Proposed Method for Probabilistic Energy Simulations for Multi-Family Dwellings

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Abstract. As regulations regarding energy use and emissions of CO₂ equivalents in buildings become more stringent, the need for more accurate tools and improved methods for predicting these parameters in building performance simulations increases. In the first part of this project, a probabilistic method was developed and applied to the transient energy calculations and evaluated using a single-family dwelling case study. The method was used to successfully predict the variation of the energy use in 26 houses built in the same residential area and with identical building characteristics and services. This project continues the development and testing of the probabilistic method for energy calculations by applying it to a multi-family building. The complexity of the building model increases as the multi-family model consists of 52 zones, compared to the single-zone model used for the single-family dwelling. The multi-family model also includes additional parameters that are evaluated, such as the domestic hot water circulation losses. This paper presents the probabilistic method applied to the building performance simulations used to predict the energy use for the multi-family building and discusses the differences between the previous and new method used in this study.

1 Background

1.1 Summary of phase one of this project

In phase one of this project, a method of doing probabilistic energy calculations was developed, hereafter called “the method” using a single-family house (one zone) by applying Monte Carlo methods on input data with different probability distributions. The generated combinations of input data, 1000 of them, were read by two modified commercial programs, VIP Energy and IDA-ICE. The software calculated the energy use for each iteration and saved the specific energy use as defined by BBR (the Swedish building code). [1], [2]

Phase 1 varied 15 different input parameters according to what variation was measured or expected using specific materials and technology. The energy use for space heating, Domestic Hot Water (DHW) (including DHW Circulation), and electricity for building services, hereafter known as “results” were then compiled and presented as a histogram and compared with the measured energy use values for 26 houses built in the same geographical area near Gothenburg, Sweden. The results from phase 1 showed that the method gave energy use distributions which were very similar to the actual measured energy use in the 26 houses. [2, 3]

Rezaee et. al. [4] have described several methods related to probabilistic energy calculations, however the method that most describes what was done in phase 1, and what will be done in phase 2, is called “probabilistic forward modelling”. This is done in practice by defining the distributions of different parameters, running the different cases and scenarios using an energy model and then compile the results using a statistical tool to produce a histogram.

Their proposed method using “probabilistic inverse modelling” [4] can be applied to the tools being developed in this project in future work by linking the energy calculation results to the individual input parameters. This was done and demonstrated by Sørensen [5]. Rezaee et. al. [4] focuses more on using this method as a design tool where the final values are fixed. In this project, the input data in the final energy calculation are never fixed and are distributions based on variations found in specific materials, products, and methods instead of distributions used when the materials, solutions or methods are unknown.

1.2 Purpose of this study

The purpose of phase two of this project, presented in this article, is to apply and develop the method using

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experiences from phase one of this project so that it can be applied to a multi-zone building model.

In this paper we will present how we will apply and modify the probabilistic energy simulation method to a 52-zone multi-family dwelling, present how the input data was formatted and show the input data values for the first scenario to be simulated.

1.3 Summary of the probabilistic method from phase 1

The probabilistic method used in this study is similar to methods used for doing a parametric study in that input parameters vary for each calculation. For “one” energy calculation, 1000 iterations are done using a fixed energy model with variable input data. However, the probabilistic method has one important difference from the parametric study, and that is the fact that all the input parameters are constant in the sense that all the materials are known. For example, the U-value of the windows are $0,9 \text{ W/m}^2\text{K}$, however measurements from Boverket showed that windows with a U-value of $0,9 \text{ W/m}^2\text{K}$ can actually have U-values between $0,7 \text{ W/m}^2\text{K}$ and $1,1 \text{ W/m}^2\text{K}$ (same sized windows).

The data group which is the exception to this is all user-behaviour based data. For these simulations, the users were assumed to be “normal” users. Extreme user behaviour and different user profiles were not considered.

Another important aspect that was taken into account was the shape of the distribution of the input parameters. In this project, three types of variations were used; a triangular distribution (T), a, in Fig 1, a uniform distribution (U), b, and a skewed triangle (left or right, SL, SR) distribution, c.

Fig. 1: The various input data distributions used in the energy calculations. (NCC AB)

The distributions were based, when possible, on measured data such as in the case of the U-values of the windows and the lambda values of the insulation. If measured statistical data for different input parameters were not available, then the form of the distribution was decided on by expert elicitation, such as in the case of specific fan power values.

After the parameters were defined according to data distribution, minimum value, design value and maximum value, 1000 different cases were generated so that the above pre-set distributions were achieved for each parameter. Two energy calculation software (VIP Energy and IDA-ICE) were used to calculate each case and then compared to measured energy use in 26 identical houses.

2 Probabilistic method and input data for multi-family buildings

The multi-family building was chosen as a next step in the evolution of the probabilistic method previously described since it adds new levels of complexity to the building model and interdependencies of parameters. Additionally, some of the parameters cannot be handled in the same way as with a single-family dwelling.

To test and verify the proposed method, the simulated results from two new versions of the transient simulation software IDA-ICE and VIP Energy will be compared to measured data, as in phase 1. Since the aim of the project is to create a method which yields statistical information about the probability of a building’s future energy use, the output from the simulations need to be compared to measured data from multiple identical buildings which were built as the simulated building model.

2.1 Calculation object

In this project, a 52-zone building will be simulated. This building concept was chosen because it is a product built throughout Sweden where the same design is used in multiple buildings. This is important because measured variations between the same building type with the same design need to be gathered to analyse the actual variation in energy performance. This will be compared to the calculated variation later in this project.

Figures 2 and 3 show the calculation object as built, and as an IDA-ICE model respectively. All objects have energy monitoring systems with energy data storage in a central database incorporated in their design.

Fig. 2: Picture of one of the calculation objects in Sweden. (NCC AB)

Fig. 3: IDA-ICE model of the calculation object.

The calculation object has 37 apartments ranging in size from 37 m² to 67 m² heated floor area, a central ventilation room, several storage rooms, a central staircase, laundry room, and electrical room. The rooms are connected to a central air handling unit with supply and extraction and a rotating heat-recovery system.

2.2 Building Simulation method and Input data

The calculation method is based on the same method reported in [1 and 2]. The building performance simulation software, in this case IDA-ICE [6] and VIP Energy [7] are further modified since phase 1 and will run a batch of 1000 simulations. The variable input parameters for each simulation are read from several text files (one file per zone plus one file with global parameters valid for all the zones). This ensures that both programs have the same input parameters.

The building simulation input file is divided up into two different types of calculations.

1. Default fixed values for all parameters.
2. Generated using Monte Carlo methods on the variable parameters.

The first type of simulation is one simulation only using the default, or design values of the different parameters. This gives a result which is equal to using conventional energy calculation methods without parametric variations.

The second group is when the Monte Carlo method is applied to the variable input data so that the different simulations have randomized input data whilst ensuring that the distributions of each variable parameter follow the pre-defined distributions of that parameter (Fig.1). In this project this text file is generated (semi-)manually to ensure the quality of the simulations in the batch. The input data does not have any dependencies defined, i.e. where a change in one parameter affects another parameter. In this project it is assumed that all variables are independent of each other. More research is needed to

define these dependencies and how they influence each other.

2.3 Input data handling – single-family vs multi-family houses

One problem which was not present in phase 1 and that needs to be addressed in phase 2, is the question of at what level the uncertainty should occur. Two important differences between the single-family building in the first phase and the multi-family dwelling in phase two are that,

- Some of the input data have different values, and
- variations occur at either a zone level (local) or a building level (global).

Parameters at a local level are parameters that can have a local effect on the different parts of the building. Apartments are an example. Each apartment is like a single-family home in that a group of people influence how the energy is used in a small part of the building. Some examples of local parameters are household electricity, DHW, and building components.

Global level parameters are parameters where individual people do not influence the parameter's performance. Elevators and lighting in the stairwell provide a service for all the people. Some people use stairs, and some will use the elevator. The total use should be some average of this. The lighting is usually on at night and off during the day. The number of people entering the stairwell does not have much effect on the energy used by the lighting. Another example is with a central ventilation system. It has one heat recovery rating for all apartments.

There are several arguments for having the variation on a global vs a local level. One is that if the variations are on a local level then they can cancel out the same parameter with an opposite variation in another part of the building. However, having the same variable set at the global level may also be considered unrealistic when compared to measured values since the energy calculations will yield more extreme energy use values. This can be illustrated when looking at variations in mineral wool lambda values. It is unlikely that the entire building will have a low or high lambda value, as can happen when the distribution is set globally.

However, if the lambda values vary in each zone, there will be cancelations of the extreme high and low values in the model which may result in the average lambda value in each iteration being closer to each other. This hypothesis will be tested later in the project to see how much the local vs global distribution affects the energy use of the building, and if it is better to just use a smaller spread with a global parameter or a larger spread with a local parameter.

In order to be able to test this difference and compare the calculated results against measured energy use data, it was decided that all parameters in the software will have the inherent capability of being local variations. However, control over local or global level variations will be controlled via the input data. For example, if an input varies on a global level, then all zones will be set to the same input value for one specific simulation run. If the input varies at a local level, then the input value will vary

as per its predetermined definition (range and shape) for each zone.

Table 1 shows the distributions (local or global) and units that the variables will have in the first energy calculation.

Table 2 shows the distribution shapes and the values for the first scenario (based on SVEBY's recommendations). Scenario 1 uses input data based mostly on expert elicitation (window U-Value and lambda value of the insulation are measured values). This is data decided upon by experts in Sweden as being valid input data for use when calculating energy use in various types of buildings. SVEBY defines the "design" value to be used. Experts in the energy calculation field with previous experience working with these buildings have defined the minimum and maximum deviation which should be realistic for the multi-family building in this study.

A concrete example of an expert elicitation can be seen in the airflow values, for example in the return air flow. An expert in HVAC installations stated that their airflow meters have a 10 % error. In addition to this, if they adjust an airflow in an apartment and it is over the design flow (minimum flow) they do not adjust the flow down again. So, a 10 % deviation in the actual airflow in the apartment is realistic, but this must be combined with a potential 10 % error with their instrument means that the actual airflow is probably not going to match the design value.

Table 1: Input parameters with variable data and their assigned level (global or local).

Parameter	Distribution - global or local scale?	Unit
A_{temp}	Global	m ²
Mineral wool, thermal conductivity	Global	W·m ⁻¹ ·K ⁻¹
Windows, heat transfer coefficient U_w	Global	W·m ⁻² ·K ⁻¹
Shading	Global	-
Solar Heat Gain Coefficient (SHGC)	Global	-
Thermal bridges	Global	%/100 of total thermal transmission of envelope
Airtightness	Global	l·s ⁻¹ ·m ⁻² , external surface at ± 50 Pa
Built in moisture	Global	kWh·m ⁻² ·a ⁻¹
Specific Fan Power - Supply air	Global	kW·m ⁻³ ·s
Specific Fan Power - Exhaust air	Global	kW·m ⁻³ ·s
Heat recovery efficiency	Global	%/100
Return air flow	Global	l·s ⁻¹ ·m ⁻²
Measurement uncertainty	Local	%
1 ROK	Local	l·s ⁻¹
2 ROK	Local	l·s ⁻¹
3 ROK	Local	l·s ⁻¹
4 ROK	Local	l·s ⁻¹
5+ ROK	Local	l·s ⁻¹
Adjustment uncertainty	Local	%
Trapphus + Övriga	Local	l·s ⁻¹ ·m ⁻²

Supply air flow	Local	(1-(% avikelse/100)) * return air flow
Supply air temperature setpoint	Global	°C
Plant losses	Global	%/100
Distribution losses	Global	%/100
Domestic Hot Water circulation losses (no free heating)	Global	kWh·m ⁻² ·a ⁻¹
Indoor temperature setpoint - Residential	Local	°C
Indoor temperature setpoint - Stairwell	Local	°C
Household electricity	Global	kWh·m ⁻² ·a ⁻¹
Domestic hot water	Global	kWh·m ⁻² ·a ⁻¹
Kitchen ventilation losses	Global	kWh·m ⁻² ·a ⁻¹
Airing losses	Global	kWh·m ⁻² ·a ⁻¹
Heat gain – number of inhabitants	-	-
1 ROK	Local	Occupants per apartment
2 ROK	Local	Occupants per apartment
3 ROK	Local	Occupants per apartment
4 ROK	Local	Occupants per apartment
5+ ROK	Local	Occupants per apartment

Table 2: Input parameters with their assigned distribution shape and preliminary values based on Sveby and some measured data (General Data).

Parameter	Shape	Expert elic.		
		Min	Des.	Max
A_{temp}	T	2399	2448	2497
Mineral wool, thermal conductivity	T	0,032	0,038	0,044
Windows, heat transfer coefficient U_w	ST	1,00	1,10	1,30
Shading	T	0,40	0,50	0,60
Solar Heat Gain Coefficient (SHGC)	T	0,49	0,52	0,55
Thermal bridges	U	0,15	0,20	0,25
Airtightness	T	0,10	0,30	0,50
Built in moisture	T	1,5	3,3	5,1
Specific Fan Power - Supply air	SL	0,75	0,75	1,05
Specific Fan Power - Exhaust air	SL	0,75	0,75	1,05
Heat recovery efficiency	U	0,77	0,80	0,83
Return air flow	T	-	-	-
Measurement uncertainty	T	0,9	1	1,1
1 ROK	T	22,5	25	27,5
2 ROK	T	27	30	33
3 ROK	T	27	30	33
4 ROK	T	31,5	35	38,5
5+ ROK	T	40,5	45	49,5
Adjustment uncertainty	T	0,9	1	1,1
Stairwell + Other	SR	0,2	0,35	0,35
Supply air flow	T	0,03	0,05	0,07
Supply air temperature setpoint	T	18,0	19,0	20,0
Plant losses	U	0,05	0,10	0,15
Distribution losses	U	0,03	0,05	0,07
Domestic Hot Water circulation losses (no free heating)	T	2	4	6
Indoor temperature setpoint - Residential	T	20,5	21	21,5
Indoor temperature setpoint - Stairwell	T	17,5	18	18,5
Household electricity	T	20	30	40
Domestic hot water	T	15	25	35
Kitchen ventilation losses	ST	1	2	4
Airing losses	T	3	4	5
Heat gain – number of inhabitants	-	-	-	-
1 ROK	T	0,98	1,42	1,86

2 ROK	T	1,19	1,63	2,07
3 ROK	T	1,74	2,18	2,62
4 ROK	T	2,35	2,79	3,23
5+ ROK	T	3,07	3,51	3,95

Scenario 2 will use more input data based on measured values instead of Sveby values. Unfortunately, this type of data is difficult to find so some will be collected from the measurement objects used in this project. Other data is currently being collected in other projects, such as the energy use of the Domestic Hot Water Circulation system in multi-family buildings.

2.4 Practical applications in the building industry

Since the building code regarding energy use in buildings in Sweden is performance based (given in kWh/m² heated floor area per year), it is advantageous to be able to accurately predict the yearly energy use of a building. Current methods involve adding a margin of safety to energy calculations and hoping that the measured energy use is lower than the required energy use or doing time-intensive parametric studies. Using the probabilistic energy calculation method outlined above has several advantages. Since the input data distributions are based on actual materials and products, the resulting predicted distribution curve for the energy use of a building design gives an indication of risks involved with those specific solutions and designs, see Ekström et. al. for further information on risk analyses using probabilistic energy calculations [8]. This method can also show which parameters have the largest potential impact on the energy performance of a specific building design. This allows a dialog with building owners or decision-makers regarding energy and economic risks within the project. An example of an economic risk for the entrepreneur is fines if the building's measured energy use is higher than agreed. A risk for a building owner is that they have a higher operating cost than planned.

However, before this calculation method can be used in the industry, it must be able to scale up to multi-zone buildings with reasonable calculation times. There must also be documentation on how this method should be used to achieve various types of results, such as a design-and-decision tool, a risk assessment tool, or a mapping tool which can help find problems. Knowledge regarding where and how the variations of the different input parameters need to be defined. Methods on how to allocate these variations, local or global variations, need to be developed based on which allocation yields the more realistic energy use distributions. More information also needs to be made available to analyse these variations in order to determine what a realistic variation is.

More powerful computers and cloud computing are opening up opportunities of applying statistical methods to energy calculations which can encompass several types of end-uses. This can be as a design and decision tool at an early phase in the building process where all parameters are unknown, risk analysis where known parameters can predict the expected spread of the energy use in the finished building or by using measured input

data to map and explain unusually high/low energy measurements in real buildings.

3 Remaining work

Remaining work within the project includes:

- Gathering more input data so that the distribution curves can be defined based on measured data instead of expert elicitation.
- Simulations need to be done using input data based on the measured properties of the materials and products used (Scenario 2).
- The energy use in several objects needs to be compiled.
- An analysis of calculated and measured energy use in several objects needs to be done.

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