House model

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Contents

1 Introduction

Building energy simulation is a vast field of research that started in the late 50's and that is still highly active nowadays. Building energy simulations are mainly used to help taking design decisions, to analyze current designs and to forecast future building energy use. Building energy modelling methods can mainly be divided into three categories:

- White box models (physics-based)
- Black box models (data-driven)
- Grey box models (hybrid)

White box models are based on the equations related to the fundamental laws of energy and mass balance and heat transfer. White box models can be differentiated in two types, *distributed* parameter models and *lumped* parameter models. Lumped parameter models simplify the description of distributed physical systems into discrete entities that approximate the behavior of a distributed system. The advantage of using lumped models is the decrease in simulation time **(Ramallo-González et al.**[1]**)**. White box models are of special interest for the design phase as they are used to predict and analyse the performance of the building envelope and building systems. Black box models are based on the statistical relation between input and output system values. The statistical relation between input and output is based on actual data. The relation between the parameters can differ based on the amount of data and the method used to analyze the relation. Currently, there is a large and active field of research about statistical models that are used on black box models **(Coacley et al.**[2]**)**. Black box models are of special interest when there is a large amount of actual input and output data available.

Grey box models are hybrid models that aim to combine the advantages of both approaches. In order to use them it is necessary to implement some equations and it is also required to have actual data of inputs and outputs.

2 White box lumped model: RC network

2.1 White box lumped model

The objective of the house model for this project is to serve as test environment for a heat pump model, which means that the house model is intended as a tool to help taking building systems design decisions. The house heating demand calculation model implemented for this project is a white box *lumped* model. Specifically, it is a RC network model consisting of resistances (R) and capacities (C). The RC network model is based on the analogy with electrical circuits. The simulation of thermodynamic systems characterizing building elements as resistances or capacities allows to simplify the model while maintaining a high simulation results accuracy **(Bagheri et al.[3], Bacher et al[4].)**.

There are several types of RC models, the most common being 3R4C models and 3R2C models which are applied on the outer and internal wall. For the simulation of simple house buildings 3R2C models perform as accurate as more complex 3R4C models **(Fraisse et al.[5])**. Considering that one of the objectives for this project is to obtain a fast but accurate simulation of a simple dwelling the 3R2C network model appeared a good starting point. In the 3R2C model two indoor temperature nodes are present in the dwelling. **with capacities (usually an air and a wall temperature) and a well-known outdoor temperature** . **Between these 3 temperature nodes 3 heat transfer resistances are present. However, the direct heat transfer between the inner walls and the outdoor air is low. Moreover, uncertainties are present about heat transfer coefficients between walls and indoor air, different indoor temperatures in the house rooms and the ground temperature which deviates from the outdoor temperature. In addition, occupancy behaviour varies strongly.** For that reason, we have made a further simplification to a 2R2C model. In section 4 it is shown that this dwelling model delivers a reliable annual energy consumption.

2.2 House Model R and C Values

This section presents the basic information for calculating a house model based on an RC network. This category of house models, analogous to electrical impedance networks, may have different numbers of R and C components and may have various component topologies. For the specific model properties, references will be given.

In heat transfer theory the basic thermal circuit contains thermal resistances. Heat transfer occurs via conduction, convection and radiation. In analogy with Ohm's Law for electricity, expressions can be derived for the heat transfer rate (analogous to electrical current) and the thermal resistances (analogous to ohmic resistances) in these three modes of heat transfer. The temperature difference plays a role analogous to the electrical voltage difference. These expressions are shown in Fig.1.

Equations for different heat transfer modes and their thermal resistances.

Transfer Mode	Rate of Heat Transfer	Thermal Resistance
Conduction	$\dot{Q} = \dfrac{T_1 - T_2}{\left(\frac{L}{kA}\right)}$	$\dfrac{L}{kA}$
Convection	$\dot{Q} = \dfrac{T_{\text{surf}} - T_{\text{envr}}}{\left(\frac{1}{h_{\text{conv}} A_{\text{surf}}}\right)}$	$\dfrac{1}{h_{\text{conv}} A_{\text{surf}}}$
Radiation	$\dot{Q} = \dfrac{T_{\text{surf}} - T_{\text{surr}}}{\left(\frac{1}{h_r A_{\text{surf}}}\right)}$	$\dfrac{1}{h_r A}$, where $h_r = \epsilon\sigma(T_{\text{surf}}^2 + T_{\text{surr}}^2)(T_{\text{surf}} + T_{\text{surr}})$

Figure 1: Heat transfer modes[6]

In [7] and [8] the expressions in Fig.1 are derived. For conduction, the expression for absolute thermal resistance is:

$$R = \frac{L}{kA} \qquad \left[\frac{K}{W}\right] \tag{1}$$

- L is the distance over which heat transfer takes place, or the thickness of the material $[m]$.
- k (also denoted with λ) is the thermal conductivity of the material. $[\frac{W}{mK}]$.
- A is the conductive surface area $[m^2]$.
- Thermal resistivity is the reciprocal of thermal conductivity and can be expressed as $r = \frac{1}{k}$ in $[\frac{mK}{W}]$

For convection and radiation the expression for thermal resistance is: $R = \frac{1}{h \cdot A}$ $[\frac{K}{W}]$.

- A is the surface area where the heat transfer takes place $[m^2]$.
- h is the heat transfer coefficient $[\frac{W}{m^2 K}]$

The R-value (in Dutch: R-waarde or R_d-waarde) of a building material [9] is the thermal resistance of a square meter surface. It can be calculated by multiplying the thermal *resistivity* with the thickness of the material in m. Alternatively it is calculated by dividing the material thickness by the thermal *conductivity* k or λ.

$$\text{R-value} = r \cdot L \qquad \text{or} \qquad \text{R-value} = \frac{L}{k} \qquad \text{or} \qquad \text{R-value} = \frac{L}{\lambda} \qquad \left[m \cdot \frac{m \cdot K}{W}\right] = \left[\frac{m^2 \cdot K}{W}\right] \tag{2}$$

Some typical heat transfer R-values are: [10]:

- Static layer of air, 40 mm thickness (1.57 in) : R = 0.18 $[\frac{m^2K}{W}]$.
- Inside heat transfer resistance, horizontal current : R = 0.13 $[\frac{m^2K}{W}]$.
- Outside heat transfer resistance, horizontal current : R = 0.04 $[\frac{m^2K}{W}]$.
- Inside heat transfer resistance, heat current from down upwards : R = 0.10 $[\frac{m^2K}{W}]$.
- Outside heat transfer resistance, heat current from above downwards : R = 0.17 $[\frac{m^2K}{W}]$.

Note: in Dutch building physics, R-values with subscripts are used:

- R_d-waarde is used for the R-value of a homogeneous building material. $R = \frac{L}{\lambda}$
- R_c-waarde (compound, construction) is used for the R-value of a surface consisting of several building materials. R_c-waarden are calculated as the surface-area weighted sum of R_d-waarden of the building materials. For the simplest roof surface, R_c is a linear combination of the R-values of the wooden joists and girders (spanten en gordingen) and the areas in between with a certain insulation material sandwich. The R-value of the insulation sandwich, in its turn, is the sum of the R-values of the materials in the sandwich. From inside out, this sandwich may consist of *e.g.* a 9.5 mm plaster board, a PIR/PUR insulation panel, an air gap and a wooden roof deck. All types of R-value have the dimension $[\frac{m^2 \cdot K}{W}]$.

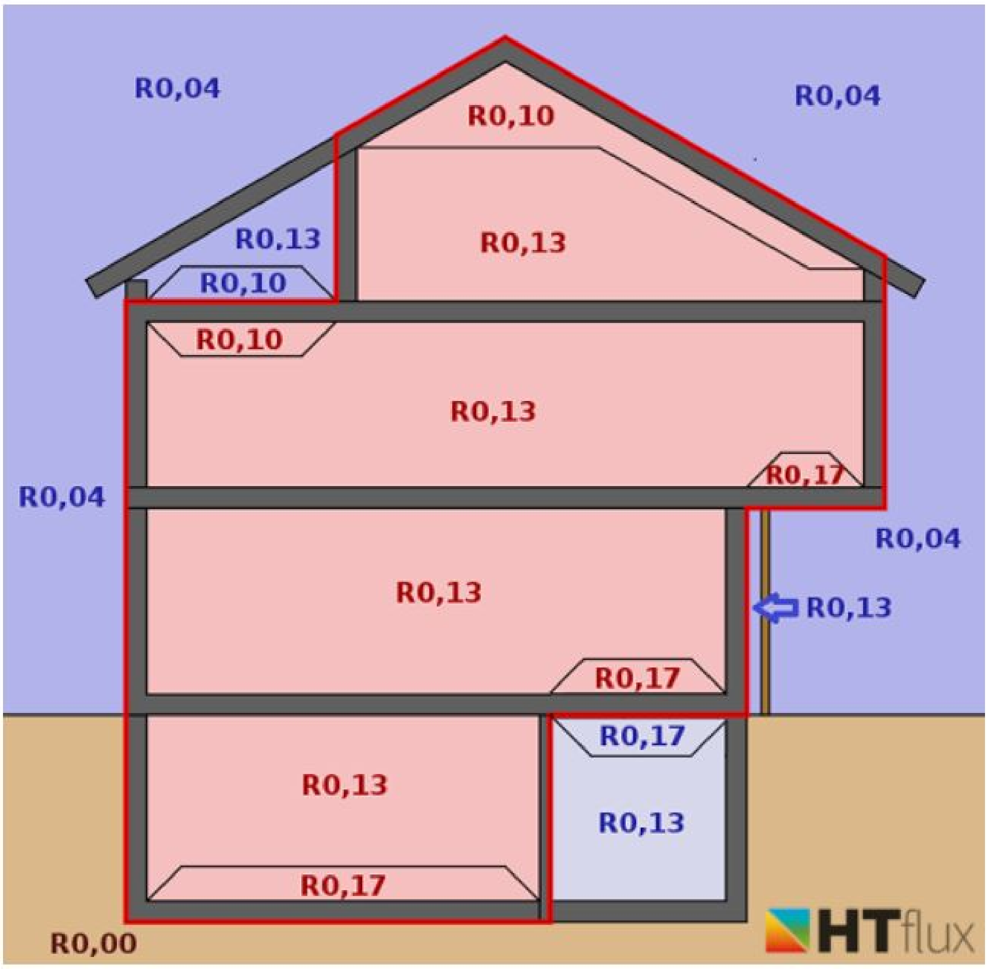

Figure 2: An overview of *R*-values for heat transfer [11].

The standard R_c-values that have been used for facades, roof and floor until 2020 are summarized in Fig.3:

Construction	New construction	Renovation
Facades [1]	Rc 4.5 m2K / W	Rc 1.3 m2K / W
Roofs [2]	Rc 6.0 m2K / W	Rc 2.0 m2K / W
Floors [3]	Rc 3.5 m2K / W	Rc 2.5 m2K / W

Figure 3: R_c Values [12]

New standard values will be used from 1-1-2021, since the building standard NEN 1068 will be replaced by the NTA 8800 standard. The old and new situation is described in "EnergieVademecum Energiebewust ontwerpen van nieuwbouwwoningen", Hoofdstuk 5: Thermische isolatie, thermische bruggen en luchtdichtheid. [13].

From 2015, the following RC values apply to new construction in the Netherlands:

Location	*RC value (NEN 1068, until 1-1-2021) [m2K / W]*	*Rc value (NTA 8800, from 1-1-2021) [m2K / W]*
floor	**>= 3.5**	**>= 3.7**
facade	**>= 4.5**	**>= 4.7**
roof	**>= 6.0**	**>= 6.3**

Figure 4: R_c Values [14]

The values used for different types of houses such as: row houses, detached houses and apartments can be found in the document "Voorbeeldwoningen 2011" [15]. An example with values for a common type of row house, built in the period from 1975 to 1991 is shown in Fig. 5:

Bouwdelen	Huidig			Besparingspakket			Investeringskosten	
	Opp. (m²)	Rc-Waarde (m² K/W)	U-Waarde (W/m²K)	Opp. (m²)	Rc-Waarde (m² K/W)	U-Waarde (W/m²K)	Per m²	Totaal
Begane grondvloer 3	51,0	0,52	1,28	51,0	2,53	0,36	€ 20	€ 1.020
Plat dak 3	-	-	-	-	-	-	-	€ 0
Hellend dak 3	68,6	1,30	0,64	68,6	2,53	0,36	€ 53	€ 3.640
Achter- en voorgevel								
– Gesloten 3	40,6	1,30	0,64	40,6	2,53	0,36	€ 21	€ 850
– Enkelglas 3	3,1		5,20	-		-	€ 139	€ 430
– Dubbelglas 3	16,2		2,90	-		-	€ 142	€ 2.300
– HR++ glas	-		-	19,3		1,80		
Zijgevel								
– Gesloten	58,4	1,30	0,64	58,4	2,53	0,36	€ 21	€ 1.230
– Enkelglas	-		-	-		-	-	€ 0
– Dubbelglas	1,8		2,90	-		-	€ 142	€ 260
– HR++ glas	-		-	1,8		1,80		

Figure 5: R_c-values for a row house type built between 1975-1991 [15]

2.3 Dwelling (envelope) model analogous to a 2R-2C network

The heat flow will be modelled by analogy to an electrical circuit where heat transfer rate is analogous to by current, temperature difference is analogous to potential difference, heat sources are represented by constant current sources, absolute thermal resistances are represented by resistors and **thermal capacitance** heat capacity ? by capacitors [16]. Figure 6 summarizes the similar term use in different fields.

type	structural analogy[1]	hydraulic analogy	thermal	electrical analogy[2]
quantity	impulse J [N·s]	volume V [m^3]	heat Q [J]	charge q [C]
potential	displacement X [m]	pressure P [N/m^2]	temperature T [K]	potential V [V = J/C]
flux	load or force F [N]	flow rate Q [m^3/s]	heat transfer rate $\dot{Q}$ [W = J/s]	current I [A = C/s]
flux density	stress σ [Pa = N/m^2]	velocity $\mathbf{v}$ [m/s]	heat flux $\mathbf{q}$ [W/m^2]	current density $\mathbf{j}$ [C/(m^2·s) = A/m^2]
resistance	flexibility (rheology defined) [1/Pa]	fluid resistance R [...]	**thermal resistance** R [K/W]	electrical resistance R [Ω]
conductance	... . . . [Pa]	fluid conductance G [...]	thermal conductance G [W/K]	electrical conductance G [S]
resistivity	flexibility $1/k$ [m/N]	fluid resistivity	thermal resistivity [(m·K)/W]	electrical resistivity ρ [Ω·m]
conductivity	stiffness k [N/m]	fluid conductivity	thermal conductivity k [W/(m·K)]	electrical conductivity σ [S/m]
lumped element linear model	Hooke's law $\Delta X = F/k$	Hagen–Poiseuille equation $\Delta P = QR$	Newton's law of cooling $\Delta T = \dot{Q}R$	Ohm's law $\Delta V = IR$
distributed linear model	... . . .	... . . .	Fourier's law $\mathbf{q} = -k\nabla T$	Ohm's law $\mathbf{J} = \sigma\mathbf{E} = -\sigma\nabla V$

Figure 6: Table of Analogies [16]

The 2R-2C house model structure is implemented as described below. The schematic of an envelope house model has been shown in figure 7 and the equivalent electrical 2R-2C network with components and topology is given in fig 8.

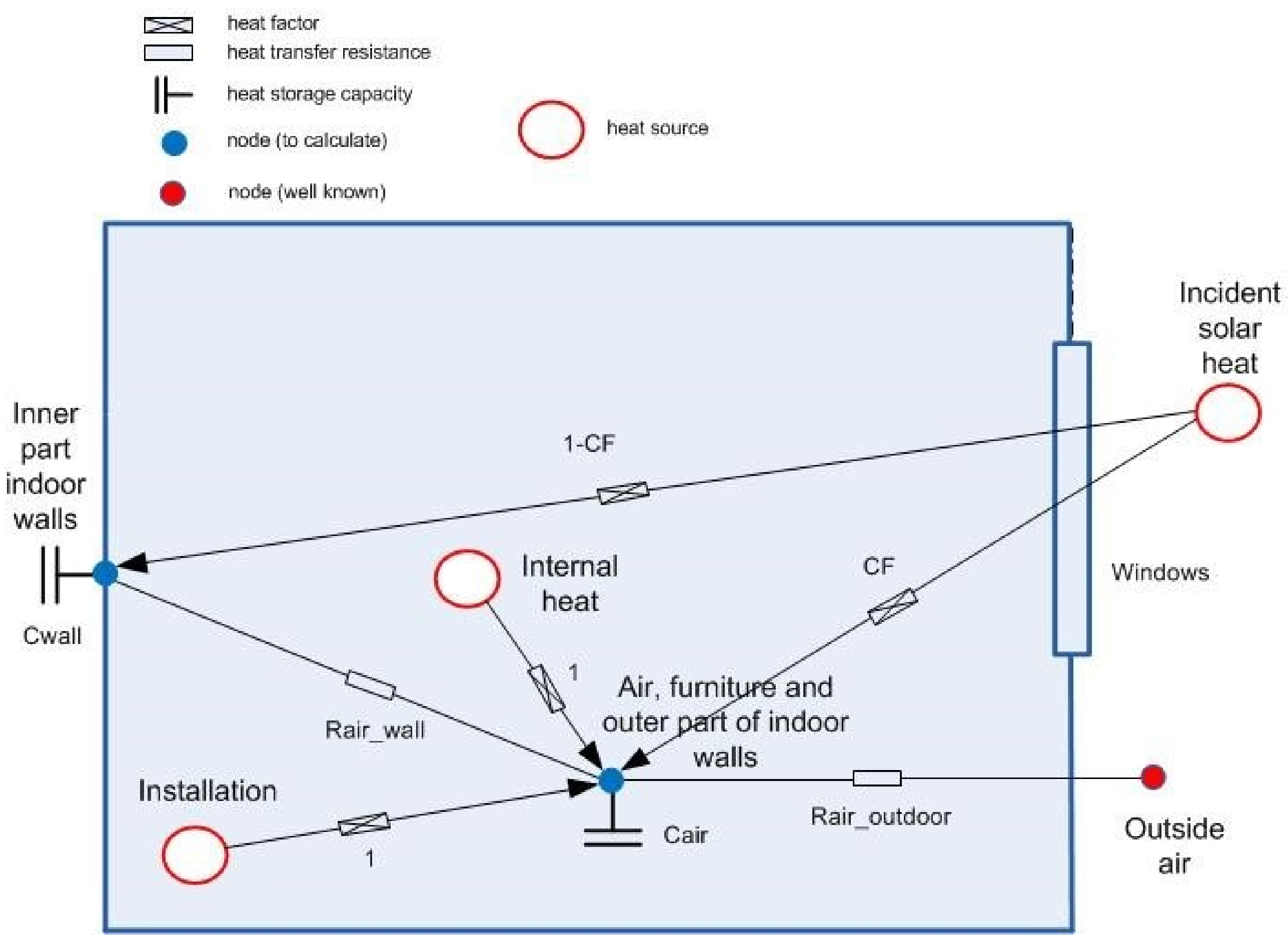

Figure 7: Schematic of envelope model

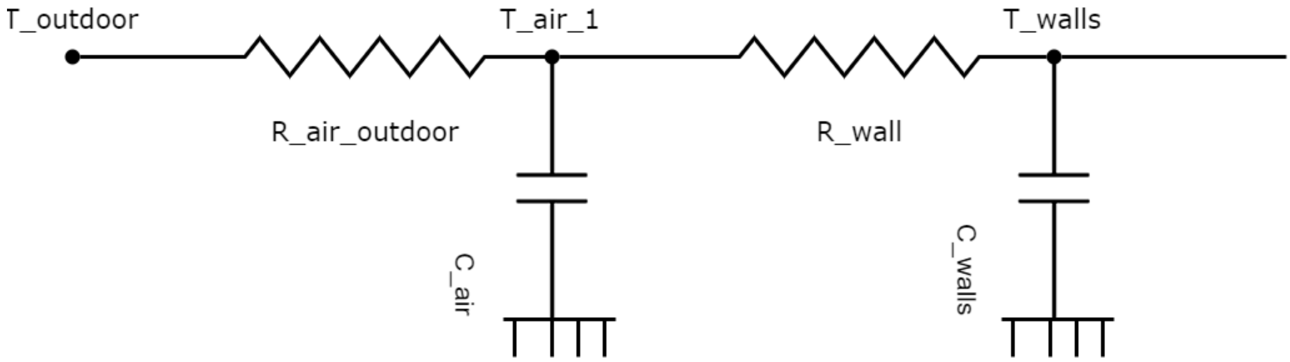

Figure 8: 2R-2C house model

The model consists of two heat capacities $C_{air,\ indoor}$ and C_{wall} and two resistances R_{wall} and $R_{air,\ outdoor}$. The incident solar energy is divided between C_{wall} and C_{air} through the convection factor CF. It is assumed that both internal heat (lighting, occupancy and electric devices) and supplied heat (installation) initially heat up the indoor air. In Fig. 7, they are fully released at the T_{air} node.

It is also assumed that furniture and the **surface part** of the walls have the same temperature as the air **and the wall mass is divided between the air and wall mass**. Thus, the heat capacity of the air node consists of the air heat capacity, furniture heat capacity and the heat capacity **of a part of the walls**. **Appendix A** presents the coefficients in the dwelling model. In the resistance $R_{air,\ outdoor}$ the influence of heat transmission through the outdoor walls and natural ventilation is considered.

For the air and wall nodes the following power balances can be set up:

$$C_{air}\frac{dT_{air}}{dt} = \frac{T_{outdoor} - T_{air}}{R_{air\_outdoor}} + \frac{T_{wall} - T_{air}}{R_{air\_wall}} + \dot{Q}_{inst} + \dot{Q}_{internal} + CF \cdot \dot{Q}_{solar} \tag{3}$$

$$C_{wall}\frac{dT_{wall}}{dt} = \frac{T_{air} - T_{wall}}{R_{air\_wall}} + (1 - CF) \cdot \dot{Q}_{solar} \tag{4}$$

- CF: convection factor (solar radiation): the convection factor is the part of the solar radiation that enters the room and is released directly convectively into the room.
- $\dot{Q}_{inst}$: delivered heat from heating system (radiator) [W].
- $\dot{Q}_{inernal}$: internal heat [W].
- $\dot{Q}_{solar}$: heat from solar irradiation [W].
- T_{air}: indoor air temperature ^{o}C.
- $T_{outdoor}$: outdoor temperature ^{o}C.
- T_{wall}: wall temperature ^{o}C.
- R_{air_wall}: walls surface resistance $[\frac{K}{W}]$.
- $R_{air\_outdoor}$: outdoor surface resistance $[\frac{K}{W}]$.
- C_{air}: air thermal capacitance (heat capacity) $[\frac{J}{K}]$[17].
- C_{wall}: wall thermal capacitance (heat capacity) $[\frac{J}{K}]$[17].

Total heat transfer of solar irradiation through the glass windows.

$$\dot{Q}_{solar} = g.\sum(A_{glass}.\dot{q}_{solar}) \tag{5}$$

- $\dot{q}_{solar}$: solar radiation on the outdoor walls $[\frac{W}{m^2}]$.
- g: g value of the glass (ZTA in dutch) [0..1][18]
- A: glass surface $[m^2]$.

3 Simulink model user guideline

The dwelling model has been fist developed in Matlab/Simulink and convert to Python later on. In the Simulink model it is possible to define the dwelling characteristics, the dwelling use data and the climate data. With some of this information the model resistances and capacities are built on a Matlab script. The resistances and capacities values are used during the year energy simulation. In sections 3.1 to 3.3 the information provided to make the simulation is presented.

3.1 Dwelling characteristics information

The dwelling characteristics taken into account in order to define the model resistances and capacities are presented in figure 9. The ventilation rate n in ach (air changes per hour) is based on a mechanical ventilation rate of 150 m3/h for kitchen, toilet and bathroom) by regulations.

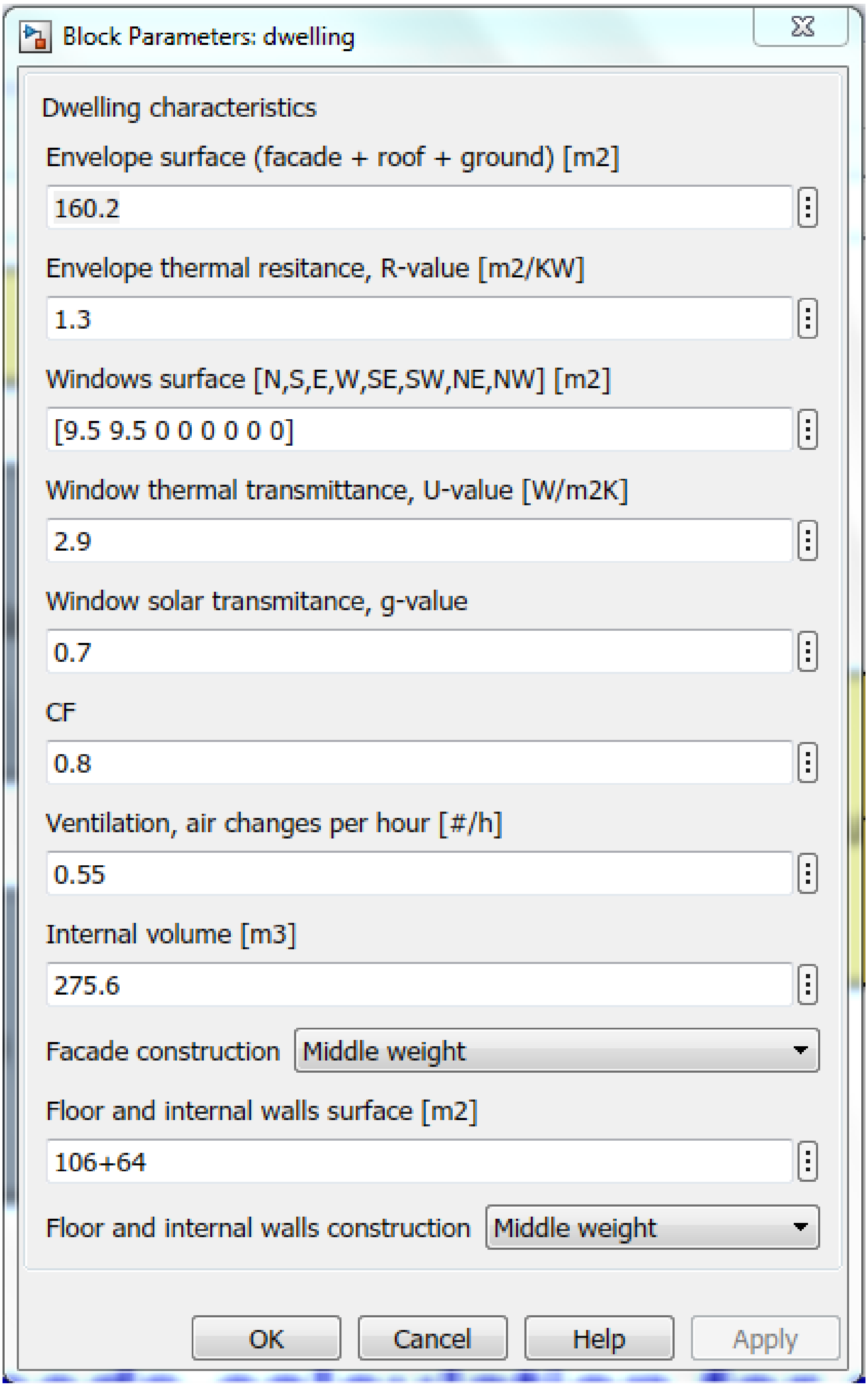

Figure 9: Dwelling characteristic model information

3.2 Dwelling use data

The dwelling use data define the schedule to be used to calculate the dwelling internal heat and the thermostat set-points. The thermostat signal is communicated to the heat pump model. The information use to define the dwelling use is presented in figure 10

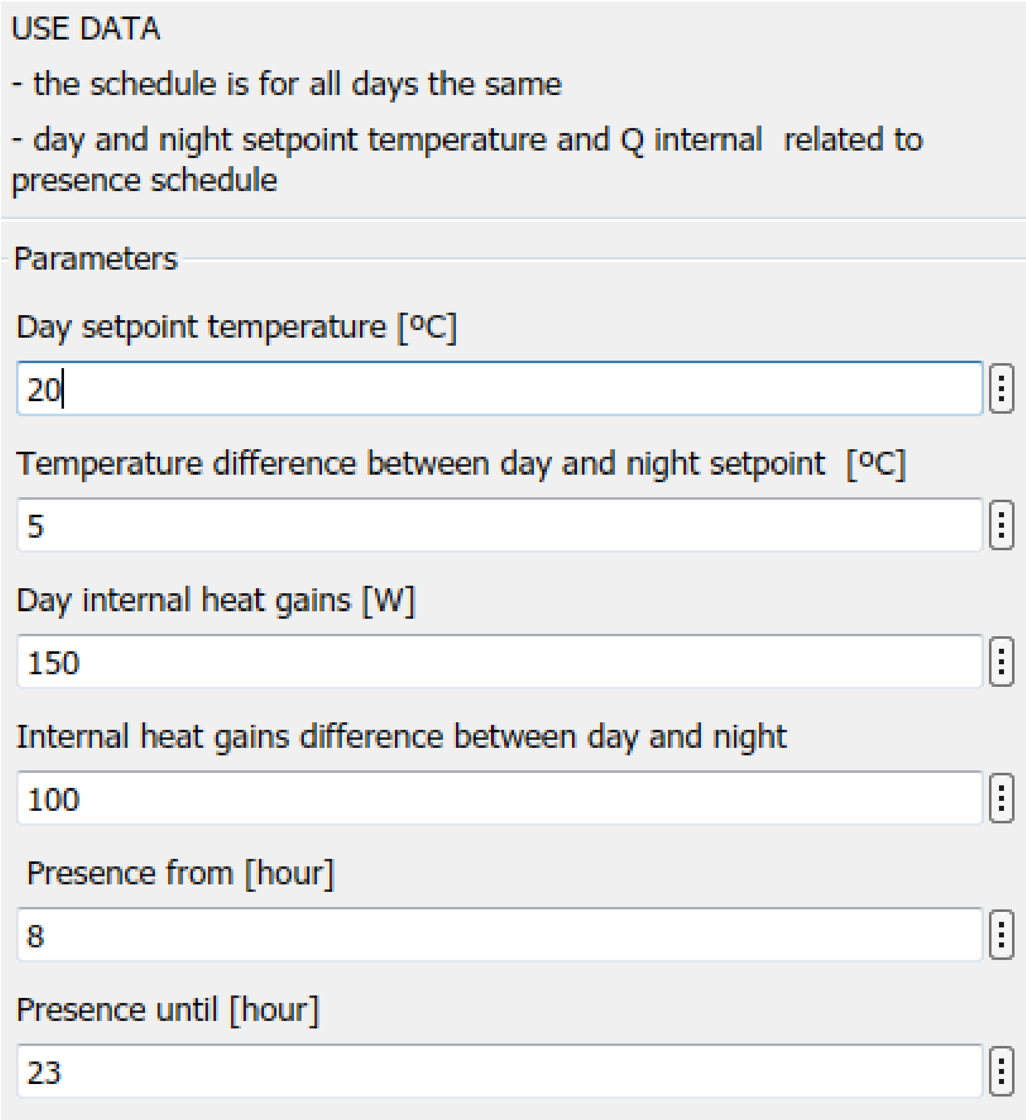

Figure 10: Dwelling use model information

3.3 Climate data

The hourly data about the outdoor temperature and the solar radiation is extracted from the NEN5060:2018 norm. This norm defines a typical meteorological year using the Finkelstein-Schafer statistical method with the climate data of 20 years period (1996-2015). The meteorological data used by the norm is updated once every 5 years.

The typical meteorological year data is the one to be used when calculating the typical energy use of the heating installation. The NEN norm offers also three other hourly climate data sets, each one with a different perceptual deviation from the typical meteorological year: 1%, 3% and 5%. These data sets are to be used when analysing the response of the heating installation under more extreme climate conditions. This is usually done for design installation purposes. The total energy use calculated with these other data sets will not give a reliable value for calculating the typical energy use. In figure 11 it is shown that is it possible to choose between the four different NEN climate data sets.

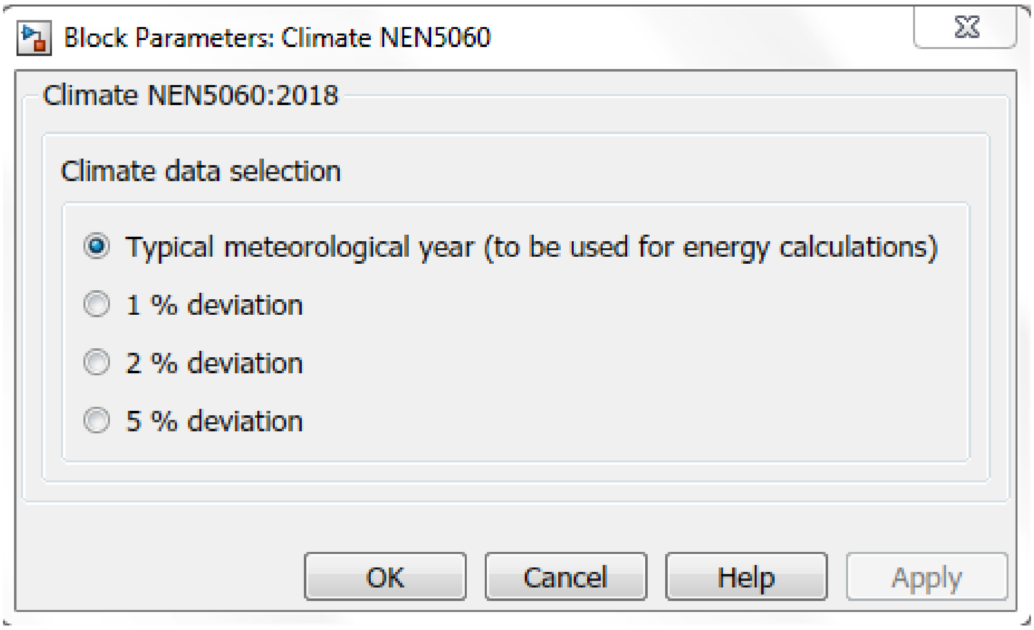

Figure 11: Climate data selection

In a pre-process the global incident radiant is calculated for North, South, East, West, North-West, North-East, South-West and South-East orientations of the façade in Matlab. The model from Perez is applied for the exchange. In this model the irradiation is split into a direct and diffuse terms.

4 Simulation, results and verification

4.1 Simulation

In order to calculate the inside temperature of the house the model considers five heat flow.

- Transmission
- Ventilation
- Solar Gains
- Internal Heat Gains
- Heating/Cooling

The model also considers the mass of the air inside the house and the mass of the walls. House characteristics data.

The document Voorbeeldwoningen 2011 Bestaande bouw published by Agentschap NL [15] will be used as a reference to determine the house characteristics. The document makes a classification of the house stock per construction type (7) and year of construction (4 time periods).

Construction type.

- Detached house (vrijstaande woning)
- Semi-detached house (2 onder 1 kap woning)
- Terraced house (rijwoning)
- Apartment block own access (maisonnettewoning)
- Apartment horizontal shared access (galerijwoning)
- Apartment block vertical shared access (portiekwoning)
- Apartment block in general (flatwoningen (overig))

Year of construction.

- Build before 1964
- Build between 1965 and 1974
- Build between 1975 and 1991
- Build between 1992 and 2005

For the first model, the data of a detached house building build between 1975 and 1991 has been used. The energy consumption sum presented in the report as the first validation mechanism for this model. In the following model development, we should look for the possibility to validate the model with the use of real data.

Climate data.
NEN 5060:2008 and 2018 nl (Hygrothermische eigenschappen van gebouwen -Referentieklimaatgegevens), will be used as the climate data for the simulations.

Internal heat gains data.
There is no reference document about the internal heat gains for dwelling in the Netherlands. We can consider that there are two people living in the house with an average working schedule. Control mechanism The heating will be controlled by a thermostat. The indoor temperature of the house is based on recommendation given on the ISSO publication Kleintje Binnenklimaat. The indoor temperature should be maintained at a minimum of 20 degrees. We could consider taking cooling into account.

4.2 Results

To test the model, we have used the data from the document Voorbeeldwoningen 2011 Bestaande bouw published by Agentschap NL [15]. We have run the model for a detached house building build between 1975 and 1991 and for row house building build between 1975 and 1991.For the detached house the model calculates a sum of the yearly energy needs of 10545 kWh. The document Voorbeeldwoningen 2011 gives a calculated energy use for heating and hot water of 1542 m3 gas. The average gas consumption of hot tap water on a Dutch household is 300 m3gas. We assume a combustion (under) value ho=35.2 MJ/m3 gas. Taking into consideration a heating system efficiency of 0.9, the energy need is 10843 kWh.

$$\frac{(1542 - 300) \cdot 35200}{3600 \cdot 0.9} = 10843[KWh] \tag{6}$$

For the row house the model calculates a sum of the yearly energy needs of 19776 kWh. The sidewalls have been considered as adiabatic walls. The document Voorbeeldwoningen 2011 gives a calculated energy use for heating and hot water of 2616 m3 gas. The average gas consumption of hot tap water on a Dutch household is 300 m3gas. Taking into consideration a heating system efficiency of 0.9, the energy need is 20219 kWh.

$$\frac{(2616 - 300) \cdot 35200}{3600 \cdot 0.9} = 20129[KWh] \tag{7}$$

The results give an indication that the model is on the right result range for detached and row house.

The plot on figure 12, show the comparison of simulation results and annual heating consumption in Voorbeeldwoningen 2011 [15]. More results can be found in Appendix B

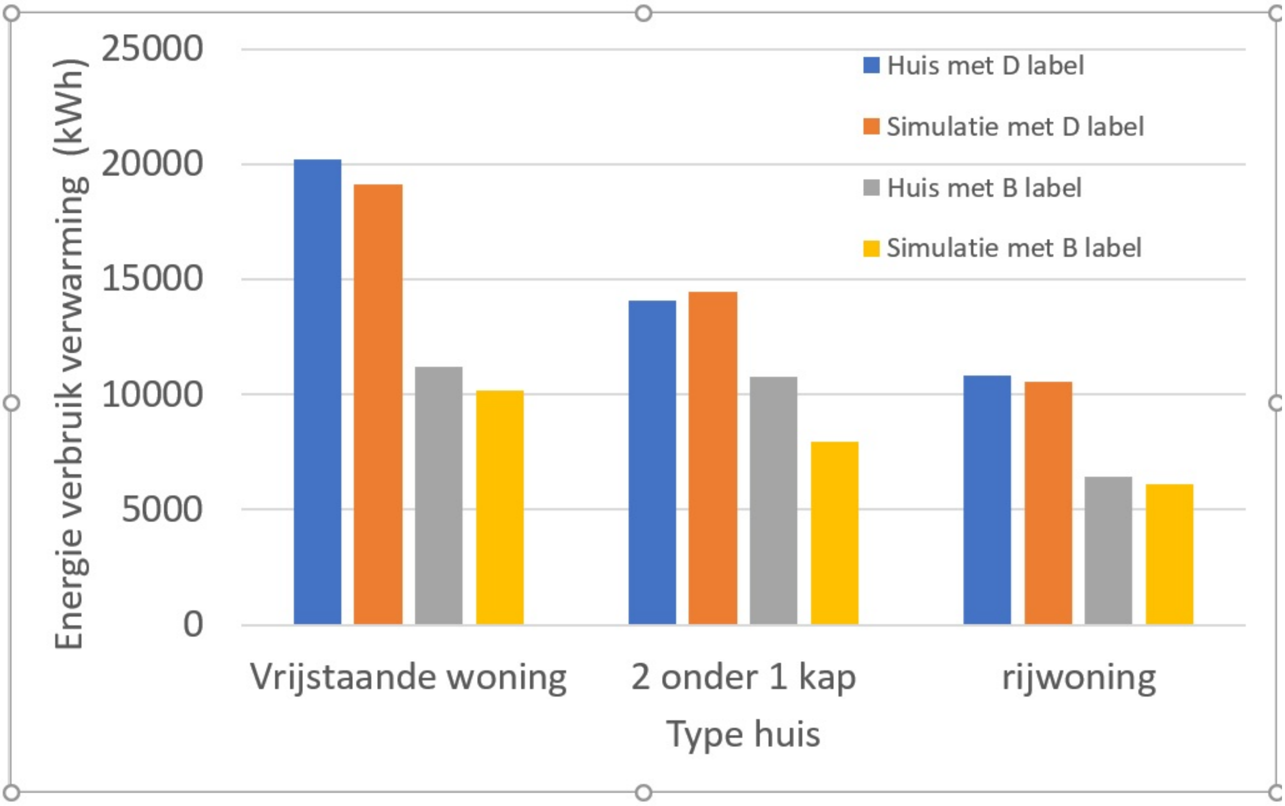

Figure 12: Simulation versus energy usage

The graph in figure 13 shows the yearly heating demand needed for difference outdoor temperature. It is clearly show the typical whether condition in the Netherlands where most of the energy use for heating happen at temperature range from 4 to 8 degree ^oC.

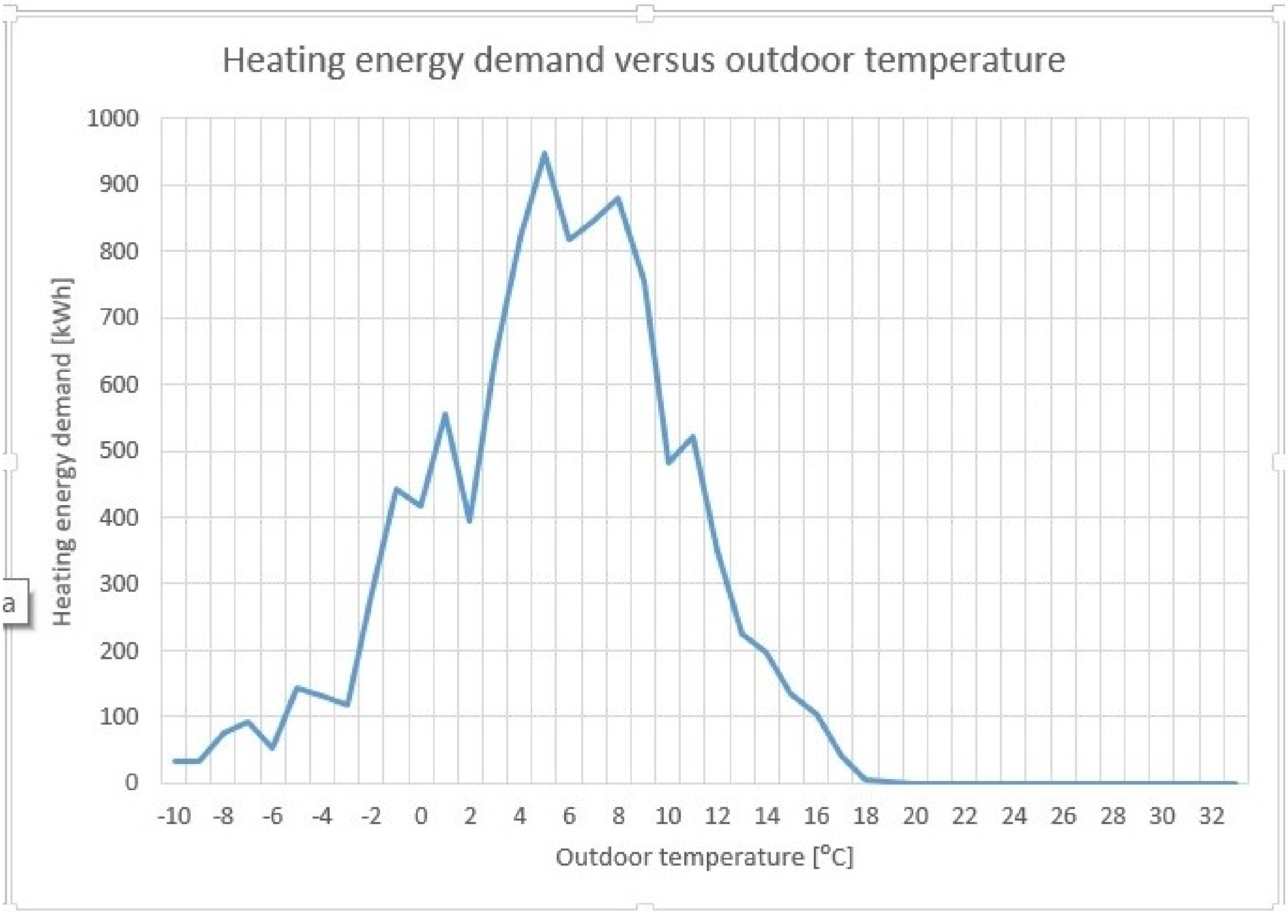

Figure 13: Simulation versus energy usage

In order to get an estimation of the minimum heating power capacity needed to maintain a specific indoor temperature for the whole year the model thermostat has been set at a constant temperature day and night. Minimum heating power capacity needed to maintain a specific indoor temperature has been shown in table 1.

Indoor temperature [^oC]	Minimum heating powercapacity [W]
18	6041
19	6335
20	6474
21	6704
22	6972
23	7144
24	7366

Table 1: Minimum heating powercapacity

5 Heat demand prediction model using machine learning.

This chapter will summarize report of the minor project students from big data module. There are 2 data sets had been used. One of these data sets was delivered by a member of HAN. It contains the weekly heat production of a house with a heat pump and a gas heating. This data set would provide the information about the heat demand, the output of the model. The other data set used was the weather data of the closest weather station (Instituut, 2019). This data set would provide the inputs to the model, consisting of the average weekly temperature, the average weekly wind speed, the average weekly sunshine duration the overall sum of sunshine duration, the average hourly precipitation and the sum of precipitation per week. This data was gained from hourly values provided by the Dutch weather service.
The heat production data was manually cleaned to get rid of outliers, measurement errors and other unwanted values. Dimensions of each column were checked, gaps filled and intervals between data checked for uniformity. As the heat production was given as an accumulative sum, the heat production per week needed to be extracted. The data was split to 70% for training and 30% for testing. As the NN was doing classification in the assignment, the evaluation had to be changed as well. New error metrics for this prediction model had to be established. Mean absolute Error, mean absolute relative error and mean absolute percentage error are a few to name.

5.1 Neural Network MATLAB toolbox.

The NN MATLAB toolbox for neural fitting was applied to the data. This toolbox applies a 2-layer feed-forward network with sigmoid hidden neurons and linear output neurons (figures 14).

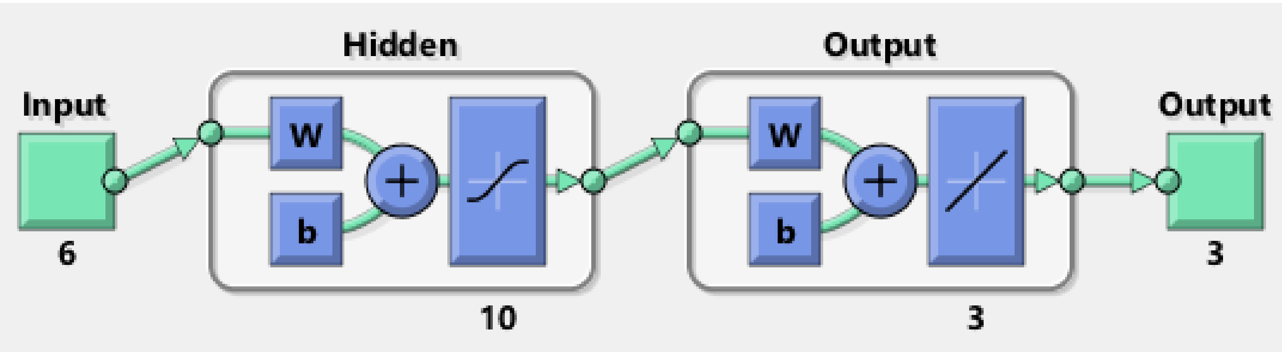

Figure 14: NN as used by the neural fitting toolbox

This network is then fed with the x_{train} and y_{train} previously generated for the manual implementation of the NN (figure 15).

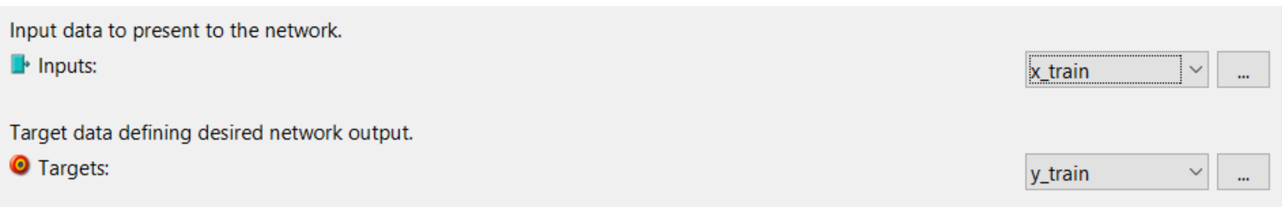

Figure 15: Input to NN

The training data set is then split up into training- test- and validation- set (figure 16). This splitting cannot be reduced to zero. As it is a toolbox function, the validation and test data set were part of the overall training algorithm, so the values were not changed. This data splitting is unconnected to the initial splitting between test and validation set. Here the training data set is internally split up by the toolbox.

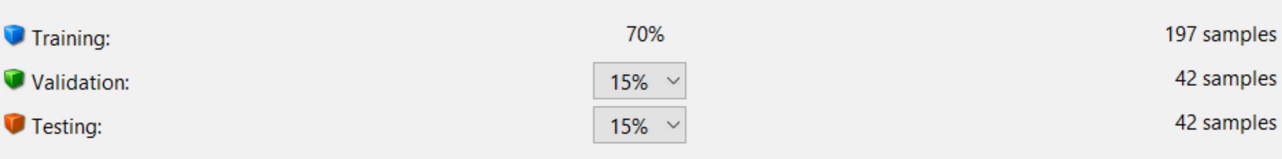

Figure 16: Training data vs Validation and Testing data ratio

For the hidden layer 10 neurons are chosen.

From the validation performance (figure 17), it can be clearly seen, that the NN is being trained quickly. By the validation performance it is determined, that at epoch 17 the NN delivers best performance so training can be stopped.

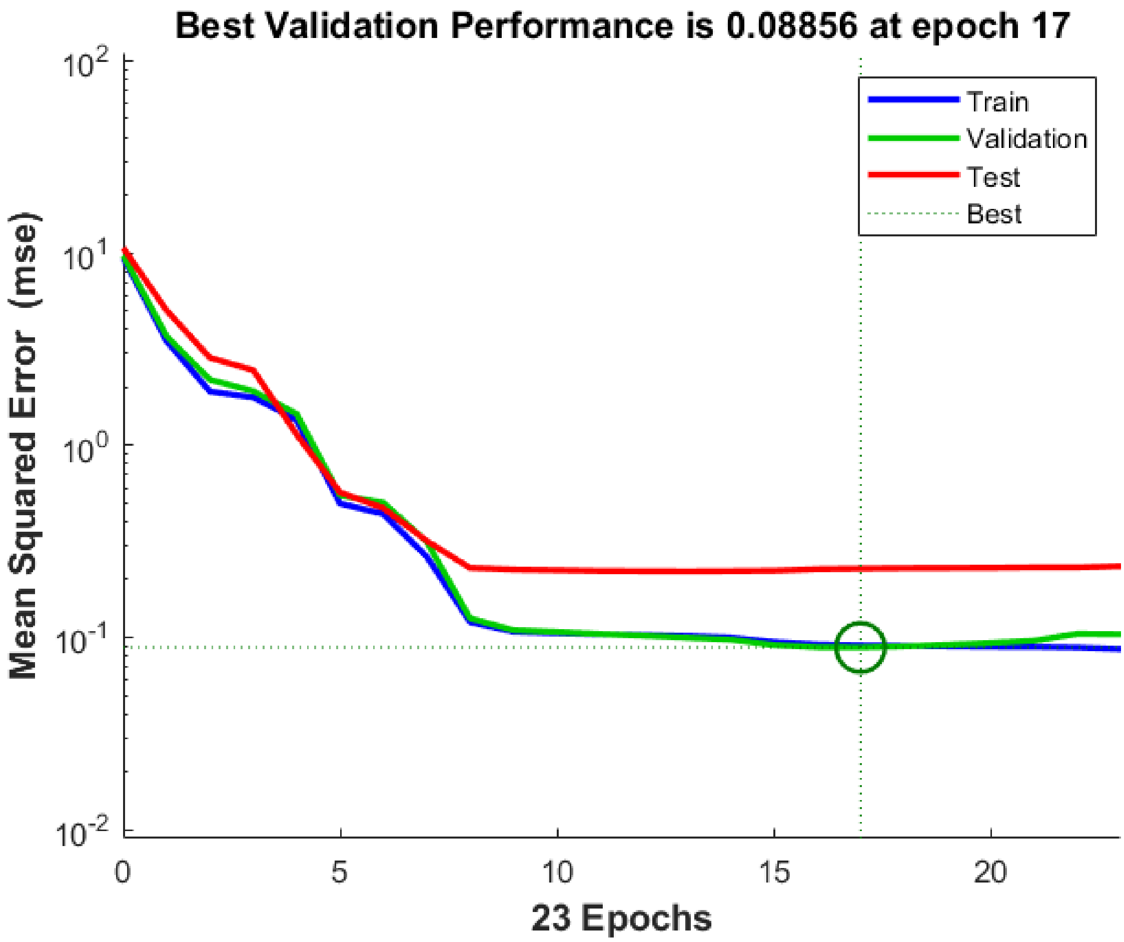

Figure 17: Validation Performance

The MSE (mean squared error) can be found in the table 2.

MSE (norm)	Training Data	Test data
Heat Pump	0.144817	0.593376
Gas	0.044751	0.218106
Combine	0.136688	0.586856

Table 2: Minimum heating powercapacity

5.2 Regression MATLAB toolbox

The regression SVM toolbox in MATLAB was employed. Using the regression model through SVM (Gaussian kernel) function, the root mean square error (RMSE) is very small and so are the other error metrics. A 5-fold cross validation is used to validate the model (figure 18).
Cross validation is also called a rotation estimation. It's very easy to see how accurately the predictive model will perform in practical settings. The data is divided into 5 portions of test data sets and training data sets for each iteration. The same test set is not used for all iterations. This testing is just an internal metric of the toolbox and can be seen as part of the training algorithm. It is independent of the initial splitting into test and training data. The cross validation is purely run on the training data. This cross validation is part of the toolbox and can't be removed.

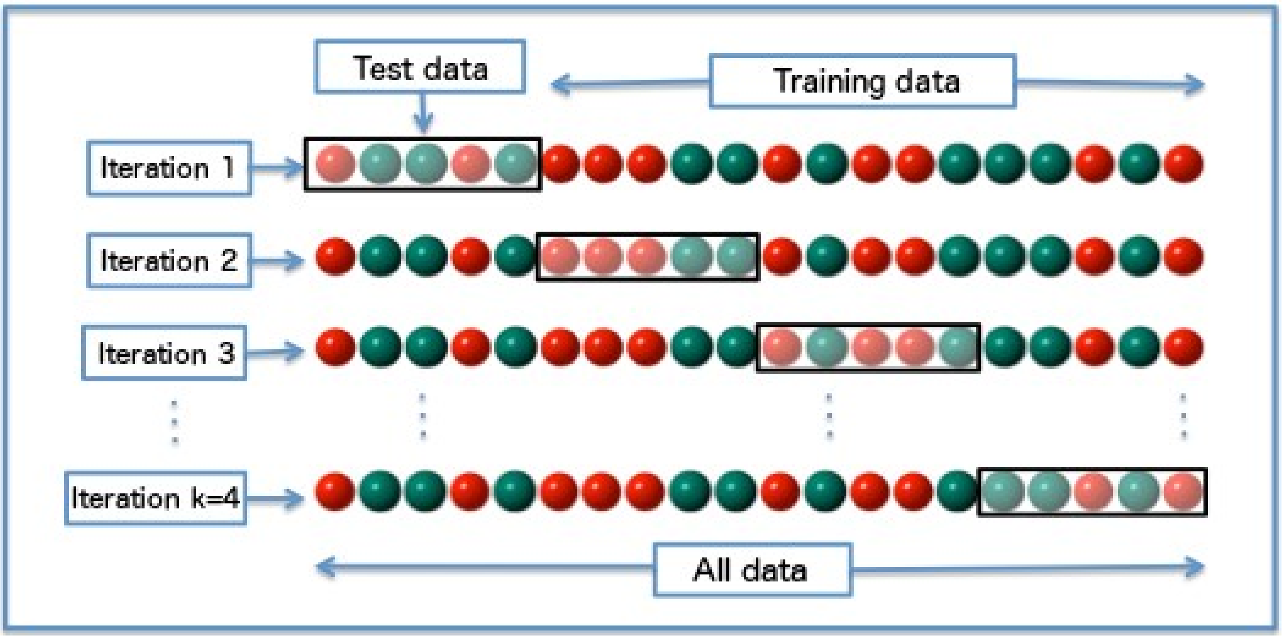

Figure 18: k-fold cross validation

The MSE is shown in the table 3.

MSE (norm)	Training Data	Test data
Heat Pump	0.178197	0.238478
Gas	0.060874	0.249772
Combine	0.167937	0.245215

Table 3: Minimum heating powercapacity

In the figure 19, the graph corresponds to the actual heat production and the predicted heat production as given by the toolbox. It can be seen here that there is a good correlation between the output (heat demand) and the temperature (x-axis, $column_1$).

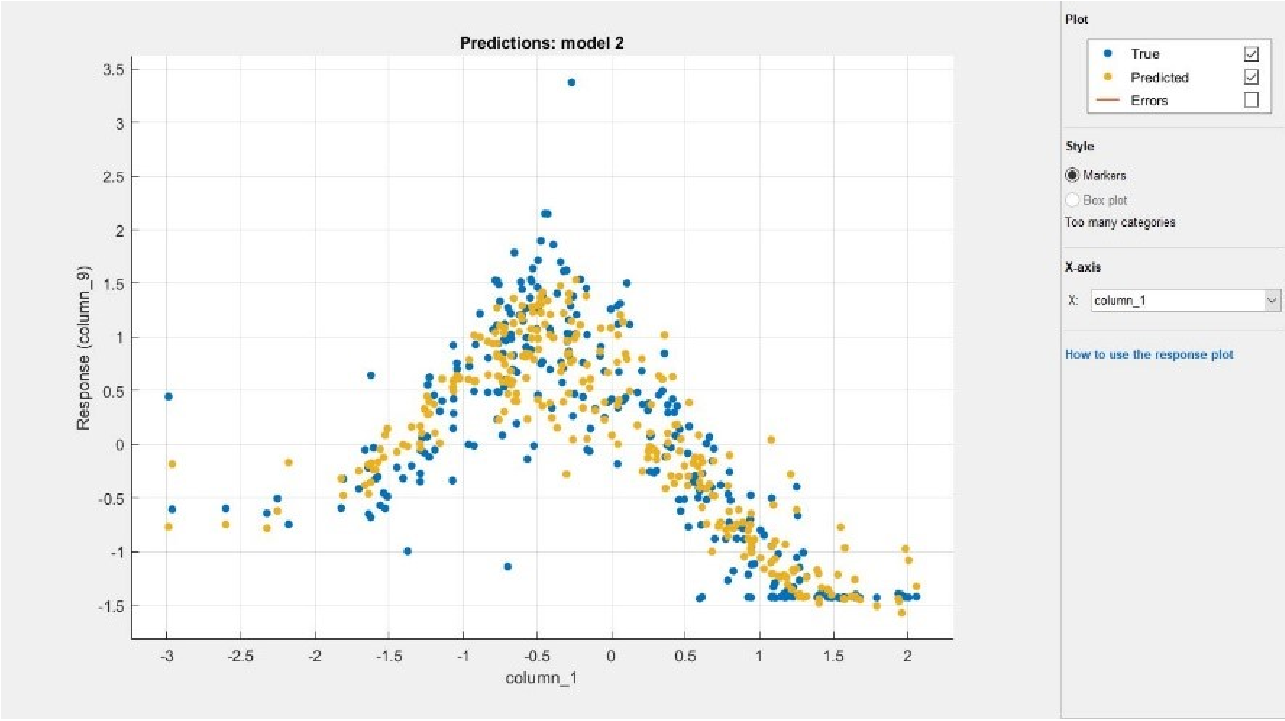

Figure 19: Predicted vs actual heat demand based on temperature

From the simulation results it could be seen that the data gives enough information for prediction. An improvement on the data set would provide better results with any prediction method. The SVM with the regression toolbox can find a correlation in the data, especially with the temperature input. The MSE for the SVM are even better than the ones of the neural network generated with the toolbox. Also, the MSE on the test data is best for the SVM generated with the regression toolbox. Although it needs training for each output individually, the SVM gives the best predictions.

A Dwelling parameters calculation

The initial parameters value for House model (row house 1975 to 1991) are listed in the table below[15]:

Initial Parameters Value			
Abbreviation	**Description**	**Value**	**Units**
A_{facade}	Envelope surface (facade + roof + ground)	160.2	m^2
$A_{internal\_mass}$	Floor and internal walls surface	170	m^2
$V_{dwelling}$	Internal volume	275.6	m^3
$R_{c,facade}$	Thermal resistance for unit area (thermal insulation), R-value	1.3	$\frac{m^2K}{w}$
U_{glass}	Window thermal transmittance, U-value	2.9	$\frac{W}{m^2K}$
n	Ventilation, air changes per hour	0.55	$[number/h]$
CF	Convection factor	0.8	
N_{facade}	Facade construction index	Light weight = 0/ Middle weight = 1/ Heavy weight = 2	
th_{facade}	Construction thickness: Light weight / Middle weight / Heavy weight	[0.1, 0.1, 0.2]	m
c_{facade}	Specific heat capacity construction [J/kgK]	[840, 840, 840]	$\frac{J}{kg \cdot K}$
ρ_{facade}	Density construction: Light weight / Middle weight / Heavy weight	[500, 1000, 2500]	$\frac{kg}{m^3}$
$N_{internal\_mass}$	Floor and internal walls construction index	Light weight = 0/ Middle weight = 1/ Heavy weight = 2	
$th_{internal\_mass}$	Construction thickness: Light weight / Middle weight / Heavy weight	[0.1, 0.1, 0.2]	m
$c_{internal\_mass}$	Specific heat capacity construction	[840, 840, 840]	$\frac{J}{kg \cdot K}$
$\rho_{internal\_mass}$	Density construction: Light weight / Middle weight / Heavy weight	[500, 1000, 2500]	$\frac{kg}{m^3}$
ρ_{air}	Density air	1.20	$\frac{kg}{m^3}$
c_{air}	specific heat capacity air	1005	$\frac{J}{kg \cdot K}$
α_{i_facade}	Heat transfer coefficient. Surface Interior thermal resistance $R_{si} = \frac{1}{\alpha_{i\_facade}}$ (R_c-waarde = 0.13, ISO 6946)	8	$\frac{W}{m^2 \cdot K}$
α_{e_facade}	Heat transfer coefficient. Surface Exterior thermal resistance $R_{se} = \frac{1}{\alpha_{e\_facade}}$ (0,04 $\frac{m^2k}{W}$, ISO 6946, external surfaces or external side of exterior wall)	23	$\frac{W}{m^2 \cdot K}$
$\alpha_{internal\_mass}$	Heat transfer coefficient. Internal wall thermal resistance $R_{air\_wall} = \frac{1}{A_{internal\_mass} \cdot \alpha_{internal\_mass}}$ Resistance indoor air-wall	8	$\frac{W}{m^2 \cdot K}$
$\rho_{internal\_masss}$	Density construction in $[kg/m^3]$	1	$\frac{W}{m^2 \cdot K}$

Table 4: Values of constants and parameters in house model.

Volume floor and internal walls construction [m^3]: $V_{internal,mass} = A_{internal,mass} \cdot th_{internal,mass}$

Ventilation, volume air flow [$\frac{m^3}{s}$]: $qV = \frac{n \cdot V_{dwelling}}{3600}$

Ventilation, mass air flow [$\frac{kg}{s}$] : $qm = qV \cdot \rho_{air}$

Calculation of the resistances.

Resistance indoor air-wall: $R_{air\_wall} = \frac{1}{A_{internal,mass} \cdot \alpha_{internal,mass}}$

U-value indoor air-facade: $U = \frac{1}{\frac{1}{\alpha_{i\_facade}} + Rc\_facade + \frac{1}{\alpha_{e\_facade}}}$

Resistance indoor air-outdoor air: $R_{air\_outdoor} = \frac{1}{A_{facade} \cdot U + A_{glass} \cdot U_{glass} + qm \cdot c_{air}}$

Calculation of the capacities.

The heat capacity of interior walls can be determined using half of the actual wall thickness because both surfaces are considered as storing energy [19].

Thermal capacity indoor air and walls: $C_{air} = \frac{rho_{internal\_mass} \cdot c_{internal\_mass} \cdot V_{internal\_mass}}{2} + \rho_{air} \cdot c_{air} \cdot V_{dwelling}$

Thermal capacity walls : $C_{wall} = \frac{rho_{internal\_mass} \cdot c_{internal\_mass} \cdot V_{internal\_mass}}{2}$

B R and C Values explanation.

In [7] and [8] the expressions in Fig.1 are derived. For conduction, the expression for $R_{th} = \frac{L}{k\dot{A}}$

The units of R_{th} are: $[\frac{K}{W}]$

$[W] = [\frac{W}{m \cdot K}][\dot{m}^2] \cdot [\frac{K}{m}]$

The units of k are: $[\frac{m}{m^2} \cdot \frac{W}{K}] = [\frac{W}{m \cdot K}]$

Thermal conductivity of material $k = [\frac{W}{m \cdot K}] = [\frac{W}{m \cdot K}] = [W \cdot m^{-1} \cdot K^{-1}]$

k is also denoted as λ

Reference: [20]

Ohm's Law: $R = \frac{U}{I} \quad [\frac{V}{A}] = [\Omega]$

Electrical resistivity: $\rho = [\frac{\Omega \cdot m^2}{m}] = [\Omega \cdot m]$ Material property.

Electrical conductivity: $\sigma = \frac{1}{\rho} = [\frac{1}{\Omega \cdot m}] = [\frac{S}{m}]$ Material property.

Electrical resistance $R = \frac{\rho \cdot L}{A}$ or $R = \frac{L}{\sigma \cdot A}$

Thermal Law: Heat flux $\dot{Q}$ in $[W \cdot m^{-2}]$

$\dot{Q} = \frac{\Delta T}{R_{th}} \quad R_{th} = \frac{\Delta T}{\dot{Q}} \quad [\frac{K}{W \cdot m^{-2}}] = [\frac{m^2 \cdot K}{W}]$

(Specific) Thermal resistivity: R_λ or $r = [\frac{K}{W \cdot m^{-2}} \frac{1}{m}] = [\frac{m \cdot K}{W}]$ Material property.

Thermal conductivity: λ or $k = \frac{1}{r} = [\frac{W \cdot m^{-2}}{K} \cdot m] = [\frac{W}{m \cdot K}]$ Material property

Thermal resistance R-value or $R_{th} = \frac{r \cdot L}{A}$ or $R = \frac{L}{k \cdot A}$

Unit $R_{th} = [\frac{m \cdot K}{W} \frac{m}{m^2}] = [\frac{m^2 \cdot K}{W}]$

R_c-value $= r \cdot L = \frac{L}{k} = \frac{L}{\lambda}$

C NEN and ISO

The list of NEN and ISO standard used in the calculation:

- NTA 8800
- NEN 1068
- ISO 6946
- ISO 10077-2
- NEN 7120
- NEN 5060[21]

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