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*KEYWORDS: Building Regulations, total energy use for heating, cooling, ventilation and domestic hot water, optimization, DseeC, low energy classification, typehouses, BE06, building simulations, BSIM 2002.*

*SUMMARY:*
*In 2005 the Danish Building regulations introduced two low energy classes for buildings in addition to tightened minimum requirements. The low energy class 1 and low energy class 2 correspond to total energy use, i.e. energy use for heating, ventilation, cooling and domestic hot water, as 50% and 75% of the minimum requirement respectively. The main purpose of introducing the low energy classes were to further support and encourage the development of low energy buildings in Denmark.*

*In 2010 it is expected that demands of the Building Regulations are tightened by 25-30% and in 2015 it is expected that the minimum demand will correspond to the low energy class 1 demands of today. In order to secure this development in the building regulations, it is essential to support the development of low energy solutions and demonstrate that the goal is well within reach of the Danish building industry.*

*This paper describes the development of a low energy class 1 typehouse. The house is based on a standard typehouse, and through an optimization process of the building constructions and heating and ventilation systems, the total energy use for the typehouse has been reduced in order to meet the low energy class 1 demands. The paper describes the original typehouse solution, optimization process and detailed simulations of the energy use and indoor climate of the optimized solution.*

## 1. Introduction

The EU Directive on Energy Performance of Buildings (EU Directive, 2002) was implemented in Denmark in 2006, and in order to comply with the directive, Denmark introduced new energy performance requirements in 2005 (Danish Building Regulations, 2005). In addition to a general tightening of the minimum requirements, the new building regulations also introduced a classification system for low energy buildings, i.e. low energy class 1 and low energy class 2 buildings corresponding to 50% and 75% of the minimum requirement respectively.

In order to stimulate the use of the new classification system and hereby induce further energy savings in new buildings, it is necessary to demonstrate how total solutions that fulfill the low energy classes can be developed without major impact on basic building techniques and economy. This is especially important in order to visualize the possibilities for the building industry and hereby start a process creating a market for low energy houses. This will pave the way for the development of new building components and system solutions that can form a basis for new low energy buildings so that the present low energy class 1 can be made a minimum demand in 2015 for standard houses.

The purpose of the project described in this paper was to develop typical typehouse solutions that fulfill the demands on low energy class 1 buildings. The development was performed in co-operation with typehouse contractors. Based on the standard typehouses chosen by the contractor, a list of energy saving measures were suggested and for each measure the reduction in total energy use was calculated using a calculation program, *BE06* (Aggerholm and Grau, 2006) described in detail in (Aggerholm and Grau, 2007). This program has been developed to fulfill the requirements in the European Standard EN ISO 13790 (EN ISO 13790, 2005) and is used in Denmark for demonstrating that new houses fulfill the energy requirements according to the Building Regulations. Using detailed calculations/simulations of the total energy use along with economic optimization procedures, new typehouse solutions that fulfill the low energy class 1 requirements were proposed and in co-operation with the contractors a final solution was chosen.

This paper describes one of two developed typehouse solutions. (Rose, 2007) describes both in detail.

## 2. Existing typehouse solution

The existing solution was a traditional Danish typehouse solution from Eurodan Huse A/S, see figure 1.

*FIG. 1: Picture of the original typehouse. The total heated area is 157 m$^2$.*

### 2.1 Constructions for the original typehouse

In figure 2 a cross-section of the house is shown. In the following the constructions are described.

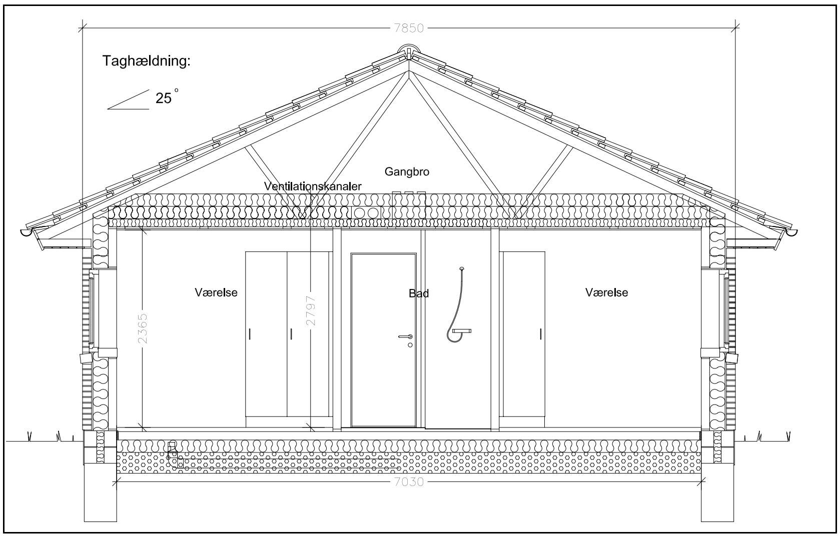


*FIG. 2: Cross-section of the original typehouse.*

Exterior walls are based on brick and lightweight aggregate clinker whole-wall elements with 190 mm insulation. The mean U-value of the exterior wall is 0.196 W/m$^2$K.

The floor construction consists of a 100 mm concrete slab, 150 mm polystyrene and 250 mm lightweight aggregate clinker. The U-value for the floor construction is 0.119 W/m$^2$K. The house is heated by both floor heating and radiators. Floor heating covers approximately 1/3 of the total floor area.

The roof construction has 385 mm insulation and a U-value of 0.092 W/m$^2$K.

Windows and doors have 92 mm wide wooden frames with a mean U-value of 1.50 W/m$^2$K. The panes have 2 layers of 4 mm glass with a 90/10 argon/air gas between, resulting in a U-value of 1.13 W/m$^2$K and a solar transmittance of 59%. The spacer profile is aluminum, resulting in a large thermal bridge. The overall mean U-value for windows and doors is 1.42 W/m$^2$K.

The most important thermal bridges (foundation and window/wall joint) have also been evaluated. The linear thermal transmittance of the foundation constructions below the exterior wall and below windows/doors are 0.103 W/mK and 0.210 W/mK respectively (calculations performed according to Danish calculation standard (DS418, 2005). The window/wall joint has a linear thermal transmittance of 0.044 W/mK for the vertical cross-section and 0.026 W/mK for the horizontal cross-section.

## 2.2 Heating and ventilation system for the original typehouse

The house is fitted with a ventilation system with heat recovery. Exhausts are placed in the kitchen (20 l/s), utility room (10 l/s) and two bathrooms (15 l/s), i.e. a total of 60 l/s (0.38 l/s per m$^2$) corresponding to a ventilation rate of 216 m$^3$/h. Inlets are placed in bedrooms, kitchen and living room. The temperature efficiency of the unit is approximately 87% (at 20 ºC indoor temperature, 50% relative humidity and 5 ºC outdoor temperature). The SEL-value (specific electricity use for air transport) is 0.8 kJ/m$^3$. The mean infiltration for this type of house is 0.05 h$^{-1}$ (typical result obtained by contractor in blower door test).

The heating system is a condensing gas furnace with a nominal effect of 14.7 kW and a maximum efficiency of 109%. The blower has a rated output of 96 W and automatic control of 0.9 W. The pump is a three step pump with power draws of 46 W, 63 W and 78 W respectively. The total standby power draw is 10 W. The reduction factor for the pump is 0.8. The supply pipe temperature is 70 ºC and the return temperature is 40 ºC. Heating is provided through a 2-string system.

The domestic hot water system has a hot water tank with a capacity of 65 l and a specific heat loss of 1.30 W/K (measured by manufacturer).

## 2.3 Total energy use for the original typehouse.

The total energy use for the original typehouse is calculated using the program *BE06*, and the result is 60.8 kWh/m$^2$ per year. This covers the energy used for heating, ventilation, cooling and domestic hot water and all electricity use is multiplied by a factor 2.5 in order to take into account the difference in $CO_2$-emmission associated with the production of this energy type. In *BE06* cooling is automatically initiated if indoor temperatures rise above 26 °C and cooling energy is assumed to be electric, i.e. the energy is multiplied by a factor 2.5. The energy frame for this particular typehouse according to Danish Building Regulations is 84.0 kWh/m$^2$ per year, so the original solution easily fulfils the minimum requirements.

# 3. Optimization of the energy performance

Optimization of the energy performance for the typehouse is achieved using a method developed at the Department of Civil Engineering at the Technical University of Denmark (Christensen, J. H., 2006-I). The main principle of the method is to determine a so-called solution space represented by the energy frame minus the energy use for domestic hot water and electricity use (typically pumps in the heating system and fans in the ventilation system). Domestic hot water use is specified as 250 l/m$^2$ for houses and electricity use for the heating and ventilation system will typically be independent of the building layout, and therefore these two elements can be withdrawn from the optimization process.

After this the remaining energy use (the solution space) is reduced by the energy use for space heating under the assumption of there being no windows in the building. The remaining part of the solution space can be used for installing windows in the house, taking into account any extra reduction in the solution space if overtemperatures are introduced when installing windows.

The method is implemented in a Pc-program, DseeC (Christensen, J. H., 2006-II) which represents the solution space graphically. Below is a short description of the results obtained with DseeC for the original typehouse.

The insulation thickness in the roof construction should be as large as possible because it is inexpensive to insulate this part of the building envelope compared to other areas.

The exterior wall should be insulated with 300 mm insulation or more – depending on which type of exterior wall is used. If the heavy wall (brick and lightweight aggregate clinker) is maintained, insulation thicknesses beyond 300 mm will be quite expensive, as the width of the foundation will need to be increased also. If a lighter wall-type is used the insulation thickness can be increased without problems, however this will also reduce the overall heat capacity of the typehouse.

Statically and economically it can be difficult to operate with insulation thicknesses (expanded polystyrene) beyond 300 mm in floor constructions. However, combinations of expanded polystyrene and lightweight aggregate clinker, as in the original solution, can be used, and this type of solution with increased insulation thicknesses is an obvious choice.

For the windows and doors it is concluded, that it is possible to reduce the total energy use for the typehouse significantly, by using the best windows/doors on the market. However, the price for using the best that the market has to offer is too high for it to be economically viable and therefore it is concluded that focus should be on increasing individual window size and orientating the windows to increase solar gains. In addition choosing a pane with a lower U-value and a "warm edge" should be considered.

With respect to the heating and ventilation system the original house already has good solutions, and therefore only slight adjustments are performed on these. The pump in the heating system could be exchanged for a more energy efficient one and by increasing focus on air-tightness of the building envelope, it is expected that the infiltration can be minimized also. Instead of having a combination of floor heating and radiators, floor heating could be used throughout the house, meaning that the temperature in the system can be reduced significantly.

# 4. Optimized typehouse solution

The optimized typehouse is shown in figure 3.

*FIG. 3: Low energy class 1 typehouse.*

## 4.1 Constructions for the optimized typehouse

In figure 4 a cross-section for the optimized typehouse is shown.

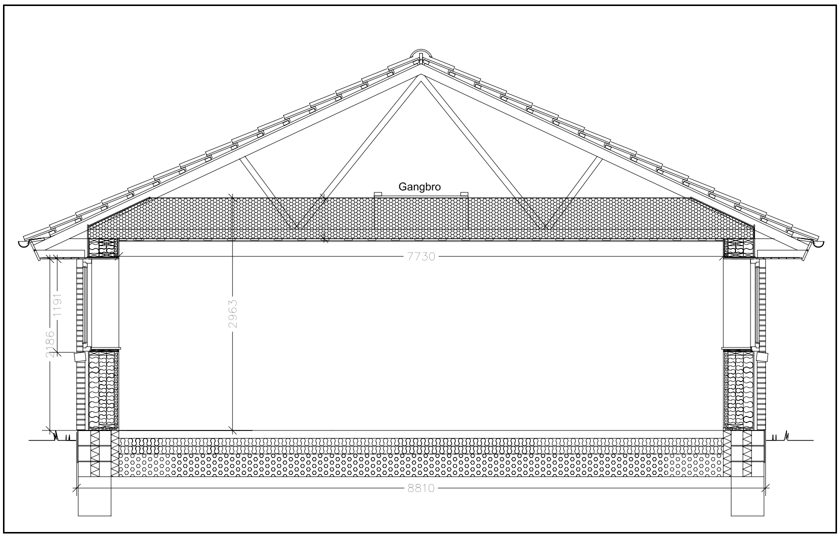


*FIG. 4: Cross-section of the low energy class 1 typehouse.*

In the optimized house the exterior walls are based on a load bearing wooden construction with a brick outer leaf. The construction has 365 mm of insulation and a mean U-value of 0.105 W/m$^2$K.

The insulation thickness of the floor construction has also been increased, so that the optimized house has 200 mm polystyrene and 290 mm lightweight aggregate clinker. This decreases the U-value for the floor construction to 0.098 W/m$^2$K.

The roof construction now has 520 mm of loose-fill stone wool resulting in a U-value of 0.081 W/m$^2$K. The loose-fill insulation thermal conductivity is somewhat higher than the batts used in the original solution, however when the insulation thickness reaches this level it is practically impossible to insulate the roof with batts.

The linear thermal transmittance of the foundation constructions below the exterior wall and below windows/doors are 0.063 W/mK and 0.093 W/mK respectively. The window/wall joint has a linear thermal transmittance of 0.059 W/mK for both the vertical cross-section and the horizontal cross-section.

Window and door frames are the same type in the optimized house as in the original house. However, the glazing has been improved as a 3-layer pane with argon has been chosen. This reduces the total mean U-value from 1.42 W/m$^2$K to 1.11 W/m$^2$K but also decreases the solar-transmission from 0.59 to 0.45. The window sizes have been increased and generally the largest areas have been orientated towards south, east and west, i.e. minimizing the area towards north. In table 1 the construction U-values and building joint ψ-values are shown for both typehouses. In table 2, the window areas and orientations are shown for both typehouses.

*TABLE. 1: Comparison of construction U-values and building joint ψ-values.*

| | U-values [W/m$^2$K] | | | | ψ-values [W/mK] | |
|---|---|---|---|---|---|---|
| | Exterior wall | Slab on ground | Roof | Windows | Foundation | Window reveal |
| Original typehouse | 0.196 | 0.119 | 0.092 | 1,42 | 0.103/0.210 | 0.044/0.026 |
| Optimized typehouse | 0.105 | 0.098 | 0.081 | 1,11 | 0.063/0.093 | 0.059/0.059 |

*TABLE. 2: Comparison of window areas in m$^2$ and orientations.*

| | North | East | South | West | Total |
|---|---|---|---|---|---|
| Original typehouse | 10.80 | 5.20 | 7.60 | 2.00 | 25.60 |
| Optimized typehouse | 9.50 | 5.30 | 16.30 | 10.30 | 41.40 |

## 4.2 Heating and ventilation system for the optimized typehouse

The pump used in the heating system has been exchanged for a Grundfos Alpha Pro with a nominal wattage of 25 W and a reduction factor of 0.4. In the optimized house there is floor heating throughout the house, which means that the temperature in the heating system can be reduced significantly (from 70 °C to 35 °C).

The air-tightness of the typehouse is expected to be lower than in the original solution, and therefore the infiltration is reduced from 0.05 h$^{-1}$ to 0.03 h$^{-1}$. Previous experiences with low energy buildings have shown that this level and even better can be reached through careful design, especially of the construction joints in the planning phase, and meticulous craftsmanship in the building phase.

The floor plan has also been changed, but this has merely been a token of the contractors wish, and does not have any significant influence on the energy use for the typehouse.

## 4.3 Total energy use for the original typehouse.

The total energy use for the optimized typehouse is calculated as 40.4 kWh/m$^2$ per year. The requirement for low energy class 1 is 40.6 kWh/m$^2$ per year, so the requirement has just been fulfilled.

## 5. Simulation of indoor climate and heating demand

In addition to the simplified calculation of the total energy use for the low energy class 1 typehouse, a simulation of the indoor climate and heat balance has also been made on an hourly basis. Detailed simulation of the indoor climate in a low energy house is necessary in order to estimate the risk of overtemperatures during summer.

The simulation was carried out using the program *BSIM* (Danish Building Research Institute, 2002). In figure 5 the *BSIM* model is shown. The model is defined with constructions and systems as described above. With the present version of *BSIM* (4, 7, 1, 18) it is not possible to simulate waterborne floor heating systems. As the floor heating system increases the heat loss to the ground, due to a higher temperature (approx. 30 °C) in the floor construction, an alternative method has been used to compensate for this extra transmission heat loss. The floor heating is simulated by lowering the ground temperature by 10 °C, corresponding to the difference between room temperature, 20 ºC, and typical floor heating temperature in a low energy house, 30 ºC. This will also influence the line loss for the foundation construction.

To document the heating demand according to the building code the set point temperature for the heating system was simulated to be 20 °C in all rooms (Aggerholm, S. and Grau, K, 2007).

In a low energy house the internal heat gains are a significant part of the heat balance. The internal heat gains from equipment and people have been simulated to be 5 W/m² according to (Aggerholm, S. and Grau, K, 2007).

The ventilation and infiltration have been simulated as described in chapter 2.2. If the room temperature gets above 23 ºC venting is activated by opening the windows.

Figure 5 shows the simulation model from *BSIM*. Each room has been simulated as a thermal zone and the air distribution between the rooms (mixing) has been set to equalize the in- and outlets from the ventilation system.

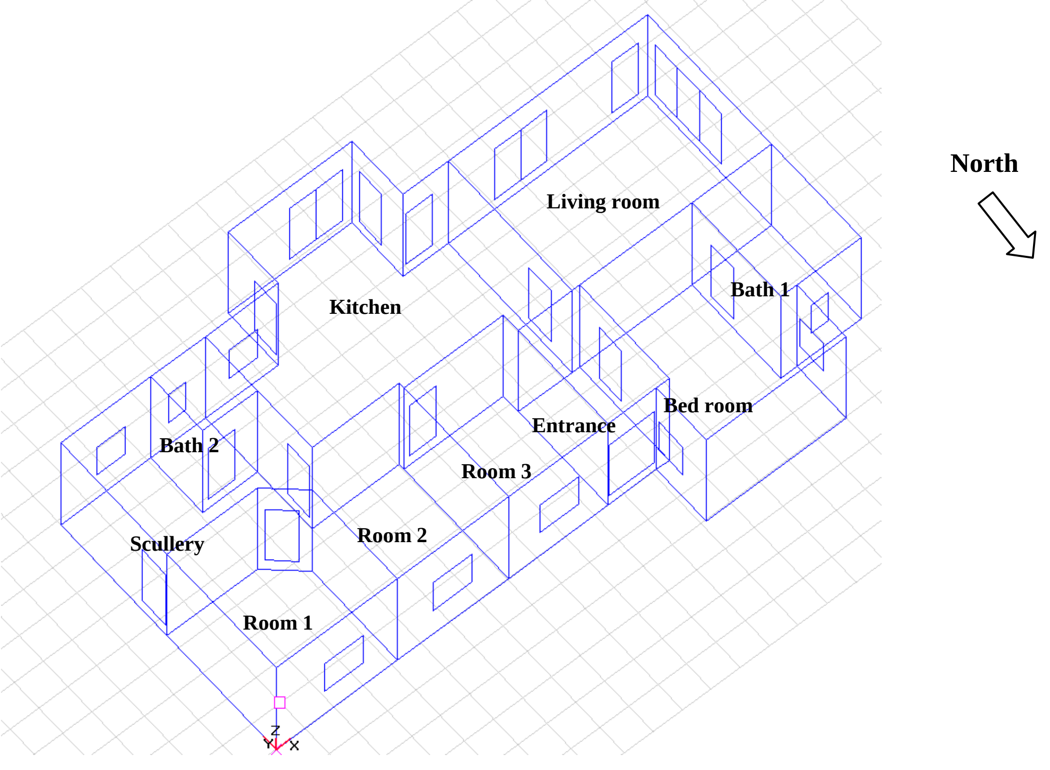


*FIG. 5: BSIM model of the low energy class 1 typehouse. The house is orientated so that the large windows of the kitchen and living room are facing south. The overhang from the roof is 0.75 m (not shown).*

The windows have a relatively large overhang from the roof, which is included in the simulation but not shown in figure 5. The overhang plays an important role when calculating the solar heat gains during the summer. To maximize the heat load from solar gains through the window it is also assumed that the house is located in an open flat country (simulated horizon angle 10º).

In figure 6 the simulation result from *BSIM* is presented. The figure shows the energy balance of the typehouse. As *BSIM* only calculates the net heat loss from the building the figure is supplemented with the results previously found by the *BE06* program regarding energy use for domestic hot water (15.4 kWh/m²), electricity use for fans and heating system (7.1 kWh/m²) and heat losses from the heating system (3.9 kWh/m²).

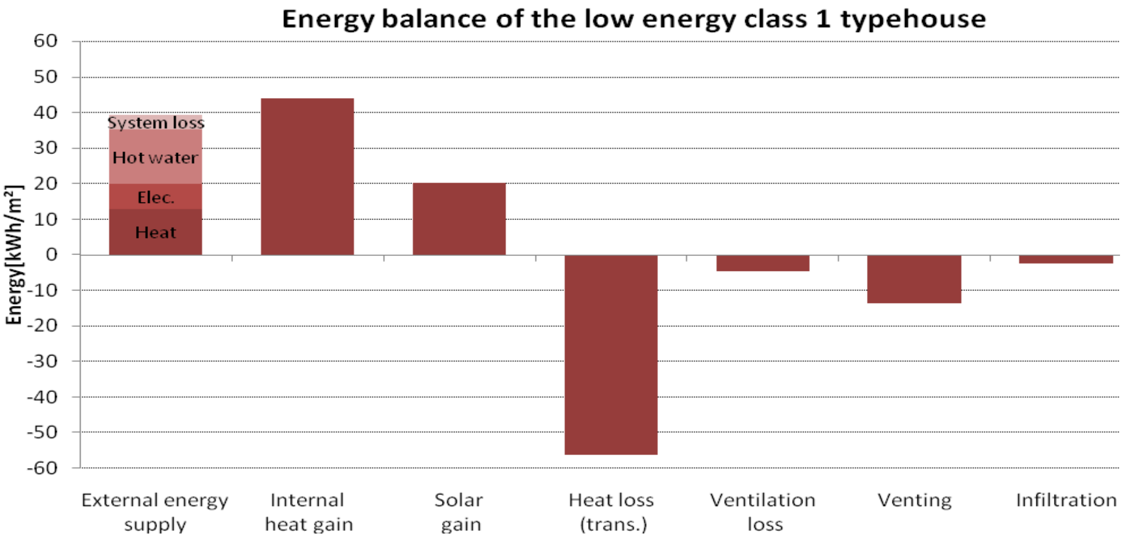


FIG. 6: Results from the *BSIM* simulation showing the energy balance of the typehouse. The electricity is multiplied by 2.5 as described in chapter 2.3. Energy consumption for domestic hot water, electricity and system loss is calculated by the *BE06* program.

It is seen that the simulated total energy consumption for heating including electricity is 39.2 kWh/m² which can be compared with the results found by the *BE06* program (40.5 kWh/m²).

The simulation results from *BSIM* also give the room temperatures for each hour. Figure 7 shows an analysis of number of hours above different temperature limits to give an indication of possible problems with overheating.

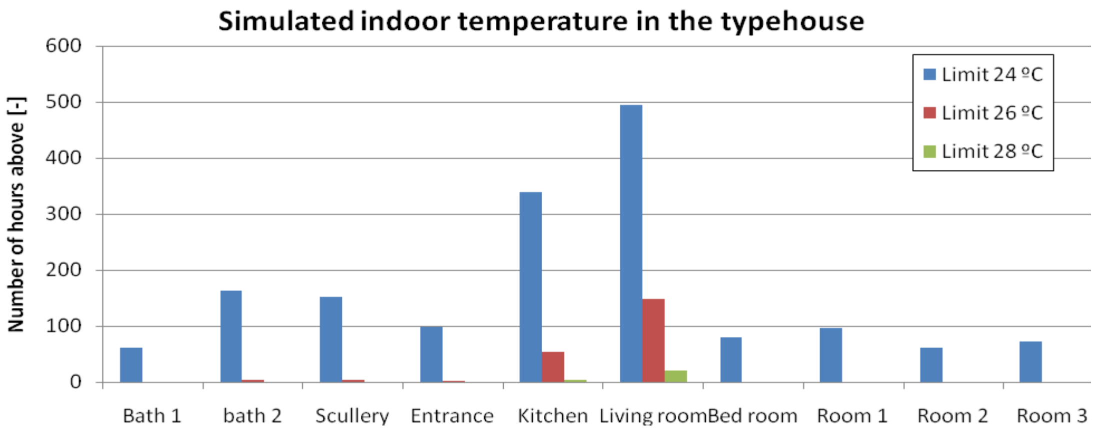


FIG. 7: Analysis of possible overheating problem. The figure shows the number of hours when the operative room temperature was above 24 ºC, 26 ºC and 28 ºC.

From figure 7 it can be seen that the living room is the room with the highest temperatures. The recommendation in Denmark for achieving a good indoor climate (Valbjørn et al, 2000) is that the indoor temperature in any room does not exceed 26 ºC for more than 100 hours per year. From figure 7 it is evident that this recommendation is almost fulfilled, and therefore the room temperature in the typehouse is assessed to be acceptable in all rooms.

## 6. Conclusions

The Danish Building Regulations have introduced two low energy classes for new buildings in order to stimulate and support the development of low energy solutions. Low energy class 1, i.e. 50% of the minimum requirement, is expected to be made the minimum requirement in 2015. In order to ensure the continued development of low energy solutions that can form the basis for meeting the future demands, it is necessary to demonstrate how low energy class 1 buildings can be developed without significant influence on basic building techniques and economy. The purpose of this project was to demonstrate how low energy class 1 typehouses can be developed from existing typehouse solutions.

This paper has described the development of a low energy class 1 typehouse. The typehouse was developed from a typical existing solution and through detailed calculations and optimization. Calculations were performed using the Pc-program *BE06*, and the total energy use was reduced from 60.8 kWh/$m^2$ per year to 40.5 kWh/$m^2$ per year hereby meeting the demand on low energy class 1, i.e. 40.6 kWh/$m^2$ per year.

Detailed simulations using *BSIM* have shown that the indoor climate of the typehouse is more or less within the typical recommendations used in Denmark, and it is concluded that this is acceptable.

At the completion of the first phase of this project, two low energy class 1 typehouses have been developed. Hereby, it has been demonstrated how the classification can be achieved for typical typehouses through adapting building constructions and systems.

## 7. Acknowledgements

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## 8. Future work

At present the developed typehouse is being built and it is the objective of the project to follow up the detailed calculations/simulations with detailed measurements of the indoor climate and energy use of the finished house.

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