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Published in:
Proceedings of the 4th International Conference on Renewable Energy Sources & Energy Efficiency

Publication date:
2013

Change in heat load profile for typical Danish multi-storey buildings when energy-renovated and supplied with low-temperature district heating

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KEYWORDS – Energy renovation, End-use savings, Yearly energy demand, Peak load, Heat load profile, Lowtemperature district heating.

ABSTRACT

Denmark has a long-term objective of being free of fossil fuels by 2050 with the energy-supply-mix for buildings being free of fossil fuels by 2035. Hence energy consumption from existing buildings needs to be decreased concurrent with the conversion from fossil-fuel supply into renewable-energy (RE) supply. When end-use-savings are implemented in buildings concurrent with the application of low-temperature district heating (DH) (supply=55°C, return=25°C) the heat demand profiles for the individual buildings will change. The reduction in peak load is important since it is the dimensioning foundation for the future DH-systems and in order to avoid oversized RE-based capacity, a long-term perspective needs to be taken. The results show that it is possible to design the DH-plants based on an average value of the 5 days with highest daily average loads without compromising with indoor thermal comfort. Applying low-temperature DH to existing buildings without changing the heating system imply reduced radiator performance, and it is of great importance that acceptable comfort temperatures can still be provided. The results indicate that it is possible to apply low-temperature DH for approximately 90% of the year without compromising thermal comfort when energy renovations are carried out.

1 INTRODUCTION

Europe has a vision of reducing energy consumption significantly. In Denmark the government has a long-term objective of being completely independent of fossil fuels by the year 2050 with the energy supply mix for buildings being free of fossil fuels already by 2035[1,2]. Therefore, urgent action is needed to meet the requirements for the future energy system. The solution is to combine energy savings and RE-supply in an optimal way. The European building stock accounts for about 40% of the overall energy use [3]. In order to reduce this energy use there is a need of reducing the energy consumption of the existing building stock, increasing energy efficiency and converting the present heat supply from fossil fuels to RE-sources.

The design of new low-energy buildings has been in focus throughout recent years and much research has been carried out in order to design optimized buildings from an energy perspective [4-8]. However, less than 1% of the building stock is in average replaced with new low-energy buildings in Europe [9], which underlines the importance of looking into the existing building stock, where the potential for energy savings is large [10-12]. Investigations have shown that the energy consumption can be reduced by about 50-75% [11-15], but it takes significant investment costs to reach very low levels of energy consumption [11]. Since existing buildings will remain for many years yet to come, it is an unavoidable factor to deal with. The future energy system will have to be based solely on renewable energy sources, which is a (mainly mental) challenge for the society. It will have to be based on different renewable energy technologies that have to interact and balance in order to ensure a system with security of supply.

DH is a sustainable way of providing space heating (SH) and domestic hot water (DHW) to buildings in dense populated areas [16]. In many countries DH systems are already established, but they face new challenges in the future. Around 60% of the heat demand is covered from DH in Denmark, which will have to be converted from the present supply technologies based on fossil fuels into 100% RE-sources, such as geothermal heat.

Supplying the existing building stock with heat from RE-supply technologies e.g. low-temperature DH from geothermal heating plants, may lead to oversized heating plants that are too expensive to build compared to implementing energy end-use savings [17,18]. Therefore reducing heat demand of existing buildings before investing in supply capacity will save half the initial capital investment, indicating the importance of carrying out energy savings now [17,18]. The marginal cost of saving one unit of energy when carrying out a renovation is about 45 €/MWh [18] and the cost of supplying one unit of heat from DH is 60 €/MWh in 2013 (w/o. taxes) and 93 €/MWh (w. taxes) [19]. According to [18] the cost of supplying one unit of heat based on geothermal heat has been estimated to be around 69 €/MWh (w/o. taxes) if accelerated energy renovations are carried out from today. This stresses the importance of carrying out energy savings in the buildings now and design the district heat production based on a long-term perspective.

Traditional DH-systems operate with a supply temperature of about 70°C and a return of 40°C. Applying low-temperature DH, with a supply temperature of about 55°C and a return temperature of 25°C, will give the opportunity to exploit the low-temperature RE heat sources i.e. geothermal heat, solar heat etc. Furthermore it will reduce the heat losses from the distribution pipes and increase the final efficiency of the system. The design concept of low-temperature DH is explained in [20], and theoretical analysis have been carried out in [21,22] and applied in [23,24]. When low-temperature DH is implemented the problem of legionella has to be considered with regards to DHW. According to the German Standards the legionella problem can be avoided as long as the water volume is less than 3 litres and the temperatures are above 50°C [25]. Using a local flat station that contains small amounts of water and is able to boost the water temperature will avoid this problem. Additionally, recent research in Sweden has shown good results by the use of UV-disinfection [26,27].

When end-use-savings are implemented in buildings connected to a DH-system the heat demand profiles for the individual buildings will change, which affects the heat profiles for the entire DH-system. A study from Sweden looks into how the end-use heat savings in buildings will affect district heating production including costs and primary energy savings [28]. They found that a significant amount of the primary energy savings was on the peak load units. In the study the peak loads are supplied from light fuel oil boilers, but in the future the peak loads will have to be covered from RE systems, which are costly. Therefore, after implementing energy-saving-measures the heat load duration profiles for the buildings are of importance since they are the dimensioning foundation for the future DH-systems. In order to avoid oversized RE-based capacity, a long-term perspective needs to be taken. The studies [29,30] investigated low-temperature DH for buildings with existing radiators focusing on the relation between supply temperature, mass flow rate, and the dimensioning on the pipe distribution system based on future and current situations.

Research dealing with a combination of low-temperature DH for existing buildings with focus on obtaining good indoor thermal comfort, concurrent with the implementation of end-use savings, is lacking. Implementing end-use-savings implies reductions in the peak loads, and investigations onto which extent it is possible to reduce the peak loads, when supplying with low-temperature DH and without compromising with the indoor thermal comfort is in focus. Furthermore the relationship between the reduction in yearly heat savings and the change in the heat load profiles is studied.

Two building blocks from the early 1900´s located in typical urban areas in Denmark are investigated, and end-use-savings are carried out concurrent with the conversion into low-temperature-DH supply.

2 METHODS

Two building blocks from Aarhus and Copenhagen have been used as case-studies for this investigation. They are both located in typical urban areas, and are from 1910 and 1906 respectively. Both of them represent a large share of the existing buildings in the urban areas with great energy-saving potentials. The existing state of the buildings is being analyzed after which energy saving measures are implemented in order to decrease energy consumptions. Three degrees of energy renovations are investigated (Table 1).

Table 1: Energy renovation levels

	New windows (w. solar shading)	Mechanical ventilation (heat recovery =85 %, min air change=0.5h^{-1})	Basement insulation	Roof insulation	Facade insulation
Deep renovation	X	X	X	X	X
Light renovation	X	X	X	X	
Window renovation	X	X			

Three different energy renovation strategies are investigated since it might be an optimistic goal to carry out deep energy renovations on all buildings within a short term. Therefore it is important to investigate different levels in order to know whether the concept of low-temperature DH can provide acceptable comfort temperatures with lighter degrees of energy saving strategies. It might also be too expensive to carry out deep energy renovations on all buildings now, since they might as well fulfil the lifetime. Afterwards it might be more reasonable to build new instead of carrying out the relative expensive renovation measures. Therefore solely changing the windows will be a relatively cheap and easy way of obtaining some savings now. Furthermore, a large share is heritage buildings and the facade is protected. Internal facade insulation needs to be applied, which is costly, takes up space from the inside, and might create problems with moisture and fungi [31,32].

The building energy simulation software IDA-ICE 4 [33] has been used for numerical simulations of determining the energy consumption before and after energy-saving measures are implemented. The DRY-weather file for Denmark is used for the simulations.

2.1 Description of buildings

2.1.1 Building in Aarhus

The building consists of 5 floors for residential living plus an unheated attic and basement. The overall heated area is on 850 m^2. The carrying construction is made of wooden beams and brick walls. There is no facade insulation, but the building went through a renovation in 1989 upgrading some parts of the building envelope. Therefore the roof is insulated with 200 mm stone wool, but the horizontal division between the ground floor and the basement has no insulation. The windows were replaced to 2-layers windows. The ventilation comes from natural ventilation from opening windows and leaks. The *deep* and *light* renovations are carried out, since the windows were already changed in 1989 and the energy saving potential for solely replacing the windows will be rather small compared to a building that has not yet been renovated. Only one floor is modelled in IDA-ICE as representative for the entire building (Figure 1).

2.1.2 Building in Copenhagen

The building in Copenhagen also consists of 5 floors for residential living plus an unheated attic and basement. The overall heated area is on 3,409 m^2, spread out on 43 apartments. The carrying construction is made of wooden beams and brick walls. There is no insulation on the facade, roof or on the horizontal division between the ground floor and the basement. The windows are old 1-layer inefficient windows. Fresh air is provided by natural ventilation from opening windows and leaks. All three degrees of energy renovations are carried out - *the deep, light* and *window* renovation. Only 3 apartments are modelled in IDA-ICE as representative for the entire building (Figure 1).

The U-values and infiltration for the constructions of both buildings before and after the different renovation measures are presented in Table 2. In order to include the heat loss from the roof and to the basement the extra heat losses from these constructions have in the models been included as a weighted average in the U-value for the facade. The thickness of the facade varies with smallest thicknesses at the top and under the windows. Hence the facade u-value is based on a weighted average representing the entire building facade. The radiators have been dimensioned based on the heat losses from the zones in the existing building by a yearly simulation with IDA-ICE. The radiators are dimensioned based on a supply temperature of 70°C and a return temperature of 40°C [34].

Table 2: U-values for the constructions before and after renovation

U-values and infiltration	**Copenhagen**		**Aarhus**	
	Existing	**Renovated**	**Existing**	**Renovated**
Facade [W/m^{2}K]	1.34	0.16	1.34	0.16
Windows [W/m^{2}K]	4.50	0.97	2.90	1.28
Roof [W/m^{2}K]	1.20	0.11	0.20	0.13
Horizontal division between ground floor and basement [W/m^{2}K]	1.20	0.16	1.50	0.30
Infiltration [h^{-1}]	0.5	0.05	0.5	0.05

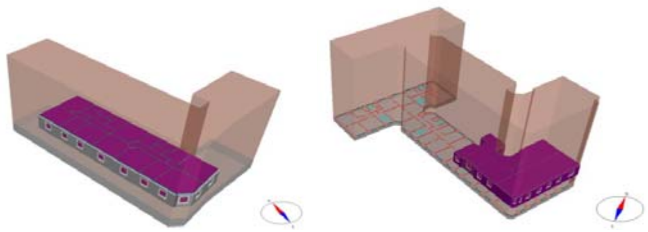

Figure 1: 3D-model of the buildings in Aarhus (left) and Copenhagen (right)

2.2 Yearly heat demand and heat load profile.

The savings in yearly heat demand are studied and compared to the savings in the peak load. Since the peak load production is very costly, it is desirable to cut off as much of the peak load as possible. Hence it has been investigated until which lower limit it is possible to dimension the peak load production and still provide an acceptable indoor thermal comfort. The savings and indoor comfort has been studied for dimensioning the peak load production based on daily average values. Furthermore it has been investigated whether it is possible to go one step further by dimensioning the peak load production based on an average of the five days with highest daily average values without compromising with the indoor thermal comfort (Figure 2).

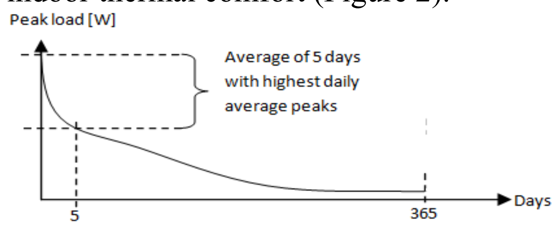

Figure 2: Sketch of duration curve for SH – daily average

2.3 Return temperature from building to DH-net with lowtemperature-DH application

When applying lowtemperature-DH it is crucial to have the same cooling of the DH-water in the system. Traditional DH-systems have a ΔT=30K (70°C to 40°C), and thus the return temperature should be 25°C when supplying with 55°C. If ΔT is decreased the mass flow rate will need to be increased in order to achieve the same power output. In order to be able to use the existing distribution pipes the mass flow rate cannot be increased, which implies that ΔT in the system needs to stay at 30K. The return water from the building to the DH-net has been logged and analysed.

3 RESULTS

3.1 Yearly energy consumption

3.1.1 Building in Aarhus

As a result of the energy saving measures, the total energy consumption has decreased as shown in Table 3. As seen, it is possible to obtain a yearly heat reduction of about 70-80% if the building undergoes a deep renovation and a total energy reduction of about 60-70%, which is in accordance with the findings in [11-15]. The differences in the reduction in yearly energy and yearly SH are due to the extra energy use for operating the mechanical ventilation. A consumption of 4-5 kWh/m^2 for the mechanical ventilation is in accordance with the findings and suggestions in [35]. When a building undergoes a renovation it is often observed that the occupants discover an increased comfort level and thereby increase the room temperature from 20°C to 22°C. The increase of 2°C results in an increased SH-demand of about 30%, which indicates the importance of the user behaviour for the obtained energy savings. When the light renovation is carried out it is seen that it is possible to reach a reduction in the SH-demand of 20-30% if the set point for the room is kept at 20 °C. If this is increased to 22 °C the energy savings are negligible, and the user behaviour is in this case crucial for the obtained savings. Low-temperature DH with a supply temperature of 55°C is applied in both renovation cases, but for the light renovation it was not possible to obtain a minimum comfort temperature of 20 °C all hours of the year. This is due to the fact that when low-temperature DH is applied the performance of the radiators are decreased with a factor 2.5 with an unchanged flow rate. If the flow is increased the performance will increase as well, but in order to obtain an acceptable cooling of the DH-water over the radiator (30K) the flow cannot be increased (see 2.3). Hence the supply temperature was raised to 70°C in cold periods. Figure 3 shows the weather-compensated supply curve, which was applied for the light renovation. Furthermore, Table 3 shows that the use of variable air volume (VAV) ventilation provides lower total energy consumptions compared to constant air volume (CAV) ventilation, which is due to extra heat losses in cold periods when using CAV. According to the requirements from the Danish Building Regulations 2010 [36] the energy consumption for residential buildings is (52.5+1650/A) kWh/m^2 = 62 kWh/m^2 including SH, DHW and energy for ventilation, with A being the heated area. By carrying out a deep renovation it is seen that it is possible to obtain an energy level in accordance with these requirements.

Table 3 Yearly energy demand and reduction compared to existing building

	Existing	Deep renovation**				Light renovation***			
	SH set point= 20 °C	SH set point= 20 °C		SH set point= 22 °C		SH set point= 20 °C		SH set point= 22 °C	
		CAV	VAV	CAV	VAV	CAV	VAV	CAV	VAV
Space heating [kWh/m^2]	133	38	29	55	43	105	94	135	123
Domestic hot water [kWh/m^2]	13	13	13	13	13	13	13	13	13
Mechanical ventilation [kWh/m^2]	-	5	5	5	4	5	4	5	4
Total [kWh/m^2]	146	56	47	72	61	123	112	153	140
SH-reduction* [%]	-	71	78	59	68	21	29	-2	8
Total energy reduction* [%]	-	62	68	51	58	16	23	-1	1

* Compared to existing building, ** Supply temperature 55 °C year round, ***Supply temperature most hours of the year, increased to 70 °C in very cold periods.

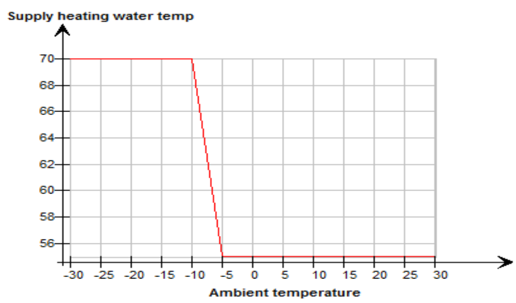

Figure 3: Weather compensated supply curve. Supply temperature as a function of the outdoor air temperature

3.1.2 Building in Copenhagen

For the building in Copenhagen it is seen from table 4 that it is possible to obtain a yearly heat reduction of about 70-80% if the building undergoes a *deep* renovation and a total energy reduction of about 60-70%, which is similar to the building in Aarhus. The mechanical ventilation system is in this building based on CAV and the consumption is seen to be slightly higher than 8 kWh/m^2, but still in accordance with [35]. When the *light* renovation and the *window* renovation are carried out it is seen that it is possible to reach a reduction in the SH-demand of 30-50% and 20-40% respectively, depending on the set point temperature for the rooms. The occupant behaviour has an increased influence on the saved SH when smaller degrees of energy saving measures are implemented. The *window* renovation only provides approximately 10% less than the light renovation, which is due to the very inefficient old windows. Hence a lot of the saved energy is due to the replacement of windows.

Low-temperature DH is implemented with a supply temperature to the building of 55 °C. It was possible to reach a minimum comfort temperature of 20 °C for all three renovation cases without having to increase the supply temperature in cold periods.

Table 4: Yearly energy demand and reduction compared to existing building

	Existing	Deep renovation		Light renovation		Window renovation	
	20° C	20° C	22° C	20° C	22° C	20° C	22° C
Space heating [kWh/m^2]	128	22	34	66	86	80	103
Domestic hot water [kWh/m^2]	13	13	13	13	13	13	13
Mechanical ventilation [kWh/m^2]	-	8	8	8	8	8	8
Total	141	43	55	87	107	101	124
SH-reduction* [%]	-	82	73	48	33	38	20
Total energy reduction* [%]	-	69	61	38	24	29	12

As for the building in Aarhus, it is possible to obtain an energy level that complies with the requirements for new buildings according to the Danish Building Regulations 2010 [36] when carrying out a *deep* renovation.

3.2 Change in heat load profile

3.2.1 Building in Aarhus

When energy savings measures are implemented in the buildings the heat load profile for the individual buildings changes. As seen from Figure 4, which shows the duration curve for daily average SH-loads, the heat demand will become more constant over the year as a result of the energy savings. The more energy-saving measures that are implemented the lower the duration curve becomes (less loads) and the more constant the heat demand is. This means that the DH-plant will have to invest in less renewable supply capacity since the peak loads are lower. Furthermore they are able to supply to a more constant demand, which results in a better economy for the DH-plants.

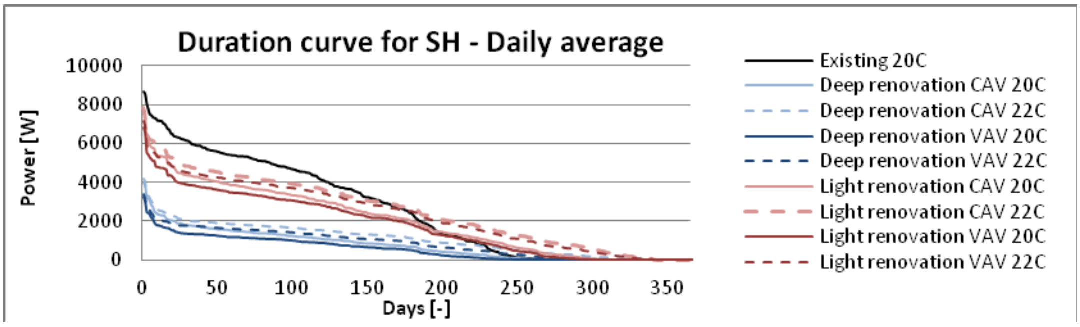

Figure 4: Duration curve for SH – Daily average

Table 5 shows the reduction in the peak load based on the hour with highest load. As seen the reduction is about 40-50% for the deep renoavation but only maximum 15 % for the light renovation.

Table 5: Reduction in peak load compared to the existing building based on hourly values

[%]	Deep renovation				Light renovation			
	SH set point=20°C		SH set point=22°C		SH set point=20°C		SH set point=22°C	
	CAV	VAV	CAV	VAV	CAV	VAV	CAV	VAV
Reduction in peak load (hourly values)	43	52	42	52	5	15	2	12

It has been investigatied whether it is possible to dimension the DH-capacity based on an average of the 5 days with the highest daily average heat loads without compromissing with the indoor thermal comfort. For this investigation one scenario for each renovation-case has been chosen. For the deep renovation the investigation is based on the scenario with VAV and a set point temperature of 22 °C, and for the light renovation the scenario with VAV and a set point on 20 °C was chosen. Table 6 shows the peak loads plus the peak load reductions compared to the existing building based on the different dimensioning foundations for the *deep* and *light* renovation respectively. Table 7 shows the thermal indoor comfort with hours outside the desired temperature range. As seen, it is possible to reach the same reduction on the peak loads as for the yearly SH reduction (Table 3) when the dimensioning of the DH-capacity is based on the average of the 5 days with highest daily average loads. It is seen that there are no hours below 20 °C for the *deep* renovation. For the *light* renovation a significant amount of hours are below the limits with the lowest temperature being 17.4 °C, which is not acceptable. If the set point for the room is raised to 22 °C during cold periods it will be possible to avoid hours below 20 °C for most hours of the year. This will increase the yearly energy consumption, but the influence will be small since it will maximum be 1.4% of the year. In case the occupants want a room temperature on 22 °C all year round, it is possible to increase the supply temperature from the DH-plant in more hours of the year in order to meet the demand. This indicates that it is possible to convert into low-temperature DH for most hours of the year without compromissing with the indoor thermal comfort.

Table 6: Reduction in peak load compared to the existing building

	Deep renovation		**Light renovation**	
	Peak load (VAV–SH set point=22°C) [W]	**Reduction [%]**	**Peak load (VAV–SH set point=20°C) [W]**	**Reduction [%]**
Hour with highest load	4918	52*	8670	15*
Day with highest average load	3361	61**	6862	22**
Average of 5 days with highest daily average load	2853	67**	6018	31**

*Reduction compared to the existing building with highest hourly load, **Reduction compared to the existing building with highest daily average load.

Table 7: Temperatures in the living zones and hours outside comfort limits

Average of 5 days with highest daily average load	**Living room 1**	**Living room 2**	**Living room 3**	**Living room 4**	**Bedroom 1**	**Bedroom 2**	**Bedroom 3**	**Bedroom 4**
Deep renovation-SH $T_{set\ point}$=22°C								
Ti_max [°C]	26,4	26,4	26,3	26,7	26,0	25,7	26,3	26,0
Ti_min [°C]	20,7	20,8	20,2	20,2	20,2	20,1	20,3	20,0
Ti<20°C	0	0	0	0	0	0	0	0
Light renovation-SH $T_{set\ point}$=20°C								
Ti_max [°C]	26,3	26,2	26,2	26,6	25,9	25,5	26,2	25,9
Ti_min [°C]	18,4	18,6	17,4	18,3	17,7	17,7	17,6	17,7
Ti<20°C	69	65	123	73	103	106	106	106
Ti<19°C	12	9	40	12	32	33	36	31
Ti<18°C	0	0	13	0	7	8	10	6
% hours below 20 °C	0,8	0,7	1,4	0,8	1,2	1,2	1,2	1,2
% hours below 19 °C	0,1	0,1	0,5	0,1	0,4	0,4	0,4	0,4
% hours below 18 °C	0	0	0,2	0	0,1	0,1	0,1	0,1
Ti<20°C with SH set point =22 °C	7	4	35	10	19	21	26	18

3.2.2 Building in Copenhagen

For the building in Copenhagen the same tendency is seen for the reduction of the peak loads and the change in the duration curve. Figure 5 shows the duration curve for SH based on daily average. As seen the heat demand becomes more constant over the year as a result of the energy savings. The more energy-saving-measures that are implemented the lower the duration curve becomes (less loads). This is beneficial for the DH-companies in terms of initial capital investment costs and degree of utilization of the plants.

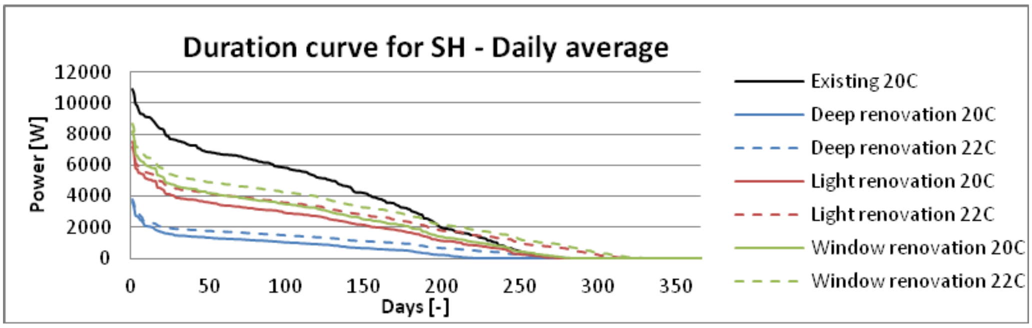

Figure 5: Duration curve for SH – Daily average

Table 8: Reduction in peak load compared to the existing building

Reduction compared to existing building (Supply = 55 °C all year)	Deep renovation		Light renovation		Window renovation	
	20° C	22° C	20° C	22° C	20° C	22° C
Hour with highest load * [%]	58	57	31	30	23	21
Day with highest average load ** [%]	67	65	34	31	25	21
Average of 5 days with highest daily average load ** [%]	72	70	43	40	34	30

*, Reduction compared to the existing building with highest hourly load, **Reduction compared to the existing building with highest daily average load.

Table 9: Temperatures in the living zones and hours outside comfort limits

	Average of 5 days with highest daily average load	**Living room 1**	**Living room 2**	**Living room 3**	**Bedroom 1a**	**Bedroom 2a**	**Bedroom 2b**	**Bedroom 3a**	**Bedroom 3b**
Deep renovation 20 °C	Ti_max [°C]	27,0	27,2	26,5	27,0	27,0	26,9	26,5	26,5
	Ti_min [°C]	18,8	19,3	18,8	18,9	19,4	19,2	18,7	18,2
	Ti<20°C	35	16	35	28	13	27	41	35
	Ti<19°C	5	0	4	4	0	0	6	4
	% hours below 20 °C	0,4	0,2	0,4	0,3	0,2	0,3	0,5	0,4
	% hours below 19 °C	0,1	0	0,1	0,1	0	0	0,1	0,1
	Ti<20°C with SH set point increased to 22C	0	0	0	0	0	0	0	0
Light renovation 20 °C	Ti_max [°C]	26,7	27,2	26,8	26,8	26,9	26,8	26,8	26,7
	Ti_min [°C]	18,3	18,6	18,3	19,0	19,2	18,8	18,3	18,6
	Ti<20°C	56	38	55	17	23	40	55	44
	Ti<19°C	14	9	12	1	0	5	4	8
	% hours below 20 °C	0,6	0,4	0,6	0,2	0,3	0,5	0,6	0,5
	% hours below 19 °C	0,2	0,1	0,1	0	0	0,1	0,1	0,1
	Ti<20°C with SH $T_{set\ point}$ increased to 22C	0	0	0	0	0	0	0	0
Window renovation 20 °C	Ti_max [°C]	26,9	27,4	27,2	26,9	27,2	27,1	27,1	27,0
	Ti_min [°C]	18,2	18,3	18,1	19,0	19,1	18,8	18,1	18,5
	Ti<20°C	64	42	62	16	29	42	61	47
	Ti<19°C	16	13	15	0	0	5	15	10
	% hours below 20 °C	0,7	0,5	0,7	0,2	0,3	0,5	0,7	0,5
	% hours below 19 °C	0,2	0,2	0,2	0	0	0,1	0,2	0,1
	Ti<20°C with SH $T_{set\ point}$ increased to 22C	0	0	0	0	0	0	0	0

Table 8 shows the reduction in the peak load based on different dimensioning foundations. As seen the reduction for the *deep* renovation is about 60 %, 65 % and 70 % for the hour with the highest load, the day with the highest average load, and for an average of the 5 days with highest daily average loads respectively. For the *light* renovation the reduction is about 30-35 % for the hour and day with highest load and about 40 % for the average of 5 days. The *window* renovation results in reductions of about 20-25 % for the hour and day with highest load and about 30 % for the average of 5 days.

Table 9 shows the hours outside the thermal indoor comfort range for the *deep, light* and *window* renovation. The set point is 20 °C and as seen it is not possible to keep a minimum temperature on 20 °C all year round. If the set-point room temperature is increased to 22 °C in very cold periods it is possible to avoid any hours below 20 °C for all renovation cases. Furthermore if the occupant wants to have an indoor room temperature of 22 °C the supply temperature of the DH-plant can be increased from 55 °C to 70 °C in cold periods. From the investigation it indicates that it is possible to supply low-temperature DH most hours of the year without compromising the indoor thermal comfort.

3.3 Return temperature from building to DH-net

The return temperatures from the building to the DH-net are presented in figure 6 and 7 for the building in Aarhus and Copenhagen respectively. In general the lower the set point for the room temperature is, the lower the return temperature becomes. Furthermore, lower degrees of renovations result in an increased return temperature. It is seen that ΔT = 30K cannot be achieved the entire year for all renovation cases. The solution to that is to increase the supply temperature when ΔT=30K is not achieved.

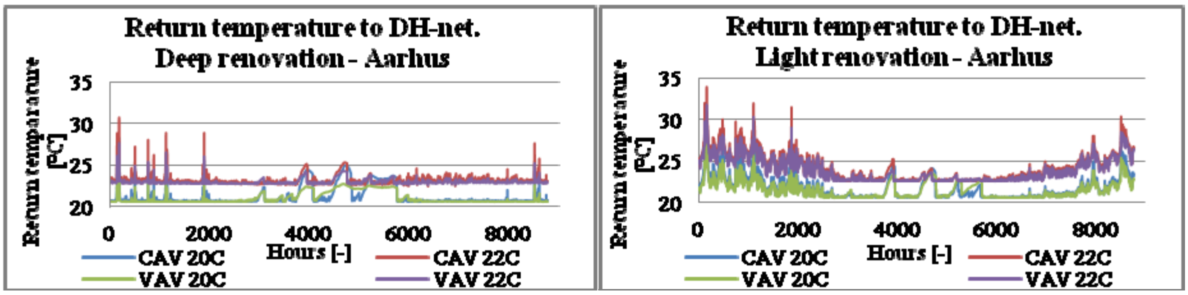

Figure 6: Return temperature to DH-net for building in Aarhus

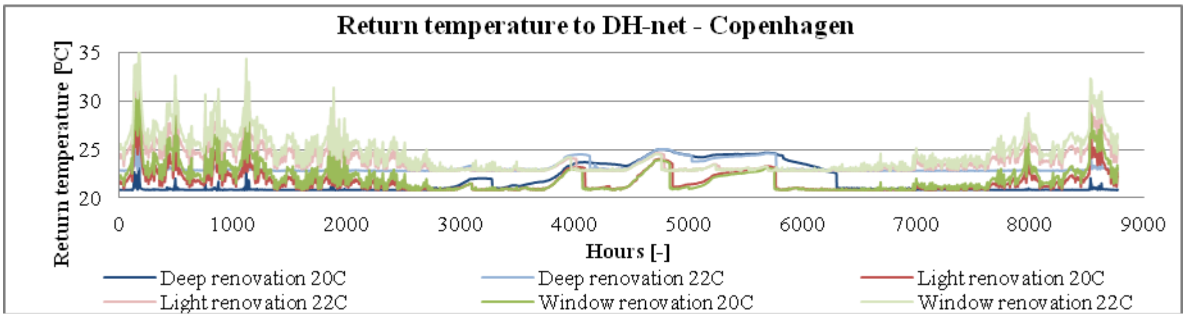

Figure 7: Return temperature to DH-net for building in Copenhagen

4 DISCUSSION AND CONSLUSIONS

Energy renovations have been carried out on two typical Danish building blocks placed in urban areas from the early 1900. It is found that the energy consumption for both buildings can be reduced to what is required for new buildings according to the Building Regulations 2010 (BR10) - approximately 50-60 kWh/m^2 when extensive energy renovation is implemented. This implies a combined solution where the facade, the roof and the basement will be insulated, the windows will be replaced with new energy-efficient windows with solar shading and mechanical ventilation with heat recovery will be installed. This is in agreement with what was found in other studies [11-15].

It has been found that if the expensive facade insulation is excluded it is possible to obtain energy savings of 30-50 % depending on whether the set point temperature for the rooms is 20 °C or 22 °C. The user behavior has a significant impact on the energy savings achieved, which to a larger extend is reflected when fewer refurbishment measures are implemented.

It has moreover been found that the heat load profiles during the year is generally decreased and more constant as a result of the energy renovation, which is of great benefit to heating companies, since they will supply to a more constant need. It will provide a better utilization of the heat capacity and thereby a better economy.

The dimensioning peak load has been found to be reduced by the same percentage as the reduction in the annual space heating, if the dimensioning is based on an average of the 5 days with highest daily average loads. Furthermore it is found that it is possible to achieve an acceptable indoor thermal comfort, with a minimum temperature of 20 °C. The reduction in peak load leads to less investment in new RE supply capacity, which is beneficial for district heating companies. Figure 8 shows the findings for possible reductions in the yearly demands and in the peak loads.

The investigation indicates that it is possible to supply the buildings with low-temperature DH for most hours of the year without compromising the indoor thermal comfort. In very cold periods it might be necessary to increase the supply temperature to 70 °C in order to meet the demands. However this will only be around 5-10 % of the year. If the occupant wants a room temperature of 22 °C then the hours of supplying with 70 °C might increase. The reason why it is necessary to increase the supply temperature is that when low-temperature DH is applied the performance of the radiators is decreased by a factor of 2.5 with an unchanged flow rate. If the flow is increased the performance will increase as well, but in order to obtain an acceptable cooling of the DH-water over the radiator (30K) the flow cannot be increased. It is crucial that the cooling of the district heating water for low-temperature DH application corresponds to traditional system (30K) in order to keep the existing DH-distribution net. Therefore the return temperature is of great importance. It was found that it is possible to obtain a return temperature of 25 °C for most cases. In general the return temperature increases when lower degrees of energy renovations are carried out, and when the set point temperature for the rooms is increased. In these cases it might be necessary to increase the supply temperature from the DH-plants.

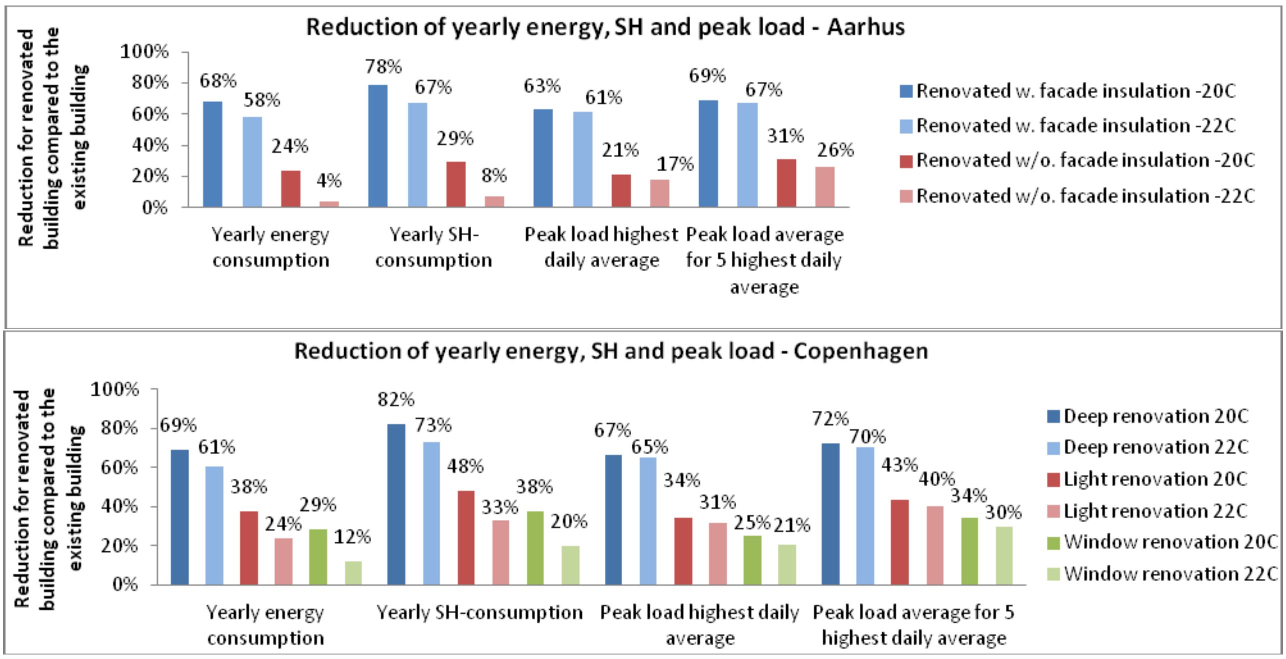

Figure 8: Reduced energy consumption and peak loads. Aarhus (upper), Copenhagen (lower)

REFERENCES

[1] The goverment, The Danish minestery of climate, Energy and Buildings, Vores Energi (in Danish), Copenhagen (2011)

[2] The Danish commission on climate change policy, Grøn Energi – vejen mod et dansk energisystem uden fossile brændsler (In Danish), Copenhagen (2010)

[3] Lechtenböhmer S, Schüring A,The potential for large-scale savings from insulating residential buildings in the EU, Energy Efficiency 2011 4:257–270

[4] Abel E, Low-energy buildings, Energy and Buildings 1994;21(3):169–74.

[5] Thyholt M, Hestnes AG, Heat supply to low-energy buildings in district heating areas: analyses of CO2 emissions and electricity supply security, Energy and Buildings 2008;40(2):131–9

[6] Chwieduk D, Prospects for low energy buildings in Poland, Renewable Energy 2001;16(1–4):1196–9

[7] Karlsson JF, Moshfegh B, A comprehensive investigation of a low-energy building in Sweden, Renewable Energy 2007;32(11):1830–41

[8] Zhu L, Hurt R, Correia D, Boehm R, Detailed energy saving performance analyses on thermal mass walls demonstrated in a zero energy house, Energy and Buildings 2009;41(3):303–10.

[9] R. Hartless, Application of Energy Performance Regulations to Existing Buildings, Final Report of the Task B4, ENPER TEBUC, SAVE 4.1031/C/00-018/2000, Building Research Establishment, Watford, UK, 2003.

[10] Weiss J, Dunkelberg E,Vogelpohl T, Improving policy instruments to better tap into homeowner refurbishment potential: Lessons learned from a case study in Germany, Energy Policy 44 (2012) 406–415

[11] Kragh J, Wittchen KM, Danske bygningers energiforbrug i 2050) (In Danish), SBi 2010:56, Danish Building Research Institute, Aalborg University (2010)

[12] Kragh J, Energirenovering af etagebyggerier (In Danish), 1.edision, The Danish Knowledge Centre for Energy Savings in Buildings, Taastrup (2010)

[13] Lund H, Möller B, Mathiesen BV, Dyrelund A, The role of district heating in future renewable energy systems, Energy 35 (2010) 1382-1390

[14] Rasmussen TV, Post-Insulation of Existing Buildings Constructed between 1850 and 1920, Department of Construction and Health, Danish Building Research Institute, Aalborg University, Hørsholm (2010)

[15] Tommerup H, Lauritsen D, Furbo S, Svendsen S, Olesen B, Andersen, RW, Heiselberg P, Johnsen K, Wittchen K, Rose J, Jensen SØ, Christiansen CH, Katic I, Heerup C, Paulsen O, Olsen L, Pedersen SV, Wit J, Energirenoveringstiltag – katalog (In Danish) , DTU Byg-Rapport R-223, Department of civil Engenieering, Technical University of Denmark (2010)

[16] Reidhav C, Werner S, Profitability of sparse district heating, Applied Energy 85 (2008) 867–877

[17] Harrestrup M, Svendsen S, Planning of the district heating system in Copenhagen from an economic perspective comparing energy-saving versus fossil-free supply, The 13th International Symposium on District Heating and Cooling, 2012, Copenhagen, Denmark.

[18] Plan C, Fremtidig fjernvarmeforsyning i samspil med energirenovering (in Danish) http://www.plan-c.dk/_files/Dokumenter/rapport/rapport_20121121.pdf

[19] Hofor, 2300 København S, Denmark http://www.hofor.dk/fjernvarme/prisen-pa-fjernvarme-2013/

[20] Dalla Rosa A, Christensen JE. Low-energy district heating in energy-efficient building areas. Energy 2011; 36:6890-6899.

[21] Olsen PK, Lambertsen H, Hummelshøj R, Bøhm B, Christiansen CH, Svendsen S, et al. A new-low-temperature district heating system for low-energy buildings. 11th International symposium on district heating and cooling; 2008. Reykjavik.

[22] EFP 2007, Udvikling og demonstration af lavenergifjernvarme til lavenergibyggeri (in Danish). Copenhagen, Denmark: Danish Energy Authority; 2009.

[23] Brand M, Dalla Rosa A, Svendsen S. Performance of low-temperature district systems for low-energy houses. The future for sustainable built environments with high-performance energy systems conference; 2010, Munich, Austria.
[24] EUDP 2008 - II, part 3: Miscellaneous investigations, CO2-reductions in low-energy buildings and communities by implementation of low-temperature district heating systems. Demonstration cases in EnergyFlexHouse and Boligforeningen Ringgården, partly in Danish, available at (June 2012): http://www.byg.dtu.dk/Publikationer/Byg_rapporter.aspx. (2011)
[25] DVGW, "W551 – Trinkwassererwärmungs- und Trinkwasserleitungsanlagen",1993, Bonn, (in German)
[26] Efsen Engineering A/S, DK-2950 Vedbæk, Denmark, http://www.efsen.dk/water-disinfection (Reached 17.12.2012)
[27] Teknikmarknad, Reduced tap water temperatures and increased Legionella protection, Report Teknikmarknad 201203_EN, Stockholm, Sweden (2011)
[28] L. Gustavsson, A. Dodoo, N.L. Truong, I. Danielski, Primary energy implications of end-use energy efficiency measures in district heated buildings, Energy and Buildings, 2011;43:38-48
[29] Tol HI, Svendsen S. Operational planning of low-energy district heating systems connected to existing buildings, Internaltional Conference on Renewable Energy: Generation and Applications, ICREGA 12; 2012, Al-Ain, United Arap Emirates
[30] Tol HI, Svendsen S. Optimal dimensioning of low-energy district heating networks with operational planning – case study for existing buildings, 11th International Conference on sustainable Energy Technologies; 2012, Vancouver, Canada.
[31] BYG-ERFA Erfaringsblad 09 10 29, Indvendig efterisolering af ældre ydermure (in Danish), 2750 Ballerup, Denmark, www.byg-erfa.dk
[32] M. Morelli, L. Rønby, SE. Mikkelsen, MG. Christensen, T. Kildemoes, Energy retrofitting a multi-family building to a "nearly-zero" energy building based on experiences from a test apartment.
[33] EQUA, IDA-ICE 4, www.equa.se/ice/intro.html, reached March 2013.
[34] Korado, www.korado.com, reached March 2013.
[35] Tommerup H, Svendsen S. Energy savings in Danish residential building stock. Energy and Buildings 38 (2006) 618-626.
[36] Danish Energy Agency, Danish Building regulations (BR10), www.bygningsreglementet.dk/, reached March 2013.