Final report

1. Project details

Project title	Bolig 2020 med lavt energiforbrug og høj brugerkomfort
File no.	64015 – 0640
Name of the funding scheme	EUDP
Project managing company / institution	IEN Consultants
CVR number (central business register)	2539 8378
Project partners	Lasse Larsen Byg A/S, Åbyhøj Nilan A/S, Hedensted BUILD, Aalborg Universitet (tidligere SBi og Byggeri & Anlæg)
Submission date	17 November 2020

2. Summary

The objective is to develop and demonstrate a new generation of low energy houses that fulfills the Building Class 2020 regulations with Near Zero Energy Consumption, and where solutions are presented to the problem of poor indoor climate at wintertime with a felt lack of fresh air supply, and poor indoor climate at summertime with too high indoor temperatures during warm days with sunshine. Finally, to address the discrepancy between predicted energy consumption and actual energy consumption, that is typically much higher than predicted.

The project is based on experiences gained by the Danish Building Research Institute (now called Build) regarding actual energy performance and indoor climate in a number of new low energy houses in Denmark and abroad.

New low energy houses have to be very airtight, and fresh air is therefore solely provided by the ventilation system with heat recovery. In order to keep energy consumption low, there is a limit to the amount of fresh air that is delivered to the building, and this amount of fresh air will at times with high occupancy be insufficient in those parts of the building where the occupants are present. Therefore, we wish to develop a demand controlled ventilation system that allows more fresh air when occupants are at home and to the rooms that they occupy, and a lower fresh air supply when the building is empty.

New low energy buildings typically have large window areas, primarily to the south and to the west. The result is that overheating occurs during warm days with sunshine. This problem might be eliminated by putting priority to large windows to the north and east. However, this cannot be accepted by the building owners, it is simply

too different to the norm and preferred design of housing. We need to deal with the problem using efficient solar shading and natural ventilation to provide a good indoor climate also when it is hot and sunny outside, and we need to avoid the temptation of installing active cooling.

Projektets formål er at udvikle og demonstrere en ny generation af lavenergiboliger som opfylder energikravet i Bygningsklasse 2020, og hvor der præsenteres løsninger på problemet med et oplevet dårligt indeklima om vinteren med utilstrækkelig tilførsel af friskluft, samt et dårligt indeklima om sommeren med for høje inde temperaturer på varme dage med solskin. Endelig så ønsker vi også at adressere forskellen mellem beregnet energiforbrug og målt energiforbrug, som typisk er væsentligt højere end det beregnede.

Projektet baserer sig på en omfattende dataindsamling foretaget af SBI (nu BUILD) vedrørende energiforbrug og indeklima i nyere lavenergiboliger i Danmark og i udlandet.

Nye lavenergihuse skal være meget tætte. Frisk luft til boligen leveres derfor udelukkende via ventilationssystemet med varmegenvinding. For at holde energiforbruget til ventilation lavt er der et maksimum på den mængde friskluft som boligen må tilføres, og denne mængde friskluft vil i perioder med høj personbelastning blive oplevet som utilstrækkelig. Vi ønsker derfor at udvikle og demonstrere et behovsstyret ventilationsanlæg som leverer mere friskluft til beboerne når de er hjemme og til de rum hvor de opholder sig, og som så reducerer mængden af friskluft når beboerne ikke er hjemme således at middelværdien svarer til bygningsreglementets krav.

Nye lavenergiboliger har typisk store vinduesarealer, primært orienteret i sydlig og vestlig retning. Resultatet er at der boligen bliver meget varm på varme dage med solskin. Dette problem kunne elimineres ved at prioritere de store vinduesarealer imod nord og øst. Men denne løsning kan ikke accepteres af de fleste bygherrer. Det er simpelthen for forskelligt fra opfattelsen af et godt design af en bolig. Derfor må vi løse problemet ved at anvende effektiv solafskærmning og naturlig ventilation i varme døgn med megen sol i dagtimerne, og dermed undgå at boligejeren vælger at installere eldrevne køleanlæg.

3. Project objectives

- The objective is to develop and demonstrate a new generation of low energy houses that fulfills the Building Class 2020 regulations with Near Zero Energy Consumption, and where solutions are presented to the problem of poor indoor climate at wintertime with a felt lack of fresh air supply, and poor indoor climate at summertime with too high indoor temperatures during warm days with sunshine. Finally, to address the discrepancy between predicted energy consumption and actual energy consumption, that is typically much higher than predicted.
- *Which energy technology has been developed and demonstrated?*

1. We developed and demonstrated a new design of a **movable exterior shading system**. The shading system is different in construction. Narrow blinds are mounted horizontally with good distance so that there is still a good view to the outside when the blinds are in position. The design provides shading from direct sunshine corresponding to a 3.5 meter overhang for south orientated windows. The architectural design is well appreciated. A design that blends well in with modern housing.
2. We developed and demonstrated a new type of **ventilation "windows**" that allows fresh air into the room without compromising safety, as there are fixed louvres on the outside. Inside there is an insulated gate to provide heat insulation when closed. This system was developed by the window manufacturer Velfac as a prototype for this project. The ventilation "windows" in combination with openable rooflights provides an excellent natural air exchange rate to cool down the building during summer days and nights.

3. We wanted to apply a **heat recuperation system for warm water from the showers**. A suitable commercial system from the German company Wagner was identified. However this system could not be implemented in Denmark as it did not fulfil the Danish norm for potable water installations. This norm does not allow hidden connections for piping, and this cannot be accommodated with the actual design from Germany. Instead we have tested the thermal performance in the laboratory of AAU. The lack of energy efficiency that could have been provided by heat recuperation from warm shower water had to be replaced by installing a small PV system, so that Building Class 2020 can be met. It should be mentioned that if the building were heated by a heat pump instead of by district heating, then the building could have met the Building Class 2020 without PV system, by choosing one of the most efficient heat pumps on the market.
4. The **control system for natural ventilation and exterior shading** was purpose built specifically for this project to allow testing of a wide range of control strategies. Now at the end of the project, a commercial control system developed by the company NICO in Sønderborg will be installed. This system provides automatic control according to the optimal control strategy identified during the 3 year demonstration and test period.

4. Project implementation

The first year was used to analyse the various possibilities to successfully implement a building design that would provide solutions to the three main challenges that we gave ourselves:

1. To implement a building that could be certified according to the Building Class 2020 with a primary energy consumption of 20 kWh/m^2/year. We wanted to develop solutions that could meet this target, if possible, without having to resort to using local solar energy on the building.
2. To implement a design where there would be no overtemperatures during summertime, without having to resort to the use of active cooling.
3. To implement a design that will provide a comfortable indoor climate with ample fresh air in the building when occupied and where the occupants would be (demand controlled ventilation)..

The main risks were seen at being :

a. Not bring able to meet the Building Class 2020 objective of 20 kWh/m2/year using passive design features only, i.e without having to resort to installing supplementary active solar energy.
b. Problems of finding appropriate technical solutions to provide individual control of fresh air inlet on a room level. Demand controlled ventilation is already well developed for use in offices, whereas implementing this on the scale of domestic housing might be a challenge. The challenge is economical as the control systems and ventilation solutions used in commercial buildings would be too expensive to implement at a small scale in housing.

The project did not develop as intended on the following points :

1. It took longer time for the developer, Lasse Larsen Huse, to identify a suitable client for the first demonstration project and sign a contract. The delay was ¾ of a year.

In September 2017, the MD of Lasse Larsen Huse resigned as MD and left the company, This was critical, as Allan Laursen was a driving force in starting the project and implementing the project. This happened after Lasse Larsen Huse had been sold by the founder Lasse Larsen to an outside investor by February 2017.

The new owner of Lasse Larsen Huse, mr Pierre Legarth, did not put priority in the project, 180 degrees to the approach of Lasse Larsen and Allan Laursen.

The new owner confirmed that they would be supporting the implementation and follow up on the first of two demonstration projects, the project in Ry. This project has by now been completed, a young couple has moved into the house, and the monitoring program was about to start.

Demonstration project no 2 was in preparation, and this project would have a heat pump as heat source, where demonstration project no 1 in Ry had district heating. It quickly became clear that the new management of Lasse Larsen Huse did not wish to move forward with demonstration project no. 2. At that time, planning of demonstration project no. 2 was well advanced, with a project in a new area in the city of Lejre on Zealand, an area where heat pump heating was mandatory.

We negotiated a settlement with the Danish Energy Agency meaning that not two but one demonstration project would be implemented, and where additional activities would be included instead :

1. Testing heat pump systems in real life, comparing the performance of ground source heat pumps with the performance of air to water heat pumps.
2. Testing the floor heating system in the demonstration project in Ry with a view of asserting whether a heavy floor heating system with a 120 mm concrete core could serve as short term storage system for a heat pump that would be controlled in a smart grid mode, i.e, where the heat pump would operate during night time where there is a surplus of renewable energy in the grid from wind energy.
3. Test of heat recuperation on warm water from showers in the bathrooms. In new low energy houses, the energy consumption for providing hot water is at the same level as the energy consumption for space heating. Therefore, it makes sense to investigate whether heat recuperation can be implemented on the bulk of hot water load, the warm water that is used in the showers. Heat recuperation on the shower water would be implemented by preheating the incoming cold water by heat exchange from the warm water that is leaving the shower basin.

5. Project results

The project had the following three objectives, and each objective were either partially or fully fulfilled:

- To implement a building that could be certified according to the Building Class 2020 with a primary energy consumption of 20 kWh/m²/year. We wanted to develop solutions that could meet this target, if possible, without having to resort to using local solar energy on the building. Also, we wanted to demonstrate a design using fairly normal design options and choices of materials, in order to keep the extra costs of achieving the Building Class 2020 certification at a minimum.

The building almost reached the Bygningsklasse 2020 level of 20 kWh/m2/year in primary energy consumption. Had the building been heated with a heat pump instead of district heating, we could have reached the 20 kWh/m²/year without resorting to using supplementary renewable energy.

- To implement a design where there would be no overtemperatures during summertime, without having to resort to the use of active cooling.

This objective was fully met. There were no overheating, even during a summer with very high external temperatures and full sunshine for weeks. See more in Appendix 3.

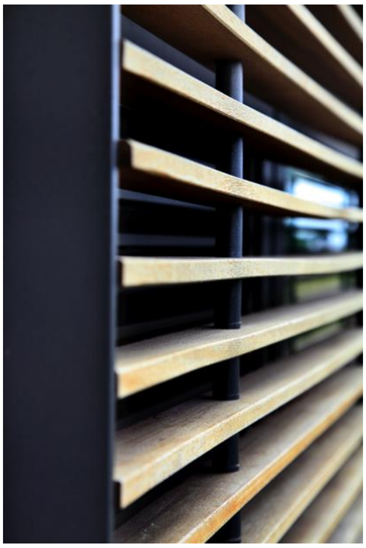
- To implement a design that will provide a comfortable indoor climate with ample fresh air in the building when occupied and where the occupants would be (demand controlled ventilation).

The installed individual dampers in each room proved unreliable and were dismantled towards the end of the project. The control of the ventilation system with heat recuperation has now been changed to operating on the CO_2 level in the outlet air rather than the CO_2 level in the individual room. Hence, then this objective was only partially fulfilled.

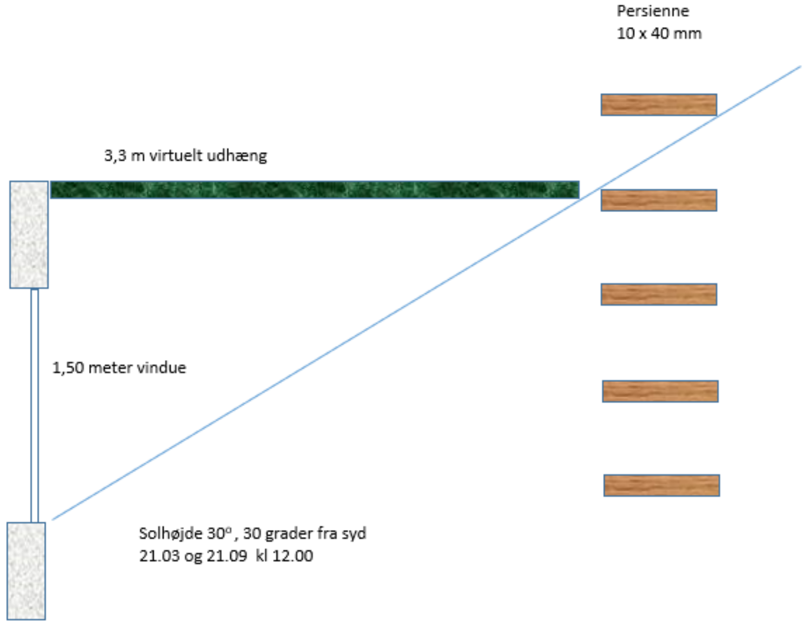
All in all, then the technical results achieved were satisfactory and as expected.

Control of indoor climate during summertime

A new system of exterior roller shades was developed. The innovation is in the construction of the shade, so that very narrow wooden blinds 10 x 40 mm can be used. This gives a very clean design and has the big advantage that there is still a view out when the blinds are pulled in front of the window.



Solar shading from the inside and the outside. The frames are in aluminium, and the blinds are in mahogany wood. The prototypes were produced by Solatek, following a detailed design developed by IEN Consultants.



The shading system is very effective in cutting off direct solar radiation, in particular for south orientated windows. Above it is illustrated that the shading effect of the 10x40 mm blinds with a distance of 40 mm, this corresponds to the shading effect of a 3.3 m overhang, at spring or autumn equinox at 12.00 hours.

In addition to solar shading, a system of natural ventilation was installed to control the indoor temperature during summertime. This system consists of two Velux roof windows with electrical actuator, both in the large central room, and 4 ventilation openings. Each ventilation opening consists of an outside fixed grille with an insect net, and an insulated door on the inside. The door is operated by an electrical actuator.



The ventilation openings in the walls were produce by the window company Velfac (a sister company to Velux)

Overall, the project produced results as expected. However, as mentioned, the demand controlled ventilation system did not fulfil expectations as we ended up with a system where the volume of inlet air is controlled depending on the CO2 level of the building rather that controlled according to the CO2 level of the living rooms and the bedrooms individually.

However, regarding control of the indoor air quality during summertime, then the results were even better than expected. Even during the hot and vert sunny summer of 2018, the temperature inside the building very seldom exceeded 25°C although outside temperatures during many days exceeded 30°C. The shading system and natural ventilation system that can cool the building down during night time, was exceptionally successful, both measured objectively (see Appendix 3) as well as subjectively. The users, Stefan and Christina are very happy with the indoor climate, and they consider this achievement as the single most attractive feature of the house.

The target group for the solutions to achieve very good indoor comfort during summertime, this would be the Type House producers. We believe that they should have the option of “excellent indoor climate” as an option for the buyers to choose. His option would consist of 3 – 4 ventilation windows, two motor driven rooflights and external movable shading in front of the main windows to the south and west, and a control system. We believe that given the proven excellent performance of the system, many would choose to add this option.

There would also be a market among clients that build individual houses of their own design. Finally, it is anticipated that the solution with external shading and ventilation windows could successfully be retrofitted to existing houses with severe overheating problems. There are many of such houses around, in particular houses built over the last two decades. They typically have large window areas that are only poorly protected against direct sunshine.

Dissemination of the results

The successful results of the project regarding natural ventilation was presented at a Danvak seminar in Aalborg on 19.01.2019. The theme for the seminar was Choose the appropriate ventilation system – based on comfort, air quality and running costs (“Vælg det rigtige ventilationsanlæg – ud fra komfort luftkvalitet og driftsudgifter”).

Several dissemination plans over the last ½ year had to be cancelled due to the Corona situation. In June 2020 we arranged a presentation of the results of the project on site for journalists. Only one professional journalist showed up !

However, now by October 2020. We have all the results of the project ready for dissemination. In November, a new commercial control system for natural ventilation and external shading will be installed. This Home Control System from NIKO in Sønderborg can deliver the control strategy that was found to be optimal:

1. Manual control of ventilation doors and automatic control of rooflights to avoid overheating.
2. Automatic control of the opening of the rooflights and closing of the external solar shading when the indoor temperature in the large central room exceeds a chosen setpoint, for instance 24 °C.
3. A schedule for night ventilation following a hot and sunny day.
4. It is possible to operate the system remotely using your mobile phone.

It should be noted that this control strategy promotes the use of passive solar energy through the windows in the heating season, Blinds are only closed when passive solar energy would lead to overheating.

6. Utilisation of project results

The results of the project will be utilized commercially as follows :

A package solution to achieve good indoor climate during summertime will be marketed by :

- NIKO with their Home Control System adapted to control shading and rooflights.
- IEN Consultants will market the external shading system via their production company Compact Heat Storage ApS. Also the manual ventilation windows from Velfac will be marketed as part of the package.

The rooflights from Velux, or other manufacturers of rooflights, will be part of this package solution, but as rooflights are almost a standard feature in new houses, this needs no special marketing efforts. The only thing to be aware of is that the rooflights must be the option with a built-in electric motor.

The companies have not yet sold systems and components developed in the project. However, from now on, there will be serious efforts by the commercial partners of the project to promote the systems and start production for sale.

For IEN Consultants/Compact Heat Storage ApS, the actual shading elements will be produced by a metal manufacturing company with an industrial powder coating facility, situated in the same industrial complex in North Zealand. The wooden blinds will be delivered from Keflico in Støvring, processed by one of their sub-contractors.

- *Describe the competitive situation in the market you expect to enter.*

The key systems of the project is the combination of natural ventilation system, opening of rooflights, the use of ventilation grilles in the façade, in combination with the exterior shading system and a control system.

Regarding exterior shading systems, there are numerous systems that can be mounted on domestic housing. However, there are no systems on the Danish market that offers this level of design and functionality. A new mounting system means that very thin wooden blinds can be mounted in a frame. This gives a very clean and minimalistic design that matches modern housing, and it gives excellent shading performance, while still offering a good view to the surroundings.

The ventilation opening for the facade were developed by the major window company Velfac. These are unique on the Danish market, and there are no known competitors.

The roof windows with motor control are sold by several producers and importers on the Danish market. However, Velux that delivered the rooflights in this case are market leaders in Denmark, and they are very accessible, meaning that this key component in the new system developed are available an can deliver at a competitive price.

The producer of the control system for natural ventilation that will now be installed, are Niko-Servodan A/S from Sønderborg. They are offering their new system NICO Home Control for this project. It is likely that other competing systems will come on the Danish market, but for now, it seems that Niko-Servodan A/S are offering an advanced system at a competitive price.

Barriers in the project.

Until now, the main barrier has been the lack of available technologies to avoid overheating in housing during summertime. The shading systems have not been adapted to housing regarding design and functionality. Typically, there have been major obstructions to a view out when in use. There have not been acceptable systems available, systems that have proven their worth.

This project has led to a proven system that has been designed specifically for domestic housing, and with a proven system performance it can be offered to housebuilders and type house companies.

The project contributes to realise energy policy objectives by offering a design of a low energy house with excellent indoor climate, and where active cooling is not needed to achieve this. An active cooling load that could easily be at the same level as the energy consumption for space heating.

Research work in the project

The project has not resulted in PhD work, and this was not the intention as per the project proposal. However, the project has contributed to the research at AAU in the area of understanding why actual energy consumption is often much higher that the predicted energy consumption. The project has produced valuable data on detailed energy consumption, user behaviour and user parameters that influence the actual energy consumption. So far, this has resulted in two research papers, see Appendix 4 and 5. Furthermore, this project has served as a stepping stone for the participation of AAU in a new major EU project on the same topic, As part of the EU project, monitoring of the Bolig 2020 demonstration project in Ry will continue for 4 years to come.

7. Project conclusion and perspective

The conclusion of the project is that we have successfully developed and demonstrated a comfort system that provides an excellent indoor climate both during winter and summertime, and therefore eliminates the notion that in order to get a comfortable indoor climate during summertime in a modern low energy building, then you need to install active cooling. That potential energy consumption could easily be at the same size as the energy consumption for space heating. So, the investment and the energy consumption are eliminated.

The next steps are to commercialise the system: Exterior movable shading, secure ventilation openings in the wall, motor operated rooflights and a control system. This will be one package offered primarily to Danish type house companies.

Furthermore, the project group consisting of the construction company DinBolig, AAU/BUILD, IEN Consultants and Compact Heat Storage ApS are commencing in developing a follow up development and demonstration project called Sustainable Housing. This project addresses the growing market outside the district heating grids, where gas and oil-fired boilers have to be phased out and replaced by electric heat pumps. We can build new low energy buildings certified according to the Energiklasse 2020, and where all electricity used to run the heat pumps will be renewable electricity drawn only when the grid has an overflow of wind energy or solar energy.

We believe that this project can have a major impact on how new low energy buildings are designed and built. Overheating during summertime is a big issue in new and newer housing, and this can at present only be avoided using electric air-conditioning. Overheating can be avoided using appropriate and proven design techniques that has been demonstrated in this project, and this will in the long run reduce the urge to install air conditioning in modern housing, and avoid excessive electricity consumption for cooling of dwellings in Denmark.

8. Appendices

1. Bolig2020 Bygningens varmebehov og Energiramme, technical report by AAU/Build
2. Bolig2020 Behovsstyret ventilation slutrapport

3. Bolig2020 Indeklima og komfort slutrapport
4. Energy performance gap of a nearly Zero Energy Building nZEB in Denmark the influence of occupancy modelling (2), Per Heisenber et al, AAU January 2020
5. Loukou_2019_IOP_Conf._Ser._Earth_Environ._Sci._352_012017 (Energy Performance evaluation of a nearly zero energy building …), by Evangelia Loukou, AAU 2019
6. Radon Report (November 2019 - Januar 2020)_RLJ (1), AAU February 2020
7. Yearly Technical Report (January - December 2019)
8. Kildebjerg Søvej 32, Energiramme 2020 certificering
9. Bolig 2020, Bygningsbeskrivelse, tegninger og fotos
10. Projektøkonomi for et kommercielt projekt.
11. Bolig 2020 demonstrationsprojekt i Ry, projekt brochure