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Energy consumption of Finnish schools and daycare centers and the correlation to regulatory building permit values

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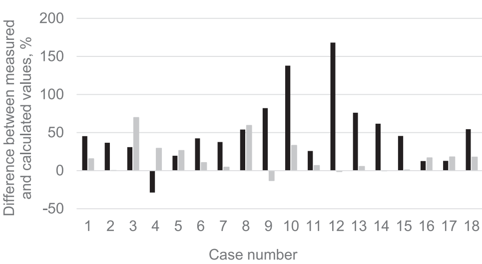
GRAPHICAL ABSTRACT



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ABSTRACT

The national building codes set requirements for building energy efficiency in many countries. The purpose of this study was to improve understanding on the measured and calculated energy efficiency of Finnish schools and daycare centers. The study analyzed the energy consumption of 134 schools and 71 daycare centers and compared the regulatory building permit calculations to measured values for 18 case buildings. According to the results, the specific electricity consumption (kW h/(m^2 a)) has increased in schools but not in daycare centers. The heating energy consumption was lower in schools, but this might be explained by that they had clearly larger gross floor area than daycare centers. When compared to the technical requirements in the building code, the actual heating energy consumption has decreased less than what the changes in the building code would suggest. The building energy consumption calculated for building permits with the monthly calculation method and standard use clearly underestimated the measured building energy consumption. The differences were larger in heating energy than in electricity consumption. In conclusion, different regulatory limit values should be considered for the two building types. The calculation methods and input data should be analyzed to ensure that they truly guide towards cost-optimal design choices.

1. Introduction

1.1. Building energy regulations and calculation accuracy

Reducing building energy consumption reduces energy costs, decreases environmental impact and improves national energy self-sufficiency. To ensure a certain level of safety and quality and to advance different goals, the legislative authors have typically set a group of demands for the building design.

Building energy regulations typically focus on the design phase. However, because these regulations have a big impact on the whole lifecycle of buildings, it is important to have a good understanding on how

Abbreviations and definitions: HDD, Heating Degree Days; HVAC, Heating, Ventilation and Air Conditioning; NBCF, The National Building Code of Finland; SFP, Specific Fan Power; TRY, Test Reference Year; Standard use, A set of fixed input data that is currently used in calculations in Finland to show the regulatory compliance of building energy efficiency

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well the building energy consumption regulations correlate to the actual energy consumption. More specifically, the correlation between the measured energy consumption and the consumption calculated for building permit is here of interest.

1.2. The goals of this study

The main goal of this study is to improve the current understanding of the actual energy consumption of new schools and daycare centers in Finland. This has been done in two phases:

a) Gather and analyze the energy consumption data from a large number of buildings to have an overview of the general trends in building energy consumption.
b) Compare the results from regulatory building energy consumption calculations to the measured building energy consumption.

The hypothesis for the first point is that the heating energy usage should be clearly smaller in newer buildings than in older buildings due to stricter energy efficiency requirements. If the energy consumption is not decreasing, there could be problems in the existing regulatory framework or some phenomena influencing building energy consumption that are not included in the current calculation methods.

The hypothesis for the second point is that the building energy consumption calculated for the building permit should be close to the metered energy consumption. If differences exist, it is possible that the cost- or otherwise optimal solutions are not chosen for the buildings.

Schools and daycare centers have been selected for this study, because they represent a large proportion of public buildings with varying complexity. The focus of this work is in new construction, although experiences from retrofitting are utilized as needed.

By addressing these goals, this paper improves the current understanding of the actual level and variance of energy consumption of the studied buildings, the impact of construction year, building size and building energy regulations and the differences between the calculated energy consumption for building permits and billed energy consumption.

1.3. Literature review

1.3.1. Energy consumption of schools and daycare centers

Comparing the energy consumption of different buildings is not a trivial task. Differences in indoor and outdoor air conditions, building type and use and the form of energy all have an impact on the final energy use. If no further procedures have been agreed on, the first default method proposed is to use the heating degree day -adjusted data of billed energy consumption (Dias Pereira et al., 2014). Buildings can also be compared with a suitable set of indicators (Sekki et al., 2017).

In a study of 68 school buildings in Luxemburg built after 1996, it was found that on average, buildings built according to more strict energy standards consumed less thermal energy than older buildings. However, in many cases the measured energy consumption was higher than the value calculated in the design phase. Furthermore, the variation in thermal and electricity consumption as a portion of the average value in the group was quite high.

Thewes et al. (2014) concluded that the mean electricity consumption of schools providing catering was approximately 10 kWh/(m^2 a) higher than in smaller buildings without it. Sekki et al. (2017) reported a 2–10% increase in energy consumption from on-site catering and 5–10% increase from a gym. In an aggregation report by BRECSU (1998), the impact of additional facilities such as swimming pools and sports halls was estimated to be around 20%, and on-site catering 7–10%. The age of the building did not always have a clear impact on building energy consumption, but larger schools were typically more energy-efficient than smaller ones. The thermal energy consumption of the buildings in kWh/(m^2 a), was not found to be dependent of the gross floor area. (Thewes et al., 2014) It should be noted that the differences in the sample sizes can affect the values of the coefficient of variation.

In a Finnish study by Sekki et al. (2015a), the new daycare centers, schools and university buildings built according to the newest Finnish energy regulations consumed less heating energy than the ones built according to older ones. Similar difference was not observed in the electricity consumption. The variation in the total primary energy consumption within the different building types was large (76–84%). One possible reason for the high variation is the amount of occupancy: On average the amount of occupancy of daycare centers in a Finnish city of Espoo was 2600 h and the density varied between and 6.8–22.1 m^2/child. Of the studied schools, 45% were in use for 3000 h/year or more and 40% were in use for 2200 h/year or less. The area per student varied from 4.7 to 59.5 m^2/student (Sekki et al., 2015b).

In a Portuguese study, the total energy consumption of secondary schools varied between 21 and 44 kWh/(m^2 * 1000 Kd), calculated per gross floor area. The authors state that the energy consumption of the six schools was lower than other buildings of the same type, but there were occurrences of higher carbon dioxide concentration than the limit values in the current legislation (Pereira et al., 2017). This would imply the possibility mean that by increasing the ventilation rate to lower the indoor air carbon dioxide concentration, also building energy consumption would increase. Santos and Leal (2012) stated that increasing the ventilation rate by 1 m^3/(h·person) in a school building resulted in an increase of modeled building energy consumption by 0.6 kWh/(m^2 a) in the climate of Finland, Helsinki.

1.3.2. Calculated and measured building energy consumption

It is important to be able to make numerical predictions of building energy consumption, because it allows setting goals and working towards them. One approach is to use statistical black-box/grey-box models to quantify the impact of different input data on the building energy consumption, such as multiple linear regression (Beusker et al., 2012), cluster analysis (Lara et al., 2015), time series forecasting (Deb et al., 2017), artificial neural networks and support vector machines (Zhao and Magoulès, 2012). In general, it seems to be possible to create fairly accurate prediction models for some well-defined and coherent groups. However, due to the large variance in the input and output data related to building energy consumption, creating a single regression equation, or similar, to accurately describe a large group of e.g. school buildings is a demanding task.

The other approach is to use white-box/grey-box models, where physical laws and equations are used to build a model for the energy consumption and possibly also for indoor air conditions. Different approaches can be used, such as the simple hourly (RC-network), monthly or dynamic calculation methods (SFS-EN ISO 13790, 2008). From Reynders et al. (2014), Kalema et al. (2008), Crawley et al. (2008) and Choi (2017) we can conclude that the simulation programs or approaches do not necessarily produce similar results even to other simulation programs of the same category without careful calibration and a good understanding from the program user.

A specific parameter that has received some attention in the literature is the heat load utilization factor. It is used in ISO 13790 (2008) to calculate the amount of indoor heat gains that reduces the space heating need. On the other hand ISO 13790 (2008) and Kalema et al. (2008) have presented results that showed good agreement with simulation results, but some other studies (Kim et al., 2013; Jokisalo and Kurnitski, 2007; Hitchin, 2017; Corrado and Fabrizio, 2007; Wauman et al., 2013) have also highlighted the differences between the current ISO 13790 approach and simulation results, and the subsequent need to modify the calculation parameters of the utilization factor.

Ultimately the choice of a suitable calculation method depends on many things, such as transparency, robustness and reproducibility (Dijk et al., 2005; SFS-EN ISO 13790, 2008). For regulatory purposes, the calculation method should be easy enough to use, so that acquiring the