Simulation Assisted Monitoring of a Multi-Family House – a renovation case study

Dietmar Siegele[1], Georgios Dermentzis[1], Eleonora Leonardi[1],
Fabian Ochs[1], Aleksandra Ksiezykl[1]
[1]Unit for Energy Efficient Building, University of Innsbruck, Innsbruck, Austria

Abstract

A multi-family house in Ludwigsburg (Germany) is renovated within the European project iNSPiRe. The building was monitored before the renovation with respect to energy consumption, thermal comfort and indoor air quality. Several building simulation models are developed for the whole building and a more detailed one for one flat. The required simulation inputs such as internal gains, user behaviour and heat distribution are derived based either on optimised calibration methods using the available monitoring data or on experience. All models are calibrated and validated against measured data. Results show that the one zone monthly calculation model (PHPP) can be used with good accuracy in case of a calibrated temperature for the 1-zone model.

Introduction and motivation

The problem of high-energy consumption of existing buildings is tackled within the EC-funded project iNSPiRe. The developed renovation packages aim to reduce the primary energy consumption to lower than 50 kWh/(m^2·a) for ventilation, heating/cooling, domestic hot water preparation and lighting.

Energy auditing can significantly contribute to identify and assess the required energy conservation measures in existing buildings. Depending on the level of available information of the building (envelope quality, indoor temperatures, energy demand, climate, user behaviour etc.) different tools with varying degree of precision and complexity might be used. Calibration of the auditing tool against monitoring and or energy billing data wound improve the accuracy, (iNSPiRe D2.2). Frequently, measured data are available only for a short period of time (e.g. part of heating season) and might be incomplete (missing temperatures of heated or unheated or adjacent zones or ground as well as distribution of the heat to the zones etc.). The objective of this work is to analyse measured data and calibrate different building models in order to investigate the possible accuracy of building models depending on the availability of information. Analytical monitoring results are presented also in Ochs et al. (2016).

Case study and monitoring concept

The building (Figure 1) analysed in this paper, a multi-family house built in the early '70s in Ludwigsburg, Germany, consists of four stories with one apartment in each floor. In basement, there is one flat, plus four rooms for common space (laundry, storage and technical rooms); the ground and first floor flats are identical and another flat is in attic floor with a west balcony. The common space in basement is not heated but influenced by the surrounding thermal zones. The staircase and a part of basement adjoin the neighbours' staircase. The east wall of the building is adjacent to the neighbour building. The areas are presented in Table 1.

Table 1: Areas of the building parts

Building part	Areas before renovation [m^2]	Heated / unheated
Basement flat	39.51	heated
Ground floor flat	91.99	heated
First floor flat	91.99	heated
Attic flat	58.05	heated
Staircase	28.75	unheated
Common space in basement	56.17	unheated
Total	**366.46**	
Treated	**332.49**	

Remark: The treated area of 332.49 m^2 will be used further for the simulations, since it is calculated assuming the common space in basement and the staircase inside the thermal envelope (as it is after renovation).

Figure 1: Outside view of the MFH in Ludwigsburg, Germany, before renovation (Wohnungsbau Ludwigsburg, WB-L, iNSPiRe D7.1)

Some refurbishment measures have been implemented previously such as adding external insulation (6 cm) and replacement of some of the windows (to double-glazed windows). In the framework of the project iNSPiRe, a deep renovation including envelope and HVAC system has been performed.

The building was monitored and analysed before and after the renovation. 14 comfort sensors (temperature, humidity and CO_2) are installed: three in basement flat two in the common areas, five in ground floor flat and four attic floor flat. Electricity consumption of each flat (expect the one in first floor) is measured and heat meters are installed to measure space heating and domestic hot water – only central for the consumption for the whole building. A weather station is placed in the outside yard to measure the ambient temperature, relative humidity and global and diffuse radiation. The monitoring of the existing building started in November 2014 and thus not the completely heating season was monitored. Additionally, the bills of oil consumption between 04/2013 and 05/2015 are available as well as the cold-water consumption.

Methodology and simulation models

The analysis of the monitoring data is supported by means of building simulation with four different models:

1. Passive House Planning Package - monthly energy balance- (PHPP)
2. Simple dynamic 1-zone model (1 node, lumped capacity)
3. Simple dynamic 6-zone model of the building
4. Detailed dynamic two star 6zone model of the flat in ground floor.

The dynamic models are simulated in Matlab/Simulink (Matlab 2013a) using the CARNOT blockset (Hafner B. 2012).

The following steps were performed for the whole building:

1. Analysing monitoring data (heat flow, temperature, relative humidity (rH), CO_2-concentration) and calculation of representative zone temperatures (as well as rH and CO_2)
2. Validation of heating demand against billing data (oil, season 2014/2015) and determination of DHW demand based on analysing cold water demand (billing data)
3. Derivation of occupation profile from monitoring data (e.g. scale standard occupation profile to measured rH, CO_2), determination of internal gains from monitored electricity consumption and heat distribution to the 4 flats and inside one flat to each room
4. Simulation of building with internal gains (persons, equipment) and heat flow from monitoring and compare measured and simulated zone temperature
5. Calibrate model by variation of infiltration/ventilation, quality of opaque and transparent envelope components to obtain a good match between measurement and simulation (season 2014/2015)
6. Validate model (against oil bill, season 2013/2014) and
7. Simulate heating demand for standard conditions and parameters

Monitoring data analysis and boundary conditions for the simulations

Based on the available measured data, different assumptions have to be made for the required inputs of the simulation models. The analysis of the monitoring data is used to estimate the boundary conditions for the simulation models.

Representative indoor temperatures

Since temperature is not measured in all rooms of the building, representative temperature should be calculated to be used or compared with the simulations results. Thus, volume weighted average temperature are calculated.

The approach is different for the 1-zone model and the 6-zone model. In case of the 6-zone model one temperature for each flat plus a temperature for the staircase is required. For the 1-zone model, a characteristic temperature representing the whole building is necessary. Due to missing measurement data for the first floor and insufficient information for the staircase, the characteristic temperature for these two zones has to be guessed. For the staircase, the temperature of the sensor in the hall of the unheated basement is assumed to be representative.

Climate data

Two set of climate data are used: a) directly from the available measurements in the demo building and b) standard Stuttgart climate data derived from Meteonorm (2009).

Electricity

For the simulation, the electricity consumption available for each flat of the building was taken directly from the monitoring results and introduced as gain to the zone. Further information of the electricity consumption in the unheated zones (such as auxiliary energies) was not available and had to be guessed. No latent gains/losses have been considered.

Occupation profile

An occupation profile for each person is used based on (IEA) and then is multiplied with the real number of persons. For the 1-zone model, a constant value has been calculated from the profile leading to a value of 0.77 W/m² for the internal load due to persons.

Heat distribution

Since only one heat meter exists to measure the total heating demand of the building, factors had to be assumed for the heat distribution to the heated zones/flats and to the unheated zones (due to the distribution losses). Additionally, the heat distribution between the rooms within one flat is also discussed in this study (see below the section for the ground floor analysis).

In the 6-zone model of the building, the heating power from the monitoring system is used as input and has to be distributed to the flats. In the considered monitoring period, only three flats are heated (the first floor was unoccupied). The heat distribution to each flat is a subject to the optimization procedure. Based on the analysis of the monitoring results, it was identified that the distribution of the heat is different at day and night time. The attic floor was mainly heated at night while for the other two flats the heating occurs all over the day. Finally, the distribution heating factors are selected by analysing the monitored and simulated indoor temperatures**.** They represent a good fit, while further work can be performed to optimize the procedure.

Heating and DHW

The measurement of the consumed energy for domestic hot water (DHW) preparation failed. Therefore, the DHW demand is determined using the oil bills. To obtain the circulation and storage losses, in addition to manual readings of the oil consumption, information from bills for the cold-water consumption have been used. The monthly analysis of the oil consumption and its contribution to heating, DHW and circulation losses are shown in Figure 2.

The DHW circulation losses contribute to heat the building. The total heat demand of the building, which is the sum of heating and circulation and storage losses (only for the heating period), is 52 kWh/(m²·a) in 2014/2015.

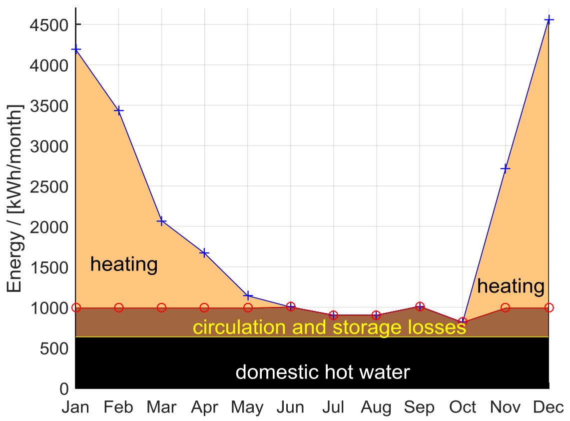


Figure 2: Oil consumption with assumed contributions to heating, domestic hot water and circulation and storage losses (assumed) in 2014/2015.

Calibration of the simulation models

Parametric study with PHPP

Initially, a parametric study has been performed using PHPP to understand the quality and the plausibility of the original assumptions (before monitoring data) for the thermal envelope and the internal gains. Six parameters were taken into consideration while the values were changed based on the experience and best practise:

- infiltration [1/h]: n_{50} changed from 2 to 1 [1/h]
- ventilation rate [1/h]: changed from 0.14 to 0.07 [1/h] (i.e. daily operation duration [h/d]: changed from 24 to 0 h/d)
- thermal conductivity of the insulation of the external walls W/(m K): improved from 0.06 W/(m K) to 0.04 W/(m K)
- improved quality of windows (U-value)
- internal gains: standard value of PHPP 2.1 W/m², changed to 3 and 4 W/m²; the internal gains for the equipment derived from the measurements and the value of 0.77 W/m² is used for internal gains due to occupancy
- set point temperature changed from 22 °C to 20 °C

From the investigation with the PHPP the following conclusions can be drawn.

- The demo building has significantly lower heating demand than expected, i.e. calculated with the information available and standard assumptions;
- There are high circulation losses, which contribute to the heating of the building and thus, to the reduction of the measured heating demand;
- There are relatively high internal gains (and there might be some electricity equipment in the common space which is not measured);
- There is likely relatively low ventilation/infiltration rate leading to relatively low ventilation losses;
- The unheated first floor (not occupied during the monitoring period) and the lack of information for the temperatures in unheated basement and the staircase increase the uncertainty in the prediction of the heating demand.
- The unknown temperature of the adjacent building leads to further uncertainty

Calibration of PHPP

Since with the modified parameters of the previous section the measured value could not be reached, additional modifications of the thermal envelope, internal gains and air losses, using measured climate data are performed to calibrate the PHPP model. The calibrated values are summarized in Table 2. Varying the indoor temperature the model is calibrated (see Variant 1 in Figure 3).

Additionally, using the calibrated values a second variant is created in PHPP. The two variants are defined as follow:

- Variant 1 (used for the calculation above): all zones including the staircase and the cellar are assumed inside the thermal envelope. A mix temperature between heated and unheated zones is required, which will be lower than the set point temperature of the flats due to including the unheated areas.
- Variant 2: only the heated zones are assumed to be inside the thermal envelope. For the boundary conditions to the unheated zones, a so-called

reduction factor (red.f) is needed to be determined. It represents a reduction of the heating degree-days with respect to the ambient temperature and thus, it is a way to set the boundary condition temperature of the unheated zones.

Table 2: Parameters before and after calibration

Quantity	Unit	Initial values	Calibrated values
internal gains	W/m²	2.1	5.45
air tightness	1/h	2	1
ventilation rate	1/h	0.18	0
U-value ext. wall	W/(m²·K)	0.7	0.43
U-value roof	W/(m²·K)	0.46	0.40
U-value basement	W/(m²·K)	2.89	2.24
U-value window	W/(m²·K)	2.8	1.1

In Figure 3, the two variants are compared to the measured data varying the indoor temperature and additionally for the variant 2 the reduction factors to the staircase/cellar (two solid blue lines).

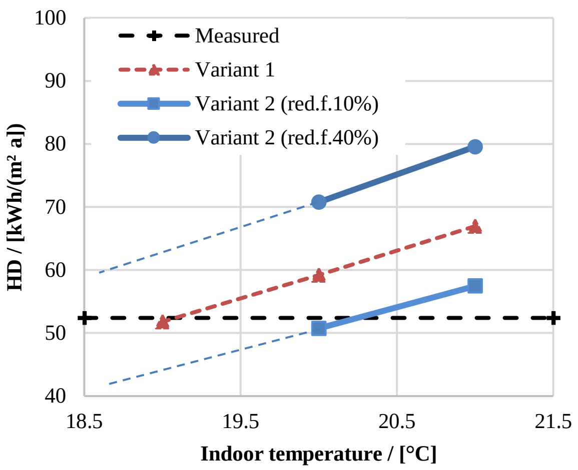


Figure 3: Influence of indoor temperature on the heating demand for the "improved" PHPP acc. to Table 2 and adapted climate data for PHPP with two variants: 1) all zones heated and 2) with flats only heated with a reduction factor of 40 % and 10 % compared to measured data in 2014/2015

In both variants, PHPP can predict the heating demand with relative good accuracy. In variant 1 an indoor temperature of 19 °C for the whole building is used leading to a heating demand of 52 kWh/(m²·a). In variant 2 the heating demand is 51 kWh/(m²·a) with an indoor temperature for the flats of 20 °C and a reduction factor of 10%, when the measured heating demand is 53 kWh/(m²·a).

1-zone model

The dynamic one-zone model was simulated with the cases as for the PHPP. A different calibration method is used. The measured heating power and the DHW circulation losses are inputs resulting to an indoor temperature which is compared with the representative building temperature obtained from the monitoring data, instead of calculating the heating demand having as input the given set point temperature. The results are in good agreement (detailed analysis can be found in Ochs et al. (2016)).

6-zone model of the building

The simulated temperatures for each flat are compared with the representative zone temperature derived from the measurements. In Figure 4, a good agreement is shown and general trends are followed for the three heated flats. In case of the unheated basement, there are some deviations that are believed to be caused by the high influence of the technical room (measured data was not available). Simulation results for first floor and staircase are not presented since these two zones were not monitored.

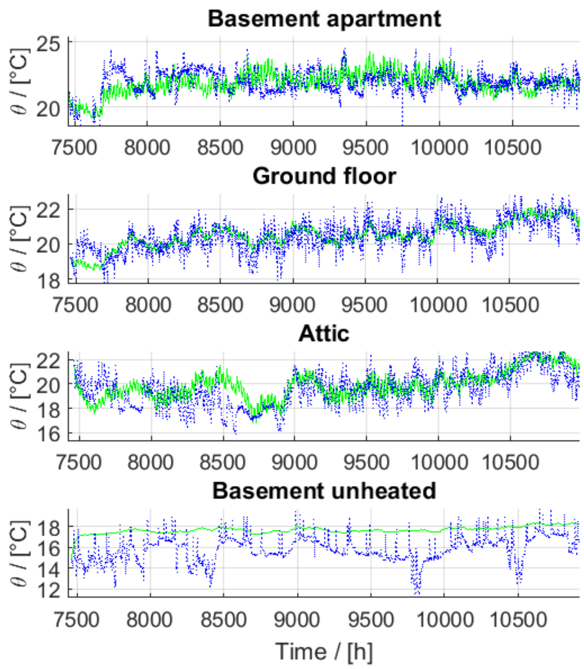


Figure 4: Simulated (with the 6-zone model, solid green lines) and representative measured temperature (dashed blue) of four zones.

Figure 5 displays the volume weighted average temperature compared to the respective monitored temperature of the whole building. There is a deviation between the two temperatures (in some cases even about 2 K) but the trends are similar.

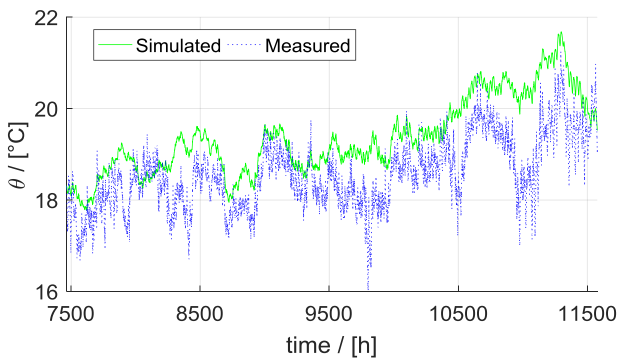


Figure 5: Comparison of six-zone model - Results from simulation and monitored values

Prediction of heating demand

The prediction of the heating demand is carried out using the calibrated models for different assumptions.

Table 3 shows results of the 6-zone model for three different cases using climate data and internal gains based on monitoring for the winter of 2013/14.

Considering the first floor as heated or unheated has only little influence on the heating demand, because of the additional internal gains, when is occupied and heated. The case with the unheated first floor shows even a higher heating demand than the case where the whole building is heated. This can be explained by the missing internal gains (around 5 W/m²) of that flat. The comparison between the measured data and the six-zone model with the heated first floor shows relative good agreement.

Table 3: Heating demand calculated with 6-zone model and comparison with measured data

Case	Specific heating demand kWh/(m²·a)
oil measurement 2013/14 with DHW losses	53
first floor heated	54
first floor unheated	61
whole building heated	63

The heating demand is calculated using standard conditions i.e. reference climate data, internal loads of 2.1 W/m^2, and 20 °C set point temperature. The results are shown in Table 4. PHPP and 1-zone model gives the same result of 96 kWh/(m²·a). A difference of 7 kWh/(m²·a) is shown between PHPP and the 6-zone model (assuming the whole building is heated),while in case of only the flats are heated the heating demand with the 6-zone model is 71 kWh/(m²·a).

Table 4: Heating demand calculated with different models for normalized conditions (Reference Stuttgart climate, internal loads of 2.1 W/m^2, and 20 °C set point temperature)

Case	Heated zones	Specific heating demand kWh/(m²·a)
6-zone model	only the flats heated	71
6-zone model	whole building heated	89
1-zone model	whole building heated	96
PHPP	whole building heated	96

As already mentioned, the building was already refurbished with 6 cm of insulation and two pane windows some years ago. It is instructive to compare the heating demand of the existing building and the one before the first renovation (without the 6 cm of insulation and with windows in original quality). Results are shown in Table 5. There is a good agreement between PHPP and 6-zone model (assuming the whole building is heated) with 192 kWh/(m²·a) and 196 kWh/(m²·a), respectively.

Table 5: Heating demand before the first renovation calculated with different models for normalized conditions (Reference Stuttgart climate, internal loads of 2.1 W/m^2, and 20 °C set point temperature)

Case	Heated zones	Specific heating demand kWh/(m²·a)
PHPP	whole building heated	192
6-zone model	whole building heated	196

The results are summarized in the following:

- The Energy Certificate from 2012 states: 127 kWh/(m²·a)
- Building as monitored in 2013/2014: 53 kWh/(m²·a)
- Building normalized (climate, occupation, usage): 96 kWh/(m²·a)
- Building normalized before first renovation: 192 kWh/(m²·a)

Detailed analysis of the flat in ground floor

In additional to the whole building study, a detailed monitoring and simulation analysis for the flat in ground floor is performed. A detailed analysis is presented in Leonardi E., (2015).

Three weeks are chosen for detailed analysis: one calibration week in December and two validation weeks one in November and one in February. The required inputs for the simulation models such as internal gains (electricity and occupancy), air coupling between the zones, window opening and heat distribution to the zones are derived from the analysis of the monitoring data using several approaches. Two optimized calibration strategies are used to individuate the heat distribution within the flat: the "valves" method and the "set point temperature" method.

The different zones of the detailed two-star simulation model are presented in Figure 6.

Figure 6: Floor plan of the ground floor flat of the demo building (WB-L) with the thermal zones used in the simulation model (from Leonardi, (2015))

Internal loads: equipment

The electric energy consumption of the flat is measured and is used to calculate the power with the goal to have the internal gains from equipment given as a daily profile. The measured values are for the whole flat. Hence, a method to distribute the measured power within the flat in each zone has to be developed. The chosen method is based on finding the standby power and distributing the peaks of the electric power by a time profile. The method uses as input the measured electricity of the flat and it distributes this into the zones. An example for one day is shown in Figure 7.

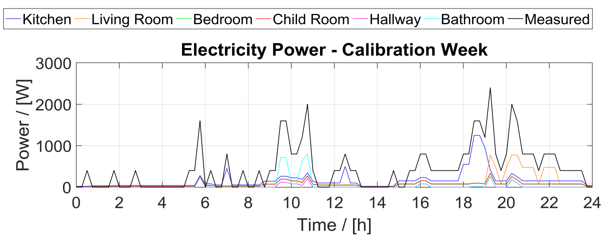


Figure 7: Measured electricity power and distribution within the flat

Internal loads: occupation Profiles

A typical occupation profile had to be assumed for each zone. Different measured data are used to derive the profiles for each zone. For the kitchen and the living room, a correlation with the peaks in the electricity is found to obtain the occupation profiles in these zones. For the sleeping rooms (Parents and Children Room (South) and Children Room (North)) a correlation with the CO_2 concentration is found based on the average daily profiles of the monitoring data. For the hallway and the bathroom, no occupation profile is considered, because the presence of the persons is negligible. However, the peaks of humidity are considered for the bathroom.

Coupling between the zones

The zones are connected between each other through the hallway (see Figure 6). In the simulation model, a constant value is considered for the air exchange. In Table 6, the values are considered based on Rojas, et al. (2015), who proposes 300 m^3/h for an open door.

Table 6: Air coupling between the thermal zones

Intersection zones	**Air exchange rate [m^3/h]**
Hallway - kitchen	300
Hallway - living room	300
Hallway - parent and child room (South)	2 x 150
Hallway - child room (North)	150
Hallway - bathroom	50

From the analysis of the measured CO_2 concentration in each room, it can be concluded that the assumption of taking a constant value for the air exchange rate is acceptable since the trend of the CO_2 concentration is similar in the zones.

Window Opening

The window opening is set manually, in order to match the measured CO_2 level and the temperatures. This can be done after the assumption of the profiles for electricity and occupation profiles. A window opening profile is considered in the living room and in the sleeping rooms only.

Heating distribution between the zones of the flat – calibration strategies

As already mentioned, distribution factors are calculated for the heat distribution to the flats and used in the 6-zone model of the whole building. In order to distribute the heating power inside the ground floor flat, two different optimization methods are implemented, one is the "valves" method and the other is the "set point temperature" method. For each method, one MATLAB optimization function is used: either *lsqnonlin* or *fminsearch*.

"Valves" method

One radiator is modelled in each zone of the flat. The radiators are implemented with a valve that controls the mass flow going into the radiators. The valves are represented with a factor that has values from zero to one. These factors are taken as constant values with respect to time. The "valves" method represents a central heating control.

A simplified scheme of the optimization is shown in Figure 8. The "valves" method is based on the factors for the opening of the valves. In particular, giving as input to the simulation model the mass flow and the flow temperature, the simulation is run for the calibration week and it gives as output the operative temperatures of the zones, which are compared with the measured temperatures. The variables are the opening of the valves and the cost function of the minimization problem is the difference between the measured and the simulated temperatures. For the optimization of the opening of the valves, the function *lsqnonlin* is used (MathWorks (2016), lsqnonlin).

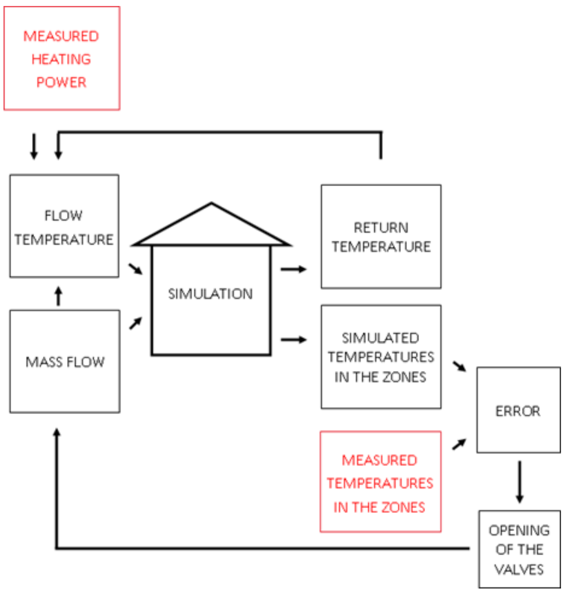


Figure 8: Optimization - valves method, (Leonardi, 2015)

"Set point temperature" method

In Figure 9, a scheme of the optimization for the set point temperature method is shown. This method works with the set point temperatures for each zone and represents the case of a room-wise control of the heat emission. A set point temperature is given to the radiators of each zone, the simulation is run and it gives as output the simulated temperatures in the rooms and the simulated heating power. The errors are calculated between the simulated and the measured heating power and between the temperatures. The set point temperatures are changed and the simulation reruns, until the errors are minimized.

fminsearch (MathWorks. (2016), fminsearch), which finds the minimum of an unconstrained multivariable function using derivative-free method, is used for the optimization of the set point temperature.

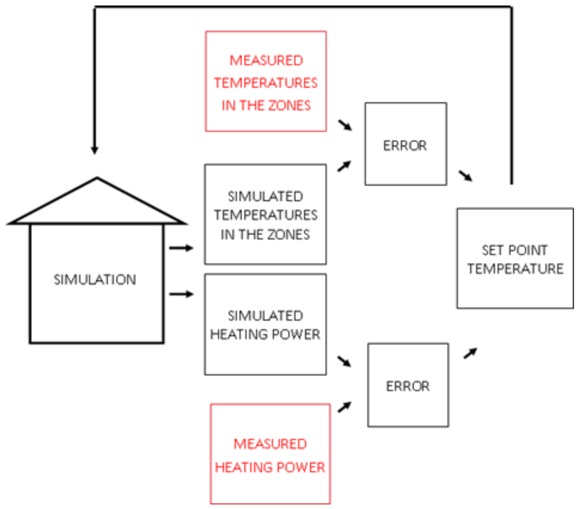


Figure 9: Optimization - set point temperature method, (Leonardi, 2015)

Results of the Calibration and Validation

Both methods, the optimization of the values of the opening of the valves and the optimization of the set point temperature, deliver quite good results. Figure 10 shows the indoor measured and simulated temperatures for the two strategies for the calibration week. For the calibration a week with low solar gains was selected. In can be concluded that the difference between the simulated and monitored temperatures is within an acceptable range for all zones.

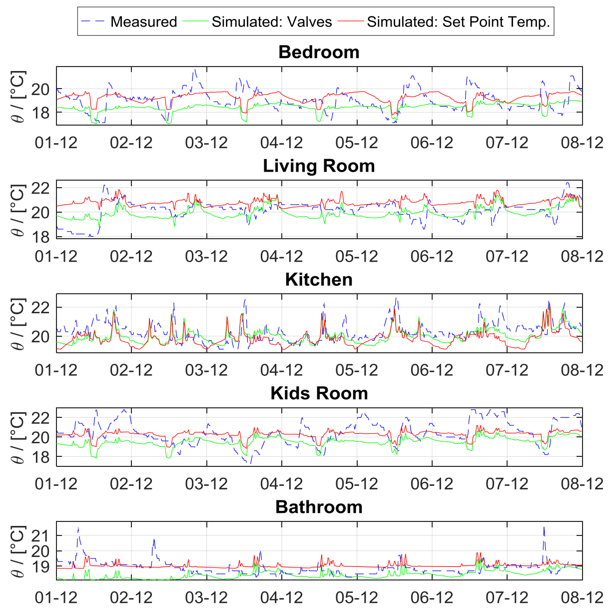


Figure 10: Comparison between simulated and measured temperatures for the valves and set point temperature method (Leonardi, 2015)

In Table 7, the root mean square errors calculated on the 15 minutes values for the two methods are shown. For both methods, it can be noticed that the difference between the error of the calibration week and the error of the first validation week (in November) is lower than the difference with the error of the second validation week (in February). Regarding the validation week of February, the error is higher than the error for the validation week of November, especially for the set point temperature method. Furthermore, in the set point temperature method there is also an error between the measured and the simulated energy that has to be considered. The “valves” method allows having a dependence on the measured heating energy, which the set point temperature method does not have. It can be concluded that the “valves”-method gives lower errors compared to the “set point temperature” method, but generally, both methods deliver satisfying results.

Table 7: Errors in temperature and heating energy for the “valves” and “set point temperature” methods

Week	Valves Method	Set Point Temperature Method	
	Error $_{Temp}$ [K]	Error $_{Temp}$ [K]	Error $_{Energy}$ [kWh]
Calibration	0.87	0.82	-12.39
Validation 1	0.68	1.01	-32.98
Validation 2	0.98	1.14	63.8

In Figure 11, Figure 12 and Figure 13, the results of the validation for the week of November are shown. All figures refer to the valve method.

The temperatures are quite well predicted with the simulation in the living room and in the bathroom. As for the calibration week, the behaviour of the people in the bedrooms has a great influence. In particular, in the children room the error is quite high, because of a change in the user behaviour. The measured temperature is quite low and lower than the calibration week. The error in the kitchen also is quite high, caused by the user behaviour. The measured temperature of the kitchen is lower than the temperature in the calibration week.

The trend of the CO_2 is quite well predicted in each room (Figure 12). In particular, the simulated CO_2 level decreases when there is the opening of the window (during the day) and increases with the presence of the people (during the night). A limitation in the sensor at 2500 ppm is also noticed.

In Figure 13, the comparison between the simulated and measured absolute humidity is shown. On average, the measured absolute humidity is simulated quite well. In the bedrooms and in the living room it can be seen that the chosen profile for the opening of the window helps to match the humidity trends. The peaks in the bathroom are quite well predicted, whereas the peaks in the kitchen are not implemented with such high values, due to very short time peaks (probably the window is opened directly after the peak).

The validation results of the CO_2 and humidity prove that the internal gains profiles for the electricity and occupancy are considered appropriately.

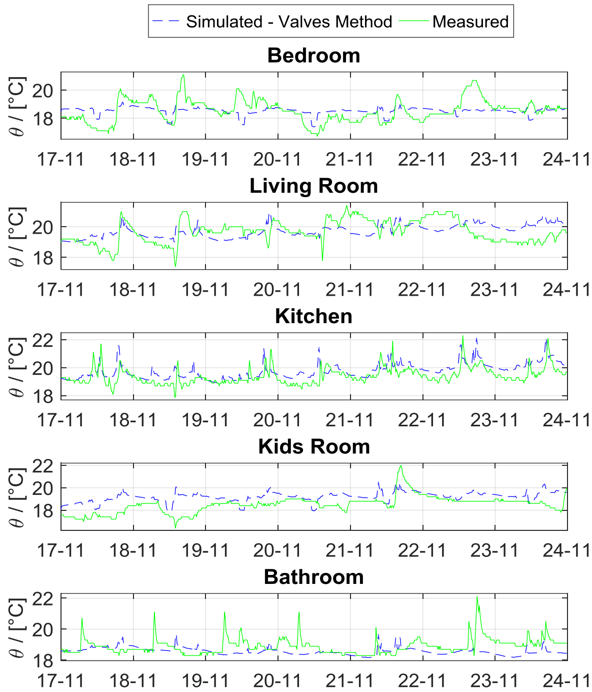


Figure 11: Comparison between simulated and measured temperature; valves method; validation week of November

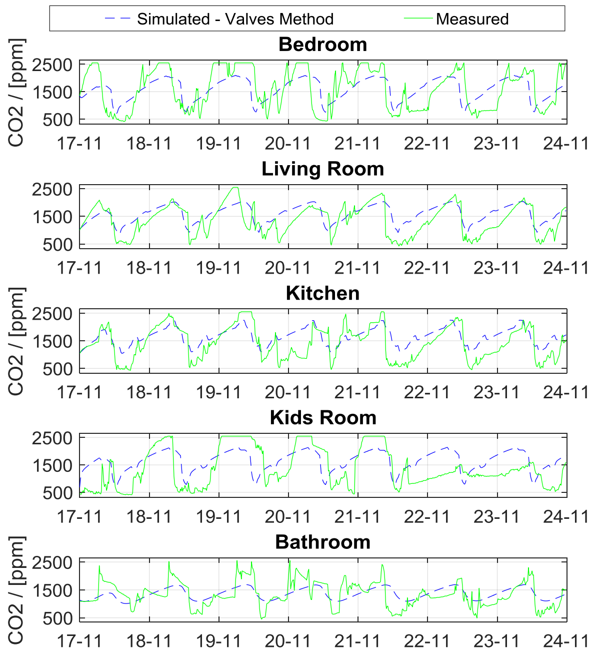
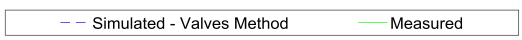


Figure 12: Comparison between simulated and measured CO2 level; valves method; validation week of November



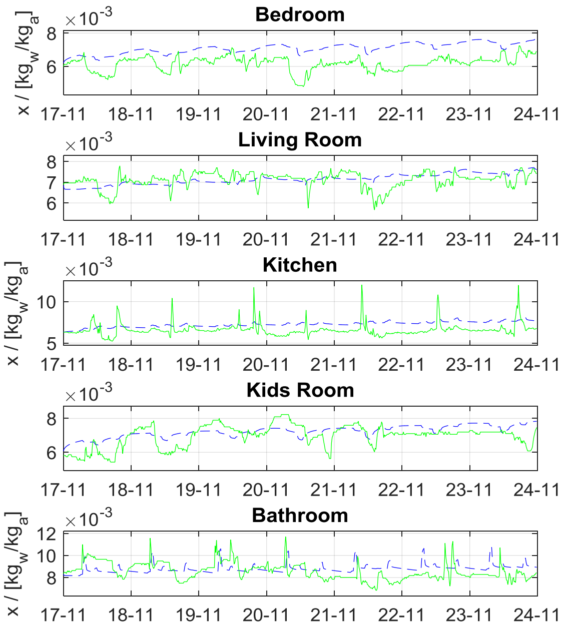


Figure 13: Comparison between simulated and measured Absolute Humidity; valves method; validation week of November

Comparison of the 6-zone model of the building and the 6-zone model of the flat

The comparison between the 6-zone model of the building and the 6-zone model of the ground floor flat presents the results of two different effects: the difference in the zoning and the difference in the model type. The flat model is a two star model, while the whole building model is an one star model.

Figure 14 shows the comparison between the temperature of the ground floor flat for the calibration week simulated: a) with the 6-zone model of the building and b) with the 6-zone model of the flat. The average temperature for the 6-zone model of the flat is calculated as a weighted average considering only the rooms where the sensors are located. It can be shown that the model of the flat can follow better the trend of the temperatures and that the model of the building reacts not so fast.

Table 8 shows the annual heating demand calculated using the two models (in case of the whole building model the first floor was unheated as it was in reality). With the model of the flat two cases are presented: one considering the opening of the window and the other with no window opening. The annual heating demand for the case with window opening is higher than the result given by the whole building model. This is reasonable because the flat model allows considering the different position of the rooms (i.e. the overheating by the sun).

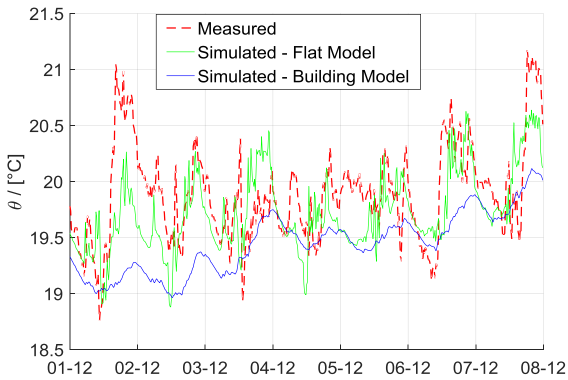


Figure 14: Comparison of the ground floor temperature between the 6-zone model of the flat and the 5-zone model of the building in the validation week of the 6-zone model of the flat

Table 8: Annual heating demand for the 6-zone model of the flat and of the whole building (with first floor unheated)

Zones	6 zone model building	6 zone model flat w\ window opening	6 zone model flat with window opening
	kWh/(m²·a)	kWh/(m²·a)	kWh/(m²·a)
Basement	294.59	-	-
Ground floor	34.36	30.80	33.65
First floor	0.00	-	-
Attic	96.21	-	-
Total	55.63	-	-

Conclusions

Different simulation building models are developed for a demonstration multi-family house before it is deeply energy renovated. The whole building is modelled as 1-zone model with PHPP and as 1- and 6-zone model with Matlab/Simulink. In addition, a 6-zone model of the ground floor flat is developed in Matlab/Simulink. The demonstration building is monitored and these data are used to calibrate and validate the models. The calibrated models are further used to predict the heating demand in standard conditions i.e. standard climate (not from specific year) and internal gains profile.

Normalized results differ significantly from the measured heating demand mainly because of climate and user behaviour (i.e. av. ventilation rate and choice of set point temperature). Multi-zone models give better accuracy but only if sufficient information for each zone (such as occupation, set point temperature) is available. Otherwise, the calibration is more time consuming and might even lead to wrong conclusions due to incorrect assumptions. The set point temperature has significant influence on the results. A one zone monthly calculation can be used with good accuracy with either a calibrated zone temperature or a calibrated reduction factor to the unheated zones.. A good agreement between the PHPP predictions and the monitoring results/oil consumption form 2014/2015 is obtained with an average set point of 19 °C (average of heated and unheated zones).

Depending on the availability of the measured data and specific conditions on site such as occupation profile and user behaviour, different calibration strategies must be used to obtain simulation models for good predictions.

Outlook: Renovation of the Building

The building is renovated during the winter 2015/2016. The monitoring system is enhanced with additional electricity and heat meters. The heating season of 2016/2017 is going to be also monitored. The energy performance of the building as well as the better comfort and indoor air quality will be analysed and compared with these before the renovation.

Acknowledgement

iNSPiRe, title: Development of Systematic Packages for Deep Energy Renovation of Residential and Tertiary Buildings including Envelope and Systems, http://www.inspirefp7.eu/, 2016. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement No 314461. All information in this document is provided "as is" and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and liability. For the avoidance of all doubts, the European Commission has no liability in respect of this document, which is merely representing the authors' view.

References

Ochs F., Siegele D., Ksiezyk A., Leonardi E. and Dermentzis G., (2016), "D5.6. Report on Data Reduction Procedure for Systems Monitored in Real Conditions, Case study Ludwigsburg" iNSPiRe, 9/2016.

Hafner B, "CARNOT 5.3," 2012

IEA SHC Task 44 Solar and heat pump systems (http://task44.iea-shc.org/)

iNSPiRe, Proposal number: 314461, title: Development of Systematic Packages for Deep Energy Renovation of Residential and Tertiary Buildings including Envelope and Systems, http://www.inspirefp7.eu/, 2016.

iNSPiRe D2.2, Report on Auditing Tool for assessment of building needs http://www.inspirefp7.eu/, 2016.

iNSPiRe D7.1, Reports on Energy Audits: Case study Ludwigsburg, Case study Madrid, Case study Verona. http://www.inspirefp7.eu/, 2016.

Leonardi E., (2015). Micro-Heat Pump for a Renovated Multi Family House – Simulation Based Analysis of the Performance and Thermal Comfort. Master Thesis.

Matlab Simulink, Mathworks, 2013a. https://www.mathworks.com/products/simulink.html (2014)

MathWorks. (2016). lsqnonlin. Mathworks: http://it.mathworks.com/help/optim/ug/lsqnonlin.html

MathWorks. (2016). fminsearch. Mathworks: http://it.mathworks.com/help/optim/ug/fminsearch.html

Meteonorm 6.1.0.20, Global meteorological database for engineers, planners and education, Meteotest, Bern, Switzerland, 2009

Passive House Planning Package (PHPP), Passive House Institute (PHI),: http://passiv.de/en/04_phpp/04_phpp.htm.

Rojas, G., Spörk-Dür, M., Venus, D., Greml, A., Krissmer, L., & Pfluger, R. (2015). *Lüften und Heizen in Passivhäuser in Österreich.* Innsbruck: STADT der Zukunft.