Optimization of the airtightness and the flow rate of air in nearly zero energy buildings

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ABSTRACT

The control of heat losses, inwards/out, in nearly zero energy buildings is of high importance. The transmission losses through the building envelope are easily reduced using larger amounts of insulation. Calculation of the impact of this action on the total energy demand of the building, is quite standard. It's however much more difficult to determine the efficiency of actions to increase the airtightness of the building and the influence of the ventilation system. A valid model for these calculations is important, as the calculation of intelligent ventilation systems is much more complex due to constant air flow rate changes, which depend on the occupancy. The flow rates fall back to the hygienic minimum when no occupancy is detected, thereby reducing heat losses and lowering fan consumption. The investment cost for the ventilation system management however, increases. This paper focusses on the optimization of these two objectives using a case study.

As first result a cost optimal solution for the project is achieved, lowering the energy consumption and reducing the investment cost of the building, due to the adjustment of the ventilation parameters and the building parameters. As second result the cost optimization, combined with dynamic simulation, learns that no extreme airtightness is needed to achieve a nearly zero energy building.

KEYWORDS

Optimization, ventilation, airtightness, monitoring, dynamic simulation

1 INTRODUCTION

Since 2006 there's a lot to do about diminution of the emission of greenhouse gasses. The Energy Performance of Building Directive (EPBD), formalized its directive 2002/91/EC in 2003. In this directive the European commission imposes all member states to evaluate the energy performance of buildings in order to encourage the reduction of the energy consumption for heating, cooling, domestic hot water, lighting, ventilation and auxiliaries. Moreover, the directive specifies that the calculation should happen on basis of a methodology which may be differentiated at regional level. It is suggested that cost-optimal measures have to be taken to achieve levels of high energy performance in order to lower the energy consumption of buildings at minimal cost. Since the financial crisis of 2007-2008, not only the European Union is concerned about this topic, but countries all around the world make efforts to optimize their buildings for energy use, construction cost and occupant comfort. Bambrook (Bambrook et al., 2011) simulated a simple model for a detached house in Sydney with IDA-ICE and TRNSYS in order to determine construction solutions in which there is no energy need for heating and cooling. A multi-objective optimization has been done to minimize the energy consumption and the net present cost, which are conflicting objectives. By doing so, the heating and cooling demand in the studied house was reduced with 94% compared to the local BASIX requirements. However in Finland, Alanne (Alanne et al., 2007) was also confronted with the optimisation problem. A study has been conducted to select the appropriate energy supply system for residential buildings, using value tree analysis for multi-criteria decision problems. A common conclusion for both studies was that there are a lot of uncertainties that should be taken into account and that several contradictory objectives have to be evaluated simultaneously. Also Diakaki (Diakaki et al., 2008) in Greece and Magnier (Magnier et al., 2010) in Canada did research on multi-objective optimizations to improve the energy efficiency of buildings at the lowest possible cost with the help of genetic algorithms and dynamic building simulations. It seems however that the quest for a singular solution in multi-objective optimization problems is difficult to determine, since every model that has been made is simplified and a lot of iterative calculations have to be executed.

A lot of research has already been carried out by authors all over the world about the optimization of insulation measures in walls, floors and roofs. Daouas (Daouas et al., 2010) investigated the optimal thickness of the insulation for building walls in the Tunisian climate. Complex Finite Fourier Transform and life cycle cost analysis were joint together to compute the most profitable thickness of the insulation layer for which the sum of the energy cost due to air-conditioning and the insulation is minimised. The Complex Finite Fourier Transform is used by Ozel (Ozel et al., 2007) as well and several formulas were deduced to derive the optimum insulation thicknesses for walls with different layer structures, glazing areas, orientations and in different outdoor climate conditions (Özkan et al., 2011, Yu, 2009). Researchers in Spain (Perlova et al., 2015, Ruiz et al., 2014) also conducted several studies to determine the optimal orientation of a building and to optimize the concept design of zero energy buildings in general. In Finland as well viability studies and optimizations are carried out (Saari et al., 2012) in order to pinpoint the energy-efficiency of measures. At last in China (Huang et al., 2012), Genetic Algorithms and Pareto-analysis are used to optimize the indoor conditions of buildings. It's clear form this list that building optimization has recently become a frequently discussed topic.

It's however difficult to evaluate the optimality of airtightness measures in an optimization procedure, because the contribution of these measures is difficult to cypher. A lot of uncertainties need to be taken into account. In Belgium (Langmans et al., 2010, Van Den Bossche et al., 2012) and Norway (Relander et al., 2012) a lot of research has been done to conclude which interfaces and joints in the building envelope are most critical when it comes to airtightness. Databases were set up so building models can be expanded and airtightness can be evaluated as well. Mostly though, the authors conclude that the developed databases cannot be used without caution, because the sum of all leakages of all joints almost never corresponds with the measured value for v_{50} during pressurisation tests. On top of that, the way pressurisation tests are validated is prone to errors, uncertainties and criticism (Okuyama et al., 2012, Fernández-Agüera et al., 2011) and alternatives are tested (Hassan, 2013). It's of high interest to evaluate the airtightness on a correct way, so the taken measures can be evaluated properly and the simulation and evaluation models can be improved (Jokisalo et al., 2009, Nabinger et al., 2011, Montoya et al., 2010). In a lot of works, repetitive pressurization tests are performed to know the effect of taken measures. In this paper, the repetitive pressurization tests are conducted to know which level of airtightness has already been achieved and when to stop doing further interventions.

In buildings with a high energy performance, the losses due to leakages of air have to be restricted to a minimum. To support this strategy one of the most common solutions is to reduce the in- and outgoing airflow to the hygienically necessary ventilation rate. This implicates a control of the airflows by installation of a system for mechanical supply or exhaust or both. Furthermore, if the system is controlled by occupancy registration (CO_2, presence, humidity…), the losses of heat through air transport can be diminished further. Meanwhile it's important to ensure a good and healthy indoor climate (Laverge et al., 2011, Laverge et al., 2013, Cho et al., 2015, Turner et al., 2013, Sherman et al., 2011). The flow rates and the choice for the ventilation system need to be optimized in order to increase the energy performance of the building with a minor investment (Santos et al., 2012, Chineret al., 2014, Laverge et al., 2013).

This paper aims at explaining an optimisation method to balance the investment costs and energy savings for demand-driven ventilation systems and measures to improve the airtightness of buildings. First the general method for optimization of building parameters is explained and the way to decide which energy saving measure is the most cost-optimal is illustrated with an example. After exemplifying the general procedure, the derivative procedures for ventilation systems and air infiltration are clarified and an optimization between several ventilation systems can be achieved. Beside a cost optimal level for the infiltration flow rate v_{50} is determined. In the final chapter of this paper, a dynamic simulation with TRNSYS is carried out to demonstrate the importance of hour to hour simulation for demand-driven ventilation systems.

2 METHODOLOGY

When energy consumption in buildings needs to be reduced, it's common practice to rely on existing concepts, like Passive House, Trias Energetica, Geothermal Home… All these existing concepts have in common that they suggest to overdo some measures that can be taken to achieve better energy performances. Passive House for example is well known for the big amounts of insulation in walls, floors and roofs and for they high levels of airtightness of the building envelope in general. Triple glazed windows are often used and a ventilation system for mechanical supply and exhaust is in almost all cases indispensable to reach the Passive House requirements. Due to these steps to decrease the energy demand for heating and cooling, the generating systems can be rather limited in power. In the Geothermal Home concept on the other hand, the share of generating techniques for heating and cooling is much larger than the share of the passive measures discussed above. The author questions whether blind application of these building concepts answers the questions of cost optimality in every way and in every situation. Each building is different after all and each house, each office building, each utility building should be considered a whole, with respect for all measures that can be taken to intervene in the energy performance, passive or active.

In order to achieve optimal levels of insulation thickness, airtightness, glass-window profile combinations, ventilation systems and of course the generating systems, the objectives for the optimization need to be determined. Since it is important to lower the energy consumption and the investment cost of the building at the same time, these two objectives will be important during the optimization process. It is however difficult to designate the combination of building parameters which corresponds with the most energy efficient solution and the least expensive combination of parameters at the same time. Reducing the energy use and lowering the investment cost are opposing objectives and lowering one of them almost inevitably brings along an increase in the other. To solve this problem, the author appeals to common sense: *'If it is more expensive to invest in measures to lower the yearly energy consumption by 1 kilowatt-hour than to invest in the necessary generating techniques to yearly produce that 1 kilowatt-hour in a sustainable way, then the investor should choose to invest in the generating techniques. The opposite story is true as well.'* It is momentous though to complement the statement by explaining why the sustainable way of energy production is of that great importance. For this kind of optimization procedure, the investigators aspire the zero energy level. When attaining this level of energy efficiency, theoretically the resident will not have to pay any energy bill at the end of a year. Overproduction of electricity during summertime by photovoltaic systems will balance the higher energy needs during wintertime. Knowing this, no yearly energy consumption has to be taken into account and no yearly energy cost (predicted for the next 30 years) needs to be derived.

This results in the practicing ratio $\Delta IC_T/\Delta E$, which has to be computed for all possible measures. In the ratio ΔIC_T is the additional cost for the taken measure and ΔE is the additional energy saving, caused by the taken measure. The ratio $\Delta IC_T/\Delta E$ has to be as low as possible, since that means a large reduction of the energy consumption can be realised at a relatively low investment cost.

Table 1: Determining the most cost optimal solution from a list of energ saving measures for buildings.

Energy saving measure	**Additional energy saving after measure [kWh]**	**Additional cost of measure [€]**	**Ratio $\Delta IC_T/\Delta E$ [€/kWh]**
Increasing the airtightness of a building from v_{50} = 6 m³/h.m² up to v_{50} = 2.5 m³/h.m²	1,321.86	469.10	0.355
Insulation of the cavity in a wall with PUR-insulation	2,563.15	18,401.20	7.179
Changing glazing from U= 2.3 W/m².K up to 1.1 W/m².K	2,277.50	4,450.89	1.954
Installation of a photovoltaic solar system with a peak power of 6,120 Wp	4,862.51	9,200.00	1.892
Installing a demand-driven ventilation system for natural supply and mechanical exhaust	3,476.42	3,500.00	1.007
Placing a heat pump and floor heating instead of an electrical floor heating	17,409.30	18,258.20	1.049

Table 1 shows an exemplary list of measures that can be taken for an exemplary detached house in Belgium. The costs have been obtained by asking quotes in local companies and the energy calculations were conducted in accordance with the applicable standards. It is clear from this table that the lowest value for the ratio $\Delta IC_T/\Delta E$ is 0.355, which corresponds to the improvement of the airtightness of the building. Only €469.1 has to be spend and already 1,321.86 kWh can be saved every future year.

2.1 Investment cost calculations

As explained earlier in this paper, only the investment cost for the energy saving measures has to be computed. Since all energy production is considered to be sustainable, no yearly energy bill is expected, provided that the investment costs for renewable generation is included with the cost of the generation system. To make a proper estimation of the investment cost for ventilation systems and airtightness measures, the research team relied on price offers from several companies. In case of ventilation systems, the calculation is easily done, since the fan cost, window lattices, piping, correct adjustment and labour cost are the only parameters to be set. It's fair enough to take all related costs from the price offer from the installation company and to sum them. A total and correct investment cost for every single ventilation system can be found that way. Table 2 shows a list of ventilation systems with the investment cost and the necessary system parameters. Note that the investment costs are VAT-exclusive and only applicable for the project the list of systems was made for.

Table 2: List of ventilation systems with their respective investment costs

System Name	Investment cost	m-factor for placement quality	Reduction factor for demand control	Heat recovery efficiency
System C	€1,500.0	1.50	1.00	n/a
Dantherm HCV5	€5,696.0	1.30	0.60	0.90
Systemair SAVE VSR 300	€4,592.0	1.25	0.54	0.90
Systeem C+ EVO II / Healthbox II	€2,394.8	1.22	0.72	n/a
Systeem C+ EVO II / Healthbox Smartzone	€2,644.8	1.22	0.45	n/a
Systeem C+ / Xtravent EcoModus Compact	€1,941.7	1.22	0.94	n/a

As far as the airtightness, the price setting is far more complicated. In the first place, it's difficult to allocate the appropriate labour time (and cost) to the airtightness improving measures since it's sometimes enough to just pay attention while construction and since the increase of the airtightness can be a secondary effect of other energy saving measures. Besides that, it's almost impossible to predict the effect of the measures on the level of airtightness. As frequently stated in the literature, one can rely on component leakage models to dimension the impact of a single measure on a single building component and sum the impact for all measures. Literature however also states there is an uncertain part in the airtightness of buildings which cannot be predicted using the component leakage method and the component leakage models often differ as a result of anomalies in the installation methods.

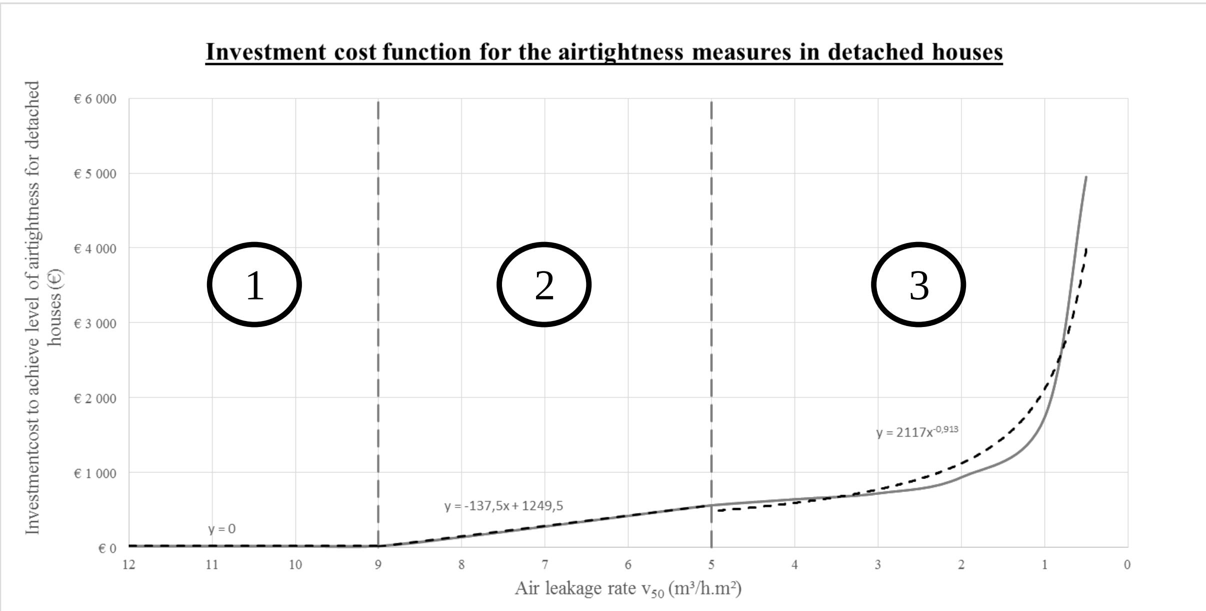

Figure 1: Investment cost function for the airtightness measures in detached houses

To be able to make a proper estimation of the effect and the investment cost of the measures to improve the airtightness, the research team contacted different companies in order to obtain the necessary information. It was possible to determine some rules of thumb with regard to the price function of airtightness. Figure 1 illustrates that three cost zones can be distinguished. Zone 1 is the zone where no investment cost for the airtightness improvement have to be accounted. No special efforts have to be done to achieve a level of airtightness corresponding with an air leakage rate v_{50} equal to approximately 9 m³/h.m². From that point on, investments need to be made to increase the airtightness of the building. In zone 2, between the air leakage rates v_{50} equals 9 m³/h.m² and v_{50} equals 5 m³/h.m², the graph shows a linear relation with the investment cost. Better values for v_{50} can be reached, but enhancing the level of airtightness over v_{50} equal to 5 m³/h.m², will involve an investment following a power function. It is shown in figure 1 that every additional investment in the increase of the airtightness, becomes more costly and thus less profitable. Knowing what has been explained earlier in this paper, the ratio $\Delta IC_T/\Delta E$ for an improvement from v_{50} = 9 m³/h.m² up to v_{50} = 8 m³/h.m² is lower than the ratio $\Delta IC_T/\Delta E$ for an improvement from v_{50} = 3 m³/h.m² up to v_{50} = 2 m³/h.m², and in this way more profitable.

2.2 Energy saving calculations

The procedure to calculate the energy savings achieved with the implementation of one of the suggested measures is in accordance with the Belgian requirements and norms. The investigators rely on the calculation methods suggested by the Belgian government in their energy regulations. The Energy Decree of November 19th, 2010 describes a structure of formulas to be used in the normalised calculation method for the energy performance of residential buildings. The optimization however only concerns ventilation and infiltration. To calculate the energy losses due to exhaust of comfortable warm air from inside the building to the outside environment, following equations need to be used.

$$Q_{V,heat,seci,m} = H_{V,heat,seci} \text{ x } (18-\theta_{e,m}) \text{ x } t_m \quad (1)$$

In equation (1) $Q_{V,heat,seci,m}$ [MJ] stands for the monthly heat loss due to ventilation in a building expressed in MJ, $H_{V,heat,seci}$ [W/K] is the heat transfer coefficient through ventilation in a building calculated with equation (3), $\theta_{e,m}$ [°C] is the monthly average outdoor temperature for Belgium and t_m [Ms] stands for the length of the studied month, both shown in table (3). The indoor temperature of the building is assumed 18°C by which means the temperature differences between rooms and between day time and night time is taken into account. It's a fair average for the overall indoor temperature of the building during an entire day. To transform the value for $Q_{V,heat,seci,m}$ in MJ to a usable value for the optimization in kWh, equation (2) is used.

$$E_{V,heat,seci,m} = Q_{V,heat,seci,m} / 3.6 \quad (2)$$

with $E_{V,heat,seci,m}$ the monthly heat loss due to ventilation in a building, expressed in kWh. In order to derive the value of the heat transfer coefficient $H_{V,heat,seci}$, equation (3) is used. The formula shows that both hygienic ventilation and in/exfiltration through the building envelope are included in the calculation.

$$H_{V,heat,seci} = H_{V,inf/exfilt,heat,seci} + H_{V,hyg,heat,seci} \quad (3)$$

In equation (3), $H_{V,inf/exfilt,heat,seci}$ is the monthly average due to in/exfiltration for heating calculations and $H_{V,hyg,heat,seci}$ the monthly average due to hygienic ventilation for heating calculations. Both variables in equation (3) are calculated below.

Monthly average characteristic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Outdoor temperature [°C]	3.2	3.9	5.9	9.2	13.3	16.2	17.6	17.6	15.2	11.2	6.3	3.5
Length of month [Ms]	2.6784	2.4192	2.6784	2.5920	2.6784	2.5920	2.6784	2.6784	2.5920	2.6784	2.5920	2.6784

2.2.1 Heat transfer coefficient for in/exfiltration

The heat transfer coefficient for in/exfiltration of air through the building envelope is the coefficient that represents the airtightness of the building. The coefficient is calculated using equation (4).

$$H_{V,inf/exfilt,heat,seci} = 0.34 \text{ x } \tilde{V}_{inf/exfilt,heat,seci} \quad (4)$$

With

$$\tilde{V}_{inf/exfilt,heat,seci} = 0.04 \text{ x } \tilde{v}_{50,heat} \text{ x } A_{T,E,seci} \quad (5)$$

In equation (5), $\tilde{v}_{50,heat}$ symbolises the air leakage rate per unit of area, with a pressure difference of 50 Pa and $A_{T,E,seci}$ is the total area of the building envelope components through which heat transfer due to transmission occurs.

2.2.2 Heat transfer coefficient for ventilation

To derive the heat transfer coefficient for hygienic ventilation, equation (6) should be applied.

$$H_{V,hyg,heat,seci} = 0.34 \text{ x } r_{preh,heat,seci} \text{ x } \tilde{V}_{hyg,heat,seci} \quad (6)$$

In formula (6), $r_{preh,heat,seci}$ is a reduction factor for the effect of preheating, which contains the efficiency of the heat recovery system. $\tilde{V}_{hyg,heat,seci}$ is the necessary hygienic ventilation air flow, required for the building. This flow can be calculated easily in accordance to the regulations, but in the calculation structure of the Belgian government, an easy formula is presented. For this paper, equation (7) is used.

$$\tilde{V}_{hyg,heat,seci} = \left[0.2 + 0.5 \text{ x } e^{\left(\frac{-V_{seci}}{500}\right)}\right] \text{ x } f_{reduc,vent,heat,seci} \text{ x } m_{heat,seci} \text{ x } V_{seci} \quad (7)$$

In this formula, V_{seci} (m^3) is the total volume of the building, $f_{reduc,vent,heat,seci}$ a reduction factor for ventilation, based on the demand-control, whether or not provided and m_{heat} a multiplication factor, depending on the ventilation system itself and on the quality of the execution. The value of the m_{heat}-factor is always between 1 and 1.5. As seen in table 2, both $f_{reduc,vent,heat,seci}$ and m_{heat} are system dependent variables which are included in the database.

3 CASESTUDY

To verify the calculation method on optimization and to determine the efficiency of the different measures that are taken, it is important to rely on a practical case. Only that way, the procedure can be validated.

3.1.1 Description of the case study

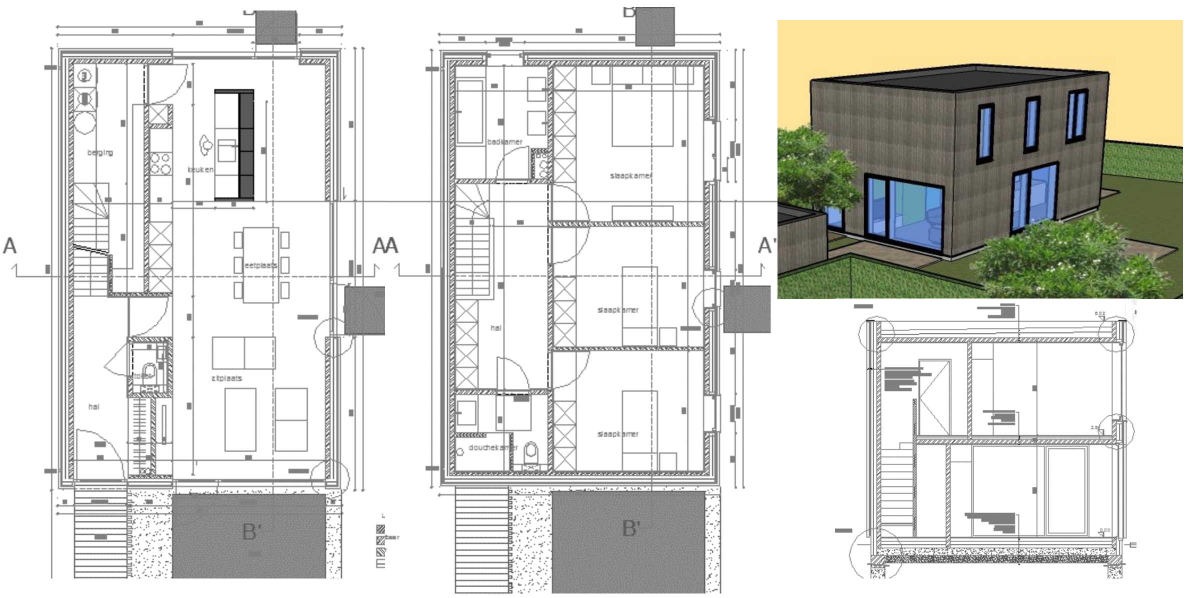

Figure 2: Case study project in Moorslede, Belgium: Floor plans, section, visualisation.

The project that has been studied is a detached house in Moorslede in Belgium. It's a two-storey home with a flat roof and a simple, rectangular floor plan, which is shown in figure 2. The house consists of an open living room and kitchen on ground level and three bedrooms and two bathrooms on the first floor level. The building is constructed out of prefabricated 'cross laminated timber'-panels. The insulation layer of the building envelope is placed around the building and the outside of the walls are finished with wooden battens.

3.1.2 Optimization procedure

In the optimization procedure a lot of variables were left open. All insulation materials were known, but no insulation thickness was determined for the ground floor, the walls and the flat roof. An optimum U-value and g-coefficient for the windows needed to be set as well and the generation system for heating and domestic hot water was also not determined yet. As for the ventilation system, a list of possible systems was provided and for the airtightness optimization, the investment cost function, illustrated above, was used.

Iterative application of the optimization procedure was started. For each iteration a decision was made between the increase of the insulation thickness in a building component by one centimetre, the change of the window type, the improvement of the airtightness by 0,5 m³/h.m², the amelioration of the ventilation system and the change of the generation system.

The optimization process resulted in the following optimum combination of parameters:
11 cm excelsior in the walls, 12 cm mineral wool on the roof, 8 cm expanded polystyrene on the ground floor, windows with a U-value of 1.14 W/m².K and a g-value of 0.28, combined with a heat pump. The optimum airtightness level was achieved at 3.0 m³/h.m² and from the list the ventilation system 'Systemair SAVE VSR 300' was selected. To verify the correctness of the optimization results, a scatterplot was generated consisting of 100 random combinations of variables and none of these combinations was more optimal than the suggested combination.

3.1.3 Results for in/exfiltration rate and ventilation

It's clear from above that the optimization procedure is a rather theoretical concept. The practical application of the optimization results is sometimes more complicated.

As told before, ventilation system 'Systemair SAVE VSR 300' was elected to be the most optimal ventilation system for the studied building. It's easy to order the ventilation system and to get it installed in the house. However, it's of great importance to appeal to professional installers who have the necessary skills to commission the system. Any minor deviation can make the system less optimal than calculated and thus sometimes a wrong choice. Decent craftsmanship is still one of the most important requirements during the building process.

In the case of airtightness, literature has shown that it's impossible to predict the impact of measures improving the airtightness of a building. Too much uncertainties play a role in the overall airtightness level of a building. Since the optimization procedure stated that an air leakage rate of 3.0 m³/h.m² is most optimal, it's wise to follow a roadmap to seal the leaks. After every step, a pressurization test has to be done to verify the impact of the measure that has been carried out. In this case a pressurisation/depressurisation test was conducted after every step using a Blower-door.

To achieve an higher level of airtightness, the following steps need to be completed. Once the desired airtightness level has been reached, the next steps don't have to be completed anymore. The roadmap below is applicable for massive wood-constructions like the one presented as case study. Other steps need to be taken when air tightening a masonry construction or a wood frame construction. Furthermore, all steps and all optimal combinations only apply on the studied project and need to be adjusted for other cases, even if the same type of construction is used.

Step 1: taping the floor seams
Step 2: taping the seams of the CLT-panels
Step 3: airtight installation of windows, doors and wall and roof ducts
Step 4: airtight installation of power outlets and light switches
Step 5: air tightening of chases for electricity and water
Step 6: taking all other possible measures to meet the Passive House standards.

It's fair to stop taking measures, when the desired value for v_{50} has been reached and when not reached yet, a thermographic camera can be of assistance to point out the leakages in the building that aren't sealed yet.

3.1.4 Dynamic simulations with TRNSYS

When studying the optimization of systems and building variables, it’s important to keep in mind the comfort for the occupants. As explained in the methodology for this research, a calculation has been carried out based on monthly average outdoor temperatures. In table (3) it is shown that the average temperature for July for example is 17.6 °C in Belgium. It’s obvious that during summertime the outdoor temperature exceeds this average for a large number of hours. Using the average outdoor temperatures is an acceptable method to determine the energy consumption for an entire year, since peaks are not important for that matter. Nevertheless, high outdoor temperatures and consequently big amounts of energy entering the building, can cause overheating for several hours. To predict the number of hours the rooms are overheated, dynamic simulation is inevitable. The temperature of all rooms in the case study building are simulated.

Dynamic simulations can also be very useful to compute the value of $f_{reduc,vent,heat,seci}$, since this value depends on the operative time of the system. After all, the system only has to work when there’s a ventilation demand. In order to evaluate whether the ventilation system has to be running or not, occupation schedules, indoor temperature monitoring, humidity evaluation… can be added to the model. The dynamic simulation makes it possible to activate and deactivate the ventilation system every time step and a truthful answer can be given concerning the energy consumption. In the dynamic model, the reduction factor for demand-control is no longer an estimation, but depends on a lot of in time variable parameters.

As for the case study, results have been extracted from the dynamic simulation model about the risk of overheating and the monthly heating demand.

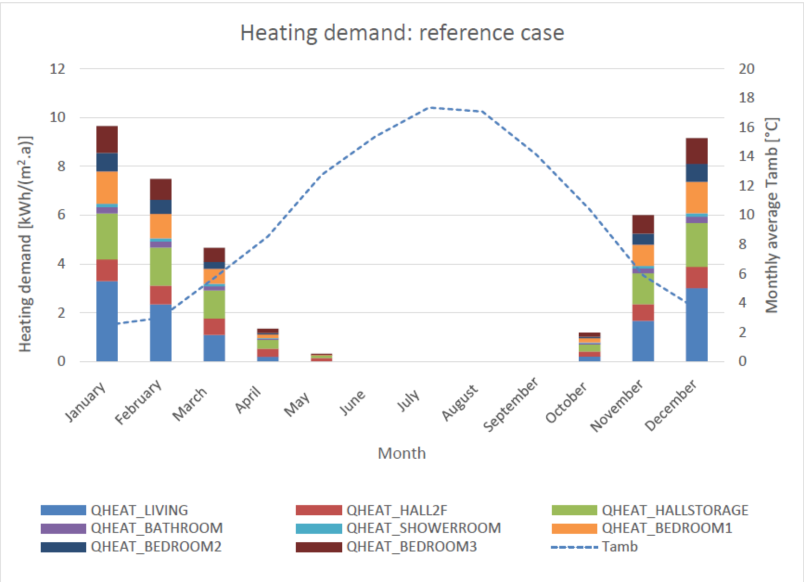

Figure 3: Monthly heating demand of the reference building per m² net floor area.

4 CONCLUSIONS

In this paper it’s been clarified how to calculate the optimal airtightness level and how the select the most cost optimal ventilation system from a list. When implementing the results of the calculation, a stepwise application of air tightening measures is in order. To make sure no unnecessary steps are taken, after each step, a pressurisation test has to be performed on the building. In that way the cost optimal solution can be pursued. As for the ventilation system, the characteristics of the system are of great importance. The quality of installation and the reduction factor for demand control have to be determined correctly before the optimization procedure starts and a yearly based optimization study can be carried out.

In order to minimize the risk of overheating, the author recommends a dynamic simulation with a time step of one hour. That way, the number of hours for which the indoor temperature in a room exceeds the maximum acceptable temperature, can be counted for an entire year. Several measures to decrease the risk can be tested by including the measures in the dynamic simulation model. Meanwhile, the demand-control can be programmed in the model and a correct energy consumption can be derived, without uncertain estimation of some variables.

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