Final report

1.1 Project details

Project title	Indoor Climate Systems in School Buildings
Project identification (program abbrev. and file)	64014-0153 EUDP-14 II
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	Gate 21
Project partners	Gate 21, Scheneider Electric denmark/Energy, Green Building Council, Airmaster, AI, Bascon/COWI, SBI-AAU-CPH, Danmarks Lærerforneing, Bjerg & Grøndahl (Vesko)/TEKMA, Ballerup Kommune
CVR (central business register)	32 11 28 46
Date for submission	30/06/2018

1.2 Short description of project objective and results

The project objective was to design and test innovative, holistic solutions taking both energy management and indoor climate into perspective. The solutions are based on the needs of users in terms of technology, the use of the school and the teaching methods, as well as a long-term view of the investments in indoor climate in relation to the subsequent operation. The solutions differ in terms of balancing technology and behavioural initiatives and have been tested in four class rooms at Skovlunde Skole Nord in Ballerup Municipality. Parallel to the testing, an evaluation tool has been developed giving municipalities in Denmark the opportunity to evaluate and choose the right solutions in future renovation projects. By using this tool, a systematic review and evaluation of relevant sustainability parameters will be obtained as the renovation is planned and implemented.

Skolerenovering i en Helhed har haft fokus på at skabe sammenhængende, innovative løsninger med fokus på bedre indeklima og energistyring i danske skoler. Løsningerne tager udgangspunkt i brugernes behov i forhold til teknik, brugen af skolen og undervisningsformer, samt et langsigtet blik på investeringerne i indeklima i forhold til den efterfølgende drift. Projektet har testet forskellige systemløsninger som balancerer teknik og adfærd, og testløsningerne har foregået på Skovlunde Skole Nord i Ballerup Kommune. Parallelt med implementeringen af testløsningerne er udviklet et evalueringsværktøj til evaluering af de valgte løsninger og til brug

ifm. Valg af løsninger i fremtidige renoveringsprojekter. Værktøjet hjælper bygningsejer med at opnå en systematisk gennemgang og evaluering af udvalgte fokusområder, efterhånden som skolerenoveringen planlægges og udføres.

1.3 Executive summary

Indoor climate in school buildings challenges the unilateral focus on energy efficiency from single technology installations. Instead, the project focuses on how coherent and communicative operating systems can support the school's the need for effective indoor climate and energy management. The project is born out of a need to find holistic solutions to the multifunctional use of schools and longer school days, which put great pressure on school buildings and requires effective energy and indoor climate management.

The thinking behind the project is to take a holistic approach to renovation projects taking the user needs that are technically and pedagogically relevant for renovation into consideration. The project attempts to meet three facets of a school renovation, including:

• An urgent need for improved indoor climate with proper ventilation, daylight, acoustics and other technical solutions to the indoor climate and work environment related issues.

• Smarter and optimized use of the school buildings, which matches the needs of the users.

• correct and efficient operation and maintenance of the technical solutions securing efficient energy management

The project team worked to identify key focus areas necessary to ensure an integrated design and implementation process of relevant systemic solutions. The design process was characterized by looking into he needs and opportunities at Skovlunde Skole Nord. The selected focus areas were:

- Mapping and establishment of baseline
- Functional requirements and construction
- Operation & Maintenance
- Energy management and consumption
- Indoor climate

Based on the above focus areas a development process was initiated. Three tracks were defined, and four classrooms picked for test and demonstration. An essential learning point when identifying the needs and goals for the school was the importance of user involvement. These inputs were also used to decide upon what technical solutions to combine and behavioral activities to initiate. Further, the user inputs were essential for gaining knowledge about the users' individuality and flexibility.

Several methods and approaches were used collecting the necessary data and information, including, metering, interviews, workshops and questionnaires. These proved valuable for identifying the major challenges and wishes for development, but also for evaluating on the initiatives implemented and taking ownership and

understanding the importance of having a good indoor climate. The effect of installing the technical solutions on indoor climate was documented through a Building management system (BMS) and indoor climate meters (IC-meter).

The project has been an important stepping stone for Ballerup Municipality in approaching renovation projects with a more holistic point of view. The experiences gathered throughout the project were relevant not only for the renovation decisions at Skovlunde Skole Nord, but also for future renovation projects within the municipal building mass.

During the project a need for replicating test solutions on a large scale making them useful for all municipalities in Denmark has been identified. Important lessons learned within this project can be transferred to future projects and Gate 21 as network is currently looking in to possibilities replication in larger scale among the municipalities.

1.4 Project objectives

The project invested a lot of resources in to identifying the test cases early in the project. Several municipalities, including Vallensbæk, Frederiksberg and Herlev, were involved in the process of finding a suitable testcase. This process took longer than planned since the original testcase, Pilehaveskolen in Vallensbæk municipality, due strategic reasons had to withdraw from the project.

Instead Ballerup Municipality stepping in to the project and Skovlunde Skole Nord was chosen as a testcase. Ballerup Municipality was very eager to get involved, and the decision use Skovlunde Skole Nord as a testcase was decided in a thorough assessment process where different schools were assessed.

The project has applied and tested the methodology of public private innovation-partnerships prior to a tender (in Danish udbudsfri OPI) – a method which was at the time not very used. The idea was to use public private innovation-partnerships as basis for the development of the holistic solutions. One of the key barriers for implementing innovative solutions within in renovation project is procurement rules. This was already addressed by the development project *Plan-C*, which aimed to promote a new renovation practice. By using the method of public private partnership prior to a tender the project could create a platform for innovative solutions where all project partners' competencies and services could be combined to create innovative solutions for the benefit of both the building owner and the users.

Below follows a description of the implementation of the different activities in the project and their connection to the different work packages.

<u>WP 1: Functional requirements</u>

The process of defining the functional requirements had already begun for Pilehaveskolen, but most of the work and methodologies could be transferred to the new test case, Skovlunde Skole Nord. Different working groups were established with the purpose of elaborating on different ideas and solutions which could be relevant to test. In relation to the work within the working groups a mapping of functional needs and issues regarding indoor climate was initiated and ended with a final design of functional requirements for test solutions (milestone 1).

Prior (and partly parallel) to defining the functional requirements a baseline of the school conditions was made. The test site was narrowed down to the teaching wing (wing 5) at Skovlunde Skole Nord. The wing constitutes of 3,600 sqm out of the school's total area of 10,730 sqm and consists of 3 floors with classrooms and other teaching facilities.

The mapping of functional needs outlined that parts of the school were heavily used and that there was a need for solutions which improved the indoor climate without compromising energy consumption. The mapping consisted of both qualitative and quantitative studies, such as interviews, workshops, questionnaires and data from indoor climate meters.

There was made an energy assessment for wing of the building. The current energy consumption at the school was also mapped and assessed. The school's building envelope and technical installations was assessed, which included insulation in roof, ceiling and exterior walls as well as the condition of windows, heating systems, heat distribution plants, radiators, ventilation systems and lighting systems. Finally, an assessment of the school's structure and operating pattern was made. The conclusion from the energy assessment was that the energy consumption was reasonable, i.e. because of the isolation and no energy used for ventilation. Further, the assessment showed that the school had focused on reducing / maintaining a low energy consumption.

Part of the mapping the building and it use was also done through interviews and workshops. The purpose of the qualitative mapping of the existing conditions was to understand the building, the use of the building and the working and learning environment. The qualitative study consisted of the following exercises:
• Mapping of the area distribution of the teaching area
• Interviews with the users (7 teachers, 7 students and 2 technical staff)
• Establishment and ongoing dialogue with a follow-up group consisting of members of the school management, teachers and representative from the working environment committee.
• A Questionnaire covering the physical environment of the school and the use of premises for all school teachers
• Mini-workshop with all school teachers to get statements about what is special about the school

All elements of the qualitative mapping helped understand the users of building, the way they use the building and feel about the work and learning environment at the school.

The project partners' different competences were a great strength for mapping the current conditions at the school and for defining function requirements. At the same time the different approaches to what is important in a renovation project differed substantively, which led to continuous discussions on interpretations of technical terms and approaches.

<u>WP2: Operation strategies and management principles</u>

The operation and management strategies were defined through different innovation processes with the purpose of discussing and combining different solutions

within the spectrum of behaviour and technology (Milestone 2). The idea was to put together stakeholders with different professional skills and create the space for development of systemic solutions and alternative solutions for using the building space.

The ideas for alternative work and relaxion spaces were also collected through workshops with the pupils in classroom 13. The purpose was to have them come up with good ideas on how to use the school buildings differently and motivate them to leave the classroom when engaging in group work activities or during breaks. The workshop led to the development of potential several solutions, three being selected, designed and implemented (see film about the initiatives and activities implemented together with the 8.x in classroom 13).

With the knowledge gathered through the innovation processes a measurement plan for test scenarios was developed to ensure that the collection and quality of data was sufficient. This was important both in relation to defining the requirements for control system, for future operation and for analysis and interpretation of data.

The operation strategies and management principles for the test solutions was based on the overall principles for the school in Ballerup. The municipalty is using the same BMS brand in all their school and it was naturally to start with the same principles. During the test phase there was as need adjusting the strategies and management principles in order to finetune the system. Since the test facility/rooms were not an integrated part of Ballerup's central BMS we were not able to implement the strategies fully.

WP3: Model and design of technical infrastructure

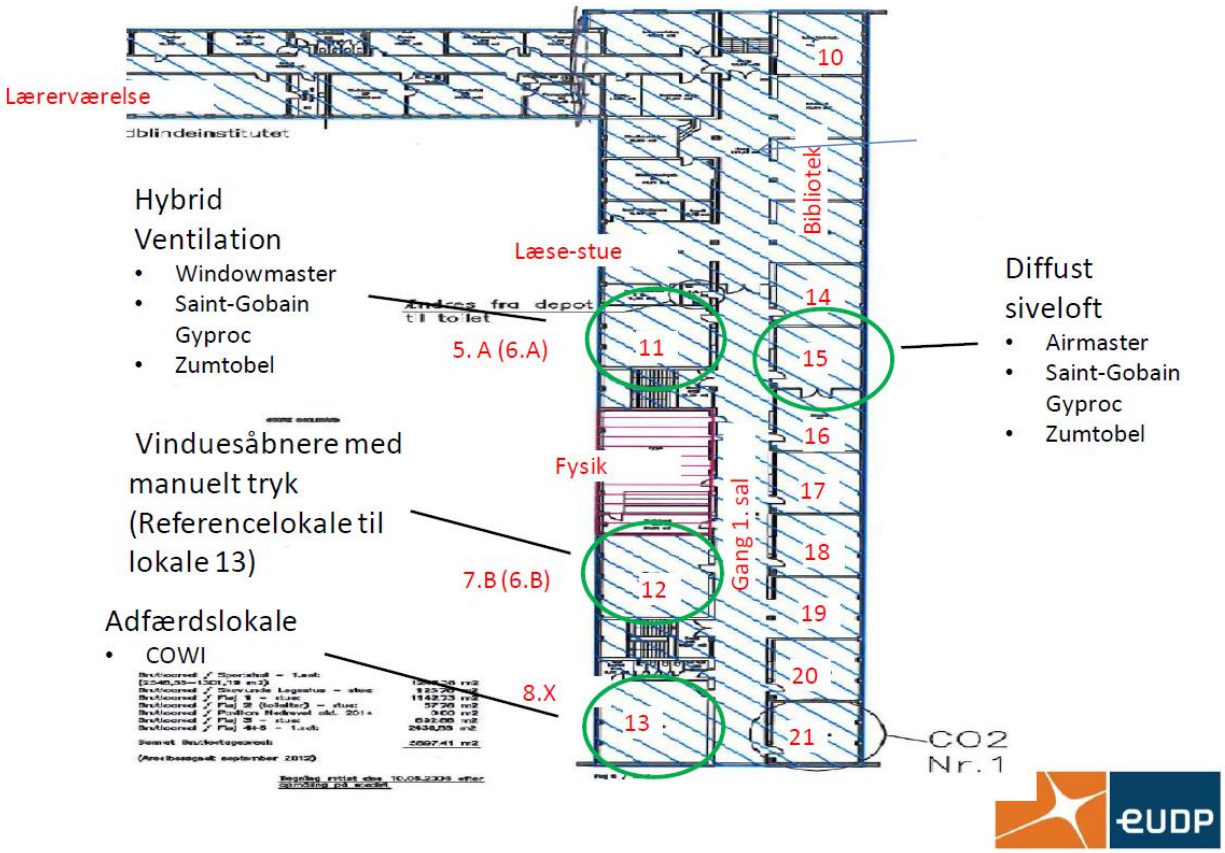
The different scenarios developed in wp2 was elaborated further upon and four classrooms, room 11, 12, 13 and 15, were chosen for different test solutions and experiments. The classrooms were selected according to the below criteria and in close dialogue with the school management and the teacher:

- size of room
- design of room
- number of students
- Orientation
- Grade
- Existing technical components

Based on the above criteria and prior discussions on relevant systemic solutions the following solutions were chosen (milestone 3):

- Classroom 11: hybrid ventilation solution and directional light, developed by Windowmaster and Zumtobel
- Classroom 15: diffuse ventilation and even spread of light, developed by Airmaster, Saint Gobain and Zumtobel
- Classroom 12: Manual Pressure to open windows
- Classroom 13: Behavioural initiatives educating the pupils in indoor climate and designing alternative creative spaces at the school.

The location of the four test rooms in wing 5 is illustrated below:



For each classroom a functional description was made.

Further, it was decided to establish a common building management system (based on KNX). Criteria measuring the CO2 level, temperature, use of different lighting functions etc. were defined.

WP4: Implementation and initiation

Following the functional description of the four class rooms a plan for implementation of solutions was prepared including a time line and roles and responsibilities. The implementation of the chosen solutions took place when the students were on autumn break 2016. The implementation process had a tight timeline leaving very little time for unforeseen situations. Due to a very structured process the implementation happened successfully, and the following months smaller correlations were made ending with a test run early January and by mid-January the solutions were put into operation (Milestone 4).

Class room 11 was renovated with a combined lighting, ventilation and heat management solution. The ventilation solution is a hybrid ventilation system combining natural ventilation through automatically controlled windows and small decentralized mechanical ventilation units with heat recovery. The opening of windows was possible only for some class rooms placed away from the train line running right by the school.

The ceilings have acoustic functionalities that are used to reduce reverberation, thus ensuring better speech understanding and less disturbing noise in rooms. Together with the lighting, simple design causes the premises to appear bright. The lighting is renovated with six suspended luminaires, which can illuminate both up and down. In addition, there are three downlights with Wall-wash function that illuminate the otherwise dark vertical surfaces, ie. the walls at the back of the room. This typically causes a feeling of sitting in a bigger room.

Class room 15 was renovated with a combined lighting, ventilation and acoustics solution. The ventilation solution is a mechanical ventilation solution with a decentralized low-energy ventilation system with high heat recovery and low noise level. The ventilation unit is placed under the ceiling above the smartboard. The unit has a heat exchanger and operates autonomously with integrated sensors and controls.

In class room 13 a course was conducted with students and teachers focused on awareness and behavioural solutions that can improve the indoor climate. As part of the initial mapping the school area was mapped. It showed that 23 percent of the school's square meters were hall ways. By comparison, 25 percent of the area is used for classrooms. The mapping was an eye opener for how much litter space which was unused. Therefore, it was investigated whether any of the school areas could be used more actively for teaching purposes.

The idea behind the initiatives in class room 13 was to work with behavioural changes and how they can influence the indoor climate. Through involvement and involvement of students and teachers, good habits were incorporated in relation to opening windows and using other areas for group work activities to reduce the amount of CO_2 in the air. The behavioural measures and the desired gain were defined in collaboration with students, teachers, the school board and the Danish Teachers' Association. The actions were adapted to the specific local area and based on the challenges that students and teachers experienced.

Class room 12 was used as a reference room to room 13.

The four class rooms were connected to a BMS platform continuously recording data on a variety of selected parameters, such as the use of the different functionalities for lighting in class room 11 and 15, LUX, brightness, PIR, CO2, room temperature, window closure, fan speed. Further, CO2-censors were installed locking data in all classrooms located in wing 5.

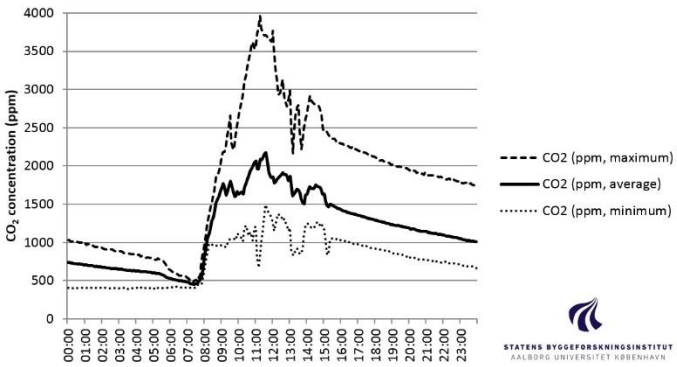
<u>Wp5: Competency development, testing and correction</u>

The performance of the four test rooms was tested from January 2017 to March 2018 (milestone 5). The indoor climate within the classrooms with technical installations was improved substantially. The CO2-level was reduced, and the temperature became more steady.

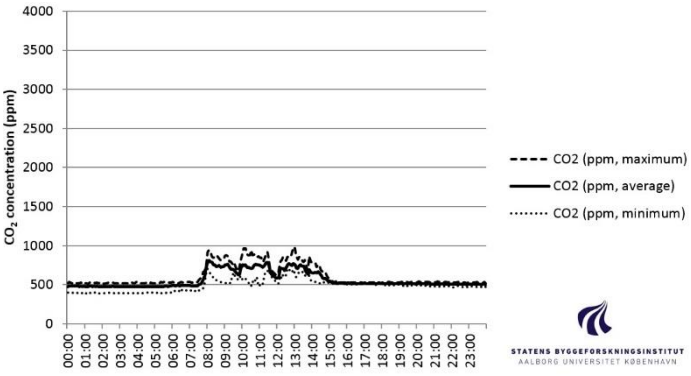
Below are two examples of the CO2 level in classroom 11 and 15 prior to the renovation and after the renovation.

Classroom 15:

Prior (week 48, 2016)

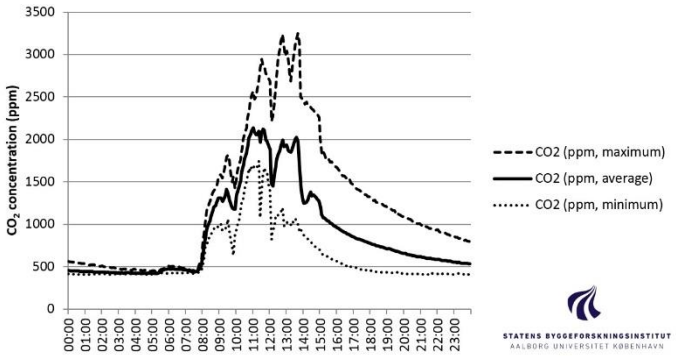


after (week 12 2017)

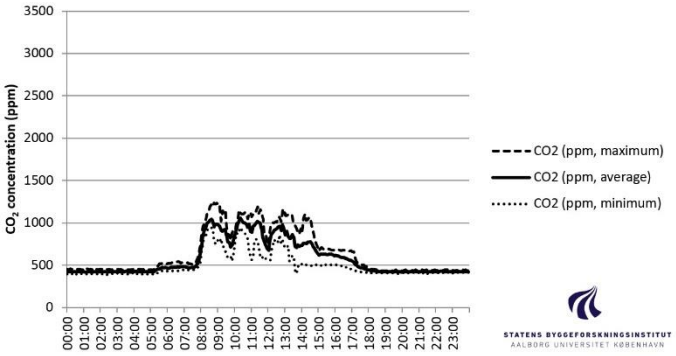


Classroom 11:

Prior (week 48, 2016)



After (week 12 2017)



The hybrid ventilation solution is designed according to legal requirements before 01.07.2017, ie. The system is adjusted so short-term peaks over 1000 ppm are allowed.

The acoustic performance was also measured and evaluated. Based on the evaluation Saint Gobain Gyproc decided to replace the acoustic ceilings with another type of acoustic ceilings to improve the acoustic further.

In November 2017 a centralized ventilation system was installed for the wing 5. classroom 12 and 13 were included in this installation, but classroom 11 and 15 remained the same.

To ensure that the solutions installed were operated and managed properly from the very start the roles and responsibilities of the technical staff, the project partners and the municipality were defined in a note. Further, a meeting was initiated between the suppliers and the technical staff giving instructions on how to operate the solutions. It turned out to be a challenge to commit the technical staff and for them to take ownership installed solutions. A potential explanation could be that the technical staff are busy operating several other schools already, but also the uncertainty about whether the solutions installed would remain after the project ended. Since the school was very satisfied with the technical solutions implemented in classroom 11 and 15 the solutions were kept.

From the very start an important part of the project was to use the experiences gained in the project to decide what type of ventilation to install in the remaining classrooms. Parallel to the testing in the four classrooms the school initiated the installation of ventilation of the entire wing (wing 5).

A lesson learned is that competency development of the technical staff it would probably have proven valuable from the very start to decide whether the different test solutions should be kept after the project or not. Giving the uncertain timeline in the project and other daily task for technical staff it was challenging raising the necessary ownership for the installed solutions.

<u>WP6: Requirement, technical, and user evaluation</u>

The installation of ventilation in classroom 11 and 15 resulted in a significant reduction in CO2 and less temperature fluctuations, which occurred during the summer

and winter months. The pupils emphasized in interviews that they have less headache and the air feels fresher. However, it was not all students who understood the functions of the ventilation system. Some were confused that the ventilation systems installed did not cool, other thought it did not work because the unit was not audible. The installed light got the most attention from the users, presumably because this you can easily see the change. Further, different settings were installed supporting different learning environments, and the students reacted very positive to this. On the other hand, some of the teachers pointed out that the different settings sometimes took away the attention from their teaching. An essential learning point from the project is, that it is important to allocate enough time to explain to the users the functions of the installed solutions (Milestone 6).

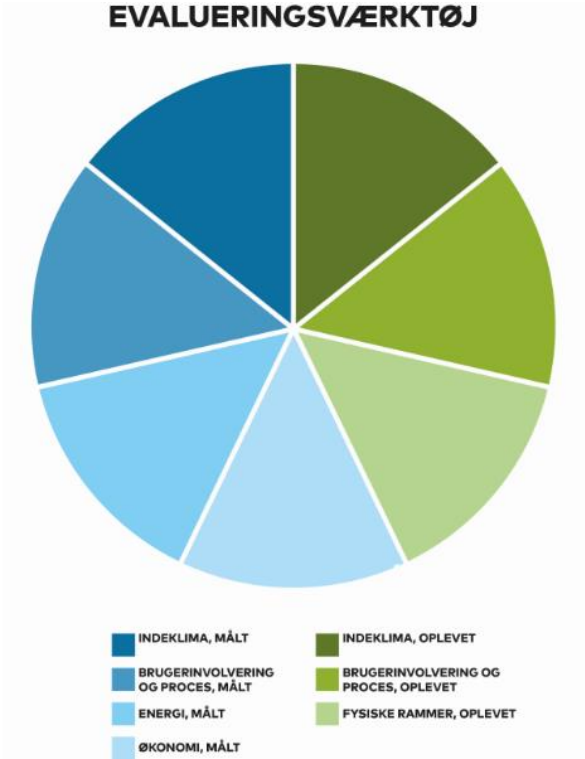
Parallel to testing of different solutions a working group within the project has developed an evaluation tool for evaluating the chosen solutions. The purpose of the evaluation tool is to support the most appropriate decisions in relation to future renovation projects. By using the evaluation tool, a systematic review and evaluation of relevant sustainability parameters will be obtained as the renovation is planned and performed.

The evaluation tool is designed to evaluate the performance of the installed solutions. The tool can also help to visualize and compare various interdependent conditions, such as indoor climate, academic learning environment, user involvement, energy, finance and well-being and health, prior to a major and comprehensive renovation process.

The evaluation tool is based on a desire to evaluate how the project's installed solutions, such as ventilation, light or acoustics, perform after a school renovation. However, the working group behind the evaluation tool recommends that the tool is used earlier in the renovation process, ie. at the beginning of the renovation process, to identify the problems and improvements are needed.

The tool is aimed at decision makers, building owners and consultants, but the consultant's role depends on when and how the building owner chooses to involve him or her. The project recommends close cooperation between the building owner and the consultant from the start to jointly develop solutions.

The benefits from using the tool are:
• Awareness of what elements should / may be part of a holistic school renewal.
• prioritize a holistic approach to evaluate different focus areas, which all affect the renovation process. For example, prioritizing indoor climate over economy.
• The costs of operating the building is considered and held against the overall economy of the renovation project
• Overview of the renovation task
• Early involvement of relevant actors, including building owners, consultant, contractors, suppliers, users, etc.
• To gain knowledge about users and their needs.



• Consider planning and implementing the renovation project in several steps.

1.5 Project results and dissemination of results

The design and test of solutions have led to new knowledge about the different solutions individually and together as a whole. This knowledge has been valuable to the suppliers involved in the project, who has gained knowledge about their products and the ability to combine them with other products. The ideas of creating systemic solutions have inspired some of the partners to develop new products, e.i. Saint Gobain who is working on a holistic indoor climate solution called AereNmore.

The knowledge gathered has also been valuable to Ballerup Muncipality in relation to getting inspired with new approaches to renovations projects and getting familiar with other products and solutions.

Throughout the project lots of knowledge about the users have been collected. The project has stressed the importance of user involvement, but successful involvement is difficult. Not all users can or should be involved, and they must be involved at the right time in order to create value.
A learning point for Ballerup Municipality has been to involve users earlier in the renovation process to get their input and acceptance to the solutions chosen. The experiences gained was used when the Municipality installed ventilation in wing 5. The teachers were asked about their opinions on where to place the ventilation channels. Their inputs resulted in some channels being moved to other places and great support to the project.

The project has had several communication perspectives seeking to influence different agendas. Several articles have been made describing the different solutions, both individually and from a holistic point of view. At the same time the project has worked to influence the political agenda and make indoor climate and energy management a hot topic. The project has held conferences outlining the challenges, but also the opportunities as well as the good experiences from the project. The latest example is the production of a pixie outlining the essence of the evaluation tool and highlighting the effect of prioritizing one topic over another (milestone 7).

1.6 Utilization of project results

The design and test of systemic solutions have led to new knowledge about the solutions individually and together as a whole. This knowledge has been valuable to the suppliers involved in the project, who has been able to test and improve their product. The test of systemic solutions has inspired some of the partners to develop new products, e.i. Saint Gobain who is working on a holistic indoor climate solution called AereNmore.

In relation to ventilation the preconditions have changed. The new legislation on ventilation which no longer allows for short-term peaks over 1000 ppm can end up challenging ventilation solutions which are not mechanical. However, this project has been a good importunity for testing the capacity of hybrid ventilation.

The project results are expected to give additional value if design and testing of different systemic solutions is scaled up to an entire building. This could give more detailed information on the financial aspects and a more correct picture of the operation and management patters and the potentials for more effective energy management. It's essential that all municipalities, no matter size and economy, have the necessary knowledge and overview of the solutions available when engaging in a renovation project.

1.7 Project conclusion and perspective

The main statement from the project is to engage in renovation projects with a holistic perspective being aware of what can be considered in a renovation process. Municipalities are often challenged by a sparse economy, but it's important to be aware of what is prioritized and what is not as well as the consequence of prioritizing one thing over another.

It is important to ensure coherence between the solutions chosen and the requirements and needs of the users of the building to support their desired learning environment. To clarify the needs and set the right goals for the building, users need to be involved several times during the renovation process.

Renovation processes are important but complex and do not necessarily look alike. Today the challenge is that many renovation projects have restrictive requirements and, in some cases, ineffective which hinders the innovative, development process. Instead there's a need for the municipalities to emphasize innovation, learning environments and commissioning.

In order to change the agenda there's a need for political attention. The project has played an important part in the indoor climate debate the last couple of years getting much attention from Real Dania, Sustain Solutions and more. These platforms should be used to communicate the project findings and put pressure on the municipalities to raise their standards for renovation projects.

Annex

Information about Skovlunde Skole Nord: https://www.gate21.dk/case-skovlunde-skole-nord/

Classroom 11. https://www.gate21.dk/case-skovlunde-skole-nord/case-skovlunde-skole-nord-lokale11/

Classroom 13:
https://www.gate21.dk/case-skovlunde-skole-nord/case-skovlunde-skole-nord-lokale13/

Film: Behavioural initiatives in 8x (class room 13): https://www.gate21.dk/wp-content/uploads/2018/03/Adf%C3%A6rd-Indeklima_-Workshop-i-8x.mp4

Classroom 15:
https://www.gate21.dk/case-skovlunde-skole-nord/case-skovlunde-skole-nord-lokale15/

Evaluation tool:
https://www.gate21.dk/evalueringsvaerktoj/

Analysis: Indoor climate measurements:
https://www.gate21.dk/wp-content/uploads/2018/06/SBi-Notat-Forslag-til-vurdering-af-indeklimaet-i-skoler-vers01.pdf

Innovation workshop:
https://www.gate21.dk/workshop-vaeltede-vaegge/

Mapping of energy consumption:
https://www.gate21.dk/wp-content/uploads/2018/03/Skovlundeskole-Nord_energikortl%C3%A6gning_Tekma.pdf

Questionnaire adults: https://www.gate21.dk/wp-content/uploads/2018/03/Ansatte_sp%C3%B8rgeskema-smiley-Q-v13-skema01.pdf

Questionnaire pupils:
https://www.gate21.dk/wp-content/uploads/2018/03/Elev-sp%C3%B8rgeskema-smiley-Q-v13-skema01.pdf

Analysis interviews:
https://www.gate21.dk/wp-content/uploads/2018/03/Sammenfatning-af-kvalitative-interviews_Bascon.pdf

More results from interviews:
https://www.gate21.dk/wp-content/uploads/2018/03/Pr%C3%A6sentation-ved-L%C3%A6rke-Andersen-COWI-resultater-fra-interviews-02052017.pdf

presentation at conference:
https://www.gate21.dk/wp-content/uploads/2018/03/Opl%C3%A6g-indeklimakonference-TI-14.-november.pdf

05.06.18 Roomvent & Ventilation 2018
A comparative study of the indoor environmental quality in renovated and non-renovated classrooms (pdf)

01.06.18 Energiforum Danmark
Vælg den rigtige ventilation

28.05.18 Indeklimaportalen.dk
Nyt værktøj kan skabe helhed i skolerenovering

24.05.18 Indeklimaportalen.dk
Case: Nu kan lærerne tage jakken af om vinteren

01.04.18 Energiforum Danmark
Det rigtige lys letter læringen

08.12.17 Gate 21.dk og CSR.dk
Indeklima på skoleskemaet giver elever ny viden og bedre vaner
Indeklima på skoleskemaet giver elever ny viden og bedre vaner

01.12.17 Gate 21.dk
Skolers indeklima til debat på konferencer
01.05.17 Energiforum Danmark
Fremtidens partnerskab hedder OPI

20.11.17 Renoveringpådagsordenen.dk
Få overblikket over din skolerenovering via nyt evalueringsværktøj

18.11.16 Building-supply.dk
Nyt innovationsprojekt forbedrer skolers indeklima

08.11.16 Folkeskolen.dk
Stort indeklima-projekt skal vise vejen frem

23.06.16 Gate 21
Workshop væltede vægge

04.08.16 Installatør.dk
Nyt projekt skal skabe bedre indeklima i folkeskolen

04.08.16 Molio.dk/Bygnet
Ny drejebog til bedre indeklima i skolen

11.11.15 Gate 21
Ventilation vandt afstemning om indeklima

06.11.15 Dagensbyggeri.dk
Skolerenoveringer i en helhed

01.08.15 Gate 21, Insight 21
Skolers indeklima får et frisk pust (pdf)