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

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Abstract

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Daycare centers used more heating energy and electricity per gross floor area than schools. The gross floor area had a correlation to the specific energy consumption (kWh/(m^{2}a)), which could explain the difference between the two building types as schools tend to be larger. The heating energy consumption was lower in new buildings but the difference was not as big as expected. Newer schools consumed more electricity than older ones. The values calculated for showing regulatory compliance for building permits underestimated the purchased energy. The differences were larger in heating energy than in electricity consumption, although heating energy is calculated in a more detailed level of those two.

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Keywords: Building permit, Daycare center, Measured building energy consumption, Monthly calculation method, School building, Standard use

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

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 life-cycle of buildings, it is important to have a good understanding on how 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 is utilized as needed.

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. For example, differences in indoor and outdoor air conditions, building type and use and the form of energy can vary. 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.

Study (Thewes, et al., 2014) concluded that the mean electricity consumption of schools providing catering was approximately 10 kWh/(m^2a) 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 (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^2a), 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 (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 hours and the density varied between and 6.8 to 22.1 m^2/child. Of the studied schools, 45 % were in use for 3000 hours/year or more and 40 % were in use for 2200 hours/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 21-44 kWh/(m^2 * 1000Kd), 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 & 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^2a) 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 & 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 (ISO 13790, 2008). These types of methods have been used and studied for example in (Reynders, et al., 2014; Kalema, et al., 2008; Crawley, et al., 2008; Choi, 2017). From these sources 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; Kalema, et al., 2008) have presented results that showed good agreement with simulation results, but some other studies (Kim, et al., 2013; Jokisalo & Kurnitski, 2007; Hitchin, 2017; Corrado & 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; ISO 13790, 2008). For regulatory purposes, the calculation method should be easy enough to use, so that acquiring the basic results would be accessible to many building designers. This would also help in keeping the costs from building design on a low level through competition of companies.

(Deurinck, 2015, pp. 11-38) has presented a literature review of the size and reasons leading the shortfalls in the predicted building energy consumption. The focus is on retrofitting existing dwellings, but it contains topics that are related to the energy efficiency of school buildings also (such as unexpected malfunction of technical issues and user behavior). One possible reason for the energy performance gap is that the widely used steady-state energy labelling tools have systematically overestimated the pre-retrofit energy consumption. This has made it more difficult to reach the energy saving targets set in the design phase. In relation to US residential buildings, similar conclusions are presented in (Polly, et al., 2011, p. 18). Based on the literature sources, the current analysis methods seem to over predict energy consumption of old residential buildings.

In a study by (Butala & Novak, 1999), the authors state that the measured energy consumption of 24 Slovenian school buildings were higher than the regulatory allowed values on average, but lower than the estimated values. In a study by (Herrando, et al., 2016), the measured energy consumption was 45 % higher for research buildings and 23 % higher for academic buildings, than what was calculated by simulations.

In a study carried out in the UK (Demanuele, et al., 2010), different operational issues and occupant behavior were found to be the major causes for differences in the designed and actual building energy consumption in school buildings. In a study conducted in three school buildings in Canada, it was noticed that the electricity consumption during night was 42–57 % of the daytime load (Ouf, et al., 2016). A study by (Montazami, et al., 2015) studied the design issues in UK schools and summarizes the root causes to three main factors: 1) The lack of optimization between internal environment factors and their impact on energy consumption, 2) The lack of understanding on how users respond to their environment and 3) The lack of adaptability related to on how the building functioning in (unknown) future conditions after it has been built. These results highlight the importance of monitoring and if necessary, reacting to the actual behavior of the building systems during use.

As a summary, there exists large variations in the measured energy consumption of buildings even within similar groups regarding the climatic conditions and building practices. A wide range of calculation tools exists to characterize the energy consumption of existing and new buildings, but the different methods and tools do not automatically produce similar results when compared to each other or to the measured energy consumption. Regarding older existing buildings, there seems to exist an over prediction phenomenon, where the buildings consume less energy than calculated. It is possible to reach good correlation between the calculated and measured building energy consumption values but typically this requires deeper quantitative knowledge of the studied building and its use.

1.4 Changes in energy efficiency requirements in Finland

In Finland, the first official building energy regulations were introduced in 1976. In the older regulations, the numerical requirements for building energy efficiency concerned only heat conduction through the building envelope. In the latest Finnish building energy efficiency requirements from 2012, also several other factors need to be considered in the building design. The outdoor air conditions of a reference year Jokioinen 2012 (Jylhä, et al., 2015) are used in the calculations (hourly or monthly, depending on the method).

Regulations that are applied for building design are the ones that are in force when the building permit application is submitted. The plans that have already been submitted do not need to be modified if the regulations change during the building process. To help compare the energy consumption of buildings with different construction years, the next paragraphs summarize the development of the main parts of the Finnish building energy regulations. The reference U-values for heated zones are shown in Table 1.

Table 1 Typical (before 1976) or requirement (after 1976) U-values [W/(m^{2}K)] for heated spaces in Finland according to the year of a building permit application.

Structure	-1975	1976-	1979-	1985-	2003-	2008-	2010-	2012-
Roof	0.47	0.35	0.23-0.29	0.22	0.16	0.15	0.09	0.09
External wall	0.81	0.4-0.9	0.29-0.35	0.28	0.25	0.24	0.17	0.17
Floor against outdoor air	0.35	0.35	0.23-0.29	0.22	0.16	0.15	0.09	0.09
Floor against crawl space	0.47	0.4	0.23-0.29	0.22	0.2	0.19	0.17	0.17
Ground slab	0.47	0.4	0.4	0.36$^{e)}$	0.25	0.24	0.16	0.16
Window	2.8	2.1-3.1$^{g)}$	2.1$^{g)}$	2.1$^{g)}$	1.4	1.4	1	1
Door	2.2	2.1-3.1$^{g)}$	0.7$^{p)}$	0.7$^{p)}$	1.4	1.4	1	1

g) = requirement for the glass area, p) = requirement for the panel area, e) = requirement is only for a six meters wide area at the building perimeter

U-values before 1976 in Table 1 are typical values of the era because no regulatory requirements were set at the time. The values from 1976 and onwards are required U-values presented in the building code. Starting from 1979, it was possible to use a heat loss balancing method where the heat losses due to higher U-values must be compensated at other envelope parts. Ventilation heat losses were included in the balancing calculations starting from 2003 and infiltration heat losses starting from 2008. In addition to reference U-values, also maximum U-values have been in force (typically 0.6 W/(m^2K) for opaque envelope parts). (Decree 176/2013, 2013; The Ministry of Environment, 1976-2012)

The air tightness and ventilation heat recovery requirements from different years in the Finnish building code are given in Table 2.

Table 2 The air tightness and heat recovery efficiency requirements from different years in Finland (from 2003 onwards). The values until 2002 are recommended values to be used in building energy calculations according to (Decree 176/2013, 2013).

Year	**-2002**	**2003-**	**2007-**	**2010-**	**2012-**
Infiltration n_{50} (1/h) and q_{50} ($m^3/(hm^2)$)	n_{50}=6.0	n_{50}=4.0	n_{50}=4.0	n_{50}=4.0	q_{50}=4.0
Annual ventilation heat recovery efficiency (for exhaust air) (%)	0	30	30	45	45

The air tightness value was previously given as the n_{50}-values (1/h), but in the latest requirements (2012) it is given as the q_{50}-values ($m^3/(hm^2)$). The relation between these two can be written as equation (1).

$$q_{50} = \frac{n_{50}}{A_{envelope}} V \qquad (1)$$

where

q_{50} is the building air tightness, $m^3/(m^2h)$

n_{50} is the building air tightness, 1/h

$A_{envelope}$ is the area of the building envelope, defined according to total internal dimensions, m^2

V is the air volume of the building, defined according to total internal dimensions, m^3

Specific Fan Power (SFP) of a typical mechanical supply and exhaust ventilation system was limited to a maximum of 2.5 kW/(m^3/s) in 2003 and 2.0 kW/(m^3/s) in 2012. The does not include the impact of separate exhausts from kitchens, toilets and similar.

Based on these values, the space heat demand in modern buildings should be roughly half or less than what it was in the buildings of early 1970s.

2 Methods and material

2.1 Description of the large sample of buildings

A sample of 134 schools and 71 daycare centers in Tampere and Helsinki region in Finland was analyzed. Both cities have altogether 280 schools and 278 daycare centers, which means that the sample represents 48 % of schools and 26 % of daycare centers for these two cities. Buildings that were included in the sample were permanent structures and had the following data available for them:

- Location of the building
- Construction year
- Gross floor area according to standard SFS-EN 15221-6:2012
- Heating energy consumption (district heating) from the year 2014 and
- Total electricity consumption from the year 2014.

The most typical reason to not include a building in the sample was the missing energy consumption data. The construction year distribution of the buildings is presented in Figure 1 Some of the buildings had both a school and a daycare center in them, in which case the building was classified as a school. This was made because of the larger number of users; it is more likely that larger part of the building would be used as a school.

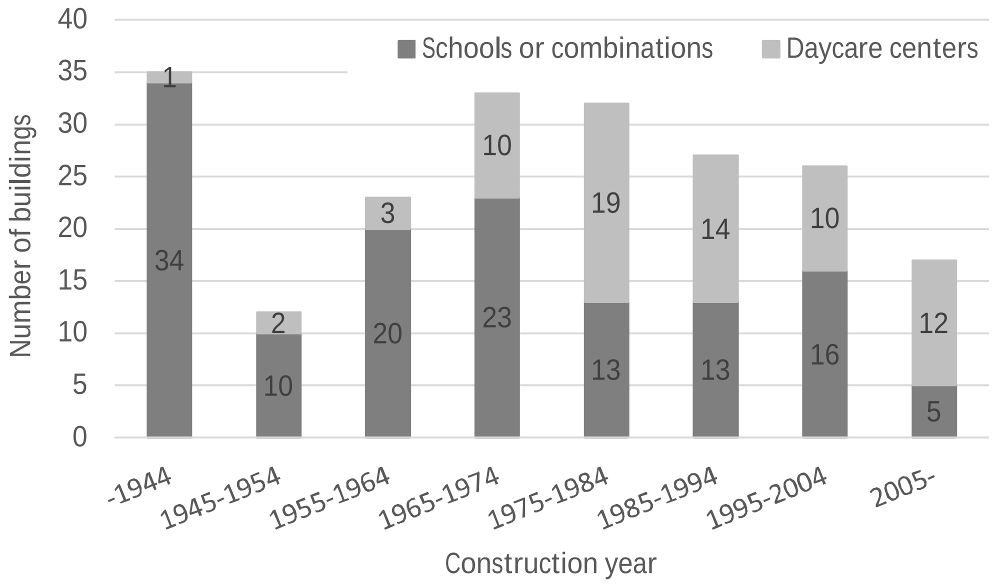

Figure 1 The distribution of the construction year of the buildings in the sample. “Combinations” means buildings in which both a school and a daycare center are being operated.

Most of the buildings in the sample were built after 1965. Over half of daycare centers were built after 1980 and over half of the school buildings were built after 1960. The gross floor area distribution of the buildings is presented in Table 6.

The heating energy and electricity consumption data was acquired from the municipalities of Tampere and Helsinki. To compare the energy consumption of buildings from two different locations and different times (Table 3), the heating energy consumption was normalized to the climatic conditions of a test reference year TRY 2012 Helsinki-Vantaa using heating degree-days (HDD) (Eq. 2).

$$Q_{ref} = \frac{HDD_{ref}}{HDD_{meas}} Q_{meas} \tag{2}$$

where

Q_{ref}	is the amount of heating energy in the reference year conditions, kWh
HDD_{ref}	is the amount of HDD in the reference year, °Cd
HDD_{meas}	is the amount of HDD in the measurement year and location, °Cd
Q_{meas}	is the measured heating energy consumption, kWh.

In Finland, the heating degree-days are calculated by assuming an indoor air base temperature of 17 °C. In autumn, the HDD are calculated from the time when the daily average outdoor air temperature is lower than 12 °C. In spring, the HDD are added to the sum when the daily average temperature is lower than 10 °C.

The HDD values used in this paper are presented in Table 3. The heating degree-days were retrieved from the Finnish Meteorological Institute website (FMI, 2016).

Table 3 Heating degree days used in the study. The heating degree days of the reference year TRY 2012 was 3952 °Cd. n.r. = not required.

City	2011	1/Dec/2013…30/Nov/2014	1/Sep/2015…31/Aug/2016	2014	2015
	°Cd	°Cd	°Cd	°Cd	°Cd
Helsinki	n.r.	3396	3267	3464	3118
Oulu	4537	n.r.	n.r.	n.r.	4119
Tampere	n.r.	3973	n.r.	4046	3619

The heating energy used for hot water was included in the heating energy data, but the exact amount of hot water usage was not available for most of the buildings. Because of this, the heating energy used for water heating was left in into the normalization done with the HDD. The error caused by this depends on the difference between the HDD of the measurement period and the test reference year and on the hot water consumption. To calculate an estimate of the error, it was defined as the difference between the correctly (water heating outside normalization) and incorrectly normalized (water heating included in the normalization) values, which can be simplified to as equation 3.

$$\varepsilon_{Qref} = Q_{meas,HW}\left(1 - \frac{HDD_{ref}}{HDD_{meas}}\right) \quad (3)$$

where

ε_{Qref} is the error in the HDD normalized heating energy consumption from leaving the water heating to the normalization, kWh/(m^{2}a).

If we assume a typical hot water net heat demand of 11 kWh/(m^{2}a), system efficiency of 0.86, 3952 Kd for reference year conditions and 4537 Kd for measurement period conditions, we get an error of 1.6 kWh/(m^{2}a), which is small compared to the absolute values in Figure 2.

2.2 Description of the 18 case buildings and of the input data for calculations

The delivered energy of 18 case building was calculated according to the methods and input values used for the Finnish energy consumption calculations for the current building permit applications. The methods and input values are presented in the National Building Code of Finland (NBCF), parts D3 (2012, mandatory) and D5 (2012, informative). The monthly quasi-steady-state calculation method is similar to the one presented in SFS-EN ISO 13790 (2008) and is an allowed calculation method for the yearly heating energy consumption. The building code allows performing the calculations with validated simulation tools, but the idea was to first test the simpler method, before moving to more complex models.

In addition to mandatory input data, information was gathered from each buildings' design documentation, which had been archived by the municipalities. Because not all the data necessary for the calculations was available, additional information was acquired from other sources. The priority of the different sources was:

1) Mandatory input data, given in the (NBCF D3, 2012), regarding the building use and climatic conditions (i.e. "standard use"), including occupancy hours, temperature set-points, ventilation rates, electricity use for appliances and lighting, hot water use and indoor heat loads

2) Building-specific input data, regarding e.g. building geometry, orientation, material properties and/or envelope U-values, building air tightness and the yearly average heat recovery efficiency
3) Informative input data, given in the (NBCF D5, 2012) and (Decree 176/2013), for the heat production and distribution efficiencies and electricity use of the heating equipment

Some of the building-specific input data of the case buildings is given in Appendix A. The mandatory input data for calculations from (NBCF D3, 2012) is given in Table 4.

Table 4 Mandatory input data for the calculations, from (NBCF D3, 2012).

	Educational building or daycare center	**Sports hall**
Climate data	Monthly averages of the official Finnish test reference year TRY2012 (Kalamees, et al., 2012; Jylhä, et al., 2015)	
Occupancy hours	8 h/day and 5 day/week	14h/day and 7 day/week
Time when the ventilation is on	10 h/day and 5 day/week	16 h/day and 7 day/week
Heating set-point, °C	21	18
Cooling set-point (informative, not used in the calculations), °C	25	25
Supply air flow rate during occupancy, $dm^3/(m^2s)$	3	2
Supply air flow rate outside occupancy hours, $dm^3/(m^2s)$	0.15	0.15
Electricity for lighting during occupancy, W/m^2	18	12
Electricity for appliances during occupancy, W/m^2	8	0
Heat release from occupants (without latent heat), W/m^2	14	5
Utilization rate k, -	0.6	0.5
Net heat demand for water heating, kWh/m^2	11	20

The heat loads seen in the previous table are calculated per net floor area, which is the same as the area defined with the overall internal dimensions according to (SFS-EN ISO 13789, 2008).

The utilization rate describes the average presence of occupants in the building. The electricity use and heat release from occupants and electrical devices is calculated according to equation (4).

$$Q = kP\frac{\tau_d}{24h}\frac{\tau_w}{7d}\Delta t \quad (4)$$

where

Q	is the amount of energy created (used) from the power source (sink), Wh/m^2
k	is the utilization rate, -
P	is the power of the source, W/m^2
τ_d	is the number of hours of use per day, h
τ_w	is the number of days of use per week, d
Δt	is the number of hours in the analyzed time period, h

The electricity consumption of lighting and user appliances becomes indoor heat loads. Half of the calculated heat losses from hot tap water circulation were added to the internal heat loads. (NBCF D3, 2012)

Two of the case buildings included large sports halls, which had to be calculated with specific rules according to the NBCF. Case building number 5 has been built in two parts. Case buildings have cooling only in the kitchen. However, kitchen can be left out from the regulation compliance calculations, because the floor area of the kitchen was under 10 % of the total building floor area. The kitchen use was assumed similar to the rest of the building as required by the regulations (NBCF D3, 2012).

Ventilation heat recovery efficiency for a full year was calculated with the standard use schedules (NBCF D3, 2012) and the heat recovery efficiency calculator of Laskentapalvelut.fi.

For thermal inertia, the tables in (NBCF D5, 2012) do not exclusively include values for schools and daycare centers, because of which the values for office buildings were used. The parameters $a_{H,0}$ and $\tau_{H,0}$ presented in section 12.2.1.1 of EN ISO 13790 for calculating gain utilization factor for heating are $a_{H,0}$=1 and $\tau_{H,0}$=15 and were used in the monthly calculation method as instructed in NBCF part D5 (2012).

The energy consumption meter reading data ("measured consumption") was gathered from web based building management systems Haahtela RES, e3 Portal, Facility Info and from the electricity and district heating company of the City of Tampere (*Tampereen sähkölaitos* in Finnish). Heating energy consumption was normalized to the test reference year conditions (Vantaa 2012) similarly as in the previous chapter.

For the case buildings, the delivered energy data is from 2015, unless there have been issues with the data. The data for case number 3 is from 2011 because in 2012, another building was finished on the site and the meters are mutual for both buildings making it impossible to have the readings only for the other building. Case buildings number 15 and 12 have the consumption data from 1st December 2013 to 30th November 2014 because case 15 had ventilation heat exchanger malfunction and case 12 had inconsistent meter readings during the year 2015. Case number 19 had had adjustment of ventilation and thus the consumption data is from 1st of September 2015 till 31st of August 2016.

The difference between the measured and calculated values was calculated according to equation (5).

$$\text{Difference} = 100\ \% * (\text{Measured}/\text{Calculated} - 1) \qquad (5)$$

where

Difference	is the relative amount by which the measured building energy consumption is bigger than the calculated, %
Measured	is the delivered building energy consumption from energy meters and invoices, kWh/(m^{2}a)
Calculated	is the calculated building energy consumption according to the input data and methods for having a building permit, kWh/(m^{2}a)

To analyze the statistical properties of different data groups, the data was first plotted as scatter plots and histograms. After that the normality and the symmetry of the distribution was analyzed. Different tests of e.g. equal means and variances have different assumptions and depending on the results of the preliminary test, it was possible to choose the correct statistical test (see Table 5).

Table 5 Statistical tests for the data analysis. The information was gathered from (NIST/SEMATECH, 2012; Sprent & Smeeton, 2001; Taeger & Kuhnt, 2014; Walpole, et al., 2012).

Goal	Test	
Test if the sample is drawn from a normal distribution	Lilliefors test (L); Anderson-Darling test (AD); Shapiro-Wilk test (SW)	
Test if the sample is distributed symmetrically	Triples test (TT) (Mandrekar & Mandrekar, 2003);	
	Data is normal	**Data is not normal**
Test if there is a statistically significant difference between the variances of the two populations (Conover, et al., 1981)	F-test (F); Bartlett's test (B);	Brown-Forsythe test (BF) (similar to Levene's test but uses median instead of mean); Fligner-Killeen test (FK) Conover squared ranks test (CSR)
Test if there is a statistically significant difference in the means (medians) of two independent samples	Student's t-test (tS) (if variances are equal); Welch's t-test (tW) (if the variances are not equal)	Wilcoxon-Mann-Whitney (i.e. Wilcoxon rank-sum) test (WMW)
Test the strength of linear (rp) or monotonic (rs) correlation between two samples	Pearson product moment correlation coefficient (rp)	Spearman rank correlation coefficient (rs)
Test if the sample mean (median) of differences is zero	Paired t-test (tp)	Wilcoxon signed-rank test (WSR) (assumes that the differences are distributed symmetrically); Sign test (S) (if the distribution is not symmetric);

If the data was not normally or even symmetrically distributed, the usefulness of log-transformation was tested. Multiple tests on the same topics were used to see, if different tests would give different results.

The sample mean and standard deviation can be used as estimates of the corresponding population parameters. However, because the estimates vary between samples, confidence intervals (CI) for these parameters were calculated using bootstrapping. It is a method where repeated samples are taken from the original sample with replacement. From each new sample the same statistics are calculated than the original one, which eventually allows creating a distribution of the parameters of interest. Bootstrapping was used to create 2000 samples, of which each the sample mean and standard deviation was calculated. The 95 % confidence interval for population mean and standard deviation was calculated as the 2.5 % and 97.5 % empirical cumulative distribution values. (Sprent

& Smeeton, 2001) The 95 % CI values for the population mean and the standard deviation were also calculated by assuming the normality of the data and using the sample parameters and t-distribution (Devore, 2012).

The Excel spreadsheet program was used for calculating the building energy consumption with a quasi-steady-state method. The Python programming language with different modules was used for all the statistical calculations.

3 Results

3.1 Energy consumption as a function of construction year

The heating energy consumption of schools and daycare centers of different construction year is presented in Figure 2.

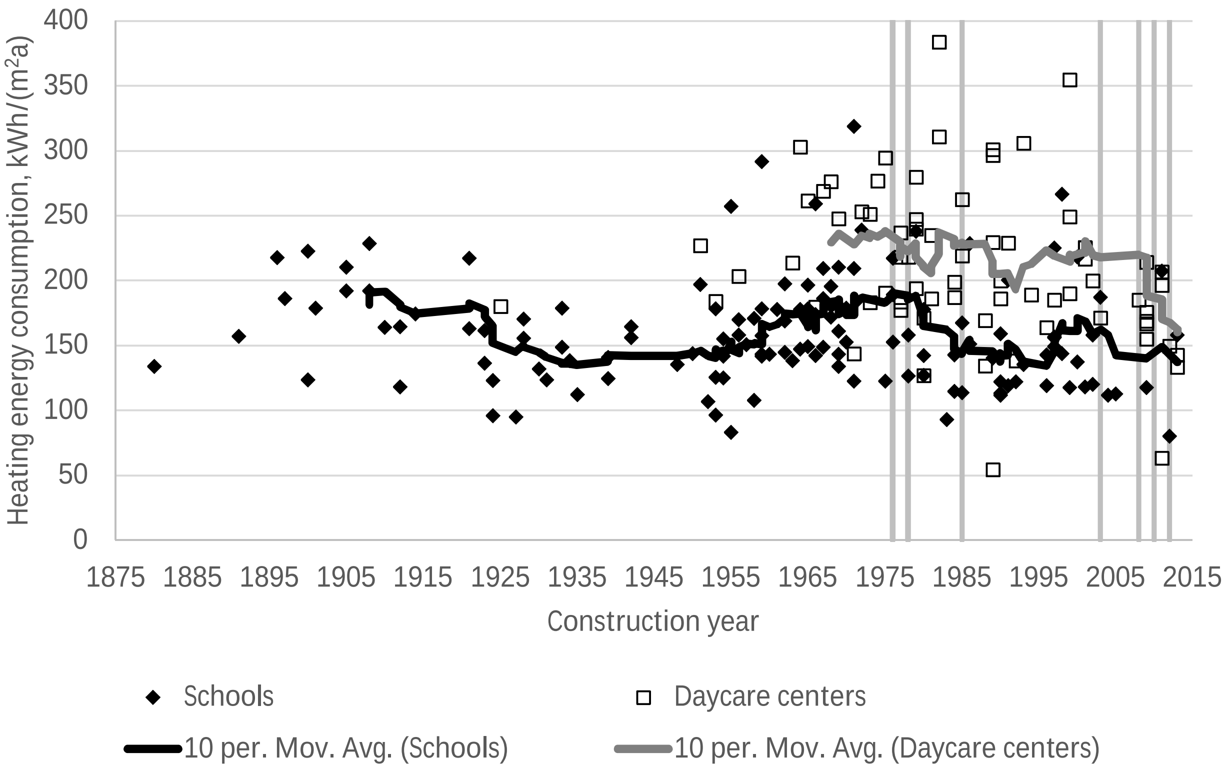

Figure 2 Heating energy consumption per gross floor area in 2014. Vertical lines represent the years, when the building energy regulations changed.

Based on Figure 2 there have been large differences in the energy consumption between buildings. On average the school buildings have had a lower heating energy consumption (in kWh/(m^2a)) than daycare centers. However, the 10-piece moving average (no. of buildings with consecutive construction years) of heating energy consumption of daycare centers has moved sharply closer to school buildings in the past few years. The newer buildings built after 1970s had a slow decreasing trend in the heating energy consumption with regards to construction year. On the other hand, the heating energy consumption of relatively new schools was on a same level compared to schools built in the 1930s.

Based on a visual inspection of Figure 2, the heating energy consumption of modern daycare centers was approximately 100 % * (160 kWh/(m^2a) – 240 kWh/(m^2a))/240 kWh/(m^2a) = -33 % lower than those built in the early 1970s. If the change is calculated only to 2008, it is approximately 100 % * (220 kWh/(m^2a) – 240 kWh/(m^2a))/240 kWh/(m^2a) = -8 %.

The electricity consumption of schools and daycare centers is presented in Figure 3.

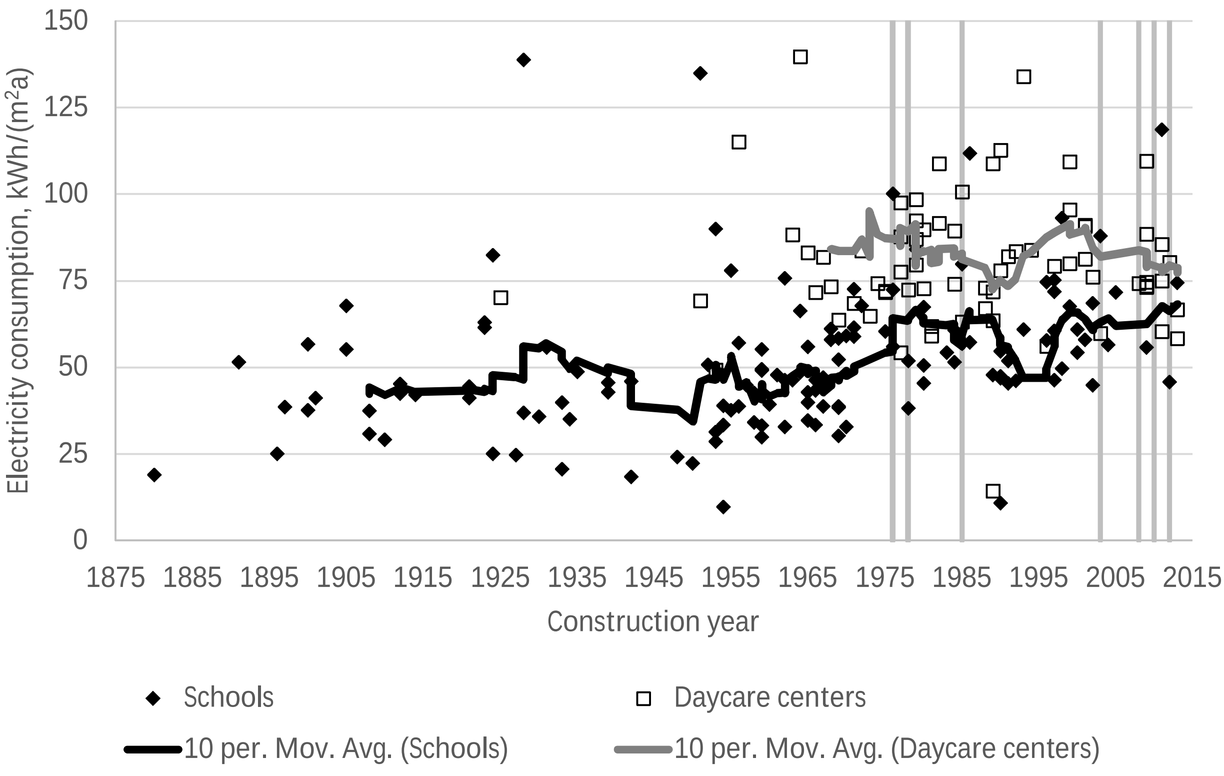

Figure 3 Electricity consumption per gross floor area in 2014.

Based on Figure 3, the electricity consumption of school buildings (in kWh/(m^2a)) was higher in newer buildings than in older buildings. The electricity consumption in daycare centers was relatively constant in buildings regardless of their construction year. On average, the electricity consumption has been a lower in the school buildings than in the daycare centers, similarly to heating energy consumption. Some basic parameters describing the data are given in Table 6.

Table 6 Basic parameters and p-values of the normalized heating energy and electricity consumption of Finnish schools and daycare centers. If the calculated p-value was less than 1e-5, it was marked as "~0". GFA = Gross floor area.

		Schools, n = 134				Daycare centers, n = 71			
Topic		**GFA**	**Heating**	**Electricity**	**Total**	**GFA**	**Heating**	**Electricity**	**Total**
Max.		16253	319	139	391	2248	383	220	492
95th		9859	232	89	323	1576	304	114	441
Mean		5374	160	52	212	1019	211	82	293
50th		5304	155	48	202	994	200	78	288
5th		1439	107	25	149	512	133	57	201
Min.		741	80	10	120	417	54	14	68
Std.		2628	42	21	52	336	59	25	73
Normality, original data	L	0.1	0.007	<0.001	<0.001	0.017	0.27	<0.001	0.16
	AD	0.027	<0.01	<0.01	<0.01	<0.01	0.096	<0.01	0.013
	SW	<0.001	<0.001	~0	~0	<0.001	0.18	~0	0.017
Symmetry, original data	TT	0.19	<0.001	0.004	~0	0.23	0.17	0.038	0.15
Normality, log-transformed data	L	<0.001	0.6	0.03	0.18	0.18	0.012	<0.004	0.041
	AD	<0.01	>0.15	<0.010	0.056	0.063	<0.010	<0.010	<0.010
	SW	~0	0.91	<0.001	0.082	0.084	<0.001	~0	~0
Symmetry, log-transformed data	TT	~0	0.49	0.38	0.044	0.35	0.64	0.45	0.98

Based on Table 6, the heating energy consumption of school buildings was approximately between 110…230 kWh/(m^{2}a) and in daycare centers between 130…300 kWh/(m^{2}a). The electricity consumption of school buildings was approximately between 25…90 kWh/(m^{2}a) and in daycare centers between 60…115 kWh/(m^{2}a).

The heating energy consumption of daycare centers was normally distributed, but otherwise the measured energy consumption values were not normally distributed. By taking the natural logarithm of the values, the heating energy consumption of schools could be transformed to normally distributed, but the transformed electricity consumption data was not normally distributed for either schools or daycare centers.

The school buildings had approximately 2–7 times larger gross floor area than the daycare centers. The distribution of the untransformed gross floor area was not normal but was symmetrical. The log-transformation made the gross floor area of daycare centers normally distributed, but not for schools. The calculated p-values from comparisons of variances and means are presented in Table 7.

Table 7 Comparison of variances and means between schools and daycare centers. The calculations were done both on the original and log-transformed data. If the calculated p-value was less than 1e-5, it was marked as "~0". GFA = Gross floor area. From the multiple choices of tests for equal variances, the correct one is underlined.

		Original data without transformations				**log-transformed data**			
Topic		**GFA**	**Heating**	**Electricity**	**Total**	**GFA**	**Heating**	**Electricity**	**Total**
Equal variances	F	~0	<0.001	0.08	<0.001	~0	0.022	0.012	0.049
	B	~0	<0.001	0.083	<0.001	~0	0.023	0.011	0.052
	BF	~0	0.006	0.77	0.021	<0.001	0.34	0.009	0.77
	FK	~0	0.011	0.93	0.024	<0.001	0.61	0.002	0.77
	CSR	~0	0.011	0.99	0.049	<0.001	0.76	<0.001	0.65
Equal means	all tests	~0	~0	~0	~0	~0	~0	~0	~0

Because of the non-normality of the data, the Conover squared ranks test for equal variances and Wilcoxon-Mann-Whitney test for equal medians were the primary tests for the original data. The logarithmic transformation did not always improve the situation, so the non-parametric tests were used. Based on Table 9, the variances of electricity consumption for schools and daycare centers were not different from each other, but the variances of heating energy consumption and floor area were. The differences between the means in both heating energy and electricity consumption were statistically significant for both schools and daycare centers.

The impact of floor area is next studied further. The specific consumption values of heating energy in schools and daycare centers is plotted against the gross floor area in Figure 4.

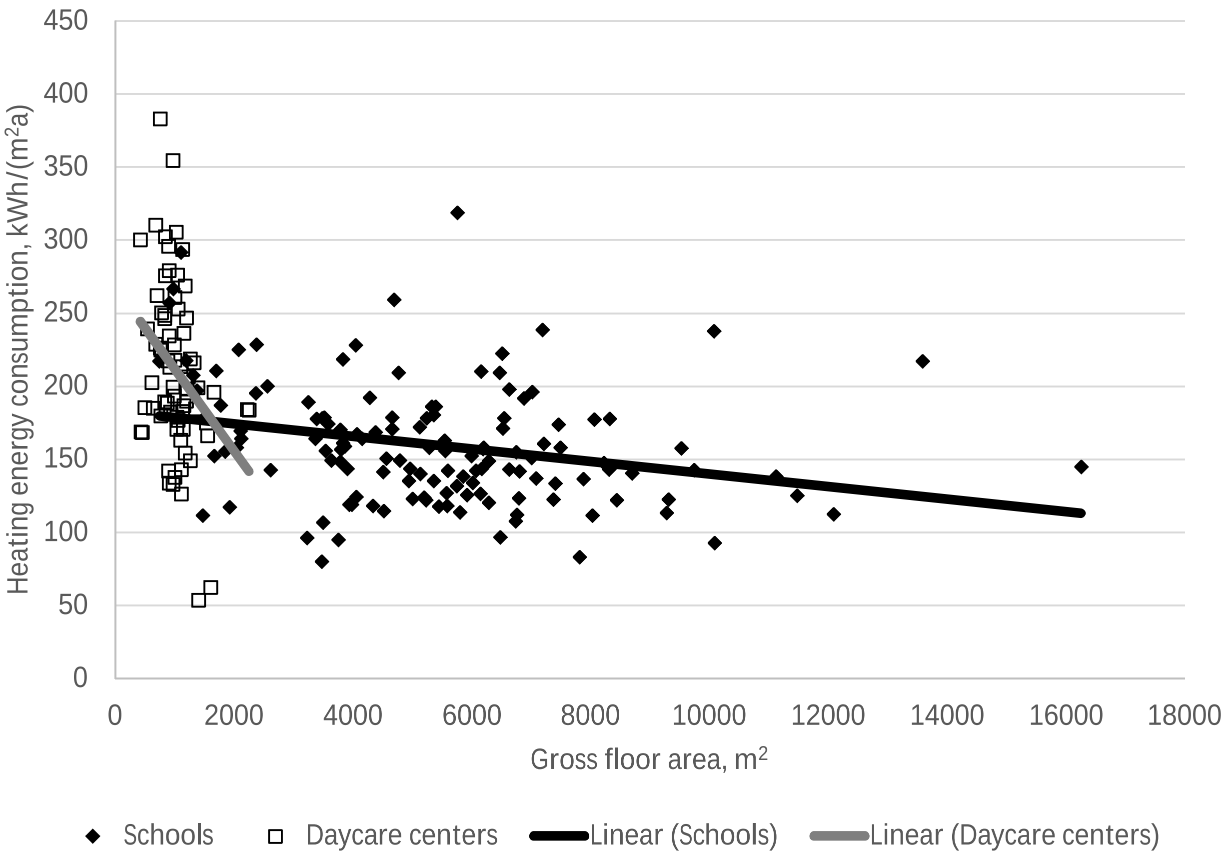

Figure 4 The daycare centers had on average smaller gross floor area and higher specific heating energy consumption than schools. The electricity consumption values had a similar behavior.

Based on Figure 4, the larger buildings had smaller heating energy consumption than the smaller buildings. When the heating and electricity consumption data was plotted separately for schools and daycare centers with a regression curve (four figures, not shown here) there was a downward slope in each of them. However, the impact for e.g. each 1000 m^2 is so small compared to the other variation, that a bigger impact is seen only with a categorical change in the gross floor area. It is also noted that the slope of the regression line is steeper for the daycare centers, which have smaller floor area.

Table 8 shows the mean and standard deviation of energy consumption values (in kWh/(m^2a)) for schools and daycare centers, calculated for each ten-year bin. The data was divided into bins to be able to estimate the time-dependent changes in the standard deviation of energy consumption. The table also shows the Spearman correlation coefficient between each data set and the lower end of the year bin. The two-sided p-value is related to the null hypothesis that the two data sets are uncorrelated. The year 1935 was used to for the year bin "< 1945".

Table 8 The mean and standard deviation of heating energy and electricity consumption in ten-year bins (GFA = Gross floor area, H = Heating energy, E = Electricity). a) The second Spearman correlation coefficient values are calculated directly from the original data.

		Construction year bins								**Spearman r.c.c.[a)]**		**Grand mean and std. of std.s for 1945-**	
		-1945	1945-1954	1955-1964	1965-1974	1975-1984	1985-1994	1995-2004	2005-	rho	p	Mean	Std
Schools													
H	Mean	159	140	165	184	154	145	158	135	-0.43, -0.12	0.29, 0.18	154	17
	Std	35	29	44	43	40	35	43	44	0.41	0.32	40	6
E	Mean	45	46	48	49	61	55	64	73	0.98, 0.46	<0.001, ~0	57	10
	Std	22	36	13	12	16	22	13	25	0.05	0.91	20	9
GFA	Mean	4667	5811	6132	5728	7253	4930	3931	5518	-0.24, 0.023	0.57, 0.79	5615	1026
	Std	2246	2526	3324	1230	3145	2208	1976	3609	0.07	0.87	2574	843
	n	34	10	20	23	13	13	16	5				
Daycare centers													
H	Mean	180	205	239	234	225	208	218	163	-0.12, -0.33	0.78, 0.004	213	25
	Std	0	21	45	45	58	69	52	39	0.57	0.14	47	15
E	Mean	70	59	114	89	81	81	82	77	0.24, 0.018	0.57, 0.88	83	16
	Std	0	10	21	44	14	27	15	13	0.33	0.42	21	12
GFA	Mean	755	1500	783	1010	949	866	1128	1226	0.40, 0.2	0.32, 0.09	1066	243
	Std	0	748	127	131	209	269	417	334	0.48	0.23	319	216
	n	1	2	3	10	19	14	10	12				

Based on the Spearman rank correlation coefficients in Table 8. the electricity consumption was higher in newer schools (both aggregated and original values) and the heating energy consumption lower in newer daycare centers (not in aggregated values, but in original data). Otherwise the p-values were so low that the null hypothesis of uncorrelation cannot be rejected in most of the cases. If the values are interpreted qualitatively, it would seem that heating energy of schools was lower in newer schools than in older ones, the gross floor area was larger in newer daycare centers than in older ones and that the standard deviation of different variables has either stayed on a same level or increased.

Table 8 also contains the mean and standard deviation of each row. These values can be compared to the results of Table 7. The standard deviation around the mean values is not high enough (17 and 25 kWh/(m^2a)), so that the corresponding means (e.g. 155 vs 213 kWh/(m^2a)) would have likely come from the same distribution. The mean values of standard deviation of electricity consumption on the other hand are closely aligned (20 vs 21 kWh/(m^2a)), which is also in-line with the results in Table 7

In Table 8 the heating energy consumption of schools decreases from the construction year bin 1965-1974 to 1975-1984 and then stays on a stationary level until the construction year bin 2005-. Similar behavior can be seen in the heating energy consumption of daycare centers. This would mean that the actions done after the energy crisis of 1970s and with the current building energy regulations have had an impact on the actual heating energy consumption of Finnish schools and daycare centers. When the time period before 1976 (before normative building energy regulations) is compared to the latest construction year bin (2005-), the heating energy decrease has been 100 % * (135-184)/184 = -27 % for schools and 100 % * (163-234)/234 = -30 % for daycare centers. When compared to the values presented in Chapter 1.4, the realized improvement of building energy efficiency has not been as great as the changes in the regulatory values would suggest (roughly 50 %).

3.2 Comparison of calculated and measured energy consumption

The calculated and measured energy consumption values of the case buildings are presented in Table 9. The 'Total' column is the sum of heating energy and electricity.

Table 9 Calculated and measured energy consumption statistics (kWh/(m^2a)) of the 18 case buildings.

	Calculated values			Measured values		
Topic	**Heating**	**Electricity**	**Total**	**Heating**	**Electricity**	**Total**
Max.	152.1	87.4	228.2	221	101.4	290.1
95^{th} p.	144.7	85.3	214.3	204.8	90.6	288.4
Mean	92.6	60.4	153	137.1	69.3	206.5
50^{th} p.	88.3	60.2	146.5	142.2	66.9	211.1
5^{th} p.	55.9	44.8	104.5	68.5	50.9	131.2
Min.	54	39.5	103.8	55.7	49.9	106.8
Std.	28.6	12.2	35.2	48	13.4	57.9

The differences between the calculated and measures values in Table 9 are quite high. On average the measured heating energy consumption was roughly 50 kWh/(m^2a) higher and the electricity consumption a little bit under 10 kWh/(m^2a) higher than the calculated values. The values were calculated per gross floor area, although the current Finnish calculation system uses net floor area. It was however noted, that as the size of the building becomes larger, the difference between these two floor areas becomes smaller. Using simple calculations, the difference is approximately 5 % in small buildings and 2 % in bigger buildings. The differences between calculated and measured values in percentage are presented in Figure 5 for each of the 18 case buildings.

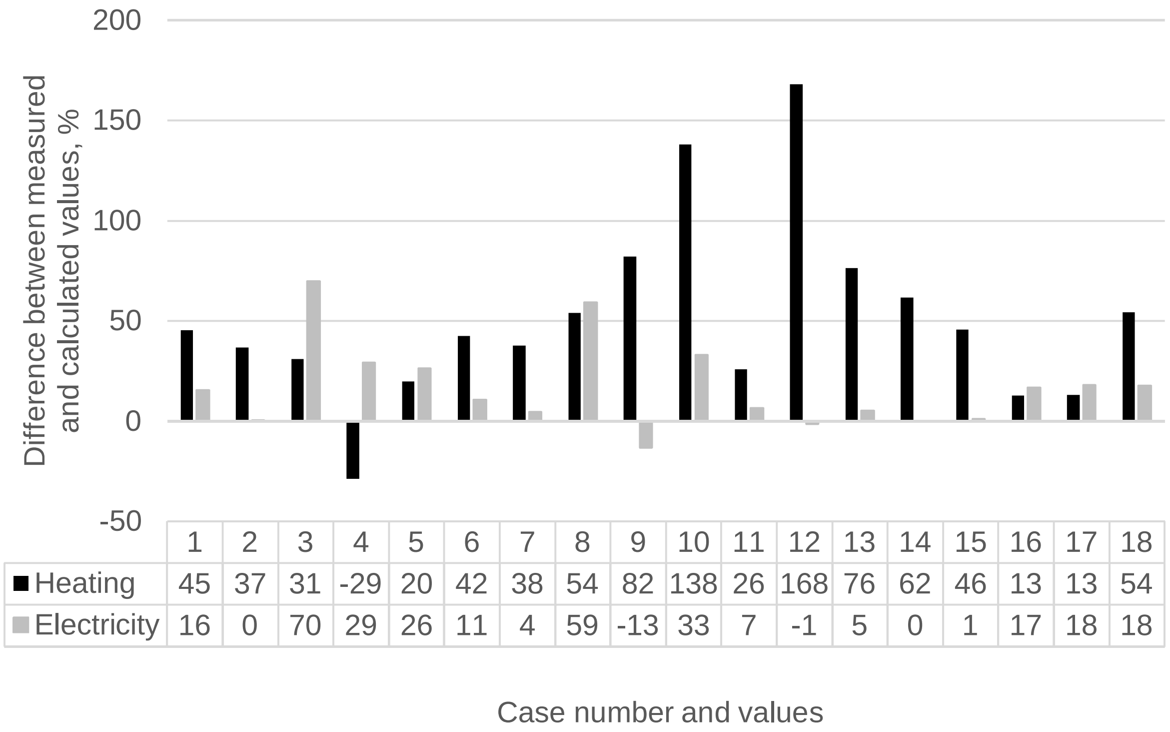

Figure 5 The differences in percentage between the calculated values according to regulations for building permits and measured values for the 18 case buildings (including both schools and daycare centers).

Figure 5 shows that there were big percentual differences especially in the heating energy consumption. The average values were 51 % for heating energy and 17 % for electricity. The cases in Figure 5 are ordered according to the construction year and there seems to be some kind of trend visible in the data. However, because the building process for each building typically has lasted for several years, identifying the exact causality between the construction year and the measured energy consumption is not obvious. Statistical parameters of the differences are given in Table 10.

Table 10 Basic parameters and p-values of the percentual differences between the calculated and measured values. The test statistics for normality and symmetry were calculated from the differences in the kWh/(m^2a) -values (measured - calculated) and for other tests from the percentage values.

Sample statistic/topic		Heating	Electricity	Total
		Differences, %		
Max.		168	69.8	94.1
95^{th}		142.4	60.8	79.6
Mean		50.8	16.6	34.6
50^{th}		43.8	13	31.4
5^{th}		6.4	-3.1	10.5
Min.		-28.9	-13.1	-9.4
Std.		44	20.5	23.2
		p-values		
Normality	L	0.55	0.09	0.44
	AD	>0.15	0.023	>0.15
	SW	0.39	0.032	0.33
Symmetry	TT	0.47	0.16	0.21
Mean/median at zero	tp	<0.001	0.004	<0.001
	WSR	<0.001	0.002	<0.001
	S	<0.001	0.008	<0.001
		95 % Confidence intervals		
Population mean	Bootstrap	31.6…71.7	7.8…26.8	23.8…45.7
	t	29.0…72.6	6.5…26.8	23.1…46.1
Population std.	Bootstrap	20.2…57.8	10.3…26.8	11.9…30.7
	t	34.0…67.9	15.8…31.7	17.9…35.8

Based on Table 10, the differences in heating energy consumption can be assumed to be drawn from a normal distribution, but the electricity consumption differences not. Differences in both can be however assumed to be from a symmetrical distribution. The null hypothesis of the mean being equal to zero can be rejected, which means that there was statistically significant difference between the measured and calculated values.

The 95 % confidence intervals for the population mean and standard deviation were quite close to each other with the two different methods. The confidence intervals for the population standard deviation had a larger difference (bootstrap vs t-distribution), but were still of the same magnitude.

The confidence intervals based on t-test assumes an underlying normal distribution (Devore, 2012, p. 285), so the bootstrap values are more appropriate for differences in electricity consumption.

4 Discussion

Many factors affect the energy consumption of schools and daycare centers. In an optimal situation, we would have a good understanding of all the processes related to the indoor air conditions, building use, targeted energy consumption level, functionality of the building and its systems and so on. This means that the energy consumption aspects presented here form only a small portion of all the matters that e.g. building owners and maintenance personnel must consider.

The standard use that is used to show the regulatory compliance, does not consider the impact of kitchens and small (less than 10 % of total floor area) gyms. Many Finnish schools and daycare centers have these and they are known to increase building energy consumption. The increased energy consumption is through higher electricity and water use and ventilation and air conditioning need. These create both higher indoor heat loads (reduces heating energy consumption) and higher ventilation heat losses.

Some Finnish buildings use electrical heaters to keep eave gutters open during spring and autumn periods (to prevent uncontrolled water leakages from roof). They can be also used to keep for example stairs and small yard areas free from snow and ice during winter. The impact of these is currently not considered in the regulatory building permit calculations, as is not the impact of outdoor lighting.

Schools and daycare centers were observed to have a wide range of occupancy hours and occupant density (Sekki, et al., 2015b). More occupancy hours require more ventilation, which affects the energy consumption according to source (Santos & Leal, 2012). On the other hand, the occupancy hours of standard use were in line with the average occupancy when compared to (Sekki, et al., 2015b). However, standard use expects the building to be used year-round, but schools have 10-week summer vacation in Finland and other shorter vacations. Daycare centers are typically also closed for some time in the summer.

The large sample of 134 schools and 71 daycare centers include many kinds of buildings with different building systems and use. Some of the buildings have had retrofitting, extensions or even new buildings built next to them, which are eventually metered with the same energy meters. These modifications have not been considered separately, but have been handled as a part of the original building, with older year of construction. Retrofitting old buildings or adding new parts to them, should hypothetically improve the energy efficiency of buildings.

The high variation in the consumption data between different buildings is visible in the literature sources and in the energy consumption data presented in this paper, both in the large and smaller sample. On one hand, this makes it difficult to compare the true performance of different buildings, because also for example indoor air conditions should be taken into account. On the other hand, the high variation would imply that there exists energy-saving potential in the building stock.

The purpose of the comparison calculations was not to reach as good equivalence as possible, but to understand the accuracy of so-called “blind” calculations. In principle, adjusting the input values of the monthly calculation method or using methods that are more sophisticated would likely improve the accuracy of the calculations. However, the monthly calculation method is currently an allowed method to show the regulatory compliance and as a part of it, fixed input values must be used. Because all new buildings must fulfill certain energy efficiency regulations and similar comparisons were not available in the existing literature, it was considered relevant to conduct the studies presented here. Further studies could use dynamic simulation tools and improved input data to identify the key points for reaching better calculation accuracy compared the measured values.

5 Conclusions and policy implications

This study analysed the energy consumption data of 134 schools and 71 daycare centers from Finland. The buildings were built between the years 1880 and 2013. The study also compared the measured building energy consumption of 18 new energy efficient schools and daycare centers to regulatory calculations results that are done for building permit applications.

Based on the analysis, the daycare centers used more heating energy and electricity per gross floor area than schools. The variance in electricity consumption for both groups was similar, but for heating energy consumption there was a statistically significant difference in the variances. From a practical point of view however, that difference is not considered very big. In that case, the results would mean that even though there is a difference on the average energy consumption of the two groups, the variation within them would be similar to each other.

The specific energy consumption (in kWh/(m^2a)) correlated with the gross floor area of the buildings. The daycare centers had both categorically smaller gross floor area and a higher specific energy consumption, compared to schools. Currently in the Finnish building energy regulations the limit value depends on the floor area for detached houses and similar. Based on the results presented here, the impact of floor area should be taken into account also in school and daycare buildings.

The measured electricity consumption was higher in newer school buildings than in older ones. The heating energy consumption of newer daycare centers had an indication of being lower than in older ones. The gross floor area of schools did not seem to have a correlation to the construction year, but a stronger correlation was found for daycare centers. When the impact of floor area increase is taken into account, it is possible that the specific energy consumption of daycare centers has not become lower due to energy efficiency measures, but only because the newer daycare centers are larger than the older ones.

The specific heating energy consumption was 27 % lower for daycare centers and 30 % lower for schools in new buildings (2005-) than for buildings built before the first official building energy regulations (1965-1975). Based on the changes in the regulatory values, such as U-values, air tightness values, exhaust air heat recovery efficiency, etc., the decrease in space heating demand should be roughly 50 % or so. This means that the heating energy consumption of schools and daycare centers has not decreased as much in the newer buildings than what the regulatory values would indicate. Based on literature sources and the high variation in the large sample, it is probable that the temperature set points, ventilation rates and the building use in general were different in the older and newer buildings, which blurred the impact of building energy efficiency measures.

The measured (billed) energy consumption of the new schools and daycare centers was clearly higher than the values calculated with the monthly steady-state method with regulatory input data for building permits.

As a summary, the electricity consumption in schools (kWh/(m^2a)) was higher in newer than in older buildings. The heating energy consumption of newer schools and daycare centers was lower compared to buildings before the first Finnish building energy regulations. This decrease however was not as big as the changes in the technical limit values would imply. The gross floor area of buildings had an correlation on the specific energy consumption (kWh/(m^2a)) and because typically the schools and daycare centers had categorically different gross floor areas, the two building types should have different energy performance targets.

The currently allowed monthly calculation method with the regulatory standard use underestimated the energy consumption of new Finnish schools and daycare centers. The differences were larger in heating energy than in electricity consumption, although heating energy is currently calculated in a more detailed level of these two in the Finnish building code guidelines. This would imply the need for building designers to carefully examine their input data, especially related to temperature conditions and heat transfer.

Acknowledgements

The acknowledgements will be added to the final version.

Appendix A

Some characteristics of the case buildings. CAV stands for constant air volume and VAV for variable air volume. The thermal inertia is a value from a table in the NBCF D5 (2012) [11]. See equation (1) for the calculation of air changes per hour (ACH).

Case	Year of construction	Purpose of use	Source of heating energy	Net floor area (m^2)	Mean U-value	Ventilation system	Infiltration (ACH)	Ventilation annual heat recovery efficiency (%)	Thermal inertia ($Wh/(m^2K)$)
1	2005	Daycare center	Oil	1307.7	0.25	CAV	0.164	44.5	110
2	2006	Daycare center	District	1250.9	0.25	CAV	0.135	75.4	110
3	2006	Daycare center	District	1694.3	0.312	CAV	0.118	84.5	70
4	2006 & 2010	Daycare center	Oil & wood pellet	2266.1	0.231	CAV	0.145	54.8&69.6	110
5	2007	School and sports hall	District	6258.5	0.286	CAV	0.074	74	160
6	2009	Daycare center	District	1051.5	0.275	CAV	0.031	60.6	160
7	2009	Daycare center	District	1329.3	0.287	CAV	0.122	55.3	70
8	2009	Daycare center	District	377.6	0.192	CAV	0.1	61.4	70
9	2009	School	District	7354.9	0.25	VAV	0.1	81.5	160
10	2011	Daycare center	District	1512.9	0.214	CAV	0.033	69.9	160
11	2011	Daycare center	District	1443.7	0.126	CAV	0.021	65.7	110
12	2011	Daycare center	District	1153.5	0.217	VAV	0.042	70.1	110
13	2011	School and daycare center	District	1149	0.205	CAV	0.033	60.5	160
14	2012	School and daycare center	District	2956.2	0.193	VAV	0.026	72.2	160
15	2012	Daycare center	District	819.9	0.26	CAV	0.06	64.8	70
16	2012	School, daycare center and sports hall	District	5165.9	0.214	CAV	0.083	60.5	160
17	2012	Daycare center	District	2028.4	0.172	CAV	0.042	68.2	110
18	2013	School and daycare center	District	4895.6	0.206	VAV	0.025	70.2	160

References

Beusker, E., Stoy, C. & Pollalis, S. N., 2012. Estimation model and benchmarks for heating energy consumption of schools and sport facilities in Germany. *Building and Environment,* Volume 49, pp. 324-335.

BRECSU, 1998. *Energy consumption guide 73. Saving energy in schools.,* s.l.: Building research energy conservation support unit.

Butala, V. & Novak, P., 1999. Energy consumption and potential energy savings in old school buildings. *Energy and Buildings,* Volume 29, pp. 241-246.

Choi, J.-H., 2017. Investigation of the correlation of building energy use intensity estimated by six building performance tools. *Energy and Buildings,* Volume 147, pp. 14-26.

Conover, W. J., Johnson, M. E. & Johnson, M. M., 1981. A Comparative Study of Tests for Homogeneity of Variances, with Applications to the Outer Continental Shelf Bidding Data. *Technometrics,* 23(4), pp. 351-361.

Corrado, V. & Fabrizio, E., 2007. Assessment of building cooling energy need through a quasi-steady state model: Simplified correlation for gain-loss mismatch. *Energy and Buildings,* Volume 39, pp. 569-579.

Crawley, D. B., Hand, J. W., Kummert, M. & Griffith, B. T., 2008. Contrasting the capabilities of building energy performance simulation programs. *Building and Environment,* Volume 43, pp. 661-673.

Deb, C. et al., 2017. A review on time series forecasting techniques for building energy consumption. *Renewable and Sustainable Energy Reviews,* Volume 74, pp. 902-924.

Decree 176/2013, 2013. *The decree 176/2013 by the Ministry of the Environment on the energy certificate of buildings (in Finnish).* Helsinki: Ministry of Environment.

Demanuele, C., Tweddell, T. & Davies, M., 2010. *Bridging the gap between predicted and actual energy performance in schools.* Abu Dhabi, UAE, World Renewable Energy Congress XI.

Deurinck, M., 2015. *Energy savings in the residential building sector. An assessment based on stochastic modelling.* Leuven: KU Leuven, Groep Wetenschap & Technologie.

Devore, J. L., 2012. *Probability and Statistics for Engineering and the Sciences.* 8th ed. s.l.:Brooks/Cole, Cengage Learning.

Dias Pereira, L., Raimondo, D., Corgnati, S. P. & Silva, M. G. d., 2014. Energy consumption in schools - A review paper. *Renewable and Sustainable Energy Reviews,* Volume 40, pp. 911-922.

Dijk, H. v., Spekman, M. & Wilde, P. d., 2005. A monthly method for calculating energy performance in the context of European building regulations. *Ninth International IBPSA Conference. Montréal, Canada, August 15-18,* pp. 255-262.

FMI, 2016. *Finnish Meteorological Institute.* [Online]
Available at: http://ilmatieteenlaitos.fi/lammitystarveluvut
[Accessed 5th May 2016].

Herrando, M. et al., 2016. Energy Performance Certification of Faculty Buildings in Spain: The gap between estimated and real energy consumption. *Energy Conversion and Management,* Volume 125, pp. 141-153.

Hitchin, R., 2017. Monthly utilisation factors for building energy calculations. *Building Services Engineering Research & Technology,* 38(3), pp. 318-326.

ISO 13790, 2008. *Energy performance of buildings. Calculation of energy use for space heating and cooling.* s.l.:International Organization for Standardization (ISO).

Jokisalo, J. & Kurnitski, J., 2007. Performance of EN ISO 13790 utilisation factor heat demand calculation method in a cold climate. *Energy and Buildings,* Volume 39, pp. 236-247.

Jylhä, K. et al., 2015. Energy demand for the heating and cooling of residential houses in Finland in a changing climate. *Energy and Buildings,* Volume 99, pp. 104-116.

Jylhä, K. et al., 2015. Hourly test reference weather data in the changing climate of Finland for building energy simulations. *Data in Brief,* Volume 4, pp. 162-169.

Kalamees, T. et al., 2012. Development of weighting factors for climate variables for selecting the energy reference year according to the EN ISO 15927-4 standard. *Energy and Buildings,* Volume 47, pp. 53-60.

Kalema, T., Jóhannesson, G., Pylsy, P. & Hagengran, P., 2008. Accuracy of Energy Analysis of Buildings: A Comparison of a Monthly Energy Balance Method and Simulation Methods in Calculating the Energy Consumption and the Effect of Thermal Mass. *Journal of Building Physics,* 32(2), pp. 101-130.

Kim, Y.-J., Yoon, S.-H. & Park, C.-S., 2013. Stochastic comparison between simplified energy calculation and dynamic simulation. *Energy and Buildings,* Volume 64, pp. 332-342.

Lara, R. A. et al., 2015. Energy audit of schools by means of cluster analysis. *Energy and Buildings,* Volume 95, pp. 160-171.

Mandrekar, S. J. & Mandrekar, J. N., 2003. Are our data symmetric?. *Statistical Methods in Medical Research,* Volume 12, pp. 505-513.

Montazami, A., Gaterell, M. & Nicol, F., 2015. A comprehensive review of environmental design in UK schools: History, confilicts and solutions. *Renewable and Sustainable Energy Reviews,* Volume 46, pp. 249-264.

NBCF D3, 2012. *D3 Energy efficiency of buildings, regulations and guidelines.* Helsinki: Ministry of the Environment.

NBCF D5, 2012. *Calculation of power and energy needs for heating of buildings, guidelines.* Helsinki: Ministry of Environment.

NIST/SEMATECH, 2012. *e-Handbook of Statistical Methods.* [Online]
Available at: http://www.itl.nist.gov/div898/handbook/eda/section3/eda35.htm
[Accessed 3 4 2017].

Ouf, M., Issa, M. & Merkel, P., 2016. Analysis of real-time electricity consumption in Canadian school buildings. *Energy and Buildings,* Volume 128, pp. 530-539.

Pereira, L. D., Neto, L., Bernardo, H. & Silva, M. G. d., 2017. An integrated approach on energy consumption and indoor environmental quality performance in six Portuguese secondary schools. *Energy Research & Social Science,* p. 21 p..

Polly, B., Kruis, N. & Roberts, D., 2011. *Assessing and Improving the Accuracy of Energy Analysis for Residential Buildings,* Golden, CO: U.S. Department of Energy. Residential Buildings Research Group. NREL..

Reynders, G., Diriken, J. & Saelens, D., 2014. Quality of grey-box models and identified parameters as function of the accuracy of input and observed signals. *Energy and Buildings,* Volume 82, pp. 263-274.

Santos, H. R. & Leal, V. M., 2012. Energy vs. ventilation rate in buildings: A comprehensive scenario-based assessment in the European context. *Energy and Buildings,* Volume 54, pp. 111-121.

Sekki, T., Airaksinen, M. & Saari, A., 2015a. Measured energy consumption of educational buildings in a Finnish city. *Energy and Buildings,* Volume 87, pp. 105-115.

Sekki, T., Airaksinen, M. & Saari, A., 2015b. Impact of building usage and occupancy on energy consumption in Finnish daycare and school buildings. *Energy and Buildings,* Volume 105, pp. 247-257.

Sekki, T., Airaksinen, M. & Saari, A., 2017. Effect of energy measures on the values of energy efficiency indicators in Finnish daycare and school buildings. *Energy and Buildings,* Volume 139, pp. 124-132.

SFS-EN ISO 13789, 2008. *Thermal performance of buildings. Transmission and ventilation heat transfer coefficients. Calculation method.* Helsinki: The Finnish Standards Association SFS ry.

Sprent, P. & Smeeton, N. C., 2001. *Applied Nonparametric Statistical Methods.* 3rd ed. s.l.:CRC Press LLC.

Taeger, D. & Kuhnt, S., 2014. *Statistical hypothesis testing with SAS and R.* s.l.:John Wiley & Sons.

The Ministry of Environment, 1976-2012. *The Finnish Building Code, parts C3 1976, 1978, 2003, 2007, 2010 and 2012,* Helsinki: s.n.

Thewes, A. et al., 2014. Field study on the energy consumption of school buildings in Luxembourg. *Energy and Buildings,* Volume 68, pp. 460-470.

Walpole, R. E., Myers, R. H., Myers, S. L. & Ye, K., 2012. *Probability & statistics for engineers & scientists.* 9th ed. s.l.:Pearson Education, Inc..

Wauman, B., Breesch, H. & Saelens, D., 2013. Evaluation of the accuracy of the implementation of dynamic effects in the quasi steady-state calculation method for school buildings. *Energy and Buildings,* Volume 65, pp. 173-184.

Zhao, H.-x. & Magoulès, F., 2012. A review on the prediction of building energy consumption. *Renewable and Sustainable Energy Reviews,* Volume 16, pp. 3586-3592.