# Impacts of common simulation assumptions in Sweden on modelled energy balance of a multi-family building

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**Abstract:** Here, we explore key input parameters and common assumptions for energy balance analysis of residential buildings in Sweden and assess their impacts on predicted energy demand of a building. Our analysis is based on dynamic hour-by-hour energy balance modelling of a typical Swedish multi-storey residential building constructed in 1972. The simulation input parameters studied are related to microclimate, building envelope, occupancy behaviour, ventilation, electric and persons heat gains. The results show that assumed indoor temperature set points, internal heat gains and efficiency of ventilation heat recovery systems have significant impact on the simulated energy demand. For microclimate parameters, the outdoor temperature, ground solar reflection and window shading gave significant variations in the simulated space heating and cooling demands. We found that input parameter values and assumptions used for building energy simulation vary significantly in the Swedish context, giving considerably different estimated annual final energy demands for the analysed building. Overall, the estimated annual final space heating demand of the building varied between 50 and 125 kWh/m$^2$ depending on the simulation dataset used. This study suggests that site-specific parameter values may be appropriate for accurate analysis of a building's energy performance to reduce data input uncertainties, as such factors may have a significant impact on building energy balance and energy savings of retrofit measures.

**Keywords:** Energy simulation, residential buildings, input parameter data

## 1 Introduction

The building sector worldwide is suggested to offer many possibilities for energy savings and climate change mitigation [1]. In the European Union (EU), the building sector accounts for 40% of the total final energy use [2] and is expected to contribute significantly to the goal to reduce total greenhouse gas (GHG) emission by 80-95% by 2050 relative to 1990 levels [3]. The energy performance of buildings directive (EPBD) [2] is a key piece of the legislations to promote improved energy efficiency of European buildings. The EPBD mandates EU member states to report the calculated energy performance of buildings based on a methodology defined at national or regional levels. In Sweden, the government is aiming to reduce total energy use per heated building area by 20% by 2020 and 50% by 2050, using 1995 as the reference [4]. The residential and service sectors in Sweden account for 40% of the national total final energy use [5], with space and tap water heating accounting for 55% of the sectors' final energy use.

Several factors influence the thermal performance of buildings and detailed analysis is important to properly estimate the energy required to operate a building. Increasingly, simulation tools are being used to support the design and construction of high-performance buildings. However, results from simulation tools have been reported to often vary from the actual monitored energy use of buildings [6-9]. Different factors are attributed to this, including inappropriate simulation input data and assumptions for building energy balance modelling. Kalema et al. [10] compared simulation results of a building modelled with different simulation tools by different researchers and noted that discrepancies due to input data were larger than those caused by the use of different tools. Wall [11] noted the simulated energy demand of a terrace house in Sweden to be 33% lower than the monitored energy demand, mainly due to uncertainties related to some input parameter values. Similar discrepancies ranging between 7-105% have been reported in different climate contexts, depending on the building type and degree of uncertainties related to various input parameters [6-9].

In this study we explore key input parameters and common assumptions used for energy balance modelling of residential buildings in Sweden and analyse their impacts on simulated energy balance of a building. Our analysis is based on dynamic hour-by-hour energy balance modelling of a typical Swedish multi-storey residential building constructed in 1972.

## 2 Methods

The general approach consists of the following: a) modelling the thermal performance of the building in its existing state based on a set of reference input parameters; b) exploring simulation input parameters and assumptions for the Swedish context and assessing their impacts on the energy balance calculation of the building.

### 2.1 Analysed building

The analysed building is located in the Kallinge area of Ronneby municipality in Sweden. It is 3-storey high and made of a concrete-frame structure with façades of brick and wood panels. There are 27 apartments and a basement in the building, with a total heated living floor area of 2000 $m^2$ and ventilated volume of 5400 $m^3$. Figure 1 shows a photograph of the building and a more detailed description of the building is given in [12]. Key construction features as well as thermal properties of the various components for the existing building are given in Table 1.

**Figure 1.** The analysed concrete-frame building in Ronneby municipality, Sweden.

**Table 1.** Thermal properties for the existing building.

| Building element | U-value (W/m$^2$ K) | Area (m$^2$) |
|---|---|---|
| Attic floor | 0.11 | 688.0 |
| Basement walls | 1.33/1.44 | 57.2/286.9 |
| Doors (clear glass windows in doors) | 3.0 | 84.5 |
| Exterior walls (wood panels & brick facades) | 0.311/0.341/0.346 | 292.0/194.0/565.0 |
| Foundation (slab on ground) | 0.26 | 688.0 |
| Windows (clear glass windows) | 2.9 | 194.5 |

### 2.2 Energy balance simulation

The VIP-Energy simulation program [13] is used to model the thermal performance of the building. The program calculates the final energy demand of a building based on the building's physical characteristics, internal and solar heat gains, occupancy schedules, heating and ventilation systems, among others. It enables whole building dynamic hourly energy balance calculations with multi-zone and detailed thermal bridges and heat storage capacity as well as one-, two- and three-dimensional modelling features of building envelope components. VIP-Energy is validated by the International Energy Agency's BESTEST, ANSI/ ASHRAE Standard 140 and CEN 15265. The reference energy balance of the building is modelled hourly with the 2013 weather data for the city of Ronneby, obtained from the meteonorm database [14].

### 2.3 Reference and varied parameters

The reference and varied input parameter values and assumptions are based on those commonly used for thermal performance analyses of buildings in Sweden and are outlined in Table 2. The parameters varied include indoor temperature set points for heating and cooling, outdoor temperature, internal and solar heat gains, microclimate, building envelope and efficiencies of ventilation heat recovery (VHR) and fan, and fan pressure. The implication of window opening for airing is explored using the suggestions by SVEBY [15] whereby 4 kWh/m$^2$ is added to the total space heating demand, and suggestions by VIP-Energy [13] whereby a margin of 0.025 l/s m$^2$ balanced air flow bypassing the heat exchanger is included in the simulation model.

**Table 2.** Reference and varied input parameter values and assumptions for energy simulation.

| Parameter | Reference | Variations | Remarks |
|---|---|---|---|
| Climate | Ronneby 2013 | +1 & -1 °C | Varied outdoor temperature |
| Horizontal angle | 20 ° | 10 & 30 ° | Shading by near-by objects |
| Wind factor | 70% | 30 & 100% | Relative to climate file |
| Solar reflection | 0% | 25 & 50% | Solar reflection into building |
| Air pressure outside | 1000 hPa | 990 & 1020 hPa | Average annual value |
| Heating set point | 21 ºC | 20, 22 & 23 ºC | Living areas, based on [11, 16-18] |
| Cooling set point | 26 ºC | 27 ºC | Living areas, based on [19] |
| Hot water use | 2.85 W/m$^2$ | No variation | Standard taps |
| Electric power use | 3.05 W/m$^2$ | No variation | Standard equipment |
| *Internal heat gains:* | | | |
| Persons | 1.0 W/m$^2$ | 1.68 & 4.30 W/m$^2$ | Based on [11, 20] |
| Lighting & appliances | 3.05 W/m$^2$ | 2.40 & 4.92 W/m$^2$ | Based on [20, 21] |
| Airtightness | 0.8 l/sm$^2$ | 0.6 & 1.0 l/sm$^2$ | Based on [22, 23] |
| *Ventilation, heat exchanger and fans:* | | | |
| Air change rate | 0.35 l/sm$^2$ | No variation | Based on [24] |
| VHR efficiency | 76 % | 80 & 85% | Based on [25] |
| Fan pressure | 400 Pa | 200 & 600 Pa | Estimated based on [13] |
| Fan efficiency | 50 % | 33 & 55% | Based on [26, 27] |
| Airing | Not considered | Considered | Based on suggestions by [13][15] |

# 3 Results

## 3.1 Reference energy demand

The reference case simulated energy demands of the building are summarized in Table 3. Space heating accounts for 61% while space cooling and ventilation each account for 2% of the annual total final energy demand of the building.

**Table 3.** Reference simulated annual final operation energy demand (kWh/m$^2$) of the building.

| Description | Space heating | Space cooling | Ventilation electricity | Tap water heating | Household electricity | Total |
|---|---|---|---|---|---|---|
| Reference | 95 | 3 | 3 | 25 | 30 | 156 |

## 3.2 Parametric variations

The effects of variations of various parameter values related to indoor air temperature, envelope airtightness, internal heat gains and microclimate on the simulated space heating and cooling demands of the building are summarized in Table 4. Positive change means the simulated heating demand is greater while negative change means that it is lower, relative to the reference case. The biggest decrease in space heating demand occurs when the reference persons' heat gains of 1.0 W/m$^2$ is varied to 4.3 W/m$^2$ while increasing horizontal angle from the reference 20% to 30%, denoting more shading gives the biggest decrease in space cooling demand for the building. The space heating and cooling demands also changed significantly when the reference indoor air temperature of 21$^o$C for heating and 26$^o$C for cooling are varied. The electrical heat gains of 2.40 and 4.92 W/m$^2$ correspond to household electricity demands of 24 and 48 kWh/m$^2$, (not shown in table) respectively.

**Table 4.** Effects of parameter variations on simulated space heating and cooling demands.

| **Description** | **Space heating** | | **Space cooling** | |
|---|---|---|---|---|
| | kWh/m$^2$ | Change from ref. (%) | kWh/m$^2$ | Change from ref. (%) |
| Reference case (ref.) | 95 | - | 3 | - |
| Parameter variations | | | | |
| *Heating set-point:* | | | | |
| 20 $^o$C | 88 | -7 | 3 | 0 |
| 22 $^o$C | 104 | 9 | 3 | 0 |
| 23 $^o$C | 112 | 18 | 3 | 0 |
| *Cooling set point:* | | | | |
| 27 $^o$C | 95 | 0 | 2 | -33 |
| *Outdoor temperature* | | | | |
| -1 $^o$C | 105 | 11 | 2 | -33 |
| +1 $^o$C | 86 | -9 | 4 | 33 |
| *Horizontal angle:* | | | | |
| 10 degrees | 90 | -5 | 5 | 67 |
| 30 degrees | 100 | 5 | 1 | -67 |
| *Ground solar reflection:* | | | | |
| 25% | 92 | -3 | 5 | 67 |
| 50% | 90 | -5 | 8 | 167 |
| *Wind load to building:* | | | | |
| 30% | 95 | 0 | 3 | 0 |
| 100% | 97 | 2 | 3 | 0 |
| *Air pressure outside:* | | | | |
| 990 hPa (-1% ) | 95 | 0 | 3 | 0 |
| 1020 hPa (+2% ) | 96 | 1 | 3 | 0 |
| *Airing* | | | | |
| VIP-energy approach | 99 | 4 | 3 | 0 |
| SVEBY approach | 99 | 4 | 3 | 0 |
| *Airtightness* | | | | |
| 0.6 l/sm$^2$ | 98 | 3 | 3 | 0 |
| 1 l/sm$^2$ | 99 | 4 | 3 | 0 |
| *Persons heat gains:* | | | | |
| 1.68 W/m$^2$ | 91 | -4 | 3 | 0 |
| 4.30 W/m$^2$ | 75 | -21 | 7 | 133 |
| *Electrical heat gains:* | | | | |
| 2.40 W/m$^2$ | 100 | 5 | 2 | -33 |
| 4.92 W/m$^2$ | 83 | -13 | 5 | 67 |

Table 5 shows the impact of variations of parameter values related to ventilation fans and the implications of VHR system with different heat recovery efficiencies for the analysed building. Implementation of VHR systems considerably decreased the space heating demand between 28 to 33% and also doubled the ventilation electricity use of the building. The simulated electricity for ventilation is about doubled when the ventilation fan efficiency is decreased to 33% from the reference 50% while an increase of the reference ventilation fan efficiency to 55% has small impact on the simulated ventilation electricity use of the building. Compared to the reference case, the simulated ventilation electricity use is increased by 2-3 kWh/m$^2$ when the reference fan pressure of 400 Pa is varied to 600 Pa. With a fan pressure of 200 Pa instead of the reference value, the simulated ventilation electricity use is decreased by 1-3 kWh/m$^2$.

**Table 5.** Effects of parameter variations on simulated space heating and ventilation electricity demands.

| Description | Space heating | | Ventilation electricity | |
|---|---|---|---|---|
| | kWh/m$^2$ | Change from ref. (%) | kWh/m$^2$ | Change from ref. (%) |
| Reference case | 95 | - | 3 | - |
| Parameter variations | | | | |
| *VHR efficiency:* | | | | |
| 76% | 68 | -28 | 6 | 100 |
| 80% | 66 | -31 | 6 | 100 |
| 85% | 64 | -33 | 6 | 100 |
| *Fan efficiency:* | | | | |
| 33% | 95 | 0 | 5 | 67 |
| *55%* | 95 | 0 | 3 | 0 |
| Fan pressure: | | | | |
| 200 Pa | 95 | 0 | 2 | -33 |
| 600 Pa | 95 | 0 | 5 | 67 |

### 3.3 Effects of extremes of parameter values

In Figures 2-4, the combined effects of the extremes of parameter values (from Tables 4 and 5) giving the highest and lowest simulated space heating demand for the building configurations are illustrated. The figures show simulated annual final energy demands, hourly heat load profiles and indoor air temperatures of the building when using the different extreme parameter datasets. To facilitate comparison, the values for the reference case are also shown in the figures. Compared to the reference case, the initial building's simulated final space heating demand is increased by 32% and decreased by 47% when the extremes of parameter values are used to perform the calculations. The simulated demand for cooling is significantly greater when the parameters giving the lowest heat demand are used. The extremes of parameter datasets result in about 40% difference in the simulated peak load of the building.

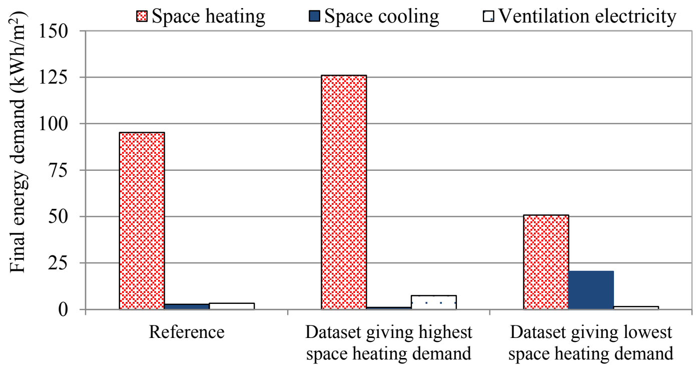


**Figure 2.** The reference case energy demands and the combined effects of the extremes of parameter values giving the highest and lowest space heating demand of the building.

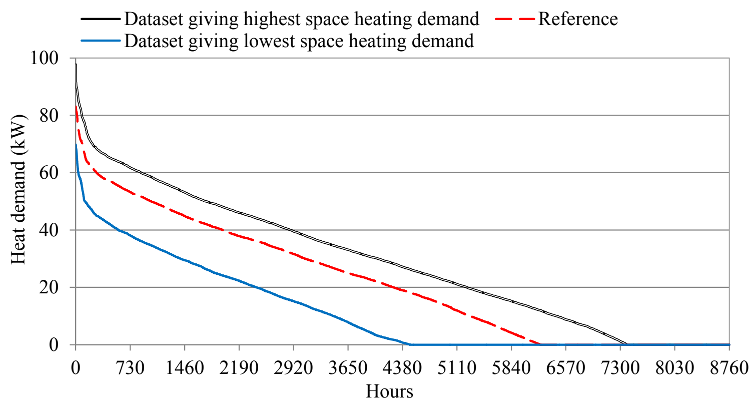


**Figure 3.** Simulated annual hourly profiles for space heating of the building, arranged in descending order.

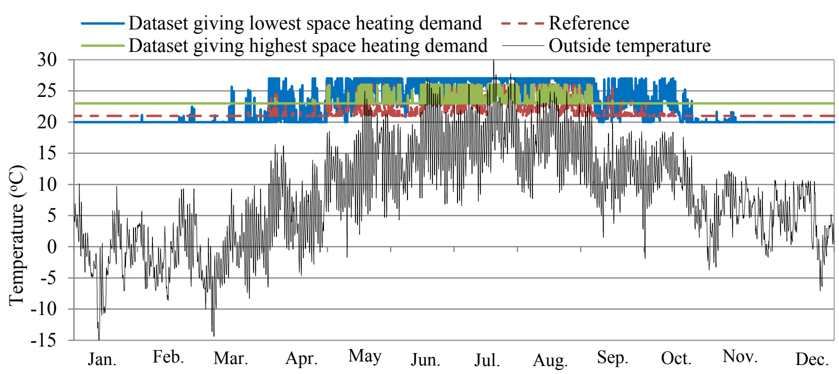


**Figure 4.** Simulated annual hourly profiles for indoor air temperature of the building, from January to December.

## 4 Discussion and conclusions

We conducted this analysis to explore the implications of input parameter values and assumptions commonly used in Sweden for energy balance calculations for residential buildings. The input parameters explored are related to indoor temperature, microclimate, building envelope, ventilation, and internal heat gains from persons and electric appliances. The analysis is based on dynamic hour-by-hour energy balance modelling of a typical Swedish multi-storey residential building from the 1970s. Our findings show that input parameters and assumptions used in energy simulations of residential buildings in Sweden vary significantly and have significant effect on the calculated energy balance of buildings. Our analysis shows that simulated annual final space heating demand of the analysed building varied between 50 and 125 kWh/$m^2$ depending on the simulation dataset used for the energy balance simulation. Household electricity demands are 48 and 24 kWh/$m^2$ when the annual final space heating demands are 50 and 125 kWh/$m^2$, respectively. Hence input parameters used in simulation models need to be characterised, transparent and appropriate, to inform accurate analyses of energy efficiency performance of buildings.

Our calculations show that assumed indoor temperature set points, internal heat gains and efficiency of VHR systems have significant impact on the simulated final energy demand of analysed building. Among the explored microclimate parameters, outdoor temperature, ground solar reflection and window shading gave significant variations in the simulated space heating and cooling demands of the building. In this analysis, variations of air pressure outside and wind load that hit the building had minor impact on the simulated building energy demand.

This analysis highlights the implications of different parameters and strategies for cooling energy demand of Swedish residential buildings. Currently, cooling demands are generally small for Swedish residential buildings as cooling needs are typically managed with strategies as shading, increased ventilation and airing. Notwithstanding, calculations by Persson et al. [18] showed that cooling energy demand for a very low energy building in Sweden can be significant compared to space heating energy demand. Tettey et al. [28] showed that the energy need for cooling of Swedish residential buildings may increase significantly under future climate conditions. Comparison of simulated building energy performance with measured and calibrated data is important, as discussed by Vesterberg et al. [29], and is not within the scope of this paper.

In summary, this study illustrates the implications of different simulation assumptions as well as parameter values used for energy balance analysis in Sweden, and suggests that site-specific parameter values may be appropriate for accurate analysis of a building's energy performance. The findings increase understanding of how various key parameter values, methods and assumptions for energy balance modelling influence simulated energy use of residential buildings in the Swedish context. Accurate analysis of buildings' energy balance is essential to identify the scale, trade-offs and cost-effectiveness of various measures to reduce space heating demand, and facilitate GHG emissions reductions.

## References


1. IPCC, *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* 2014.
2. Directive 2010/31/EU, *Directive 2010/31/EU of the European Parliament and of the Council of 19 May2010 on the energy performance of buildings (Recast), Official Journal of the European Union. L 153, 18/06/2010.*
3. European Commission, *2050 low-carbon economy. Acessed at http://ec.europa.eu/clima/policies/strategies/2050/index_en.htm on 12/04/2017.* 2016.
4. Swedish Government Bill 2005/06:145, *Swedish Government Bill 2005/06:145 National Programme for Energy Efficiency and Energy-smart Construction. Accessed at http://www.government.se/information-material/2006/05/national-programme-for-energy-efficiency-and-energy-smart-construction/ on 12/04/2017.*
5. Swedish Energy Agency, *Energy in Sweden 2015. Accessed at www.energimyndigheten.se on 12/04/2017.* 2015, Energimyndigheten.
6. Daly, D., P. Cooper, and Z. Ma, *Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings.* Energy and Buildings, 2014. **75**: p. 382-393.
7. Karlsson, F., P. Rohdin, and M.-L. Persson, *Measured and predicted energy demand of a low energy building: important aspects when using Building Energy Simulation.* Building Services Engineering Research and Technology, 2007. **28**(3): p. 223-235.
8. Menezes, A.C., et al., *Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap.* Applied Energy, 2012. **97**: p. 355-364.
9. Karlsson, J.F. and B. Moshfegh, *Energy demand and indoor climate in a low energy building—changed control strategies and boundary conditions.* Energy and Buildings, 2006. **38**(4): p. 315-326.
10. Kalema, T., et al., *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, 2008. **32**(2): p. 101-130.
11. Wall, M., *Energy-efficient terrace houses in Sweden: Simulations and measurements.* Energy and Buildings, 2006. **38**(6): p. 627-634.
12. Dodoo, A., U.Y.A. Tettey, and L. Gustavsson, *On input parameters, methods and assumptions for energy balance and retrofit analyses for residential buildings.* Energy and Buildings, 2017. **137**: p. 76-89.
13. StruSoft, *VIP-Energy, Version 2.1.0* StruSoft AB, Editor. 2012: Sweden. http://www.strusoft.com/products/vip-energy
14. Meteotest, *METEONORM 7: Global meteorological database for engineers, planners and education,*. 2015, Meteotest.

15. SVEBY, *Brukarindata bostader version 1.1. Accessed at http://www.sveby.org/hur-anvander-jag-sveby/berakning/ 29th June, 2015*. 2013.
16. Boverkets Byggregler, *Boverkets Författningssamling, The national Board of Housing Building and planning, Karlskrona. Accessed at http://www.boverket.se on 10/04/2017, (In Swedish)*. 2015.
17. Gustavsson, L., et al., *Primary energy implications of end-use energy efficiency measures in district heated buildings.* Energy and Buildings, 2011. **43**(1): p. 38-48.
18. Persson, M.-L., A. Roos, and M. Wall, *Influence of window size on the energy balance of low energy houses.* Energy and Buildings, 2006. **38**(3): p. 181-188.
19. Tettey, U.Y.A., A. Dodoo, and L. Gustavsson, *Primary energy implications of different design strategies for an apartment building.* Energy, 2016. **104**: p. 132-148.
20. Elsland, R., I. Peksen, and M. Wietschel, *Are Internal Heat Gains Underestimated in Thermal Performance Evaluation of Buildings?* Energy Procedia, 2014. **62**: p. 32-41.
21. SVEBY, *Brukarindata bostader version 1.1. Accessed at http://www.sveby.org/hur-anvander-jag-sveby/berakning/ 29th June, 2015*. 2013.
22. Zou, Y., *Classification of buildings with regard to airtightness*, in *Department of Civil and Environmental Engineering*. 2010, Chalmers University of Technology Götenborg, Sweden.
23. Liu, L., P. Rohdin, and B. Moshfegh, *Evaluating indoor environment of a retrofitted multi-family building with improved energy performance in Sweden.* Energy and Buildings, 2015. **102**: p. 32-44.
24. Boverkets Byggregler, *Boverkets Författningssamling, The national Board of Housing Building and planning, Karlskrona. Available at http://www.boverket.se (In Swedish)*. 2015.
25. Swedish Energy Agency, *FTX-aggregat hus med 130 m2 boyta. Available at https://www.energimyndigheten.se/Hushall/Testerresultat/Testresultat/FTX-aggregat-hus-med-130-m-boyta/?tab=1*. 2010.
26. Camfil. *City pollution. AirMail No. 2*. 2014 [cited 2015 September 3]; Available from: http://www.camfil.se/FileArchive/Brochures/Airmail/AirMail_2014_2_EN.pdf.
27. Brelih, N., *How to improve energy efficiency of fans for air handling units.* REHVA Journal, 2012: p. 5-10.
28. Tettey, U.Y.A., A. Dodoo, and L. Gustavsson, *Energy use implications of different design strategies for multi-storey residential buildings under future climates.* Energy, 2017.
29. Vesterberg, J., S. Andersson, and T. Olofsson. *The influence from input data provided by the user on calculated energy savings*. in *10th Nordic Symposium on Building Physics, Lund, Sweden, 15-19 June, 2014*. 2014.