User Related Input Data for Energy Usage Calculations the Case of Low Energy Schools in Sweden

Branko Simanic[1,3,*], Dennis Johansson[1], Birgitta Nordquist[1] and Hans Bagge[2]

[1] Building Services, Faculty of Engineering LTH, Lund University
[2]Building Physics, Faculty of Engineering LTH, Lund University
[3]Skanska Sverige AB, Teknik
*branko.simanic@skanska.se

Abstract. In order to calculate building energy usage, apart from the technical characteristics, user related factors needs to be determined. Unless the user related factors are determined by specific project, the idea is to apply a standardized list of input data for a normal operation during a normal year, so the calculated energy value does not depend on variation of these factors. Such list was issued by Boverket (The Swedish National Board of Housing, Building and Planning) in a document named BEN1 in 2016, and updated in BEN2 in 2017. A disadvantage of this list is that, the part about schools is based on references that are rather older and sparse and needs to be updated.
This paper investigates the user related input data in 10 newly built low energy schools in Sweden and compares those to BEN2. It also compares the schools' calculated energy performance to the BBR25 requirement, the latest national building codes and recommendations. The schools are investigated in this research as there is a demand for about 1 000 elementary schools to be built in Sweden in the coming 10 years.
The paper shows significant user related effect to energy usage and importance for the standardized user related input data for energy calculations. Future research aims to verify these calculations and user related input data with measured data for the chosen schools.

Keywords: low energy schools, user related input data, calculated energy.

1 Introduction

The total energy needed for a building is influenced, not only by technical characteristics, but also by user related factors such as tenant electricity and domestic hot water (DHW) usage. When focusing on the technical design stage, it is therefore important to have the same basic conditions for user related factors, so that the calculated energy value does not depend on variation of these factors. Unless there are specific reference values for the building project, the ideas is to apply the same reference values for all objects. For this reason Boverket (The Swedish National Board of Housing, Building and Planning) has issued user related input data for the calculation of energy usage during normal operation and a normal year for a new building construction or retrofit in a document named, BEN2 [1]. A disadvantage of this list is that the part for elementary and secondary schools is based on older references which needs to be reviewed [2].

The lack of standardized user related input data has been identified as a big challenge for data collection [3]. One line of research has focused on particular parameter such as occupancy [4], [5] and [6]; DHW usage in multifamily dwellings [7], [8] and artificial light control and another line has focused on probabilistic building simulation models in order to predict occupant behavior influence on energy usage [9], [10]. However, there are few studies considering user related input data for schools [4], [5].

This paper investigates user related input data in several recently built low energy schools and ongoing projects in Sweden, and compares these to BEN2. It also compares the schools' theoretically calculated energy performance to BBR25 (Swedish national building codes and recommendations) [11] requirement, the latest national building codes and recommendations, issued by Boverket, which is heading towards near-zero energy building (N-ZEB) codes. We assume that these low energy schools will meet the N-ZEB requirements which are to be implemented by 2021, according to EU/2010/31 directive, article 2 [12]. Low energy schools are determined as their calculated energy usage is 75% of the applied BBR requirement. Only elementary schools are considered and are presented by their code names as they want to stay anonymous.

This paper considers the elementary schools only as there is a demand for about 1 000 elementary schools to be built in Sweden in the coming 10 years which is a consequence of population growth [13]. By 2024 population will be increased from 10 to 11 million [14]. 20 large ongoing school projects were listed in Byggvärlden, a building construction magazine, in Sweden 2016 [15]. 30 new schools will start to be built in Gothenburg, the second largest city in Sweden, in 2019 [16].

Table 1. Nomenclature used in this paper

Atemp	Space heated area above 10°C in square meters
BBR	Swedish national building codes and recommendations
BEN	Swedish national codes and recommendation in order to determine building energy usage during normal operation and normal year
DH	District heating
DHW	Domestic hot water
E_{BP}	Energy for building property (electricity), not tenant electricity
E_{cool}	Energy for space cooling
E_{DHW}	Energy for DHW production
E_{SH}	Energy for space heating
EP_{pet}	Energy performance requirement
F_{geo}	Geographical correction factor
GSHP	Ground source heat pump
HDH	Heating degree hours (°C h/year)
IAQ	Indoor air quality

$q_{average}$	Average fresh air flow (liter/(s m²))
PE	Primary energy factor for energy source
PV	Photo voltaic
N-ZEB	Near - zero energy buildings
SH	Space heating
VAV	Variable air volume ventilation

2 Swedish national building codes and recommendations for energy use, BBR and BEN

In BBR25 in chapter 9 (dedicated to energy performance), Boverket has introduced a primary energy as the energy usage requirement. Primary energy factors (*PE*) are 1.6 for electricity and 1 for other energy sources (district heating/cooling, biofuel, oil, and gas). By 2021 these factors will probably turn into 2.5 for electricity and 1 for the other energy sources [17]. In BBR25 EP_{pet} requirement for school building is 80 kWh/(m²$_{Atemp}$ year) plus supplement for air flows, see equation 1. EP_{pet} includs energy for space heating/cooling, domestic hot water DHW and building property electricity E_{BP} to drive HVAC system, BMS, elevators, roof defrosting etc., see equation 2. EP_{pet} does not include tenant electricity. To EP_{pet} is added a factor that covers geographical/climate differences for space heating F_{geo}, where the lowest value is 0.8 and the highest is 1.9. Overall U value requirement in BBR25 is 0.6 W/(m² K).

In order to obtain building construction permit from the local authority a project must submit theoretically calculated EP_{pet} which must comply with actual BBR requirement. To calculate EP_{pet}, a project specific users related input data can be used or a list of input data for e.g school buildings for normal operation during a normal year. Such list is issued by Boverket in BEN1 [18] and the latest updated in BEN2 [1]. Prior to BEN the Sveby (Swedish building industry standards for energy and buildings), introduced a list of user related input data for educational buildings [2] in May 2016.

There are several types of buildings listed in BEN2: dwellings, residential buildings, offices, children day cares, elementary school and gymnasiums, high schools and universities [1].

Primary energy number EP_{pet} requirement for commercial buildings (which addresses school buildings) is:

$$EP_{pet} = 80 + 70 \cdot (q_{average} - 0{,}35) \tag{1}$$

Where $q_{average}$ is average fresh air flow (liter/(s m²$_{Atemp}$)) during heating season, where maximum can be 1. EP_{pet} (kWh/(m²$_{Atemp}$ year)).

Primary energy number EP_{pet} is calculated as:

$$EP_{pet}=\sum^{6}_{i=1}((E_{SH,i}/F_{geo})+E_{cool,i}+E_{DHW,i}+E_{BP,i}) \cdot PE_i/A_{temp} \qquad (2)$$

Where: "i" is type of energy source. EP_{pet}, E_{SH}, E_{cool}, E_{DHW}, E_{BP} in (kWh/(m^2_{Atemp} year)), A_{temp} in (m^2_{Atemp}), F_{geo} and PE are constants.

3 Comparison among several low energy school projects

The energy performance of 10 Swedish elementary schools compares to BBR25 energy requirement and their user related input data to BEN2 in table 2 and 4. These schools were built or have being built under the older versions of BBR. Neither BEN1 nor BEN2 were used in these school projects. The school "A", has used Sveby's input data list [2] in the later stage of its' construction. Energy engineers in these school projects estimated user related influence usually based on their experience and/or project specific data.

The chosen schools applied earlier versions of BBR. In these versions the energy performance requirement were based on purchased energy and there were different requirements if electricity is used for the space heating or not.

The schools are chosen by several criteria. The most important is to be a low energy school and recently built, and their calculated energy usage must be 75% of actual BBR requirement, as their energy performance can comply with year 2021 energy requirements. Another criteria is an established measurement data export from the building management system, as the schools are going to be monitored during one year period. Each school projects have calculated their energy demand based on the project specific data and the projects estimations.

Among the projects the energy performance requirement varies, as there have been several BBR issued during the last several years, where the requirements for electrically heated and non-electricity heated buildings were separated, see first column in table 2.

Mainly IDA ICE [19] a dynamic computer simulation tool was used to calculate energy usage. Another simulation tool used in one school was VIP Energy [20] .

Table 2 compares calculated energy usage according to applied BBR for each school project and to BBR25 requirement which has been calculated in this paper. The schools' energy calculations were made for normal usage and normal year. Estimated electricity production by solar photovoltaic do not account in calculated energy usage in this paper. Table 2 shows that the calculated energy is about 75% of the applied requirement, so the schools meet BBR25 EP_{pet} requirement which makes them relevant in this study.

Table 2. Energy performance of the listed schools

School name (code name)	Energy performance according to applied BBR (purchased energy)		EP_{pet} according to BBR25 (primary energy)	
	Requirement/ (kWh/(m²$_{Atemp}$ y))	Calculated/ (kWh/(m²$_{Atemp}$ y))	Requirement/ (kWh/(m²$_{Atemp}$ y))	Calculated/ (kWh/(m²$_{Atemp}$ y))
S	55	38	80	70
N	91	62	91	75
K	80	33	80	44
B	75	38	80	60
Va	80	51	84	68
Vi	80	51	80	60
Ve	88	40	88	52
L	60	34	88	56
A	65	26	110	50
G	65	54	80	61
Average	74	43	86	60

The table 3 shows data such as building year, size, climate, shape, type of ventilation, thermal resistance and source of space heating and DHW production.

Table 3. Building year, size and some other features of the listed schools

	In operation since	Floor area/ (m²)	HDH/ (°C h/y)	Envelop area/volume ratio/ (m²/m³)	Ventilation system	Overall U value / Windows U value/ (W/(m²K))	Heating energy source/ renewable energy
S	Aut. 2016	4 764	102600	0,38	VAV	0.23 / 0.9	GSHP
N	Spr. 2017	8 125	92800	0,44	VAV	0.45 / 0.85	DH
K	Aut. 2016	11 222	102600	Unknown	VAV	0.18 / 0.8	DH/Solar PV
B	Aut. 2014	8 051	111500	0,39	VAV	0.2 / 0.9	GSHP
Va	Aut. 2017	9 000	111500	0,31	VAV	0.37 / 0.9	DH
Vi	Aut. 2016	1 725	118000	Unknown	VAV	0.21 / 0.9	DH
Ve	Aut. 2015	3 233	92800	Unknown	VAV	0.21 / 0.8	DH/GSHP/ Solar H
L	Aut. 2016	898	99600	Unknown	VAV	0.26 / 1	GSHP/Solar PV
A	2018	9 073	92800	0,41	VAV	0.28 / 1	GSHP/Solar PV
G	2018	4 690	92800	0,37	VAV	0.3 / 0.9	DH/Solar PV

The shape of the school buildings are pretty similar, usually made of several rectangular blocks joint together by corridors and smaller rooms. They are mainly two floors buildings, a few are with one floor only. Almost all of them have sport hall and fully equipped kitchen facility with dining hall, apart from “Vi” and “L”. “Ve” and “G” do not have sport hall. Each block has usually its own centralized ventilation system. The schools do not have separate comfort cooling systems.

Average annual outdoor temperature varies from 5.5 to 7°C. Heating degree hours (HDH) numbers are taken from Swedish standard HVAC tables [21]. Some schools are at the very south of Sweden, two of them are as north as Stockholm, and others are in between.

Table 4 shows user related input data from the chosen schools and BEN2. The air flow column indicates operational time for the ventilation system and its air flow. There are basic (minimum) and forced (maximum) air flows. In the simulation/practice, the air flows are somewhere between basic and forced air volumes as the VAV system is implemented in the schools. The ventilation system in the kitchen and the dining hall can have a shorter and the sport hall longer operational hours. Almost each classroom has its own airflow's control system that can depend on: presence detectors, room air temperature and/or CO_2 level. One or the most two parameters to control the VAV system are usually used.

The sun shading column includes both fixed and variable sun shading. The variable solar shading includes interior and exterior solar shading devices, which can be influenced by the users. Two different numbers per school, in table 3, means that there are different shading system depending on façade orientation.

The DHW includes thermal losses for the DHW recirculation circuits. BEN2 excludes these losses in the DHW number. The kitchen's energy is included in the tenant electricity and its' DHW usage is a process energy. These two are not included in BBR's energy requirement.

The airing column presents energy losses due to opening of windows/doors by users. The value 4 kWh/(m^2_{Atemp} year) is based on earlier reference [22].

The tenant electricity (lighting and equipment) is not included in EP_{pet} calculation but it emits free heat and contributes to space heating. In some schools lighting and equipment are estimated to be on during 52 weeks/year, in one is 39 weeks/year, the others are in between. The tenant electricity can be as low as 8 kWh/(m^2_{Atemp} year) and as high as 35 kWh/(m^2_{Atemp} year). It shows the complexity to predict user related electricity usage and how large variations can be even though the schools in practice are having the same energy efficient type of lighting and equipment and its amount.

The average values in table 4 are based on the values of the chosen schools.

Table 4. User related input data list for elementary/secondary school building and its' implementation in the listed schools

	Indoor air temper.	Air flow	Sun shading	DHW	Tenant electricity	Personnel	Airing
	Minimum air Temperature/ (°C)	Basic/forced (l/sm²)/(l/sm²) Time (h/d/w)/(h/d/w)[1)]	User related control	Not including losses for DHW recirculation/ (kWh/(m² year))	Annual value (kWh/m² year) to calculate PET Lighting/(W/m²) Time/(h/d/w)[1)] Equipment/ (W/m²) Time (h/d/w)[1)]	Person density/ (persons/m²) Time/ (h/d/w) [1)] Person heat effect/ (W/person)	Annual value to calculate EP_{pet}/ (kWh/(m² year))
BEN 2	22	3/-[6)] (10/5/44)/-[6)]	0.65	2/η_{DHW}	22 5 (10/5/44) 5 (10/5/44)	0.067 (6/5/44) 80	4/η_{SH}[3)]
S	21	0.5/2.2 (7/7/52)/(7/7/52)	0.29 – 0.5	4.6[5)]	7.8 2(11/5/52) 2 (7/5/52)	0.06-0.3 (7/7/52) 108	1.86
N	21	0.5/2.7 (6/5/52)/(6/5/52)	0.5	6[5)]	19 4(11/5/52) 3.5 (8,5/5/52)	0.06 (8,5/5/52) 120	2
K	21	1.3/1.9 (5/5/40)/(5/5/40)	0.75	4[5)]	8 3(8/5/40) 2 (8/5/40)	0.058 (8/5/40) Unknown	Unknown
B	21	1.4/2.8 -/(13/5/52)	0.24–0.51	3.2[5)]	35 12(12/5/52) 2 (6/5/46)	0.13 (5/5/46) 108	1.86
Va	21	0.35/2 -/(10/5/52)	0.5	15[5)]	30 6(10/5/52) 5.5(10/5/52)	0.032 (5/5/52) 108	4
Vi	22	-/2.6 -/(9/5/39)	0.43	5.3[5)]	17 1.5(9/5/39) 8 (9/5/39)	0.11 (9/5/39) 70	Unknown
Ve	21	Unknown	0.1-south	5.2[5)]	Unknown 10(11/5/52) -	Unknown (11/5/52) 80	Unknown
L	21	-/1.8 -/(15/5/52)	0.35	10[5)]	15 - 5.8 (10/5/52)	0.1 (7.5/5/52) 80	4
A	20	0.94/3 -/(12,5/5/52)	0.33 – 0,5	6,1[5)]	14.4 3.5(9/5/44) 3.5(9/5/44)	0.067 (7,5/5/39) 80	4
G	21	0.8/2.6 -/(10/5/44)	0.2-0.45	20[5)]	20.2 3.8(10/5/44)[4)] 2,5(10/5/44)[4)]	0.067 (8/5/44) 80	4
Average	21	0.9/2.4 -/(10/5/49)	0,41	8.5[5)]	18.4 5(10/5/46) 4(8.5/5/46)	0.08 (7.5/5/46) 94	3.1

[1)] Operational time: hours per day, days per week and weeks per year.
[2)] η_{DWH} annual efficiency for DHW production in building
[3)] η_{SH} Annual efficiency for space heating production

4) Part load during holiday time
5) Including hot water recirculation thermal losses
6) The value from BEN1 as it was excluded from BEN2

3.1 Calculated values for space heating, DHW, building property energy and EP_{pet}

Figure 1 shows calculated values of energy for: space heating E_{SH}, domestic hot water E_{DHW}, building property energy E_{BP}, and EP_{pet} in relation to the average value. The values are calculated according to BBR25. The EP_{pet} are very concentrated and near the average value, 60 kWh/(m²$_{Atemp}$ year).

The E_{DHW} values are very scattered as the DHW usage are depending on each project estimation. 2 of 10 schools have very high DHW value which increase the average value. The difference in the estimated values shows how important is to have the standardized input data.

On the other hand, the E_{SH} values are very much concentrated as they are calculated by the energy simulation programs and based on specific input data from each project which are possible to calculate or obtain from vendors. Climate variations cannot be seen in E_{SH} as the geographical factors F_{geo} are included in the calculations.

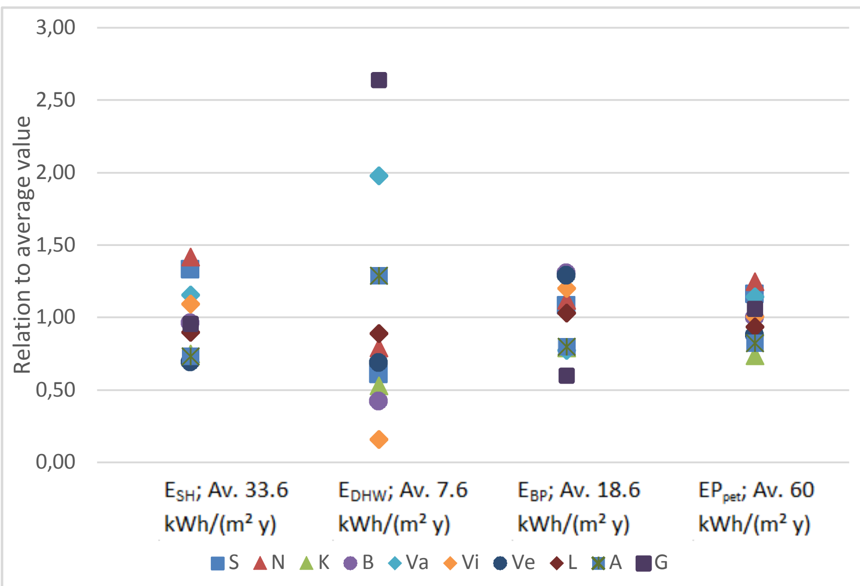

Fig. 1. Calculated values in relation to average value for each school

The ventilation systems in some schools are in operation 52 weeks and at the others about 39 weeks per year. These variation can be seen in E_{BP} results. It varies between

11 and 24 kWh/(m^2_{Atemp} year), the average value is 18.6 kWh/(m^2_{Atemp} year). As the specific fan performance has been required in all latest BBR and is 1.5 kW/m^3/s or better, the variation mainly depends on operational hours and average air flow. The operational hours is the user related parameter. The air flows are also depending on the users as the VAV system is applied in the schools.

The average values of user related parts: E_{DHW} and E_{BP} contribute for 45% of the total energy EP_{pet}. This give us a picture how strong is the user related impact on the overall energy performance.

4 Discussion and Conclusion

The schools used in this study have been built between 2013 and 2017. They are all very well insulated and have similar: shape, ventilation system, and windows and therefore have similar technical conditions regarding energy performance. The average calculated energy performance for the listed schools is 60 kWh/(m^2_{Atemp} year), where 55% is energy for space heating, 15% for DHW, and 30% for building energy property. The user related parameters have tendency to vary a lot, as they are estimated by each energy consultant. The results show that the DHW varies between 3.2 to 20 kWh/(m^2_{Atemp} year), the tenant electricity between 8 and 35 kWh/(m^2_{Atemp} year), or the ventilation operation varies between 39 to 52 weeks per year. However, the user related part contributes to almost 45% of the total energy, so the estimations on users' related parameters have strong impact on the building energy performance.

The calculated values for the space heating or building property energy are more concentrated. Estimations on technical details (such as: size of cold bridges, fan efficiency etc.) can be calculated or obtained from vendors, and therefor they do not cause large variations on the energy calculations. On the other hand, the estimations on soft, user related, details can cause large variations between projects. They are difficult to obtain, calculate and therefore to estimate. These variations illustrate how important is the standardized user related input data list, such as BEN2, to calculate the energy usage during normal operation and a normal year. However, such list should be based on solid reference values. The reference values in BEN2 for Swedish schools are rather old and sparse and there is a need for newer and more reference values for these type of buildings which is a main goal of this study.

This paper shows significant effect of building users' on energy usage and a need for standardize user related input data for the energy calculations. Another line of researchers investigate probabilistic simulations models of occupants' behavior which also need estimated ranges of impact/input data.

The user related input data has been difficult to summarize for the schools, as pupils and staff work flows are moving around the building between classroom, common areas, labs, music rooms, dining room, sport hall etc. Such flows of pupils and staff can be simulated in different ways in building energy simulation programs. Some of the schools' energy reports are comprehensive and have sufficiently enough information on input data. Some reports are very short and content very few information on input data, and the others are in between. There is not defined standard on energy report format by BBR. Thermal comfort and indoor air quality cannot be read from the energy reports.

Another aspect that can affect the energy performance is pupils/personnel interaction with building management system, such as an interaction with temperature/moving sensors, radiator thermostats, ventilation system with a positive or negative intentions. However, those aspects has not been attended to study in this paper.

The energy calculations will be verified and input data list reviewed by monitoring seven out of listed ten schools during one year period. At the same time thermal comfort and IAQ will be evaluated.

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