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Method for probabilistic energy calculations – variable parameters

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Abstract

Building regulations in Sweden require that an energy calculation is done for every building to show that the building design meets the maximum specific energy use as outlined in the Swedish Building Code. The result of this energy calculation is always one number, for example a building might use 89 kWh/m^2 year when the building regulation requires 90 kWh/m^2 year. This level of reporting can lead to conflicts if the measured energy use is over the calculated energy use. With the current tools you need to do a time-consuming parametric study in order to see which risks are associated to the design and material properties.

This paper is part of a project called "Calculation method for probabilistic energy use in buildings" and is developing and testing the application of Monte Carlo simulations using two popular energy calculation tools developed in Sweden. The goals of the project are; to look at which input parameters have the largest influence on the result; to begin defining a realistic spread of the most significant parameters; to study the advantages and disadvantages of probabilistic energy calculations; and to look at the discrepancies between calculated and measured energy use.

This paper presents the results of the first stage of the study defining which input parameters should vary and defining a realistic spread of the values of these parameters. Out of all the input parameters in the case object, it was determined that the method should be tested with 16 parameters with variable values. This paper also presents the preliminary results of an energy calculation done on a real object using the variable parameters and 1000 iterations compared to the base calculation without Monte Carlo simulations.

Keywords: Energy simulations, IDA-ICE, VIP Energy, statistical input, monte carlo

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1. Introduction

1.1. Swedish Code and Practice

Since July 1, 2006, building regulations in Sweden require that an energy calculation is done for every building to show that the building design meets the maximum specific energy use as outlined in the Swedish Building Code [1] [2]. The specific energy use is given in the units kWh/m^2 A_{temp} year. A_{temp}, according to BBR, is the floor area which is heated above 10 °C. The building code also requires that the energy use of the building be followed up within two years after delivery. Since then, various stake holders have been very interested in the actual performance of the building compared to the calculated energy use. This has resulted in a numerous studies looking at the calculated versus measured energy use. Some examples of these studies can be seen in: [3] [4] [5] [6] [7] [8].

The Swedish building industry had a difficult time after the implementation of the new building code based on the performance of a building. The new building code was very different and due to the lack of experience within the building sector, there were many failed projects in which the actual specific energy use was higher than the calculated specific energy use.

An interesting study was done by Annika Nilsson [3] of the Bo01 housing expo in Malmö three years before the building code change. This study gave an indication of the challenges that the building industry had to face if they were to be successful in accurately predicting the specific energy use of a building. In the Bo01 case, all the buildings had a specific energy limit set to 105 kWh/m^2 usable floor area per year so that all the energy used by the area would be covered by locally produced renewable energy sources. Unfortunately, the thesis showed that there was a large gap between energy calculations and measured energy use. None of the 10 buildings studied met their target. Most objects were between 40-60 % over their calculated values (pg 55). The worst case had an energy use of over 300 % higher than calculated. One of the biggest problems identified was the lack of good input data, pg 115. At this time there were not many studies about how much energy different aspects of buildings really used. Energy calculations before were not verified so it was difficult to find input data based on Swedish households. Additional weak points which were identified included problems with the solar gain calculations, lack of thermal bridges, wrong indoor temperatures, as well as a weak knowledge on how to make a building energy efficient by utilizing different components together. [3]

An organization eventually evolved with the purpose of standardizing user data. Sveby, short for Standardize and Verify Energy performance in Buildings, was created with financing from the Swedish Energy Agency and 15 stakeholders from the Swedish building sector with the purpose of defining different input data for energy calculations [9]. This has helped improve energy calculations greatly since the input data is based on measured input data.

Sveby has also held two Energy Calculation Competitions, one for a multi-family building and one for a school. The objects in the calculation were real objects which had extensive measurement data. The competition tried to simulate the Swedish building process and different energy calculations were done for different phases in the building process. The final energy calculation was compared to the object's real energy performance. The competition was used at a test for new input data. Their competitions have analyzed differences in energy calculations related to software, users, input data and methods used. The results varied about 11 % despite the same availability to input data and materials. The results also varied with different software. An important conclusion from the competitions is that the quality of the energy calculations depended on the individuals, and not the tools. Another important conclusion from the first energy calculation competition was that a safety margin of at least 10 % [10], pg 32] was recommended. The conclusion from the second energy competition was that, while the spread between submissions was less than the previous competition, the safety margin should be twice as high when compared to the first competition (i.e. 20 %) because the school used less energy than the residential building [11]. [10] [11]

1.2. Energy calculation programs

One of the earliest energy calculation programs to come out for a computer in Sweden was a program called ENORM 1000 in 1988. The purpose behind this program was to compare the actual building against a reference building defined by the Swedish building code. If the actual house had a lower calculated energy use then it was ok. [12]

The two programs used in this study are descendants of earlier programs which came out after this. VIP+, originally developed by Skanska, came out in 1990 and also calculated against a reference building. VIP+ was a dynamic program calculated an energy balance for the building every hour. VIP+ was primarily focused to residential buildings. The contemporary version of this program is known as VIP Energy. [12]

IDA Indoor Climate and Energy (ICE) came out in 1998 from Brisdata. IDA ICE is a general simulation program in which custom components built by the users can be added to any building model. IDA ICE was generally better suited to commercial buildings and more advanced models than other programs from this era. IDA ICE has continued with the same name. [12]

The result of an energy calculation is always one number. For example a building approved by the building code might be calculated to use 89 kWh/m^2·year even though it is very close to the building regulation of 90 kWh/m^2·year. The building code recommends that safety margins must be used so that the risk of the building going over the limit is low, however the building code does not define the safety level. In some cases a safety margin can mean a more expensive project, and if the contract is based on price, it is possible that the winning bid has not applied a safety margin. This level of reporting can lead to conflicts between the building owner and entrepreneur if the measured energy use is over the energy use defined in the contract or the Swedish building code. In the worst-case scenario the entrepreneur has given an energy guarantee to the building owner and can be thus required to pay compensation to the building owner or improve the building at their own cost until it meets the requirements in the contract.

1.3. Safety Margins

In order to take into account the risks associated with input data, users, and building quality, with the current energy calculation tools you can either to do a time-consuming (i.e. expensive) parametric study or apply a safety margin to the results. A parametric study can allow the project to see which risks are associated to the design and material properties; however they are not usually done due to the increased cost. Applying safety margins are a cheap method of lowering the risk, however all studies focused on this method have difficulty recommending a suitable safety margin because of the large variation between calculated and measured energy use. [10] [11] [13]

In order to go away from the discussion of safety margins and have a method of bringing risk into an energy calculation, a new method for calculating energy use in buildings was needed. Previous research showed that even since the 1990s there has been some interest in applying probabilistic methods in energy calculations [14] [15]. This idea has become more popular the last few years and studies have been done looking at the usability of Monte Carlo simulations on input data [16]. They noted a large variation in their result, from 49 to 156 kWh/m^2 year while only varying five input parameters. An important conclusion in their study was that the input data must be realistic and handle carefully otherwise the results will not be valuable.

1.4. Calculation method project

This paper is part of a project called “Calculation method for probabilistic energy use in buildings” and is developing and testing the application of Monte Carlo simulations using two popular energy calculation tools developed in Sweden. The goals of the project are; to look at which input parameters have the largest influence on the result; to begin defining a realistic spread of the most significant parameters; to study the advantages and disadvantages of probabilistic energy calculations; and to look at the discrepancies between calculated and measured energy use. Out of all the input parameters available in the case object, it was determined that the method should be tested with 16 parameters with variable values. The results show the preliminary results of an energy calculation done on a single-family home using variable parameters and 1000 iterations compared to the base calculation without Monte Carlo simulations.

2. Method

2.1. Input parameter inventory

Since the purpose of this project is to develop a method of doing energy simulations whilst applying Monte Carlo variations on some input parameter, it was critical to find and use realistic input data in the simulations. Sixteen input parameters were chosen to vary according to a realistic variation that would be expected in regards to material properties and user behavior. It is important to note that there is not enough data to define the distributions for most input parameters, however all variations presented are based on a source with some data. A simple distribution was based on the limited data available and the experience of the project's working group in order to test the calculation method. The different types of distributions are shown in Figure 1. Future work is needed to improve the distributions of the different input parameters.

Figure 1: (a) Triangular distribution (b) Uniform distribution (c) Skewed triangular distribution

2.2. Energy calculations

Energy calculations will be done for three objects in this project, one standard single-family home (test case), one passive house single-family home and one multi-family building. This study shows the preliminary result from the standard single-family home. The final results from all three calculations will be reported in future publications.

In order for this to be possible, two energy calculation software companies, Equa and StruSoft, have developed heavily modified versions of their most popular energy calculation software based on VIP Energy and IDA ICE respectively. Lund University has developed algorithms which generate the input-data text file used by both programs. The programs can read how many calculations will be done, as well as read the specific values to be used in the current energy calculation and can export the Swedish specific energy use value for each run.

Each test case for the programs include randomly generated values for each of the input parameters with the distributions as described above in Figure 1 and below in Table 1. This then gives us a distribution of the calculated energy use where the uncertainties in the input parameters are taken into account. We can then estimate quantiles for the calculated energy use that provide an upper bound for the energy use with prescribed certainty. There is also an uncertainty coming from that we use a finite number of random samples for the input parameters. This uncertainty can also be taken into account using bootstrap techniques.

3. Results and Discussion

Table 1 shows the results of the input parameter inventory for the test case.

Table 1. The results from the input parameter inventory for the test case.

Parameter	Symbol	Unit	Initial Value for calculation	Variation	Distribution
Lambda value of mineral wool insulation	λ	W/mK	0,038	±0,006	Triangular
U-value of windows	U-value	W/m^2K	0,9	±0,2	Triangular
g-value of windows	g	-	0,4	-0,2	Skewed triangular

Thermal Bridges	Ψ	% of U*A	25	±10	Uniform
Buildings Airtightness	q_{50}	l/sm² External surface area @ 50 Pa	0,3	±0,2	Triangular
Indoor temperature	T	°C	21	±0,5	Triangular
Supply Fan Specific Fan Power (SFP)	SFP_{Sup}	kW/m³s	0,75	+0,30	Skewed triangular
Extraction fan SFP	SFP_{Ext}	kW/m³s	0,75	+0,30	Skewed triangular
Heat recovery efficiency of Supply and Extract ventilation	η	-	0,8	±0,03	Uniform
Supply air flow	q_{Sup}	l/sm² Atemp	0,35	±0,13	Triangular
Unbalance (extraction air flow)	q_{Ext}	l/sm² Atemp	$q_{Ext}= q_{sup}$ - variation	±0,03	Triangular
Hot water circulation losses	Q_{VVC}	W/m² Atemp	1,72	±1,59	Uniform
Household electricity	Q_{house}	W/m² Atemp	4	±1,15	Uniform
Heat generated by people	Q_{pers}	W/m² Atemp	1,92	±0,44	Triangular
Domestic Hot Water use	E_{DHW}	kWh/m² Atemp yr	20	±10	Triangular
Kitchen Ventilation Losses	E_{KV}	kWh/m² Atemp yr	3	±1	Triangular

The following preliminary results for the calculated energy use were obtained, see Figure 2. We here supply the average and median energy use as well as the 90 % upper quantile with and without finite sample correction. The finite sample correction is done by a bootstrap technique to assess the uncertainty coming from a finite sample size of 1000. The original energy use requirement according to BBR for the house below was 110 kWh/m^2 year. The original energy use calculation showed an energy use of 70 kWh/m^2 year.

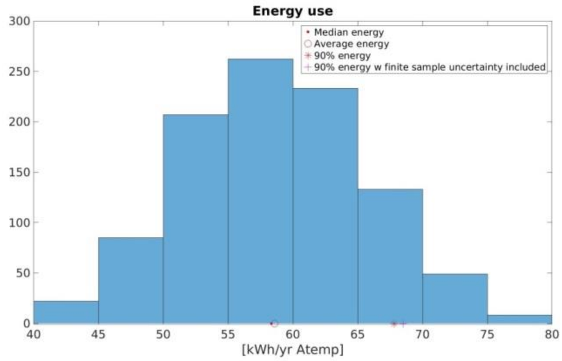

Figure 2: Preliminary results for the standard single-family home using the input data from Table 1.

4. Conclusions

The preliminary results show a nicely shaped normal distribution when using the defined variable parameters. The building requirement for this building during the time of construction was 110 kWh/m^2 year and the energy calculation done by NCC showed that the building should use about 70 kWh/m^2 year.

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References

[1] Boverket, ”Boverkets byggregler - föreskrifter och allmänna råd, BBR (Boverkets building code - regulations and general advice, BBR, in Swedish),” 2016. [Online]. Available: http://www.boverket.se/contentassets/a9a584aa0e564c8998d079d752f6b76d/konsoliderad_bbr_2011-6.pdf. [Använd 25 01 2017].

[2] Boverket, ”Uppföljning av nya byggnaders specifika energianvändning (Follow-up of new buildings specific energy use, In Swedish),” 2009. [Online]. Available: http://cisbo.dk/sites/default/files/Uppfoljning_nya%20byggnaders_specifika_energianvandning.pdf. [Använd 22 01 2017].

[3] A. Nilsson, ”Energianvändning i nybyggda flerbostadshus på Bo01-området i Malmö (Energy use in newly built multi-family dwellings at Bo01 in Malmö, In Swedish),” Lund University, Lund, 2003.

[4] H. Bagge, A. Elmroth och L. Lindstrii, ”Energianvändning och inneklimat i två energieffektiva småhus i Västra Hamnen i Malmö (Energy use and indoor climate in two energy efficient single family dwellings in the western harbour in Malmö, In Swedish),” Department of Building Physics, Lund University, Lund, 2004.

[5] C. Irminger Street, ”Beräkning och uppföljning av energianvändning i lokalbyggnader - Förenklad indata till en avancerad beräkningsmodell (Calculation and follow up of energy use in a commercial building - simplified input data for an advanced calculation model, In Swedish),” Department of Building Services, Lund University, Lund, 2008.

[6] J. Wellholm, ”Avvikelser mellan beräknad och faktisk energianvändning i byggnader - fallstudie av en fastighet byggd 2012 (Differences between calculated and actual energy use in buildings - a case study of a building from 2012, in Swedish),” Uppsala University, Uppsala, 2012.

[7] P. Filipsson och J.-O. Dalenbäck, ”Energiberäkningar - Avvikelser mellan projekterat och uppmätt energibehov - Förstudie (Energy calculations - Differences between calculated and measured energy demand - A prestudy, in Swedish),” Department of Building Services, Chalmers, Göteborg, 2014.

[8] E.-L. Kurkinen, P. Filipsson, S. Elfborg och S. Ruud, ”Difference between calculated and actual energy use - Energy Control during the construction process, in Swedish,” SP Technical Research Institute of Sweden, Borås, 2014.

[9] Sveby, ”Om Sveby (About Sveby, in Swedish),” [Online]. Available: http://www.sveby.org/om-sveby/. [Använd 23 01 2017].

[10] Sveby, ”Resultat från energiberäkningstävling för ett flerbostadshus (Results from the energy calculation competition for a multi-family house, in Swedish),” 2012. [Online]. Available: http://www.sveby.org/wp-content/uploads/2012/01/Etavlingsrapport-Sveby-111003.pdf. [Använd 23 01 2017].

[11] Sveby, ”Utveckling av energiberäkningar – Energiberäkningstävling för Hedlundaskolan (Development of energy calculations – Energy calculation competition for Hedlunda school, in Swedish),” 2016. [Online]. Available: http://www.sveby.org/wp-content/uploads/2016/11/Sveby-Energiber%C3%A4kningst%C3%A4vling-1609281.pdf. [Använd 23 01 2017].

[12] B. Bergsten, ”Energiberäkningsprogram för byggnader - en jämförelse utifrån fuktions- och användaraspekter (Energy calculation programs for buildings - a comparison from a function and user perspective, in Swedish),” 2001. [Online]. Available: https://www.sp.se/sv/index/research/effektiv/publikationer/Documents/Projektrapporter/Rapport%2001-03.pdf. [Använd 23 01 2017].

[13] U. Janson, ”Lämpliga säkerhetsmarginaler i energiberäkningar - säkerhetsmarginal för osäkerheter i indata (Suitable safety margins for energy calculations - safety margins for uncertain input data, in Swedish),” SBUF Report 13106 from www.sbuf.se, Stockholm, 2017.

[14] Y. Jiang och T. Hong, ”Stochastic Analysis of Building Thermal Processes,” *Building and Environment,* vol. 28, nr 4, pp. 509-518, 1993.

[15] T. Dyrstad Pettersen, ”Uncertainty analyses of energy consumption in dwellings,” NTNU, Trondheim, 1997.

[16] R. Almeida och N. Ramos, ”Influence of input data uncertainty in school buildings energy simulations,” i *10th Nordic Symposium on Building Physics Proceedings*, Lund, 15-19 June, 2014.