Energy and Buildings 105 (2015) 247–257

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Impact of building usage and occupancy on energy consumption in Finnish daycare and school buildings

Tiina Sekki [a,*], Miimu Airaksinen [b], Arto Saari [c]

[a] Aalto University Properties Ltd, Finland
[b] Technical Research Centre of Finland, Finland
[c] School of Engineering, Department of Civil and Structural Engineering, Aalto University, Finland

ARTICLE INFO

Article history:
Received 10 April 2015
Received in revised form 22 June 2015
Accepted 16 July 2015
Available online 26 July 2015

Keywords:
Measured energy consumption
Building usage
Energy efficiency indicators
Daycare centres
Schools

ABSTRACT

The facility strategy of the City of Espoo emphasises improvements in the energy efficiency and efficient use of buildings. The design phase of a building is crucial and when the building is in operation, it is crucial to use control systems correctly. Further, in order to encourage relevant efficiency efforts, it is essential to know how to measure energy efficiency in the building operation phase. This requires an understanding of the correlation between building occupancy, space efficiency and energy efficiency.

Energy efficiency is typically measured as energy consumption per unit of area kWh/m^2 per annum. The specific energy consumption is an effective way to measure the technical properties of a building and to guide its design but it neglects issues related to building occupancy and space efficiency.

This paper explores ways in which building usage and occupancy influences the measured energy consumption in Finnish daycare centres and school buildings. The study adopts existing energy efficiency indicators and introduces a new indicator for building energy efficiency which takes into account both space and occupancy efficiency.

1. Introduction

Increasing energy efficiency constitutes one of the key actions reducing greenhouse emissions throughout the building lifecycle [1]. As Junnila and Horvart [2] showed, 80–90% of the environmental impacts of buildings are generated when in operation. Previous studies have focused on technical improvement measures instead of examining the effects of building occupancy. However, several studies have indicated that occupancy has a high impact on the energy consumption [3,4].

Sekki et al. [5] found that in different educational building types, the newer buildings require less heating. Further, no such noticeable correlation emerged for electricity consumption. However, in terms of primary energy consumption, the consumption trend is on the rise. The study concluded that the growing primary electricity consumption and the difference between the buildings resulted from increasing use of the premises. Examination of energy consumption is especially relevant for buildings like schools and colleges, where the occupancy profiles have some unique features (such as high variability within small time intervals and often periods of low but non-zero occupancy) [6].

The European Union has given careful consideration to the public sector by imposing special legislation and by running targeted projects for economic support. Energy performance and energy management in public buildings has been investigated in several significant publications [7–14]. It is evident that the issue of improving the energy performance of public buildings, and specifically school buildings, raises much interest. The matter is even more relevant today since the Member States, in implementing the Directive 2012/27/EU [15], must define strategies and decide on retrofit energy actions to undertake on their existing public building stock.

1.1. Building usage, occupancy and energy efficiency

This article explores building usage in such building types as daycare centres and schools. The efficiency of building usage is affected by space efficiency measured in m^2/person and building occupancy. Building occupancy is impacted by the operating times (number of daily hours, weekly days and yearly days) and occupancy levels (percentage of occupants present at a given moment). Thus, building occupancy can be calculated as a multiplication of yearly operating times and average occupancy levels or by counting total person hours (sum of hours each building occupant has

* Corresponding author at: Lämpömiehenkuja 2 A, FI-02150 Espoo, Finland.
E-mail address: tiina.sekki@aaltonet.fi (T. Sekki).

http://dx.doi.org/10.1016/j.enbuild.2015.07.036
0378-7788/

spent in the space studied). In this article, building occupancy is calculated as the number of occupants and yearly operating times.

Space efficiency is affected by space design. According to Hietanen [16], space efficiency correlates almost directly with energy consumption when buildings are refurbished. The more effectively a given building is occupied, the less space is needed for a given number of people and, thus, the lower the space heating energy consumption per person. The same applies to the operating times of a building; it can have several purposes at different times of the day (e.g. organising leisure activities in a school after regular school hours).

However, it should be highlighted that when space efficiency is significantly boosted, measures must be taken to guarantee a sufficient quality of indoor climate. According to Milton et al. [17], the rate of ventilation seems to affect the incidence of respiratory diseases. In addition to ventilation, the occupant density seems to affect it [18], and subsequently Saari et al. [19] indicate that investment in the quality of indoor climate is cost-effective when the economic effect of indoor climate on health and productivity are taken into account in addition to the costs of investment, operation and maintenance. Insufficient ventilation without mechanical cooling may cause a substantial loss of productivity.

Traditionally energy efficiency is expressed in kWh/m^2. While this metric is useful when comparing the physical properties of buildings in the design phase, it can favour unsustainable ways of employing buildings in the operation phase. In fact, lower space efficiency (m^2/person), shorter operating times of buildings (per day, per week, per year) or lower levels of occupant can lead to a situation in which one building seems more energy efficient in kWh/m^2 than another building with similar physical properties which is utilised more efficiently.

This result was provided by Dooley [20], who adopted energy simulations to compare energy efficiency in terms of three indicators:

- specific energy consumption (SEC),
- energy intensity of usage (EIU) and
- specific energy consumption adjusted for person hours.

These indicators were compared with the different space efficiencies and daily operating times of an office building. When SEC was adopted, it appeared that energy efficiency decreased slightly when the office layout grew more efficient. However, with the other two indicators, the effect was radically opposite. When the daily operating times varied, SEC encouraged shorter working hours per day, while the other two indicators considered the building more energy efficient when it was used longer per day.

Forsström et al. [21] suggest approaching the effects of occupancy on energy efficiency indicators with SEC adjusted for building utilisation rate (SEC_{UR}). In addition, the study proposes an indicator called energy intensity of usage (EIU), which refers to the energy use of the building divided per user.

In addition to SEC, Dooley [20] also applied energy consumption per user. This indicator is similar to the one shown in [21] (SEC_{UR}), which proposes an indicator called energy per area per occupied hours. A variety of indicators that consider occupancy or space efficiency are presented by Huovila et al. [22]. For such indicators to be applied, it is critical to monitor building occupancy levels in a reliable way, which is challenging. The estimations that can be found in literature often rely only on facility managers' observations or surveys, which might yield inaccurate results.

1.2. Connection to the City of Espoo's facility strategy

Efficient use of facilities has been emphasised in the City of Espoo facility strategy. Improving energy efficiency is achieved primarily for economic reasons. In the future, the buildings will offer more advanced services. The use of services is guaranteed by extending the operating times. Space efficiency is typically fixed already in the design phase and the building operating times are fixed based on the building's specific purpose of use.

There should be articulate procedures and indicators in the City of Espoo facility strategy to accomplish building energy management more effectively. Also a need for an advanced monitoring has been identified. However, this requires occupancy level monitoring, which is challenging to perform in a reliable and inexpensive way. The energy efficiency of the City of Espoo buildings is measured as energy consumption per unit of area, in this context in kWh/m^2. There is a need to identify and develop indicators that can be applied to assess changes in energy consumption.

1.3. Objective of the study

The objective of this study is to examine the influence of building usage and occupancy on the measured energy consumption. The evaluation is based on the yearly usage of buildings and occupancy data and actual, measured energy consumption. The study focuses on evaluating the different possibilities to indicate energy efficiency and how the indicator can be used to make the right choices.

2. Research method

This study was conducted by adopting statistical and qualitative research methods. Mean values and correlations were statistically examined. Case study methodology was employed to compare alternative indicators of energy efficiency. The indicators express the annual energy consumption of a building with different functional units. The indicators under scrutiny are presented in Table 1.This study was divided into two phases:

- In the first phase, the influence of building usage and occupancy on the overall measured energy consumption is analysed.

Table 1
The indicators used in this study.

Indicator name	Unit
Specific energy consumption (SEC)	kWh/m^2
Energy intensity of usage (EIU)	kWh/number of occupants (children, student, personnel) kWh/yearly operating times
Specific energy consumption adjusted for occupancy (SEC_O)	kWh/m^{2}o, $0 \le o \le 1$ o = the ratio of actual daily person hours to the highest possible daily person hours. In this article we use the highest possible person hour's value 24.
Specific energy consumption adjusted for usage and space efficiency ($SEC_{u,s}$)	kWh/m^{2}u, $u = nt_{avg}/((A/a_{ref})t_{ref})$ where n is the actual number of student or children using the building, t_{avg} is the average number of hours present daily per person, A is the total area studied. The parameters a_{ref} and t_{ref} are normalising factors: a_{ref} is the amount of space per children or student and t_{ref} represent normal working hours, in this paper we use the value 5.5 h in schools and value 11.5 h in day care centres. For a_{ref} both actual and design figures from the City of Espoo's design guidelines were used.