Energy Renovation of Buildings for Combined Use in Existing Urban Area

Marlene Stenberg Hagen Eriksen

Master Thesis

26 April 2010

DTU Byg

Title:

Energy Renovation of Buildings for Combined Use in Existing Urban Area

Project Period:

October 2009 – April 2010

Supervisors:

Carsten Rode

Peter Weitzmann

ECTS Points:

35

Comprise:

Main report

Appendix

CD

Preface

The present project is a Master thesis prepared at DTU Byg, Department of Civil Engineering from October 2009 – April 2010.

The thesis is an individual project, inspired by the CONCERTO project, ECO-life, concerning development of a CO_2 neutral urban area in Høje-Taatrup Municipality.

This project contains an investigation of the potential for energy renovation of the existing buildings in the area, verified by a case study.

Thanks are owed to those who during the project have shared information, knowledge and time for discussion.
Especially Steen Olesen from Høje-Taastrup Municipality,
Reto Hummelshøj from COWI, Hedehusene District Heating,
Høje Taastrup District Heating, and the citizens of Hedehusene who contributed with information of buildings in the existing area.

Further thanks are owed to family and friends for patience and support during the project.

26 April 2010
Marlene Stenberg Hagen Eriksen

Abstract

The present project is an investigation of the energy renovation potential of buildings in an existing urban area.

The project is inspired by the CONCERTO project ECO-Life that concern development of a CO_2 neutral urban area. A smaller part of the project area concern existing buildings along Hovedgaden in Hedehusene. Those buildings are investigated in the present project.

A survey of the area is conducted to clarify the initial energy conditions of the buildings and the energy supply in the area. It is based on information in the BBR directory and interviews with citizens in the area.

With the initial survey as underlying basis, general energy renovation proposals are presented and evaluated regarding the existing buildings in the area. The result of the evaluation showed a large renovation potential for several building types in the area.

To verify the showed potential of energy renovations calculations are done by use of BSim and BE06.
A representative building for combined use is investigated regarding individual energy renovation proposals. The results show that replacement of windows, re-insulation of external walls, tightening of the building envelope and an energy renovation of the heating system cause the largest decrease in the heating demand of the building.

A combination of the proposals was further investigated. The results of an extensive renovation show large potential for the reference building. The energy consumption is decreased 77 %. Furthermore the building fulfills the regulations for new buildings in the current building regulation, BR08.

The method used for evaluation of the renovation potential is discussed along with considerations of a general potential in Denmark. Finally barriers for performing energy renovations and possible solutions are discussed.

Table of Contents

1 Introduction

With an increasing awareness of energy consumption and CO_2 emission in the population, several municipal initiatives for reducing the CO_2 emission have been presented around Denmark during the last years. A main part of the initiatives is a reduction of the energy consumption for operation of existing buildings, as it constitutes 40 % of the total energy consumption in Denmark.

In the Danish municipality Høje-Taastrup the aim is to become CO_2 neutral in 2022. As part of this a new CO_2 neutral urban area (1) is developed and realised in the CONCERTO project ECO-life (2). In the project part of the aim is to optimise both existing buildings and the energy supply in order to make it more efficient and sustainable. The existing buildings should be renovated to the standard for new buildings.

The above has inspired to this project. It aims at being a preliminary investigation of the possibilities for energy renovation of existing buildings in the northern part of the project area, Vision Gammelsø.

This project will present a preliminary investigation of the area that will survey facts of the area investigated and of the buildings regarding age, use, etc. Further it will contain information of the existing energy supply in the area and future plans for this. The information will primarily be obtained from the BBR directory and citizens in the area. The survey leads to a categorisation of the existing building stock in the area.

The survey is followed by a description and an analysis of relevant energy renovation proposals for the buildings in the area. The proposals are evaluated regarding influence on the energy consumption, the expenses, and the existing energy supply. The aim of the energy renovation proposals is to reach low energy consumption, mainly independent of economic reflection.

To verify the energy renovation proposals presented, a building type is chosen for a case study. In the study the proposals will be individually investigated by use of relevant building calculation tools and the influence on the energy consumption of the building will be evaluated. Further it is investigated how low energy consumption can be obtained by combination of the presented proposals.

In conclusion the results found in the case study will be discussed and it will be evaluated if the existing buildings should be renovated or demolished. The barriers preventing implementation of energy renovation will be clarified with relation to the present project and possible solutions will be discussed.

2 Preliminary Investigations of Hovedgaden in Hedehusene

In this section a preliminary investigation of an existing town area around Hovedgaden in Hedehusene will be performed.

2.1 Investigation Demarcation

The investigation is initiated with a demarcation of the area. It is followed by a section describing the main framework and regulations for the specific area.
When the overall guidelines are presented a short historical draft of the area and a minor registration, mainly regarding traffic and buildings in the area is performed.

Basic information of buildings will be sought in the national directory of buildings, BBR (Bygnings- og Boligregistret), from where information of all buildings in Denmark can be extracted. BBR contains information of age, use and size of the buildings as well as larger renovations and type of energy supply. Further general information of the energy supply and the individual energy consumption of the buildings are sought.
This is followed by an investigation of energy renovations performed on buildings in the area. However the amount of information obtainable is depended on the willingness of the owners. Finally the buildings in the area are divided into groups and the representative building type is described.

The investigations done will be used as underlying basis for analyses of the energy condition of the buildings and to propose renovations.

2.2 Area Demarcation

Hedehusene is a typical Danish provincial town, with a train station, a trade area near the station, and large areas with mostly low-rise terraced houses. The area is the northern part of Vision Gammelsø (3), where a part of the stated goal is to renovate existing buildings to fulfil the present building regulations (2). In appendix F a map of the area for Vision Gammelsø can be seen.
The area investigated can be seen in Figure 1 marked by the red dotted line.

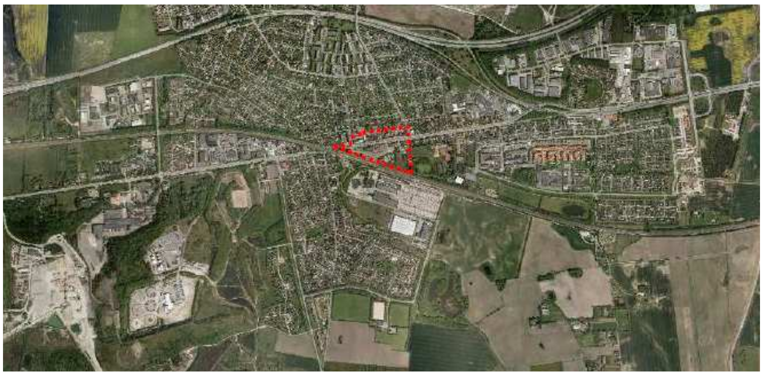

Figure 1 Hedehusene seen from above; North is up, the map is not dimensionally stable (4).

In Figure 2 a more detailed photo of the area can be seen. The area is still marked with the red dotted line.

Figure 2: The area investigated; North is up, the map is not dimensionally stable (4).

Towards north the area is demarcated by large parking spaces spread over large areas. The parking area is located under the red line in Figure 2. Towards east, the area is demarcated by Kallerupvej and Hedevolden. Towards south the area is demarcated by the railway and towards west, the demarcation is Vesterkøb. The roads can be seen in Figure 3 or in larger scale in appendix F.

Figure 3 the road system in the investigated area; north is up, the map is not dimensionally stable (4).

The road going by the train station and Gammelsøhøj is Hotelvej, the name is not displayed in Figure 3.

2.3 Current Regulations in the Area

The plans and visions for the area can be seen in the development strategy, the municipality plan for land use, guidelines for use of urban areas, and the local plan. In the following section the relevant parts of the plans for the area will be sketched.

In the municipality plan from 2006 strategies for Vision Gammelsø are presented, thus including strategies for the area investigated. It is stated that the existing area around the train station and Hovedgaden need to be changed both regarding area use and functionality, thus break down the physical and visual boundary the railway is. Further good connections between the old and the new parts of the town are important both for vulnerable road users and cars (5).

In the development strategy 2010 it is described that the Vision Gammelsø area is meant to contribute to a general lift of Hedehusene. The vision is that development of the area will result in a unified town where the existing part of Hedehusene is natural connected to the Vision Gammelsø area.

In order to integrate the existing town area and the new area, an overall program for Vision Gammelsø has to be developed and it is important that sustainability is taken into consideration as part of the development of the town area (3).

In the framework plans for the area a description of the plans regarding use of the area and magnitude of the buildings is given. The area around Hovedgaden is for centre purpose, including retail, clinics, offices, public services, cinemas, hotel, restaurants and other non profiting amusements. In the area the magnitude of the plot ratio for buildings may not exceed 50 percent. However if a compiled project securing parking and recreational areas is presented it is possible to increase the plot ratio up to 60 percent. Buildings along Hovedgaden have to be built in 2-2½ stories facing the street and the centre can go up to 4 stories (6).

The future plan for the area, according to the municipality is an architectural competition, that can fulfil the requirements set in the development strategy and the framework plans. With an architectural competition it might be possible to make a densification of the area (7).

It is evaluated that energy renovation of buildings in the existing area would contribute to lifting the area and unifying it with the new area developed.
As the plot ratio in the area has not reached 50 percent, there are still possibilities for development of the area. Therefore the plans for the area will not limit the energy renovation proposals for the area; instead there is a possibility to integrate the energy renovation as a part of the larger plans for the area.

2.4 Buildings Listed or Worthy of Preservation

As part of the survey, it is investigated to what extent the buildings are listed or worthy of preservation. A listed building is administrated by the state while buildings worthy of preservation are administered by the municipality. They can point out buildings in the municipal plan or devise district plans that state rules for preservation. The city council have to approve of changes regarding the expression of the building. A building is typically pointed out as worthy of preservation due to its local importance (8). In the municipality of Høje-Taastrup there are no listed buildings.

The area investigated is assigned to the town plan 4.18. However several sub areas have been designated to smaller district plans that overrule 4.18. The district plans are numbered

4.18.x. In those, a few buildings is characterised as worthy of preservation. Their categories are unknown.
The buildings concerned is the old railway station parallel to the railway, the old post office and an old warehouse that relates to the station (9). In the same area Hovedgaden 437D is placed. It is also worthy of preservation and specific regulations for the building is set in (10). The last building worthy of preservation is located on the corner of Hovedgaden and Kallerupvej indicating the beginning of Hovedgaden (11).

In the area between Hovedgaden and the railway a burial mound worthy of preservation is placed, the placement is described in 4.18.6.

The number of buildings worthy of preservation is limited thus evaluated not to prevent an overall energy renovation of the area. It is allowed to change the inside of the buildings thus it should be possible to make reasonable energy renovation. In (12) a project of energy renovation in listed buildings can be seen.

2.5 Area History

The town, as it is known today, is built up around the station area, where the first station was build in 1847. This building however, was demolished in favour of the station seen today. The first house in Hedehusene can be dated back to 1642.

The development of the town started in the late 1890s, where the first shops where established along Hovedgaden. The late development was due to the location less than one Danish mile (7.5 km) from Roskilde and thus treating regulations made it illegal to built houses for merchants. The growth of the town was caused by large factories such as the tileworks or the gravel plant, mainly situated south and west of the railway. As the factories caused the growth, Hedehusene developed into a town of workers up through the first part of the 19th century.
Today most of the old industrial companies are no longer active and the town is a suburb of Copenhagen with a town centre, a few larger shops and a couple of office buildings built from 1970s – 1990s as well as smaller shops that still remain and in use (13).

2.6 Area Description

When looking at the area of investigation there is some main things worth of registration.
The railway cut the town into two and is noisy when trains pass by. The four tracks running are heavily trafficked with 13 passenger trains and 2 goods train an hour (14), as this is a part of the railway connecting the western and eastern part of Denmark. Trains stop in Hedehusene typically twice an hour and in the rush hour up to four times an hour in both directions. In connection with the railway are the train station and a bus terminal that at north borders to parking areas for the shopping centre.

The main street, Hovedgaden, cuts through the area leading cars from Roskilde to Copenhagen. Previously this road was the main road between the two cities; however in the 1960s a highway was built north of the town which eased the traffic at Hovedgaden (13). At both sides of the road there are pavements, cycle track and possibilities for car parking. The road has two tracks and is separated by traffic islands through the area investigated. Pedestrian crossings are only seen in relation to larger intersections by Vesterkøb and Kallerupvej see appendix F.

2.7 Knowledge of Buildings in the Area

In this section knowledge obtained of the buildings in the area is presented.

2.7.1 Age and Use of Buildings in the Area

The area around Hovedgaden consists of three different types of building as seen in Figure 4. Residential buildings indicated with blue, buildings for commercial use indicated with red, and buildings for combined use indicated with green.
The categories are based on information from BBR, and are not evaluated regarding the amount of square meters used for either of the purposes.

Figure 4: Marking of different use of buildings in the area. Green is combined use, blue is residential use and red is commercial use, the map is not dimensionally stable, north is up (4).

In the area north of Hovedgaden most of the buildings are built mainly in the beginning of the 19th century and until the 1950s. A few are built later on during the 1970s and until now. The buildings from the early period account for almost half of the buildings in the area and are mainly for combined use. They face Hovedgaden since smaller shops in the ground level are entered from there. Parts of the buildings have within the last 10 years been refreshed with new paint on the facades.

In the area south of Hovedgaden the age of the buildings are diverse. In the south east corner of the area along Hedevolden the buildings were built during the 1960s and are residential buildings typical of the time. Along Hovedgaden the larger buildings containing shops are built from the 1970s and up until now. In appendix A more specific notes of the age etc. of the buildings can be seen. The information is based on information in BBR.

As the description indicates there is a large diversity of the buildings in the area. Most buildings are for combined use, followed by buildings for residential use and the buildings for commercial use are the fewest. In Figure 4 it can be seen that no buildings for residential use are located along Hovedgaden, they are drawn back from the street, where the buildings for commercial or combined use are located.
Buildings for combined use are a quality for the combined life in a small town as Hedehusene.

2.7.2 Specific Knowledge of Buildings in the Area

To obtain more specific and private information as heating costs, a letter was sent out to the citizens in the area. The letter can be seen in appendix B. Large parts did not respond to the request in the letter and telephone calls were therefore performed.

In general, the participants responding to the letter was owners of residential buildings. Many buildings north of Hovedgaden are owned by one part and administrated by another, which in many cases led to loss of the request. However, some administrators were quite willing to participate with information of heating cost when requested by telephone. The result was participation around 24 %.

From the interviews performed as much information on the buildings as possible were collected. No specific buildings were chosen, regarding telephone contact, but it was tried to obtain knowledge of buildings from all time periods and for all types of use.

The amount of information obtained was diverse, and the main priority was to get information on the heating costs and energy renovations performed. Most administrators had no knowledge of constructions and systems in the buildings and in these cases only information of heating costs were recorded. The owners of the buildings were more often able to answer specific questions of the building envelope and the technical installations.

The investigations showed that most buildings during time have been renovated or otherwise had an extension. Even though the information found in BBR is of little detail, it can be seen that renovations mainly took place around or during the 1990s. A review of some building projects in the municipality archives show that several citizens, in the late 1970s and 1980s, utilised a subsidy from the state to renovation of buildings. Typically the windows have been replaced or the amount of insulation at the ceiling has been increased. Information obtained can be found in appendix A.

As most renovations have been performed in the 1990s or earlier the buildings a potential for an extensive energy renovation is expected. There are of course buildings recently energy renovated or newly built, which due to their energy standard is of little interest, yet they are evaluated to be few.

It is evaluated that the information obtained are not enough to be representative for all building types in the area, however it indicates an overall standard.

2.8 Existing Energy Supply in the Area

The energy supply is investigated to find out if it is possible to take in the supply as a part of the energy renovation of the area. This investigation is performed with information from BBR, Hedehsuene District Heating, Høje Taastrup District Heating, and the building owners.

2.8.1 Registered Energy Supply

In the area a large part of the buildings are connected to the local district heating central. There are however no obligation for connection thus some buildings have an alternative supply. In appendix A information of the supply in the buildings can be seen. The existing district heating grid in the area is seen in Figure 5, north is up (15).

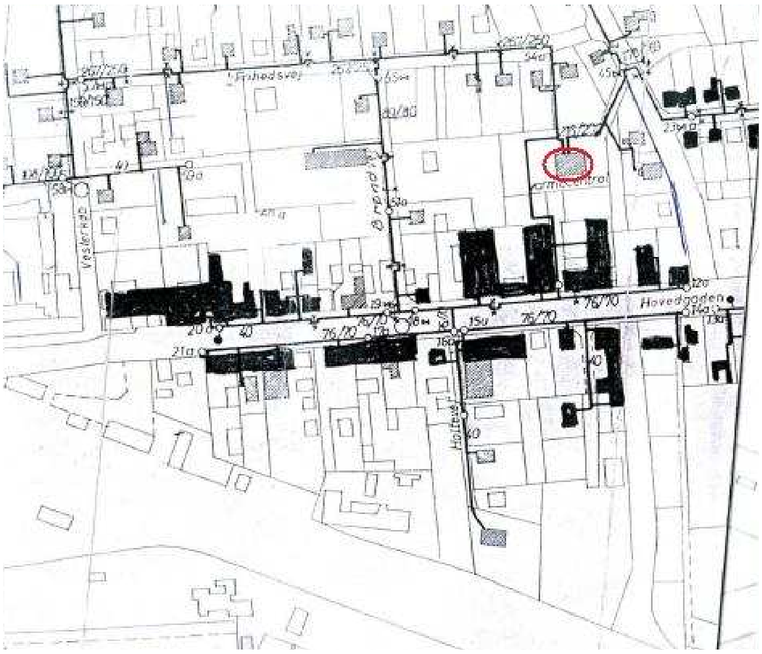

Figure 5: District heating supply in the investigated area. The district heating central is marked with a circle (15).

As seen, two main pipes are supplying the district heating area. One pipe supplies the eastern part of the district heating area, and the other pipe supplies the western part of the district heating area. The western supply is, shortly after leaving the central, divided into two pipes. One pipe is going north supplying larger areas north and northwest of Hovedgaden (outside the figure).

The other part of the western supply pipe is going south supplying the area around Hovedgaden. As can be seen there is a connection between the north and south pipes along the street Brøndvej. The location of Brøndvej can also be seen in appendix F. The detached string supplying the buildings around Hovedgaden leaves possibility for an area with low temperature district heating.

In the buildings there are both direct and indirect district heating according to the citizens. Unfortunately, it has not been possible to get information on the technical or common regulations for district heating delivery or information of energy consumption in the area from Hedehusene District Heating due to illness.

In the area approximately 10 buildings are not connected to the district heating grid. Those are located in the south east and south west parts of the area. The buildings in those areas are mainly supplied by fuel oil.

The district heating is supplied from the energy transmission company VEKS, where a large part of the energy production is based on waste incineration. The CO_2 emission from the production is for Høje Taastrup District Heating 131 g/kWh (16) and it is estimated that the value for Hedehusene District Heating is the same.

2.8.2 Plans for Future Energy Supply in the Area

The local district heating company is placed in between areas of Høje Taastrup District Heating, thus have no possibilities for further development. The district heating pipes in the area around Hovedgaden have furthermore been renovated in 2004-2005, thus there are no plans of renovating in near future (15).

A merger between Hedehusene District Heating and Høje Taastrup District Heating have for a long time been a wish from the municipality, as it would result in savings. A negotiation of a merger is ongoing and Høje Taastrup District Heating expects to deliver a recommendation of the merger at the end of April 2010. As a part of this, a technical report with status of the two systems is delivered at the end of January 2010. This is to determine at what state the district heating grid are in and to be able to evaluate the economical consequences of a merger (17).

2.9 Categorisation of Buildings in the Area

In this section the buildings in the area will be divided into groups in order to present qualified renovation propositions.
Typical constructions and systems of the buildings are described.

2.9.1 Building Types in the Area

The subdivision of the buildings is based on the information presented in the sections above and in appendix A. When there is no exact knowledge of the buildings they are classified by the building regulations valid at the time they were built according to BBR.

The division criteria are use of the building, the year it was built according to BBR and for some the possibilities for renovation. The time period are divided with regard to changes in building styles or building codes. A short draft can be seen in appendix C. In Table 1 the groups can be seen.

Table 1 Groups of buildings in the area.

Group	Building Type	Time period
A	Combined	1890-1929
B	Residential	1890-1929
C	Commercial	1890-1929
D	Combined Residential	1930-1949
E	Combined Residential Commercial	1950-1960
F	Combined	1961-1979
G	Residential	1961-1979
H	Commercial	1961-1979
I	Combined	1980-
J	Residential	1980-
K	Commercial	1980-

2.9.1.1 Group A - Buildings for Combined Use 1890-1929

The largest group of buildings is compiled in this group. It includes most buildings along the north side of Hovedgaden and few on the south side. There are two building types equally represented in this category; examples of those can be seen in Figure 6. In the buildings the commercial part of the buildings is typically the largest.

Figure 6 Examples of buildings for combined use from the period 1980-1929.

It is evaluated that most of the buildings in this group are built with massive brick walls, due to the time they are built. Buildings from the last part of the period might have hollow walls as this technique found favour in the late 1920s and the

1930s. The original windows are with one window pane and could be in both wooden and steel frames. The roof constructions are originally made with the common used timber size of the time assumed to be 5.5” to 6.5”.
If the buildings have a basement or a crawl space, they are typically unheated. The horizontal divisions originally are wooden with an integrated layer of clay to prevent fire from spreading. The energy supply is district heating in the majority, only a few are supplied with liquid fuel.
It is assumed that some of the buildings have installed mechanical exhaust or ventilation.

During time renovations have been performed on all buildings, both to reduce the consumption of energy and maintain constructions. Typically one pane windows are replaced by double glazed windows and the ceiling is re-insulated.
Initially, it is expected that there is a renovation potential in re-insulation, replacement of windows, tightening of the building and renovation of the heating central.

2.9.1.2 Group B – Buildings for Residential Use 1890-1929

The group contains only three buildings from around 1900 that are all for residential use.

Figure 7 Hovedgaden 504B a building in group B.

The constructions of the buildings in this group are very alike the ones in Group A. However it is assumed that all are built with massive brick walls. One of the buildings is even with timber framing.

For two of the buildings it is known that energy renovation has been performed by replacement or improvement of windows. Further, there is known of re-insulation in one of the buildings. Ongoing maintenance during the years, including energy renovations, is expected as the buildings are private residential buildings.

Still there is an energy renovation potential for the buildings in this category. It is evaluated that re-insulation, replacement of windows and optimisation of the heating central are relevant proposals.

2.9.1.3 Group C - Buildings for Commercial Use 1890-1929

Only a few buildings from this time period are only for commercial use. Two of the four buildings can be seen in Figure 8.

Figure 8 Buildings in group C.

The buildings in group C are initially the same as presented in Group A and B regarding constructions and heating installations. However as they are for commercial use installations for lighting and ventilation are common.

Buildings of this age have been maintained during the years and energy renovations to some extend has been performed. However, it is difficult with certainty to determine to which extend. In all probability large parts of the hollow walls have been re-insulated and the windows have been replaced.
A potential for renovation regarding re-insulation, replacement of windows and an optimisation of the lighting and ventilation systems are expected.

2.9.1.4 Group D – Buildings for Combined and Residential Use 1930-1949

It is chosen to compile commercial and residential buildings in one group since there are only three buildings from this time period. Further two of the buildings are worthy of preservation. Two examples of buildings in this category can be seen in Figure 9.

Figure 9 Tow of the buildings in group D, both worth of preservation.

For the buildings in this group two ways of constructing external walls are equally alike. One is massive walls at the ground floor due to construction stability and at the first floor hollow walls due to general shortage during the time period. The other type of wall is with a back wall of concrete, a cavity and facing of bricks.

It is evaluated that the horizontal division towards the ground, a basement or crawl space is cast concrete. In this time period all constructions are minimised, to make them appear simple and light, thus original windows is with steel frames and one window pane. As insulation gained acceptance during this time period, there might originally be 2 to 5 cm of insulation in the construction. The roof constructions are expected to have standard measure of the time, assumed to be 5.5” or 6.5”.

The buildings are heated with district heating and one is heated by electricity.

As the group contain buildings worthy of preservation the renovation performed on the outside during the years is assumed to be scarcely. Double glazing has most likely been implemented or the windows have been replaced.

Further hollow walls might also have been re-insulated.

It is most likely possible to optimise the lighting system in the buildings for combined use. For all buildings it is possible to optimise the heating central or replace the existing heating supply.

2.9.1.5 Group E – Buildings for Combined, Residential and Commercial Use 1950-1960.

In this group the main common characteristic is the time period as it only contains four buildings. In Figure 10 a building in the category is seen.

Figure 10 Hovedgaden 425 is one of the buildings in group E.

The buildings are evaluated to have hollow walls with a brick facing. The construction might be scarcely insulated on the inside. The divisions are of concrete and there might be a basement or a crawl space.

The windows are double glazed windows. The roof is of typical timber size used at the time. In this time period also flat roofs are used.

During this time period central heating becomes common, thus it is evaluated that the buildings are originally equipped with a central heating system.

The buildings for commercial use are expected to be equipped with ventilation and lighting installations.

It is expected that renovation, also regarding energy, has been performed. However it is unknown to what extent. It is assumed that hollow walls have been re-insulated and that windows have been replaced.

In this category there is potential for energy renovation. It is possible to re-insulate, replace windows, optimise or renovate the heating central and for the commercial buildings large savings on the lighting and possibly ventilations systems is expected.

2.9.1.6 Group F – Buildings for Combined Use 1961-1979

The group contain three buildings with a large area and a central location in the townscape. Two of the buildings can be seen in Figure 11 below.

Figure 11 Hovedgaden 514A-516A two buildings in group F.

The buildings are evaluated to have a framework of reinforced concrete. The horizontal divisions are un-insulated concrete slabs. The envelope is furthermore of elements mounted on the framework and insulated corresponding to the building regulations at the time. The windows are doubled-glazed and the buildings contain installations for both hot water and heating.
Ventilation of the buildings is expected to be in accordance with the buildings regulation of the time they were build.

In this group no larger energy renovations are expected. However it is known that a new heating central have recently been installed in one of the buildings and in another it is a future plan. Further the building envelop could be re-insulated, the ventilation and lighting systems could be optimised. This is expected to reduce the energy consumption significantly.

To be able to finance a renovation of the building envelope, a well known opportunity is to mount prefabricated penthouses on the existing roof. This is possible as the building constructions are of reinforced concrete and the roof is flat (18). Regarding energy it is an advantage as the roof does not need to be insulated and the amount of insulation in the new constructions is not limited by existing constructions.

Since this solution is only relevant for this type of building, it will not be further investigated.

2.9.1.7 Group G – Buildings for Residential Use 1961-1979

The group contains residential buildings from the 1960s located along Hedevolden.

The buildings can be characterised as typical Danish standard houses from the time period. They are built of massive Leca blocks in a thickness of 21-23 cm. The roof was originally flat also of Leca blocks. There is a crawl space where pipes for water and heating are led. The buildings are originally with double-glazed windows and naturally ventilated. All the buildings are supplied with fuel oil.

Several of the buildings have been renovated, also regarding energy. This includes re-insulation of outer walls and ceiling when constructing a roof with a rise, as well as new or partly new installations for heating.
Proposals for energy renovation of this building type are a well developed field. An example can be seen in (19).

2.9.1.8 Group H – Buildings for Commercial Use 1961-1979

The only building in this group is the centre. The building can be seen in Figure 12 below.

Figure 12 Hovedgaden 429, the centre, it is the only building in group H.

The building is built with a framework of reinforced concrete, horizontal divisions of un-insulated concrete slabs and a flat roof. The envelope is evaluated to be scarcely insulated and windows are expected to be double-glazed. Ventilation of the building is expected to be in accordance with the building regulation of the time it was built.

It is unknown to how large extent the building has been renovated, however nothing regarding energy is expected. There is a large renovation potential in this building, however, this should be seen in a larger perspective of the general planning of the area and will therefore not be investigated further.

2.9.1.9 Group I – Buildings for Combined Use 1980-

This group contains only one building, which can be seen in Figure 13.

Figure 13 Hovedgaden 417-419 a building for combined use in Group I.

The building is from the early 1980s and built as prescribed in the building regulations of the time. The building envelope is of light concrete, insulation and bricks and the windows are double glazed.

There has probably been no energy renovation of the building envelope or the installations in the building. The potential is therefore evaluated to be large, for example by reuse of surplus heat generated by freezers.

2.9.1.10 Group J – Buildings for Residential Use 1980-

There are only two buildings in this group. The buildings can be seen in Figure 14.

Figure 14 Kallerupvej 1A-B is the only buildings in group J.

They are built in 2007 and are so resent that energy renovation is evaluated not to be cost-effective, thus there will be no proposals in the following for the buildings in this group.

2.9.1.11 Group K – Buildings for Commercial Use 1980-

The largest group of buildings for commercial use is compiled in this group. All the buildings are placed south of Hovedgaden and examples can be seen in Figure 15 and Figure 16.

Figure 15 Hotelvej 11 a typical building only for commercial use from 1987.

Figure 16 Hovedgaden 407 another typical building for commercial use from 2002.

The main part of the buildings in this group is built according to the building regulation of 1982. The constructions are designed to meet the U-values required at the time.
The ventilation system is designed with reference to set values for the specific rooms. Further the regulations demanded an effective energy recovery, however, exceptions were possible if this could not be reasonable implemented.

It is evaluated that there has not been performed any energy renovation since construction and that a potential is present. However the proposals might not be cost-effective as the initial standard of the buildings are acceptable.

2.10 General Energy Condition of Buildings

In general the area is characterised by a few newer and many mainly older buildings. The level of energy renovation of the buildings during time has been difficult to obtain.
However, investigations indicate a large potential and need for energy renovation of the existing buildings, both regarding constructions and systems in the buildings.

An energy renovation is assumed to be comprehensive for most buildings in the area in order to reach low energy consumption.

This might change the expression of the buildings, which gives rise to a discussion of architectural characteristics and the importance of maintaining characteristics in the area.

It is evaluated that only a few buildings besides the buildings worthy of preservation have been kept in coherence with the original architecture. An extensive energy renovation is therefore a possibility to effectively lower the energy consumption in the area, reinstate significant architectural features and obtain a common expression in the area around Hovedgaden.

A specific investigation of the buildings in group A will be performed to document the potential for a reduction of the energy consumption. Group A is chosen as the building type are high represented, thus renovation of those buildings would have significant influence on energy savings in the area.

2.11 Energy Renovation as Part of an Overall Town Strategy

In this section energy renovation of the buildings are tried set in perspective of the overall town strategy.
A clear vision according to the municipality is to integrate the existing area around Hovedgaden and the area of Vision Gammelsø south of the railway. This is supported by the aim of the ECO-life project where it is stated that buildings in the existing area should be energy renovated.

In section 2.3 the regulations and visions for the existing town area is shortly described. On this basis this section will contain ideas and suggestions of how the two areas can merge and appear as a common town centre for Hedehsuene. The suggestions will have a reduction of the energy consumption and an energy renovation as the motivating factor.
The ideas are emerged during a study trip to the area in December 2009 together with several smaller walks through parts of the area during the project period.

2.11.1 Suggestions for a Common Town Centre

To integrate the two areas a physical connection across the railway is needed both for vulnerable road users and for car traffic.

This connection could for example be an extension of a by-street of Hovedgaden between no. 407 and no. 415 as shown at Figure 17. Along the new street low energy buildings with same use as seen along Hovedgaden could be built, and in that way the new connection would be a natural extension of Hovedgaden. Further an architectural appearance like found in the old buildings along Hovedgaden would merge the new low energy area and the older town centre.

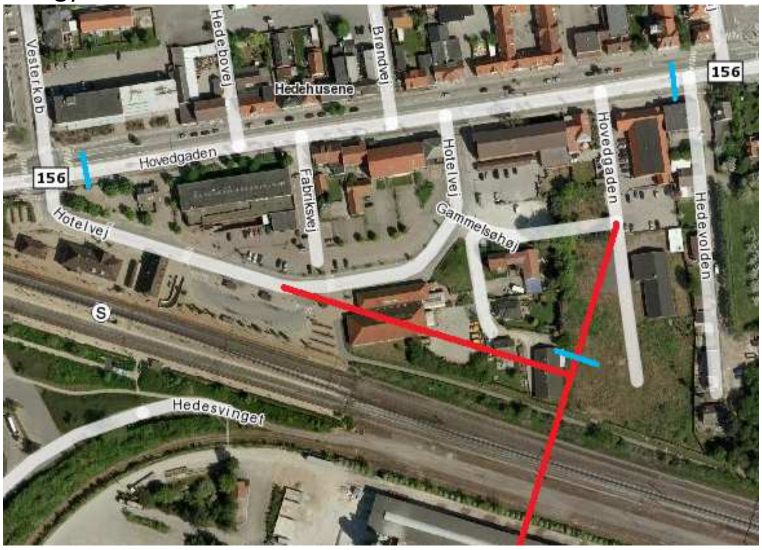

Figure 17 Connection across the railway, the figure is not dimensionally stable (4), north is up.

A further development of the solution could be closing of Hovedgaden and a part of the new connection for car traffic. This is shown with light blue marks in Figure 17. Instead car traffic is lead of an extension of Hotelvej by the station.
The solution naturally leads the pedestrians from the Vision Gammelsø area into the old town centre. The closing of the main street would give space for an extensive energy renovation of the existing buildings. Further there would be possibilities for small green oases with focus on renewable energy, for example small windmills and LED street light.

The presented plans would cause large changes in the street life. An energy rehabilitation of the buildings in the area around Hovedgaden would be a natural part of the changes in the area. Further the solution proposed brings knowledge of energy savings into the street life by windmills or street speed bumps generating electricity for street lighting or charging stations for electrical cars.

An alternative connection between the existing area around Hovedgaden and the Vision Gammelsø area could be along the existing street Hedevolden, see Figure 17.
The slope in the terrain from Hovedgaden towards the railway could be utilised by letting the new road be in the same level as

Hovedgaden and the space underneath the road could be used as car parking facilities.
This however would not integrate the new and the existing town centre, but might be more effective regarding traffic.

The proposals presented are seen in perspective of energy renovation of the buildings and the area. It is not a final proposal but ideas of how energy renovation can be a part of the overall strategy in the area.

3 Renovation Proposals

In this section general energy renovation proposals will be presented with reference to experience from the Danish energy labelling arrangement or literature where the proposals are further described.

3.1 Aim of the Energy Renovation Proposals

The aim of the energy renovation proposals is that they in combination can decrease the energy consumption classifying the buildings as a Low Energy Class II buildings or better.

The proposals are divided into five overall topics, under which more specific renovation proposals are presented. The presentation will connect the general proposals to the specific building types presented in section 2.9.1 by use of tables. In those tables proposals relevant for the specific building types are indicated with a dot. For some groups there are several dots as the groups contain buildings for different use.
The content of the proposals are described underneath the tables. The influence of a proposal on the energy consumption is expressed as an obtainable U-value for the construction. This is chosen, as the need for improvement is dependent on the initial situation, as are the possible savings. In all proposals the point of reference is typically none or sparsely insulation.
It is chosen not to evaluate the proposals from cost-effectiveness point of view. It is expected that a low energy class cannot be obtained if only cost-effective proposals are considered as profitability of an initiative decrease with a higher initial standard of the building. A statement of the expenses of the proposals is however presented.

The five overall proposals are presented in order of which proposals typically would be recommended performed first. They can be chosen and conducted as individual renovation initiatives. However, some of the proposals are recommended combined to optimise the energy renovation, as will be pointed out in the text.

3.1.1 Regulation for Energy Demand in Buildings

In the present Danish Building Regulations, BR08, the energy demand of the building is dependent on the use of the building.

The energy demand includes energy for heating, hot water production and electricity for building operation. In residential buildings the electricity for building operation includes pumps and fans, whereas for commercial buildings lighting is also included in the calculation. To encourage a reduction of electricity for building operation it is multiplied by 2.5.

For new residential buildings, dormitories, hotels etc.:

- BR08 standard: (70 + 2200/A) kWh/m^2/year
- Low Energy Class II: (50 + 1600/A) kWh/m^2/year
- Low Energy Class I: (35 + 1100/A) kWh/m^2/year

For new buildings used for offices, schools, institutions etc.:

- BR08 standard: (95 + 2200/A) kWh/m^2/year
- Low Energy Class II: (70 + 1600/A) kWh/m^2/year
- Low Energy Class I: (50 + 1100/A) kWh/m^2/year

A is heated floor area (gross area)

For buildings for combined use the energy demand is weighted between the residential and commercial parts. If one use is equal to or larger than 80 % of the floor area or more than this will dictate the energy demand.

If a renovation concern more than 25 % of the building envelope or 25 % of the latest public property value the building part or system has to fulfil the current regulations in BR08, if the initiatives individually are cost-effective.

BR08 contain both the requirements for the energy demand and maximum U-values for different constructions (20).
However by use of the values the energy consumption will not correspond to a low energy class, thus the values recommended for passive houses are used as guideline.

- The U-values of exterior walls, floors and ceilings should be ≤ 0.15 W/m^{2}K, but for buildings in open sites the values is recommended to be 0.08-0.10 W/m^{2}K.
- The U-value for windows including linear losses should be < 0.85 W/m^{2}K.
- The g-value for window panes should be ≥ 0.5
- The heat exchanger in the ventilation system should have a heat recovery of ή ≥ 0.75 and an electricity consumption of ≤ 0.4 Wh/m^3 air volume (21).

The proposals might cause increase in space needed for insulation, in order to obtain the low energy consumption desired. This along with the economy needed to obtain the low energy consumption might be a barrier for the owners of the buildings. However it is chosen that low energy consumption is the main goal of the proposals.

3.2 Energy Renovation of the Building Envelope

The building envelope contributes for all building groups presented highly to the heat loss and thus the energy use of the building. The initial investigation is therefore of the building envelope.
For all types of renovation of the envelope there is a risk of collision with for example the architectural expression, an overall town strategy or preservation of a building.

In Table 2 the proposals regarding the building envelope relevant for the different building groups are presented.

Table 2 General proposals for energy renovation of the building envelope.

	Building envelope				
Group	Re-insulation of external walls	Re-insulation of Horizontal divisions and ground floors	Re-insulation of roofs	Replace-ment of windows	Tightening of building envelope
A	•	•	•	•	•
B	•	•	•	•	•
C	•	•	•	•	•
D	•	•	•	•	•
E	•	•	•	•	•
F	•	•	•	•	•
G	•	•	•	•	•
I		•	•	•	•
K		•	•	•	•

The different proposals in the table are hyperlinks to relevant proposals.

Re-insulation of the buildings envelope is the most typical form of energy renovation. Yet it is still relevant, as seen in Table 2.

Performing re-insulation of a building placement of the vapour barrier in the construction is important. The vapour barrier should be placed on the warm side of the insulation, thus as close as possible to the heated room. However moist problems are typically caused by leaks in or perforating of the vapour barrier. The risk of mechanical perforation can be reduced by a placement in between the insulation, yet maximum 1/3 into the insulation layer from the warm side. Further information can be found in (22).

3.2.1 External Walls

There are different ways to re-insulate the external walls, depending on the wall construction.

Injected Insulation

Injected insulation should be chosen for hollow walls. The re-insulation is performed by blowing a re-insulation material into the existing cavity as seen in Figure 18.

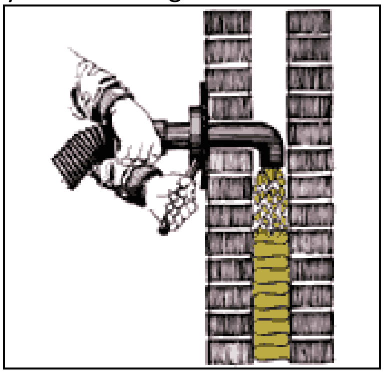

Figure 18 Insulation injected into a hollow wall (23).

Before performing a re-insulation of the hollow wall it is important to secure the initial condition of the wall. This will avoid an increased destruction of the construction, due to changed temperatures in the construction. More information regarding this can be found in (24) and (25).

The profitability of the re-insulation depends on the wall construction, if the ties are of steel or massive brick. For walls with ties of massive brick the thermal bridges are large and the transmission coefficient will not be reduced as much as for a wall with ties of steel, where the thermal bridges are smaller.

If a low energy class has to be obtained, the injected insulation has to be combined with external insulation. This will eliminate the thermal bridges and a lower U-value can be obtained.

The expenses are 125 DKK/m^2 including VAT according to (26).

The U-value of a 300 mm hollow wall with a cavity of 80 mm can be improved from 1.49 W/m^2K to 0.53 W/m^2K. In the calculation is assumed a lining percentage of 5 % and that steel ties are used. If additionally 200 mm of insulation is added on the outside, a U-value of the construction will be approximately 0.13 W/m^2K. Calculations are according to (23).

External Insulation

This method is possible for both hollow, massive brick and light walls. Insulation applied on the exterior of an external wall is the correct way regarding moisture in the construction and it reduces thermal bridges. Yet, external re-insulation often collides with the architectural appearance of buildings as seen in Figure 19.

Figure 19 External re-insulation of the facade (23).

When external insulation is chosen, windows should be mounted along to the facade, to obtain most possible sunlight and to decrease the linear losses around the windows (27).
In Figure 20 a building where external re-insulation is performed can be seen. To the left the original building is seen and to the right the same building is seen after re-insulation of the facade.

Figure 20 External re-insulation performed in practice (28).

The solution is expensive. The price for 100 mm of insulation with plaster is 1,700-2,300 DKK/m^2 excluding VAT and further increase in thickness will increase the expenses (29).
For a solution using Rockwools RockBase Facadebatts with plaster the U-value of a 350 mm massive brick wall can be improved from 1.40 W/m^2K to 0.15 W/m^2K by use of 220 mm of insulation (23).

Interior Insulation

An interior insulation of the external walls is possible to perform without changing the outer architectural appearance of the building, thus of interest for buildings worthy of preservation. However a problem could be interior arrangements such as stucco or the existing central heating system.

Figure 21 Internal re-insulation of external wall (23).

If it is chosen to insulate from the inside as seen in Figure 21 tightening the building is highly relevant. Irregularities in the vapour barrier will decrease the tightness of the building but also increases the risk of problems with condensation and mould in the closed construction.

The price for 100 mm of mineral wool class 37 in a timber frame with a finish is 800-1,000 DKK/m^2 excluding VAT. If a steel frame is used instead the expenses will increase 100-200 DKK/m^2 excluding VAT (29). The decrease in the U-value of the construction will be 30 % poorer than seen for the exterior re-insulation, as the thermal bridges will not be eliminated (30).

3.2.2 Horizontal Divisions and Ground Deck

The horizontal divisions considered in this section are divisions facing a basement or crawl space and division facing an attic. Flat roofs will be described in section 0.

Injected Insulation

This method is used in hollow wooden horizontal divisions with no room for insulation bats or working craftsmen in the adjacent room. The amount of insulation is limited by the construction size, which makes it difficult to obtain a low U-value. The principle of the proposal can be seen in Figure 22.

Figure 22 Insulation injected into a horizontal division (23).

The material used is inexpensive with a price around 100 DKK/m^2 excluding VAT (31).
The U-value for a typical horizontal division of 100 mm with an internal layer of clay can be improved from 1.09 W/m^{2}K to 0.45 W/m^{2}K. Depending on the thickness of the deck, the U-value can be improved to 0.29 W/m^{2}K with 150 mm of insulation (23).

Insulation Above or Underneath a Division

The most typical form of re-insulation is performed on surface of the division facing an unheated attic, often by use of insulation batts. The condition of the existing insulation should be evaluated before reused and sufficient ventilation has to be secured. Lack of ventilation can cause moisture accumulation, thus causing damage and mould growth on the adjacent constructions.

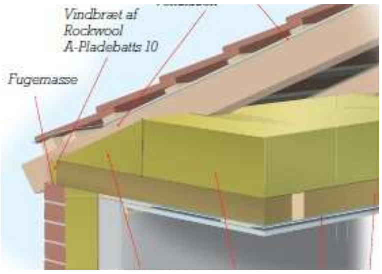

Figure 23 Re-insulation of horizontal division facing unheated attic (23).

The expenses for 100 mm of insulation class 38 are 100-150 DKK/m^2 excluding VAT. This price will increase if a gangway should be constructed and if the thickness of the insulation is increased (29). A construction with 4.5 % wood and 340 mm of Rockwool Flexibatt insulation will result in a U-value of 0.1 W/m^{2}K (23).

Insulation underneath a division is relevant when the division is facing basements and crawl spaces.
When insulating against a crawl spaces, large caution is needed. If the crawl space is naturally ventilated it is recommended to

insulate with a total maximum of 150 mm of insulation. At the same time heat and moisture conditions in the crawl space have to be improved, in order to avoid problems with mould as the moist balance is changed due to the re-insulated division. This is thoroughly described in (32). This solution would improve the U-value to 0.25 W/m^{2}K. Furthermore it is recommended that parts of the 150 mm of insulation should be injected in the division if possible. The vapour barrier should be placed right beneath the floorboard (32).

For a normal basement with a sufficient height, it is possible to mount insulation bats underneath the division as seen in Figure 24.

Figure 24 Re-insulation underneath horizontal division (23).

A construction with 10 % wood and 285 mm of insulation with Super flexi A-batts result in a U-value of 0.11 W/m^{2}K (23).

Typically re-insulation of the ground deck is a comprehensive renovation. The solution can by placement of insulation between the deck and the foundation reduce the thermal bridges along the foundation. Further moist and radon barrier has to be included in the construction above the concrete deck. The solution can be seen in Figure 25 and is also possible for buildings with a crawl space. The space will be filled with Leca and the ground deck will be placed above. This could be chosen to avoid moisture problems.

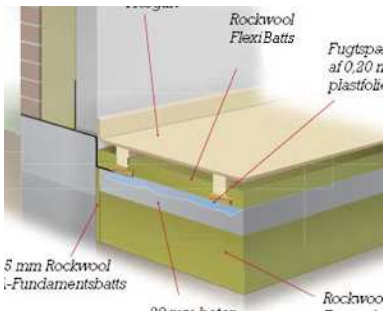

Figure 25 Re-insulation of ground deck (23).

For a construction with 200 mm of insulation underneath the concrete deck and 70 mm above, the U-value is 0.12 W/m^2K (23).

3.2.3 Roof Constructions

There are many possibilities for re-insulation of roofs, as there are many different roof types. Thus it is chosen to divide the proposals into internal and external insulation.

Internal Re-insulation

It is possible to re-insulate both flat roofs and slanting roofs from the inside. This can be done independent of an extensive renovation of the roof. For the slanting roof the insulation is mounted inside as seen in Figure 26.

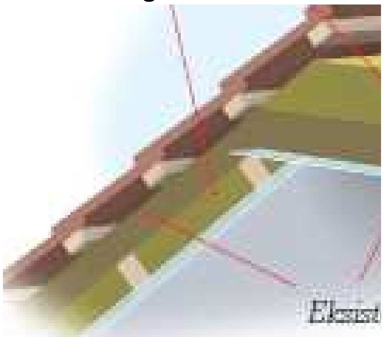

Figure 26 Re-insulation mounted on the inside of a slanting roof side, the bright insulation is the new insulation (23).

There might be a need for an extension of the construction, as the thickness of the insulation has to be around 300 mm, which will obtain space in the adjacent room.

Figure 27 Re-insulation of the attic below the slanting roof (23).

In connection to a re-insulation of a slanting roof, the attic below the slanting roof should also be insulated as seen in Figure 27. When this is done, warm installations should be on the inside of the new insulation. Further they should be insulated as described in section 3.3.4.

The typical expenses of 100 mm insulation for the entire roof are 1,300-1,700 DKK/m^2 excluding VAT and the price will increase with 6-8 DKK/m^2 for an increase in thickness (29).
The U-value of an un-insulated attic below the slanting roof can be improved from 1.85 W/m^2K to 0.12 W/m^2K by use of 295 mm Rockwool Flexibatts (23).
The U-value of a roof with 10 % of wooden rafters can be lowered to 0.12 W/m^2K by use of 335 mm of Rockwool Super Flexibatts (23).

Internal insulation of all roofs should be combined with tightening the building, if the internal are anyway stripped. See also section 3.2.5 for tightening of the building.

For built-up roofs it is possible to inject insulation by use of insulation sheets that will be lifted by the insulation and in that way secure ventilation above the sheet (23).
The expenses are 600-800 DKK/m^2 excl. VAT for 100 mm of injected insulation plus remounting and mounting of fascia boards (23).

External Re-insulation

This solution is possible for both slanting roofs and flat roofs, typically in connection with renovation of the roof. On flat roofs it is possible to mount new insulation on the existing construction, whereas for slanting roofs, an extension of the existing construction is needed. When the re-insulation is performed on an external surface the initial space is maintained se Figure 28.

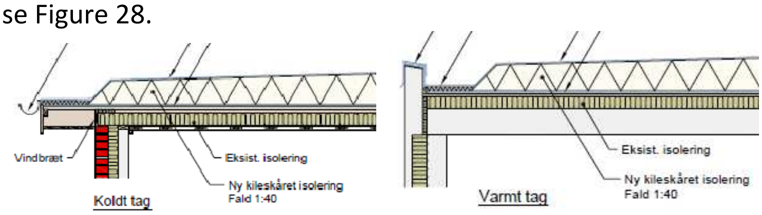

Figure 28 Re-insulation of cold and warm roofs respectively (29).

The expenses are estimated to be 900-1,100 DKK/m^2 excluding VAT for an average thickness of 110 mm of insulation (29).
For flat roofs a U-value of 0.10 W/m^2K can be obtained by use of 380 mm of insulation in a solution from Rockwool ProRock Systemtage. This solution can be used on wooden, concrete and steel constructions (23).

Replacement of Dormers

Older dormers are typically sparsely insulated. Since dormers are often narrow a good solution is to replace the existing ones instead of insulation on the inside, further the prefabricated once are well tightened (33).

A prefabricated dormer can according to the manufacture have a U-value 0.31-0.17 W/m^{2}K depending on the thickness of the insulation that spans from 145 mm to 240 mm (34).

3.2.4 Replacement of Windows

Replacement of windows is relevant in order to reduce heat loss and improve the indoor climate, by reducing draught and downdraught. For residential buildings the sunlight should be utilised as a passive heat sources and for commercial buildings the sunlight has to be controlled in order to avoid overheating and glare problems.

Depending on the existing windows in the buildings, two types of solutions are proposed.
If the buildings have older windows worthy of preservation, for example with framework, an inner window with an energy pane can be mounted, as this will reduce the heat loss from the window without disfiguring the architecture. The solution can be seen in Figure 29.

Figure 29 Old window with inner window with energy pane (29).

The costs are 2,000-3,000 DKK/m^2 excluding VAT depending on the chosen type. For a typical original window with one pane this solution will result in a U-value of 1.3 W/m^{2}K (29).

When the existing windows are replaced, a solution with low energy window is recommended. There is a constant development in the field, thus the market should be investigated before a window is chosen.
An example is the window Pro Tec 7 Uni showed in Figure 30. The frame is of composite material and wood. The window is a 3 layered glazing with warm edges and a krypton filling.

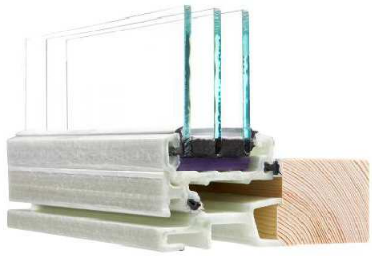

Figure 30 A PRO TEC 7 Uni window from Pro Tec windows (35).

The U-value of the frame is 1.4 W/m^{2}K. The linear thermal transmittance of the spacer is 0.035 W/mK. Those values are calculated with a centre U-value for the glazing of 0.52 W/m^{2}K (36). Further data of the window can be seen in appendix D.

For commercial buildings the choice of window also depends on the demand for lighting in the building. A high light transmission will give much daylight. However at the same time overheating should be prevented by low solar energy transmittance, the g-value.

The general lighting level in both offices and shops has to be minimum 200 LUX, and for some tasks a higher level is required (37). The lighting level should be obtained by use of daylight, however for deep rooms there will most likely be a need for artificial lighting.

New windows can be a large investment. Windows however influence both the energy consumption and the indoor climate. Therefore it can be difficult to evaluate the cost-efficiency as the indoor climate is not evaluated in relation to this. However an energy renovation in this field will be noticeable regarding energy consumption of the building.

3.2.5 Tightening of the Building Envelope

To obtain low energy consumption it is important to focus on the tightness of the building. A high uncontrolled air change caused by infiltration, leads to a large heat loss. It is typically seen where the building envelope is penetrated and in joints between construction parts. In Figure 31 the uncontrolled air change is shown.

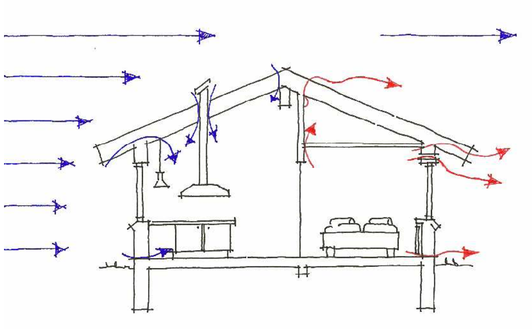

Figure 31 Infiltration in buildings (20).

In Table 3 typical values for tightness of buildings can be seen.

Table 3 Typical values for tightness of buildings (23).

Tightness	Air change [h^{-1}]
Very leaky	2
Leaky	1
Normal	0.7
Tight (low energy houses)	<0.4

The leakages can be found by use of a blower door test and tracer gas or a thermo graphic camera. Leakage is typically handled when other types of renovation is performed, as thorough tightening demands removal of the entire inside of the building and can be difficult to accomplish. In Figure 32 examples of where tightening is important is shown.

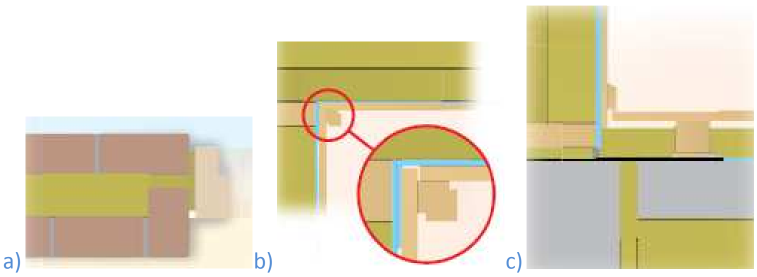

Figure 32 Tightening: a) wall/window, b) roof/wall c) wall/foundation (23).

In Figure 32 the aim of building tightening is seen. The air change is controlled with air taken in and exhausted through openings constructed for the purpose, independent on the wind.

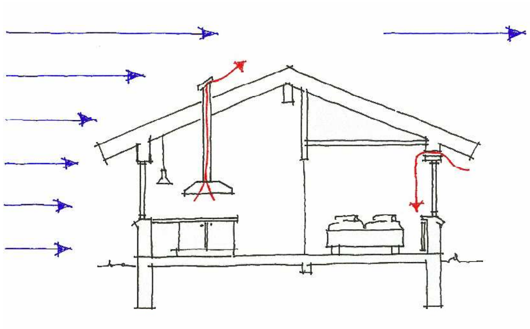

Figure 33 Controlled air change in a tightened building (20).

Tightening the building cannot stand as an individual proposal, as a minimum air change of 0.5 h^{-1} according to the building regulations have to be maintained.

The required air change can be obtained by use of both natural and mechanical ventilation. However, since users of buildings are often poor at maintaining the ventilation rate through natural ventilation, a ventilation system with heat recovery is recommended for control of the indoor climate (29). When installing a ventilation system it is important to maintain it, in order to obtain a high air quality and avoid bacteria growth in the system. Energy renovation proposals regarding the ventilation system can be seen in section 3.4.2.

3.3 Energy Renovation of the Heating System

The heating system is a central part of the energy performance of a building. When the heat loss from the building envelope is reduced by re-insulation and tightening, the heating system should be renovated in order to optimise the total energy consumption. The heating system needs regular maintenance and some inspections are required according to BR08 depended on the energy supply in the building (20).

An individual investigation of the specific systems is needed before considering the energy renovation proposals.

In Table 4 the subsequent proposals relevant in the different building categories are shown.

Table 4 General proposals for renovation of the heating installations.

	Heating installations					
Group	Renovation of district heat exchanger	Hot water production	Replace-ment of pumps	Insulation of pipes	Central control and thermostat valves	Replacement of existing heating source
A	•	•	•	•	•	•
B	•	•	•	•	•	•
C	•	•	•	•	•	
D	•	•	•	•	•	•
E	•	•	•	•	•	
F	•	•	•	•	•	
G				•	•	•
I	•	•	•	•	•	
K	•	•	•	•	•	•

A heating system consists of a heating central, distribution pipes, and units for heat emission. A well operated heating system is important for the utilisation of the supplied energy.

The heating central typically contains a unit to transform the supplied energy, for example a district heat exchanger, a hot water tank or exchanger, pumps, pipes and a control unit. Centrals are built differently for different use. In smaller residential buildings several components are compiled into one unit. For lager buildings the central is built of independent components in situ.
The possibilities for renovation of the heating central are dependent on the type of supply used. In this case there will be proposals for district heating, fuel oil and electric heating

3.3.1 Renovation of District Heat Exchanger

There are two types of district heating systems; a direct and an indirect system. In the area investigated both types are represented.

The direct district heating systems are either with or without a shunt. If the system contains a shunt there will also be a pump for distribution of heating in the system. In both cases it is possible to install a new compact and efficient unit combined with flow temperature control by the outdoor temperature (38). A replacement of an installation from before 1990 will give a reduction in energy for heating of 1,000-1,500 kWh. The calculation is for a 130 m^2 single-family house from the 1970s (39). However savings can also be obtained for buildings for commercial and combined use.

When an older system is remained after a renovation that reduces the need for heating, problems with the control valve will typically occur. However this can be met by installation of a control of the pressure difference (39).

The indirect district heating system is equipped with a heat exchanger. The district heating exchanger should be regularly acid-washed, in order to keep up the efficiency.
If the exchanger is older than 10-15 years it should be replaced by a new insulated unit. This will give a reduction in energy for heating of 1,300-1,650 kWh. The calculation is for a 130 m^2 single-family house from the 1970s (39) and as for the direct installation it is evaluated that savings will also be possible for buildings for combined and commercial use.

In combination with a reduction of the heat loss from the building, it will be possible to lower the flow temperature in the system and thereby increase the efficiency of the heat exchanger.
The expenses for installation of a district heat exchanger depend on the existing system however a minimum price is 15,000-30,000 DKK including VAT for small residential buildings (29).

3.3.2 Hot Water Production

There are different types of hot water production units, in this case hot water tanks and hot water exchangers are represented. A renovation of the hot water tank should contain an acid-wash and a re-insulation of the tank, if the existing insulation is broken or non-existing. If the installations are placed in an unheated room re-insulation will affect the temperature in the room.

For hot water exchangers it is also important to avoid lime deposits, as these reduce the efficiency of the exchanger. This can be helped by regular acid-wash. If the existing exchanger is un-insulated it should be insulated or replaced by an insulated exchanger.

If the district heating flow temperature is lowered, problems with too low temperature in the tank or from the exchanger might occur. This could be met by mounting a heat pump or solar collectors that would be able to boost the temperature to the level demanded. Such an installation could possibly be shared between buildings if they are placed adjacent.

3.3.3 Replacement of Pumps

Replacement of pumps is relevant for pumps for circulation of heating and hot water in buildings where the existing pumps are older than 3 years or without regulation.

Depending on the age of the existing pumps a reduction of electricity for operation of pumps, by choosing an A-pump, can be from 149-324 kWh/year (40). The prices of the pumps are dependent on the required size.

3.3.4 Insulation of Pipes

This energy renovation proposal is relevant in unheated rooms where heating and hot water pipes are un-insulated, scarcely insulated or the existing insulation is damaged. This typically occurs near the heating central, in a basement or a crawl space, and in the attic under the slating roof. The influence of the renovation depends on the initial situation of the insulation and the placement of the pipes. For example narrow space can cause difficulties regarding sufficient amounts of insulation or a location outside the building envelope can cause large heat losses.

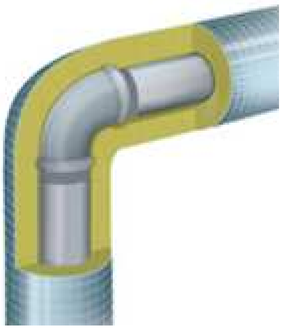

Figure 34 Flexible pipe insulation with external reinforced aluminium foil (23).

The product is in-expensive and the heat loss can be significantly reduced. For an un-insulated 22 mm pipe, with a temperature difference between the pipe and the ambient of 40°C, 40 mm of insulation can decrease the heat loss from 38 W/m to 5.8 W/m (23). The reduction is dependent on the thickness of the pipe, the temperature difference, and the thickness of the insulation.

3.3.5 Central Control and Thermostat Valves

Control of the heat emission in buildings is a central part of reducing the energy consumption. If there is no central control of the flow temperature, it is recommended to install a control regulated by the outdoor temperature. This will reduce the temperature of the water circulating in the heating system.

To adjust the amount of heating supplied to a room by the radiators, thermostat valves are important. If there are no

valves installed or they are older than 12 years, they should be replaced by new thermostat valves. New valves can be preset, in order to get the highest cooling across the radiators. Further the control possibilities for new thermostats are more flexible (41).
A replacement can give a reduction of 5 % in the energy consumption for heating, depending on the initial situation (42).

3.3.6 Replacement of Existing Energy Supply

A replacement of the existing energy supply is relevant if the buildings are supplied with other than district heating. Regardless of the type of energy supply, fuel oil or natural gas, the lifetime of the heating central will be limited and due to the technological development within the last 10 years a replacement of the existing heating unit would be beneficial both regarding the heat loss and the CO_2 emission.

It is recommended that all buildings in the area should be connected to the district heating central, when the existing heating system is worn-out or immediately for buildings that are electrically heated. This would make is possible to reduce the CO_2 emission by supplying district heating based on renewable energy as waste incineration, wind turbines or large solar plants.

3.4 Ventilation Systems

Due to different demands, most ventilation systems are various. Independent of the type of system maintenance, a regularly inspection, and regulation of the system will optimise the energy consumption for ventilation. For larger systems, above 5 kW, an inspection every fifth year is mandatory.
In recent years there has been a development of components and operation units for ventilation systems, thus, it is relevant to renovate older systems.

Table 5 General proposals for renovation of ventilation systems.

	Ventilation		
Group	Optimisation of existing system	Installation of system with heat recovery	Reuse of surplus heat from production
A	•	•	
B		•	
C	•	•	•
D	•	•	
E	•	•	
F	•		
G		•	
I	•		•
K	•		•

3.4.1 Optimisation of Existing Ventilation System

Where to focus in renovation of a ventilation system is dependent on the specific systems, if it is mechanical exhaust or balanced mechanical ventilation, the components used and the age of these.

For a system with mechanical exhaust it is relevant to optimise the operation strategy. This can be done by use of timers controlled by the need for exhaust in given rooms. It can also be relevant to replace parts of the exhaust unit, with new more efficient units. Alternatively, it could be relevant to expand the system to also contain air inlet and thereby utilise the heat removed with the exhaust air. An expansion of the existing system demands space for installations, which can be a barrier and alternatives to the typical duct system might have to be considered.

For a balanced mechanical ventilation system energy renovation can be done, on among others, the heating recovery unit, the fan, and the operation strategy. Older heat recovery units and fans can be replaced with new and more energy efficient units. The operation strategy should be optimised, as the demands in the ventilated areas can have changed since the system was implemented. This could be caused by the amount of people or the equipment in the rooms (43). In (44) further information on ventilation systems can be found.

3.4.2 Ventilation System with Heat Recovery

Installation of a ventilation system with heat recovery is relevant in order to control the air change and to reduce unnecessary waste of energy. When installing a system it is important to choose a unit with high heat recovery, an efficient fan and to avoid electrical heating surfaces. Further the system has to fulfil the requirements set in BR08 for the SPF-value. There are different maximum values depending on the building type and the ventilation system (20).
If possible a typical system with ducts and a central unit can be installed. However in existing buildings lack of space for technical installations can be a barrier. This can be handled in various ways, for example placing a compromised decentralised unit that can supply a room or a smaller area by use of a minimum of ducts.

A ventilation system is expensive to acquire and regular maintenance is required. The savings of course depend on the initial situation and the benefit will not only be a presumed decrease in energy consumption but also typically a significant improvement of the indoor climate. This is shown to have a positive influence on the efficiency of the employees, yet it is difficult to evaluate economically.

3.4.3 Reuse of Surplus Heat from Produced Cooling

For buildings with demand for cooling, for example in a cold store, there might be a possibility for using surplus heat from the process to preheat ventilation air or hot water. This is relevant for commercial buildings or buildings for combined. The use of surplus heat for preheating water is most relevant for buildings for combined use. In (45) an estimate of the potential from the Danish organisation for the business community can be seen. However as there are taxes on reuse of surplus heat from refrigerated counters and display freezers in Denmark surplus heat is typically let out without reuse. In comparison it is mandatory to reuse the surplus heat from production in Switzerland (46).

3.5 Lighting Systems

Lighting is often responsible for a large part of the electricity consumption especially in commercial buildings. In those buildings there are demands for sufficient light during day time and some companies prioritise to have lights on during night time. The requirement for general lighting level is 200 LUX and in (37) further information of specific room types can be found.
Old lighting systems often generate large amounts of surplus heat, which reduce the heat needed from the heating system. However this is uncontrollable and has to be removed by ventilation in order to maintain an acceptable indoor climate and further electricity is multiplied by 2.5. An optimisation of the lighting system will affect the heating balance, the energy consumption and the indoor climate. Thus, it is possible to obtain large savings on the energy consumption both for lighting and the ventilation system.
Recommendations regarding energy reduction of lighting systems can be found at (40).

In Table 6 energy renovation proposals for lighting systems in the buildings are presented. Generally, a renovation of the lighting system should be designed for the specific buildings after thorough examination. Even though renovation of the lighting system might be expensive, the potential for savings are large.

Table 6 General proposals for renovation of the lighting system.

	Lighting		
Groups	Optimisation of existing lighting system	Replacement of lighting fittings	Reuse of heating from lighting
A	•	•	•
B			
C	•	•	
D	•	•	•
E	•	•	•
F	•	•	•
G			
I	•	•	•
K	•	•	

There are many possibilities for a reduction of energy consumption in an existing lighting system. This could be replacement of the light sources, replacement of light fittings, or installation of automatic control of the light with motion sensors.

3.5.1 Optimisation of Existing Lighting System

The easiest, and often most inexpensive, solution is to replace the existing light sources with an energy saving light bulb. This initiative is supported by the EU decision on phasing out the incandescent light bulbs, which started 1 September 2009. An alternative is LED light bulbs which is the most energy efficient solution. However, they do not yet exceed 20W. If the representation of colours is important, the incandescent bulbs can be replaced by an energy-efficient halogen bulb, though it is not as energy efficient as an energy saving or a LED light bulb (40).

Another energy renovation initiative is automatic control of the light sources. This could be by a set timer regulation activated by the user, it could be a dimmer controlled by the measured daylight in specific zones, or it could be on-off regulation controlled by a clock. These regulations will reduce the usage time of the lighting system thus save energy.

3.5.2 Replacement of Light Fittings

A more extensive renovation of the existing lighting system is replacement with new energy efficient fittings. Before acquiring a new lighting system, the need in the specific building should be analysed and according to (40) a few demands should at least be fulfilled. The regulatory requirements should be followed, glare should be avoided, the representation of colours, the Ra-value, should be larger than 80, in locations with daylight the

system should be daylight controlled, and finally some technical demands for the fittings have to be fulfilled.
There are different types of fittings on the market and they are available with energy consumption as low as 4.0 kWh/m^2/year. The low energy fixtures secure the demand for lighting using less energy than conventional fittings (40).
The savings are, as for other proposals, dependent on the initial situation and a replacement of the existing lighting system has to be combined with implementation of control of the system.

3.5.3 Reuse of Heat from Lighting

If it is not possible to optimise the lighting system to avoid surplus heat, there might be other possibilities for reuse of the generated heat. A solution could be to use the surplus heat to preheat ventilation air, hot water, or other parts of the building, for example by use of a heat pump. This solution is could be relevant in buildings for combined use.
The temperature of the air that should be reused has to be at least 30 °C to obtain a reasonable COP of the unit. However, another possibility is to have a common heat exchanger and when the outdoor temperature is around 16 °C the inlet in the commercial part will be from the outside and only the exhaust will pass the heat recovery unit and the air for the residential part will in this way be preheated. However, the difference in the amount of air will influence the COP of the system.
There might be barriers, regarding settlement of accounts.

3.6 Energy Supply

Renovation of the individual buildings in the area should be combined with renovation of the energy supply system as a combined renovation will give the largest savings.
There are different solutions for renovation. They can be divided into central or decentralised solutions.

3.6.1 Decentralised Solutions for Energy Supply

The decentralised solutions are characterised by an energy production in relation to the individual building. This could be solar heating systems for heating of hot water, heating pumps both for heating of hot water and room air, and further small windmills or solar cells could be mounted and supply electricity.
The type of supply could be relevant for buildings placed in fringe areas.

Solar Heating

The typical solar heating system heats hot water, and can supply 60-70% of the energy for heating of hot water, with highest efficiency during summer. Solar heating can also be a supplement to room heating. The economy in this solution is dependent on the system. However, if the use of hot water is large, the savings will also be (47).

Heat Pumps

There are different types of heat pumps for heating and hot water production. They utilise different sources, thus different efficiencies can be obtained.

- Air to air heat pump
  The pump utilises the outdoor air to heat up a building. The system is easy to mount and some can during summer be used as air conditioners.
- Air to water
  The pump utilises the outdoor air to produce both heating and hot water.
- Earth to water
  By use of the pump, the temperature of the earth is utilised by circulation of liquid. The method is effective enough to fully supply a building with both heat and hot water. The largest effect of the system is seen in well insulated houses. The facility is the most effective of those mentioned, but also the most expensive. Further, a large area for placement of pipes in the ground is needed for geothermal heat pumps.

For all heat pumps electricity for operation is required. However, installation of heat pumps reduces the expenses, especially if the initial supply is fuel oil or natural gas. The expenses for installation of heating pumps vary dependent on the pump chosen. The air to air pump is most inexpensive with a price around 20,000 DKK while the expenses for a geothermal heat pump are up till 110,000 DKK (48).

Windmills

Windmills are typically linked to large areas with room for many units producing electricity for the electricity grid. However smaller windmills placed at building roofs producing electricity for the specific building are developing. In Figure 35 two proposals for small windmills can be seen.

a)  b) 

Figure 35 Small windmills placed on building roofs (49) and (50).

The windmill in Figure 35 a) is a WG 600 from ProCure that according to the company can produce 100-500 kWh/year if placed in open country. The windmill in Figure 35 b) can produce 1,500 kWh/year.

It is evaluated that a small windmill can be mounted for 35,000-65,000 DKK (51).

The produced electricity is of course dependent on wind speed and the surroundings. The windmills are a contribution to the electricity, but cannot stand as an individual proposal.

Further the proposal also has to be evaluated regarding appearance and noise.

Solar Cells

There has during the later years been a development of solar cells for production of electricity. In Denmark there are mainly two types of solar cells at the market.

- Crystalline solar cells based on silicon crystals have the highest efficiency and are the most common in the market. They are typically mounted in frames underneath a glass and mounted on a roof. However they can also be mounted as an integrated part of the building envelope.
- Amorphous solar cells are thin layered cells based in non crystalline silicon. The production costs regarding energy and materials are low, however not as efficient as the crystalline cells.

Further CIS thin layered solar cells have been developed. They are not based on the silicon technology, but a similar efficiency is obtained (52). In Denmark a plant of 1 kW, corresponding to approximately 10 m^2, can produce up to 900 kWh/year, when connected to the electricity grid (53).

It is possible to have electricity produced by solar cells subtracted in the calculation of the energy consumption of the building.

3.6.2 Centralised Solutions for Energy Supply

In a centralised solution it is beneficial that all buildings in the area are connected to the district heating system and the energy supplied by the central grid is produced from renewable energy. The principle for the centralised energy supply solutions is that large amounts of energy are produced in large plants of for example, wind turbines or solar collector panels.

Energy to the district heating central in Hedehusene is supply by VEKS. VEKS is an energy transmission company, where the district heating produced is from both waste incineration, surplus heat from CHP plants and large industrial companies. In Figure 36 the distribution from the supplying companies can be seen.

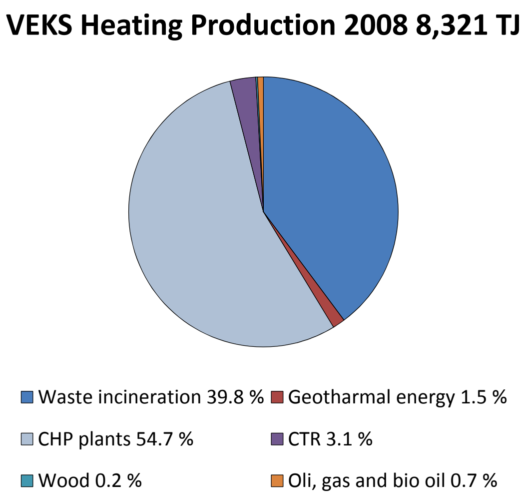

Figure 36 Heating production for VEKS 2008 including high pressure hot water. CTR is another energy transmission company (54).

As seen approximately 40 % of the district heating is produced by waste incineration, which is defined as CO_2 neutral energy. There is however room for implementation of renewable energy and a larger investigation of the potential have been performed. From this it is seen that the CHP plants can convert to biomass, however other renewable energy solutions should be implemented over time as experience is gained on the field (55).

If the energy is further supplied to the building at a low temperature, heat losses in the grid can be reduced. However, if this should be a possibility, the heating demand of the buildings has to be low.

In the ECO-Life project large solar heating plants and a heat pump utilising the high flow temperature in VEKS central grid is a possibility supplying the new area with low temperature district heating (2).

3.7 Tools for Energy Renovation Proposals

The energy renovation proposals presented can be used as input in detailed energy renovation tools. In those tools combined proposals are generated by use of information of a chosen building. In literature there are several examples of those tools that have different approaches to the problem.

In a Danish project called EPROJ a tool for calculation of the annual energy consumption of buildings were developed in the 1990s. In the model large amounts of data of existing constructions were found for different building categories in the BBR register. The data is a catalogue describing the expected energy condition in the building stock at the time. Further it contained information of the heating installations and patterns of behaviour regarding consumption of electricity and hot water as well as requirements for indoor climate.
This was the underlying basis for calculation of energy consumption for building categories in BBR, thus the tool could be used in planning of energy strategies.
Further the model could compare two scenarios and thus able to present an expected saving in and costs of an improvement of the building (56).

Another more developed example of similar tool is programs EPIQR and TOBUS. For residential and commercial buildings respectively they visualise both the initial situation and the result of a chosen renovation.
From an initial choice of building constructions and systems that are representative for the building investigated a calculation is performed. The results show the energy consumption, the indoor climate, and the costs, thus it is possible to see the influence of a specific choice on those values (57) and (58).

The energy renovation proposals presented in this project could be the basis input to a similar program.

3.8 Energy Renovation Proposals in Perspective

From the energy renovation proposals presented, it is evaluated that technological possibilities for renovation are present.

It is estimated that some of the largest savings in energy consumption, for the building envelope, can be seen by replacement of windows, insulation of the external walls and tightening of the building. The number of marks in the tables presented indicates a potential in many of the presented building groups.

For the heating system it is estimated that the largest savings will be seen with a renovation or replacement of the existing heating unit along with control of the flow temperature.
Further a reduction of the heat loss from warm installations is estimated to be significant for a reduction of the energy consumption.

Regarding ventilation systems the large savings is expected to be found where a heat recovery unit is installed and with an adjustment of the existing systems to the needed air change.

It is estimated that for the lighting system the largest savings in the energy consumption is seen with a re-placement of the existing system combined with an automatic control.

The investigations show a lager potential for performing energy renovation, still the potential in the individual situation are depended of the initial situation and should be evaluated for every specific building. An example is a hollow wall with brick ties. For that wall type the energy saving potential will not be as large as for a hollow wall with steel ties. As the re-insulation in the wall with brick ties will not reduce the significant constructive thermal bridges.

The energy renovation proposals will in the following section be tested in a case study of building type A. As they are largely represented a reduction in energy consumptions in those buildings are significant for the area.

4 Specific Calculations of Energy Renovation Proposals

In this section the energy renovation proposals presented in section 3 are further investigated. The aim is to show the influence of the proposals on the energy consumption of a reference building, both as individual proposals and combined.

A reference building will be described. This will include short descriptions of the constructions and systems of the building along with relevant information of for example use. The reference building will be modelled in BSim. To verify the reference model as representative for the buildings investigated a specific model is constructed.
Further the influence of the individual energy renovation proposals on the heating demand for the reference building is investigated. Finally relevant proposals are combined in an energy optimised model to clarify the energy consumption obtainable.

To verify the calculations done in BSim the Danish tool for calculation of the energy demand of buildings BE06 is used. From this the total energy consumption for building operation can be found.

More specific information of the construction and the systems in the models can be found in appendix D and E.

4.1 Tools for Calculations

For the investigation, BSim is used as the main tool. BSim is chosen as it is possible to analyse and compare different solutions regarding both energy and thermal indoor climate. The program does not take the heat loss from installations, energy for hot water production, or energy for pumps in consideration.

The calculations in BSim are based on weather data from a Danish Reference Year and thus, a realistic calculation of the energy demand in a building is expected.
In the program the building envelope and the systems in the building are described in detail and time schedules for use are constructed.

In BE06 relevant models are calculated. A BE06 calculation that fulfils the requirements is required as documentation to get a building license and a building classified as low energy building. The calculations in BE06 are based on design temperatures, the electricity use for building operation is multiplied by a factor of 2.5, and only separate building use can be simulated.

4.2 Building Type for Investigation

Focus of the investigations is on building type A that are buildings from before 1930 and for combined use. Typically they contain a commercial part in ground level and a residential part at the first floor. They are represented in large number in the area, thus, are a large factor in the overall plan strategy of the existing area and most likely also in other similar areas in Denmark.

A specific geometry is the underlying basis of the reference model, however to a large extend standard values for the systems are used. This will influence the results of the investigations, but it is estimated that a reference model with standard values will give a more general impression of which energy renovation proposals are beneficial for all buildings in group A. Furthermore, it is expected that a more general model can lead to more representative conclusions.

4.3 The Reference Model

The building used as underlying basis is Hovedgaden 498 in Hedehusene seen in Figure 37. The building is 243 m^2. The commercial part contains a sports shop with 2 employees. The opening hours are approximately 50 hours per week.

Figure 37 The building used as underlying basis for the reference model.

The original part of the building is from 1897 and an extension was built in the 1950s. The residential part is 111 m^2 (gross area) placed in the original building. The number of residents is unknown. The commercial part is 132 m^2 (gross area) placed in the extension and part of the original building facing the street.

A plan of the ground floor can be seen in.

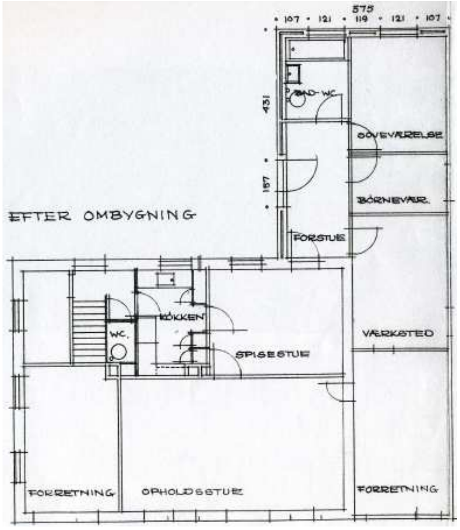

Figure 38 Floor plan of the reference model, 1954.

The decor seen today is a bit different. The residential part is in the original building facing the garden including “køkken” and “spisestue”. The rest is for commercial use, divided by only a few lighter walls.
The room height in the side building is 2.5 m. In the ground floor in the original building the room height is 2.8 m. At the first floor the room height is 2.6 m.

The building is evaluated to be in a poor condition regarding energy. It is estimated that most of the constructions are original, except from the walls in the extension and the roof on the original building, that have been renovated during time.

Drawings of the building can be seen in appendix G.

4.3.1 The Geometry of the Building

In the following section construction parts will be presented. The materials and values of the constructions are based on drawings, experience, and literature (59), (60) and (61). Further information on the constructions can be seen in appendix D.

Exterior Walls

The exterior walls in the original building are 1½ stone (350 mm) massive brick in the ground floor and the gables at the first floor are 1 stone (230 mm) massive brick.
In the extension the main wall type is 30 cm re-insulated hollow wall and a smaller part of the wall facing the street is estimated to be 1 stone massive brick.
In Table 7 U-values of the constructions can be seen.

Table 7 U-values of exterior walls in the reference building.

Wall type	Exterior wall 1½ stone	Gables 1 stone	Hollow wall re-insulated
U-value [W/m^{2}K]	1.54	2.04	1.40

Roofs

There are several roof types in the building.
On the original building the slanting roof is with 150 mm of insulation and tiles.
The roofs on the dormers are estimated to be with 50 mm insulation facing the attic.
On the extension a built-up roof construction is facing the main street. The construction is insulated with 100 mm of insulation.
At the remaining extension facing the garden the ceiling is with 50 mm of insulation between the trusses.
In Table 8 U-values of the constructions can be seen.

Table 8 U-values of roofs in the reference model.

Roof type	Slanting roof	Dormer roof	Build-up roof	Ceiling
U-value [W/m^{2}K]	0.36	0.71	0.41	0.62

Horizontal Divisions and Ground Floors

In the original building all horizontal divisions are estimated to be constructed the same way, but with different thicknesses, depending on loads. The horizontal division facing the attic is estimated to be of 6” x 6” beams with 5 cm clay in-between. Between the storeys, against the basement and the crawl space the beams are estimated to be 9” x 9”.
The ground floor in the extension is built as a traditional ground deck with 50 mm of insulation above the concrete deck.
In Table 9 U-values of the constructions can be seen.

Table 9 U-values of divisions and ground floor in the reference building (60).

Division type	Facing attic	Facing crawl space	Ground floor extension
U-value [W/m^{2}K]	0.77	0.72	0.32

The linear loss along the foundation is determined by use of (59) to be 0.59 W/mK.

Basement and Crawl Space

There is a smaller basement of approximate 10 m^2 under the original building. The basement contains the heating installations and the hot water tank. Further, there is a crawlspace under the original building. It is estimated to be approximate 0.5 meters high and ventilated by openings of approximate 8.1 x 10^{-3} m^2. There are two ventilation openings on the front of the building and two similar openings on the back are expected.

The external walls of both basement and crawlspace are estimated to be 350 mm concrete. The linear loss along the foundation is determined by use of DS 418 to be 0.29 W/mK (59).

Windows

The windows and the door in the commercial part of the building facing the street are single glazed with steel frames. The rest of the windows in the building are double glazed windows with wooden frames and the doors are expected to be wooden insulated doors.
In Table 10 data for the windows can be seen.

Table 10 Window data for the reference building.

	One layer glazing [Ug]	Steel frame [U_f]	Double glazed windows [U_{tot}]	Massive door
U-value [W/m^2K]	5.7	2.8	2.7	0.1

The linear losses between the windows and the walls are by use of (59) determined to be 0.17 W/mK.

4.3.2 Systems in the Building

In the following the systems connected to the building are presented. A typical feature for buildings in group A is that the commercial part of the buildings is for different use, thus the systems in the buildings are different. Standard values are therefore used for both equipment and people load in the reference model.

Schedules for Use

In the residential part of the building all systems are scheduled to be on always in accordance with (62).
In the commercial part the use is manly 45 hours per week according to (62), except for the heating and the lighting system. However opening hours for shops have increased during time and the 45 hours per week are estimated not to be representative for a typical shop. Therefore, an analysis of the opening hours influence on the energy consumption will be conducted.

Heating Installations

The heating system is common for the residential and commercial part. The maximum available effect for the heating system is defined by the dimensioning transmission loss to be

26 kW. The calculation can be seen in appendix D. The set point of the heating system is 20 °C with reference to (62). The heating system is expected to be with dual strings and manually controlled thermostat valves.

It is expected that there is no control of the flow temperature by the outdoor temperature, because the system is a direct district heating system without a shunt. The fixed part of the heating system is estimated to be 3 %, from size, placement, length of pipes in the buildings, and the flow temperature.
The system is not turned off during summer, as early simulations showed that it would cause temperatures around 16-17 °C in the morning outside the heating season. This is assumed to be due to the poor energy condition.

There is no night-time drop in temperature in the commercial part of the building. It is estimated that the temperature is not centrally controlled and a night-time drop in temperature should be manually conducted, which is assumed to be unlikely.

The district heating enters the building in the basement where a hot water tank of 200 litres with 25-50 mm of insulation is placed. The hot water is heated by the district heating. The pipes in the basement are estimated to be iron pipes with a diameter of ½”-1” and 20 mm of insulation. The total heat loss from the heating installations in the basement is determined by BE06 to be 8.5 kWh/m^2/year, with values from (61).

The energy consumption for heating of hot water is determined by BE06 to be 23.6 kWh/m^2/year.

In the model enclosed on the appended CD-Rom more key figures can be found.

Natural Ventilation – Venting and Infiltration

The building is naturally ventilated, by opening of windows and leakages in the building envelope. It is difficult to determine the precise values, and therefore is calculated by use of standard values. The venting in the building is assumed to start at 24 °C.
In the residential part the basic air change is 1.3 h^{-1} and the maximum air change is 10 h^{-1}.
The venting rate for the commercial part is 1.9 h^{-1} as the basic air change, with possibilities to go up to 5.4 h^{-1}.
The values are calculated according to (62), the calculations can be seen in appendix E.

Infiltration in buildings is dependent on the tightness of the building. A high infiltration can be caused by different factors as

inaccuracy during construction or for older buildings leakages around windows and doors. In the reference building the infiltration is set to 1 h^{-1}. It is chosen that this value is not influenced by the wind or temperature difference.
A sensitivity analysis will be conducted to investigate the influence of this parameter.

The infiltration in the basement is estimated to be 0.1 h^{-1}, as the air change is due to opening of the door to the basement.

The infiltration in the crawl space is estimated to be 0.8 h^{-1} according to (59), however a sensitivity analysis will be conducted to investigate the influence of the value.

Lighting System

Lighting is only considered for the commercial part of the building. The loads are estimated by use of (61) where typical values for different room types are given. The load used is 2.17 kW for a manually controlled system which is on during openings hours. Further, 25 % of the lighting is evaluated to be turned on during night, which is evaluated to be typical for this type of building.

Equipment Load

For equipment load in the building, standard values according to (62) are used. It is set to 3.5 W/m^2 for the residential part and 6 W/m^2 for the commercial part.

People Load

The people load is standard values according to (62). The people load is set to 1.5 W/m^2 for the residential part and 4 W/m^2 for the commercial part of the building.

4.3.3 Simulation Results

The energy balance of the reference building calculated in BSim can be seen in Figure 39.

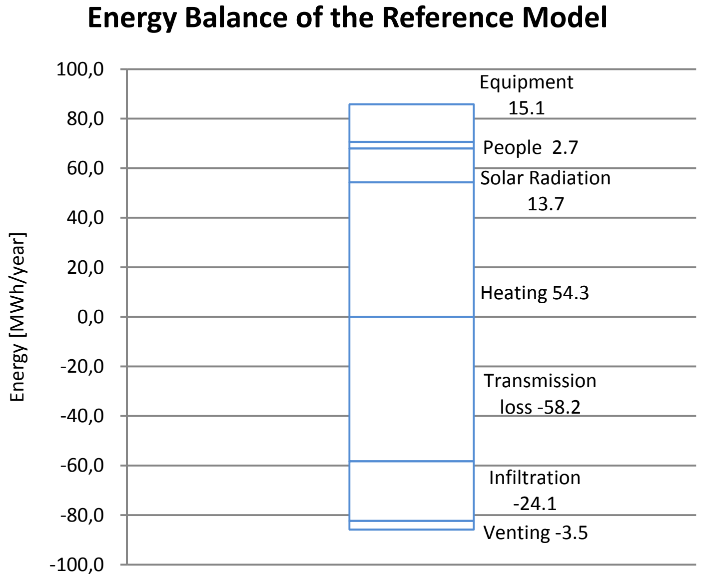

Figure 39 Energy balance of the Reference model.

The total heating demand of the building is 54.3 MWh/year corresponding to 224 kWh/m^2/year. It is seen that the transmission loss and the infiltration contributes significantly to the heat loss of the building. The large heat loss was expected due to knowledge of the building constructions, however an infiltration corresponding to approximately 30 % of the total loss of the building, show the large influence of this value.

The heat loss is covered mainly by heating, but also the equipment contributes by approximately 18 % of the total heating demand, due to loads from the lighting system.

Corresponding calculations of an older master builder home from 1927 have been performed in (63). Calculations showed a demand for heating a little higher, thus the values calculated in the present are estimated to be acceptable.
However compared to information from the owner of the building the value calculated is high. According to the owner the yearly expenses for heating is around 30,000 DKK corresponding to 40 MWh/year. This is approximately 75 % of the calculated value.

The result presented in Figure 39 is for the whole building; however, as the residential and commercial part contributes with different loads the energy balance presented in Table 11 is divided into separate units.

Table 11 Energy balance for the reference building, divided by use.

Energy balance [kWh/m²/year]	The building as a whole	Residential part	Commercial part
Heating	223.6	227.1	220.7
Infiltration	-99.1	-99.0	-94.0
Venting	-14.4	-9.7	-18.5
Solar Radiation	56.1	37.0	72.3
People load	11.1	13.2	9.4
Equipment	62.2	30.7	88.6
Transmission loss	-239.6	-199.3	-278.7

In the table it is seen that the residential part use more heat than the commercial part, which is due to the lower contribution from both solar radiation and equipment. Those values are two to three times as large in the commercial part as the residential part.

Figure 40 below show the mean temperatures in the building.

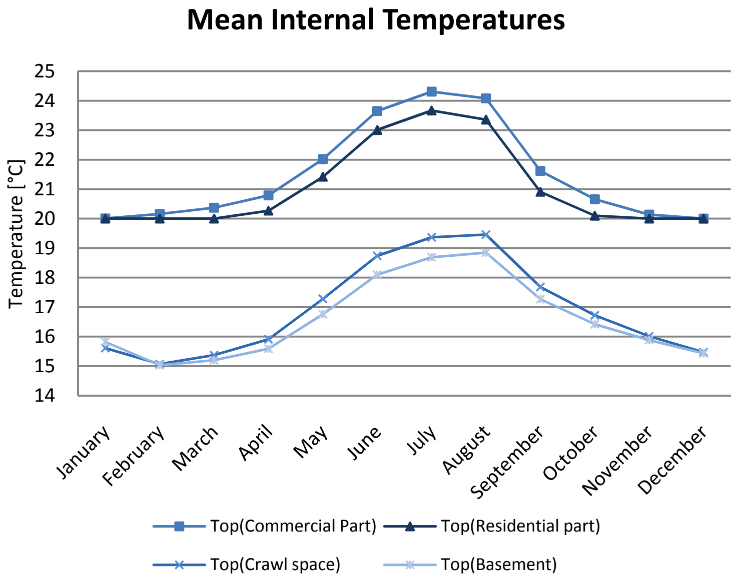

Figure 40 Internal temperatures in the reference building during the year.

A lower temperature in the basement than in the crawl space was unexpected. It should be noted that the heat loss from the installations in the basement are not implemented in this model. It was expected that the mean temperature for the basement would be around 14°C, with the heat loss from the installations included in the model. A further investigation of the impact of the heat loss on the temperature is presented in the following.

As expected the temperature in the commercial part of the building is higher than in the residential part. This is both due to the higher internal loads, but also caused by the possibilities for venting, which is only possible in the commercial part during opening hours.

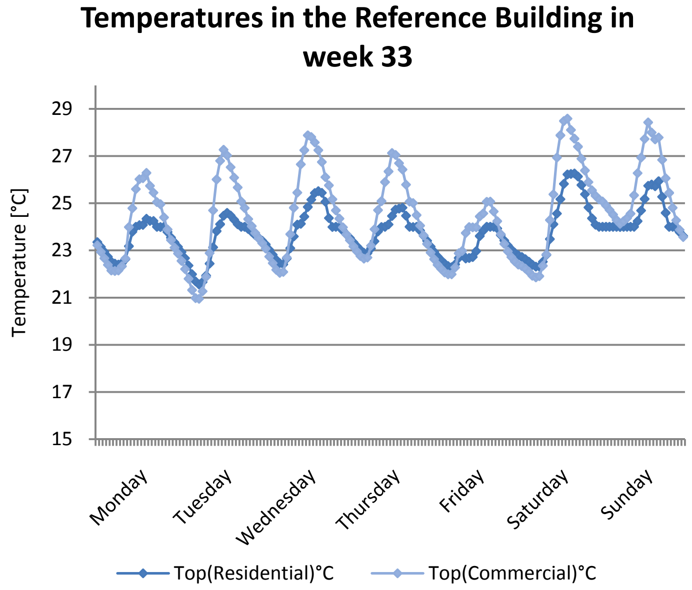

Figure 41 Temperatures in the reference building in week 23.

In Figure 41 the temperatures in the building in a specific week is shown. It can be seen that the temperatures are high both in the commercial and the residential part. From Monday to Thursday the temperature is above 25 °C in the commercial part during opening hours.

In Table 12 the amount of hours above 25 °C, 26 °C and 27 °C is seen.

Table 12 Temperatures above 25 °C in the refernce building.

	May	June	July	August
Hours above 25 °C	75	178	254	236
Hours above 26 °C	51	134	183	161
Hours above 27 °C	19	100	112	101

The recommended upper temperature limit for department stores is 25 °C during summer, for indoor climate class II according to (64). The number of hours above 25 °C indicates a poor indoor climate.

Data for the reference model is implemented in BE06. A simulation for a single-family house is chosen, as a combined building is not possible. This is compensated for by multiplying the equipment and people load by a factor calculated from the usage time. The key figures from the BE06 simulation are seen in Table 13.

Table 13 Key figures from calculation of the reference model in BE06.

Contribution from	Energy demand [kWh/m^2/year}
Heating	230.0
Light	40.4*2.5
Hot water	23.6
Heat loss from installations	8.5
Total	**363**

The total energy consumption is 363 kWh/m^2/year.

In Table 14 the total energy demand of the reference building is calculated by use of the heating demand calculated in BSim and electricity for light, energy for heating hot water and heat loss from installations are from a BE06 calculation.

Table 14 Energy consumption of the reference building by use of BE06 and BSim.

Contribution from	Energy demand [kWh/m^2/year}
Heating	223.6
Light	40.4*2.5
Hot water	23.6
Heat loss from installations	8.5
Total	**357**

The total energy consumption of 357 kWh/m^2/year corresponds to a G on the scale in the Danish energy labelling agreement. The scale spans from A to G, where A corresponds to Low Energy Class I (61). From this can be evaluated that the energy consumption of the building very high.

The calculations show high loads from solar radiation and lighting in the commercial part as expected. However the total energy consumption of the building is high.
There is a good consistence in the heating demands found in BSim and BE06, thus it is evaluated that BSim can be used as the calculation tool in the further investigations.

4.3.4 Analysis of System Parameters

Some parameters in the reference model are investigated further, to find the influence the energy balance. The reference model is used as basis for the calculations.

Infiltration in the Building

The value is as earlier described determined from an estimate of the buildings age and condition. To determine the correct value for the infiltration a blower door test should be performed, however, this was not possible in the current situation.

The investigation will be done in steps of 0.1 h^{-1} in the interval 1-0.5 h^{-1} as this is the minimum air change according to the building regulations (20). In older buildings the infiltration corresponds to the ventilation in the building, as the leakages provide a high air change. However when a building is tightened a minimum ventilation rate have to be maintained to obtain a good indoor climate.
In Figure 42 the influence of the infiltration on the heating demand is seen.

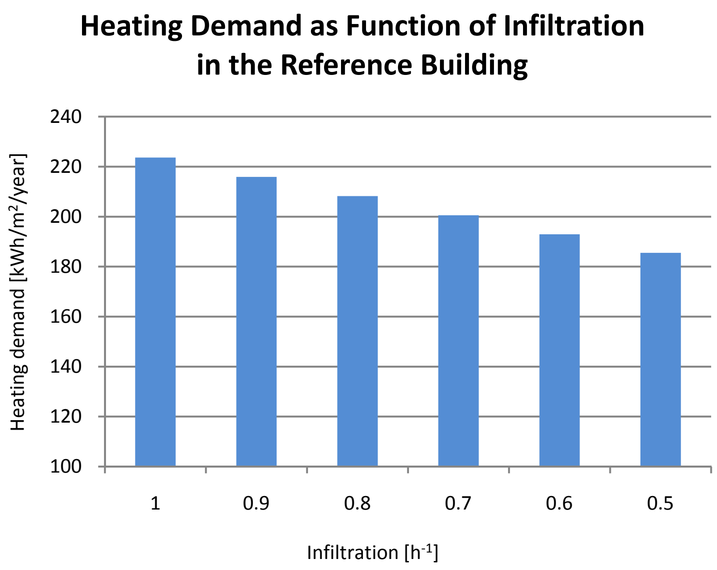

Figure 42 The infiltrations influence on the heating demand.

A decrease in the heating demand is seen as the infiltration is decreased. The total decrease is 38.1 kWh/m^2/year corresponding to 17 % of the demand for heating in the reference model.

A smaller increase in venting during the year is seen, which is caused by the higher internal room temperatures that will increase as the uncontrolled air change is decreased.

The result is as expected a decrease in the heating demand, as the uncontrolled air change is decreased.
From this result it could be discussed which value should be chosen for the future simulations. Even small changes in the value affect the energy balance of the building. As the value is not known, it might as well be 0.7 h^{-1} as 1 h^{-1}, yet it is not expected to be as low as 0.5 h^{-1}. It is chosen to continue using an infiltration at 1 h^{-1} and keep the large influence of this parameter in mind when evaluating the energy renovation proposals.

Heat from Installations in the Basement

The heat contribution from installations is relevant to investigate as it is known to affect the energy balance of the building, due to heat transmission from adjacent rooms. The value is calculated to be 0.23, see appendix E.
In the investigation the contribution spans from 0 to 0.23 kW mainly in steps of 0.05 kW. It is known to be temperature dependent, however, this is neglected in this calculation.

The calculations show a decrease in the heating demand of 3 kWh/m^2/year with increased heat loss from the installations. A change in the value in this range does not influence the heat balance in the building significantly.

However, the temperatures in the basement and the crawl space are affected. Figure 43 show mean temperatures in the basement. The influence on the temperature in the crawl space is small thus the temperature is not implemented.

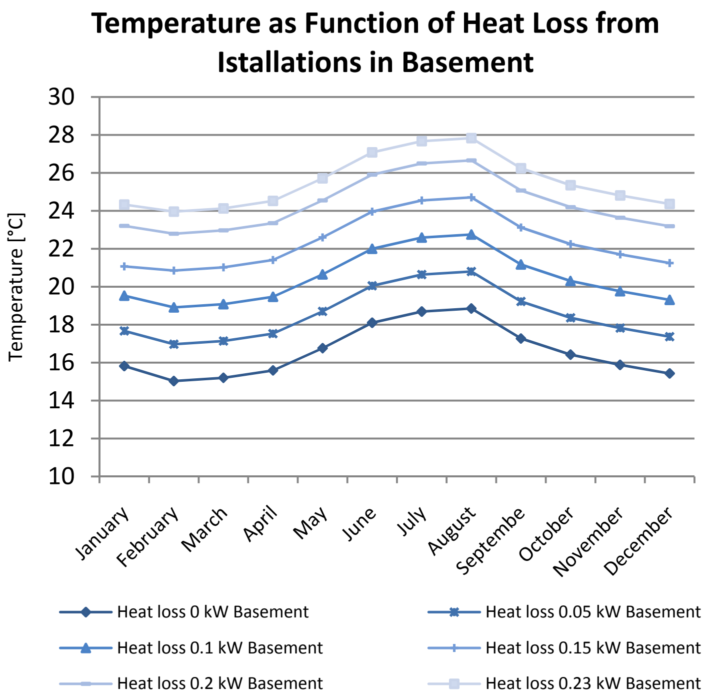

Figure 43 Temperature in the basement and crawl space with different heat loss from installations.

The mean temperature in the basement increases as the heat loss from the installations increase from around 17 °C to around 26 °C. The increase in temperature is evaluated to reach an unlikely level, even though the installations are estimated to be poorly insulated. Yet it is also evaluated that a heat loss around 0.05-1 kW is low for heating installations that are estimated to be more than 40 years old. A value of at least the 0.2-0.3 kW was expected.

From the investigations it is evaluated not to implement the heat loss from the installations. Furthermore the temperature in the basement reaches levels that are evaluated to be extreme and unlikely. The heat loss from the installations will therefore be added to the heating demand of the building after the simulation.

Infiltration in Crawl Space

The infiltration in the crawl space is investigated as an actual value has not been measured. The investigation is done in steps of 0.1 h^{-1} from 0.3 h^{-1} to 0.8 h^{-1}.
The results can be seen in Figure 44.

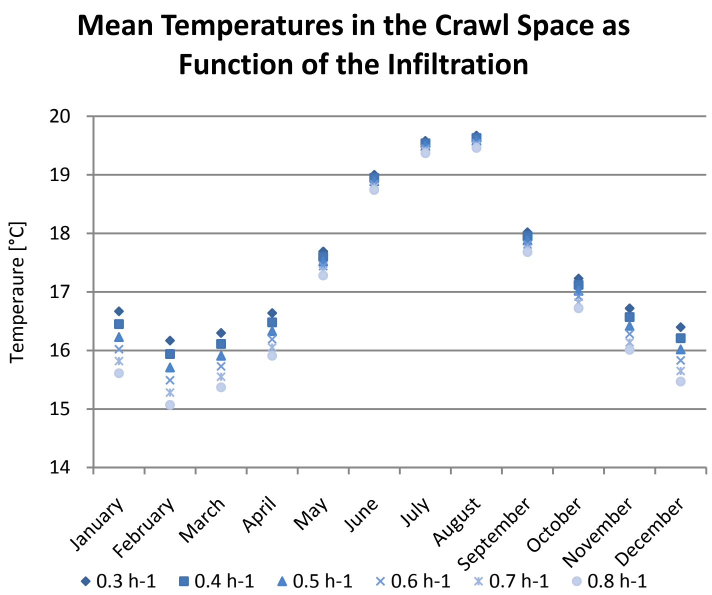

Figure 44 Mean temperatures in the crawl space as function of the infiltration.

As expected the parameter influences the mean temperature in the crawl space. The largest influence is seen during winter where the difference is 1.1°C. During a year the difference in the heating demand is less than 1 kWh/m^2 when using an air change of 0.3 h^{-1} compared to 0.8 h^{-1}. The influence on the heating demand is thus evaluated to be small.

The sensitivity analyses showed the infiltration is a sensitive parameter and that the value should be considered carefully as it has a large influence on the heating demand. However the other parameters investigated did not influence the heating demand of the building.

4.4 A Specific Model

A specific model is made in order to compare specific knowledge of the specific building to the general reference model and clarify if the reference model is a reasonable approach. From this it is evaluated if the reference model can be used in the further investigations of energy renovation.

4.4.1 The Systems

In the specific model, specific knowledge of the building is implemented.
In the areas where specific knowledge deviates from reference values a short description is given below. Most deviations concern systems in the commercial part of the building that were evaluated not to be representative for buildings in group A.

Heating System – and Cooling

The heating system in the commercial part of the building is replaced by a heat pump. The heat pump is a split air conditioner, for both heating and cooling. The heating effect is 3.80 kW, the cooling effect is 3.30 kW and the COP is 2.75.

Lighting System

The lighting system has a calculated load of 2.5 kW during opening hours and 0.84 kW during closed hours. The system is manually controlled by an on/off regulation and is on during opening hours. The calculation can be seen in appendix E.

Equipment Load

The equipment in the commercial part is estimated to consist of a cash register and a computer for orders. This corresponds to a load of 0.19 kW. The calculation can be seen in appendix E.

People Load

The total load is estimated to be 0.3 kW. The calculation can be seen in appendix E.

Schedules for Use

Further it is known that there are more opening hours than 45 hours per week, therefore the usage time for the commercial part will be increased to 50 hours per week.

4.4.2 Simulation Results

The result of simulations of the specific model is a heating demand of 52.8 MWh/year, which is 1.5 MWh/year lower than the reference model corresponding to a decrease of 3 %, 22.5 MWh/year is supplied by the heating pump. The heat balance of the buildings can be seen in Figure 45.

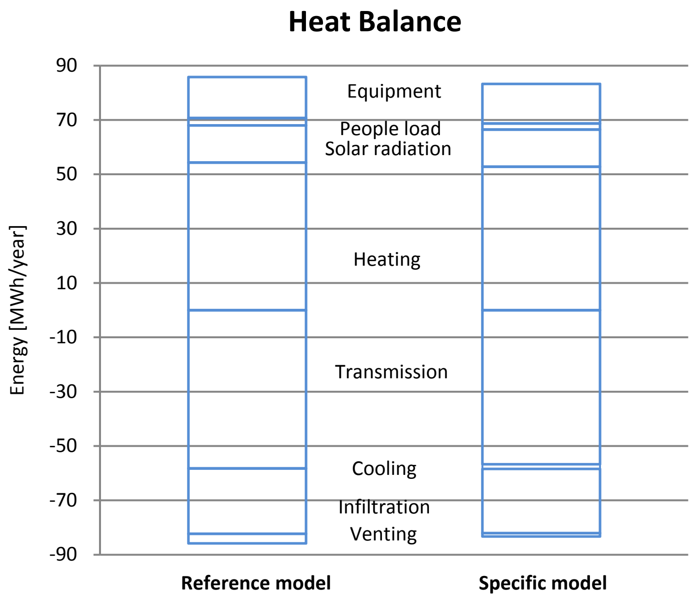

Figure 45 Comparison of heat balance for the reference and the specific model.

The difference in the heating balance of the two models is insignificant indicating that the reference model is an acceptable approximation of the specific case studied.
There are smaller differences as the venting part is lowered in the specific model due to the installed air conditioner.

The choice of heating supply causes another deviation between the models. For the specific model 22.5 MWh/year is supplied by the heating pump, using 7.2 MWh/year electricity. With reference to the total energy demand of the building, this value has to be multiplied by 2.5. Yet the owner of the building will experience a saving, even if the expenses for electricity increase. A calculation of the total CO_2 emission will show the difference between the two solutions as seen in Table 15.

Table 15 CO_2 emission from the reference and the specific model.

	Reference Model	Specific model
District heating [kWh/year] (emission 131 g/kWh) (16)	54345	30322
Electricity [kWh/year] (emission 451 g/kWh) (65)		7195
Total CO_2 emission [Ton]	**7.1**	**7.2**

In Table 15 it is seen that even though the owner of the building will experience a reduction in costs, the emission is increased which is a problem in a CO_2 neutral area. However a larger difference was expected.

From simulations of the specific model it is concluded that the reference model, to a large extent, is representative. In this case the difference in energy supply causes a difference in electricity for operation of the building. However a heat pump is not currently expected to be the most common heat supply in buildings in group A.

4.5 Investigation of Energy Renovation Proposals

It is investigated how the energy renovation proposal presented in section 3 as individual proposals influence mainly the heating demand and how low energy consumption can be obtained when they are combined.

To investigate this, the energy renovation proposals are implemented in the reference model.

4.5.1 Impact of the Individual Energy Renovation Proposals

The results are divided into groups of constructions or systems it concerns, all are compared to the reference building, which has an initial energy consumption of 54.3 MWh/yaer.

External Walls and Tightening of the Building

The different proposals that are underling for the simulations are shortly described.
Re-insulation of the external walls is with 220 mm of insulation.
Internal re-insulation is mounted in a wooden framework.
For tightening of the building a value of 0.3 h^{-1} is assumed obtained.
The windows are replaced by the window presented in section 3.2.4. The U-value of the windows is 0.7-0.8 W/m^2K. The glass is three layered with a krypton filling. The g-value for the glazing is 0.5 and the light transmission is 0.71.
Figure 46 show the effect of the energy renovation proposals for the external walls and tightening on the heating demand.

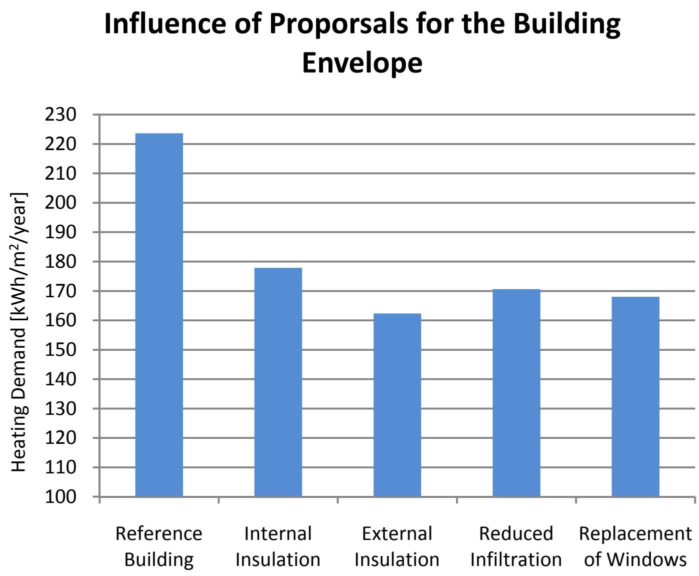

Figure 46 Energy renovation proposals for the building envelope.

As expected, the external re-insulation of the walls has the largest impact causing a decrease in the heating demand of 27 %. The reduction is caused by a decrease in transmission loss.

It is seen that a decrease in infiltration to 0.3 h^{-1}, as earlier discussed have a large impact on the heating demand. The reduction of the heating demand corresponds to 24 %. As the infiltration is decreased higher indoor temperatures are attained. This proposal however should always be followed by installation of mechanical ventilation to obtain the minimum required air change.

The impact of a replacement of the windows corresponds to a decrease in the heating demand of 25 %. This proposal can stand as an individual initiative.

For all proposals the large savings are related to a poor initial situation.

Roof Constructions

In Figure 47 the renovation proposals concerning the roof constructions are presented.

At the ceiling in the extension 350 mm insulation is added, a total thickness of 400 mm is obtained.

The flat roof is re-insulated on the external by use of 280 mm insulation, a total thickness of 380 mm insulation is obtained.

The external insulation of the slanting roof is with 335 mm of insulation.

The dormers are replaced by new dormers with an insulation thickness of 240 mm.

The horizontal division facing the attic in the original building is re-insulated by injection of 60 mm insulation in the division and further 300 mm insulation batts above the division.
In the latter solution the existing insulation is replaced by insulation with a thermal conductivity of 0.034 W/mK and further 220 mm are added on the inside.

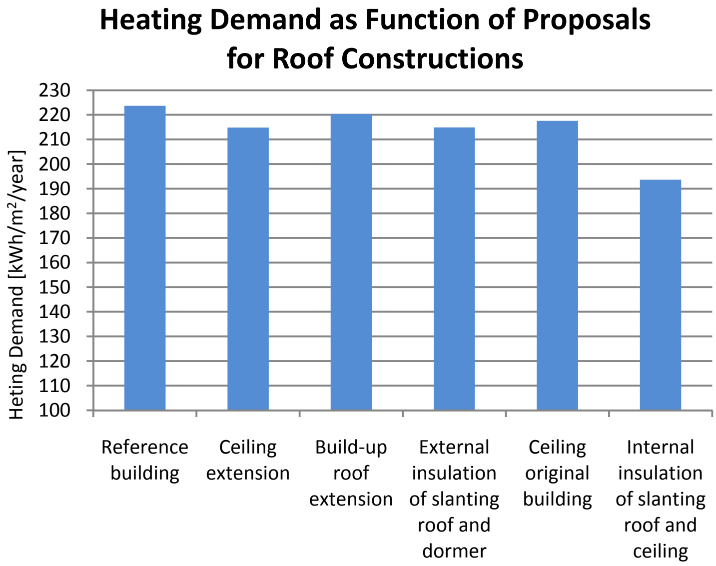

Figure 47 Energy renovation proposals for roof constructions.

The proposals as individual initiatives do not have significant influence on the energy balance. The decrease in heating demand is from 1% to 4 % for the first four initiatives. This is evaluated to be caused by the small individual areas compared to the total envelope area. For the latter proposal a decrease in 13 % is seen.

Horizontal Divisions

Re-insulation of the ground deck and the horizontal division against the crawl space is investigated.
The ground deck is with 270 mm of insulation above and below the concrete deck and further 15 mm insulation along the foundation to minimise the thermal bridges.
The horizontal division facing the crawl space is insulated by injected insulation and mounting of insulation underneath the deck in the crawl space. The insulation corresponds to a U-value of 0.25 W/m^2K.
The result can be seen in Figure 48.

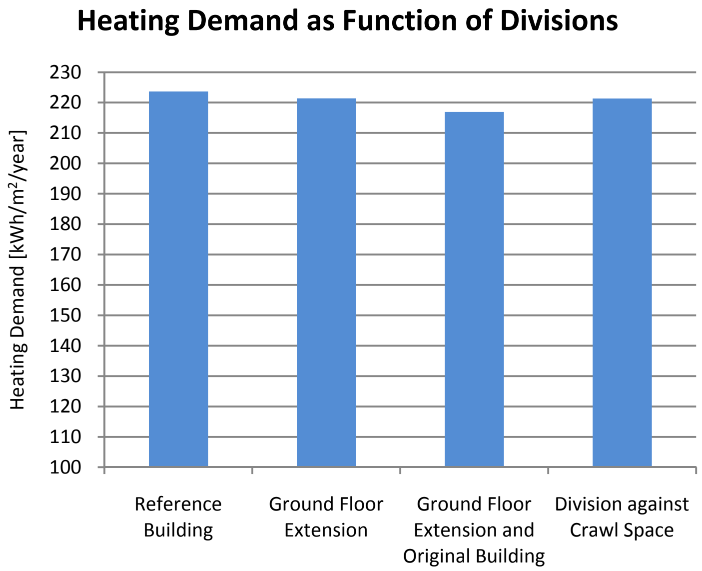

Figure 48 Energy renovation proposal for ground deck and horizontal division.

It is seen that the initiatives have an insignificant influence on the heating demand. However the largest influence is seen for a proposal where the crawl space is replaced by a typical ground deck and the existing deck is re-insulated.

In Figure 49 both temperature and relative humidity in the crawl space after re-insulation of the horizontal division are shown.

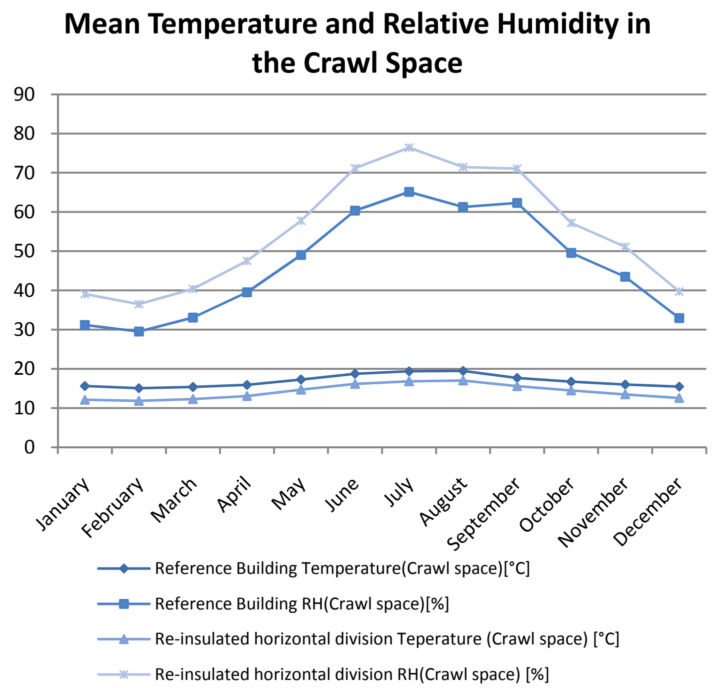

Figure 49 Temperature and Relative Humidity, RH, in crawl space after insulation of horizontal division.

From the figure it is seen that re-insulation of the division causes an increase in both temperature and relative humidity. During summer the mean relative humidity is above 70 %. This can cause problems if the temperature decreases just a few °C, as this would increase the relative humidity. Further investigation show that during summer the relative humidity in the crawl space reaches 100 % several times and longer periods with high relative humidity is seen.
Mould growth is expected when the relative humidity is 75-85 % and the temperature above 5 °C.
The results indicate that an alternative to re-insulation of the horizontal division against should be chosen.

Heating System

In the renovation proposal for the heating system a district heat exchanger and an outdoor temperature control of the flow temperature is installed. This control makes it possible to implement central night-time drop in temperature in the commercial part of the building. The result of the simulation can be seen in Figure 50.

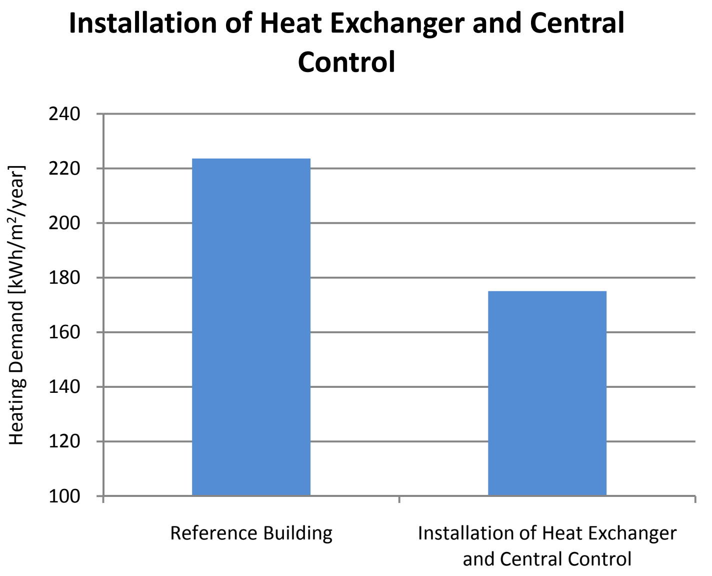

Figure 50 Energy renovation proposal for the district heating control.

It is seen that the proposal decrease the heating demand with 22 %. The result indicates that it is important to also focus on optimising the systems in the building, as large savings can be obtained.

Lighting System

The lighting system is expected to generate large amounts of surplus heat in the reference building. However, the high U-value of the windows in the commercial part of the building is expected to cause a large heat loss, equalising the surplus heat from the lighting system. Yet the balance will be changed when the building is renovated.

In Figure 51 the impact of renovation of the lighting system in the reference building can be seen. Further information on premise for the calculation can be seen in appendix E.

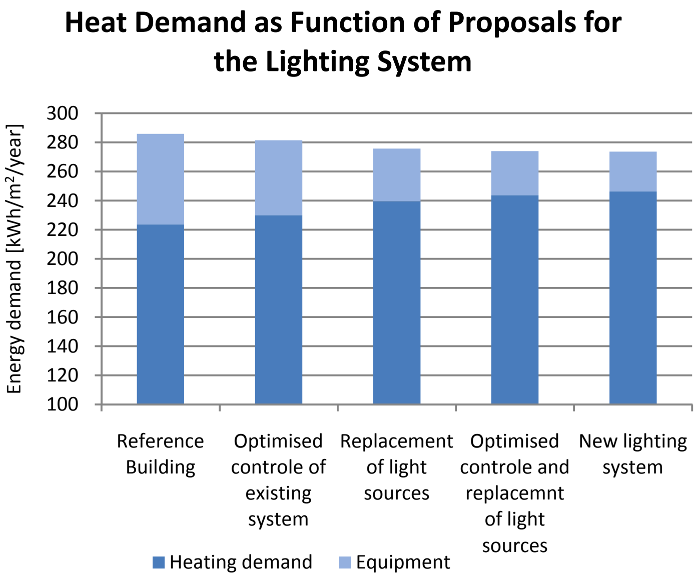

Figure 51 Heat demand as function of renovation proposals for the lighting system.

Optimising the lighting system causes an increase in the heating demand for the building. This is due a reduction by half in energy contribution from the equipment.

It is preferable to heat the building by use of the heating system instead of surplus heat from the lighting system. Further a decrease in the loads from lighting is preferred regarding ventilation.

Installations in the Basement

For the installations in the basement a hand calculation is made to find the energy consumption after an increased insulation of the existing installations. 200 mm of insulation is added both to pipes and the existing hot water tank. In a calculation in BE06 this leads to a heat loss of 2.8 kWh, which compared to the reference model is a third. The input parameters can be seen in appendix E.

With a re-insulation of the basement the temperature is expected to decrease, thus the moisture balance will change.

4.5.2 Evaluation of the Impact of the Proposals

The simulations show that external insulation of the walls, replacement of the windows, tightening of the building, and renovation of the heating system are the main factors for reducing the heating demand in the building. Furthermore reducing the electricity consumption for building operation by renovation of the lighting system will be beneficial.

Even if the object of the simulations has been to investigate individual proposals, some are connected. Examples are replacement of windows and tightening of the building. Further an external re-insulation of the wall is for this building type connected to an external re-insulation of the roof to maintain normal proportions.

Not all energy renovation proposals showed large decrease in the energy demand, however, it is still expected that in combination the proposals can bring down the energy demand for the building significantly.

4.5.3 Sensitivity Analyses of Selected Energy Renovation Proposals

Some of the building elements are investigated more in detail to evaluate the influence of smaller changes on the energy consumption. This is done where there has been lack of specific knowledge or where the smaller changes are expected to have an influence.

Thickness of Insulation

Two proposals for re-insulation are selected for a further investigation, as they have a large influence on the appearance of the building and the space available for users.

External Insulation on External Walls

The investigations performed of external insulation of the external walls are in steps of 10 mm from 0 to 220 mm.

In Figure 52 below the heating demand as a function of thickness of the insulation is seen.

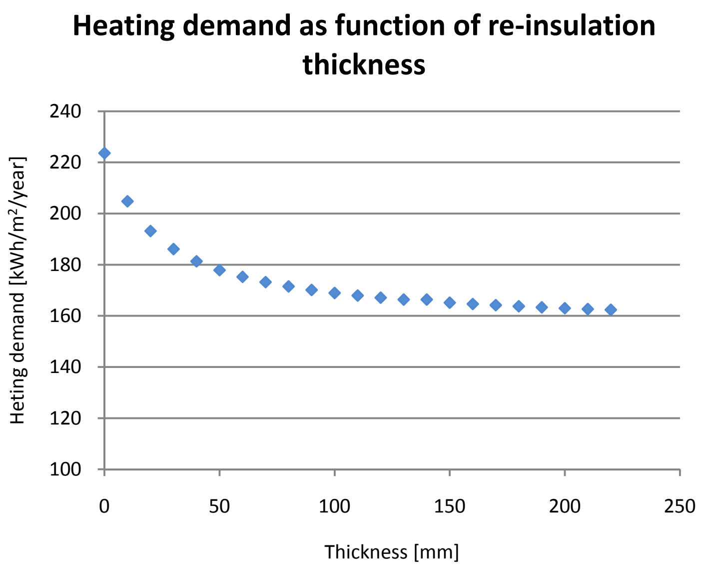

Figure 52 The heating demand as function of re-insulation of external walls.

The largest impact on the heating demand is seen for the first 10 mm of insulation added. If the thickness is increased above 150 mm the influence in the heat demand is not significant. However insulation above 150 mm is expected to have a larger influence on a low energy building.

External re-insulation of the external walls is known to be expensive and those expenses can be reduced by reducing the thickness of the insulation without influencing the heating demand significant. Later the influence of reducing the insulation will be investigated for the optimised model.

Internal Insulation of Roof and Ceiling in the Original Building

The Internal insulation of the slanting roof side is also investigated. This solution is less comprehensive for the building owner compared to external insulation. However, it causes a reduction of the room height. The investigation is in steps of 10 mm from 0 to 220 mm. Further the proposal includes a replacement of the existing insulation to insulation with a thermal conductivity of 0.034 W/mK.

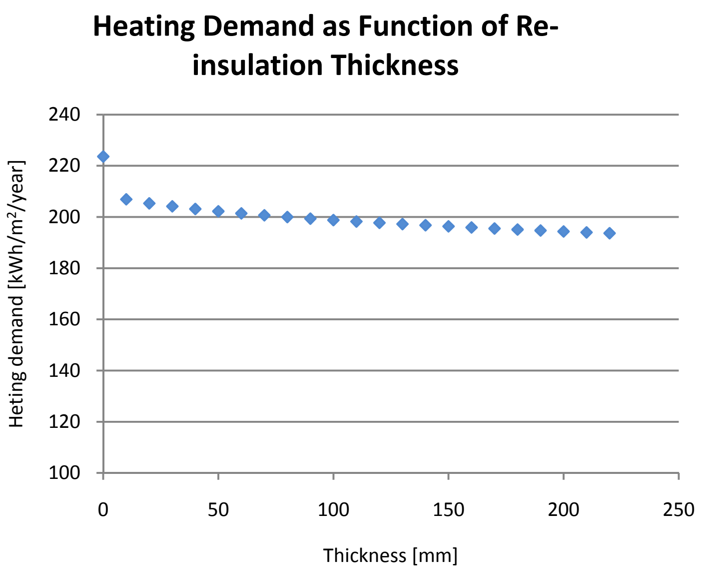

Figure 53 Decrease in heating demand as a function of internal insulation of roof and ceiling in the original building.

In Figure 53 a significant decrease in the energy demand for heating is between the initial situation and the first 10 mm is seen. This is evaluated to be the effect of replacement of the existing insulation. From the figure it can further be seen that the decrease in heat demand is twice as large for the first 100 mm as for the next 100 mm.

The result of the simulations also for this proposal urge to a discussion of economy versus the lowest energy consumption, as was the case for the external insulation.

Usage Time

It is chosen to investigate the influence of the usage time of the commercial part of the building, as the limit for opening hours are changing. Extreme examples are IKEA or large grocery stores that are open for around 70 hours per week. The long opening hours are not the expected development for all commercial buildings in Hedehusene. However, the simulations will show how the long hours influence the heating demand.

The simulations are conducted in intervals of 5 hours from 45-70 hours per week. 66 hours were chosen instead of 65 hours to simplify the model. The results can be seen in Figure 54 below.

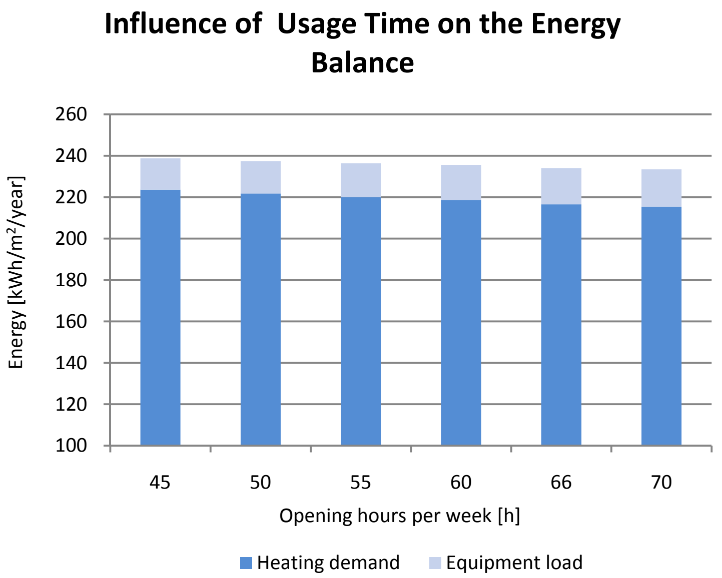

Figure 54 Investigation of the usage times influence on the energy balance.

As expected the load from equipment increases with increasing hours, thus causing a decrease in heating demand. The effect was however expected to be larger.

Replacement of Windows

Replacement of windows is one of the solutions with a large influence on the energy consumption in the building. Still it is also an expensive initiative and therefore tree solutions for replacement of windows are investigated.
The effect of standard energy windows are investigated in two stages. The window is a three layered glazing with a coating and a wooden/aluminium frame. The total U-value of the window is 1.3-1.4 W/m^{2}K.
At stage one only the windows with one layered glazing in the commercial part is replaced. At stage two all windows in the building are replaced with standard energy windows.
The last proposal is with the window presented in section 3.2.4. Dependent on the window size a total U-value is 0.7-0.8 W/m^{2}K.

The influence of the proposals on the heating demand in the building can be seen in Figure 55 below.

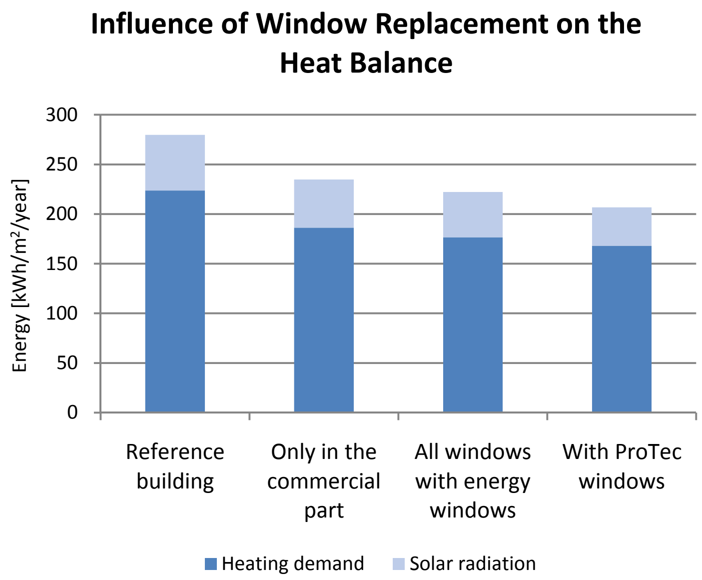

Figure 55 Replacement of windows.

The heating demand decreases with 37 kWh/m^2/year corresponding to 17 % by replacing the windows in the commercial part. This was expected as the initial situation was very poor. The difference in the heating demand is further decreased when the low energy windows are chosen.
The solar radiation is decreased with a replacement, which is a benefit regarding overheating in the commercial part of the building as this influence the energy consumption for ventilation.

Evaluation of Sensitivity Analyses

The more detailed investigation show the dilemma of energy renovation clearly, as different solutions could be chosen depending on the aim of the renovation.
Therefore the result of the investigations in this section should be used as a tool for evaluating energy versus economy, which makes it possible to choose solutions that will give the lowest energy consumption at the disposal economy.

4.5.4 Lowest Energy Consumption Obtainable

It is investigated how low an energy consumption that is obtainable by use of the energy renovation proposals set. The underlying basis is the individual proposals investigated in section 4.5.1.
The energy demand for new buildings is, for a building corresponding to the reference building calculated to be:

- BR08: 101.7 kWh/m^2/year
- Low Energy Class II: 74.0 kWh/m^2/year

For comparison the energy demand for the reference building by BSim was found to be 357 kWh/m^2/year.

External Walls

For the external walls the energy renovation proposal with external insulation is chosen. This is chosen as it is most correct regarding building physics, it eliminates existing thermal bridges, it does not decrease internal area, and it is possible at the same time to renovate the facade of the building.

Roof on the Original Building

The solution for the roof in the original building is closely related to the choice for the external walls. To eliminate proportion problems in the building exterior insulation is chosen.

The Heating System

Due to re-insulation, tightening and optimising of the systems in the building, the design heat loss of the building is decreased, the calculation can be seen in appendix D. A district heat exchanger is installed along with flow temperature control by the outdoor temperature. Further this solution will make mechanical night-time drop possible.

Mechanical Ventilation

As the building envelope is tightened a need for mechanical ventilation occurs in order to obtain an air change that fulfils the regulations. According to BR08 an air change of at least 0.5 h^{-1} is required for the residential part of the building. To minimise the energy consumption for heating of the inlet air, the ventilation system is equipped with a heat recovery unit with an efficiency of at least 80 % (19) and an SFP-value according to (20).

For the commercial part the regulations are set in (64). The important parameters for designing a ventilation system in a commercial building is the use of the building, how pollutant the building is, the indoor CO_2 concentration, and the internal loads from equipment and solar radiation. The design situation during summer is the method resulting in the highest air change, while winter is the lowest. The system is a VAV system. In this case the internal heat load results in a maximum air change of 6.7 h^{-1}. The calculation can be seen in appendix E.

When implementing a ventilation system in an existing building placement of ducts and unit might be a challenge due to lack of space, however, there are different ways to solve this problem and the space issue is therefore neglected in this project.

The Lighting System

Regarding the lighting system it is chosen to replace the existing fittings and implement a new lighting system. With the system a general lighting level above 200 LUX is maintained and the effect of the fittings is 4.7 W/m^2 (40).

4.5.5 Results

The result of the BSim simulation using all the energy renovation proposals relevant for the reference building type can be seen in Figure 56.

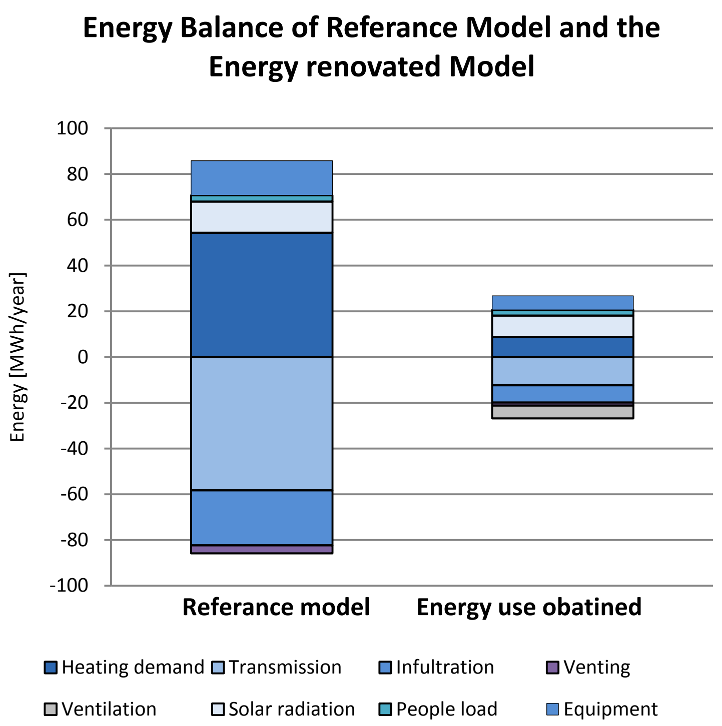

Figure 56 The energy balance for the Reference model and the lowest energy obtainable.

It can be seen nearly all elements of the heating balance is affected by the energy renovation. The demand for heating is reduced to 8.8 MWh/year, corresponding to 36.3 kWh/m^2/year. Further, the equipment load, including lighting, is reduced by more than half and the infiltration is significantly decreased.

The mean temperatures in the residential and commercial part of the building have increased during spring and autumn. However in the commercial part of the building the mean temperature is lowered during summer. The increased temperature during spring and autumn combined with a lower temperature during summer is an indication of an improved indoor climate.

The temperature is seen for the specific week also investigated for the reference model in Figure 57.

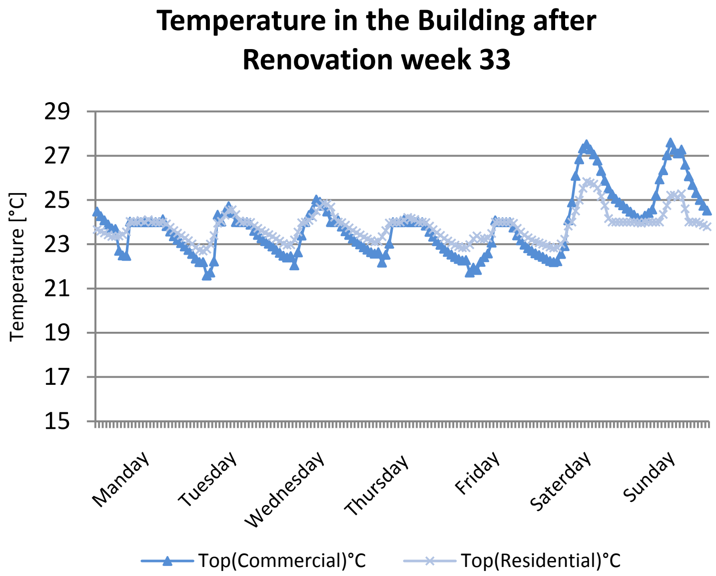

Figure 57 Temperature in the building after renovation week 33.

Compared to the reference building the temperatures have decreased from above 26 °C to below 25 °C. This indicates a better indoor climate. In Table 16 the hours above 25 °C is shown.

Table 16 Temperatures > 25 °C in the commercial part after energy renovation.

	May	June	July	August
Hours above 25°C	54	153	157	151
Hours above 26°C	35	89	113	98
Hours above 27°C	12	52	66	56

As can be seen there are still a large number of hours above the desired temperature. However the result include hours during closed hours where either ventilation or venting is used.

A calculation of the optimised model is done by use of BE06 as two separate calculations that are afterwards area-weighed and added. The key figures can be seen in Table 17.

Table 17 Key figures from BE06 for the energy renovated building.

Energy demand [kWh/m²/year]	Reference building	Residential part 111/243	Commercial part 132/243	Total (area weighed)
Heating	230	34.2	25.7	
Light	40.4		11*2.5	14.9
Ventilation		3.7*2.5	7.2*2.5	14.0
Electricity for pumps		0.8*2.5	0.7*2.5	1.9
Hot water	23.6	15.7	7.4	11.2
Heat loss from installations	8.5	3.0	2.6	2.8
Total	363	65.6	84.1	**75.6**

The total energy consumption in BE06 is 75.6 kWh/m^2/yaer.

When the energy consumptions from lighting, ventilation etc. Is added to the result found in BSim the total energy consumption is 81.1 kWh/m^2/year.

According to the calculation the energy demand for the building fulfils the demand for new buildings in BR08, but not Low Energy Class II, where the limit is 74.0 kWh/m^2/year. However, even though the energy consumption is not reduced to a low energy class, the energy demand for heating has been reduced by 77 %.

Also the energy for heating hot water and for building operation has been reduced, as a minimum by half, however the choice of mechanical ventilation increase the electricity used for ventilation.

4.5.6 Further Possibilities for Energy Optimisation

The combination of the proposals show that the energy renovation proposals presented can bring the buildings below the minimum demand of the building regulation.
However, even more efficient solutions of the building constructions along with specific calculations and optimisation of the ventilation system might bring the building type to even lower energy consumption.

As the minimum demand in the building regulations is fulfilled, there are different possibilities for the further work. An investigation of what would bring the building into Low Energy Class I could be interesting; however also the impact of some of the investigations performed in section 0, could be interesting.

Reduction of External Insulation

It is investigated if the thickness of external insulation on the external walls can be reduced to 150 mm without going above the desired energy demand.

Simulations in BSim show that the reduced insulation thickness results in a heating demand of 9.2 MWh/year corresponding to 37.9 kWh/m^2/year. The remaining factors added have not changed significantly and a total energy demand for the building will be 82.7 kW/m^2/year, which still fulfils the requirements.

In this case it is possible to reduce the external insulation and consider an economical perspective while the requirements are still fulfilled. It should however be mentioned that the reduction in construction expenses will result in an ongoing expense as it will increase the heat demand and thereby the yearly expenses.

Change of the Set Temperature for Heating

Also an increase in the set temperature after a renovation is investigated, as this is known typical to be increased after a renovation from 20 °C to at least 21 °C due to comfort. The simulation in BSim shows that the changed set temperature causes an increase in the heating demand of 1.3 MWh/year. This possible saving that is not met by the building owners corresponds to 15 % of the heating demand obtainable with 20 °C.

Low Temperature District Heating

The further perspective of the renovation also concerns the energy supply. It is therefore investigated if it is possible to maintain the heating demand in the building if the temperature in the district heating grid is lowered.
The following equation is used for the calculations (66).

$$\Phi = a \cdot \left[\frac{t_f - t_r}{\ln\left(\frac{t_f - t_i}{t_r - t_i}\right)} \right]^{1.3} \qquad [1]$$

Where:

Φ	Transmission loss [W]
a	Radiation size
t_f	Flow temperature [°C]
t_r	Return temperature [°C]
t_i	Internal temperature [°C]

For the initial situation it is assumed that t_f: 70 °C, t_r: 40°C, t_i: 20°C, transmission loss: 6279 W, which result in the following size for the radiators in the reference building.

a = 67

When the temperature in the district heating grid is lowered it is assumed that the following temperatures are possible. t_f: 45 °C,

t_r: 25°C, t_i: 20°C. By use of [1] the possible heat emission from the radiators with the current temperatures is calculated.

$$\Phi = 1773 \text{ W}$$

The heating demand for the energy renovated building is calculated to be 800 W, which is fulfilled.
From this it is evaluated that the reference building after an energy renovation can be prepared for low temperature district heating. However if the temperature is lowered to 45°C there will be a need for boosting the temperature for hot water, for example by use of a heating pump or a solar collector.

Further Optimisation of the Energy Optimised Building

More efficient solutions might be obtained by use of for example vacuum insulation. With a thermal conductivity of approximately 0.008 W/mK this should be able to decrease the transmission loss from the constructions significantly (67).

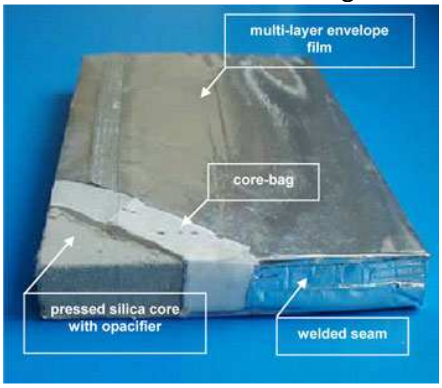

Figure 58 Vacuum insulation (68).

As the material is relative new there is no experience with life time of the material. It is however expected that the vacuum will slowly decrease as time goes by, yet an insulation effect twice as good as for typical mineral wool insulation is expected (68). Regarding windows even more efficient frames exists on the marked, which also will decrease the transmission loss.
Further, when the external walls are insulted with external insulation a re-insulation of footing could be a part of this and would decrease the linear loses of the building.

4.6 Evaluation

The case study shows that it is possible to reduce the energy consumption by 77% and fulfil the requirements in BR08 for new buildings. The objective of an energy renovation in the area around Hovedgaden set for the ECO-Life project in Annex I (2) is thus possible.

Several smaller sensitivity analyses have been performed for the reference model. Showing that it is important to focus on the uncontrolled air change caused by infiltration and be aware of the re-insulations impact on the change in moisture balance, for example in the crawl space.

Further the calculation of the individual energy renovation proposals showed that some of the more comprehensive renovation proposals have the largest influence on the heating demand in the building. Examples are replacement of the window, replacement of the existing heating unit and external re-insulation of the exterior walls.
However, as the proposals are also expensive it was investigated and found possible to evaluate expenses versus the energy consumption for parts of the building envelope and still fulfil the minimum requirements in BR08 for new buildings.

A change in the indoor set temperature after an energy renovation was investigated. The results showed that the increase in temperature corresponded to an increase in the heating demand of 15 % for the energy renovated building.
Further investigation of the energy renovated model showed that with the existing heating system the building could be supplied by low temperature heating.

It is expected that a further optimisation can reduce the energy consumption even further. This combined with an optimised energy supply, the CO_2 emission can be reduced even further.

From the results presented it is shown the proposals presented in section 3 are relevant and in combination can reduce the energy demand in buildings in group A. Further the results show where to place focus regarding energy renovation.

5 Discussion

This section will contain discussions of energy renovation in different perspectives found relevant from the investigations performed.

5.1 Validation of the Reference Model

The results found in this project are based on a reference model, where qualified assumptions and standard values are used for both systems and constructions. The standard values were chosen in order to make the model representative and indicate a general renovation potential of the buildings in group A.

To verify the reference model it was compared to a specific model, where all data known were implemented. The results showed agreement for the heating demands and the reference model was thus evaluated to be representative.

Further, sensitivity analyses of parameters have been performed to evaluate some of the values chosen for the calculation. Especially the infiltration of the building had significant influence on the energy demand.

The investigation also showed that individual use of the building has a large influence on the obtainable energy demand. This is seen, for example, regarding long opening hours where electricity for lighting is increased and, thus is the energy consumption.

Another example is an increase of the internal set temperature. In a standard calculation 20 °C is used according to the regulations (20). However it is seen that after renovation users of the buildings typically increase the indoor temperature to at 21 °C or higher (69). Thus investigations showed an unfulfilled saving at 15 % of the possible saving.

Further, the values used for heat load from people and equipment were also standard values. However, it could be argued that the values were a bit high, both regarding activity and equipment. Instead a value typical for shops could have been calculated and implemented. This might have given a more precise calculation.

All the different parameters will influence the results generated and it might cause inconsistence with the actual energy consumption. Thus expected savings might not be obtained, as also measurements show (63).

Either the information of the preconditions of the calculations has to be more explicit, making the users able to evaluate the obtainable savings.
Or the preconditions should be changed were deviation are know, as for the higher internal set temperature. For other values, a further development of standard values would be beneficial, as the standard values make it possible to compare results for different buildings for the same use.

It is evaluated that the discussion should be taken further, since with the current regulations the deviation between the calculated and the real energy consumption will be significant. Thus, urban areas presented as low energy areas will most likely have a higher energy use than initially calculated.

5.1.1 The Initial Situation and Expected Results

As described the initial situation influences the results of the calculations and in general the initial situation for the reference building was estimated to be poor.
The results showed a large energy consumption in the reference building, both compared to the energy labelling arrangement and the information from the owner. The calculated energy consumption for heating is around 25 % higher than the approximated information from the owner.
This could indicate that the initial situation was evaluated too conservatively, which can only be verified by thorough examination of the constructions and systems. However, at the same time the reference model has to be representative, thus a conservative assessment can be beneficial.
Further, a better initial situation will not be a problem from an energy perspective, thus the renovation has begun and there will still be a large potential for reduction of the energy consumption. Still, the profitability will decrease with an increase in the initial standard, thus a further renovation might not be performed if it is not cost-effective. Even though the construction parts or the systems are not near a reasonable standard compared to the present regulations.
A resent decision in the parliament will however change the requirements set in the building regulations regarding energy renovation. This includes set values for heat loss from building constructions and windows and a set energy efficiency of heating installations, ventilation systems, and pumps (70). This will most likely increase the energy renovations performed, also for building parts that have already undergone renovation.
In the reference building the initial standard of the roof and the hollow walls is higher due to a higher initial standard, thus the results of the simulations were not as significant as expected.

It was expected that there might be a potential for reuse of surplus heat in the commercial part of the building. It does not seem that there is a real possibility for this, due to low temperatures, thus the obtainable efficiency of the recovery will be low. The temperatures are kept low by optimised lighting and ventilation systems.
However, for buildings with cooling production in the commercial part, large possibilities are seen as described in the text.

Further, the simulations showed that insulation of the horizontal division facing the crawl space influenced the relative humidity in the crawl space. However the energy optimised solution was performed with a horizontal division of wood. This could be questioned, since a replacement of the crawl space with a typical ground deck would reduce the risk of mould problems in the building. This is preferred and will influence the lifetime of the building.

5.1.2 From Reference Building to General Potentials

The results found in this project show that the presented energy renovation proposals can reduce the energy consumption of the buildings in group A. Those buildings are approximately 90-100 years old and for combined use.
As the building type is a significant part of the building stock in the area, an energy renovation of those buildings would have a significant influence on the energy consumption and CO_2 emission in the area. However, the type of buildings is evaluated to be represented in large scale around Denmark in similar areas.
Thus there probably is a large potential of energy renovation as presented in this project in similar areas in Denmark.

The renovation potential of the buildings is dependent on the building stock the given place. For a large number of buildings it will be possible to perform an extensive renovation. However also for buildings worthy of preservation other studies show large potential without changes in the external expression of the building (63).

5.2 Renovation or Demolition

The aim of the renovation was to bring the energy consumption down to a level corresponding to the requirements for new building according to BR08 (20). This was shown to be possible with an extensive renovation.

The results are satisfying as there is also room for economical considerations without exceeding the requirements. However, in 2010 the building regulation is renewed again and the energy demand corresponding to Low Energy Class II will become the new upper limit.

With a toughening of the regulations the extensive renovation proposed in this project will no longer fulfil the requirements. It will thus be relevant to question a renovation compared to a demolition. Large amounts of energy are used to renovate buildings in order to save energy. And the energy consumption of the building will in 5-10 years time still be large compared to new houses built. Thus a demolition of the existent building and construction of a new would to a larger extend secure the future of the building.

However, a thing to take into consideration is that the existing buildings in group A should be remained since they represent a building style worthy of preservation and are the core of Hedehusene. Further, a demolition will be expensive, both regarding disposal of the existing building and construction of new ones. Furthermore the buildings are private property, hence the choice of a demolition depend on the willingness and economy of the owner.

It is evaluated that renovation of old buildings should be in consideration of the architecture. Nonetheless, an extensive renovation is a possibility for an improvement of the existing worn out town centre, and might contribute to a sharpened architectural profile in the area. From this perspective the building investigated should be renovated and not demolished.

5.3 Barriers for Implementations of Energy Renovation Proposals

As a perspective of the project it is interesting to clarify why energy renovations are not performed in larger scale.

An investigation of barriers for energy renovation of rental homes has been performed by SBI in 2008 (69).
According to this the initial attitude towards energy renovation is dependent on the type of owner of the building. The professional landlords rarely prioritise the building or the inhabitants unless there is an economical benefit.
The smaller investors on the contrary seek a profit in a short perspective. They aim at the best conditions obtainable within the economy available (69).

In the area investigated both type of building owners are seen.

The barriers mentioned in (69) are divided into groups regarding regulations for rent, the attitude of the inhabitants, technical knowledge, public regulations, profitability, and architecture.
Initially the incentives for the owners do not exist, as their main aim is to offer a low rent and the tenants are at the same time against price-raising renovations. They prefer the money is used for maintenance.
Regarding technical knowledge an argument is that the smaller investors and administrators have a limited knowledge of constructions and the possibilities for energy improvements of their buildings (69). This was also the experience from contact to some of the administrators in this project.
Further knowledge of energy renovation possibilities for the specific building types instead of general considerations is requested. An example of this is energikoncept.dk a digital tool that displays consequences of the solutions (69). However not all building types are presented in the tools available.
A more extensive public regulation is requested as a way to increase the energy renovations and critique is made of the existing energy labelling arrangement (69).

The subject of more public regulation has already been mentioned shortly earlier, and resent initiatives have been taken to mobilise energy renovation. However the possibilities for regulation in the area of energy renovations could be questioned. Ineffectiveness regardless of the existing technology and wealth during the later years indicates that regulations are the only way to get extensive energy renovations started.

The lack of profitability of the energy renovation proposals along with a need for public subsidy or deduction is another barrier mentioned in (69).
One proposal is to change the current measurement for profitability of energy renovations. This is expected to increase the number of energy renovations which would further be beneficial for a price development of the initiatives. As repetition of a solution give experience in an area, thus the price of the work will decrease, as the project is defined.

Regarding the architectural barriers it is a common attitude that an external re-insulation of external walls is not a possibility as it will ruin the townscape. However this is connected to a lack of available examples that can show what the proposal entails (69).

During this project all type of barriers has been experienced.

There are many opinions of what architecture is and for some, age is equal to worthy of preservation or at least a renovation that does not change the appearance of the building.
However many buildings in the area investigated have during the years been used and some misused, which clearly appears in the townscape. For some buildings it is thus evaluated that an energy renovation can bring the buildings into the present and underline architectural characters.
Lack of knowledge is also seen, which influences the attitude regarding changes of the present situation. In this case, with a municipality project, it is important to keep up a high level of information and dialog as this might otherwise be the largest barrier. Therefore, information and involvement of citizens is a focus area in the ECO-Life project and the vision of a CO_2 neutral municipality in 2022. A local climate association have already been started and ongoing arrangements in the local area are performed.

The attitude among the citizens spoken to during the project is that energy renovation is performed along with other renovation projects. Examples are an increased thickness of insulation of the roof when a flat roof is replaced by a roof with a pitch. Another example is external insulation of the exterior walls in connection with an extension. Further renovations are typically performed when age or technical state forces it.

It is evaluated that a fundamental change in attitude is needed along with public regulations in order to accomplish more energy renovations. These changes have to replace short economic perspectives with more consideration of life time of the building.

5.4 Possibilities for Implementation

In the previous sections possibilities and barriers for realisation of energy renovations have been presented and discussed. There are however, a need for tools that can connect the present technology and the aim of a decrease in energy consumptions from buildings.

ESCO – Energy Saving COmpany

In an ECSO partnership energy renovation of one or more buildings is performed by an ESCO-company. The renovation will be financed by the reduction in energy consumption obtained. The ESCO-company take care of implementation of the renovation initiatives and vouch for the energy savings and there by exempt the client off the economical risk connect related to a large energy renovation. The payment to the ESCO-

company depend on the obtained saving and the investment typically has to be repaid before the contract ends (71).
The typical ECSO-model is reserved for public buildings and large industrial companies (72). However, examples show that also private owned buildings can sign an agreement with an ESCO-company (73).

SUBSIDY

During time, public subsidy has been a part of the motivation for energy renovation. The subsidies have been for replacement of windows, installation of solar collectors, and recently in 2009 for specific parts of energy renovation.
Currently there is a public subsidy for replacement of an existing oil boiler in residential buildings. The subsidy is dependent on which type of new heating supply is chosen. The largest subsidy is given for installation of geothermal energy (74).
Further, Lolland Kommune, a fringe municipality, offers a local subsidy. For private residential buildings subsidy is possible for general renovation of the buildings (75).

The presented tools are two different ways to motivate energy renovations. ESCO is a new solution in Denmark and is based on an active participation from the owner of a building in order to get the best result. Further, the solution is until now typically seen for public buildings.
The subsidy agreements, however, is typically for private residential buildings. Furthermore subsidy agreements often consider or maybe even give specific technologies preferential treatment. This could be caused by the strict regulations that are needed for a subsidy.
Subsidy agreements are an instant economical support compared to for example an ESCO agreement where the economical benefit has to be seen in a longer perspective.
However it is estimated that a combination of the two, for example regarding the financial part would result in more energy renovations performed. The subsidy would then be given to coherent projects, instead of individual initiatives.

As a solution to the large energy renovation potential seen in residential buildings, climate package solutions, smaller ESCOs have been made in Middelfart Kommune. The first example of smaller climate packages where several renovation projects compiled in one tender (72).

As part of the aim of reducing the CO_2 emission in the municipality Høje-Taastrup is working on climate packages as a private alternative to a part of an ESCO agreement.

ESCO might be the future solution for all building types. However, there must be some adjustments, to meet the requirements of all type of building owners.

5.5 Status of the ECO-Life Project

The project started in January 2010 and the main focus have until now been on preliminary tasks.

In the municipality of Høje-Taastrup an initial proposal for the climate packages have been presented in the middle of April. The packages concern energy renovation of single-family houses from the 1960s and 1970s.

The concept of the climate packages is made in perspective of local associations, consisting of private owners, homeowner’s associations etc., for example climate associations.

The associations can benefit from internal experience and consolidate renovations in a common tender. The packages will not include a financial solution, but refer to possibilities.

However they aim at being a tool to generate possibilities for energy renovation based on the owner’s motivation and expectations for a renovation (76).

6 Conclusion

From preliminary investigations of buildings in the area energy renovation proposals have been presented and the potential for energy renovation in the area were evaluated to be high for the majority of the buildings.

In the case study a specific building type, buildings for combined use from before 1930 were investigated. The results of individual energy renovation proposals showed that the largest reduction in the heating demand is obtained by replacement of windows, renovation of the heating system and external re-insulation of the external walls.

Further investigation of an extensive energy renovation of the reference building showed an energy consumption of 81.1 kWh/m^2/year. This corresponds to a decrease in the energy consumption by 77 %. The result is an energy consumption lower than required for new buildings today and thereby the aim of renovation of existing buildings set in the ECO-Life project is obtainable.

The case study is based on calculations performed on a representative building for the building type chosen. Calculations were performed by use of BSim for detailed calculation of the heating demand in the building and verified by use of BE06. Correlation between the results was seen for calculations of both the reference building and the energy renovated building.

Since the renovation proposed is extensive it has been discussed if the buildings should be demolished instead of being renovated, yet, it is evaluated that an extensive renovation would contribute to an improvement of the existing townscape in the area.

7 List of Figures

8 List of Tables

9 Bibliography

1. **Høje-Taastrup Kommune.** Byen - Ny CO2-neutral bydel. *Høje-Taastrup Kommune.* [Online] [Cited: 15 2 2010.] http://htk-klima.odeum.com/dk/byen/ny_co2-neutral_bydel/.

2. **Hummelshøj, Reto M; et al.** *Seventh Framework Programme Priority - Annex I - "Description of Work" - ECO-Life.* 2009.

3. Kommuneplan 2010: Vision Gammelsø - Ny byudvikling i hedehusene. *Høje Taastrup Kommune.* [Online] [Cited: 8 12 2009.] http://kommuneplan.htk.dk/dk/udviklingsstrategier/hoeje-taastrup_kommune_-_vide_rammer/vision_gammelsoe_-_ny_byudvikling_i_hedehusene/.

4. Krak: Kort. *Krak.* [Online] [Cited: 07 12 2009.] http://map.krak.dk/.

5. **Byrådscentret, Høje-Taastrup Kommune.** *Udviklingsstrategier, Tillæg til kommuneplan 2000, bind 1.* s.l. : Høje-Taastrup Kommune, 2006.

6. Forslag til Kommuneplan 2010 - Arealanvendelse - Rammebestemmelser fot enkeltområder - Hedehusene Bymidte. *Høje-Taastrup Kommune.* [Online] [Cited: 27 11 2009.] http://htk-end.odeum.com/dk/arealanvendelse/rammebestemmelser_for_enkeltomraader/enkeltomraader/forslag/359.htm.

7. **Færregaard Jensen, Dorthe.** *Udviklingskonsulent, Høje-Taastrup Kommune.* [interv.] Marlene Stenberg Hagen Eriksen. Uge 47 2009.

8. Fredede bygninger - Om fredede og bevaringsværdige bygninger - Bevaringsværidge huse. *Kulturarvstyrelsen.* [Online] 2 10 2009. [Cited: 5 1 2010.] http://www.kulturarv.dk/fredede-bygninger/om-fredede-og-bevaringsvaerdige-bygninger/bevaringsvaerdige-huse/.

9. **Høje-Taastrup Kommune.** Stationsforpladsen. *Lokalplan nr. 4.18.8.* s.l. : Høje-Taastrup Kommune, 1988.

10. —. Et område vest for stationspladsen. *Lokalplan nr. 4.18.13.* s.l. : Høje-Taastrup Kommune, 1998.

11. —. Butikker, liberalt erhverv, restaurationsvirksomhed, offentlig service, kulturelle aktiviteter, boliger o.l. *Lokalplan nr. 4.18.14.* s.l. : Høje-Taastrup Kommune.

12. **Strunge Jensen A/S.** *Energirenovering i fredede bygninger.* s.l. : Realea, 2009. ISBN: 978-87-92230-16-4.

13. **Trier, Else.** *Høje-Taastrup Kommune i fortid og nutid.* s.l. : Høje-Taastrup Kommune, 1995.

14. Byrådscentret - 5. spor - fakta ark. *HTK.dk.* [Online] [Cited: 9 4 2010.] http://www2.htk.dk/Byraadscenter/5_spor/Faktaark_Kapacitet.pdf.

15. **Fjernvarme, Hedehusene.** *Varmemesteren.* 2 November 2009.

16. Miljø - Miljødeklaration - Høje Taastrup Fjernvarme a.m.b.a. *VEKS Energi til dig på Vestegnen.* [Online] [Cited: 10 4 2010.] http://www.veks.dk/Home/Links/H%C3%B8je%20Taastrup%20Fjernvarme.aspx.

17. **Bjerregaard, Rudi.** *Direktør Høje Taastrup Fjernvarme.* 6 Januar 2010.

18. **Engholst, Lene.** Eksempel 19, Projekt SOLTAG. *SBi Statens Byggeforskningsinstitut.* [Online] 9 10 2009. [Cited: 19 4 2010.] http://www.sbi.dk/byggeteknik/bygningsdele/tage/anvisningomtagboliger/eksempelsamling/eks19.

19. Værktøjer - Energiløsninger - Samlet Katalog med energiløsninger. *Videncenter for energibesparelser i bygninger.* [Online] 2010. http://www.byggeriogenergi.dk/28228.

20. BR08 Bygningsreglementet. *Erhvervs- og Byggestyrelsen.* [Online] 1 4 2009. [Cited: 1 2 2010.] http://www.ebst.dk/br08.dk/br07/0/54.

21. Passivhus Definition. *Alt om Passivhuse.* [Online] [Cited: 2 28 2010.] http://www.altompassivhuse.dk/221-kriterier.html.

22. **Brandt, Erik.** Dampspærrer - Udførelse og detaljer mod opvarmede rum. *BYG-ERFA Erfaringsblad (39) 08 06 30.* 2008.

23. *Rockwool.* [Online] www.rockwool.dk.

24. **Berteksen, Niels Haldor.** Fugt- og frostskader efter hulmursisolering. *BYG-EFRA Erfaringsblad (21) 95 09 07 2. udgave.* 1995.

25. **Bertelsen, Niels Haldor.** Indblæsningsfejl og -skader ved isolering af hulmur. *BYG-ERFA Erfaringsblad (21) 95 09 06.* 1995.

26. Hulmursisolering. *Arkitekon Energy.* [Online] [Cited: 20 2 2010.] http://www.arkitekon.dk/default.php3?ID=4801&RecordID=40165.

27. **Christensen, Georg.** Udvendig facadeisolering med puds på mineraluld. *BYG-ERFA Erfaringsblad (41) 99 12 20.* 1999.

28. Facade isolering. *Roskilde Isolering ApS .* [Online] [Cited: 14 4 2010.] http://www.roskilde-isolering.dk/vi-tilbyder/facade-isolering.html.

29. **Tommerup, Henrik; et al.** *Energirenoveringstiltag, Udkast.* 2010.

30. **Christensen, Georg and Koch, Anne Pia.** Indvendig efterisolering af ældre ydermure. *BYG-ERFA erfaringsblad (31) 09 10 29.* 2009.

31. Etageadskillelse. *E. H. Isolering I/S.* [Online] [Cited: 11 4 2010.] http://www.ehisolering.dk/.

32. **Bunch-Nielsen, Tommy and Christensen, Georg.** Risiko ved udeluftventilerede krybekældre. *BYG-ERFA Erfaringsblad (19) 09 12 30.* 2009.

33. Viden om - Nye kviste på eksisterende huse. *Bolius.* [Online] 14 4 2010. [Cited: 18 2 2010.] http://www.bolius.dk/viden-om/facader-og-tage/artikel/nye-kviste-paa-eksisterende-huse/.

34. Produkter - Kviste. *Taasinge.* [Online] [Cited: 1 3 2010.] http://www.taasinge.dk/cms/page336.asp.

35. Nyt vindue isolerer 60 % bedre. *Pro Tec Windows.* [Online] [Cited: 12 4 2010.] http://www.protecwindows.com/Components/GetMedia.aspx?id=8730e09e-6764-4af7-b8f5-be78fd2d5a89.

36. Produkter - Pro Tec 7 uni. *Pro Tec Windows.* [Online] [Cited: 1 3 2010.] http://www.protecwindows.com/da/produkter/PRO%20TEC%207%20uni/Dokumentation.aspx.

37. *DS 700 Kunstig belysning i arbejdslokaler - 6. udgave.* s.l. : Dansk Standard, 17 06 2005.

38. Produkter - Fjernvarmeunits. *Danfoss Redan A/S.* [Online] [Cited: 2 3 2010.] http://dk.redan.danfoss.com/Content/5d284c7a-50cf-4610-83be-3042a6a5484f_MNU17351123_SIT193.html.

39. **Hvenegaard, Claus M., et al.** *Den lille blå om varme.* s.l. : Dansk Energi, 2008.

40. El-sparefondens hjemmeside. [Online] http://www.elsparefonden.dk.

41. Nysted varmerådgivning - Radiatortermostater. *Nysted Fjernvarmeværk A.m.b.a.* [Online] [Cited: 19 4 2010.] http://www.nystedvarme.dk/showpage.php?pageid=26869.

42. Forbrug & Besparelser - Energiselskabernes spareindsats - Regler for opgørelser og dokumentation - Katalog for standardværdier. *Energistyrelsen.* [Online] [Cited: 16 3 2010.] http://www.energistyrelsen.dk/da-DK/ForbrugOgBesparelser/EnergiselskabernesSpareindsats/Reglerforopgorelserogdokumentation/Katalog_for_standardvaerdier/Sider/Forside.aspx .

43. Living - Energirenovering - Produkter til renovering. *Exhausto.* [Online] 15 4 2009. [Cited: 18 2 2010.] http://www.exhausto.dk/composite-3252.htm.

44. **Hvenegaard, Claus M.** *Den lille blå om ventialtion.* s.l. : ELFOR, 2002.

45. *Afgifter Bremser Genbrug af Energi.* **Ranis, Troels.** s.l. : DI Organision for erhvervslivet, 2009.

46. *Supermarkeder kan gøre store mængder af kulkraft overflødig.* **Krøyer, Kent.** 2009, Ingeniøren.

47. Om solvarme. *Alt om solvarme.* [Online] [Cited: 19 4 2010.] http://www.altomsolvarme.dk/22-om-solvarme-fr.html.

48. **Sander, Kirsten, Clasen, Gusta and Felland, Jan Bo.** Viden om - Varmepumper. *Bolius - Boligejernes Videnscenter.* [Online] 13 10 2009. [Cited: 12 4 2010.] http://www.bolius.dk/viden-om/energi/artikel/varmepumper/#Hvilke-typer-varmepumper-findes-der.

49. Billeder af vores små vindmøller. *ProCure.* [Online] [Cited: 19 4 2010.] http://www.procure.dk/billeder_moeller.htm.

50. Forside - Byvindmøller.dk. *Logik & Co.* [Online] [Cited: 19 4 2010.] http://logik.dk/site/byvind/en-masse-naleojer.

51. **Jens Peter Houe.** En vindmølle på taget giver lys i lampen. *Politikken.dk.* [Online] [Cited: 19 4 2010.] http://politiken.dk/klima/klimadig/article869673.ece.

52. **Sander, Kirsten, Lindegaard, Dea and Felland, Jan Bo.** Viden om - Solceller. *Bolius.* [Online] [Cited: 19 4 2010.] http://www.bolius.dk/viden-om/byg-nyt-hus/artikel/solceller/#Hvilken-type-solceller-findes-der.

53. Solceller - Introduktion - Nettilslutning. *SolENErgiCentret.* [Online] [Cited: 19 4 2010.] http://www.solenergi.dk/SEC/visTekst.asp?id=48.

54. Om VEKS - Varmeproduktion - Driftsåret 2008. *VEKS - Energi til dig på vestegnen.* [Online] Maj 2009. [Cited: 19 4 2010.] http://www.veks.dk/Om%20VEKS/Varmeproduktion/Driftsaaret.aspx.

55. *Varmeplan Hovedstanden.* s.l. : CTR, Københavns Energi, VEKS, 2009.

56. **Lorentzen, Jesper.** Introduktion til EPROJ . *Energistyrelsens varmemodel.* s.l. : Energistyrelsen, 1997.

57. **Flourentzos, F, Droutsa, K and Wittchen, K B.** EPIQR Software. *Energy and Buildings.* s.l. : ELSEVIER, 2000. 31.

58. TOBUS - An Eorupean method and software for office building refurbishment. *Energy and Builsings .* s.l. : ELSEVIER, 2002. 34.

59. Beregning af bygningers varmetab 6. udgave. *DS 418 .* s.l. : Dansk Standard, 03 04 2002.

60. **Knudsen, H.P.** *Lærebog i Opvarmning og Ventilation - den almindelige del.* s.l. : Hagen & Sørensen - Odense, 1961.

61. **Energistyrelsen.** *Håndbog for enrgikonsulente, version 3.* s.l. : Energistyrensen, 2008. ISBN 978-87-7844-813-2.

62. **Aggerholm, Søren.** *SBi-anvisning 213, Bygningers energibehov, Beregningsvejledning.* s.l. : Statens Byggeforskningsinstitut, 2008.

63. **Tommerup, Henrik.** *Energirenovering of murmesterhus.* s.l. : BYG.DTU, 2004. ISBN 87-7877-168-4.

64. **Dansk Standard.** Indoor environmental input parameters for design and assesment of energy performance of buildings adressing indoor air quality, thermal environment, lighting and acoustics. *DS/EN 15251.* s.l. : Dansk Standard, 2007.

65. **Dong Energy.** Generel deklaration Østdanmark 2008. *Dong Energy.* [Online] [Cited: 28 3 2010.] http://www.dongenergy.dk/SiteCollectionDocuments/PDF_filer/El/Eldeklaration/Eldeklaration_maj2009_%C3%98st.pdf.

66. **Christensen, Kaj.** *Varmeanlæg, Undervisningsnotat.* s.l. : BYG.DTU, 2003.

67. **FHBB - Switzerland, EMPA - Switzerland, ZAE-Bayern - Germany, TU Delft - Netherlands, KTH Stockholm - Sweden, Dr. Eicher + Pauli AG - Switzerland.** *HiPTI - High Performance Thermal Insulation IEA/ECBCS Annex 39: Vacuum Insulation in the Building Sector, Systems and Applications.*

68. **Landing, Tove and Gerlach, Lena.** Leksikon - Vacuum Isolering. *Landing arkitekter + konsulenter A/S.* [Online] Juni 2008. [Cited: 19 4 2010.] http://www.dsbo.dk/Home/area1/Leksikon/Vacuumisolering/tabid/478/Default.aspx.

69. **Jensen, Jesper Ole and Clementsen, Anne.** *Barrierer for energibesparelser i private udlejningsboliger.* s.l. : SBI, 2008.

70. Nyheder og Presse - Pressemeddelelser - Fart på energibesparelser i boliger. *Økonomi - og Erhvervsministeriet.* [Online] 11 februar 2010. [Cited: 19 4 2010.] http://www.oem.dk/sw27720.asp?trackingid=1074&newsletterid=854.

71. *ESCO - et ægteskab.* **Wied, Martin Dam and Spanning, Maja Rüttel.** s.l. : Energiforum Danmark, 2010.

72. **Videncenter for energibesparelser i bygninger.** Tjen penge - Indgå et ESCO-Samarbejde. *Videncenter for energibesparelser i bygninger.* [Online] [Cited: 21 4 2010.] http://www.byggeriogenergi.dk/25059.

73. **ESCO Gruppen.** ESCO trin for trin. *ESCO Gruppen.* [Online] [Cited: 21 4 2010.] http://www.escogruppen.dk/trin_for_trin.html.

74. **Energistyrelsen.** Skrotditoilefyr.dk. *Energistyrelsen.* [Online] [Cited: 21 4 2010.] http://www.skrotditoliefyr.dk/da-DK/Sider/Skrotditoliefyr.aspx.

75. **Lolland Kommune.** Projekt Energilandsby Horslund - Tilskud til energirenovering. *Lolland Kommune.* [Online] 31 3 2010. [Cited: 21 4 2010.] http://www.lolland.dk/Bo_p%C3%A5_Lolland/Mulighedernes_Land/Projekt_Energilandsby_Horslunde/Tilskud_til_energirenovering.aspx.

76. **Puggaard, Anja, et al.** *Klimapakker til energirenovaring of 60'er og 70'er boliger - Start Klimapakke.* 2010.