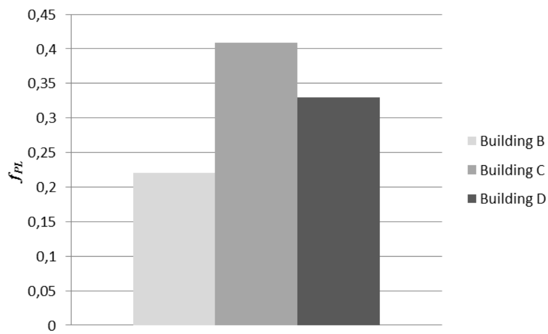

Fig. 4 f_{PL} raiting

The f_{PL} factor correctly revealed the presence of thermal storage systems. Although building C outperforms building D in terms of the EI_v indicator value by almost 78%, building D has a 20% lower peak load impact factor due to the use of an ice thermal storage system. Building B also extends its lead over building C, i.e. a 46% lower f_{PL} against an 18% lower EI_v. However, these results should be treated with caution since building B is a retail building and has hence a significantly different equipment density from buildings C and D which are office buildings.

4. Consclusion

Because energy efficiency of buildings is important for achieving national and international goals to decrease energy use and reduce the emissions of greenhouse gases, there have been a number of directives released within the framework of the EU, such as the Energy Performance of Buildings Directive (EPBD 2010/31/EU), whose aim is to reduce energy use and increase the energy efficiency of buildings. Assessment of energy performance is the first and most effective step to achieve the latter.

In this study the energy performance for cooling purposes of five existing commercial buildings is assessed using four different energy performance indicators calculated from real performance data, of which two were newly defined, namely the coefficient of temperature-sensitivity and the peak load impact factor.

In addition to demonstrating the limitation of the use of energy intensity per unit of conditioned area on commercial buildings, one result seems especially promising, i.e. the results for the coefficient of temperature-sensitivity. It was shown that the latter can be used in combination with the energy intensity per unit of conditioned volume to identify buildings with high internal cooling loads. The peak load impact factor also performed as expected, i.e. it correctly identified the use of cold storage systems.

Nevertheless, the obtained results should be interpreted carefully due to the small sample of buildings and because some influences like occupancy density or the indoor air temperature set points were not taken into account due to the lack of this information. Consequently, the proposed indicators will have to be applied on a larger sample of buildings, preferably on data from different time periods, in order to verify if they are correctly defined and to determine their threshold values

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