ENERGY EFFICIENT RENOVATION OF HERITAGE RESIDENTIAL BUILDINGS USING MODELICA SIMULATIONS

Van Kenhove Elisa[1], Aertgeerts Arnout[2], Laverge Jelle[1], Janssens Arnold[1]
[1]Research group Building Physics, Construction and Climate Control, Department of Architecture and Urban Planning, Ghent University, Belgium
[2]Research group Simulation of Thermal Systems, Department of Mechanical Engineering, KULeuven, Belgium

ABSTRACT

Historic homesteads can be found on a large scale in Europe and particularly in Flanders. In Flanders there are hundreds of homesteads in desperate need of renovation. Within the framework of the Europe 2020 objectives both CO_2 emission and energy use need to be reduced with 20% by 2020. Unlike for the average residential building renovation, focus lies on synergy between respect to heritage and achieving an optimal energetic effectiveness. The object of this research is a case study homestead in Bruges, named the Schipjes.

The first step in energy efficient renovation is to lower energy use by optimizing the building physics, therefore dynamic simulations in Modelica are performed to evaluate primary energy demand, especially for heating, and thermal comfort.

The second step is the choice of the most energy efficient technical installations for a district heating system as will be used for Schipjes. Five different scenarios or combinations of heat production and distribution systems are developed as input options for future research simulations and energetic equations in Modelica.

INTRODUCTION

Context

The simulations done in this study are part of the IWT Proeftuin experimental fieldproject ‘residential building renovation: innovation in energy efficient renovations’. The purpose of the Proeftuin is to stimulate scalable and reproducible renovation concepts in order to obtain affordable solutions. Research is being carried out on the basis of real renovation projects, of which the Schipjes in Bruges is one. The Universities of Ghent and Louvain are working on this project with the owner and developer of social housing (OCMW Bruges & De Schakelaar), Studiebureau Boydens and producers (Viessmann-Belgium & Microtherm).

The project the Schipjes in Bruges aims to stimulate energy optimization in renovation of historic homesteads [*Figure 1*]. This building typology can be found on a large scale in Flanders and in Europe. In Flanders there are hundreds of homesteads in desperate need of renovation. Within the framework of the objectives of Europe 2020 both CO_2 emission and energy use need to be reduced with 20% by 2020. The historic building segment is in need of innovative and progressive thinking. Unlike for the average residential building renovation, focus lies on synergy between respect to heritage and achieving an optimal energetic effectiveness.

Figure 1 Historic homestead in Bruges: the Schipjes

Objectives - 1/ primary energy demand -35% by improved building physics (object of this paper)

The renovation case study homestead consists of 11 quasi identical residential buildings in the historic city center of Bruges.

The building renovation consist of optimizing the building shell by insulating the houses, improving the air tightness and implementing ventilation solutions to allow low temperature heating using radiators combined with floor heating. The building physics solutions should be performed respecting the heritage value and should result in at least 35% decrease in energy demand.

Objectives - 2/ energy efficient technical installations (future research)

The heat production of the homestead will be collective in the future by implementing a district heating network. Energy efficiency scenarios for future research will lead to the right choice of technical installations to be used.

Challenges for the Schipjes homestead

The Schipjes homestead was built in 1902 and the most recent renovation was performed in the nineties. As to building shell there is no floor or wall insulation present, only the roof has an insulation package of 80mm. Insulating the buildings is a challenge because the in and outside of the building are protected by monument care and there are no cavity walls. The windows are equipped with single glazing, replacing them by traditional double glazing is not an option because of the monument protection.

As to technical installations the current heating system consists of a hearth on gas in the living room and the other rooms are heated by radiators attached to the hearth. The efficiency of these appliances is below 80%. Domestic hot water (DHW) is produced by an electrical boiler. As a consequence the buildings have quite a bad energetic score.

Methodologies for energy efficient renovations

The energetic renovation consists of two major parts: 1/ the optimization of the building physics to lower the energy demand and 2/ the selection of energy efficient technical installations (heat and DHW production and distribution units, ventilation system).

Methodologies - 1/ building physics optimization to lower energy demand by 35%

The building shell is optimized by insulating the walls and floor. The base of the floor is a reinforced concrete slab, making it impossible to lower the floor in order to add a large insulation package. Leveling up the floor is not an option either since this has the effect that the interior doors must be cut at the bottom. Research is performed on thin insulation materials with a low lambda value, resulting in the use of vacuum insulation panels (VIP). These are high performance microporous insulation panels covered in an impermeable outer envelope which is heat sealed under vacuum to optimize the thermal performance. The vacuum within the insulations ensures that the panels have a very low thermal conductivity (Promat, 2013). Because of this very low thermal conductivity, vacuum insulation panels are the ideal insulation when optimal performance is necessary in minimal space such as is the case here, even though the panels are expensive and the execution must be done carefully to avoid leakages in the outer envelope. 35mm of vacuum insulation panels equals 125mm PUR or 190mm mineral wool. The comparison of VIP with different insulation materials can be seen in *Figure 2*. The floor will be insulated by 20mm vacuum insulation panels with a lambda value of 0.009W/mK to lower the U-value from 2.87W/m²K to 0.39W/m²K.

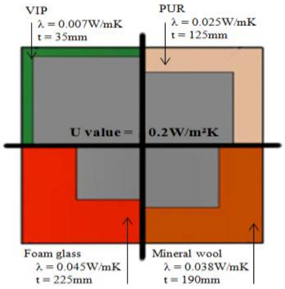

Figure 2 Comparison of VIP with different insulation materials

The walls are single brick walls with a total thickness of 268mm. As mentioned before the out and inside of the buildings are protected, this means that the appearance of both sides cannot be changed. These boundary conditions imply an innovative interior insulation solution. The insulation study started by analyzing the area of the different rooms. The interior building surface requirements are based on the demands of the VMSW (VMSW, 2008). In *Table 1* the requirements for the case study building are stated. The results of an interior surface analysis by varying the insulation package is shown in *Table 2*. The demands of the VMSW are not reached in the living room en bedroom for the current situation without insulation. In Schipjes the VMSW demands are not binding but they give a good estimation of acceptable surfaces. The study proves that implementing a traditional material insulation package of 170mm lowers the internal building surface by 14% (from 48.33m² to 41.83m²), this would totally change the dimensions of the rooms which is not an option for these small heritage buildings.

Table 1 Interior building area requirements

	Interior area requirements	
Rooms	VMSW demands [m²]	Schipjes [m²]
Living room	≥ 20m²+2m²/person	≥ 22
Kitchen	≥ 4m²+0.5m²/person	≥ 4.5
Toilet	≥ 1.17m²	≥ 1.17
Bedroom	≥ 12m²	≥ 12
Bathroom	≥ 3m²+0.5m²/person	≥ 3.5
Hall	≤ 10% of total area	≤ 4.83
Total area		48

Table 2 Interior building size with different insulation packages

Rooms	Schipjes 0mm [m²]	Traditional insulation 170mm [m²]	VIP 20mm [m²]
Living room	21.73	19.54	21.42
Kitchen	7.32	6.29	7.07
Toilet	1.65	1.09	1.58
Bedroom	10.79	9.43	10.51
Bathroom	3.61	2.92	3.49
Hall	3.23	2.56	3.12
Total area	48.33	41.83	47.20

Innovative interior insulation options are investigated. One of the boundary conditions for these heritage buildings is that the rooms could not be reduced by more than 20mm on each side. The challenge was to find an insulation material with a low lambda value which is applicable in this situation. Due to the heritage value the indoor walls could not be thermically interrupted to permit a continuous insulation layer, this means that the insulation must also be applied on the first meter of the indoor walls where they meet the outer walls. The solution that will be applied is a 15mm insulating aerogel plaster. It achieves a thermal conductivity of 0.028W/mK, which is two to three times better than conventional insulating plasters. Lightweight aerogel granulate is the primary additive used in this high-performance lime-based insulating plaster. Thanks to its outstanding properties aerogel insulating plaster is ideal both for use in the renovation of old buildings to modern energy standards, as well as for thermal insulation of historic buildings and structures.

Permeability to water vapour is absolutely guaranteed, thereby practically excluding the possibility of surface condensation or mould growth (Fixit, 2013). The plaster is equally suitable for in and outdoor use, here it will be sprayed on the inside of the outer walls to lower the U-value from 3.33W/m²K to at least 1.5W/m²K. According to the Belgian norms the risk of surface condensation is small when the walls have a temperature factor f larger than 0.7 (EQUATION 1), in this case it is equivalent with a U-value lower than 1.5W/m²K for the brick walls.

$$f = (\theta_{si}-\theta_e)/(\theta_i-\theta_e) \geq 0,7 \qquad (1)$$

A U-value of 1.5W/m²K corresponds to an insulation thickness of 11mm [*Table 3*].

Table 3 Calculation of the U-value of the outer wall with an insulation layer thickness of 11mm

Outer wall	t [m]	λ [W/mK]	R [m²K/W]
i			0.130
Aerogel plaster	**0.011**	0.028	0.393
Brick	0.268	1.323	0.130
e			0.040
U [W/m²K]			**1.443**

The maximum layer thickness of 20mm corresponds to a U-value of 0.99W/m²K [*Table 4*].

Table 4 Calculation of the U-value of the outer wall with an insulation thickness of 20mm

Outer wall	t [m]	λ [W/mK]	R [m²K/W]
i			0.130
Aerogel plaster	**0.020**	0.028	0.714
Brick	0.268	1.323	0.130
e			0.040
U [W/m²K]	0.288		**0.986**

Additionally the air tightness needs to be improved. A blowerdoor test was conducted and resulted in an average n_{50}-value of 10.44/h (v_{50} depressure 1363m³/h, v_{50} overpressure 1402m³/h) [*Figure 3*].

Figure 3 Blowerdoor test to measure the air tightness

Thermographic tests showed that the biggest leakages were caused by the openings around the window frames and front door [Figure 4].

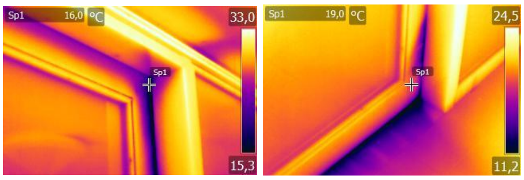

Figure 4 Result of thermographic test: leakages around the window frames

The aim is to lower the n_{50} air tightness value to 1/h by replacing the windows and the front door.

Ventilation system A will be replaced by a mechanical ventilation system D with highly efficient heat recovery.

The windows are equipped with single glazing, due to the monumental value it is not allowed to change them by standard double glazing. The windows will be replaced by ultra thin double glazing (3/3/4) with Krypton cavity filling with an U-value of 2W/m²K.

Building structure optimization is hence reached by using 20mm VIP insulation on floor, 15 mm insulating aerogel plaster on the inside of the outer walls in addition to the existing 80mm roof insulation, optimizing airtightness, implementing ventilation system D and double glazing.

Methodologies - 2/ selection of energy efficient technical installations (production and distribution units of heating and DHW): 5 scenarios

The aim is to implement a district heating system for the Schipjes. Different options for heat production are investigated:

- Boiler on fossil fuels (natural gas, fuel oil)
- Pellet boiler (biomass)
- CHP (combined heat and power)
- Air to water heat pump (HP)
- Geothermal HP
- Air to water gas absorption HP
- Geothermal gas absorption HP
- Solar collectors

Furthermore three different heat distribution systems have been examined:

- High temperature network (HT)
- Low temperature network (LT)
- Intermittent network

From these heat production and distribution options five scenarios or combinations are retained which will be simulated in Modelica.

The pellet boiler (biomass) looked promising but was ultimately eliminated as generator due to the production of particulate matter and the problem of supply and storage of pellets, these disadvantages should not be minimized in the center of Bruges.

Scenario 1 - HT network with condensing gas boiler + solar collectors + central storage + decentralized DHW module.

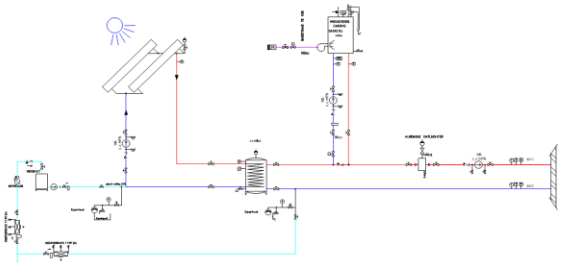

Figure 5 Scenario 1 - high temperature network

Scenario 1 is a reference scenario. The central heat buffer is charged by solar collectors. In case the depart temperature is not high enough, the gas boiler will heat the water additionally until the desired depart temperature is reached. The boiler is therefore in series with the buffer tank [*Figure 5*].

DHW and central heating water is prepared with a decentralized module in each house. This happens with two separate heat exchangers (one for the production of DHW and one for heating) within the same local module, because there is no local buffer for DHW. The production of DHW happens instantaneously [*Figure 6*].

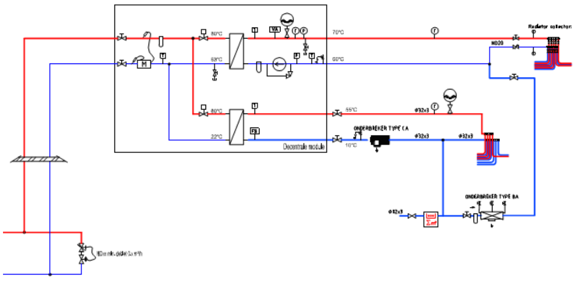

Figure 6 Scenario 1 - decentralized DHW module

Scenario 2 - HT network + CHP + gas boiler + local storage.

In the long term, CHP is less suitable to feed a district heat network because district heat networks of the fourth generation are working on very low temperatures (<50°C). There is a temperature difference between the CHP output and the low temperature or intermittent network, since the targeted number of working hours cannot be realized and the CHP therefore cannot be profitable.

Scenario 3 - In scenario 3 an intermittent network with air/water heat pump + gas boiler + decentralized heating buffer is investigated [*Figure 7*].

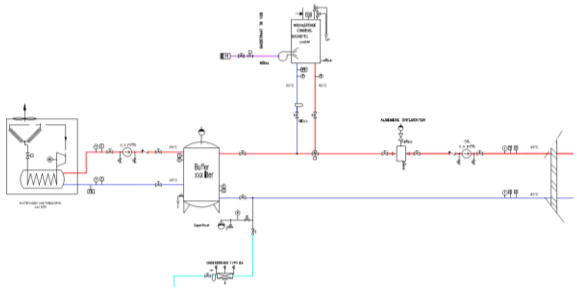

Figure 7 Scenario 3 - intermittent network

Scenario 4 - Intermittent network with borehole energy storage field + heat pump + gas boiler + decentralized heating buffer [*Figure 8*].

Two reservations can be made about a borehole energy storage field: one has to take into account the regeneration of the ground and question whether it is possible to carry out drillings in a homestead.

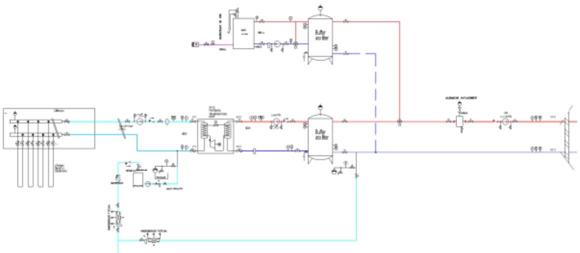

Figure 8 Scenario 4 - intermittent network

Scenario 5 - LT network with borehole energy storage field + heat pump + gas boiler + booster heat pump DHW [*Figure 9*].

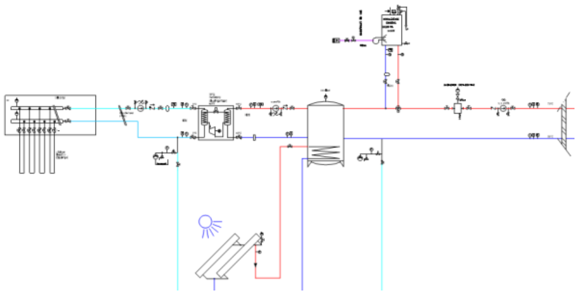

Figure 9 Scenario 5 - low temperature network

Scenario 5 consists of a booster heat pump for the production of DHW. The decentralized heat buffer is in parallel with the booster heat pump. In the buffer there is a heat exchanger located for the instantaneous production of DHW [*Figure 10*].

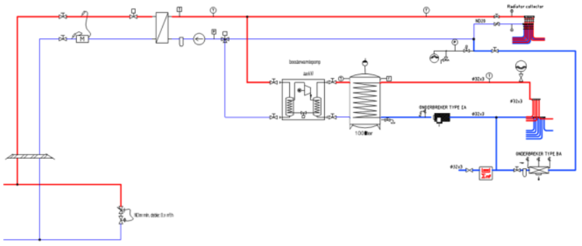

Figure 10 Scenario 5 - booster heat pump DHW + buffer

The energetic equation of the five different scenarios in Modelica should lead to the choice of technical installations. The results of this study are outside the scope of this paper.

SIMULATION

Simulation environment Modelica

To compile the simulation model, the 'Modelica' (URL: http://www.modelica.org) dynamic simulation environment will be used. This equation based programming language is non-proprietary and object oriented, making it extremely appropriate for the development of multi-scale models such as required here (Wetter et al., 2006). Extensive libraries for the simulation of buildings and their services have recently been developed in IEA EBC annex 60 (Wetter et al., 2013).

Simulation model 1 - house model with 5 submodels

Two simulation models have been developed. Model 1 elaborates on one of the 11 houses. The model is a combination of five submodels: ‘structure’, ‘heating system’, ‘ventilation system’, ‘occupancy’ and ‘electricity network’ [*Figure 11*].

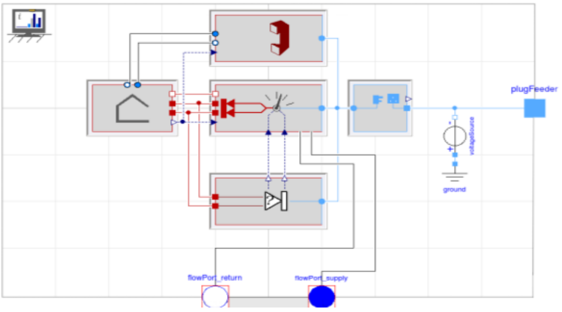

Figure 11 Simulation model 1 - modeling of 1 house: combination of submodels

The two major submodels for the study objective, ‘structure’ and ‘heating system’, are treated below.

Model 1 - Simulation submodel ‘structure’

First model 1 (one representative house) is elaborated, submodel ‘structure’ being the main share. Each ‘structure’ submodel is constructed as a multi-zone unit of six zones: living room, kitchen, toilet, bedroom, bathroom and hall [*Figure 12*].

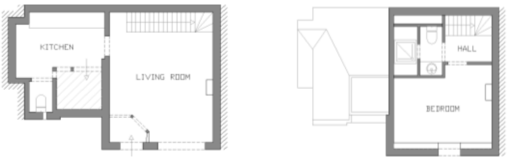

Figure 12 Floor plan 0 and +1

Next to the number of zones, submodel ‘structure’ includes building shell parameters such as: surface and volume of zones, material characteristics of the walls, floor and roof (λ [W/mK], U-value [W/m²K], c [J/kgK], ρ [kg/m³]), parameters of the windows (U_g [W/m²K], U_f [W/m²K], φ) and n_{50} values [*Figure 13*].

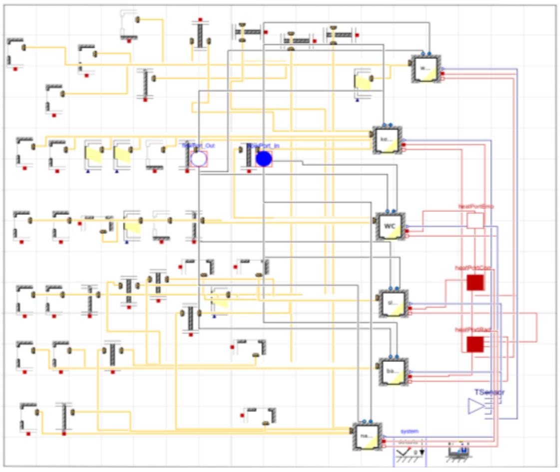

Figure 13 Submodel ‘structure’: modeling of the zones, walls, floor and roof

Model 1 - Simulation submodel ‘heating system’

A detailed dynamic simulation model of the heating system is performed [*Figure 14*]. The model is varied into six models (current state and the five scenarios elaborated above under methodology) of all 11 houses with district heating system, using different heat production units, storage units and control system. Modelling of the production units is refined with the correctly dimensioned power outputs and real performance curves.

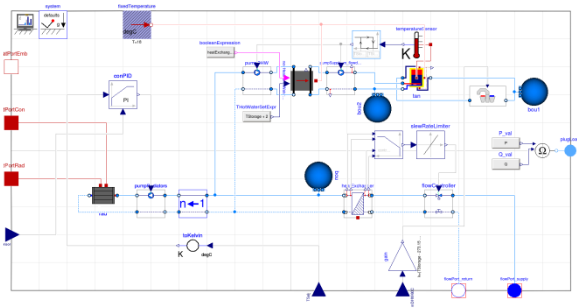

Figure 14 Submodel ‘heating system’

The simulation results to compare the energy efficiency of the five technical scenarios are not included in this paper, they are the object of future research. In this paper the focus lies on building physics optimization and comparison of energy demand before and after renovation without changing the heating system.

Simulation model 2 - homestead model

Afterwards model 1, incl. its submodels, is extended to a second homestead model in which all 11 houses are connected through pipelines [*Figure 15*]. The building spatial configurations of all 11 houses are equal, only the orientations are not. The orientations are adapted in the submodel ‘structure’ for each house separately.

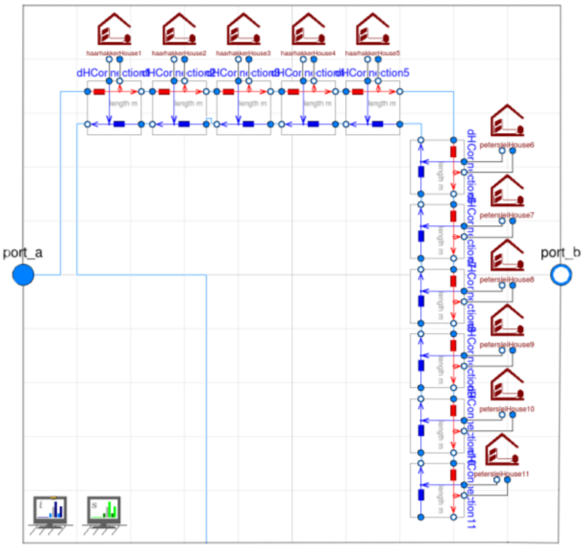

Figure 15 Simulation model 2 - modeling of homestead of 11 houses connected through pipelines

Model 2 - Two variations: current and optimized homestead

Two variations on simulation model 2 are developed (without changing the technical installations).

The first is the current situation without floor or wall insulation, thin package of roof insulation, single glazing, bad air tightness and ventilation system A.

The second variation of simulation model 2 represents the energetically optimized building with floor, wall and roof insulation, double glazing, optimized air tightness and a mechanical ventilation system D with heat recovery. The building physical solutions should result in at least 35% decrease in energy demand.

Validation

The validation of simulation models 1 and 2 (with current heating system) is based on measurements and calculations according to ASHRAE Guideline 14 (hourly calibration data: MBE < 10%, C_v(RMSE) < 30%) (ASHRAE, 2002).

$$MBE\ [\%] = \frac{\sum_{period}(Sim.-Meas.)_{interval}}{\sum_{period} Meas._{interval}} * 100 \qquad (2)$$

$$C_v(RMSE)[\%] = \frac{\sqrt{\frac{\sum_{period}(Sim.-Meas.)^2_{interval}}{N_{interval}}}}{\frac{\sum_{period} Meas._{interval}}{N_{interval}}} * 10 \qquad (3)$$

The model of the current situation before renovation is validated based on temperature measurements in all buildings, analysis of the energy use by comparing the invoices and a coheating test in one building (Delghust et al., 2012). The second, energetically optimized, building model is validated based on heat loss calculations (transmission, ventilation and infiltration losses) for the different rooms.

DISCUSSION AND RESULT ANALYSIS

Primary energy demand (-65%) - calculations before and after renovation

Heat loss calculations are performed to determine the transmission, ventilation and infiltration heat loss for each zone [*Table 5*]. The calculations are conducted according to standard NBN 62-003 with an outside temperature of -8°C for the city of Bruges, this is the average outside temperature which is exceeded only one day a year in general (NBN B 62-003, 1986).

Table 5 Building model before renovation - heat loss calculation

HEAT LOSS	Φtrans [W]	Φvent [W]	Φinf [W]	Φn [W]
Living room	3047	685	1045	**4910**
Kitchen	1120	0	255	**1400**
Toilet	73	53	0	**127**
Bedroom	2307	238	360	**2962**
Bathroom	1047	0	121	**1168**
Hall	249	0	100	**349**
Σ	7843	976	1881	**10916**

The building envelope will be optimized by adding insulation on the outer walls and in the floor. An aerogel plaster layer of 15mm will be applied on the inside of the outer walls, since the outside is protected and cannot be changed. Vacuum insulation panels of 20mm will be placed underneath the floor decking. Single glass will be replaced by double glass. The air tightness will be improved from a n_{50}-value of 10/h to a n_{50}-value of 1/h by replacing the windows and front door. Ventilation system D with heat recovery will be implemented. According to the heat loss calculations [*Table 6*] the combination of these measures lowers the total normalized heat demand with 65% (=1-(3855/10916)).

Table 6 Energetically optimized building model after renovation - heat loss calculation

HEAT LOSS	Φtrans [W]	Φvent [W]	Φinf [W]	Φn [W]
Living room	1335	28	100	**1503**
Kitchen	632	0	24	**668**
Toilet	43	5	0	**49**
Bedroom	973	10	35	**1037**
Bathroom	519	0	12	**531**
Hall	57	0	10	**67**
Σ	3559	43	181	**3855**

Primary energy demand (-58%) - simulations before and after renovation

Simulations have been carried out for the current situation before renovation [*Figure 16*] and the energetically optimized building model after renovation [*Figure 17*]. The primary energy demand from these simulations is compared with the results of the calculations. In the simulations the average outside temperature of the past ten year is used in contrast to the -8°C used in the calculations. This means that the energy demand will be at least a factor two lower in the simulations.

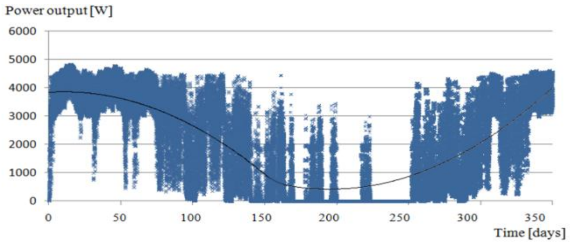

Figure 16 Building model before renovation - simulation of yearly energy demand

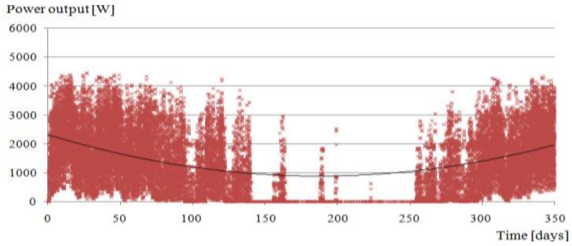

Figure 17 Energetically optimized building model - simulation of yearly energy demand

In simulations the cumulative sum of the yearly heat demand after renovation is 42% of the cumulative sum of the yearly heat demand before renovation, this results in a 58% decrease in energy demand, which has the same magnitude as the heat loss calculations [*Figure 18*]. The premise was that the building physics solutions of the optimized building model should result in at lease a 35% decrease in energy demand, this requirement is abundantly achieved according to the calculations and simulations.

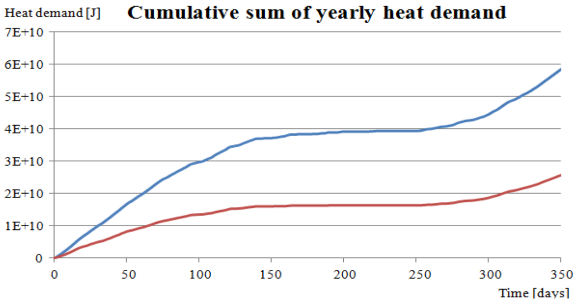

Figure 18 Simulation of the cumulated sum of yearly heat demand. Comparison between building model before renovation and energetically optimized building model

Adaptive thermal comfort (ATC) - calculations

Decreasing the energy demand without guaranteeing or even improving the thermal comfort makes no sense. Measurements were carried out in eight houses to determine the winter comfort, the remaining three houses were not inhabited during that period of time. The following graphs show the weekly average temperature for the living rooms [*Figure 19*] and bedrooms [*Figure 20*] from 15 November 2014 till 16 January 2015. The average weekly temperature reached in the living room is 19,7°C.

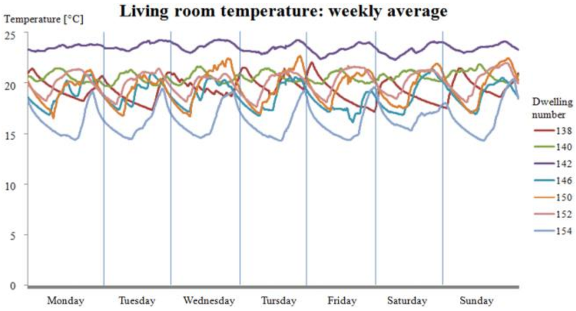

Figure 19 Weekly average temperature of living rooms obtained through measurements

The average weekly temperature reached in the bedroom is 16,3°C. For both rooms this is below the comfort temperature of 21°C in winter. It can be deducted from the measurements that the current heating system is not well dimensioned, especially for the bedroom.

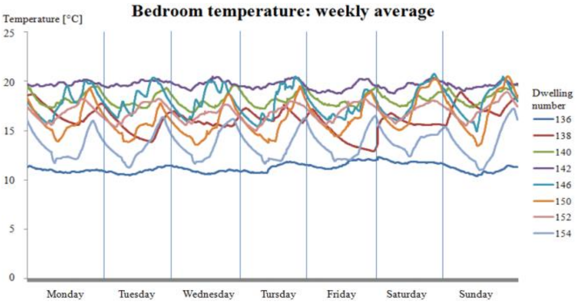

Figure 20 Weekly average temperature of bedrooms obtained through measurements

The ATC model shows that for the bedrooms of houses 136, 138, 152 and 154 all measured temperatures are beyond the 65%-comfort range. For houses 140 and 150 only 1.61% of the temperatures lays within the 65%-comfort zone, houses 142 and 146 have respectively 33.87% and 4.84% of the temperatures within the 90% comfort zone [*Figure 21, Table 7*].

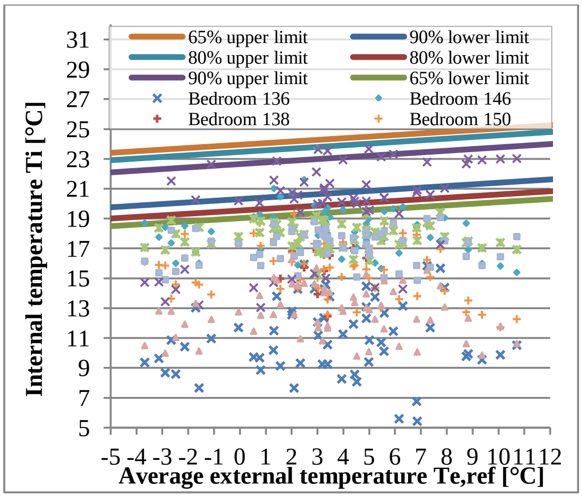

Figure 21 Measurement before renovation - adaptive thermal winter comfort of the bedrooms

Table 7 Measurement before renovation - adaptive thermal winter comfort of the bedrooms

ATC	136	138	140	142	146	150	152	154
Temperatures within the 90% comfort zone [%]	0.00	0.00	0.00	33.87	4.84	0.00	0.00	0.00
Temperatures within the 80% comfort zone [%]	0.00	0.00	0.00	67.74	9.68	0.00	0.00	0.00
Temperatures within the 65% comfort zone [%]	0.00	0.00	1.61	72.58	20.97	1.61	0.00	0.00

The ATC model shows that for the living room of house 154 all measured temperatures lay beyond the 65%-comfort range. For house 138 only 1.61% of the temperatures lays within the 80%-comfort zone, houses 140, 142, 146, 150 and 152 have respectively 59.68%, 17.74%, 9.68%, 16.13% and 64.52% of the temperatures within the 90% comfort zone [*Figure 22, Table 8*].

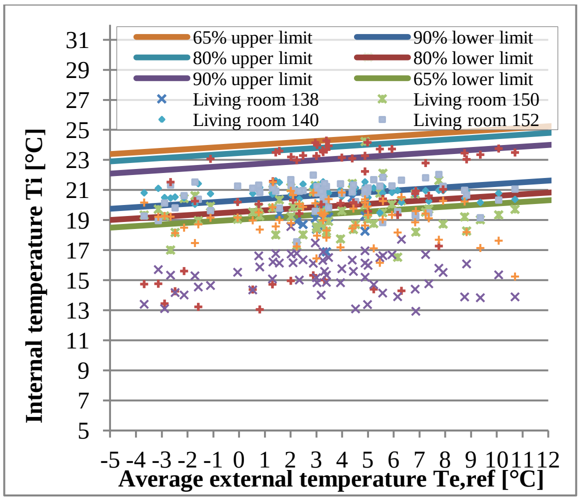

Figure 22 Measurement before renovation - adaptive thermal winter comfort of the living rooms

Table 8 Measurement before renovation - adaptive thermal winter comfort of the living rooms

ATC	138	140	142	146	150	152	154
Temperatures within the 90% comfort zone [%]	0.00	59.68	17.74	9.68	16.13	64.52	0.00
Temperatures within the 80% comfort zone [%]	1.61	88.71	61.29	27.42	37.10	82.26	0.00
Temperatures within the 65% comfort zone [%]	3.23	98.39	74.19	43.55	53.23	88.71	0.00

Adaptive thermal comfort (ATC) - simulations

To determine the thermal winter comfort before renovation, temperature measurements were performed. The results of the measurements were used to make the simulation model more accurate and to validate.

The ATC model shows that according to the simulation model 37.10% of the average living room temperatures lays within the 80%-comfort zone. Moreover 27.42% of the average bedroom temperatures lays within the 80%-comfort zone [*Figure 23*, *Table 9*]. In the simulation model the bedroom temperatures are also lower than the living room temperatures, this is similar to the performed measurements. The simulation results are not exactly equal to the results of the measurements, this can be explained by the large influence of user behavior which is not caught in detail in the simulations in which an average user profile is used (Delghust et al., 2012).

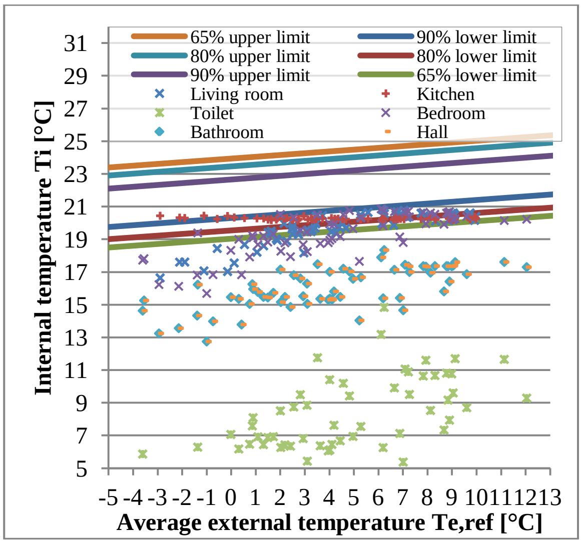

Figure 23 Simulation of the situation before renovation - ATC

Table 9 Simulation of the situation before renovation - ATC

ATC	Living room	Bedroom
Temperatures within the 90% comfort zone [%]	0.00	0.00
Temperatures within the 80% comfort zone [%]	37.10	27.42
Temperatures within the 65% comfort zone [%]	67.74	50.00

CONCLUSION

Summary

The aim of this study is to achieve an energy efficient renovation of a heritage residential homestead, namely the Schipjes in Bruges. Calculations and simulations prove that it is possible to lower the primary energy demand beyond the set target of 35% by optimizing the building shell whilst respecting the heritage value. According to the calculations and simulations the goal is outreached, with a decrease in energy demand by respectively 65 and 58% whilst obtaining an optimal thermal winter comfort.

Limitations and directions for future research

In this paper the focus lies on building shell optimization. The results of the proposed simulations on energy efficiency of the district heating system with comparison of the different production units, different storage units and different control systems will be the area for future research.

NOMENCLATURE

f = temperature factor

$\theta_{si} / \theta_e / \theta_i$ = surface / outside / inside temperature

ACKNOWLEDGEMENTS

This research is founded by the Agency for Innovation by Science and Technology-Belgium (IWT), Project 140125. The authors thank the partners of the Proeftuin R&D building projects.

REFERENCES

ASHRAE Guideline 14. 2002. Measurement of energy and demand savings. Atlanta, USA.

Delghust, M., Laverge J. et al. 2012. The influence of user behaviour on energy use in old dwellings: case-study analysis of a social housing neighbourhood, proceedings, UGent, Belgium.

Delghust, M., Laverge, J. et al. 2012. Analysing energy use in residential neighbourhoods, proceedings, UGent, Belgium.

Fixit. 2013. Aerogel insulating plaster system - handling guidelines, Switzerland.

NBN B 62-003. 1986. Berekening van de warmteverliezen van gebouwen, Belgian Standard, Brussels, Belgium.

Promat. 2013. Slimvac Vacuum Insulation Panels, Belgium. URL: www.microthermgroup.com, last visited and updated on 08/05/2015.

VMSW. 2008. C2008, leidraad voor bouwheren en ontwerpers van sociale woningen, Belgium.

Wetter, M., Haugstetter, C. 2006. Modelica versus Trnsys - a comparison between an equation-based and a procedural modeling language for building energy simulation, proceedings, UTRC, USA.

Wetter, M., van Treeck, C. et al. 2013. IEA EBC annex 60 New generation computational tools for building and community energy systems, USA and the Netherlands.