Final report

1.1 Project details

Project title	Construction of load-bearing, stability enhanced and easy assembled Polyurethane (PUR) construction panels and implementation in full-scale, experimental, energy-optimized residential housing project
Project identification (program abbrev. and file)	PUR-LOAD
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	DC-System Insulation A/S Nordvestvej 8 9600 Aars
Project partners	Grontmij A/S Granskoven 8 2600 Glostrup CVR no. 48233511 NKM Tegnestue A/S Oustrupvej 28 9600 Aars CVR no. 14820582 Kuben Management A/S Ellebjergvej 52, 3. 2450 København SV CVR no. 28693036 Smart City DK Erhvervsdrivende Fond Hjulmagervej 55 9000 Aalborg CVR no: 32365167 Aalborg Universitet Frederik Bajers Vej 5 9220 Aalborg Øst CVR no: 29102384
CVR (central business register)	10504708
Date for submission	31.01.19

1.2 Short description of project objective and results

English description:

The purpose of the present project is to implement a unique, full-scale demonstration project using special energy-efficient and load-bearing polyurethane panels for both exterior walls, roofing, floor deck and terrain deck. The project is implemented with the construction of a number of row-houses in close cooperation with a pilot customer.

The principal applicant has for many years developed and manufactured non-load bearing insulation panels especially for large refrigeration and freezing rooms and warehouses. Through a series of scale, proof-of- technology trials the principal applicant has in cooperation with selected partners, tested a number of principles of the technology for residential construction with positive results. In this project the partner circle will demonstrate how it is possible to integrate the load-bearing structure of the panels in the production process and thus develop a product with particularly valuable properties which go beyond the obvious thermal qualities of polyurethane. The benefits can be described as follows:

- Polyurethane has an insulating capacity which is approx. 33% better than commonly used insulation products. The improved insulation value gives the possibility to construct buildings with sleeker exterior walls.
- Integrated supporting structure in the element, which ensures a simple and error-reducing assembly process as well as a shortened construction time
- An integrated building envelope that reduces the possibility of building damage due to weather conditions both during construction and during subsequent operation
- A lightweight construction for improved working environment for executing contractors.

The use of polyurethane insulation in construction particularly as facade insulation panels without load-bearing function is a technology that has been used in a number of years e.g. in Germany. In Denmark polyurethane is not commonly used compared to the dominant mineral based insulation products. Though polyurethane is commonly used outside Denmark, it is used almost exclusively focusing on the specific thermal properties of insulation panels. This reduces the advantage of polyurethane elements to a marginal consideration of better insulation value between competing products. In Denmark the improved thermal qualities have not been sufficient to change the market position.

In this project, the partner circle will demonstrate that when a number of other functionalities besides thermal properties are integrated into a polyurethane panel we will achieve a technology with a competitive advantage through a significant number of advantageous features that can be implemented in many housing projects both in the domestic and international markets.

Danish description:

Formålet med herværende projekt er at gennemføre et fuldskala demonstrationsprojekt med brug af særligt energieffektive og lastbærende polyurethanpaneler til både bærende facademure, tagdæk, etagedæk, terrændæk og lette skillevægge. Projektet gennemføres med opførelse af 23 boliger som tæt-lav byggeri i tæt samarbejde med en udvalgt pilotkunde.

Hovedansøger har igennem en årerække udviklet og produceret ikke-lastbærende isoleringspaneler særligt til køle- og fryserum. Gennem en række skalaforsøg har hovedansøger sammen med udvalgte partnere afprøvet principiel anvendelse af teknologien til boligbyggeri i skalaforsøg med positive resultater. Med dette projekt ønsker en partnerkreds omkring teknologien at demonstrere, hvordan det er muligt at integrere lastbærende og stabilitetsgivende konstruktion for panelerne i produktionsprocessen og hermed udvikle et produkt med særligt værdifulde egenskaber for elementbyggeriet. Fordelene kan kort opregnes til:

- Anvendelse af Polyurethan som central isoleringskomponent. Polyurethan har en isoleringsevne der er ca. 33% bedre end en række almindeligt anvendte isoleringsprodukter. Den forbedrede isoleringsværdi kan bl.a. medføre, at bygninger kan opføres med slankere facademure.
- Integreret bærende konstruktion i elementet, der sikrer en simpel og fejlreducerende montageproces samt en forkortet byggetid
- En integreret klimaskærm, som reducerer mulighed for byggeskader som følge af vejrlig både under opførelse og i forbindelse med efterfølgende drift
- En let konstruktion, der sikrer forbedret arbejdsmiljø for de udførende entreprenører

Anvendelse af polyurethan som isoleringsmateriale i byggeriet særligt som facadeisoleringspaneler uden lastbærende funktion er en teknologi som har været anvendt i en årerække bl.a. i Tyskland. I Danmark har udbredelsen været betydeligt mindre i forhold til især markedsdominerende mineraluldsbaserede produkter. Selvom udbredelsen i udlandet er stor, er denne kendetegnet ved at polyurethan anvendes udelukkende med fokus på de særlige termiske egenskaber - som isoleringspaneler. Hermed reduceres polyurethanelementets fordel til udelukkende en marginal betragtning om bedre isoleringsværdi, der bl.a. i Danmark i har været tilstrækkelig til at øge udbredelsen.

I dette projekt vil partnerkredsen derimod demonstrere, at når en række øvrige funktionaliteter udover termiske egenskaber integreres i et polyurethanpanel opnås en teknologi med et betydeligt antal fordelagtige egenskaber, som kan implementeres i store dele af boligbyggeriet.

1.3 Executive summary

The aim of this project is to design a load-bearing insulation panel which could be used in construction of residential or office buildings. The company which develop this element is DC-System Insulation A/S – a producer of sandwich panels with focus on industrial or warehouses. The task is also to test the product, obtain relevant documentation and certificates, set up production line for this product, deliver marketing and sales strategies as well as perform demonstration project – erect a full-size building which will display the achievements of this research. Moreover, the

house is to be used as full-scale laboratory and a test site, for various measurements including thermal imaging, measurements of the energy consumption and indoor climate parameters, humidity inside the envelope of the building and more. The actions are performed with other participants of the project, listed in the beginning of this report. The ultimate goal, which has been achieved, is the introduction of the new product on the market and gain clients for future cooperation.

1.4 Project objectives

Current state of technology

Polyurethane is a classification of a group of materials characterized through the chemical reaction between di- or polyisocyanat and a di- or polyalkohol (polyol). Through the chemical process polyurethane can achieve a number of characteristics of which the most important here is the process leading to thermoplastic characteristics used in insulation panels.

The Polyurethane panels are created through a casting process, where the liquid Polyurethane is distributed into a mold through a foaming process physically or chemically. The foam insulation properties result from the formation of a large number of closed cells containing an insulating gas. The cells are created through the use of a foaming agent / propellant which evaporates during the manufacturing process and is encapsulated as gas bubbles in the polyurethane material and/or as a reaction product (CO2) between di-isocyanate and water. Depending on the manufacturing process the density typically varies between 20-240 kg/m3. Prior to casting a panel, the mold is prepared with a front and a back plate. This means, that the casting process also includes the embedding of a panel back and front made from e.g. steel and fiber cement.

The manufacturing process is semi-automated, so that each mold can be set according to specific requirements for width, height and depth (within the exterior physical boundaries of the mold) allowing for a customization process necessary for the manufacturing of building components.

DC-System Insulation has been developing and supplying insulation panels for large cooling and freezing facilities for the past 40 years of which 85% of the production goes to export markets.

In recent years the company has begun a process of adopting its insulation technology to the market for residential housing with a growing demand for sufficient insulation to reduce energy consumption. The new market is entered because insulation made on the basis of Polyurethane has a substantial advantage in insulation value compared to other insulation products. A comparative table of thermal capacities of different materials is shown below:

Batts, plader o.l.		
Celleglas	38 - 50	0,038 - 0,050
Mineraluld	32 - 43	0,032 - 0,043
Polystyren	34 - 41	0,034 - 0,041
Vakumisolering	5 - 6	0,005 - 0,006
Vacu Pad	7 - 11	0,007 - 0,011
Aerogel	14 - 18	0,014 - 0,018
Aerorock	19	0,019
PUR	21	0,021
Grey EPS	31	0,031

[1] Videnscenter for Energibesparelser i Bygninger, November 2011, rev. 2012

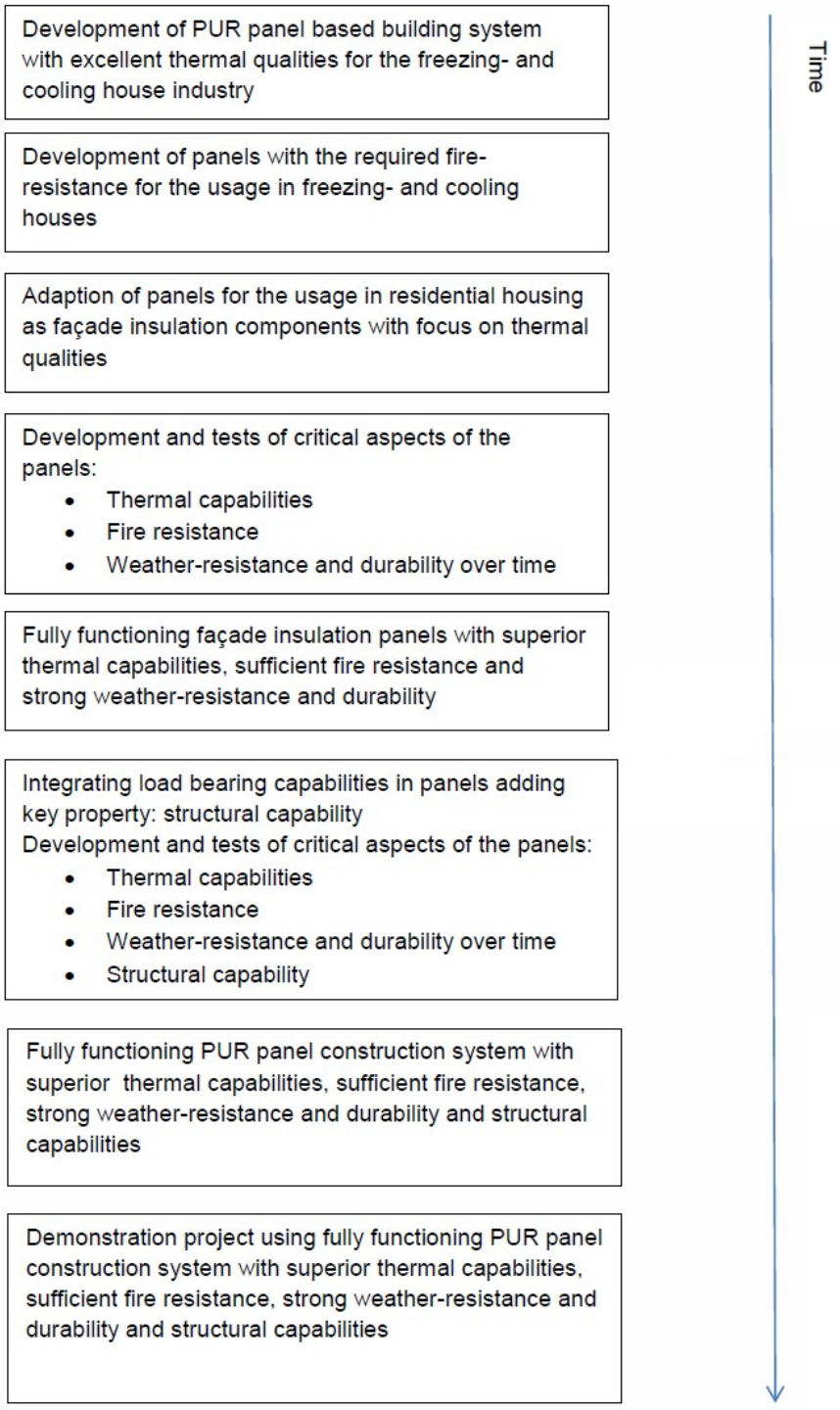
Thermal capacity is not the only important product characteristic for insulation used in the construction of residential housing. The following also play an important role:

- Fire-hazard
- Environmental effects
- Indoor climate
- Usage and adaptability
- Price

The technology which will be developed and implemented in this project will fulfill all of these product characteristics.

Technology roadmap

The technology originates from the manufacturing of thermal panels for cooling and freezing houses, which have specific product requirements which differ somewhat from the requirements of conventional construction. When the strategic decision to address the market for residential building systems was made a testing process was initiated in order to prove the principles of the technology used in residential buildings. The technology roadmap drawn for the technology development include a number of already completed laboratory and field trials as well as externally facilitated trials exploring key characteristics of the technology.



As the illustration of the roadmap shows, a key point in the road map is of course the reconfiguration of the technology developed and refined for freezing- and cooling houses to fit the requirements of residential housing construction. The development process was initiated in 2010 and lead by co-owner and director of sales and product development Allan Andersen, DC-System Insulation A/S.

When the strategic choice of entering a new market with a reconfigured technology was made it was also acknowledged, that key properties of the technology needed to be proved through both in-house and external testing in order to prove both the superiority of the technology but also the potential usage as a building component in construction projects that differ somewhat from cooling and freezing house construction. Therefore, three key properties of the technology where identified as potential show-stoppers, meaning that if these properties would not be present in a

thermal panel used as building component, the technology would not be able to meet the necessary requirements of the market. The key properties were identified as:

1) Thermal capabilities
2) Fire resistance
3) Weather-resistance and durability

The thermal capabilities of the panels were quite easy to prove given the extensive testing and research on polyurethane used in insulation panels. The superiority of polyurethane measured only on insulation capability has for long been acknowledged and needs no further elaboration.

Fire resistance, however, was also identified as a key property given the fact, that the building code has strict rules regarding flammability and potential fire hazard in relation to building components used as part of the building envelope. Unlike insulation made from e.g. mineral wool, polyurethane is somewhat flammable, meaning that it needs to be encapsulated in a manner which meets the requirements for residential housing. Therefore, external testing of the fire resistance of the panels used as facade panels has been conducted by Dansk Brand- og Sikringsteknisk Institut (DBI), an approved technological serviceprovider (GTS-institut). The results of the test have been very positive followed by approval. This means that the panels, when properly encapsulated can be integrated as building components especially in the building envelope. The test results are included as annex.

The third critical property: weather-resistance and durability, was identified because even though the panels could be used just by proving the thermal and fire resistance qualities the life expectancy of the panel plays a very important role. From a customer´s point of view, the economic proposal of using a specific building component both relates to the purchasing price and the erection costs, but it also very much relates to the maintenance and operations of the building after construction. Therefore, it was necessary to prove, that the estimated lifetime of the panels used for construction purposes would at least be in accordance with the average lifetimes of other and comparable construction component.

Since the average liftetime norm for building components is 50 years accelerated climate effect and aging tests using water, heat and cold were conducted in order to estimate the possible decomposition of the panels over time. The tests were conducted by Teknologisk Institut, an approved technological serviceprovider (GTS-institut) simulating the conditions that the panel will be exposed to during its lifecycle. The test results show, that the panels only suffer from minor deterioration meaning that they have a durability aligned with or better than other commonly used building components. Test results are included as annex.

Supplementary to the externally facilitated test a number of internally facilitated tests have been conducted mainly in smaller projects in Denmark, where the panels have been used in single family homes as non- loadbearing facade panels.

The public housing association, Aars Boligforening was the pilot customer for some of the initially completed internally facilitated tests and this has led to an agreement with the public housing association to act as pilot customer in the coming full-scale demonstration once the technology reaches the final development stage. The

full-scale demonstration project will be carried out on a site in the city of Aars in the region of Northern Jutland.

Development of the technology

As the abovementioned steps in the technology roadmap show, the key principles of the technology are proven, but in itself these will not suffice in giving the technology a competitive edge. As the competitor analysis shows non-loadbearing PUR panels used as insulation are already used as construction components also in residential buildings supplied by strong competitors. At the same time substituting insulation systems also address the same market. Instead of fighting for a small share of the market for facade insulation panels, DC System Insulation wants to further develop the technology by adding another key property: structural capabilities.

The nature of the manufacturing process of PUR panels makes it possible, to integrate a loadbearing structure in the production of the panel itself. When this is done, the panel will achieve potentially gamechanging capabilities, since it can now be used as part of a structural building system and not just as a simple insulation component in the building envelope. The transition from component supplier to system supplier is not a simple process, but DC System Insulation A/S already has as strong presence in the market for cooling- and freezing houses as a systems supplier with the core competencies to support it.

By adding the key structural property, the competitive landscape is also radically changed, therefore close attention has been paid to the competitive situation in the market for structural building systems.

In order to complete the development process towards implementation in the full-scale demonstration project the following necessary steps have been identified:

Integration of loadbearing and stability supporting capacities

A major advantage of the usage of PUR technology as insulation in buildings is of course its thermal capabilities which are superior to the commonly used insulation materials such as mineral wool. However, as a stand-alone insulation material the PUR panel does not provide any novel alternative that is not already offered by a number of international suppliers, none of which have been able to alter the market conditions for insulation in residential housing projects. The radical advantage and novelty of the technology of course lies in the ability to integrate structural capabilities in the panel thus moving in from a simple insulation material to an integrated building system. The integration of structural capabilities will reposition the technology as a core part of the building structure and at the same time provide outstanding thermal qualities. In relation to this. The transition to structural component also requires supporting development for integration with other building components that are required to fit with the PUR structure. This includes carrying foundation, installation channels and installation systems.

Interlocking mechanisms for joining panels for supporting walls, deck and roof construction.

Given that the panels will have a structural and not just a thermal function the interlocking of the panels will have a critical function. This means that the current interlocking mechanisms need to be reevaluated and redesigned in order to fulfil relevant structural criteria.

Manufacturing process

A key focus will be on the optimal manufacturing process for the structural panels. The market for residential housing has a high price sensitivity, which means, that superior technology which is not competitively priced will most likely not gain market shares. Since the manufacturing process though somewhat automated still to some extend is labor intensive the development process will also incorporate the sufficient adaption of the manufacturing set-up. This will mainly require analysis and implementation of routines and workflows since the physical production facilities and the existing manufacturing lines give room for flexibility in the physical set-up.

The process for further development consists of initial desk research followed by a number of scale tests and evaluations leading to the best possible product configuration. The key principles of the technology are already individually established, so the development process carried out in this project will be concentrated on merging the individual functionalities into one system as well as developing and choosing materials and manufacturing process which provides the best possible product under relevant price constraints.

The projects contents and activities

The development challenges that are faced are reflected in the organization of the project´s workpackages illustrated below:

Work Package 7
Project management, project Co-ordination and dissemination
WP leader: DC-System Insulation A/S
WP Participants: Kuben Management A/S, Den Erhvervsdrivende Fond SmartcityDK

Work Package 1
Analysis, requirements and specifications
WP leader: DC-System Insulation A/S
WP participants: Aalborg Universitet, Grontmij A/S

Work Package 2
Product development
WP leader: Grontmij A/S
WP participants: DC-System Insulation A/S, Aalborg Universitet, Arkitektfirmaet Christensen & Rottbøll A/S, Kuben Management A/S

Work Package 3
Manufacturing and manufacturing process optimization
WP leader: DC-system Insulation

Work Package 4
Demonstration project
WP leader: Christensen & Rottbøll A/S
Participants: Grontmij A/S, Aalborg Universitet, Kuben Management A/S,(Aars Boligforening, pilot customer)

Work Package 5
Project evaluation
WP leader: DC-System Insulation A/S
Participants: Christensen & Rottbøll A/S, Grontmij A/S, Aalborg Universitet, Kuben Management A/S,(Aars Boligforening, pilot customer)

Work Package 6
Marketing Strategy development
WP leader: DC-System Insulation A/S
Participants: Kuben Management A/S

Work Package 1: Analysis, requirements and specifications

In the work package the demand specifications will be set based on both analysis of results from previous tests, architectural requirements[2] and especially requirements stipulated in building regulations. The demand specifications will be defined both for a short term, medium term and long-term scope in accordance with the building regulations which will come in effect in the year 2015 (BR15), the expected building regulations of 2020 (BR20), including both structural requirements, fire hazard requirements, acoustic requirements, air tightness requirements a.o. For the long-term scope analysis of trends and forecasts for future demands and legislation (beyond 2020) will also be included, given that energy efficiency and energy optimization In buildings will set increasingly higher standards for the construction sector supported by legislation.

The analysis also includes a view on the environmental implications of the technology. Though the main focus of the project is energy-optimization and construction efficiency, environmental requirements are expected to play a more important role in building regulations in the future. This means, that the demand specification will also include considerations for environmental requirements.
Based on the demand specification a gross list of possible product configurations will be prepared to form the basis for scale testing and evaluation

Objectives
To prepare an analytical foundation for the development of demand specifications for the technology related to both current, upcoming and future building regulations and other requirements including a gross list of possible product configurations for scale testing.

Milestones
1) Complete demand specification
2) Complete gross list of possible product configurations

Work Package 2: Product development

This central workpackage will contain the activities related to developing the panel technology which incorporates the key characteristics:

- Loadbearing capacity
- Stability enhancement
- Fire hazard reduction
- Acoustics
- Interlocking mechanisms
- Thermal capabilities

[2] Though the structural and thermal capabilities of the product play an essential role, when it comes to residential housing the aesthetic qualities is also of very high importance, meaning that any structural building component needs to be aligned with various architectural demands. Otherwise the technology will not be able to match competing technologies when it comes to the aesthetic building design.

The product development process will be conducted as an iterative process based on a gross list of potential product configurations developed in work package 1.
The product development will include manufacturing of scale installations for testing also including physical handling and mounting. Based on the test results the individual product configurations will be evaluated and the most promising will be selected for a small-batch manufacturing process.

Objectives
To test and evaluate potential product configurations based on scale testing and based hereon to select the most suitable for small-batch manufacturing also taking into consideration cost of raw materials and components. Testing also includes testing by external parties, which will be used as basis for approval of the technology to be used in full scale projects.

Milestones

1) Testing and evaluation of potential product configurations including:
    - Development and testing of loadbearing capacities
    - Development and testing of stability enhancement
    - Development and testing of fire resistance
    - Development and testing of acoustic conditions
    - Development and testing of interlocking system

2) Selection of most suitable product configuration based on the above mentioned as well as an initial cost analysis on components and raw materials.
3) External testing of most suitable product configuration to form basis for final approval of technology usage in full scale projects

Work Package 3: Manufacturing and manufacturing process optimization

The work package includes small-batch manufacturing of one or more of the selected product configurations having passed external testing. Since the market for the technology is somewhat price sensitive and the operations of the manufacturing line make up a considerable part of the manufacturing costs, the right manufacturing line set-up is crucial. Given the flexibility of the current production facilities based on semi-automated processes it will be possible to run a number of small-batch manufacturing processes in order to test and evaluate the right combination of product configuration, manufacturing process and manufacturing costs.

Objectives
To test and evaluate selected product configurations through small-batch manufacturing in order to pick the most suitable product configuration for full scale demonstration project.

Milestones

1) Testing and evaluating of manufacturing process based on selected product configurations. The testing will be conducted on an adaption of one of the existing production lines and based on the production of small-batch.
2) Selection of final product configuration based on evaluation of combination of product, manufacturing process and manufacturing costs.

Work Package 4: Demonstration project

The project revolves around the full-scale implementation of the technology in a demonstration project in collaboration with Aars Boligforening, a public housing association in Northern Jutland registered in the municipality of Vesthimmerlands Kommune. Both Aars Boligforening and Vesthimmerlands Kommune support a strategy of pushing the frontiers of energy-optimized residential buildings and thereby improving the attractiveness of local settlement and regional industry development. Aars Boligforening has with the endorsement of Vesthimmerlands Kommune received a pre-project grant of 250.000 dkr. to explore the potential of

energy-efficient construction and the current application is part of the local effort within this area. A location for the project in the city of Aars has been identified and planning preparations have been initiated in order to accommodate the full-scale demonstration project if the application is processed favourably by the EUPD evaluation committee.

Objectives
The primary objective of the work package is to successfully manufacture, deliver and mount the construction system as part of the prepared residential construction project in the city of Aars.

Milestones
1) Manufacturing, delivering and mounting floor decks and suspended floor decks based on most optimal product configuration
2) Manufacturing, delivering and mounting supporting exterior wall elements based on most optimal product configuration
3) Manufacturing, delivering and mounting roof deck elements based on most optimal product configuration
4) Manufacturing, delivering and mounting non-loadbearing partition walls based on most optimal product configuration

Work Package 5: Project evaluation

The evaluation process of the project is divided into three related to the central processes of the building system creation: a) product configuration, b) manufacturing process c) handling, logistics and mounting.
All three aspects need to be aligned in order to secure future mass production and full-scale market introduction of the technology. The evaluation includes both technical and economic feasibility studies based on the completed project.

Objectives
Individual evaluation of the aspects of the project within product development, manufacturing and mounting as well as a holistic evaluation containing joint evaluation all aspects under given economic constraints.

Milestones
1) Completing evaluation of product development process including suggestion for further improvements
2) Completing evaluation of the manufacturing process including suggestions for further improvements
3) Completing evaluation of the handling and logistics process ex- and on-site including suggestions for further improvements.
4) Completing rapport containing evaluations

Work package 6: Marketing strategy development

The marketing strategy work package will be completed in correlation with the evaluation process, since the evaluation will reveal data on economic feasibility determining market penetration strategy. The marketing approach has been roughly outlined in the market section of the application, but an operational strategy will be developed in correlation with the acknowledged project results.

Objectives:
Development of operational marketing strategy

Milestones:
1) Completing collection of relevant technical and economic data from project evaluation.
2) Completing marketing strategy rapport for domestic market.

Work package 7: Project management, project coordination and dissemination

Project management plays a central role for this project given that the success depends on a coordinated development effort both within manufacturing engineering, construction engineering, architectural engineering and eco-engineering. The individual development processes requires different skillsets within engineering provided by different partners, who in turn also have to take into consideration that the individual results of the development processes will affect each other.

DC-System Insulation will as product champion coordinate the development process, which includes organization of the project time schedule, establishing project organization including project group and individual workgroups, milestone evaluation as well as project administration including budget revisions,
reporting and dissemination.

Objectives:
Enable a development process and establishing a project organization which will facilitate the process towards the full-scale demonstration project.

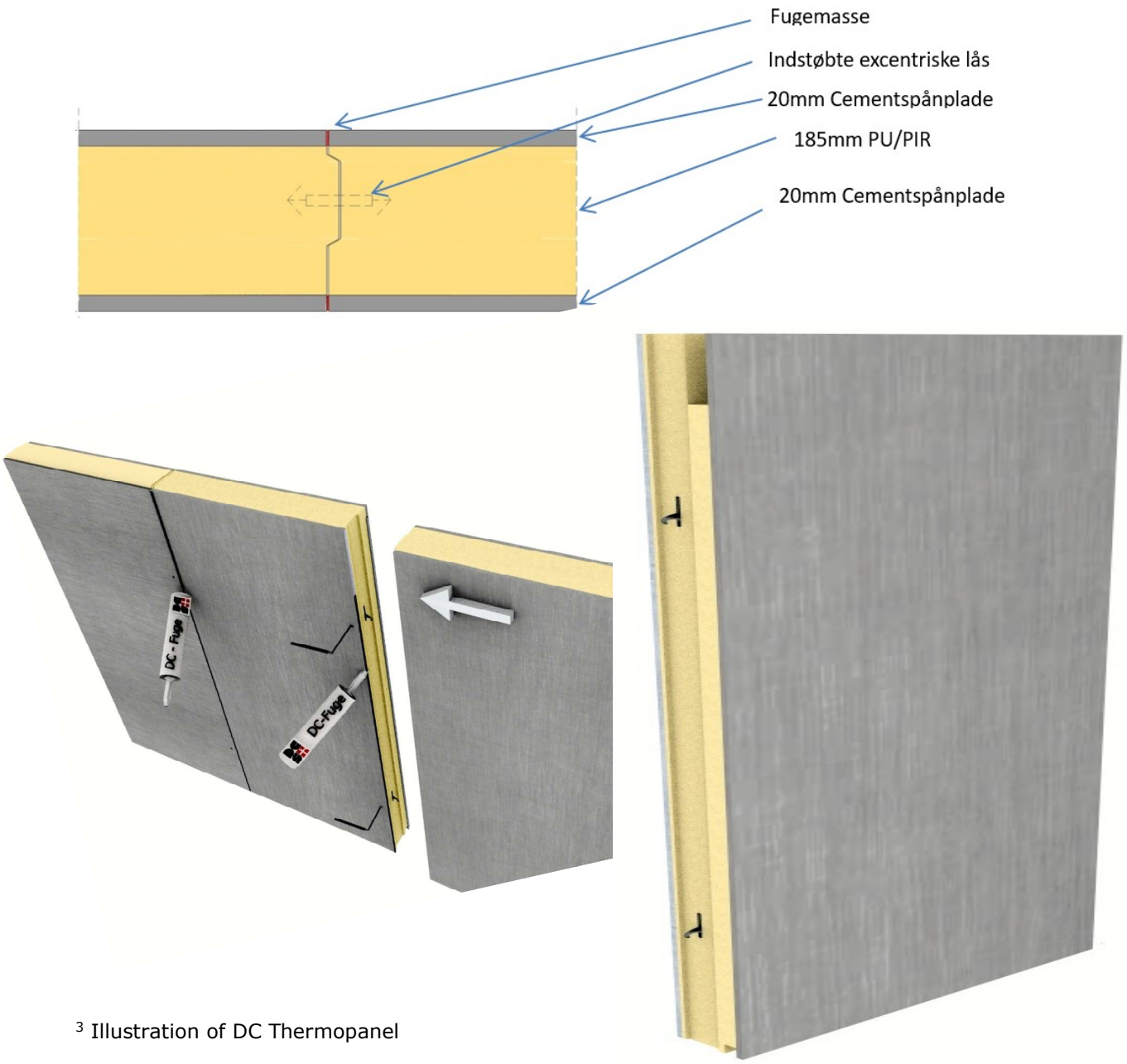
Milestones:
1) Completing establishment of project organization including principles of day-to-day operations
2) Facilitating project group meetings
3) Completing budget revisions and financial reporting
4) Completing project end evaluation
5) Completing execution of dissemination plan

1.5 Project results and dissemination of results

After iterative design process including analysis of many different variations of the materials, their thickness and layout, an element with two 18 mm thick fibre-gypsum plates and PU/PIR foam core (standard DC foam) has been introduced and initially tested according to the objectives stated earlier in chapter 1.4.

Unfortunately, the plate material (fibre-gypsum board) proved to be prone to structural deterioration due to ageing process and environment conditions. In particular moisture operation on the board made it susceptible to water intake. It resulted in lower flexural strength and caused difficulties in use of nails or screws in the panels connections as the mechanical connectors were not properly anchored in the board.

All in all, the product design (external load-bearing plates) has been altered into an element with two 20 mm thick cement bonded particle boards. This solution provided superior strength and durability. Therefore, this product has been developed and tested as the final design of the new DC-System merchandise targeted at the residential buildings share of the prefabricated elements market. The panel has been named as Thermopanel.



[3] Illustration of DC Thermopanel

The list of experiments, measurements and certification tests covers all aspects of new product introduction – from new marketing strategy creation, thru technical design and approval, to manufacturing optimization. Moreover, the demonstration project has been performed as erection of a full-scale Test House (residential building of 115 m^2) which structure consists entirely of Thermopanels under the study. More information about the Test House design and its construction are included in the Annex.

It can be speculated that the technical development of this new panel played the most important role in the entire project since it needs to fulfil many strict requirements of different kind. It is worth mentioning that the product has been tested both in the private laboratory of DC-System Insulation A/S as well as public, renowned institutions such as Aalborg University and DBI - The Danish Institute of Fire and Security Technology. The most significant tests/approvals are:

- Application for European Technical Assessment for DC ThermoPanels to be used as loadbearing sandwich panels in buildings issued by ETA Denmark. This document indicates that the product has been accepted to the ETA declaration process which consists of many different kind analyses and investi-

gations (some of them have been already conducted and fulfilled). It will take however some time to accomplish the entire checklist required by ETA Denmark.
- DBI fire technical assessment of the panel as external wall to be a load bearing element in accordance with REI 30 requirement. Moreover, the product "DC Thermopanel" in relation to its reaction to fire behavior is classified: B. The additional classification in relation to smoke production is: s1. The additional classification in relation to flaming droplets/particles is: d0.
- *Dansk Indeklima Mærkning* - indoor climate, hygiene, health and environment are documented with the Danish Indoor Climate Labeling that product does not release harmful substances.

Besides above-mentioned documents, many other reports have been obtained throughout EUDP project period. They include tests of thermal capabilities, moisture isolation properties, stability and loadbearing capacity, connections strength, long-term deformations (creep factor), interlocking mechanisms and acoustic isolation. Besides, number of tests in full-scale building (the Test House) have been performed. They include thermal imaging, air tightness investigation (blower door test), energy consumption simulations and temperature/moisture monitoring inside external wall. Results of the above-mentioned experiments are available as reports or certificates in the annex attached to this report.

Even though the main manufacturing optimization process took place from September 2014 till the end of 2016 (see Gantt diagram attached in the annex), including manufacturing line set-up and testing, minor enhancements are still taking place to improve the production performance. It should be pointed out, that those amendments are targeted at the manufacturing efficiency increase. The production line is already capable of delivering high quality elements without any flaws which are then successfully shipped and used in erection of various projects.

The results of the project are being demonstrated as core part of the presentations that DC-System performs for its potential clients or architects who work with modern, prefabricated insulation elements technology. They are also communicated during the integrated design process with projects managers or engineers – for examples, DBI certificates are issued when it comes to design of fire protection solutions together with fire engineers working on given project. On top of that, number of the EUDP project outcomes are used in the marketing materials such as leaflets, brochures, website etc. Last but not least, the Test House is a great demonstration and somewhat compilation of the research conducted. It is therefore used as a showroom and proof of the company's capabilities in delivering high quality product in combination with smart technology which combines simplicity and speed of construction together with superiority of technical performance of the building, comparing with traditional methods of erection.

The main marketing and sales focus have been put on multi-family residential areas. After realization of several projects of various kind, size and complexity, this sort proves to be most attractive from manufacturing and economic point of view. Therefore, by raising awareness of the new product among architects (by means explained in the previous paragraph), DC-System cooperates with design offices that willingly utilize Thermopanels as the core part of their projects. Some of the executions can be seen in the annex with the references.

1.6 Utilization of project results

The outcome of the project has a great impact not only on the technical solutions, knowledge and engineering know-how, but also on the sales and marketing aspects of the entire company. Apart from the precise data obtained, which enable DC-System to fulfil all the requirements for construction of residential/office buildings, the pursue of the best quality product gives yet another example to the market that DC-System is one of the world leaders in sandwich panels production.

The utilization of project results starts with initial stages of the projects – marketing materials and product presentations. At this point, thermal properties as well as load-bearing capacity and fire resistance (in a compact, relatively thin element) are demonstrated to provide potential clients with understanding of Thermopanels superiority over traditional construction methods. Moreover, detailed presentations take place to explain thoroughly the technology and standard solutions involved in Thermopanel design process to third-party architects and engineers working with DC products.

On top of the above-mentioned benefits, the results give, obviously, better understanding of the product, its properties and range of application. It delivers documentation which is needed to illustrate safety of the building designed in this technology and present high energy efficiency and good indoor climate properties. Having all of these, the company can undertake more demanding projects, knowing that their product can easily withstand all environmental and client's personal requirements.

Having finished the EUDP project and developing the new product successfully, DC-System does not want to stop at the current stage. Thermopanel and its production processes will be optimized further to sustain high strength and its general performance but perhaps simplify other technical solutions (joint details) or the manufacturing process. There are also possibilities of introducing other elements, compatible with Thermopanel to deliver complex system with further advantages such as use of solar cells.

Herewith is the reference list with some of the biggest projects that DC-System Insulation A/S has executed with use of the new product (Thermopanel).

2015 Denmark DC Test house, 2 floors - 115 m², Aars

2016 Denmark The student house, 3 floors , Aalborg

2017 Denmark Office building, 2 floors - 636 m² , Svenstrup

2017 Greenland Villa, 3 floors - 360 m² , Nuuk

2017 Greenland Villa, 3 floors - 360 m² , Nuuk

2018 Denmark Apartment buildings, 2 floors-26 highly-insulated apartments, Sunds

2018 Denmark Apartment buildings, 2 floors-26 highly-insulated apartments, Sunds

2018 Denmark Apartment buildings, 1 floor-30 highly-insulated apartments, Rønne

1.7 Poject conclusion and perspective

To sum up EUDP project aimed at development of the new product for residential buildings proved to be a complex task spanning from fundamental market analysis and requirements definition, thru technical investigation and scale experiments, till sales and marketing strategy creation and full-scale demonstration project erection. The results in all of those aspects are positive and in general the work can be definitely described as very fruitful.

Therefore, DC-System is investigating and analysing possible next steps (further projects) covering development of DC Thermopanels for roofs with compatible solar cell system as the roof cladding or load bearing roofing elements for industrial buildings. The main focus of the former will be to provide another part of the Thermopanel system to form complex scheme for green residential buildings design, whereas the latter will compliment the existing solutions for the industrial buildings with a panel that could span between RC or steel structure (beams or girders) and withstand all the loads.

DC-System would like to thank EUDP and all the participants of the project and hopes to cooperate in the future to seek for yet another advanced sandwich panels technology expansion.

Annex

List of performed tests / obtained certifications or documents:

1) *ETA Denmark* - Application for European Technical Assessment for DC Thermopanels to be used as loadbearing sandwich panels in buildings,
2) *DBI* - Fire technical assessment: Thermopanel fulfils the requirements for a loadbearing wall with the classification REI30,
3) *DBI* - Reaction to Fire Classification: The product "DC Thermopanel" in relation to its reaction to fire behavior is classified: B. The additional classification in relation to smoke production is: s1. The additional classification in relation to flaming droplets/particles is: d0,
4) *Klimalab AAU* - Air leakage analysis in accordance with DS/EN 13829 for the Test House,
5) *MOE* – Energy consumption calculation for the Test House: complies with building class 2020 requirements,
6) *Dansk Indeklima Mærkning* - indoor climate, hygiene, health and environment are documented with the Danish Indoor Climate Labeling that product does not release harmful substances,
7) *AAU* – elements' properties testing for DC Thermopanel materials, including: thermal conductivity, heat capacity, and sorption isotherms,
8) *AAU* – measurements of Test House indoor climate and temperature/ humidity inside external wall + indoor climate simulations (over long period of time),
9) *AAU* – Linear heat losses analysis: thermal imaging and computational simulations (FEM),
10) *AAU* – Sound insulation is documented with measurements at certified institution and EDB analysis,
11) *AAU* – Pressure and tensile strength are documented with tests,

12) *AAU* – Flexural tensile strength is documented with tests,

13) *AAU* – E-module and G-module are documented with tests,

14) *AAU* – Shear bearing capacity of element joints is documented by tests,

15) *AAU* – Deformation development over time is documented with creep coefficient experiments,

16) *AAU* – Traction carrying capacity of joints in elements is documented with tensile tests,

17) *AAU* – Tensile and load carrying capacity for mechanical fastening / screws are documented.