Calculation of energy use in the Swedish housing

Description of the building energy simulation model EABS: Energy Assessment of Building Stocks

ÉRIKA MATA
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Preface

Apart from the Kyoto Protocol agreement[1], European Union committed to reducing its overall emissions by at least 20% by 2020, compared to 1990 levels (Commission of the European Communities, 2008). So called "non-CO_2" measures (referring to non-CO_2 pollutants, such as black carbon, methane, low-lying ozone and nitrogen compounds) have the most cumulative CO_2 emission reduction potential, while the second choice with the most potential for mitigating climate change is energy conservation. The lower the CO_2 stabilization level to be achieved, and the sooner, the more important this choice becomes. Furthermore, estimated sectorial[2] economic potential for global mitigation for different regions as a function of carbon price in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments, is determinant for the buildings´ sector (IPCC, 2007). Despite the increasing effort in regulation in recent years, the energy consumption and CO_2 emissions in the EU´s building stock continue to grow. Specifically, building HVAC[3] systems account for almost half the energy consumed in EU buildings (Pérez-Lombard, 2008). Thus there is now a need to explore and assess retrofitting measures for reduced energy use in the existing building stock. Besides climate change, security of energy supply and competitiveness[4] are also good reasons to promote energy saving in buildings.

Current goals for the reduction of energy use in Sweden, as stated in the program of the Swedish Environmental Objectives Council (Miljömålsrådet, 2009[5] are given as 20 % less specific energy use by year 2020, and 50 % less by year 2050 in comparison to the reference year 1995. In year 2009, the Swedish National Board of Housing, Building and Planning (Boverket) conducted a large field investigation (the BETSI programme), which focused on the status of the building stock in terms of energy use, technology status, indoor air quality, damages and maintenance. The data were collected on 1800 buildings, where 1400 were residential and the rest commercial buildings. In addition, Boverket commissioned from the Department of Civil and Environmental Engineering at Chalmers a numerical investigation on energy saving potentials in existing residential buildings, based on the 1400 sample collected in the BETSI investigation, and for a list of energy efficiency measures (23 in total).

For the purpose of the Boverket's numerical investigation, the building energy simulation programme EABS was developed at the Division of Building Technology, Chalmers, and in cooperation with the Division of Energy Technology, Department of Energy and Environment, Chalmers. The task included model development, model application for the calculation of energy use in the existing residential stock for year 2005 (the reference year in the study) and estimations of energy savings after various energy efficiency measures are applied in the buildings. In addition to the energy results, the programme gives the estimates of costs and carbon intensities of fuels and the estimated capital costs for the efficiency measures. Results of this numerical investigation are partially published by Boverket (Boverket, 2009) and in more details in Mata et al. (2010a and b).

EABS is a bottom-up engineering model where the calculation of energy use of a sample of individual buildings is based on the buildings' physical properties and the energy use for building service systems and domestic appliances. The programme is particularly adjusted to read the databases with the input data from the BETSI investigation. However, the energy

---

[1] Industrialized countries agreed to collectively reduce their GHG emissions by 5.2% for the period 2008-2012 compared to their emissions in 1990.

[2] For the sector "Residential and commercial buildings". The other sectors studied are: Energy Supply, Transport and its infrastructure, Industry, Agriculture, Forestry, Waste management.

[3] Heating, Ventilation and Air Conditioning systems

[4] A nation's competitiveness can be viewed as its position in the international marketplace compared to other nations of similar economic development (Önsel et al., 2008).

[5] Environmental Objectives Council (Miljömålsrådet). www.miljomal.nu

calculation routine is general and as the whole programme is described in this report in details, it is made open to anyone to build up a similar programme or to adjust the existing one to the inputs from other databases.

We would like to thank Björn Mattsson from Boverket for his valuable comments throughout the process. PhD student Vahid M. Nik from Chalmers is gratefully acknowledged for writing the code in Matlab and comment on this present report. Professor Filip Johnsson from Chalmers is equally acknowledged for contributing with his comments on the present report.

We hope the work will help both decision makers and researchers. We also hope it will contribute to the development of mechanisms and tools to achieve energy savings in the building stock.

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Érika Mata

Angela Sasic Kalagasidis

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Notations

A	Heated floor area	m^2	Input	
A_c	Specific heat gain from appliances	W/m^2	Input	
c_p	Specific heat capacity	J /kg K		
d_i	Layer thickness	m		
C	Effective heat capacity of a heated space (whole building)	J/K		Eq.12
D_{Cool}	Annual heating energy demand for space cooling	kWh/y	Output	Eq.26
D_{El}	Annual heating energy demand for electricity	kWh/y	Output	Eq.43
D_{Heat}	Annual heating energy demand for space heating	kWh/y	Output	Eq.25
D_{HotW}	Annual heating energy demand for hot water production	kWh/y	Output	Eq.27
E_{Tot}	Total annual energy demand	kWh/y	Output	Eq.44
H_w	Specific heating power demand for hot water production	W/m^2	Input	
Hy_P	Specific electric power demand for operation of hydronic pumps	W/m^2	Input	
H_{Rec_Eff}	Efficiency of the heat recovery unit	0-1	Input	
I_{sol}	Intensity of global solar irradiation on a horizontal surface	W/m^2	Input[6]	Eq.7
j	Hour in a year	h		
L_c	Specific heat gain from electric lights	W/m^2	Input	
O_c	Specific heat gain from people	W/m^2	Input	
P_c	Response capacity of the cooling system	W/K	Input	
P_{fh}	Specific heat gain from ventilation fans (due to heat dissipation)	W/m^2	Input	
P_h	Response capacity of a heating system	W/K	Input	
Per_{HPinH}	Percentage of heating and cooling demand provided by heat pumps	0-1	Input	
q_{App}	Heat gain due to appliances	W		Eq.9
Q_{App}	Annual consumption of electricity for the operation of domestic appliances	kWh/y	Output	Eq.33
q_{BuiS}	Heat dissipated from ventilation fans	W		Eq.11
Q_{BuiS}	Annual dissipation of heating energy from ventilation fans	kWh/y	Output	Eq.35
q_{Cool}	Cooling demand	W		Eq.21
q_{Fan}	Electricity consumption by fans	W		Eq.40
Q_{Fan}	Annual consumption of electricity for the operation of ventilation fans	kWh/y	Output	Eq.39

---

[6] In the weather file, see Appendix 5.

q_{Heat}	Heating demand	W		Eq.19
q_{HeatR}	Heat recovered by mechanical supply-exhaust ventilation system (Från- och Tilluft med värmeåtervinning X FTX)	W		Eq.23
Q_{HeatR}	Total heating energy recovered by mechanical supply-exhaust ventilation system (Från- och Tilluft med värmeåtervinning X , FTX)	kWh/y	Output	Eq.36
$q_{HeatR\ FVP}$	Heat recovered by an exhaust air heat pump (frånluftsvärmepump, FVP)	W		Eq.24
$Q_{HeatR\ FVP}$	Annual heating energy recovered by FVP	kWh/y	Output	Eq.37
q_{HotW}	Heating power demand for hot water production	W		Eq.22
Q_{HR}	Total heating energy recovered	kWh/y	Output	Eq.38
q_{HyP}	Electric power demand for the operation of hydronic pumps	W		Eq.42
Q_{HyP}	Annual consumption of electric energy for the operation of hydronic pumps	kWh/y	Output	Eq.41
q_{int}	Total internal heat gains	W		Eq.7
q_{Lig}	Internal heat gains due to lighting	W		Eq.8
Q_{Lig}	Annual consumption of electric energy for the operation of electric lighting	kWh/y	Output	Eq.32
q_{Occ}	Internal heat gains due to people	W		Eq.10
Q_{Occ}	Annual heating energy generated by people	kWh/y	Output	Eq.34
q_r	Solar radiation gains through windows	W		Eq.6
Q_r	Annual heating energy due to solar radiation gains through windows	kWh/y	Output	Eq.31
q_t	Transmission heat losses through a building envelope	W		Eq.1
Q_t	Annual transmission heat losses through a building envelope	kWh/y	Output	Eq.28
q_v	Ventilation heat losses (sanitary and	W		Eq.5
q_{vNat}	Heat losses due to natural ventilation	W		Eq.4
Q_{vNat}	Total heating energy losses due to natural ventilation	kWh/y	Output	Eq.30
q_{vSa}	Heat losses due to sanitary ventilation	W		Eq.2
Q_{vSa}	Total heating energy losses due to sanitary ventilation	kWh/y	Output	Eq.29
S	Total exterior area of a building envelope	m^2	Input	
SE	Total energy saved due to the application of a certain measure	m^2	Output	Eq.49
S_i	Total interior wall area	m^2		
S_w	Total window area (area of window openings)	m^2	Input	
S_c	Maximum cooling power of a cooling	W	Input	

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S_h	Maximum heating power of a heating	W	Input	
SFP	Specific Fan Power	W/l/m^2	Input	
T_{autumn}	Average indoor temperature during autumn	C	Output	Eq.48
T_{int}	Indoor air temperature	C		
T_{out}	Outdoor air temperature	C		Eq.8
Tr_{max}	Maximum desired indoor temperature	C	Input	
Tr_{min}	Minimum desired indoor temperature	C	Input	
T_s	Window solar transmittance	-	Input	
T_{spring}	Average indoor temperature during spring	C	Output	Eq.46
T_{summer}	Average indoor temperature during	C	Output	Eq.47
T_v	Set point temperature for natural	C	Input	
T_{vent}	Temperature of supply air	C		Eq.3
T_{winter}	Average indoor temperature during winter	C	Output	Eq.45
t_y	1 $year$ = 8760 h/year · 3600 s/h			
U	Mean U value of a building	W/ m^{2}K	Input	
V_c	Sanitary ventilation rate	l/s/m^2	Input	
V_{cn}	Natural ventilation rate	l/s/m^2	Input	
W	Weight coefficient for the type building	-		
W_c	Solar shading coefficient for a window	-	Input	
W_f	Part of the total window area covered by window frames	-	Input	
ρ	Density	kg/ m^3		

1 Introduction

Calculations of energy use in the representative buildings have been carried out by a non-commercial energy simulation program, which is developed in the Matlab programming language (www.mathworks.com) and which requires Simulink toolbox (Mata and Sasic Kalagasidis, 2008). The simulation programme consists of two parts – a Simulink model, which solves the energy balance for buildings, and a code written in Matlab, which handles input and output data from the Simulink model. The two will be referred to as “the Simulink model” and “the code”. The code was originally developed by Vahid Nik, PhD student at the Division of Building Technology Chalmers.

This report summarizes the modelling equations and formulas that are in-built in the Simulink model and the definition of input and output data. The outlook of the Simulink model and the programme lines of the code are given in appendices.

The simulation programme aims to be used to estimate the effects of various efficiency measures applied to an entire building stock (as opposed to detailed simulation models for individual buildings). Thus, complexity of the model had to be limited in order to use inputs from available databases and to execute the calculations in a short time. Therefore, buildings are described in the model through a restricted number of parameters expressing the basic feature of the energy use in buildings. These include: total heated floor area and air volume, total surface of external walls and windows and the average values for thermal conductance of walls and windows (U values), ventilation flow rates, solar transmittance of windows and internal heat gains. The internal thermal inertia of a building is characterized by its thermal time constant. The outputs from the model are also given in an aggregated form for the building stock considered and contain data on final energy consumption for space heating and cooling, ventilation, appliances and hot water.

Prior to the Boverket’s project, the accuracy of the Simulink model was tested and validated on two reference buildings: one office building located in Barcelona (Spain) and one residential building in Köping (Sweden) (Sasic Kalagasidis, 2006). Results for the office building are reasonable but not in a full agreement with measurements due to uncertainties in some of the input values. As for the residential building, there is a good agreement between the calculated and measured data: measured consumption in 2002 was 97.4 kWh/m^{2}year, and the calculated demand for the same year is 98.2 kWh/m^{2}year (Mata et al., 2009).

In the project with Boverket, the Simulink model has been validated for the Swedish residential building stock. Of course, the results depend on the quality of the input data describing the characteristics of the building stock. The division into different representative buildings and weighting coefficients is crucial. Measured or statistical data of energy consumption for the entire stock are necessary to verify the buildings´energy consumption calculated by the model and the code. Finally it is also important to have available weather data for the different locations. In this work, Boverket was responsible of providing all the data sets mentioned before. However, it could be done somehow else.

All modelling issues have been discussed with Boverket at several occasions and the final version of the simulation programme that appears here is fully adjusted to the needs of the Boverket’s project.

2 Energy balance model for a heated space - the Simulink model

2.1 Heat losses

As the most of the residential buildings in Sweden are heated to the same temperature throughout, with relatively small internal and solar heat gains, the division of a building in thermal zones is not required in energy calculations, but the whole building can be treated as one thermal zone (CEN, 2004).

2.1.1 Transmission heat losses

Transmission heat loss, q_t, of a single zone building at a given calculation time, t, is defined as:

$$q_t(t) = U \cdot S \, [T_{out}(t) - T_{int}(t)] \qquad (1)$$

Where:

U is the average thermal transmittance of the building envelope (W/m^{2}K)

S is the overall surface of the building envelope (m^2)

$T_{out}(t)$ is the instantaneous outdoor air temperature (^{o}C)

$T_{int}(t)$ is the instantaneous indoor air temperature (^{o}C), calculated according to 2.3.2

The values for T_{out} are provided in a weather file, which is explained in Appendix 3.

2.1.2 Ventilation heat losses

Ventilation flow rate is composed of two parts: sanitary ventilation and natural ventilation. While the sanitary ventilation stands for the minimum ventilation flow rate in buildings, the natural ventilation is used only when the indoor air temperature exceeds some upper comfort limit, T_v. Thus, the need for natural ventilation occurs normally in summer.

Heat loss due to the sanitary ventilation is modelled as:

$$q_{vSa}(t) = \frac{V_c \cdot A \cdot (\rho c_p)_a}{1000} \cdot [T_{vent}(t) - T_{int}(t)] \qquad (2)$$

Where:

V_c is the sanitary ventilation rate (l/s/m^2)

ρ_a is the density of the air (1,2 kg/m^3 at 20°C and 30% relative humidity (Hagentoft, 2005))

${c_p}_a$ is the specific heat capacity of the air (J/kg K)

A is the heated floor area in a building (m^2)

T_{vent} is the temperature of supply air (°C)

The value for the sanitary ventilation flow rate is provided at the national level and equals to 0.35 l/s/m^2 of the heated floor area in residential buildings (Boverket, 2009).

In buildings without heat recovery from exhaust air, the temperature of the supply air equals outdoor air temperature. If a heat recovery system is present, the supply air is preheated by the exhaust air; in such case and as long as the outdoor air temperature is below 15 °C, the temperature of the supply air is found as:

$$T_{vent}(t) = T_{out}(t) + H_{Rec\_Eff} \cdot [T_{int}(t) - T_{out}(t)] \qquad (3)$$

Where H_{Rec_Eff} is the efficiency of the heat recovery unit (0-1).When the outdoor air temperature exceeds 15 °C, $T_{vent}(t) = T_{out}(t)$.

Cooling of the building by natural ventilation, known also as 'free cooling', is used whenever the indoor temperature exceeds the set point temperature for natural ventilation, T_v:

$$q_{vNat}(t) = \frac{V_{cn} \cdot A \cdot (\rho c_p)_a}{1000} \cdot [T_{out}(t) - T_{int}(t)] \qquad (4)$$

if $T_{int}(t) > T_v(t)$

Where V_{cn} is airflow rate for natural ventilation (l/s/m^2).

Total heat loss /gain due to the ventilation is then:

$$q_v = q_{vSa} + q_{vNat} \qquad (5)$$

2.2 Heat gains

Heat gains include heat generated in the building by heat sources other than the space heating system, e.g.:

- solar gains through windows
- metabolic gains from occupants
- heat generated by appliances, lighting devices and ventilation fans.

In the model, all heat gains except the solar gains through windows are referred to as "internal heat gains".

2.2.1 Solar gains through windows

Since the aim of the simplified model is to be used for representative buildings, no specific orientation of windows is considered. The window is one and horizontal. The window area corresponds to the total area of all windows on a building. The difference in solar irradiation on differently oriented facades is compensated by a constant, 0.65, which is explained further in Appendix 6.

Solar gain from the solar radiation through windows reads:

$$q_r = T_s \cdot W_c \cdot W_f \cdot S_w \cdot I_{sol} \cdot 0.65 \tag{6}$$

Where:

T_s is the coefficient of solar transmission of the window (0-1)

W_c is the shading coefficient of the window (0-1)

W_f is the frame coefficient of the window (0-1)

S_w is the total surface of windows of the building (m^2)

I_{sol} is the global irradiation on horizontal surface (W/m^2)

The values for I_{sol} are provided in the weather file, which is explained in Appendix 5.

2.2.2 Internal heat gains

Internal heat gain, q_{int}, in the building reads:

$$q_{int} = q_{Lig} + q_{App} + q_{Occ} + q_{BuiS} \tag{7}$$

Where:

q_{Lig} is the heat generation by light sources, (W)

q_{App} is the heat generation by appliances, (W)

q_{Occ} is the heat generation by occupants, (W)

q_{BuiS} is the heat generation by ventilation fans, (W)

Each source of internal gains is found as an average value for the building, in respect to the total heated floor area:

$$q_{Lig} = L_c \cdot A \tag{8}$$

$$q_{Avv} = A_c \cdot A \tag{9}$$

$$q_{Occ} = O_c \cdot A \tag{10}$$

$$q_{BuiS} = P_{fh} \cdot A \tag{11}$$

Where:

L_c is the average specific heat gain due to lighting in the building[7] (W/m^2)

A_c is the average specific heat gain due to domestic appliances in the building (W/m^2)

O_c is the average specific heat gain due to people in the building (W/m^2)

P_{fh} is the part of the electrical energy consumed by the ventilation fans that goes as heat into the indoor air (W/m^2)

2.3 Heat use

2.3.1 Effective internal heat capacity of the building

Effective internal heat capacity of the building, C, represents the thermal inertia of the building. It is found by summing the volumetric heat capacities of the layers in direct contact with the internal air, such as internal layers of exterior walls, internal walls and middle floors:

$$C = \sum \rho_i \cdot c_{pi} \cdot S_i \cdot d_i \tag{12}$$

Where:

ρ_i is the density of the layer, (kg/m^3)

c_{pi} is the specific heat capacity of the layer (J/kg K)

S_i is the area of the layer (m^3)

d_i is the thickness of the layer (m), determined according EN ISO 13790.

The sum is done for all layers of each element, starting from the internal surface and stopping at the first insulating layer. According EN ISO 13790, the maximum thickness is 10 cm or the middle of the building element, whichever comes first.

---

[7] Due to the specific requirements from Boverket, this input was equivalent to the electricity consumption of a lighting device. It could be however specified in another way..

2.3.2 Calculation of indoor air temperature

The lumped model assumes that the indoor air temperature and the temperature of all internal layers are the same. The change of indoor air temperature in each time step is found from the differential energy balance equation:

$$C \cdot \frac{d\,T_{int}(t)}{dt} = q_t(t) + q_v(t) + q_r(t) + q_{int}(t) \qquad (13)$$

Where the heat gains and losses on the right-hand side of the equation are explained in sections 2.1 and 2.2.

This equation is numerically integrated in the Simulink model by using the explicit time scheme:

$$\int_t^{t+\Delta t} \frac{dT_{int}(t)}{dt} dt = T_{int}(t+\Delta t) - T_{int}(t) \qquad (14)$$

Thus, the air temperature in the next time step, $T_{int}(t+\Delta t)$, is found from the known values from the current time step, t:

$$T_{int}(t+\Delta t) = T_{int}(t) + \frac{q_t(t) + q_v(t) + q_r(t) + q_{int}(t)}{C} \qquad (15)$$

Note that equation 13 does not include heat delivered by heating or cooling systems and, for that reason, the resulting temperature represent the so-called free-running indoor air temperature. This results if of interest, for example, during summer for a building with free-cooling by natural ventilation. Determination of indoor air temperature in a building with active heating or cooling is described hereafter. However, the integration principle, which is described by equations 14 and 15, is the same.

2.3.3 Heat demand for building heating and cooling

Heating demand is defined as the heat power needed to maintain the indoor air temperature at a given level. A simple "on-off" control system is used in the model, where:

- Heating is ON if the indoor air temperature is less than the set point temperature for heatingTr_{min},
- Otherwise, the heating is OFF.

Common value for Tr_{min} is 21°C. The value used for the Boverket study was 21.2 °C, the measured average value for all residential buildings (Boverket, 2009).

The energy balance equation for this case reads:

$$C \cdot \frac{d\, T_{int}(\mathrm{t})}{dt} = q_t(\mathrm{t}) + q_v(\mathrm{t}) + q_r(t) + q_{int}(t) + q(t) \qquad (16)$$

wherefrom the heating (or cooling) demand is found as

$$q(t) = C \cdot \frac{d\, T_{int}(\mathrm{t})}{dt} - [q_t(\mathrm{t}) + q_v(\mathrm{t}) + q_r(t) + q_{int}(t)] \qquad (17)$$

If the indoor temperature in the next time step is found lower than the set point temperature for heating:

$$T_{int}(t + \Delta t) < Tr_{min}$$

The heating demand is increased for:

$$C \cdot [Tr_{min} - T_{int}(t + \Delta t)] \qquad (18)$$

The heating demand is present as long as $q(t) > 0$ and $T_{int} \leq Tr_{min}$.

Giving a heating system with a finite heat capacity, P_h, and response time, S_h, the heat delivery from the heating system is found as:

$$q_{Heat}(t) = P_h \cdot C \cdot [Tr_{min} - T_{int}(t + \Delta t)]$$

And: (19)

$$q_{Heat}(t) \leq S_h$$

Where:

P_h	is the proportional term of a proportional controller (-)
S_h	is the max power available from the heating system (W)
Tr_{min}	is the minimum desired indoor temperature (C)

Because of these physical limitations of the heating system, it can happen that the maximum power from the heating system is less than the heating demand, e.g.

$$q(t) > S_h$$

In such cases the indoor air temperature in the building is below the set-point temperature.

$$T_{int} < Tr_{min}.$$

In a similar way, the cooling demand can be found as the heat needed to maintain the indoor air temperature below the upper comfort limit, Tr_{max}. The cooling demand is calculated by expression 18 and it is present as long as $q(t) < 0$ and $T_{int} \geq Tr_{max}$.

The cooling power of the cooling system is found as:

$$q_{Cool}(t) = P_c \cdot C \cdot [T_{int}(t + \Delta t) - Tr_{max}] \qquad (20)$$

And:

$$q_{Cool}(t) < S_c$$

Where:

P_c is the proportional term of a proportional controller (-)

S_c is the max power available from the cooling system (W)

Tr_{max} is the maximum desired indoor temperature (C)

However, the cooling demand is not a required output in this study, so the parameter S_c is set to 0 and therefore the cooling demand is not calculated.

2.3.4 Heat demand for hot water production

The heat needed for the hot water production is found as:

$$q_{HotW} = H_w \cdot A \qquad (21)$$

Where H_w is the average specific heat demand for hot water production (W/m^2).

2.4 Heat recovered

2.4.1 Heat recovered by heat exchanger

In buildings with mechanical supply-exhaust ventilation system (*Från- och Tilluft med värmeåtervinning X (FTX)* in Swedish), a part of the heating demand for the sanitary ventilation losses can be recovered in a heat exchanger:

$$q_{HeatR} = q_{vSa} \cdot H_{Rec\ Eff} \qquad (22)$$

Where H_{Rec_Eff} is the efficiency of the heat exchanger.

This heat is used for the pre-heating of the supply air (see equations 2-3).

2.4.2 Heat recovered by exhaust air heat pump

If an exhaust air heat pump (*FrånluftsVärmePump (FVP)* in Swedish) is included in the building, a part of the heating demand for the sanitary ventilation losses can be recovered. The process or heat recovery depends on the outdoor air temperature:

$$q_{HeatR\_FVP}(t) = V_c \cdot A \cdot \left(\rho c_p\right)_a \cdot Per_{HPinH} \cdot (T_{int}(t) - 5) \qquad \text{if } T_{out} < 5\,°C \tag{23a}$$

$$q_{HeatR\_FVP}(t) = V_c \cdot A \cdot \left(\rho c_p\right)_a \cdot Per_{HPinH} \cdot (T_{int}(t) - T_{out}), \qquad \text{if } T_{out} > 5\,°C \tag{23b}$$

Where Per_{HPinH} is the percentage of heat provided by the heat pumps (0-1).

3 Outputs

The outputs of the simulation model are composed of 17 sets of data, for each of the 1384 buildings simulated. The results involving integration over time are calculated in the Simulink model, while the others are found in the code by simple summation.

Further explanations about the output files of the simulation (including the further calculations written in the code) are given in Appendix 1.

3.1 Annual heat use

Annual heat demand for space heating, cooling and hot water production is found as:

$$D_{Heat} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{Heat}(t)dt \qquad \text{[kWh/y]} \qquad (24)$$

$$D_{Cool} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{Cool}(t)dt \qquad \text{[kWh/y]} \qquad (25)$$

$$D_{HotW} = \frac{1}{3.6 \cdot 10^6} \cdot \sum_0^{8760} q_{HotW} \cdot 3600 \qquad \text{[kWh/y]} \qquad (26)$$

Where $t_y = 1\ year$ = 8760 h/year · 3600 s/h.

Given that in this study the inputs are constant, eventually equation 26a could also be expressed:

$$D_{HotW} = 8.76 \cdot q_{HotW} \qquad \text{[kWh/y]} \qquad (27)$$

3.2 Annual heat losses and free cooling

Annual heat losses from the building include annual losses by transmission and sanitary ventilation

$$Q_t = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_t(t)dt\,, \text{ if } q_t(t) < 0 \qquad \text{[kWh/y]} \quad (28)$$

$$Q_{vSa} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{vSa}(t)dt, \text{ if } q_{vSa}(t) < 0 \qquad \text{[kWh/y]} \quad (29)$$

The annual cooling of the building due by natural ventilation is referred to as free cooling:

$$Q_{vNat} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{vNat}(t)dt, \quad \text{if} \quad q_{vNat}(t) < 0 \quad \text{[kWh/y]} \quad (30)$$

This result is not very valuable regarding to heating demand, since natural ventilation is designed to be extra ventilation for summer conditions, when indoor temperature is above certain temperature (T_v), and therefore it´s a realistic strategy to calculate cooling demand.

It would be more useful to plot the value when it´s contributing to cool down the building ($if\ q_{vNat} > 0$), but it´s not done since cooling demand is not of interest if this project.

3.3 Annual heat gains

Annual heat gains to the building due to solar radiation through windows, lighting, appliances, occupants and ventilation fans are:

$$Q_r = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_f(t)dt \qquad \text{[kWh/y]} \quad (31)$$

$$Q_{Lig} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{Lig}(t)dt \qquad \text{[kWh/y]} \quad (32)$$

$$Q_{App} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{App}(t)dt \qquad \text{[kWh/y]} \quad (33)$$

$$Q_{Occ} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{Occ}(t)dt \qquad \text{[kWh/y]} \quad (34)$$

$$Q_{BuiS} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{BuiS}(t)dt \qquad \text{[kWh/y]} \quad (35)$$

Where $t_y = 1\ year$ = 8760 h/year · 3600 s/h.

3.4 Annual heat recovered

This result refers to the buildings with a heat recovery unit included in the ventilation system:

$$Q_{HeatR} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{HeatR}(t)dt, \quad \text{if} \quad T_{out}(t) < 15\ C \qquad \text{[kWh/y]} \quad (36)$$

$$Q_{HeatR\_FVP} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{HeatR\_FVP}(t)dt \qquad \text{[kWh/y]} \quad (37)$$

Where $t_y = 1\ year$ = 8760 h/year · 3600 s/h.

Therefore, the total heat recovered is found as the sum of the heat recovered by the supply-exhaust ventilation system and the heat recovered by the exhaust air heat pump:

$$Q_{HR} = Q_{HeatR} + Q_{HeatR\_FVP} \qquad \text{[kWh/y]} \quad (38)$$

Where:

Q_{HeatR}	is the annual heat recovered by the supply-exhaust ventilation system
Q_{HeatR_FVP}	is the annual heat recovered by the exhaust air heat pump

3.5 Annual consumption of electricity

For the operation of the ventilation fans:

$$Q_{Fan} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{Fan}(t)dt \qquad \text{[kWh/y]} \quad (39)$$

$$q_{Fan} = SFP \cdot V_c \cdot A \qquad \text{[W]} \quad (40)$$

Where:

q_{Fan}	is the electrical power demand for the operation of fans
SFP	is the Specific Power (SFP) demand for the operation of Fans (W/l/m^2)
t_y	is 1 year= 8760 h/year · 3600 s/h.

For the operation of hydronic pumps:

$$Q_{HyP} = \frac{1}{3.6 \cdot 10^6} \cdot \int_0^{t_y} q_{HyP}(t)dt \qquad \text{[kWh/y]} \quad (41)$$

$$q_{HyP} = Hy_P \cdot A \qquad \text{[W]} \quad (42)$$

Where:

q_{HyP}	is the electrical power demand for the operation of hydronic pumps

Hy_P is the specific power demand for the operation of hydronic pumps, (W/m^2)

The electricity consumption for the operation of lighting devices and domestic appliances is considered to be equal to the heat released from these devices, as described by expressions 32 and 33.

$$D_{El} = Q_{App-} + Q_{Lig} + Q_{Fan} + Q_{HyP} \tag{43}$$

3.6 Total energy demand

Total energy demand

$$E_{Tot} = D_{El} + D_{Heat} + D_{Cool} + D_{HotW} - Q_{HR} \tag{44}$$

where:

D_{El} = annual electricity demand, including the electricity required for lighting, appliances, hydronic pumps and fans (kWh/yr)

D_{Heat} = annual heating demand (kWh/yr)

D_{Cool} = annual demand for cooling (kWh/yr)

D_{HotW} = annual heat demand for hot water (kWh/yr)

Q_{HR} = annual heat recovered (kWh/yr)

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Appendix 1. Inputs and outputs of the simulation: Specification of the Excel files

A1.1The input file

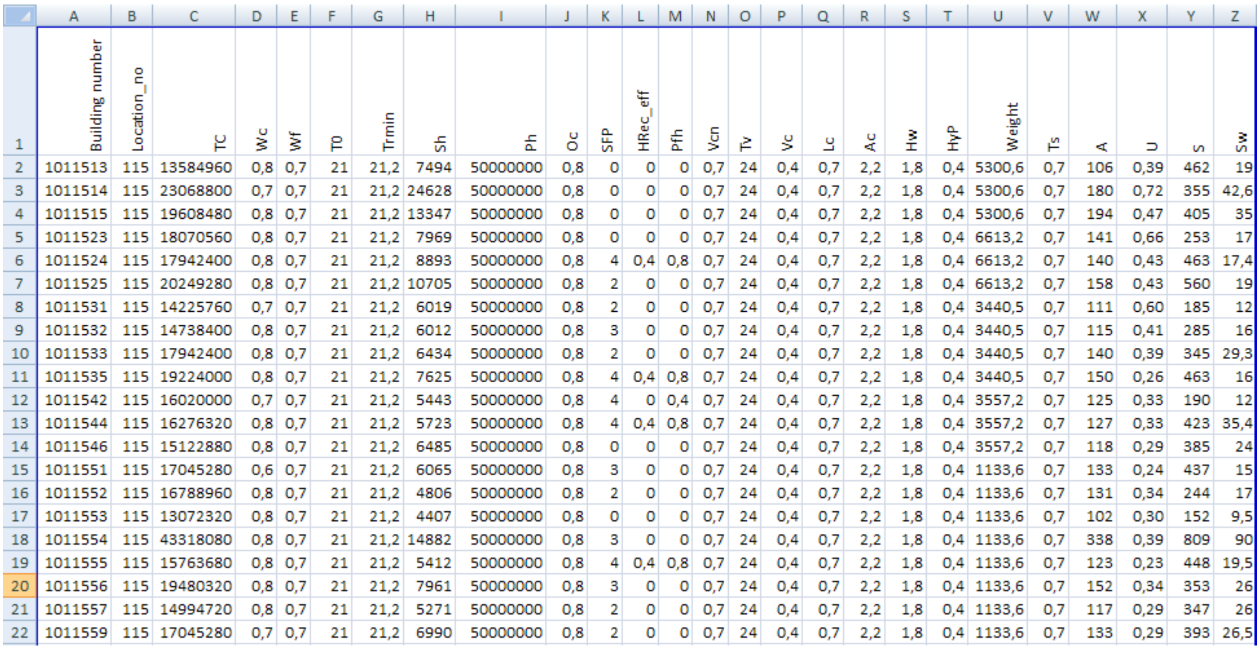
The input file has to be created according to the following specifications:

First row has to correspond exactly to each one of the input names set below. However, the order of the columns is not important.

As from second row, the values are set for each of the objects (buildings) to be simulated, in one row per building.

No empty cells are allowed, a cero (0) has to be set instead.

Figure 1 shows and example of an input file.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	Building number	Location_no	TC	Wc	Wf	T0	Trmin	Sh	Ph	Oc	SFP	HRec_eff	Pfh	Vcn	Tv	Vc	Lc	Ac	Hw	HyP	Weight	Ts	A	U	S	Sw
2	1011513	115	13584960	0,8	0,7	21	21,2	7494	50000000	0,8	0	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	5300,6	0,7	106	0,39	462	19
3	1011514	115	23068800	0,7	0,7	21	21,2	24628	50000000	0,8	0	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	5300,6	0,7	180	0,72	355	42,6
4	1011515	115	19608480	0,8	0,7	21	21,2	13347	50000000	0,8	0	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	5300,6	0,7	194	0,47	405	35
5	1011523	115	18070560	0,8	0,7	21	21,2	7969	50000000	0,8	0	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	6613,2	0,7	141	0,66	253	17
6	1011524	115	17942400	0,8	0,7	21	21,2	8893	50000000	0,8	4	0,4	0,8	0,7	24	0,4	0,7	2,2	1,8	0,4	6613,2	0,7	140	0,43	463	17,4
7	1011525	115	20249280	0,8	0,7	21	21,2	10705	50000000	0,8	2	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	6613,2	0,7	158	0,43	560	19
8	1011531	115	14225760	0,7	0,7	21	21,2	6019	50000000	0,8	2	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	3440,5	0,7	111	0,60	185	12
9	1011532	115	14738400	0,8	0,7	21	21,2	6012	50000000	0,8	3	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	3440,5	0,7	115	0,41	285	16
10	1011533	115	17942400	0,8	0,7	21	21,2	6434	50000000	0,8	2	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	3440,5	0,7	140	0,39	345	29,3
11	1011535	115	19224000	0,8	0,7	21	21,2	7625	50000000	0,8	4	0,4	0,8	0,7	24	0,4	0,7	2,2	1,8	0,4	3440,5	0,7	150	0,26	463	16
12	1011542	115	16020000	0,7	0,7	21	21,2	5443	50000000	0,8	4	0	0,4	0,7	24	0,4	0,7	2,2	1,8	0,4	3557,2	0,7	125	0,33	190	12
13	1011544	115	16276320	0,8	0,7	21	21,2	5723	50000000	0,8	4	0,4	0,8	0,7	24	0,4	0,7	2,2	1,8	0,4	3557,2	0,7	127	0,33	423	35,4
14	1011546	115	15122880	0,8	0,7	21	21,2	6485	50000000	0,8	0	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	3557,2	0,7	118	0,29	385	24
15	1011551	115	17045280	0,6	0,7	21	21,2	6065	50000000	0,8	3	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	1133,6	0,7	133	0,24	437	15
16	1011552	115	16788960	0,8	0,7	21	21,2	4806	50000000	0,8	2	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	1133,6	0,7	131	0,34	244	17
17	1011553	115	13072320	0,8	0,7	21	21,2	4407	50000000	0,8	0	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	1133,6	0,7	102	0,30	152	9,5
18	1011554	115	43318080	0,8	0,7	21	21,2	14882	50000000	0,8	3	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	1133,6	0,7	338	0,39	809	90
19	1011555	115	15763680	0,8	0,7	21	21,2	5412	50000000	0,8	4	0,4	0,8	0,7	24	0,4	0,7	2,2	1,8	0,4	1133,6	0,7	123	0,23	448	19,5
20	1011556	115	19480320	0,8	0,7	21	21,2	7961	50000000	0,8	3	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	1133,6	0,7	152	0,34	353	26
21	1011557	115	14994720	0,8	0,7	21	21,2	5271	50000000	0,8	2	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	1133,6	0,7	117	0,29	347	26
22	1011559	115	17045280	0,7	0,7	21	21,2	6990	50000000	0,8	2	0	0	0,7	24	0,4	0,7	2,2	1,8	0,4	1133,6	0,7	133	0,29	393	26,5

Figure 1 Example of an input file.

In the following page, table 1 presents a list of the inputs required in the model.

Table 1 All the inputs are defined in the glossary, and additional information and equations can be found in the Sections specified in the table.

Input name	**Description of the input**	**Unit**
Building number	Boverket´s identification number for the building	-
Location_no	Weather region	-
A	Area of heat floor space	m^2
Ac	Average constant consumption of the appliances	W/m^2
HRec_Eff	Efficiency of the heat recovery system	%
Hw	Demand of hot water	W/m^2
HyP	Consumption of the hydro pumps	W/m^2
Lc	Average constant lighting load in the building	W/m^2
Oc	Average constant gain due to people in the building	W/m^2
Pfh	Heat losses of the fan	W/m^2
Ph	Response capacity of the heating system	-
S	Total external surfaces of the building	m^2
SFP	Specific Fan Power	$W/l/m^2$
Sh	Maximum hourly capacity of the heating system	W
Sw	Total surface of windows of the building	m^2
T0	Initial indoor temperature	C
TC[8]	Effective heat capacity of a heated space (whole building)	J/K
Trmin	Minimum indoor temperature	C
Ts	Coefficient of solar transmission of the window	%
Tv	Tint to start opening windows/nat ventilation	C
U	Mean U value of the building	W/ m^2C
Vc	Sanitary ventilation rate	$l/s/m^2$
Wc	Natural ventilation rate	$l/s/m^2$
Vcn	Shading coefficient of the window	%
Weight	Coefficient to scale up the type to the Building Stock	-
Wf	Frame coefficient of the window	%

---

[8] This input is called C throughout this report.

A1.2 The output file

There are two output files per each input file simulation. They are named automatically according to the name of the input file and the date when the simulation is run.

1) File “*Input File Name_Date*.xls” has two sheets. In every sheet, each row corresponds to one of the buildings studied:

Sheet “Energy”

This sheet has 22 columns.

It has one row per each of the buildings studied, according to the order plotted in the first column “Building_ID”.

Table 2 List of outputs of the sheet “Energy”. Grey cells are provided also as inputs, but they are plotted with the outputs to provide some information about the buildings.

	A	Building_ID Area (m^2) Type	
Column	**Output**	**Description**	**Unit**
1	D_{Cool}	Cooling Demand	kWh/y
2	Q_{vSa}	Sanitary Ventilation	kWh/ y
3	$\frac{Q_{vSa}}{A}$	Specific Sanitary Ventilation	kWh/ m^{2}y
4	Q_t	Transmission losses through the envelope	kWh/y
5	$\frac{D_{HotW}}{A}$	Hot Water Demand	kWh/m^{2}y
6	$\frac{D_{Heat}}{A}$	Heating Demand	kWh/m^{2}y
7	Q_r	Solar Radiation gains	kWh/y
8	Q_{Occ}	Occupancy	kWh/y
9	Q_{Lig}	Lighting Consumption	kWh/y
10	Q_{App}	Appliances	kWh/y
11	Q_{HyP}	Pumps Hydro	kWh/y
12	Q_{Fan}	Vent Fans	kWh/y
13	D_{HotW}	Hot Water Demand	kWh/y
14	Q_{HeatR}	Heat Recovery	kWh/y
15	$Q_{HeatR\ FVP}$	Heat Recovery FVP	kWh/y
16	D_{Heat}	Heating demand	kWh/y
17	W	Weight	
18	E_{tot}	Total Energy Use	kWh/y
19	$E_{tot} \cdot W$	Weighted Total Energy Use	kWh/y
20	$(E_{tot})_0$	Baseline Total Energy Use	kWh/y
21	$(E_{tot} \cdot W)_0$	Weighted Baseline Total Energy Use	kWh/y
22, cell	$\sum[(E_{tot} \cdot W)_0 - (E_{tot} \cdot W)_i]$	Total energy saving	TWh/y

Sheet “Temp”

This sheet has four columns.

It has one row per each of the buildings studied, according to the order plotted in the first column "Building ID" of the sheet “Energy”.

The value in the cell is the average annual temperature inside the building for each of the four seasons in the year, in Celsius grades (C).

Table 3 List of outputs of the sheet “Temp”

Column	Season	Temperature shown	
A	Winter (21st December - 20th March)	$T_{winter} = \frac{\sum_{j=8500}^{8760} T_{int} + \sum_{j=1}^{1896} T_{int}}{2160}$	(45)
B	Spring (21st March – 20th June)	$T_{spring} = \frac{\sum_{j=1897}^{4105} T_{int}}{2208}$	(46)
C	Summer (21st June - 20th September)	$T_{summer} = \frac{\sum_{j=4106}^{6314} T_{int}}{2208}$	(47)
D	Autumn (21st September - 20th December)	$T_{autumn} = \frac{\sum_{=6315}^{8499} T_{int}}{2184}$	(48)

Where j is the number of the hours in the year.

2) File “*Input File Name_Date_*Energy.xls”

Finally, a 2nd file is plotted to provide only the results of total energy demand; the file is used by Boverket to order the measures according to their cost-efficiency.

This file has only one sheet, and there is one row for every of the input files simulated. There are four columns:

Table 4 List of outputs of the second output file

Column				
A			Building_ID	
B	$(E_{tot})_0$		Baseline Total Energy Demand	kWh/y
C	E_{tot}		Total Energy Demand	kWh/y
D	$SE = (E_{tot})_0 - E_{tot}$	(49)	Energy saving	TWh/y

Appendix 2. Systems and subsystems

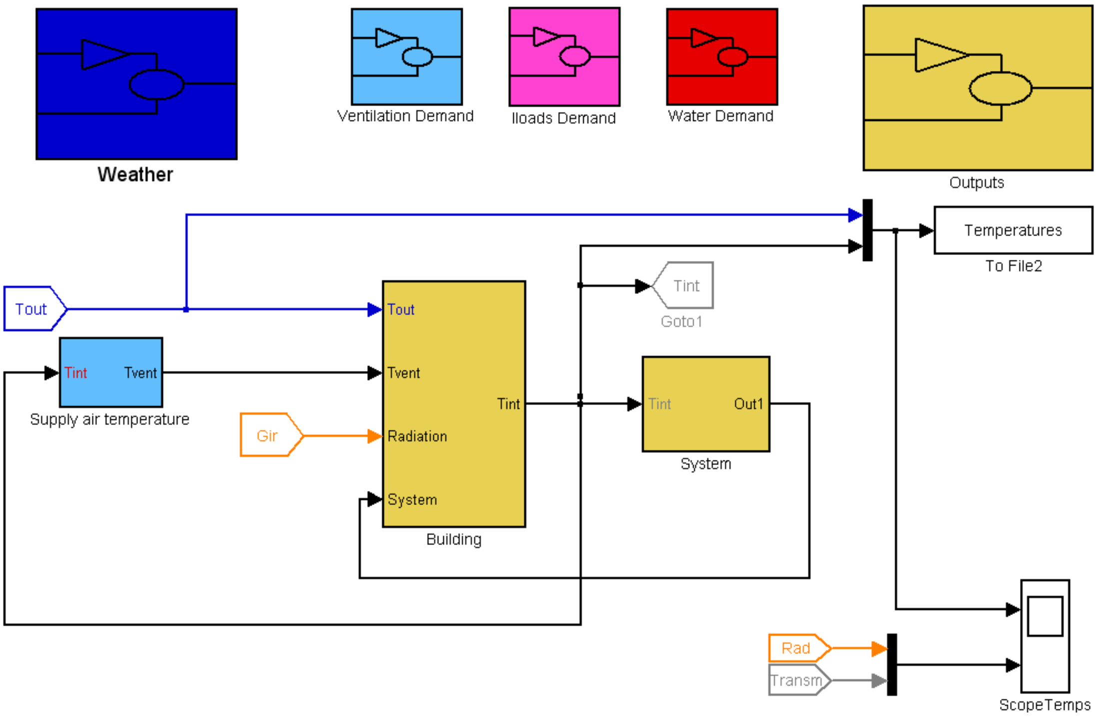


Figure 2 Main system of the model "Building Boverket"

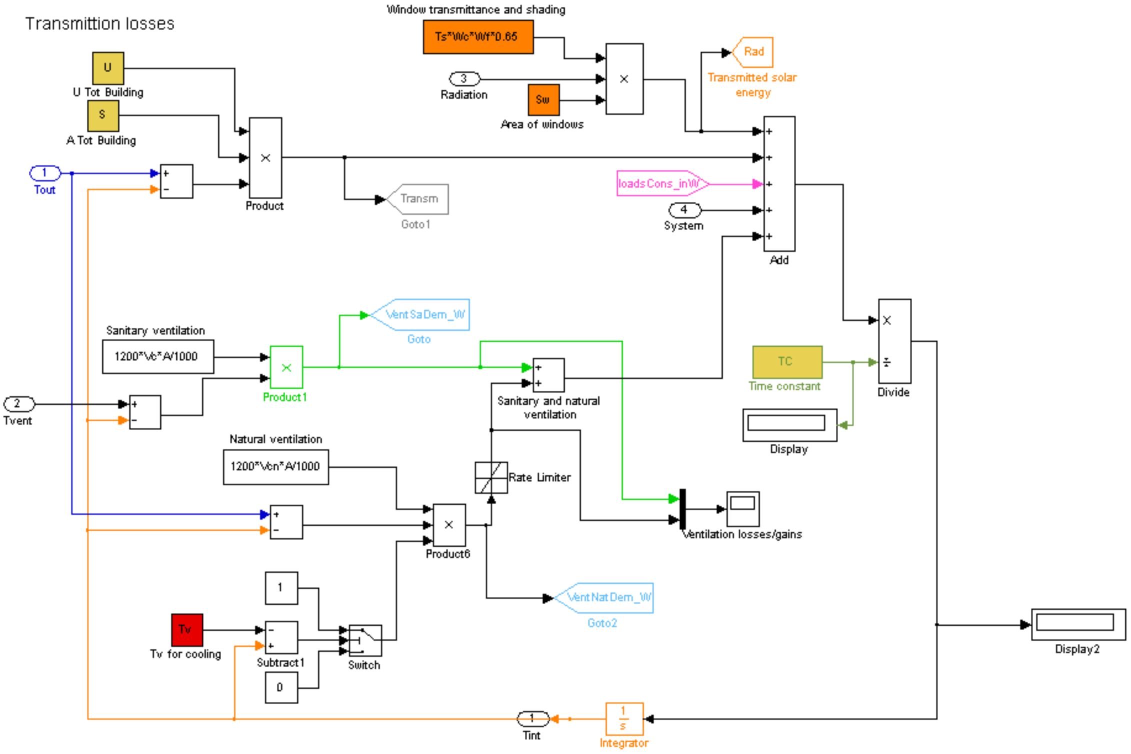


Figure 3 Subsystem "Building" in model "Building Boverket"

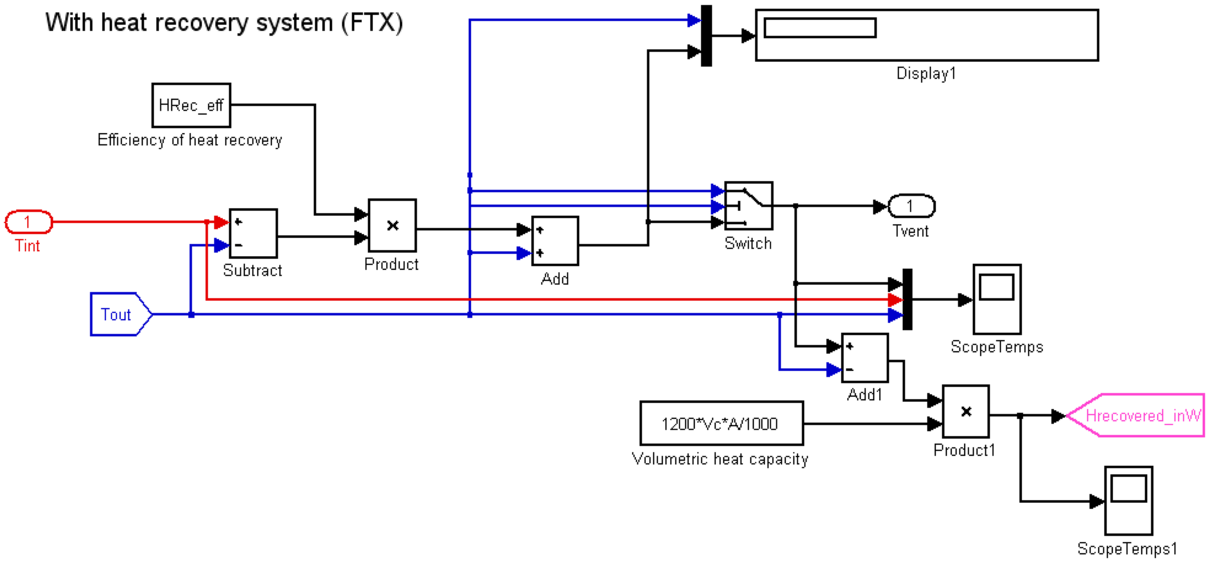


Figure 4 Subsystem "Supply air temperature" in model "Building Boverket"

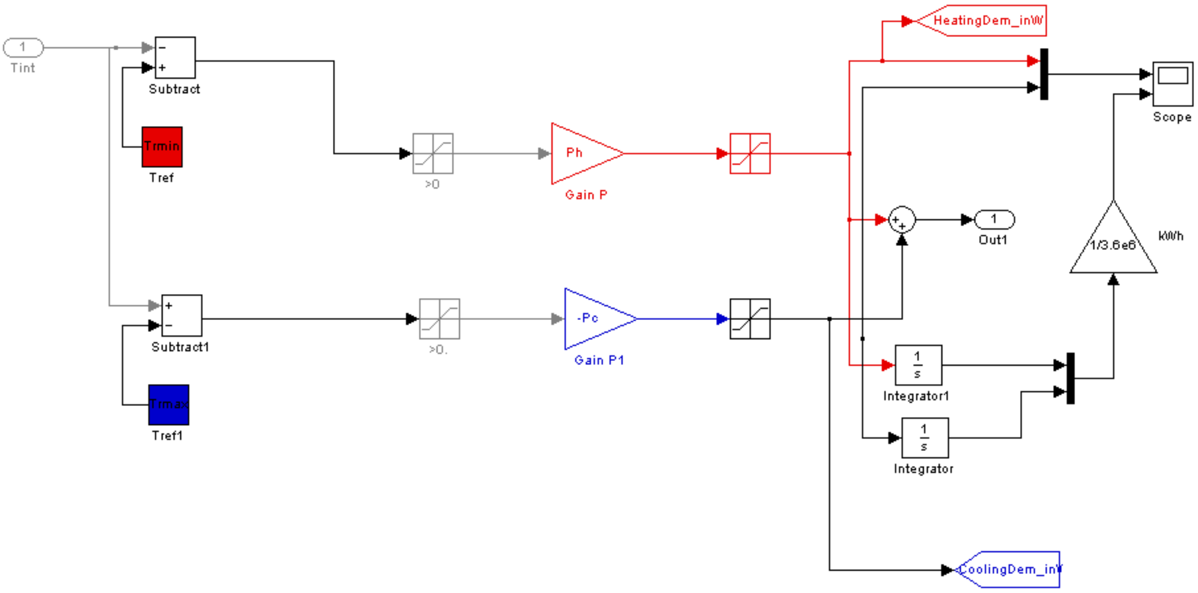


Figure 5 Subsystem "System" in model "Building Boverket"

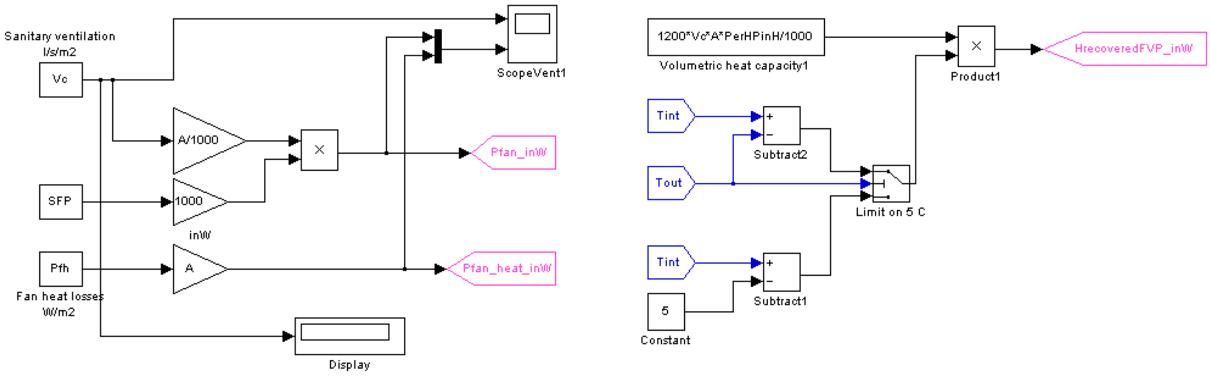


Figure 6 Subsystem "Ventilation Demand" in model "Building Boverket"

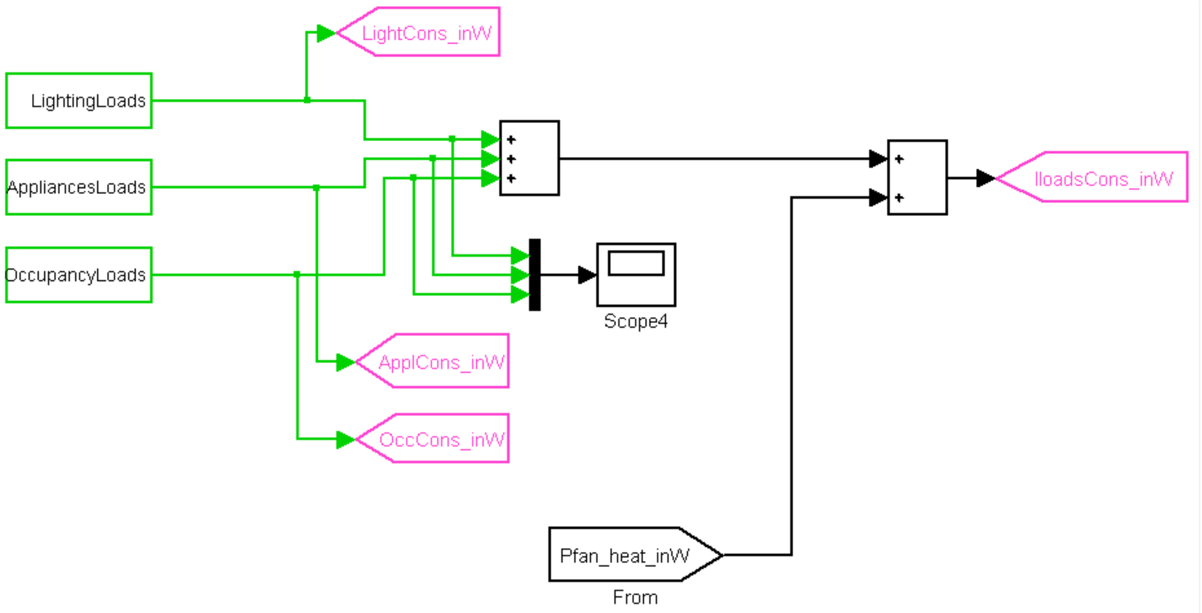


Figure 7 Subsystem "Iloads Demand" in model "Building Boverket"

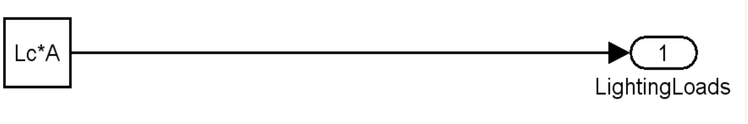


Figure 8 Subsystem "Iloads Demand/Lighting Loads" in model "Building Boverket"

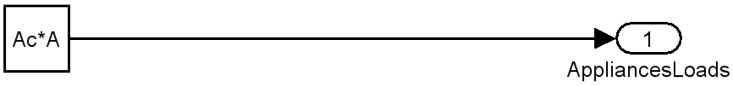


Figure 9 Subsystem "Iloads Demand/Appliances Loads" in model "Building Boverket"

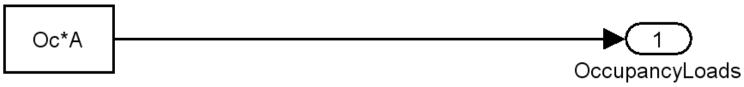


Figure 10 Subsystem "Iloads Demand/Occupancy Loads" in model "Building Boverket"

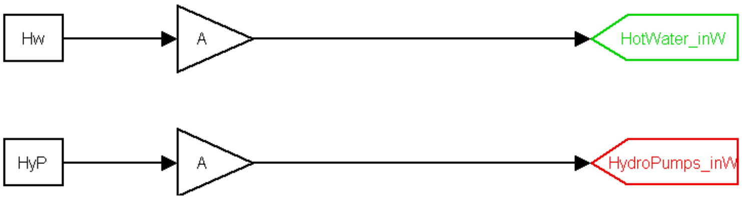


Figure 11 Subsystem "Water Demand" in model "Building Boverket"

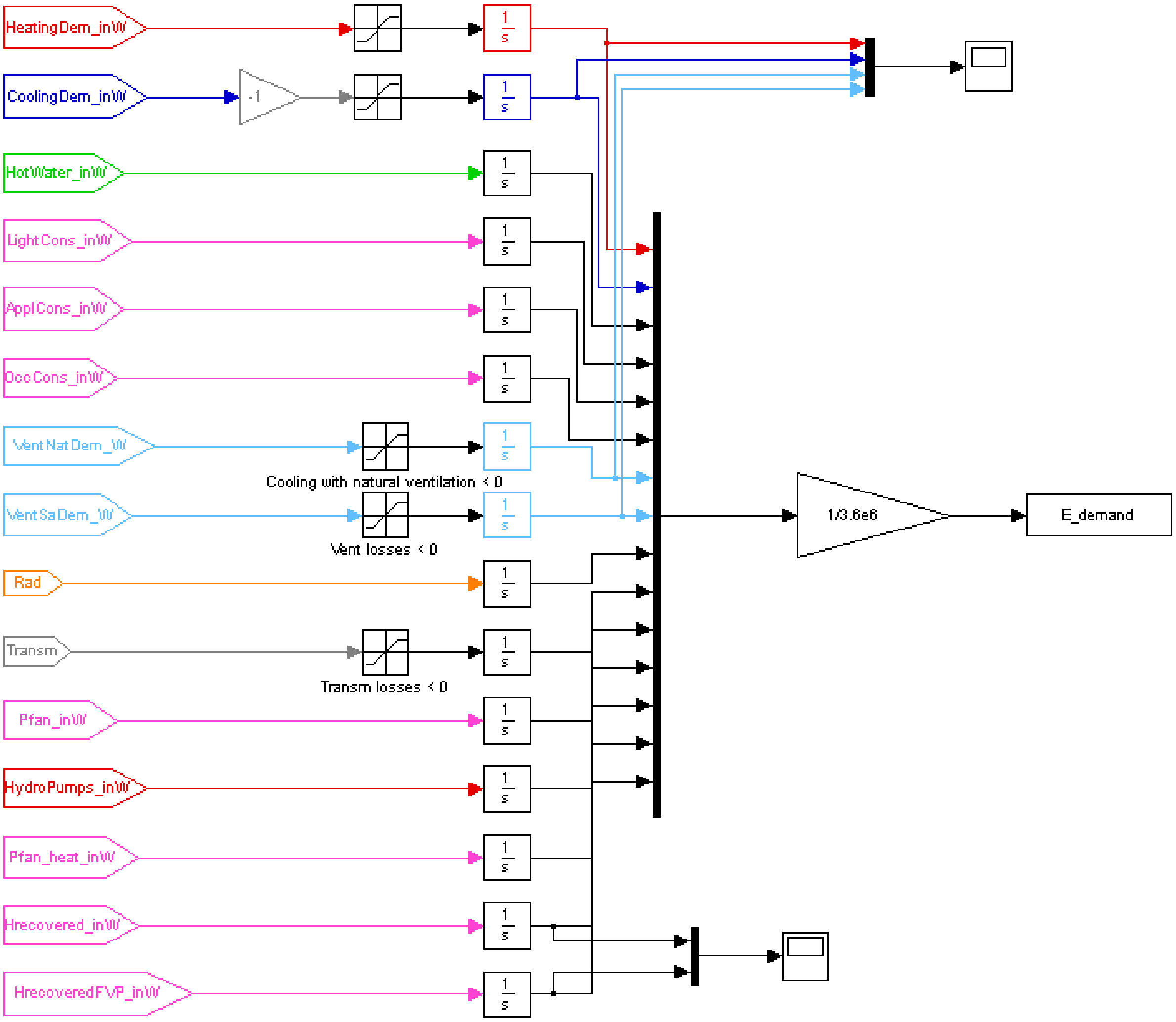


Figure 12 Subsystem "Outputs" in model "Building Boverket"

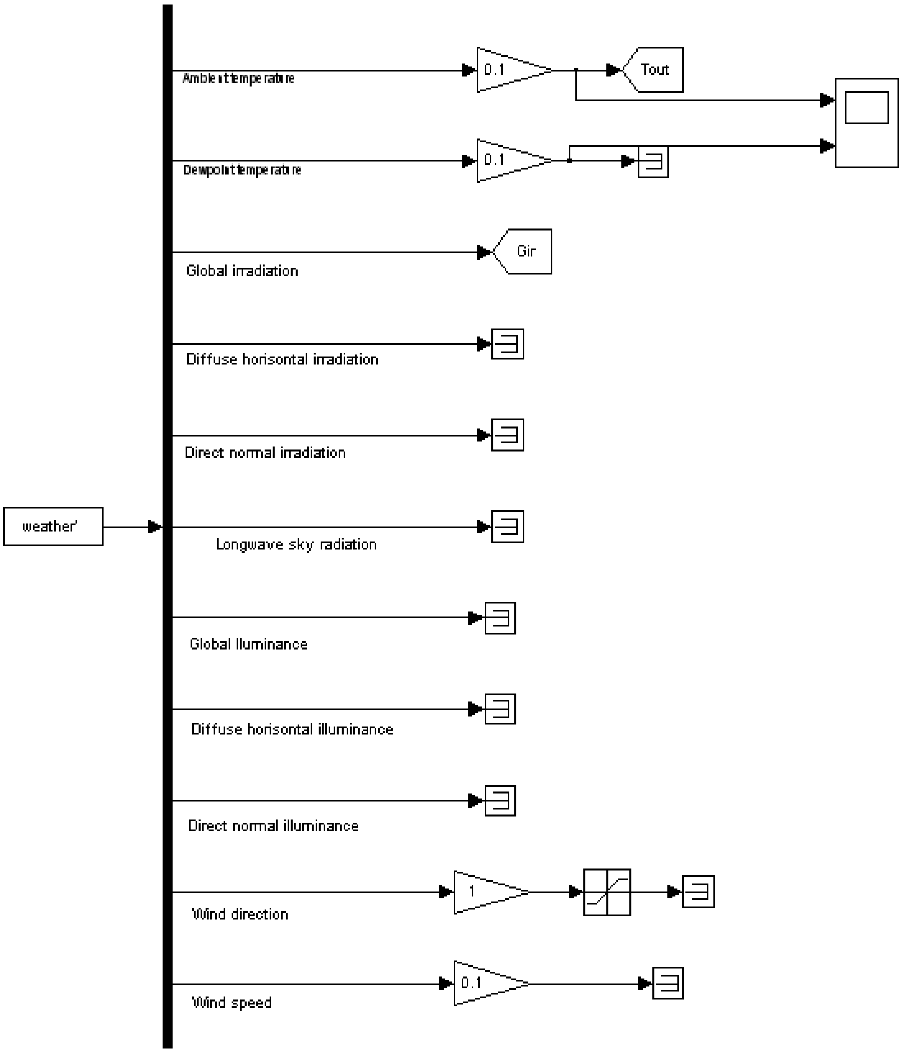
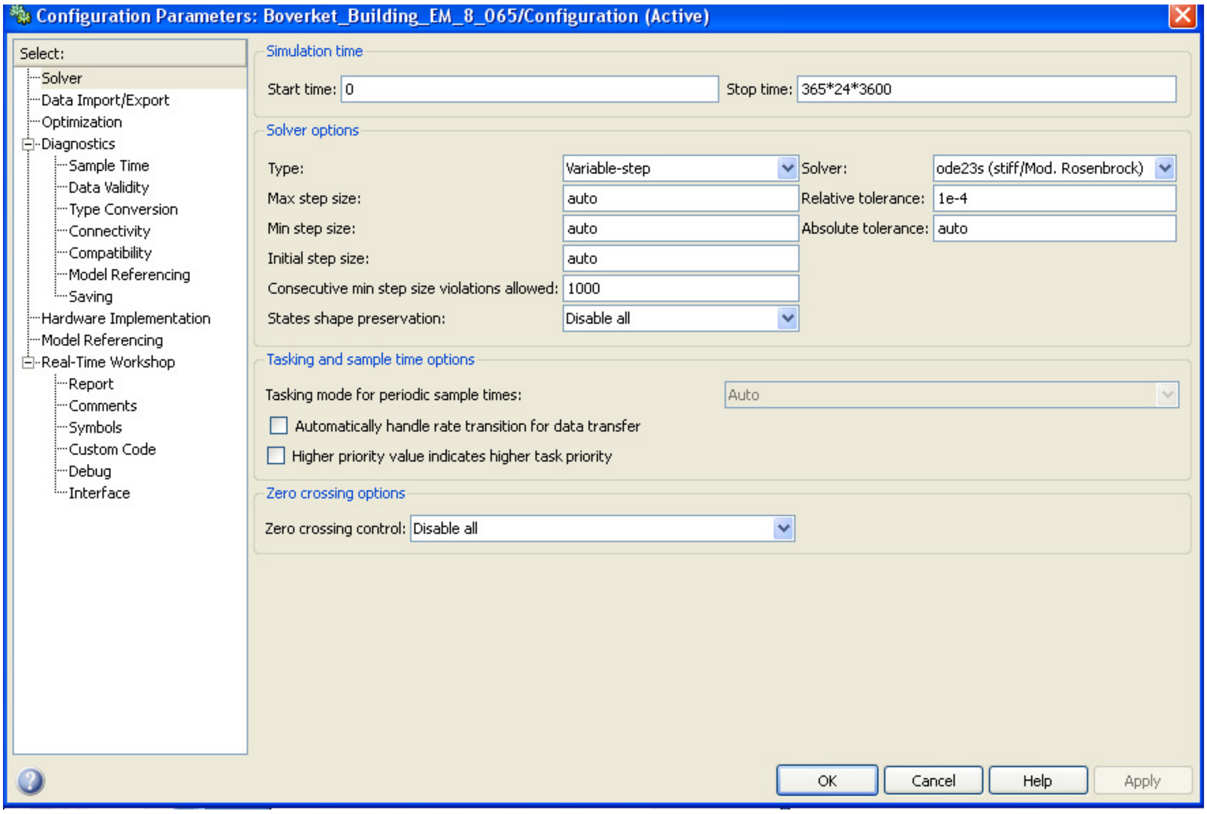


Figure 13 Subsystem "Weather" in model "Building Boverket"

Appendix 3. Configuration parameters

Configuration parameters are set as shown in the following Figure 14.



Configuration Parameters: Boverket_Building_EM_8_065/Configuration (Active)

Simulation time

Start time: 0

Stop time: 365*24*3600

Solver options

Type: Variable-step

Solver: ode23s (stiff/Mod. Rosenbrock)

Max step size: auto

Relative tolerance: 1e-4

Min step size: auto

Absolute tolerance: auto

Initial step size: auto

Consecutive min step size violations allowed: 1000

States shape preservation: Disable all

Tasking and sample time options

Tasking mode for periodic sample times: Auto

☐ Automatically handle rate transition for data transfer

☐ Higher priority value indicates higher task priority

Zero crossing options

Zero crossing control: Disable all

Figure 14 Configuration parameters

Appendix 4. Matlab code

This code is originally developed by Vahid Nik, PhD student at the Division of Building Technology Chalmers. Some minor changes were introduced by the authors during the Boverket’s project.

manager_structured_E0

Contents

- Finding column number of each parameter
- Arranging the data according to its location
- Doing simulation for the locations
- Saving results in excel file with headings

```
 clear all
clc
for ii=9:17     % ii is the counter of number of input files (Atgard 1.xls....Atgard 25.xls)
   iistr=int2str(ii);
   [NUMERIC,TXT,RAW]=xlsread(['aggregerat_utan23_alla ' iistr '.xls']); % Reading the input file
   NameFile=['ResultAgg_utan23_alla ' iistr ' , ' date];
```

Finding column number of each parameter

```
   Building_no_column=strmatch('Building number',TXT(1,:),'exact');
   Location_no_column=strmatch('Location_no',TXT(1,:),'exact');
   A_column=strmatch('A',TXT(1,:),'exact');
   U_column=strmatch('U',TXT(1,:),'exact');
   S_column=strmatch('S',TXT(1,:),'exact');
   TC_column=strmatch('TC',TXT(1,:),'exact');
   Wc_column=strmatch('Wc',TXT(1,:),'exact');
   Wf_column=strmatch('Wf',TXT(1,:),'exact');
   Sw_column=strmatch('Sw',TXT(1,:),'exact');
   Ts_column=strmatch('Ts',TXT(1,:),'exact');
   Va_column=strmatch('Va',TXT(1,:),'exact');
   T0_column=strmatch('T0',TXT(1,:),'exact');
   Trmin_column=strmatch('Trmin',TXT(1,:),'exact');
   Trmax_column=strmatch('Trmax',TXT(1,:),'exact');
   Sh_column=strmatch('Sh',TXT(1,:),'exact');
   Sc_column=strmatch('Sc',TXT(1,:),'exact');
   Pc_column=strmatch('Pc',TXT(1,:),'exact');
   Ph_column=strmatch('Ph',TXT(1,:),'exact');
   Oamp_column=strmatch('Oamp',TXT(1,:),'exact');
   Oc_column=strmatch('Oc',TXT(1,:),'exact');
   Os_column=strmatch('Os',TXT(1,:),'exact');
   Od_column=strmatch('Od',TXT(1,:),'exact');
   SFP_column=strmatch('SFP',TXT(1,:),'exact');
   HRec_eff_column=strmatch('HRec_eff',TXT(1,:),'exact');
   Pfh_column=strmatch('Pfh',TXT(1,:),'exact');
   Vcn_column=strmatch('Vcn',TXT(1,:),'exact');
   Tv_column=strmatch('Tv',TXT(1,:),'exact');
   Vamp_column=strmatch('Vamp',TXT(1,:),'exact');
```

```
   Vc_column=strmatch('Vc',TXT(1,:),'exact');
   Vs_column=strmatch('Vs',TXT(1,:),'exact');
   Vd_column=strmatch('Vd',TXT(1,:),'exact');
   Lamp_column=strmatch('Lamp',TXT(1,:),'exact');
   Lc_column=strmatch('Lc',TXT(1,:),'exact');
   Ls_column=strmatch('Ls',TXT(1,:),'exact');
   Ld_column=strmatch('Ld',TXT(1,:),'exact');
   Aamp_column=strmatch('Aamp',TXT(1,:),'exact');
   Ac_column=strmatch('Ac',TXT(1,:),'exact');
   As_column=strmatch('As',TXT(1,:),'exact');
   Ad_column=strmatch('Ad',TXT(1,:),'exact');
   Hw_column=strmatch('Hw',TXT(1,:),'exact');
   HyP_column=strmatch('HyP',TXT(1,:),'exact');
   PerHPinH_column=strmatch('PerHPinH',TXT(1,:),'exact');
   Weight_column=strmatch('Weight',TXT(1,:),'exact');
   Type_column=strmatch('Byggnads-typ',TXT(1,:),'exact');
```

Arranging the data according to its location

```
  L=NUMERIC(:,Location_no_column);
   k=1;
   a(k)=L(1);
   p(1).loc=find(L/a(k)==1);
   L(p(1).loc)=nan;
   while max(isfinite(L))==1
      next=min(find(isfinite(L)));
      a(length(a)+1)=L(next);
      p(length(a)).loc=find(L/a(length(a))==1);
      L(p(length(a)).loc)=nan;
   end

   for i=1:length(a)
      Location(i).ID=a(i);
      Location(i).Place=p(i).loc;
      Location(i).Number=length(Location(i).Place);
   end
```

Doing simulation for the locations

```
  for j=1:length(Location)
      temp=load (['weather_' num2str(Location(j).ID) '.txt']);     %or load (['weather_' 
locations(j) '.mat'])
      Weather_tot(j).ID=Location(j).ID;
      Weather_tot(j).data=temp;
   end
   k=0;
   for j=1:length(Location)
      weather=Weather_tot(j).data';
       weather(2,:)=weather(2,:)*10;
   %    weather(12,:)=weather(12,:)/10;
   %    Tg=mean(weather(2,:));
      Loc=Location(j).Place;
      for i=1:length(Loc)
          k=k+1
          U=NUMERIC(Loc(i),U_column);        %Mean U value of the building
```

```
         S=NUMERIC(Loc(i),S_column);        %Total external surfaces of the building(m2)
         A=NUMERIC(Loc(i),A_column);        %Area of heated floor space (m2)
         TC=NUMERIC(Loc(i),TC_column);      %Thermal capacity of the indoor layers
         Wc=NUMERIC(Loc(i),Wc_column);      %Shading coefficient of the window: 0-1
         Wf=NUMERIC(Loc(i),Wf_column);      %Frame coefficient of the window: 0-1
         Sw=NUMERIC(Loc(i),Sw_column);      %Surface area of the window
         Ts=NUMERIC(Loc(i),Ts_column);      %Window transmittance: 0-1
         Va=NUMERIC(Loc(i),Va_column);      %Air volume inside the building
         T0=NUMERIC(Loc(i),T0_column);      %Initial temperature of the indoor
         Trmin=NUMERIC(Loc(i),Trmin_column); %Start temp. for heating
         Trmax=NUMERIC(Loc(i),Trmax_column); %Start temp. for cooling
         Shmax=NUMERIC(Loc(i),Sh_column);    %Maximum power of the heating system
[W/h]
         Scmax=NUMERIC(Loc(i),Sc_column);    %Maximum power of the cooling system
[W/h]
         Pc=NUMERIC(Loc(i),Pc_column);      %Response capacity of the cooling system
         Ph=NUMERIC(Loc(i),Ph_column);      %Response capacity of the heating system
         Oc=NUMERIC(Loc(i),Oc_column);      %Heat from people (per m2)
         SFP=NUMERIC(Loc(i),SFP_column);    %Specific Fan Power:0-4 [kW/m3/s]
         HRec_eff=NUMERIC(Loc(i),HRec_eff_column); %Efficiency of the heat recovery:0-
1 [%]
         Pfh=NUMERIC(Loc(i),Pfh_column);    %Heat losses of the fan: 0.5-3(W/m2)
         Vcn=NUMERIC(Loc(i),Vcn_column);             %Natural    ventilation    through
windows(l/s/m2)
         Tv=NUMERIC(Loc(i),Tv_column);             %Set-point   temperature   for   natural
ventilation(C)
         Vc=NUMERIC(Loc(i),Vc_column);      %constant (l/s/m2)
         Lc=NUMERIC(Loc(i),Lc_column);      %constant Lighting W/m2
         Ac=NUMERIC(Loc(i),Ac_column);      %constant Appliances W/m2
         Hw=NUMERIC(Loc(i),Hw_column);      %hot water demand [W/hour]
         HyP=NUMERIC(Loc(i),HyP_column);    %hydro pumps demand [W/m2]
         PerHPinH=NUMERIC(Loc(i),PerHPinH_column); %percentage of heat provided by
heat pumps[0-1]
         Weight(Loc(i))=NUMERIC(Loc(i),Weight_column);
         FloorArea(Loc(i))=NUMERIC(Loc(i),A_column);
         BuildingType(Loc(i))=TXT(Loc(i)+1,Type_column);

         sim('Boverket_Building_EM_8_065.mdl',[0 weather(1,end)]);
         load Temperatures.mat; load E_demand.mat

         Building_info(Loc(i)).ID=RAW(Loc(i)+1,Building_no_column);
         Building_info(Loc(i)).Energy=E_demand;
         Building_info(Loc(i)).Temperature=Temperatures;
         Building_info(Loc(i)).Area=A;
         Building_info(Loc(i)).BuildingType=BuildingType(Loc(i));

      end

   end %end of j


   for i=1:length(Building_info)
      Building_ID(i)=Building_info(i).ID;           %ID
      Floor_Area(i)=Building_info(i).Area;          %Area of heated floor space (m2)
```

```
    Building_Type(i)=Building_info(i).BuildingType;     %Type of building [S,F,L]
    Energy=Building_info(1,i).Energy;                %ID

    Energy_demand(1,i)=Energy(3,end);                %Cooling demand, kWh/y
    Energy_demand(2,i)=Energy(9,end);                  %Sanitary ventilation losses, specific,
kWh/m2/y
    Energy_demand(3,i)=Energy(9,end)/FloorArea(i);           %Sanitary  ventilation  losses,
kWh/m2/y
    Energy_demand(4,i)=Energy(11,end);               %Transmittion losses, kWh/y
    Energy_demand(5,i)=Energy(4,end)/FloorArea(i);          %Specific  hot  water  demand,
kWh/m2/y
    Energy_demand(6,i)=Energy(2,end)/FloorArea(i);            %Specific  heating  demand,
kWh/m2/y
    Energy_demand(7,i)=Energy(10,end);               %Transmitted solar radiation, kWh/y
    Energy_demand(8,i)=Energy(7,end);                      %Heat  from  people  (occupancy),
kWh/y
    Energy_demand(9,i)=Energy(5,end);                %Heat from lights, kWh/y
    Energy_demand(10,i)=Energy(6,end);               %Heat from appliances, kWh/y
    Energy_demand(11,i)=Energy(13,end);              %Energy for hot-water pumps, kWh/y
    Energy_demand(12,i)=Energy(12,end);              %Energy for fans, kWh/y
    Energy_demand(13,i)=Energy(4,end);               %Hot water demand, kWh/y
    Energy_demand(14,i)=Energy(15,end);              %HeatREc, kWh/y
    Energy_demand(15,i)=Energy(16,end);              %HeatREcFVP, kWh/y
    Energy_demand(16,i)=Energy(2,end);               %Heating demand, kWh/y
    Energy_demand(17,i)=Weight(i);               %Weight
    Energy_demand(18,i)=Energy(2,end)+Energy(5,end)+Energy(6,end)...
      +Energy(12,end)+Energy(13,end)+Energy(4,end)-Energy(15,end);
%Heating+lights+appliances+fans+pumps+hot water-HEAT RECOVERED

    if ii==0
      E0_TotalE(i).ID=Building_ID(i);
      E0_TotalE(i).E=Energy_demand(18,i);
      E0_TotalE(i).weights=Energy_demand(17,i); %weights for all buildings
      E0_TotalE(i).total=E0_TotalE(i).E*E0_TotalE(i).weights;  %Total,  e.g.  weighted
energy
      save E0_TotalE E0_TotalE

    end

    Energy_demand(19,i)=Energy_demand(18,i)*Energy_demand(17,i);   %Total  energy  *
weight

    if ii~=0
      load E0_TotalE
      place=nan;
      for kj=1:length(E0_TotalE)
        bb(kj)=E0_TotalE(kj).total; %all buildings from E0
        if isfinite(strmatch(cell2mat(Building_ID(i)),cell2mat(E0_TotalE(kj).ID)))==1;
          place=kj;
        end
        Energy_saving(1)=round((sum(bb(:))/1000000000)*1000)/1000; %weighted E0 for
all buildings
      end
      Energy_demand(21,i)=E0_TotalE(place).E;
```

```
            Energy_demand(20,i)=Energy_demand(21,i)*Energy_demand(17,i);%Weighted      E0
for selected buildings
            Energy_demand(22,1)=(sum(Energy_demand(20,:))-sum(Energy_demand(19,:)))/1e9;
%Energy savings for the measure [TWh/y]
            Energy_saving(ii+1)=round((Energy_demand(22,1)*1000))/1000';
        end

        Temperature(1,i)=mean([Building_info(1,i).Temperature(3,8544:end)
Building_info(1,i).Temperature(3,1:1991)]); %Winter
        Temperature(2,i)=mean(Building_info(1,i).Temperature(3,1992:4175)); %Spring
        Temperature(3,i)=mean(Building_info(1,i).Temperature(3,4176:6359)); %Summer
        Temperature(4,i)=mean(Building_info(1,i).Temperature(3,6360:8543)); %Autumn
    end
```

Saving results in excel file with headings % Defining headings

```
    ResultsHeading1                         =                         {'Building
info',",",'1','2','3','4','5','6','7','8','9','10','11','12','13','14','15','16','17','18','19','20'};

ResultsHeading2={'ID','Area','Type','Cooling','SanVent_sp','SanVent','Transm','HotWater_sp',
...

'Heating_sp','Solar','Occup','Lights','Appliances','PumpsHydro','Fans','HotWater','HeatRec','He
atRecFVP','Heating','Weight','Total energy','Weighted total energy','Weighted E0'};
    ResultsHeading3={",'m2',",'kWh/m2y','kWh/y','kWh/y','kWh/y','kWh/m2/y','kWh/m2/y',...

'kWh/y','kWh/y','kWh/y','kWh/y','kWh/y','kWh/y','kWh/y','kWh/y','kWh/y','kWh/y',",'kWh/y','
kWh/y','kWh/y'};
    if ii~=0
        ResultsHeading1 = [ResultsHeading1,'21','22'];
        ResultsHeading2 = [ResultsHeading2,'E0','Savings'];
        ResultsHeading3 = [ResultsHeading3,'kWh/y','TWh'];

        % For the second Excel file
        ResultsHeading4 = {'Building info','1','2','3'};
        ResultsHeading5={'ID','E0','Total energy','E0-Total energy'};
        ResultsHeading6={",'kWh/y','kWh/y','kWh/y'};
    end
    ResultsHeading7={'Mean indoor temperatures, deg C'};
    ResultsHeading8={'Winter','Spring','Summer','Autumn'};
```

Writing in Excel files

```
    if ii==0
    xlswrite(NameFile,ResultsHeading1,'Energy','A1');
    xlswrite(NameFile,ResultsHeading2,'Energy','A2');
    xlswrite(NameFile,ResultsHeading3,'Energy','A3');
    xlswrite(NameFile,Building_ID','Energy','A4');
    xlswrite(NameFile,Floor_Area','Energy','B4');
    xlswrite(NameFile,Building_Type','Energy','C4');
    xlswrite(NameFile,round(Energy_demand)','Energy','d4');
%       xlswrite(NameFile,(round(Energy_demand(22,1)*1000))/1000','Energy','Y4'); %so that
the energy savings in TWh/y have decimals
    xlswrite(NameFile,(round(Temperature'*10))/10,'Temp','A3');
    end
```

```
  if ii~=0
  xlswrite(NameFile,ResultsHeading7,'Temp','A1');
  xlswrite(NameFile,ResultsHeading8,'Temp','A2');
  xlswrite(NameFile,ResultsHeading1,'Energy','A1');
  xlswrite(NameFile,ResultsHeading2,'Energy','A2');
  xlswrite(NameFile,ResultsHeading3,'Energy','A3');
  xlswrite(NameFile,Building_ID','Energy','A4');
  xlswrite(NameFile,Floor_Area','Energy','B4');
  xlswrite(NameFile,Building_Type','Energy','C4');
  xlswrite(NameFile,round(Energy_demand)','Energy','d4');
  xlswrite(NameFile,(round(Energy_demand(22,1)*1000))/1000','Energy','Y4'); %so that the
energy savings in TWh/y have decimals
  xlswrite(NameFile,(round(Temperature'*10))/10,'Temp','A3');

  xlswrite(NameFile,ResultsHeading7,'Temp','A1');
  xlswrite(NameFile,ResultsHeading8,'Temp','A2');
  end
  % For the second Excel file
  if ii~=0
    xlswrite([NameFile ' Energy'],ResultsHeading4,'Sheet1','A1');
    xlswrite([NameFile ' Energy'],ResultsHeading5,'Sheet1','A2');
    xlswrite([NameFile ' Energy'],ResultsHeading6,'Sheet1','A3');
    xlswrite([NameFile ' Energy'],Building_ID','Sheet1','A4');
    xlswrite([NameFile ' Energy'],round(Energy_demand(21,:))','Sheet1','B4');
    xlswrite([NameFile ' Energy'],round(Energy_demand(18,:))','Sheet1','C4');
    xlswrite([NameFile ' Energy'],round(Energy_demand(21,:)-
Energy_demand(18,:))','Sheet1','D4');
    xlswrite('E_save',Energy_saving');
  end


  save ii ii %saving the counter
  clear all
  load ii
  if ii~=0
    load Energy_saving
    save Energy_saving Energy_saving
  end
end  % end of the ii counter.
```

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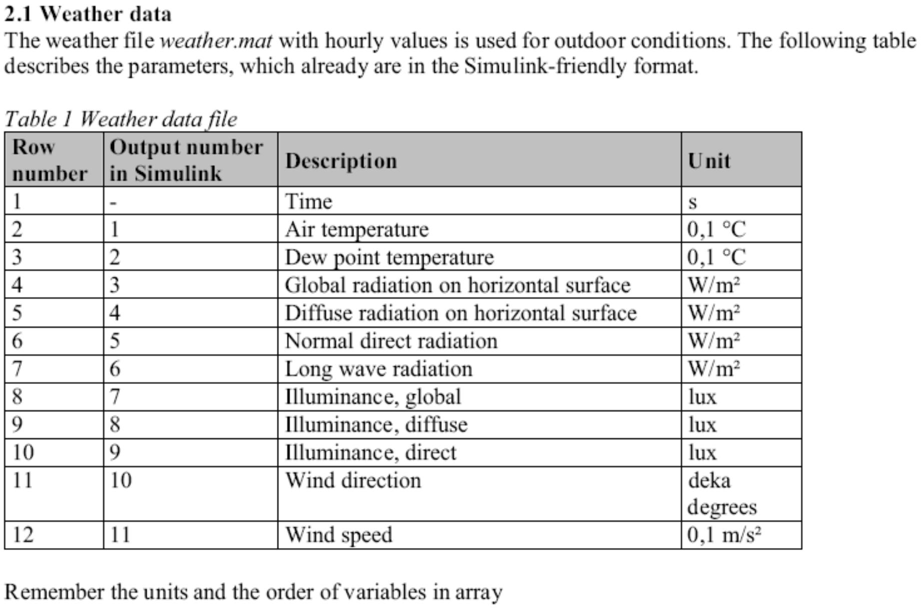
Appendix 5. Weather file

Weather file is created according to the structure required in the International Building Physics Toolbox (Sasic Kalagasidis, A. et al., 2006). The weather file is used in Matlab as a .txt file, which can be created from a normal Excel file. The file has to include the inputs described in Figure 15. The number of columns always has to be 12, so a 0 value has to be set for the unknown inputs. However, for this project only the data in rows 1, 2 and 4 are required for the simulations.



2.1 Weather data

The weather file *weather.mat* with hourly values is used for outdoor conditions. The following table describes the parameters, which already are in the Simulink-friendly format.

Table 1 Weather data file

Row number	Output number in Simulink	Description	Unit
1	-	Time	s
2	1	Air temperature	0,1 °C
3	2	Dew point temperature	0,1 °C
4	3	Global radiation on horizontal surface	W/m^2
5	4	Diffuse radiation on horizontal surface	W/m^2
6	5	Normal direct radiation	W/m^2
7	6	Long wave radiation	W/m^2
8	7	Illuminance, global	lux
9	8	Illuminance, diffuse	lux
10	9	Illuminance, direct	lux
11	10	Wind direction	deka degrees
12	11	Wind speed	0,1 m/s^2

Remember the units and the order of variables in array

Figure 15 Weather data file (Sasic Kalagasidis, A. et al., 2006)

Appendix 6. Simplified model for the calculation of the solar energy transmitted through windows. Analysis on the impact of solar radiation.

Solar radiation gains through windows vary during the course of a day and also with the window orientation, inclination, glazing type, framing, shading devices, etc. When all this information is available, it is possible to estimate the solar gains in an accurate way by using the building simulation tools. However, in databases for larger building stocks, only limited information about the windows is given and that normally includes the total glazing area, number of panes and the thermal transmittance (U-value) – i.e., no information about the window distribution on the facades. In order to overcome such constrain, we have simplified the calculation of solar gains through windows by modelling all windows on the building as one horizontal window. The difference between solar irradiation on differently oriented facades and horizontal plane is compensated by a constant. The numerical tests that supported this simplification are given hereafter. The whole analysis is made by a building simulation programme HAM-Tools, capable for transient energy simulations in buildings and in particular for the detailed calculations of transmitted solar energy through windows (Sasic Kalagasidis et al. 2006).

A6.1 The building

The building used in this study is a five-storey residential house located in Köping, Sweden (lat=59.51 long=16.01) (Figure 1).

Figure 16 Facade of the test building, facing towards NW.

The thermal properties of the building are shown in Table 5.

Table 5 Thermal properties for the building envelope of the house in Köping.

Layer	Unit	λ W/mK	d m	U W/m²K	Area m2
Exterior wall	Facing brick	0.60	0.120	0.26	1320
	Gypsum board	0.22	0.009		
	Insulation	0.04	0.170		
	Gypsum board	0.22	0.013		
Ground floor				0.30	737.5
Roof				0.17	764
Windows				1.4	233

The total floor of the building, at the basement, is 760 m^2, calculated from the outer dimensions (length and width). This value is sized down to 737.5 m^2 to account for unheated balconies. In the simulations, the entire heated floor area of all the 5 floors is included, giving a heated floor area of 3208 m^2 (BOA area). The latter value is calculated as 87 % of the total outer floor area of the 5 storeys:

$$A_{BOA} = 737.5 \cdot 5 \cdot 0.87 = 3208 \text{ m}^2$$

Ventilation

The house is supplied with outdoor air by a mechanical ventilation system giving a ventilation airflow rate of 0.8 ach^{-1} during daytime and 0.4 ach^{-1} during nighttimes. No heat exchange takes place between exhaust and supply air.

Windows

The windows are triple-glazed. A constant transmission coefficient for solar radiation 0.6 is used.

Table 6 Distribution of windows on the facades, for the house in Köping

Orientation (vertical inclination)	Horizontal	NE	SE	SW	NW	Total
Window area, m^2	0	33	84	33	84	A_{Total}=234
Window area as a part of the total window area, in %	0	0.14	0.36	0.14	0.36	1

Internal heat gains

Internal heat gains from occupants and use of electric appliances is set to 2.2 W/m^2 during day and 2.9 W/m^2 during night.

Indoor temperature

The building is heated to 21° C throughout the year.

A6.2 Solar gains through windows

Table 7 Transmitted solar energy through differently oriented unobstructed (clear) windows for the location Köping (based on the weather data from 2005), calculated by HAM-Tools

Window orientation	Horizontal	NE	SE	SW	NW
Solar energy through a window, kWh/m2/y	645	242	509	674	356
Part of the energy coming to the horizontal surface, %	100	38	79	104	55

By using the data given in the Table, we can find the intensity of solar radiation on vertical surfaces as:

$$I_{NE} = 0.38 \cdot I_H$$

$$I_{SE} = 0.79 \cdot I_H$$

$$I_{SW} = 1.04 \cdot I_H$$

$$I_{NW} = 0.55 \cdot I_H$$

where $I_H = 645\,\text{kWh/m}^2\text{/year}$ is the transmitted solar energy through a horizontal window.

The transmitted solar energy through each window is then given as:

$$A_{NE} \cdot I_{NE} = 33 \cdot 0.38 \cdot I_H = 0.14 \cdot A_{total} \cdot 0.38 \cdot I_H = 0.05 \cdot A_{total} \cdot I_H$$

$$A_{SE} \cdot I_{SE} = 84 \cdot 0.79 \cdot I_H = 0.36 \cdot A_{total} \cdot 0.79 \cdot I_H = 0.28 \cdot A_{total} \cdot I_H$$

$$A_{SW} \cdot I_{SW} = 33 \cdot 1.04 \cdot I_H = 0.14 \cdot A_{total} \cdot 1.04 \cdot I_H = 0.15 \cdot A_{total} \cdot I_H$$

$$A_{NW} \cdot I_{NW} = 84 \cdot 0.55 \cdot I_H = 0.36 \cdot A_{total} \cdot 0.55 \cdot I_H = 0.20 \cdot A_{total} \cdot I_H$$

whereA_{Total} = 234 m^2.

The sum of all parts at the right-hand sides of the above expressions:

$$(0.05 + 0.28 + 0.15 + 0.20) \cdot A_{total} \cdot I_H = 0.68 \cdot A_{total} \cdot I_H$$

The constant 0.68 should compensate for the difference between I_H and the solar irradiation on vertical differently oriented surfaces.

The energy consumption for heating in the building in Köping is calculated for four different cases, which differ only in the placement of windows:

1. "Koping_Boverket_windows" - the windows placed as they are in reality
2. "Koping_Boverket_windowsS" - all windows are placed on the south wall
3. "Koping_Boverket_windowsH068"- all windows are placed on the roof and the area is multiplied with 0.68 (the model presented above)
4. "Koping_Boverket_windowsH" - all windows are placed on the roof

In all cases the function of Venetian blinds was activated (see Sasic Kalagasidis et al. 2006 for the details) and the intensity of solar radiation is reduced as presented in the Table 8

Table 8 Transmitted solar energy through the windows with Venetian blinds

Window orientation	Horizontal	NE	SE	SW	NW
Solar energy through a clear window, kWh/m^2/y	645	242	509	674	356
Solar energy through a window with Venetian blinds, kWh/m^2/y	419	169	325	445	254
Part of the transmitted energy compared to the case of a clear window, %	65	70	64	66	71

Table 9 Energy consumption for heating in the building in Köping

Case	Total energy, MWh/year	Total energy, kWh/m^{2}y
Koping_Boverket_windows	315.83	98
Koping_Boverket_windowsS	306.29	95
Koping_Boverket_windowsH068	320.51	100
Koping_Boverket_windowsH	313.89	98

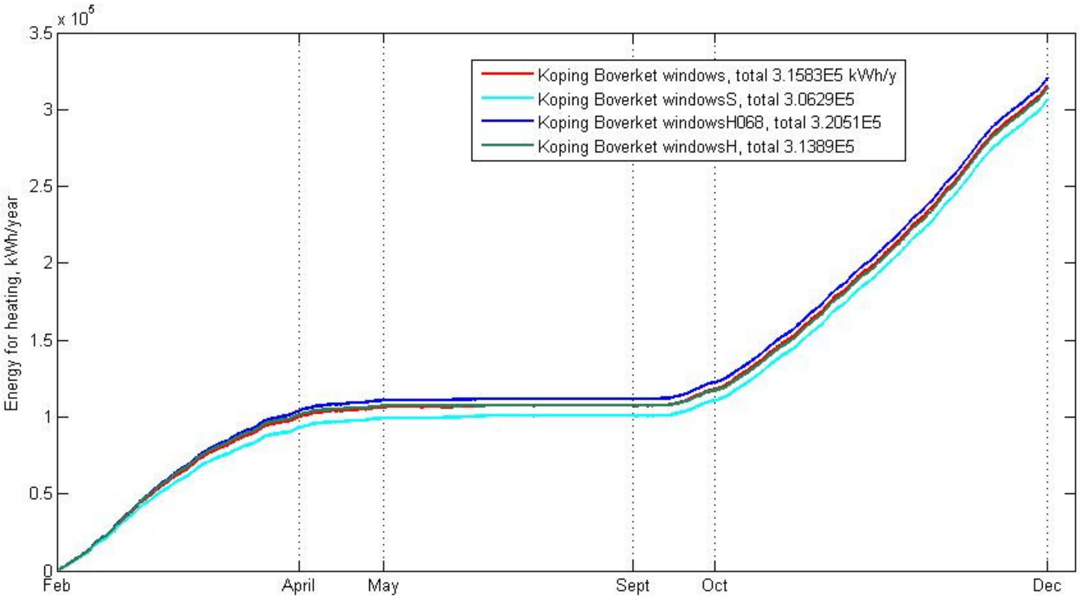


Figure 17 Comparison of the results obtained

From the analysis we can see that the simplified model H068 gives reasonable accurate results compared to the case with detailed windows placement. The value of the constant depends on the distribution of windows on the facades. For the Boverket's project, the constant 0.65 is used instead of 0.68. Note however, that this conclusion is applicable for the Swedish climate conditions and for the residential buildings with normal window/floor ration (up to 20 %).