Final report

1. Project details

Project title	Automatiseret auditering og kontinuerlig commissioning af næste generations bygningsstyringssystemer
File no.	64019-0081
Name of the funding scheme	EUDP
Project managing company / institution	University of Southern Denmark/ SDU Center for Energy Informatics
CVR number (central business register)	29283958
Project partners	- SDU Center for Energy Informatics - Schneider Electric Danmark A/S - ReMoni - Sweco Danmark A/S - Region Hovedstaden - Odense Universitetshospital
Submission date	06 March 2024

2. Summary

Summary (English):

Overall, confidence at the building design stage and simply claiming that the building management system (BMS) will operate properly and improve energy efficiency, doesn't ensure proper operation of the different building systems and components. The BuildCOM project was driven by industry and customer needs. It responds to the increasing demands for energy efficiency, comfort, and safety in the buildings sector. The project has brought together academic researchers, industrial companies, and public partners, resulting into the development and demonstration of an innovative first-its-kind set of tools for automated BMS auditing and continuous building commissioning. The software has three major capabilities, initial BMS auditing, BMS retro-commissioning and continuous building commissioning. Thus, the proposed software is of a major aid to the design, development and operation of next generation building management systems. The BuildCOM project set of tools are designed, developed, implemented and demonstrated in four case studies:

1. MMMI building at the University of Southern Denmark, Odense,
2. Bornholm Hospital emergency building 23B,
3. Odense University Hospital Blodbanken, Stærmosegårdsvej 6, Odense

4. Schneider GreenHouse Building in Ballerup,

Implementing the proposed solution, the customers and building owners are able to have higher energy efficient newly built and existing buildings, lower operation costs and less emissions from day one and throughout the building operation phase.

Based on the work carried out in the project, the project team has reported and disseminated the idea, technical approach, methodology, results, and findings throughout the project life. The dissemination activities have resulted in a list of published papers in international journals, conferences, and technical magazines.

In addition, the commercial partners have set an initial list of a users' group of building owners as a potential group for the project solution implementation and application by the project commercial partners. This work group will provide a platform for knowledge building and sharing within the project. Moreover, this end users' group will form candidates for implementing developed software after the project ends. In terms of the commercial exploitation of the project results, it should be noted that the solution developed can be implemented as a package of three tools, or in the form of standalone applications, where each tool can be implemented individually depending on the case study, the building in use, and the customer wish. The commercial partners Schneider Electric, ReMoni, and Sweco will consider the initial findings of the development and demonstration activities in the project as a basis and are to follow up with additional investigations in terms of implementing and providing the solution and the corresponding tools as a service delivered to customers on top of their current offerings.

Summary (Dansk):

Tillid til et fuldt funktionelt og effektivt styresystem til bygninger (BMS) i designstadiet er ikke en forsikring for, at de forskellige systemer og komponenter i bygningen opererer effektivt og fejlfrit. BuildCOM-projektet var drevet af behov fra industrien og klienter og en øget efterspørgsel på energieffektivitet, komfort, og sikkerhed i bygningssektoren. Projektet har samlet forskere, selskaber fra industrien, og offentlige partnere, hvilket har resulteret i udviklingen og demonstrationen af innovative værktøjer til automatiseret revision og continuos commissioning af bygninger. Den udviklede software har tre primære funktioner, initial BMS-revision, BMS retro-commissioning, og continuos commissioning. Dette har stor værdi for udviklingen af fremtidige styringssystemer til bygninger. De udviklede værktøjer i BuildCOM-projektet er designet, implementeret, og demonstreret gennem fire case-studies:

1. MMMI building at the University of Southern Denmark, Odense,
2. Bornholm Hospital emergency building 23B,
3. Odense University Hospital Blodbanken, Stærmosegårdsvej 6, Odense
4. Schneider GreenHouse Building in Ballerup,

Ved at implementere de præsenterede værktøjer har klienter og bygningsejere mulighed for at højne energieffektiviteten, og sænke driftsomkostninger samt emissioner af nye og eksisterende bygninger gennem hele driftslevetiden.

Baseret på arbejdet udført i projektet har partnerne rapporteret og videreformidlet idéen, den tekniske fremgangsmåde, metoden, samt resultater gennem hele levetiden for projektet. Dette har resulteret i en række publicerede artikler i internationale tidsskrifter, konferencer, og tekniske magasiner.

Ydermere har de kommercielle partnere identificeret en liste af potentielle bygningsejere, hvor de præsenterede løsninger kan blive implementeret efter projektet slutter. Dette danner også grundlaget for vidensdeling internt i projektet. I forhold til kommerciel udnyttelse af løsningerne præsenteret i projektet, kan det nævnes at disse kan blive implementeret som en pakke af tre redskaber eller som tre enkeltstående applikationer, der

kan implementeres afhængigt den specifikke bygning og klientens ønsker. De kommercielle partnere, Schneider Electric, ReMoni, og Sweco påtænker at bruge erfaringerne fra projektet som udgangspunkt til at videreudvikle og implementere løsningerne som en overbygning på deres nuværende produkter.

3. Project objectives

To increase the efficiency of the energy sector and reduce carbon dioxide emissions, it is vital to have energy efficient buildings with high performance and low energy consumption and corresponding emissions. A building management system (BMS) is generally defined as the 'Brain' of the building. Building management systems aid in improving occupant comfort and productivity and, enhance the operational efficiency of building energy generation and supply systems. A BMS is an integrated building automation and energy management system. It is fully capable of monitoring the energy performance of buildings, managing, and controlling the different building services, including mechanical and electrical systems, and it establishes smooth interaction between various building components and units. However, confidence at the building design stage and simply claiming that the BMS will operate properly, and that its various functions thus will improve the energy efficiency of the building compared to reference numbers, doesn't ensure proper operation of the different systems and components. Generally, there is a clear mismatch between the actual energy performance of a building and the expected levels, referred to as the 'building performance gap'.

Today, commissioning of BMS is done manually and is therefore expensive and error prone. There is a large potential in implementing initial commissioning and auditing of newly installed BMS, especially in view of the new Directive (EU) 2018/844 which requires that all non-residential buildings shall be equipped with BMS by 2025. Retro-commissioning of upgraded existing building management systems has an equivalent importance. Generally, as the building goes into the operation phase, major modifications could happen. This includes upgrading of building services and components, installing new automation and control devices, modification in the building automation and management strategy and upgrades in the software and hardware components of the BMS itself. Bearing in mind that any of these modifications will have a large effect on the energy performance of the building, implementing a retro-commissioning and auditing of the BMS is indispensable to ensure a proper function of different features and smooth integration of various systems and devices. Currently, retro-commissioning of the BMS is often either insufficiently comprehensive in its execution, limited to the level of the modification occurring, or it is not conducted at all. Moreover, considering the increasing complexity of building automation systems and the growing integration of IoT (Internet of Things) and intelligent devices along with the advanced and smart self-governing devices and controls, a systematic and automated building management systems initial and retro- commissioning process along with a comprehensive continuous commissioning framework is needed to aid the development and operation of next generation building management systems.

This project aim was to advance the state-of-the-art through the development and demonstration of an innovative set of tools for building management systems automated auditing and continuous building commissioning.

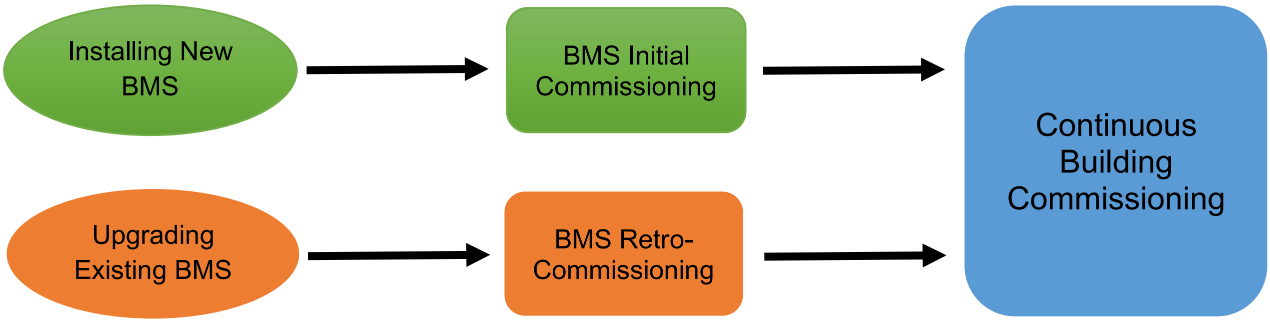

Fig. 1. Overall framework of the proposed BuildCOM auditing and commissioning software

This first-of-its kind software applications aim to have three major capabilities and features:

1. Initial commissioning of BMS
2. Retro-commissioning of BMS
3. Continuous building commissioning

For the first two software features, the BMS auditing process includes both initial commissioning of newly installed BMS in newly built and existing public and commercial buildings, and retro-commissioning of upgraded and modified BMS in existing public and commercial buildings. The auditing process is based on the requirements and regulations of the European Standard EN 15232 "Energy performance of buildings – Impact of Building Automation, Controls and Building Management" and the auditing and certifying building management systems methodology developed by the European Building Automation and Controls Association (eu.bac). The auditing covers various BMS services and automation functions, including temperature control, indoor air quality control, lighting, heating, cooling, ventilation, domestic hot water, drivers and motors, performance monitoring, technical alarms and power management, diagnostic information, central operation and settings and remote controls.

The third software feature allows for automated holistic continuous building commissioning and performance testing throughout the operational phase of the building. This has built on the research findings of the International Research Project COORDICY, 'ICT-driven Coordination for Reaching 2020 Energy Efficiency Goals in Public and Commercial Buildings', in particular the development of an Online Energy Performance Monitoring and Evaluation Tool (ObepME), aiming to integrate the overall continuous commissioning tool within new AC-BMS software. The ObepME tool comprises a set of building performance tests which was developed to meet the strict Danish building regulations and energy efficiency requirements. These tests target various building subsystems including heating, ventilation, and air conditioning (HVAC) components and units, to assess the building performance and ensure that the building performs as expected. The tool has two main inputs: simulations from whole-building dynamic energy performance model and actual data collected onsite from various meters and submeters in the building. Based on these two inputs, performance tests are carried out within the tool to automatically and continuously compare actual building performance to expected performance baseline set by the simulations. ObepME was developed and demonstrated within COORDICY by the Center for Energy Informatics at University of Southern Denmark in collaboration with Schneider Electric and is at TRL4. The project aims to develop it further to TRL7-8.

4. Project implementation

In terms of the project technical implementation, an overall project plan was designed and implemented at the project design stage. In this regard, the project is composed of five interlinked work packages (WPs), with corresponding activities and sub tasks, where each task defined is related a work package delivery.

In the sections below, a brief summary on the actual work carried out under each WP is provided:

WP1: Project Management

WP1 has been running from day 1 and throughout the project lifetime. Muhyiddine Jradi from SDU Center for Energy Informatics is serving as the project manager with the aid of the established steering committee representing all key partners. The work comprises of daily project management and coordination, project progress monitoring, risk management, project plan adjustment, periodic project reporting and writing of final project report to EUDP.

First of all, it is good to highlight that based on the discussion between all the project partners, a project acronym was selected 'BuildCOM' in addition to a project logo.

The continuing activity of project management was mainly concerned with making sure that WP leads coordinates bilaterally, the communications that are necessary for a coherent project execution. An important part of this is holding common project meetings. A project kick-off meeting, being a first common project meeting, was held at the University of Southern Denmark in October 2019, and it was agreed among all the partners to hold common project meetings timely every half year with full participation from all partners. Unfortunately, the COVID19 pandemic was a barrier for holding a physical meeting, so virtual online meetings were held in April 2020, November 2020, May 2021. In addition, physical meetings were held in December 2021 at Schneider Electric Greenhouse building in Ballerup and in June 2022 at the University of Southern Denmark in Odense.

A major milestone under WP1 is the completion and delivery of the project collaboration agreement in January 2020, with the contribution and confirmation of all project partners.

Also, a project webpage was created, and a logo was designed as shown below.

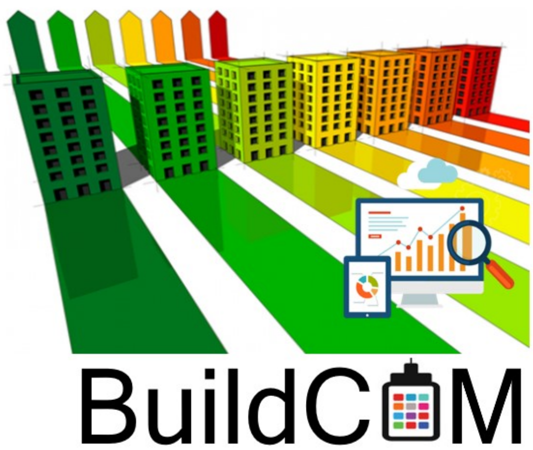

Fig. 2. BuildCOM project logo

WP2: Development of Building Management Systems Auditing Process

The main aim of WP2 is the development of a systematic and comprehensive methodology for building management systems auditing, covering both initial commissioning and retro commissioning of building management systems. Based on the overall discussion between project partners, it was agreed that the methodology to be developed should have a clear distinction between BMS auditing on one side, and BMS initial and retro commissioning on the other side. The work under WP2 has moved forward smoothly and following the time plan very well with no major delays.

Regarding building management systems auditing, a list of building management system specifications and functions to consider as part of the auditing process was defined and highlighted. The development of this list took into account the guidelines of the European Standard EN 15232 "Energy performance of buildings – Impact of Building Automation, Controls and Building Management", Directive (EU) 2018/844 requirements and the EU initiatives towards the establishment of a common smart readiness indicator (SRI) of buildings. The result is a hybrid qualitative-quantitative multi-criteria holistic framework for building automation and control systems auditing and smartness evaluation. Under this framework, eight building domains are highlighted, including: heating, domestic hot water, cooling, ventilation, lighting, dynamic envelope, electricity and monitoring and control domain. Each of these domains comprise a set of services to be audited and evaluated, summing up to 60 different building services in total.

To aid the assessment of installed building automation systems, different impact criteria are considered. Depending on the selected functionality level of specific service, each impact criterion is evaluated differently. The five criteria considered under the proposed methodology are: 1) Energy Efficiency; 2) Maintenance and fault prediction; 3) Energy flexibility; 4) Comfort; 5) Information to occupants. A points-based grading score is introduced to quantify the effect of functionalities on the five considered impacts. The building automation system evaluation takes the actual building environment into account as it is possible to exclude certain domains, thereby adapting the assessment to local climate and building type. The developed building management process auditing process was tested considering three case study buildings, OU44 teaching building and MMMI office building at the University of Southern Denmark in addition to a smart home, Home For Life, in Aarhus.

Regarding the initial commissioning and retro commissioning of building management systems, a methodology for automated step response tests in buildings was designed and developed. The aim of such tests is to ensure a proper integration of a newly designed BMS or a retrofitted BMS, in addition to ensuring a proper communication and response of various energy systems in the building with the overall holistic building management system. Three major type of step response tests were designed, a room temperature test, ventilation system test, and cooling/heating supply plant test. For each of these tests, major parameters, inputs, outputs and test success conditions are defined and highlighted based on literature studies, project partners input and practical needs. The major initiation parameter of each test is manipulating system setpoints by the BMS and recording and evaluating response and impact of the targeted energy system. The methodology was tested and demonstrated using generic fabricated data.

WP3: Development of a Software for Automated BMS Auditing and Continuous Building Commissioning

The project work under WP3 has proceeded in a good shape with respect to the project time plan. The first completed task under WP3 was upgrading the ObepME (Online Building Energy Monitoring and Evaluation) tool which was developed within COORDICY 'ICT-driven Coordination for Reaching 2020 Energy Efficiency Goals in Public and Commercial Buildings' project earlier, by the Center for Energy Informatics at University of Southern Denmark in collaboration with Schneider Electric. The ObepME tool upgrade includes definition of new and more generic set of building performance tests which was developed to meet the strict Danish building regulations and energy efficiency requirements. These tests target various building subsystems including heating, ventilation, and air conditioning (HVAC) components and units, to assess the building performance and ensure that the building performs as expected. In addition, the online and automated energy modelling, calibration, and validation process is refined and upgraded and a demonstration in a university teaching building was carried out.

Moreover, using the BMS auditing and smartness evaluation framework developed in WP2, an innovative holistic tool which provides a first-of-its kind instrument for buildings building automation and control systems assessment and smartness evaluation is designed and presented. The IBACSA tool relies on the hybrid qualitative-quantitative multi-criteria driven holistic framework developed in WP2. The preliminary demonstration and implementation of IBACSA in three case study building, OU44 and MMMI university buildings and Home For Life house in Aarhus, along with shows the capability and potential of the tool in auditing various building automation and control features, evaluating the control levels and reporting the impact of upgrades and retrofits. In addition, the holistic tool nature, simple interface, minimal inputs, and generic assessment framework make the tool applicable to assess any building automation and control systems with no modifications, regardless of the BACS nature and complexity. Thus, the tool provides full flexibility for the assessor to modify and implement any new BACS controls and designs and compare them in order to select the most appropriate design for the considered case study.

The third tool developed under the BuildCOM project is ‘AUSTRET’, employing the methodology for automated step response tests in buildings designed and developed in WP2. AUSTRET is the first-of -its kind fully automated and online application for step response testing, developed as a close collaboration between project partners Schneider Electric, SDU CEI and ReMoni. AUSTRET can be implemented as a basis for BMS initial and retro-commissioning in existing or retrofitted medium to large-sized buildings with the capability of receiving actuator commands and responsible to provide updated state of several state variables. In this regard, Firstly, Schneider SmartConnector RESTful EWS Gateway was employed where endpoints were configured to serve resources from Schneider EWS Server in a RESTful manner. On top of that, a Python application was designed and developed to communicate with Schneider EWS Server by manipulating resources with actions using standard HTTP Request and Response method. Furthermore, a monitoring and evaluation dashboard was also designed and developed by using a high-level Javascript library called Plotly.js to plot trend logs for inputs and outputs values of the step response test.

WP4: Demonstration of the Software in Case Study Buildings

WP4 deals with demonstration and evaluation of the developed set of tools under WP3 in multiple case study buildings. The first completed task was identification of specific case study buildings for demonstration. In this regard, the aim was to choose buildings of different size, age and use to provide a more holistic demonstration and allow better evaluation of results. The four case study buildings are:

1. MMMI building at the University of Southern Denmark, Odense,
2. Bornholm Hospital emergency building 23B,
3. Odense University Hospital Blodbanken, Stærmosegårdsvej 6, Odense
4. Schneider GreenHouse Building in Ballerup

Overall, WP4 aims at the actual and practical demonstration and evaluation of the tools developed. Thus, the three tools, ObepME, IBACSA, and AUSTRET are implemented and demonstrated in case study buildings.

In terms of actual demonstration and implementation, and due to COVID 19 impacts, the decision agreed on by all the project partners, was to proceed with all the case study work simultaneously, and thus the demonstration and implementation of the various tools has proceeded in parallel in the four different buildings mentioned above at different pace and progress phases. This is one major change implemented in the project plan where the initial plan set in the Gantt chart was to proceed in the demonstration phase as case by case. Nevertheless, and although it was forced by COVID 19, the change in the plan and moving forward in the cases in parallel has demonstrated positive impacts and allowed more time to gather information, set up the tools for demonstration, collection of results, and analysis of the overall impacts.

In this regard, the table below highlights the major demonstration and implementation activities completed in each of the case study buildings under the BuildCOM project. As highlighted in the table:

1- IBACSA was successfully demonstrated in all the 4 case study buildings.
2- AUSTRET was successfully demonstrated in the MMMI SDU building and the Schneider Electric Greenhouse Building in Ballerup.
3- ObepME was successfully demonstrated in MMMI SDU. Bornholm Hospital building 23B, and OUH Blodbanken in Odense.

Table 1. Tools demonstration in the four case study buildings

<table>
<tr><th>Case / Tool</th><th>MMMI SDU</th><th>Bornholm Hospital 23B Building</th><th>OUH Blodbanken Odense</th><th>Schneider Electric Greenhouse</th></tr>
<tr><td>IBACSA</td><td style="background-color:#00B050"></td><td style="background-color:#00B050"></td><td style="background-color:#00B050"></td><td style="background-color:#00B050"></td></tr>
<tr><td>AUSTRET</td><td style="background-color:#00B050"></td><td></td><td></td><td style="background-color:#00B050"></td></tr>
<tr><td>ObepME</td><td style="background-color:#00B050"></td><td style="background-color:#00B050"></td><td style="background-color:#00B050"></td><td></td></tr>
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WP5: Project Results Dissemination

WP5 is dedicated to the dissemination of the project's results, in both public and commercial interest, during the whole project period.

Under WP5, all the project partners took part in the project results dissemination plan development and implementation.

An initial activity in terms of project communication is the creation of a project page and shared folder where project description and activities as well as documents and specifications are shared between project partners and external audience. In addition, all project partners have committed in the first kick-off meeting to communicate the project idea and scope within their respective organization and network.

In terms of results dissemination, a large number of research articles were developed and published in international journals and conferences, in addition to industry-devoted magazine articles presenting the project idea and major deliverables to practitioners, industrial bodies and engineers in the field. Moreover, the project was presented in multiple national and international seminars and workshops by the project team members.

Furthermore, the three commercial partners involved in the project, Schneider Electric, ReMoni and Sweco set plans and actions to ensure the proper exploitation of the project results, aiming towards securing a smooth transition from development and demonstration to commercial and market inclusion. In this regard, the commercial partners have set an initial list of a users' group of building owners as a potential group for the project solution implementation and application by the project commercial partners. This work group will provide a platform for knowledge building and sharing within the project. Moreover, this end users group will form candidates for implementing developed software after the project ends.

Challenges and Risks:

The demonstration phase of the project has exhibited major challenges and risks throughout the project lifetime. First of all, the impacts of COVID 19 have delayed the work multiple times and has led to postponement in terms of setup and implementation in the buildings. Considering that two out of the four buildings are healthcare buildings, there were strict rules and guidelines for accessing those building for meetings or actual implementation. This has delayed the work and the demonstration. However, the project team has maintained communications, even though virtually the majority of the time, and managed to complete the projects tasks as expected and deliver the results on time with no extension on the initial project set time.

Besides the obvious risks that something could go wrong during the actual real case study implementation and demonstration, the biggest risk was maintaining the coordination between all involved parties that needs to be on point for everything to come together at the end. This was challenging considering that the project has partners of different backgrounds, sizes, types and applications. These risks were overcome through a direct coordination between the project manager and the steering committee and regular meetings, timely reporting and active integration of each partner at each stage and in each decision. This approach proved successful and allowed completion of the technical workpackages WP2 and WP3 and reaching the set milestones and deliverables. Such coordination along with the multitude of expertise from different project partners was also key towards attaining successful implementation and demonstration in WP4.

Another risk faced in the overall project implementation was the unavailability of some data and information on the case study buildings HVAC systems and building services or the delays in receiving and sharing those among partners. This of course threatens the successful demonstration of the project tools and solution in the case study buildings. This risk was overcome and faced by the close coordination and involvement of the facility management departments at all the case study buildings. The corresponding facility management department, in close coordination with the representative of each partner in the steering committee, were able to take responsibility and provide data when needed with some acceptable margin of delay, and also find alternatives in case of missing data or information.

The last risk we wanted to highlight has appeared in the last phases of demonstration in the project, mainly due to the increasing threats of cyber-attacks. This has majorly affected the way, rate, and capacity of sharing data and information, as well as connecting software components and platforms across the partners systems. One example was the coordination and the integration of the ObepME tool and the continuous commissioning platform at OUH Odense Blood bank building. Due to strict constraints put in place at SDU and also at OUH, major issues were highlighted in terms of the system integration. This has threatened finalizing the implementation in the case study. However, the IT teams from both partners were out in direct communication and contact and an alternative solution for data flow, share, and communication was developed and implemented.

5. Project results

The aim and objective of the project was obtained in accordance with the original project plan highlighted in the Gantt chart developed at the project design phase. The Project was split into 5 WPs, three technical WPs in addition to a management WP and a dissemination WP. The general results from technical WP's are briefly described below. In addition, the work and activities carried out as well as the deliverables of the project were reported and documented in reports and published papers as highlighted in WP5.

The project has a list of technical milestones which are repoorted below. Although there have not been any direct commercial results produced during the project, one commercial milestone was set at the project design phase which is 'CM1: Formation of an end users group of building owners'. In this regard, the commercial partners, Schneider Electric, ReMoni, and Sweco have developed and highlighted an initial list of a users' group of building owners as a potential group for the project solution implementation and application by the project commercial partners. This work group will provide a platform for knowledge building and sharing within the project. Moreover, this end users' group will form candidates for implementing developed software after the project ends. direct commercial milestones or deliverables.

In this regard, it was highlighted that the solution is to be used in a wide range of applications and domains, primarily aimed at end-users with a strong facility management department, including Universities, Healthcare, Large Real-estate, Design & Planning organizations, Municipalities, Regions, and Building authorities.

In the sections below, a brief summary on the main results and findings obtained under each of the WPs is provided:

WP1: Project Management

The aim of WP1 to provide a proper and effective management of the overall project progress on various perspectives, including technical and economic aspects. In this regard, this WP has resulted in the creation of detailed project activity plans, daily project management and coordination, project progress monitoring reports, risk management plan, periodic project reporting to EUDP and the development of the final project report. Muhyiddine Jradi from SDU Center for Energy Informatics has served as the project manager. In addition, a steering committee was formed with the responsibilities to oversee and ensure the project progress throughout the different phases in addition to monitoring and evaluating the progress of tasks and deliverables. In addition, for each WP, a WP leader is appointed by the project management, and was responsible of preparing detailed WP-plans in accordance with overall project plans, leading WP work and reporting to the project manager.

In terms of project group meetings, a project kick-off meeting was held at the University of Southern Denmark in October 2019, and it was agreed among all the partners to hold common project meetings timely every half year with full participation from all partners. Thus, 5 project group meetings were held, three virtual meetings due to COVID 19 and two physical meetings at Schneider Electric Greenhouse building in Ballerup and at the University of Southern Denmark in Odense.

A major milestone under WP1 is the completion and delivery of the project collaboration agreement in January 2020, with the contribution and confirmation of all project partners.

The major deliverables attained under WP1 are as follows:

- **D1.1** Project planning and follow-up on progress in the different work packages
- **D1.2** Coordinate cross work package synergies and interfaces
- **D1.3** Project meetings and coordination between partners
- **D1.4** Secure economic and administrative reporting according to rules
- **D1.5** Periodic reports to EUDP

WP2: Development of Building Management Systems Auditing Process

A list of technical specifications and functions of BMS to be audited and tested was developed. A hybrid qualitative-quantitative multi-criteria holistic framework for building automation and control systems auditing and smartness evaluation was designed and developed, as shown in Figure 3. Regarding the initial commissioning and retro commissioning of building management systems, a methodology for automated step response tests in buildings was developed, as shown in Figure 4.

Fig. 3. A hybrid qualitative-quantitative multi-criteria holistic framework for building automation and control systems auditing and smartness evaluation

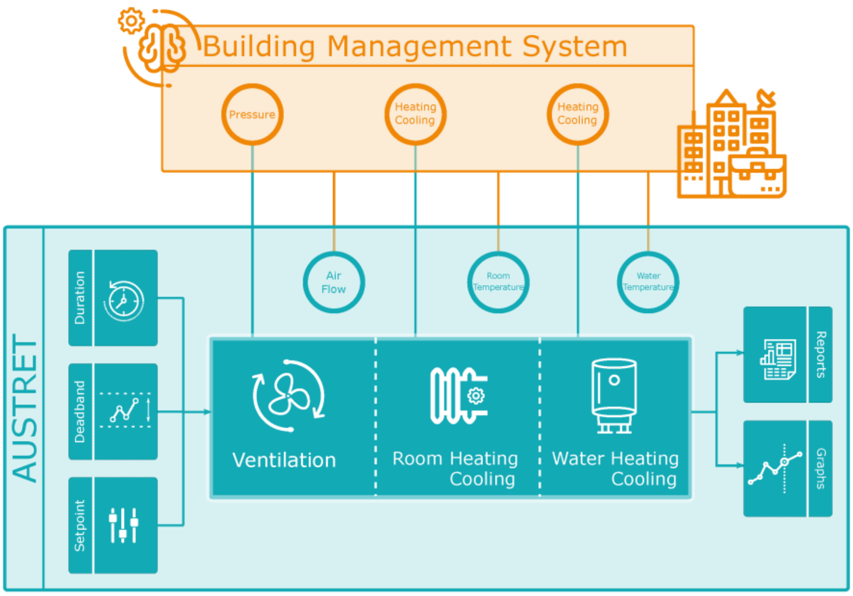

Fig. 4. A methodology for automated step response tests in buildings

The major deliverables attained under WP2 are as follows:

- **D2.1** A list of technical specifications and functions of BMS to be audited and tested
- **D2.2** A holistic process for building management systems auditing to serve as a backbone for both initial BMS commissioning and retro-commissioning of upgraded BMS

The milestones met under WP2 are as follows:

- **M1** Building management system auditing process developed

WP3: Development of a Software for Automated BMS Auditing and Continuous Building Commissioning

Employing the methodologies developed in WP2, the work under WP3 was completed with the design and development of three innovative tools as follows:

1- **ObepME: Online Building Energy Monitoring and Evaluation tool for continuous building commissioning**. The ObepME tool comprises a set of building performance tests targeting building energy systems and components. ObepME has two inputs: simulations from whole-building energy performance model and actual data collected onsite from building meters and submeters. Performance tests are carried out within the tool to automatically and continuously compare actual performance to expected performance baseline set by the simulations. Screenshots of the ObepME tool dashboard in the OUH building are provided in Appendix 5.

2- **IBACSA: A first-of-its kind interactive tool for Building Automation and Control Systems Auditing and Smartness Evaluation**. IBACSA deals with the different building domains, evaluating building services functionality levels. IBACSA employs a hybrid qualitative-quantitative multi-criteria holistic framework, considering eight major building domains, quantifying the impact of the select-ed control levels against five major impact criteria: (1) Energy efficiency, (2) Maintenance and fault prediction, (3) Energy flexibility, (4) Comfort and (5) Information to occupants. With the provided capabilities, IBACSA serves as a potential instrument for BACS initial and retro com-missioning processes. A screenshot of the IBACSA tool interface is provided in Appendix 2.

3- **AUSTRET: A first-of-its kind Automated Step Response Testing Tool for Building Automation Systems**. AUSTRET is developed as a close collaboration between project partners Schneider Electric, SDU CEI and ReMoni. The application evaluates building systems including, ventilation, room heating and cooling, and water heating and cooling modules in a building. A user-friendly interface with comprehensive reporting platform was developed. Bootstrap toolkit has been fully applied in aligning styles and layouts of HTML elements. java Scripts including validation rules, button click events, report data serialization is completely implemented for handling users' interactives generated from AUSTRET's UI. Codes for handling HTML templates rendering are developed. All HTTP requests for achieving communication between AUSTRET and Schneider Electric system have been developed and tested. A data logger was developed and attached to AUSTRET for archiving data generated during step response test. A thread scheduler and handler has been developed and tested to ensure parallel execution of step response test and data logger. A screenshot of the AUSTRET tool interface is provided in Appendix 3.

The major deliverables attained under WP3 are as follows:

- **D3.1** Combined BMS auditing and continuous building commissioning framework
- **D3.2** BuildCOM software for automated BMS auditing and continuous building commissioning

The milestones met under WP3 are as follows:

- **M2** BuildCOM software developed

WP4: Demonstration of the Software in Case Study Buildings

WP4 aims at the implementation and demonstration of the three tools developed in WP3 in four case study buildings. In brief, the demonstration and implementation related to each of the developed tools is as follows:

1- **ObepME** was implemented in MMMI building, BH building 23B and OUH Blodbanken. The implementation in OUH Blodbanken is in its final stages. A report was developed for the MMMI building continuous commissioning implementation and for the implementation in the BH building 23B.

2- **IBACSA** was implemented in MMMI building, BH building 23B, Schneider Electric Greenhouse Building, and OUH Blodbanken, and respective reports were generated.

3- **AUSTRET** demonstration was divided into two phases, a lab-testing phase and a real case study implementation phase. In terms of the lab testing, a heating system prototype was built in SDU living lab at MMMI building. In addition, a fan system prototype was built with a complete setup: Fan, ventilation duct, valve, pressure sensor and control unit. Pictures of the developed and built testing setups are provided in Appendix 4. Automated step response tests were successfully performed using AUSTRET, and the results of the preliminary testing were collected and assessed. The second phase of testing is a real demonstration in a real building case study. The case study for implementation is the Schneider Electric Greenhouse Building. A ventilation system in the building was considered and step response testing on the ventilation system air pressure as well as the preheating coil operation were carried out and demonstrated. The obtained results were documented and reported.

The major deliverables attained under WP4 are as follows:

- **D4.1** Demonstration of the set of tools implementation in four case studies
- **D4.2** Evaluation of the set of tools for BMS initial and retro- commissioning and building continuous commissioning
- **D4.3** Building management system certification in the case studies considered based on the auditing implemented

The milestones met under WP4 are as follows:

- **M3** Evaluation of the set of tools implementation in SDU MMMI building
- **M4** Evaluation of the set of tools implementation in Schneider Electric Greenhouse
- **M5** Evaluation of the set of tools implementation in Bornholm's Hospital B23 building
- **M6** Evaluation of the set of tools implementation in OUH Blodbanken

WP5: Project Results Dissemination

WP5 aims at an effective and wide dissemination of the project's results, in both public and commercial interest, during the whole project period.

In the BuildCOM project, the project team has reported the project idea, technical approach, methodology and findings throughout the project life. The dissemination activities have resulted in a list of published project papers in international journals, conferences, and technical magazines, listed below, and attached to this report as appendices in addition to others under development.

In addition, two articles regarding the design and development of IBACSA as a first-of-its kind interactive tool for building automation and control systems auditing and smartness evaluation 'IBACSA: Interaktivt Bygningsværktøj' in addition to the importance of BMS commissioning and auditing in smart buildings 'Hvad er en intelligent bygning?' were published in HVAC magasinet. This is to ensure that the message and the project idea and approach reach not only to academic journal papers and reports readers but also to consultants, engineering, practitioners, authorities and public bodies.

Nevertheless, and although COVID 19 impacts and constraints have limited workshops and physical meetings, the project approach and findings were presented by the project manager in Energiforum 2021 workshop in

March 2021. This is in addition to presenting various project aspects and findings in multiple international conferences as presented in the list of presentations below.

It shall also be mentioned that the dissemination phase will be extended to even after the project final report, where the project commercial partners and the public partners are willing to present and disseminate the project findings in related workshops and seminars in Denmark after the project completion.

In addition, the commercial partners have set an initial list of a users' group of building owners as a potential group for the project solution implementation and application by the project commercial partners. This work group will provide a platform for knowledge building and sharing within the project. Moreover, this end users group will form candidates for implementing developed software after the project ends.

The major deliverables attained under WP5 are as follows:

- **D5.1** Communication & dissemination plan for the project
- **D5.2** Newsletters to interested parties
- **D5.3** Project presentation materials
- **D5.4** Press releases and media placement
- **D5.5** Seminars and workshops to general public and industrial networks
- **D5.6** Articles & features

The milestones met under WP5 are as follows:

- **CM1** Formation of an end users' group of building owners

<u>List of presentations related to the project:</u>

1. M. JRADI, 'The trade-off between deep energy retrofit and improving building intelligence in a university building', *The 12th Nordic Symposium on Building Physics* (NSB 2020), September 7-9, 2020, Tallinn, **Estonia**.
2. M. JRADI, 'Is your building automation and control system properly designed and installed?', *Building simulation Conference 2021 (BS2021)*, September 1-3, 2021, Bruges, **Belgium**.
3. J. BJØRNSKOV, 'Retro-commissioning of OUH Odense Building', Internal thesis presentation, September 10, 2021, Odense, **Denmark**.
4. M. JRADI, 'Online energy performance monitoring and evaluation for continuous commissioning in a Danish office building', *BuildSim Nordic 2022 conference*, August 21-22, 2022, Copenhagen, **Denmark**.
5. M. JRADI, 'Auditing and Smartness Evaluation of Building Automation and Control Systems', The 6th International Workshop on Advances in Energy Science and Automation (AESA 2022), Feburary 25-27, 2022, Guangzhou, China.
6. M. JRADI, 'IBACSA: An interactive tool for building automation and control systems auditing and smartness evaluation', December 2, 2020, Dalarna, **Sweden**.
7. M. JRADI, 'Smart buildings and smart data - Research results on data, behavior, commissioning and energy consumption', *Energiforum 21Live*, March 9, 2021, Glostrup, **Denmark**.
8. M. JRADI, 'Continuous commissioning of future energy efficient buildings', *19th International conference of sustainable energy technologies (SET 2022)*, August 16-18, 2022, Istanbul, **Turkey**.

9. M. JRADI, ‘Design and Smartness Evaluation of Building Automation and Management Systems in Danish Case Studies’. *The 9th International Conference on Energy and Environment Research (ICEER 2022)*, September 12-16, 2022, Porto, **Portugal**.

List of publications related to the project:

1. M. JRADI, N. BOEL, B.E. MADSEN, J. JACOBSEN, J.S. HOOGE, L. KILDELUND, BuildCOM: Automated auditing and continuous commissioning of next generation building management systems, *Energy Informatics* 2021, 4(1):1–18.
2. A. SANTOS, N. LIU, M. JRADI, AUSTRET: An Automated Step Response Testing Tool for Building Automation and Control Systems, *Energies* 2021;14(13), 3972.
3. S. ENGELSGAARD, E.K. ALEXANDERSEN, M. JRADI, IBACSA: Interactive Building Tool, *HVAC Magazine* 2021;57:20-27.
4. J. BJØRNSKOV, M. JRADI, C. VEJE, Automated demand-side flexibility identification and utilization in energy optimization, *Energy Informatics* 2021.
5. M. JRADI, Dynamic Energy Modelling as an Alternative Approach for Reducing Performance Gaps in Retrofitted Schools in Denmark, *Applied Sciences* 2020, 10(21), 7862.
6. S. ENGELSGAARD, E.K. ALEXANDERSEN, J. DALLAIRE, M. JRADI, IBACSA: An interactive tool for building automation and control systems auditing and smartness evaluation, *Building and Environment* 2020;184, 107240.
7. M. JRADI, N. LIU, K. ARENDT, C.G. MATTERA, An automated framework for buildings continuous commissioning and performance testing–A university building case study, *Journal of Building Engineering*, 2020, 101464.
8. J.A. ENGVANG, M. JRADI, Auditing and Design Evaluation of Building Automation and Control Systems based on eu. bac System audit–Danish Case Study, *Energy and Built Environment* 2020;2:34-44.
9. M. SINGH, M. JRADI, H. SHAKER, Monitoring and Evaluation of Building Ventilation System Fans Operation using Performance Curves, *Energy and Built Environment* 2020;1:307-318.
10. S.O. JENSEN, M.K. PEDERSEN, M. GRIMMIG, C.H. CHRISTIANSEN, N. BOEL, J. HANSEN, T. GLARGAARD, M. JRADI, What is an intelligent building?, *HVAC Magazine* 2020;8:25-30.
11. J.M. PEDERSEN, F. JEBAEI, M. JRADI, Assessment of Building Automation and Control Systems in Danish Healthcare Facilities in the COVID-19 Era, *Applied Sciences* 2022;12(1):427.
12. M. JRADI, Is your building automation and control system properly designed and installed?, *Proceedings of the Building simulation Conference 2021 (BS2021)*, September 1-3, 2021, Bruges, Belgium.
13. M. JRADI, The trade-off between deep energy retrofit and improving building intelligence in a university building, *Proceedings of the 12th Nordic Symposium on Building Physics* (NSB 2020), E3S Web of Conferences 172, 18002.
14. J. BJØRNSKOV, M. JRADI, C. VEJE, Component-level recommissioning of a newly retrofitted danish healthcare building, *Journal of Building Engineering* 2022;51:104277.
15. M. JRADI, N. Liu, Online energy performance monitoring and evaluation for continuous commissioning in a Danish office building, *Proceedings of the BuildSim Nordic 2022 conference* in Copenhagen, August 2022.
16. M. JRADI, Design and Smartness Evaluation of Building Automation and Management Systems in Danish Case Studies. *Proceedings of the 9th International Conference on Energy and Environment Research (ICEER 2022)*, Porto, Portugal, September 2022.

17. A. SANTOS, N. LIU, M. JRADI, Design, development and implementation of a novel parallel automated step response testing tool for building automation systems, Buildings 2022;12:1479.

6. Utilisation of project results

With the demonstration activities carried out within the project considering four case study buildings, it could be noted that the project results are already in use in the actual real applications even before the project is finished. For example, the ObepME continuous commissioning tool is already setup and operating automatically and continuously as part of the performance monitoring and fault detection and diagnostics at the MMMI SDU building and OUH Blodbanken, while it is running offline in the Bornholm Hospital B23 building. The tool already aided the capture of major issues in the buildings. For instance, Figure 5 below shows an example on fault detected in the domestic hot water system due to a controller malfunction at the level of the storage tank supply side, and Figure 6 shows an example of fault detected in the ventilation preheating system due to a system fan operation controller malfunction. Another example on the results utilization is the AUSTRET tool currently being implemented in the Schneider Electric Greenhouse building in Ballerup as a basis for building automation system step response testing and performance evaluation in a continuous and automated manner. In this regard, Figure 7 highlights successful step response tests carried out in the building for the case of the ventilation system preheating loop.

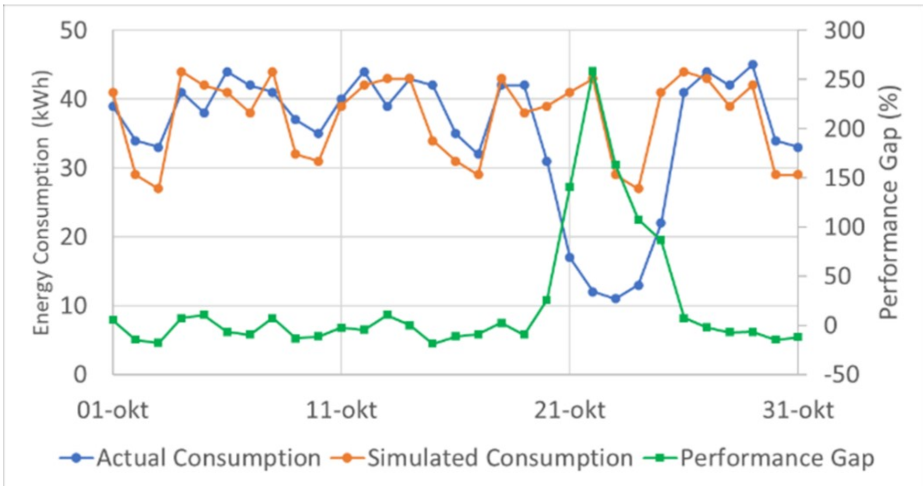

Fig. 5. A fault detected in the domestic hot water system

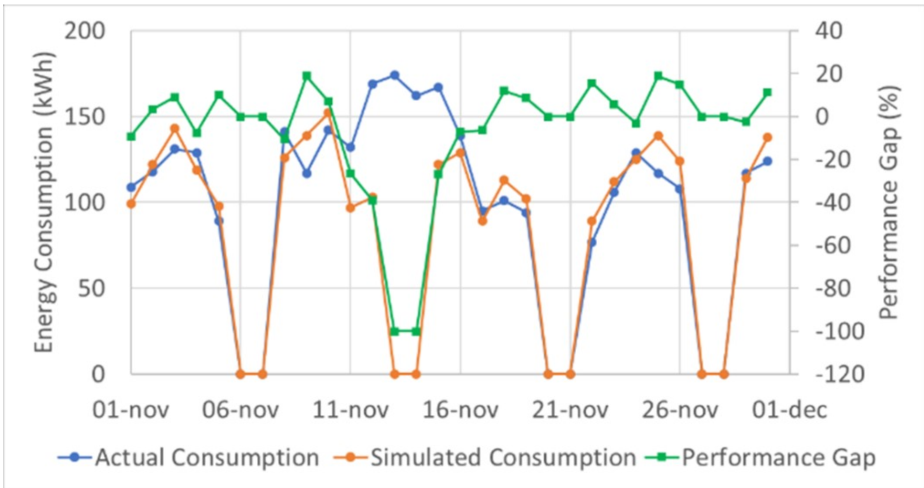

Fig. 6. A fault detected in the ventilation preheating system

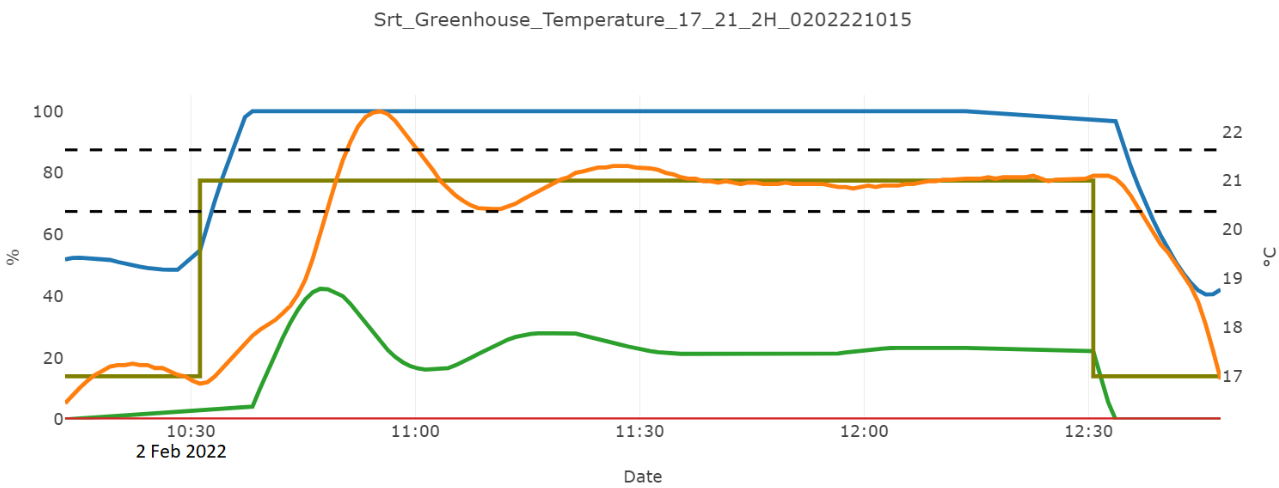

Fig. 7. A step response test with an increasing temperature set point of the ventilation system supply air

While the project activities and planned deliverables are met within the planned three years project lifetime, the technical work carried out and the findings obtained will be used as a basis which should be built on top of it for future technical development and commercial exploitation. Overall, the results developed in the project will in principle, to different extents, be utilized by all the project partners, including the research organization, commercial partners and public partners.

First of all, the technical work carried out and the design and development of the proposed solution with the three tools presented have opened the door for additional investigations and specific challenges to be investigated and develop upon it in the future. As the three developed tools as part of the proposed solution are first-of-their-kind in the field of building automation systems auditing and commissioning as well as buildings continuous commissioning, these first versions are always in need for upgrades, further developments, and modifications. Thus, additional testing of the three tools is still in need. Although the tools were demonstrated in four case studies, the number of cases and time allowed of demonstration within the project is still to some extend limited, and there is a need after the project to test the tools on a larger set of buildings of different types, uses, applications and systems configurations. For example, schools are good candidate for further setup and testing of the AUSTRET tool, in addition to citizen centres, city halls, libraries, and public buildings. Such buildings are unique in design, use and systems involved and include plenty of common rooms which could be challenging for the tools implementation. The further testing and development of the tools will be crucial for effective and prompt market penetration and proper commercial exploitation of the project. Moreover, one question which is still to be answered is how much data is needed from the building for the ObepME tool to be capable to serve as a basis for continuous commissioning and fault detection and diagnostics. Different buildings will have different metering and sensing networks and capacities, so how would that affect the implementation. All these questions are valid and natural questions where a research organization as SDU prompt will be to investigate on them and address the challenges and issues from a technical perspective utilizing the results of the project.

In terms of the commercial exploitation of the project results, it should be noted that the solution developed can be implemented as a package of three tools, or in the form of standalone applications, where each tool can be implemented individually depending on the case study, the building in use, and the customer wish. This provides flexibility for the project commercial partners to be able to exploit the development and demonstration findings on a wider perspective and considering various options and services in offering their clients.

Based on the project team expectations, the project results can be marketed in a year time after the project completion, both as complete technology and system features and in parts considering the three tools and applications developed. The solution will be offered by the two industrial companies ReMoni and Schneider Electric to their new and existing customers within the building sector. In addition, the solution will be communicated via articles on the companies' websites and via social media platforms with video presentations of the platform incl. feedback from pilots.

The project will strengthen the relationships between ReMoni and Schneider Electric as it only demonstrates the first steps of potentials in data harvesting and advanced analytics for building performance evaluation and assessment. This solution will be relevant for all applications in the target segments both within new built projects, building renovation and retrofit projects. ReMoni and Schneider Electric both have an individual and collaborative go to market strategy, offering complementary services to their mutual client base.

The solution is expected to be implementable in its first version ready in one year after the project period on Danish projects. It is expected to require more setup to make it stable enough to go to the international market, but this market should be available soon after DK release.

The commercial partner Schneider Electric will consider the initial findings of the development and demonstration activities in the project as a basis and are to follow up with additional investigations in terms of implementing and providing AUSTRET as a service delivered to customers on top of their EcoStruxure Building management platform. Schneider Electric will take the lead on this activity, but ReMoni and Sweco are subcontractors to the overall solution, with ReMoni providing the sensors and data analytics service and Sweco providing the energy consultancy services. In addition, ReMoni will also follow up and consider the findings regarding the implementation and demonstration of ObepME for performance monitoring and continuous commissioning and investigate the potential of proving the solution as a service to their current and new customers on top of the ReSave platform.

The project has not at this point led to direct increase in turnover or employment. However, pending the decision on when to go for a final commercial project implementation phase, the results will see direct commercial utilization in line with the expectations of the original application. Based on the additional testing and further assessment and evaluation, the commercial partners will then be able to develop concrete business plans and go-to-market strategies.

One of the main market risks that may face the project solution commercialization is that the demand for the proposed solution will not be as expected after the project completion. However, a principal criterion for the project team throughout the project activities and lifetime is that the project deliverables need to be driven by the industry and customers needs. Due to the growing demands for energy efficiency and environmental targets in the building sector, there is a constant demand for innovative solutions to reduce energy consumption in buildings, optimize the performance and reduce the cost of operation. The project industrial partners have an existing national and international customer base that always requires new innovative, proactive, and automated services to ensure their sustainability optimization and target achievement. Thus, they expect that the demand will rise for the proposed technology in the next years, especially in light of the new building automation directive from the EU. Furthermore, the technology can be sold as a stand-alone product as well as being integrated into already existing products.

Another major risk that may hinder the project results exploitation is the lack of qualified staff to implement the developed solution within the project. The project team have been aware about this since day one, and thus, the BMS design and development team along with the systems control and automation testing team at Schneider Denmark are very much involved since throughout all the stages of the project and comprise major part of the solution preliminary testing and demonstration in the case study buildings within the project. In addition, the staff at ReMoni have also been in continuous collaboration with all partners in terms of adapting current sensing and solutions to the needs and requirements of the new solution presented. Thus, it is expected that the team will have the required capabilities and expertise to implement the solution after the project.

In terms of the involvement of PhD students, Mr. Jakob Bjørnskov, PhD student at SDU Center for Energy Informatics, have been involved in the project since day 1, with his PhD entitled 'Digital Twins for Building Applications'. He has contributed majorly in WP3, in terms of the development of the tools, mainly AUSTRET and ObepME, and in WP4 with the demonstration of the solutions in MMMI SDU building and OUH Blodbanken in Odense. Mr. Jakob has also been in direct contact and collaboration with the project commercial partners, which was crucial and key for his PhD studies, providing practical and industrial perspectives in addition to the academic and research aspects. Also, the project methodology and applications have also been used in teaching as part of two courses within the Energy Technology education program at SDU, namely 'Building Energy modeling and simulation' and 'Smart Buildings'.

7. Project conclusion and perspective

The BuildCOM project was able to successfully addressed the major challenges and critical issues highlighted at the design phase of the project related to the design, installation, setup, and operation of building management systems in energy-efficient buildings and set the backbone for future development and design of next generation building automation systems which aids in possessing energy efficient systems, provides absolute comfort, empowers occupants with information, adapts operations to energy grid situations and facilitates strategic maintenance.

The BuildCOM project, driven by industry needs and end users demands, has developed three innovative first-of-its-kind tools for automated BMS auditing and continuous building commissioning, and demonstrated these tools in four actual case study buildings to assess the feasibility and applicability as well as reporting the added value. The following are major conclusions on the solution development and demonstration as well as future insights for further applications.

Regarding ObepME:

- ObepME is the first initiative towards setting up an automated online platform for building energy performance monitoring and evaluation. The tool was demonstrated successfully to serve as a basis for continuous commissioning of building and a backbone for fault detection and diagnostics.

- ObepME implementation in the MMMI building in Odense has shown a prompt impact, highlighting two major faults: a fault related to the domestic hot water system due to a controller malfunction at the level of the storage tank supply side, and a fault detected in the ventilation preheating system due to a system fan operation controller malfunction. In both cases, the technical services team was alarmed, and prompt reactions were in place to solve the issues. The estimated cost savings in the period of implementation has averaged around 2200 DKK per week.
- ObrpME implementation in the Blodbanken OUH building in Odense has highlighted the need for two dashboards, one to show to the building user with high level information, and the other being a more detailed technical dashboard for the use of the technical services team.
- Also, ObepME demonstration in the different case study buildings highlight the differences in terms of the tool performance in properly metered buildings (OUH building) and in poorly metered buildings (Bornholm B23 building). One major question to be answered after additional investigations is what the level of accepted metering is and sensing in the building to implement a proper continuous commissioning tool.
- Overall, ObepME demonstration has highlighted the added value of using a dynamic energy model rather than using static models with plenty of assumptions, but also indicated the need for a more generic data-driven modelling approach.

Regarding IBACSA:

- IBACSA is the first-of-its kind interactive tool for building automation and control systems auditing and smartness evaluation. The tool was demonstrated usefully in the four case study buildings, along with multiple additional national and international buildings, aiming to audit and evaluate the design of the corresponding building automation system.
- The results show that there are large differences in the control and functionality levels of the BACS in the considered buildings, mainly depending on the building age, type, services, and technical systems.
- IBACSA implementation in a set of Danish buildings shows that the ventilation system domain scored relatively high in the considered three buildings, highlighting the importance of this domain in Danish buildings to attain proper indoor air quality and thermal comfort.
- On the other hand, it was clear that the domestic hot water domain scores relatively low in most of the considered Danish buildings, highlighting that this domain needs to be considered more seriously in the Danish facilities in terms of the automation and control capabilities and functionalities.
- The worst scoring criterion in the considered buildings was Flexibility and Storage, with the absence of energy storage onsite and the lack of connection to the grid being two major reasons.
- In terms of improvements and impacts, IBACSA allows investigating the added value of retrofitting of the functionalities of the BACS aiming to enhance the level of energy efficiency in general. For the case of the Bornholm hospital B23 building, the resulting reduction in energy consumption was calculated to be around 25%. This reduction corresponds to 110 MWh, with an annual economic savings of approximately 10.45 k EUR.
- A major improvement and further investigation into enhancing and upgrading IBACSA would be through integrating live consumption data as an input to the tool, which will upgrade the tool from being a static design evaluation tool to become a whole life-cycle operational tool.

Regarding AUSTRET:

- AUSTRET is an innovative tool for automated step response testing tool for building automation systems. It was also implemented and demonstrated in a couple of case study buildings to assess and evaluate the feasibility and applicability.
- AUSTRET testing at the MMMI building in Odense has demonstrated the crucial need for mapping tools and application programming interfaces to allow a smooth interaction between the devices, the automation system and the server running the tests.

- AUSTRET demonstration has shown that the tool is capable to run multiple tests and on various rooms and spaces at the same time. However, an important note to be considered is that the energy supply system capacity should be always respected and not stressed too much.
- The response time of space heating temperature control was found to be fairly long and could extend to 2 or 3 days depending on the building in question.
- On the other hand, the response time of ventilation preheating loop control was found to be faster and could be completed in a time ranging between half an hour and 2 hours.
- The response time of ventilation pressure systems was found to be very fast, and a test can be completed in 10 to 15 mins.
- The tool automated approach has demonstrated time and resources savings as well as eliminating human error and faults in configurations.
- Security is still a big concern when developing digital solutions. The current version of AUSTRET relies the most on the security of the local network and the access of the local firewall. In addition, a simple authentication process was developed. In practice, there is a need for more development to ensure quality security methods, including the use of cryptography and a strict certification process to guarantee a trustful handshake.

Overall, the BuildCOM project has progressed smoothly throughout the project life, despite the negative impacts of COVID 19 on various domains and on every single organization in the projects. The collaboration between the different partners was very fruitful, where various expertise has been blended together to develop and demonstrate the proposed solution. The project findings were very well reported and disseminated in over than 18 publications and in various national meetings and workshops and international conferences.

The future steps to be taken are partly technical and partly commercial. In terms for the technical development, the three tools developed are at their version 1 stage and additional testing and investigation and a further demonstration on a wider pool of buildings is needed to fully validate and demonstrate the solution before it goes to the market. Additional features can be added, and certain specifications of the tools can be upgraded in order to exploit the capabilities to the full extend in a commercial context. Commercially, although ethe commercial partners in the project have been in direct connection throughout the project life and had major part in the development and demonstration, still additional assessment and evaluation of the solution is needed internally in each organization but also additional steps towards unifying the efforts among the partners is needed.

In terms of the commercial exploitation of the project results, it should be noted that the solution developed can be implemented as a package of three tools, or in the form of standalone applications, where each tool can be implemented individually depending on the case study, the building in use, and the customer wish. The commercial partners will consider the initial findings of the development and demonstration activities in the project as a basis and are to follow up with additional investigations in terms of implementing and providing the solution as a service delivered to customers on top of their current services and business solution. The further testing and development of the tools will be crucial for effective and prompt market penetration and proper commercial exploitation of the project.

8. Appendices

The list of appendices included along this final project report are as follows:

1- Project Gantt Chart with milestones and deliverables

2- Screenshots of the IBACSA tool interface

3- Screenshots of the AUSTRET tool interface

4- Step Response testing beds setup for heating and ventilation fans

5- Screenshots of the ObepME tool dashboard interface in OUH Blodbanken

6- Major activities completed in each of the case study buildings in BuildCOM

7- M. JRADI, N. BOEL, B.E. MADSEN, J. JACOBSEN, J.S. HOOGE, L. KILDELUND, BuildCOM: Automated auditing and continuous commissioning of next generation building management systems, Energy Informatics 2021, 4(1):1–18.

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21- M. JRADI, N. Liu, Online energy performance monitoring and evaluation for continuous commissioning in a Danish office building, Proceedings of the BuildSim Nordic 2022 conference in Copenhagen, August 2022.

22- M. JRADI, Design and Smartness Evaluation of Building Automation and Management Systems in Danish Case Studies. Proceedings of the 9th International Conference on Energy and Environment Research (ICEER 2022), Porto, Portugal, September 2022.

23- A. SANTOS, N. LIU, M. JRADI, Design, development and implementation of a novel parallel automated step response testing tool for building automation systems, Buildings 2022;12:1479.

24- M. JRADI, automated auditing and continuous commissioning of next generation building management systems, World Society of Sustainable Energy Technologies (WSSET) magazine, 12(4), 2020.