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PREFACE

This is the third progress report of the Brains for Building's Energy Systems (B4B) project, which started on May 1, 2021. In this project, a consortium of 39 partners aims to offer (future) solutions for the most important challenges of building management: energy wastage, comfort complaints and high operational costs. The Brains for Buildings project aims to tackle these challenges by empowering utility buildings with "brains".

This progress report highlights our activities and results in the third year. For more information and an overview of published reports, journal articles and recorded webinars, visit our website or contact us at contact@brains4buildings.org.

Delft, May 30, 2024

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1 INTRODUCTION TO THE B4B PROJECT

Figure 1: Link to Brains4Buildings Animation explaining the project in 1,5 minutes.

1.1 Ambition: offering (future) solutions for the most important challenges of building management

Even in the most modern utility buildings, 10-30% of energy is wasted due to malfunctioning installations and unexpected user behaviour. In many cases, the indoor air quality needs to be improved, and the operating costs are high. Smart meters, building management systems and the Internet of Things allow the collection of large amounts of data. Using this data to reduce energy consumption, increase comfort, respond flexibly to user behaviour and local energy demand and supply, and save on costs for installation maintenance is seen as promising but needs to be developed and implemented. Real-time analysis and use of large amounts of data require Machine Learning and Artificial Intelligence. However, current models and algorithms are not yet fast and efficient enough to make buildings "smarter", and implementation is cumbersome and time-consuming. Given the complexity, a collaboration of parties throughout the value chain and an open-source approach is a must to achieve scalable and integrated solutions and system innovation in the installation sector.

1.2 Objectives

The goal of the B4B project is to add operational intelligence to buildings. Buildings need “brains” for self-diagnosis and self-optimization to save energy, consider the user and be an active part of the energy system. These brains represent a large market value due to the impact these “brains” have on energy bills, health and comfort of occupants, operations and maintenance costs and ease of use. To this end, the B4B project wants to contribute to the development and market introduction of such smart systems in utility buildings by:

– Developing operating systems equipped with intelligent algorithms that guarantee the comfort, health, and well-being of the users, guaranteeing their privacy and thus improving the adoption of smart systems.
– Developing control systems that reduce energy waste, increase the use of self-produced (renewable) energy and enable adjustable flexibility regarding the heat/cold/electrical grid,
– Reducing costs for smart building control systems and improving business cases for facility managers, building owners and service providers that capture the value of the entire energy system in the built environment.

The B4B project has the objective to contribute to the MOOI innovation themes: i) making the (collective) heat and cold supply more sustainable ii) flexibility of/for the energy system (in the built environment), and iii) smart energy use in/between buildings by its users.

1.3 Approach: five integrated work packages

The project is grouped into four work packages, in which work is integrated into the required development of smart building control. Figure 2 provides an overview of the work packages and shows that the activities are organised around open living labs and use & validation cases. Methods, models, and algorithms developed in the work packages are first tested in one or more living labs and then validated in use and validation cases. The fifth work package, 'B4B Learning Communities', focuses on disseminating knowledge.

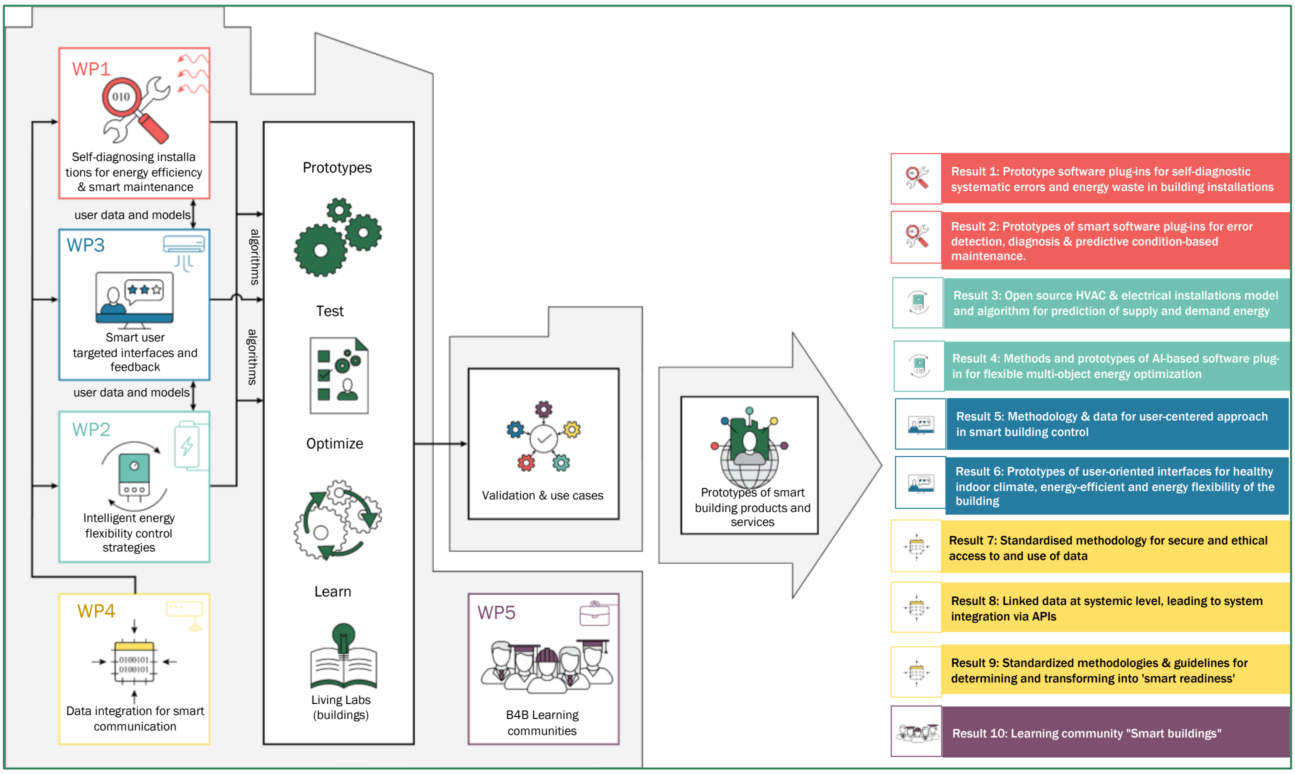


Figure 2: Five work packages organised around living labs & use/validation cases leading to 10 tangible results.

- **WP 1 'Self-diagnostic in installations for energy efficiency and smart maintenance'** focuses on developing smart diagnostic systems to reduce energy losses in buildings by continuously identifying faults in the functioning of the building in an automated manner. These diagnostic systems can also be applied for performance maintenance planning, energy-flexible buildings and decentralised control systems where users play a major role. This work package uses results from WP2 and WP3 and provides diagnostic insights into WP3.
- **WP 2 'Intelligent control strategies for energy flexibility'** focuses on developing smart control models to increase the flexibility of buildings concerning supplying and consuming heat, cold and electricity from/to the grid outside the building. The control models are multi-objective, meaning they are not only about cost optimisation but also aim to optimise CO2 reduction, comfort, and maximum use of local resources. This work package uses the user scenarios developed in WP3 and provides WP1 with insights into the different control strategies.
- **WP 3 'Smart user-oriented interfaces and feedback'** focuses on developing user interfaces (end-users, facility managers and building owners) to ensure an energy-efficient and healthy indoor environment and encourage users to engage in energy-efficient and energy-flexible behaviour. WP3 provides methods and data to WP1 and WP2 and uses diagnostic insights from WP1.
- **WP 4 'Data integration for smart communication'** ensures data connectivity between applications and data security, ethical use, and standardisation. This WP investigates the use of linked building data (LBD) and building semantic representations to support API-level system integration. Because of the diversity of legacy systems, system-level integration is much more important than data-level integration of individual systems from different manufacturers. That is why the B4B project focuses on integration at the API level.

– **WP 5 'B4B Learning Communities'** ensures that knowledge and experiences are shared in a learning community, resulting in the development of new collaborations, business models and practical applications in educational programs.

1.4 Open innovation

The B4B activities are executed in an open innovation setting, i.e., methods, and algorithms will become publicly available. This will greatly reduce company development costs and thus improve the business case. This is tested within the project by helping the companies develop their products based on the findings in the living labs. To create these conditions for good open cooperation, the B4B project is set up around living labs (test locations in offices and educational buildings) as a first validation step to prototype, test and evaluate products and services in a protected environment) (**circle 1**).

Several consortium partners validate these open-source results for scale-up and integration possibilities in use and validation cases. This means that results from the first circle are validated by consortium partners in test environments for their potential for scaling up (**circle 2**).

In addition, we distinguish a **circle 3** that includes a broad group of potential users and (market) parties interested in the project results or wish supporters to disseminate these results to their supporters further.

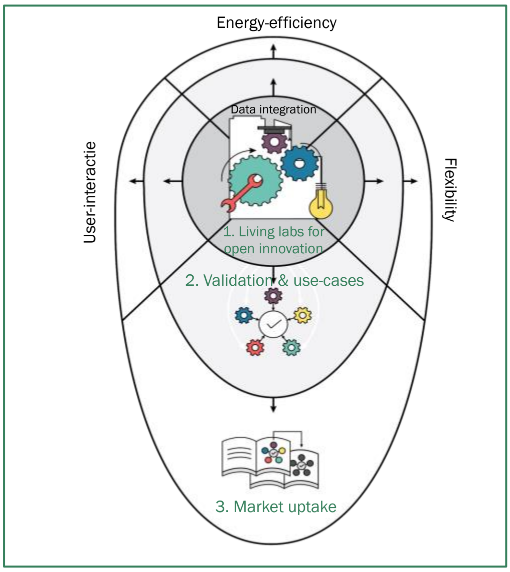


Figure 3: Collaboration around three circles: living labs (circle 1), use & validation cases (circle 2) & potential users & market parties

1.5 Project partners

Figure 4: Overview of project partners

2 ACTIVITIES AND RESULTS FOR YEAR 3

2.1 Summary of highlights in Year 3

The B4B project activities are organised around use cases in living labs. The living labs include various education and office buildings currently in use, for which historical and current data were available. They are used for small-scale testing of proof-of-concepts to collect data for further development of methods and algorithms. After successful small-scale testing, the proof-of-concept is next validated in use cases. In the project's third year, much effort was put into further testing the proofs-of-concept of systems and methods and setting up further testing and validation in use cases with industry partners. The third year of the project was dedicated for further experiments in the living labs and organising the use-cases.

2.2 WP 1: Self-diagnosing installations for energy efficiency and smart maintenance

Result 1: Prototype Bayesiaan Network-based software plug-ins for self-diagnostic of errors and energy waste in building installations.

In the past 2 years, different Diagnostic Bayesian Networks (DBN) were set up at different aggregation levels and sensor environments (sensor-rich and sensor-poor). In year 3, the results of the pre- and post-processing phases using historical data and the first version of a DBN library for the diverse HVAC system components were reported. For this, a comparison of 18 AHUs has been realised; both reports are currently under review.

Next to this, most activities in year 3 have focussed on designing and executing multiple live tests in Kropman Building and in TUD Building 28. In these tests, different faults were introduced in the Air Handling Unit of both buildings (see example in Figure 5). The realisation of these experiments was not straightforward, as intervening in a live environment may be tricky from the viewpoint of the users and the operating engineers. Some faults were introduced during the day, others at night or weekends; some faults were conducted as hardware faults, and others as changed signals in BMS or software faults. All these faults validate the DBN: are the faults identified when present, and does the system not wrongly identify absent faults? (see Figure 5)

Most important in year 3 was constructing a real-time environment for the DBN of Air Handling Units (AHU). In this environment, the real-time data stream from the BMS of Building 28 is fed to a computer, in which the DBN analyses the faults (see DBN in Figure 6). For this prototype, many discussions were led about the meaning of real-time in a thermal context and in buildings where it normally takes weeks or even years to identify a fault. For this reason, it was decided that the prototype would be diagnosed at the day/week level.

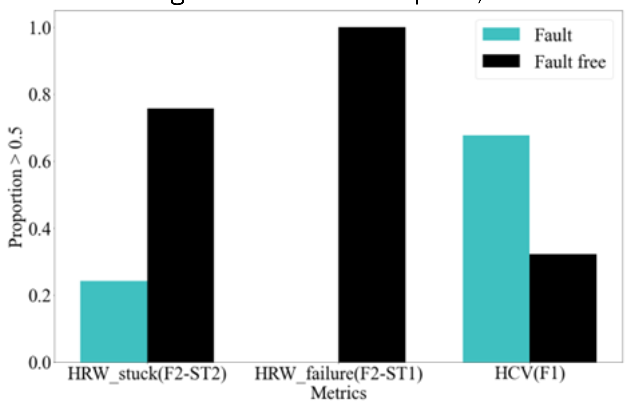


Figure 5: Example of results in Building 28

Finally, a start was made to extend the DBN from the AHU towards the complete HVAC system, including room level and its occupants and heating and cooling systems. In Building 28, the room is centrally controlled. A complete DBN for the system has been set up. A first analysis of the results relating to the experiments in Building 28 will be conducted in year 4.

Table 1: Example of conducted tests in the AHU

Case	Date	Time	Component	Induced Fault
1	08-03-2023	9:00-16:00	HRW	Stuck at 80%
2	27-02-2023	9:00-16:00	HRW	Stuck at 50%
3	09-11-2023	9:00-16:00	HRW	Stuck at 30%
4	08-11-2023	9:00-16:00	HRW	Stuck at 10%
5	22-03-2023	9:00-16:00	HRW	Failure
6	28-02-2023	9:00-16:00	HCV	Stuck at 10/40/100%
7	27-03-2023	9:00-16:00	HCV	Stuck at 75%

Case	Date	Time	Component	Induced Fault
8	02-02-2023	9:00-16:00	Normal	None

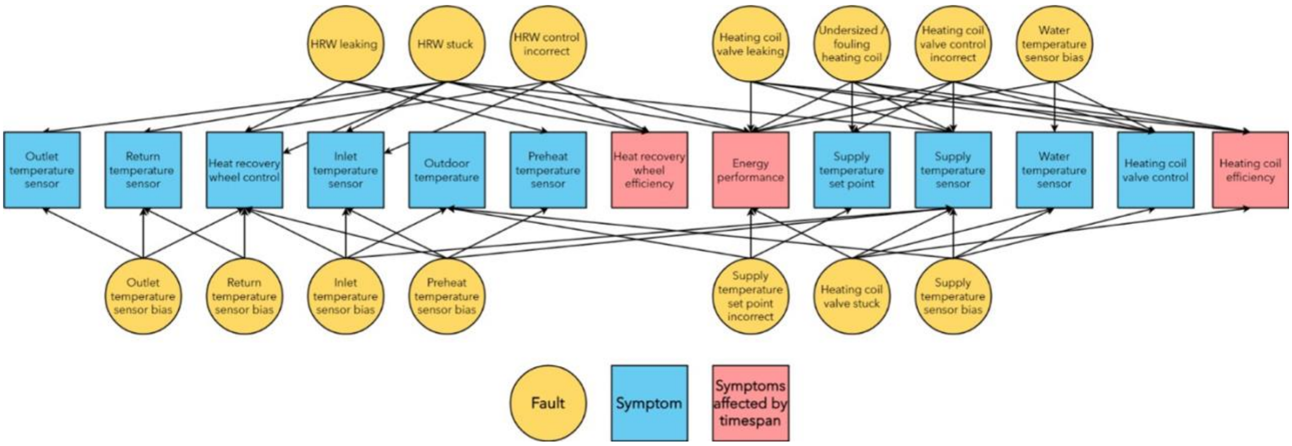


Figure 6: DBN of AHY Building 28 for real-time diagnose

Result 2: Prototypes of ML- and knowledge- based software plugs-ins for error detection, diagnosis & predictive condition-base maintenance

Activities in the past years focussed on the first experiments at Kropman Building, the development of a Pareto-lean approach to the impact of faults using data from SPIE, experiments by several partners with diverse types of sensors (like vibration ones), the use of virtual sensors and diverse modelling techniques, platforms and ML-algorithms. This has been continued by several partners during year 3. During year 3 even more experiments were conducted at Kropman building to test ML approaches to fault detection.

Research was conducted on KPIs for building performance in collaboration with IEA-EBC Annex81. More than 400 KPI's were found, meaning that there is a need for meta-KPIs. Research into this meta-KPI's will continue.

As a continuation of last-year results on Pareto-Lean approach, the fault prioritisation framework has been further developed, extended and tested, resulting in a combination of ML-Based and model-based faut detection algorithms (Figure 7). Detected faults result in a BMS alert. The methodology was tested in heating and cooling modes.

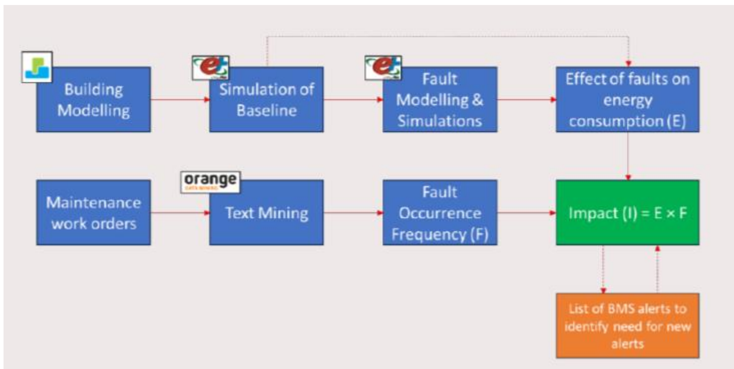


Figure 7: Fault prioritisation framework

A start was made to extend the DBN of the AHU with the room level and its occupants. In the Kropman building, the rooms are equipped with personalised indoor climate control at each workplace level. Experiments were conducted in the Kropman building, and the results were first analysed. An interesting result (see Figure 8) is that some AHU faults may contribute to *increased* comfort. (e.g. there is less draught).

Finally, SPIE conducted research on data-driven predictive maintenance. As heat pumps (and chillers) are becoming very current and critical to indoor comfort, they were chosen as a case study. The internal signals from sensors and controls in heat pumps are unavailable to the BMS, so 6 heat pumps on the Philips campus Best have been equipped with sensors. The data will be monitored and analysed during a measurement campaign of 6 months to discover specific patterns indicating degradation of components before failure. Before this, research on failure modes and their effects was carried out during year 3, and ways of determining degradation patterns were investigated (see Figure 9)

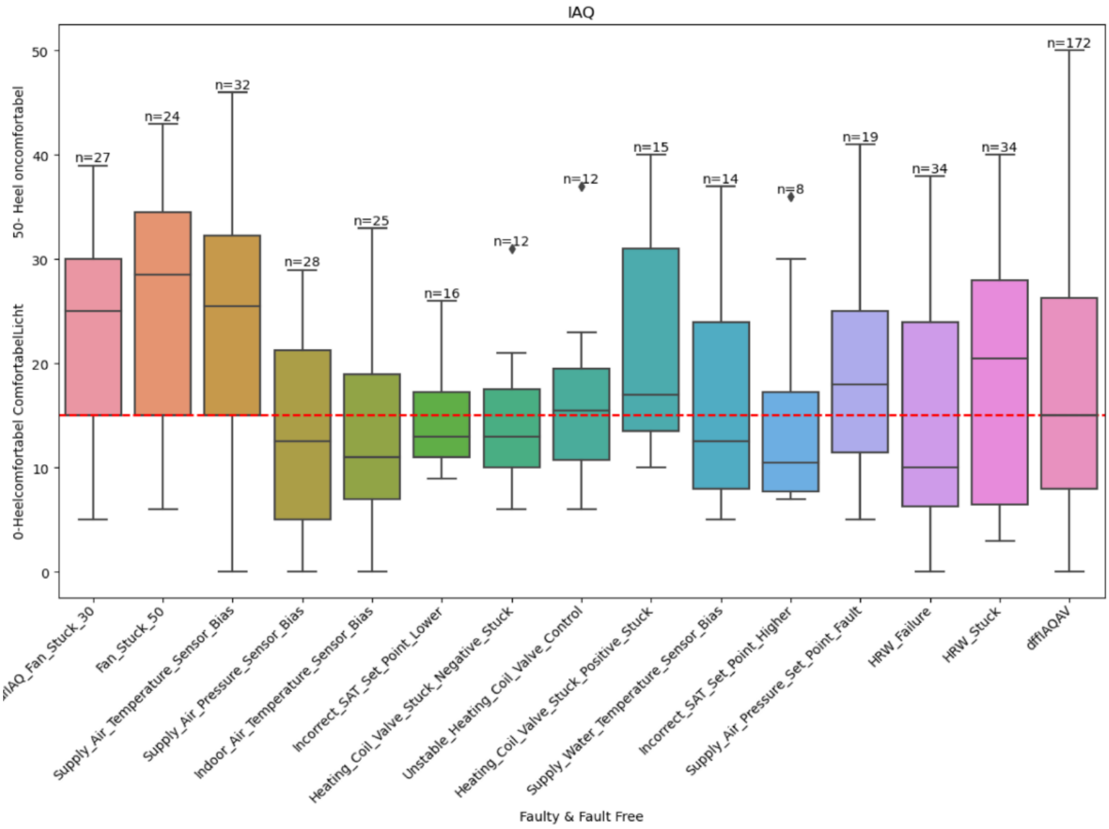


Figure 8: Effect of HVAC faults on thermal comfort

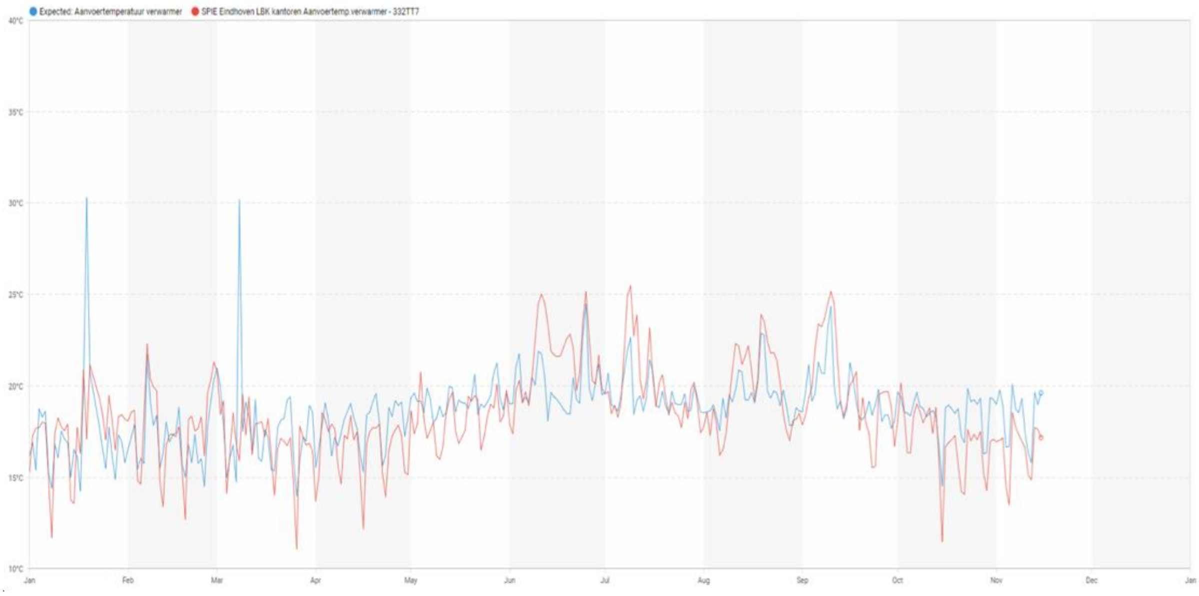


Figure 9 Example of failure detection

2.3 WP 2: Integrated energy flexibility and control

Result 3: Open-source HVAC & electrical installations model and algorithm for prediction of supply and demand energy.

HHS developed a method for energy flexibility assessment with static data. The results were presented at an international conference in Finland. The method uses the information on building construction and building services characteristics collected from the energy certification reports to generate a score of different energy flexibility KPIs and indicate what can be improved to increase energy flexibility. The method was tested with the information from the EPA-U reports from 3 buildings one case study of B4B and two from the portfolio of Rijksvastgoedbedrijf).

The method developed was improved with a proposal for energy flexibility building categorisation, replacing the scoring system used in the first version of the method. The improved method has been tested with a larger sample of Rijksvastgoedbedrijf's portfolio. The categorisation has also been used to define the most common building service configurations among the office buildings of Rijksvastgoedbedrijf.

Project partners finished developing and testing several models. These models will be used later to test the flexibility of buildings (thermal inertia, installations). Three models with different applications have been developed, tested and validated.

– TNO (Hybrid building model): Development of a physical-based component model for an air handling unit (including separate models for the fan, the heat recovery wheel, and the heating and cooling coil), for a chiller, induction units, and for PV supply. The model was applied for testing and calibration at the living lab TNO Stieltjesweg in Delft.

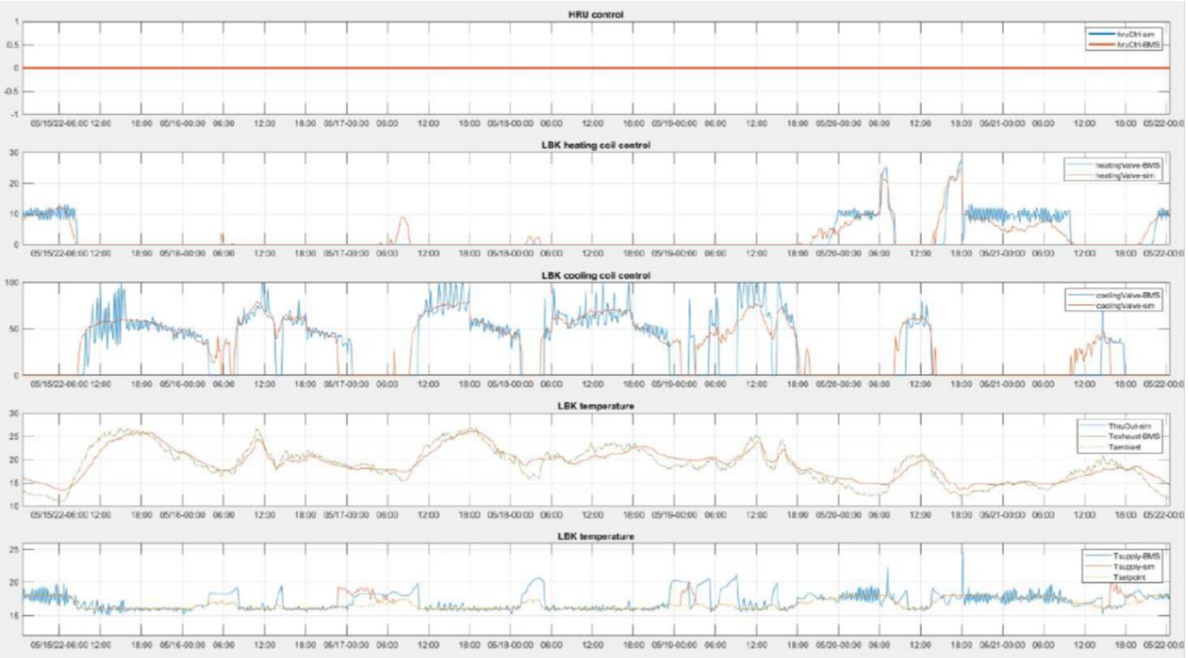


Figure 10: Simulated and measured results Sunday, May 15, up until May 21, 2022.

– HHS (Modelica building model with IBPSA libraries). The conference paper prepared the previous year about the method to assess energy flexibility using the open-source Modelica language was presented at an international conference in Finland (Dols et al., 2023). The test model of a simple residential house with a heat pump and ventilation system was created using the IBPSA library IDEAS. The open-source software OpenModelica was used to run the simulations. The paper proposes different visualisations for the presentation of the energy flexibility KPI's. In the next phase, a simplified version of the HHS case study building was modelled, using the IBPSA IDEAS library. The results of this attempt to simulate the HHS building with IBPSA libraries making use of OpenModelica showed that despite the great potential of this approach, the complexity of the model, the lack of documentation and the user-unfriendly debugging process made OpenModelica may not be the best choice. The current work of the HHS focuses on modelling the same building using EnergyPlus with the open-source software OpenStudio.

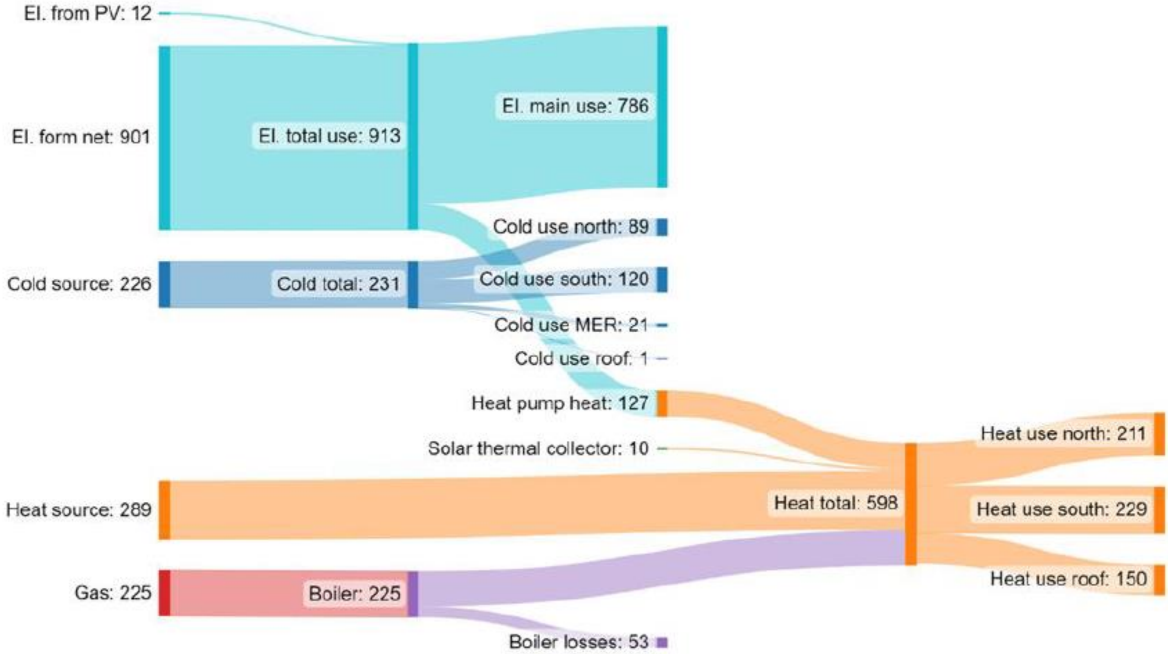


Figure 11: Energy flown in the HHS building in Delft (MWh)

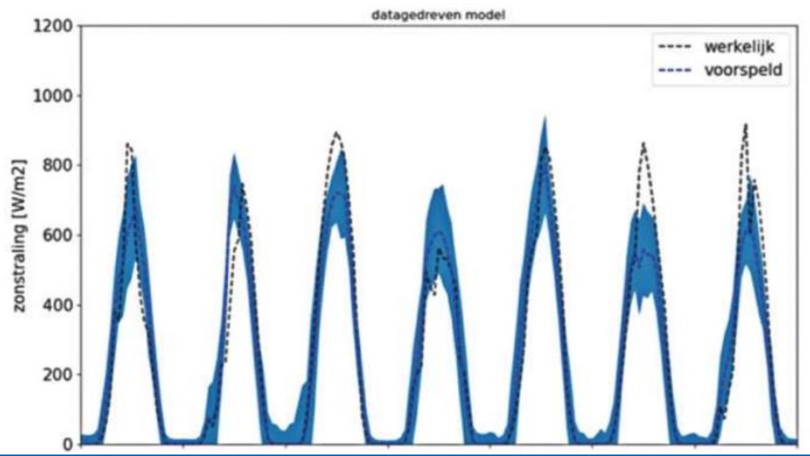
- Windesheim (Grey model relating to CO_2 and occupation) A grey box model to derive recent and current ventilation flow rate over time based on monitoring data on CO_2 concentration and occupancy, as well as deriving recent and current occupancy over time, based on monitoring data on CO_2 concentration and ventilation flow rate was developed. The model was created using data collected in 6 Windesheim University of Applied Sciences office rooms for 3 weeks during autumn 2022.
- DWA tested various black box models to predict the PV solar system that can be used to optimise the demand and supply to the grid in the context of net congestion. The models tested are based on the algorithms Random forest, Extra trees with the addition of Gradient Boosting and Artificial Neural Networks.
- O-Nexus worked on testing a white-box and a black-box model to predict the energy use of buildings. The aim is to apply this model to SME buildings, but because of the lack of SME energy building data to test the models, residential building energy data has been used.
- Peutz has also developed a black-box model that uses limited measurement data of temperature, humidity and air pressure to predict instantaneous and expected solar radiation. The prediction is possible because of the intrinsic links between these measured values and cloud cover. The model accuracy has also been increased by supplementing the input data with physical model data. The model's results to predict instantaneous and expected solar radiation have been published on a TVVL magazine article.
- 

Figure 12: The prediction of solar radiation.

Result 4: Methods and prototypes of AI-based software plug-in for flexible multi-object energy optimization

Work for this result focused on developing control and optimisation algorithms for assessing and exploiting the energy flexibility of buildings' thermal inertia. TU Delft developed a flexibility assessment and corresponding control design methods using building thermal mass and continuous control variables. Implemented in academic simulation studies assuming 2-stage demand response request architecture (see Figure 13).

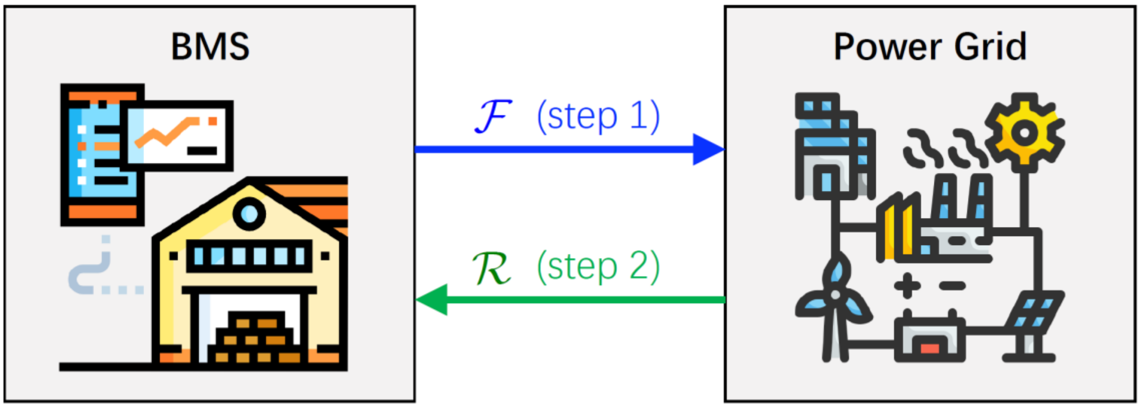


Figure 13: Two-stage demand response request architecture used for building energy flexibility assessment and exploitation via robust predictive control.

The goal is to shift energy usage in response to demand response (DR) requests based on quantitative robust flexibility assessment and predictive control while ensuring comfort constraints. The two-stage approach first calculates available energy-use flexibility based on forecasts and uncertainty representations. Then, the corresponding building control is realised in response to real-time demand-response requests. The developed flexibility management control approach (i.e., assessment and robust predictive control) was extended to binary (on/off) type control actions (e.g., heat pumps) in Figure 14.

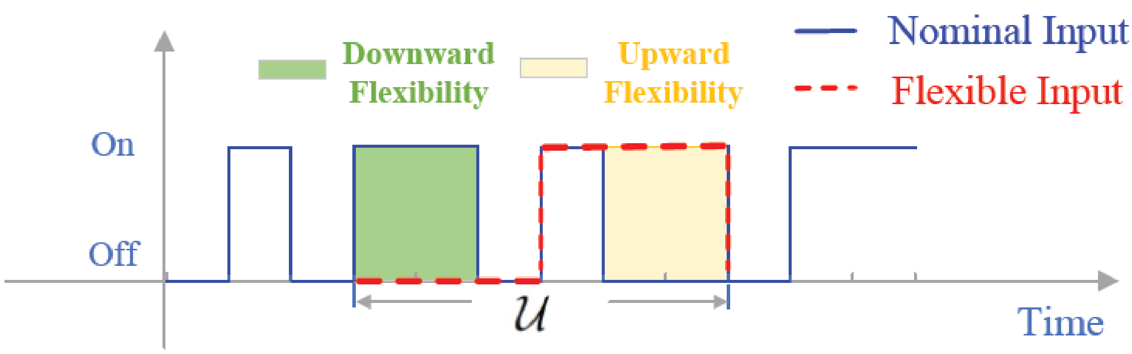


Figure 14: Flexibility control scheme for on/off type building equipment.

TU Delft developed and implemented a modelling approach and MPC controller for flexible and cost/energy-efficient domestic hot water supply in a Kropman use-case office building using heat pumps and thermal storage tanks in practice. This work involved control-oriented modelling of the heat pump and thermal storage tanks (see Figure 15), developing a hot water demand prediction model (SARIMA), and implementing a mixed-integer MPC solution to minimise energy costs and fulfil supply temperature and HP constraints. We observed energy savings in our experiments on the order of 6% and 10 % in terms of reduced consumption and costs, respectively. In addition, we demonstrated experimentally the system's energy use flexibility in response to artificial DR requests (see Figure 16).

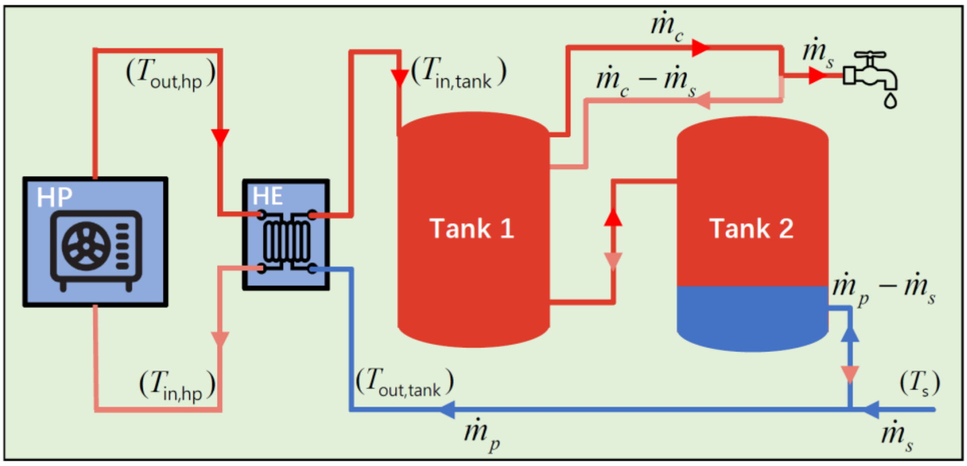


Figure 15: Schematic overview of the domestic hot water supply system in Kropman's use-case office building.

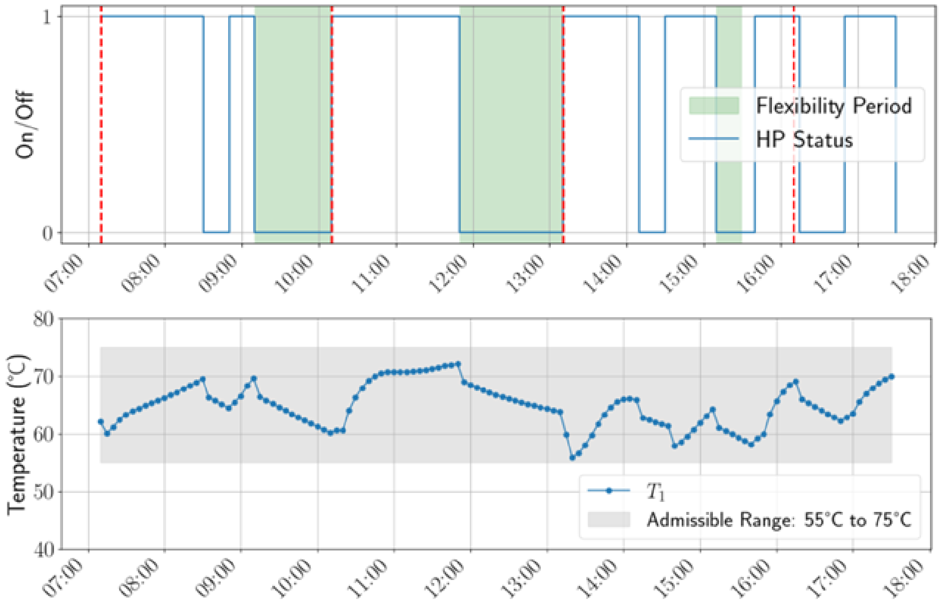


Figure 16: Experimental demonstration of shifting energy usage based on demand-response request.

Deerns is working on a proof of concept and adaptation of the data-driven predictive model developed during the IPIN project. This model depends on 2 variables: (1) outdoor air temperature and (2) indoor surface temperature. They developed two data-driven models (multilinear regression equation) that predicted the heating demand of the whole building 1 hour in advance. These models are based on the thermal balance of a building and are trained with a data set length of 2,5 months.

The next step is further. testing and validating a prototype software plug-in for flexible multi-objective energy optimisation. For this aim, the following use cases and living labs are in place:

- Pulse Building (TUD campus): The objective is to test automatic energy-flexible indoor climate control for selected rooms. The API is now ready for Initial testing of functionalities
- HHS Building Objective is to set up a similar experiment as in the Pulse building.
- Stieltjesweg Building (TNO): The objective is to perform a comparative study of different MPC approaches in a simulated environment.
- De Garage (The Green Village) by O-Nexis & Deerns. The objective is to test and improve the optimization/control algorithm developed by O-Nexus & validate Deerns predictive model. The test has been in place since November 2023. The first phase (approx. 2 months) included a zero-measurement, where the energy behaviour of the building is measured. After that, steering technology will be released (see Figure 17).

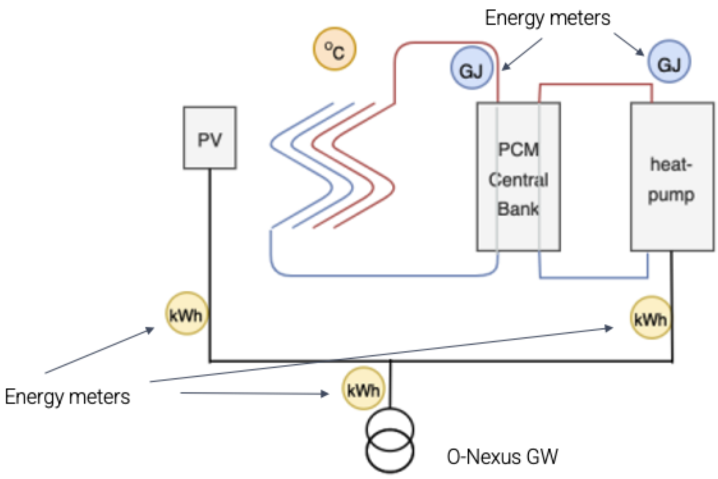


Figure 17: Test set-up of O-Nexus at The Green Village

2.4 WP 3: Smart user-targeted interfaces and feedback

Result 5: Methodology & data for user-centered approach in smart building control

Research in year 3 by TUe, UNICA and HHS focused on collecting self-reporting comfort data. A mobile app and a smartwatch application were developed to obtain self-reporting data from the building's occupants.

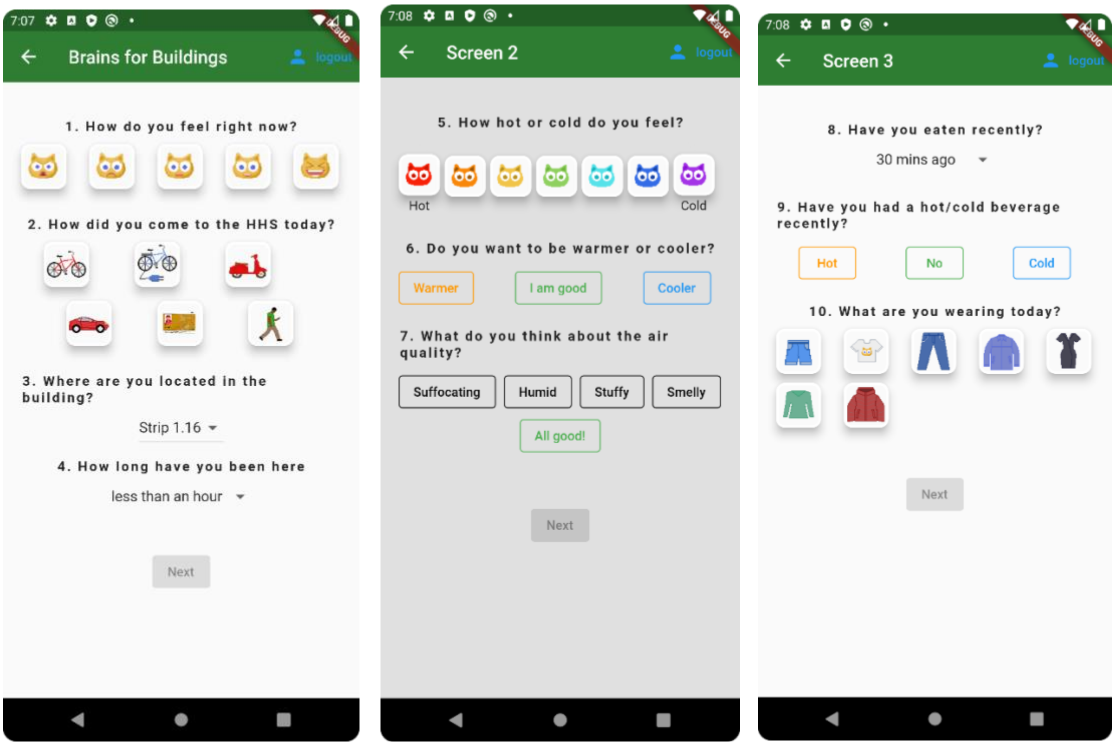


Figure 18: Screenshots of the mobile comfort App.

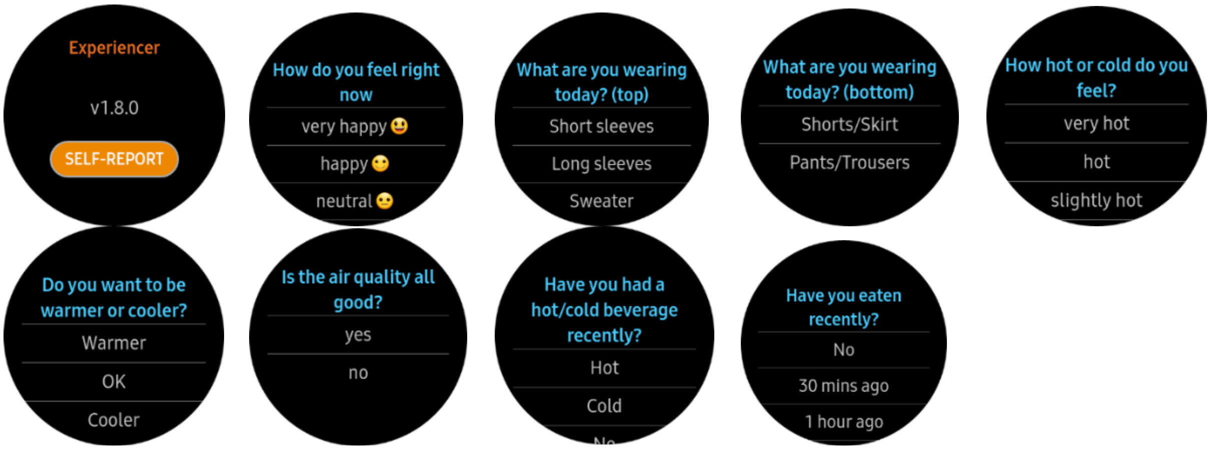


Figure 19: Screenshots of the smartwatch application

Data gathering was intended to develop personalised thermal comfort models using self-reporting data that are more accurate than the existing models, such as the PMV or the adaptive model. The thermal comfort model can be used to determine and predict the comfort of occupants in the building. The model can also be integrated into FDD systems using 'complaint data' as indicators of faults in the building. The research was conducted in the HHS living lab in The Hague together with Unica. The personalised thermal comfort model based on self-reporting data was more accurate in predicting thermal comfort than the PMV or the adaptive model.

A method was developed to understand the variables affecting thermal energy. This approach allows us to determine what variables have more influence on thermal comfort, therefore allowing for more flexible indoor conditions in buildings to support building flexibility. Based on explainable AI, the method was tested using data collected at the HHS living lab in The Hague.

The user aspect of energy flexibility was investigated as a problem at the Philips Campus. We investigated if there is room to minimise cooling needs through behavioural change (on the one hand, by operating the facilities differently and, on the other, by changing behaviour such as working from home or clothing choices). One of the recommendations was to improve the interaction between end-users and the climate systems by providing more clear information on the systems' functionalities and how the systems' interfaces can be used better.

Result 6: Prototypes of user-oriented interfaces for healthy indoor climate, energy-efficient and energy flexibility of the building.

Various partners have been working on the redesign of interfaces:

- Spectral: Prepare their systems to allow for new client (mobile apps iOS and Android) integrations and scale from current data streams to newer data requirements.
- HAN/Spectal: Redesign their interface. An interactive prototype is developed based on the earlier requirements resulting from this WP.
- TNO/Philips: Improve existing interfaces at the Philip Campus as part of the solution for the flexibility problem. While studying the user aspect of the flexibility issues, it became clear that the systems were not always used effectively due to usability problems. The objective of the further study is to improve the communication of the interfaces to the end-users.
- TUD/Office Vitae: Development of Office Vitae interfaces in the Green Village in Delft. This work involves an outdoor digital voting box, an indoor comfort survey and sensor measurements for comfort and light spectrum.
- TUe: Develop a self-reporting app to collect comfort data from building occupants.

2.5 WP 4: Data integration for smart communication

Result 7: Standardised methodology for secure and ethical access to and use of data.

This result was already finished in year 2.

Result 8: Linked data at systemic level, leading to system integration via APIs

A reference software architecture was developed in year two, including initial data flow procedures (see Figure 20). This year, this system architecture and several data flow procedures (data transfer and exchange) were implemented and tested in the project's living labs, with different success levels. Implementations were performed in the following Living Labs primarily:

– Atlas Living Lab
– TU Delft Building 33
– Kropman Living Lab

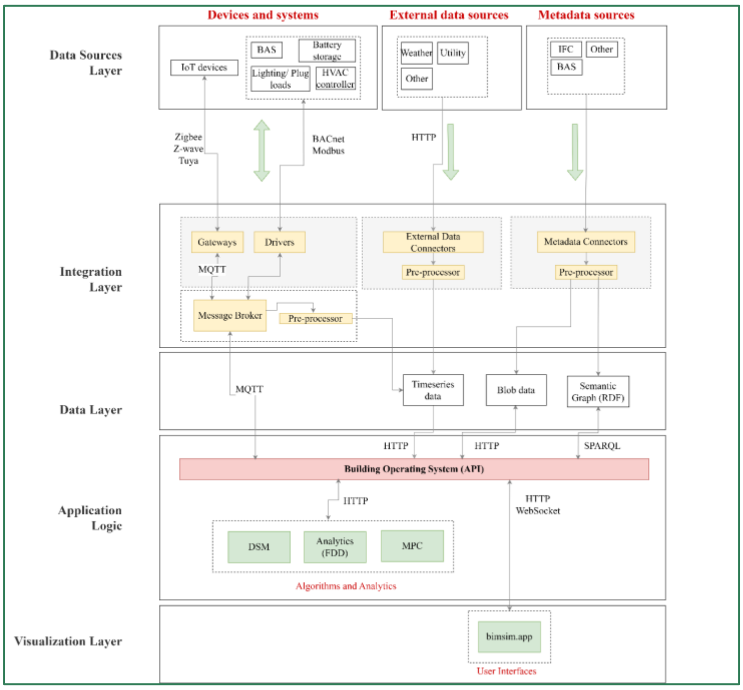


Figure 20: Reference architecture for smart buildings.

Two main experiments have been performed

– #GenerateMyMetadataSchema experiment (TUD and TUe Living Labs). In this experiment, we investigated how a metadata schema can be built for any building to advance it to become a smart building. Such metadata schemas are important as they provide much contextual data (which devices are located, where, and what they measure). This leads to a 5-step procedure to create a BRICK- and LBD-based data set starting from data acquired from a BMS provider (e.g. Honeywell, Johnson Control). This has been tested successfully for TU Delft and TU Eindhoven cases. It proved more difficult to make this #GenerateMyMetadataSchema generally applicable since each building typically has its own BMS provider and, even more so also, very different naming conventions (see Figure 21). Nevertheless, a stepwise procedure and open transformation code are available and have been used

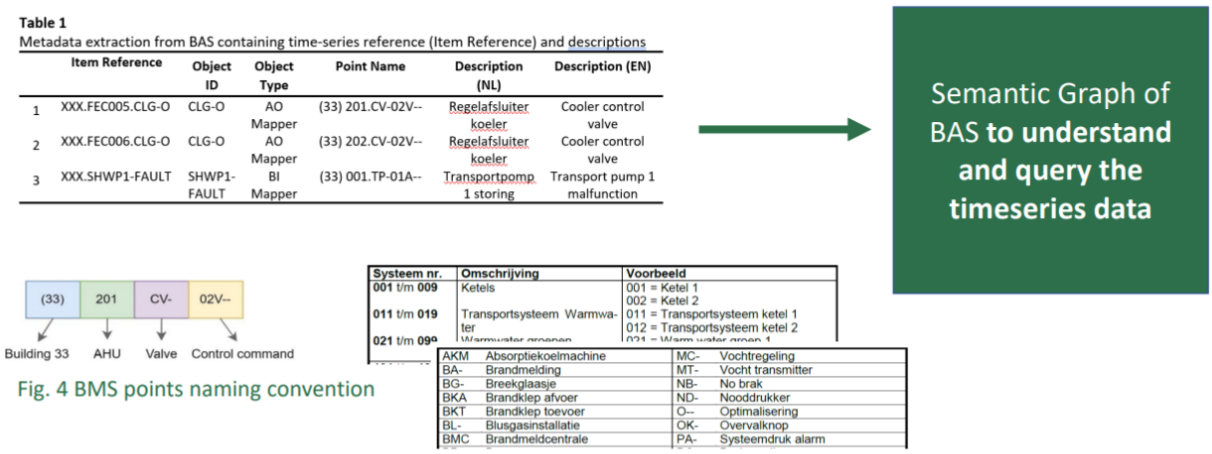


Figure 21: Identifiers in Johnson Control Manual

– #RealTimeDataAccess experiment (Kropman Living Lab): This experiment investigated to what extent data can be tracked in real-time using the available system architecture and subsequently intervene in the building (Model-Predictive Control – MPC). This is tested using the systems of the Kropman building, which is one of the only buildings where access to the control API and domain expertise (engineering) are available. For this test, energy flexibility was targeted, in which energy use is monitored for both the building (HVAC system) and its car park (EV-charging stations). Depending on demand and supply, energy use is controlled and optimized.

The above tests and the reference software architecture have also been taken as examples in other living labs, e.g., Haagse Hogeschool.

Furthermore, a draft "Roadmap for leveraging Smart Buildings: A practical roadmap for achieving asset management goals through data-driven building solutions" has been produced. This roadmap is a guide that should help any relevant stakeholder in the Netherlands to get started with data-driven smart building technology and includes results and findings from the B4B consortium members working within the various work packages (see Figure 22)

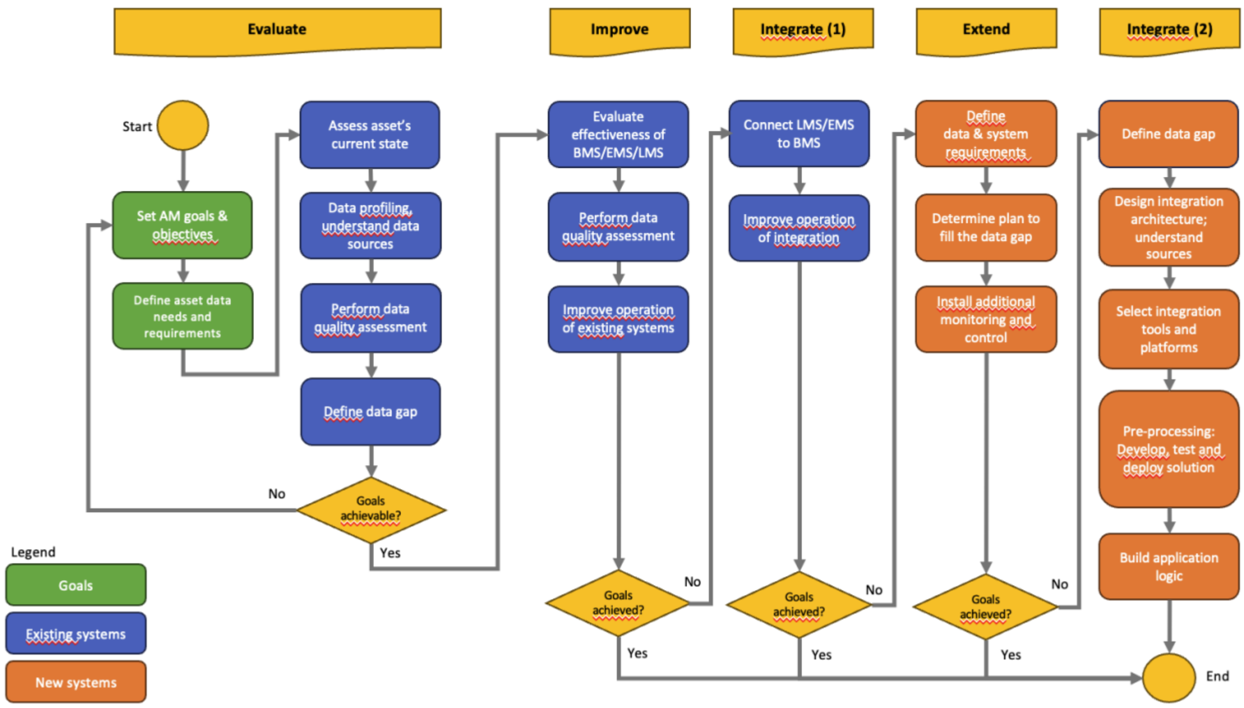


Figure 22: Screenshot of the draft outline for Roadmap for leveraging Smart Buildings: A practical roadmap for achieving asset management goals through data-driven building solutions

Result 9: Standardized methodologies & guidelines for determining and transforming into 'smart readiness'

Deliverable D4.04: Guidelines to make every building "smart", incl. specification of the Smart Readiness Indicator, have been delivered in year 2. Work on this result in year 3 included:

- Deerns continued working on the Smart Building Assessment procedure internally
- Evaluation of how the B4B project works on smart building assessment relates to the Smart Readiness Indicator (SRI). This indicated that the calculation procedure for the SRI score has not been considered in the European Commission's final recommendations, and this procedure is left open to the individual European member states.
- W-E Adviseurs has initiated the implementation of the Smart Readiness Indicator (unofficial calculation procedure) in their software GPR Gebouw.

Standardization activities and opportunities have been listed from the start of the project. This has led to a list of standards (NEN, CEN, ISO, CENELEC) in different categories related to the project and the overall topic of smart buildings: Smart Buildings, IT, Real Estate, Systems, and Smart Cities.

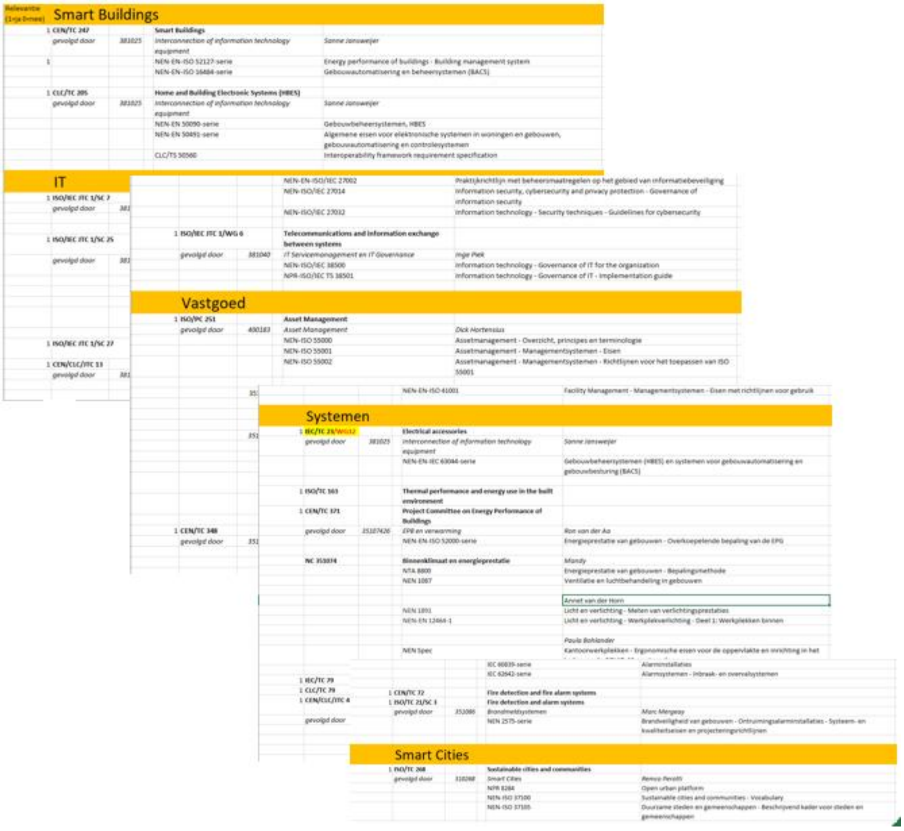


Figure 23: Screenshot of available standards relevant to the development of smart buildings.

While it was hoped that the B4B project could contribute to developing and evaluating the Smart Readiness Indicator, this proved impossible due to the current uncertain state of this standard in ongoing European standardisation efforts. Furthermore, the number of available standards for the smart buildings sector proved very significant, with many details in several directions. Most of these standards are unclear to the people involved with smart buildings. It was, therefore, decided to list available standards to a comprehensible degree, such that anyone working with or aiming for a smart building can find the standards that he or she needs.

2.6 WP 5: Learning Community

Result 10: Learning community "Smart buildings"

Building the learning community

We had another 2 consortium meetings in which consortium partners met (attendance between 60-70 participants) to discuss progress within the project. Various workshops were organised to exchange ideas further and develop good practices on specific topics.

We continued with our monthly online Brains4Buildings webinars, which are open to all people interested in smart buildings (inside and outside of the consortium). In these one-hour webinars, we delve deeper into a specific topic.

We organised an online symposium with IEA Annex 81, “Data-driven Smart buildings,” on “Scaling adoption of Automated Operational Intelligence for Energy Productivity in Smart building”. The session included presentations and panel discussions with partners involved in the IEA Annex 81 task and the Brains 4 Buildings project. About 100 people participated in this event.

Through these activities, presentations at seminars and conferences, and our presence on LinkedIn, we gradually built a broader (international) learning community and an online repository of “smart building” topics. The full list of webinar slides and recordings can be found on our website.

Building knowledge platforms/websites

TU Delft knowledge platform developed by TU Delft was further filled with information for different target groups. The platform is targeted at:

– Data scientists who want to learn about energy, HVAC, and control technology.
– Energy, HVAC, and control engineers who want to learn about data science.

This platform must evolve into a repository with information for different target groups. The platform is currently under internal review. Next, the platform will be opened to a broader public and integrated with other learning community activities, including a handbook for data integration and the knowledge website developed by the DGBC.

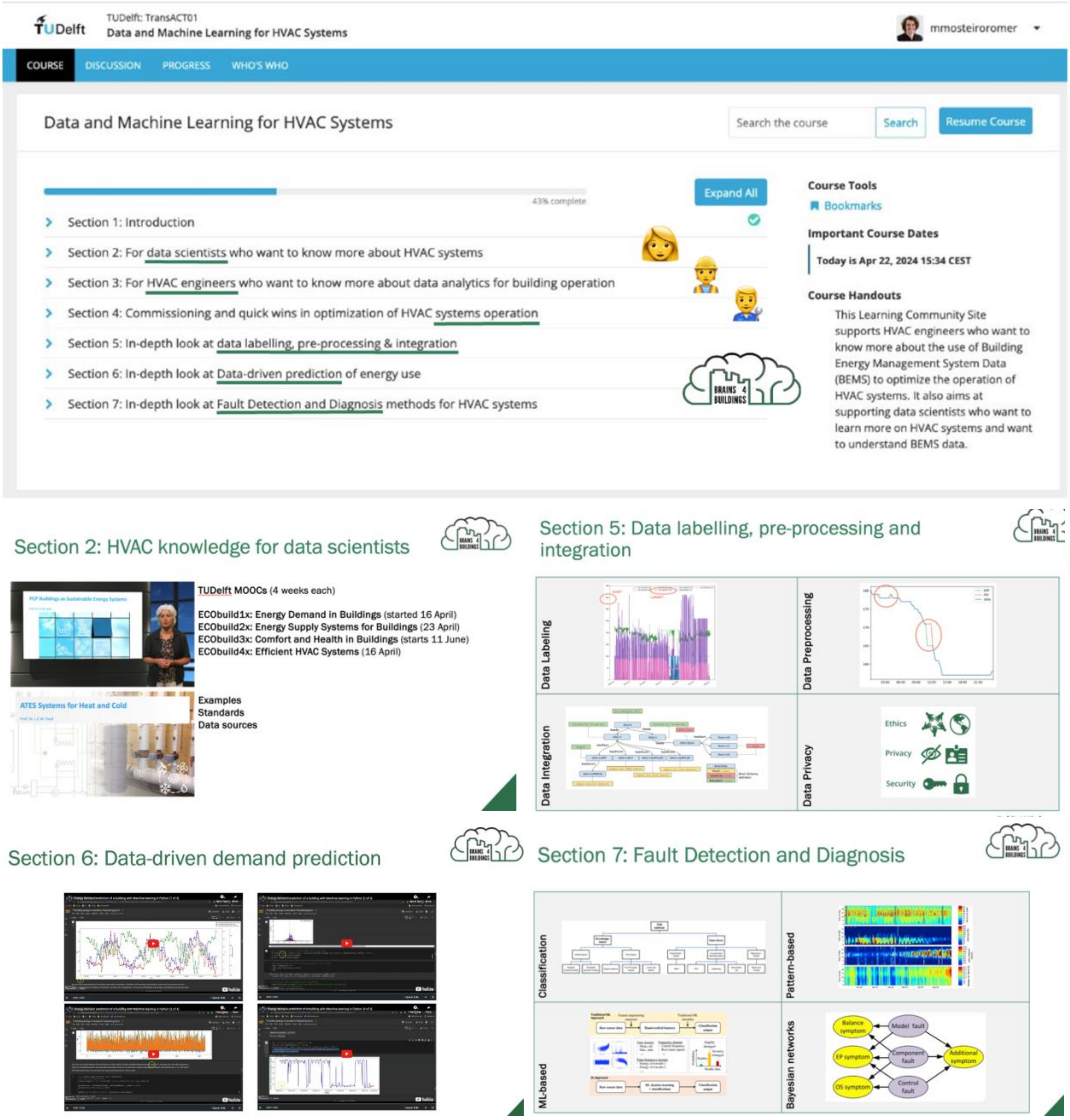


Figure 24: Screenshot of the knowledge platform.

The DGBC is developing a knowledge platform that will be part of the DGBC website. Through this platform, the DGBC will make B4B knowledge available, accessible, and applicable to the market and will ensure that knowledge on smart buildings is shared and updated after the B4B project is finished. The platform will include:

– Library: easy and accessible information linked to other sources
– Toolbox for CO2 reduction
– Knowledge Platform

– Learning tracks for different target groups

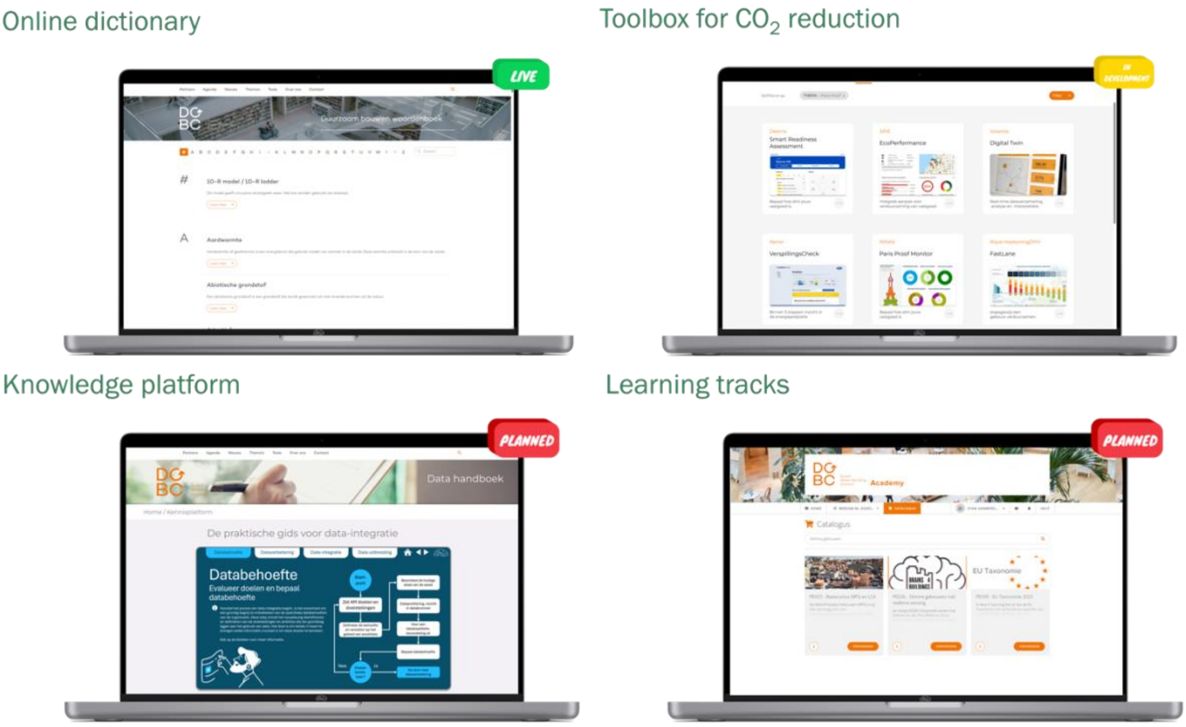


Figure 25: Screenshot of the website to be developed by the DGBC

3 OTHER ISSUES

3.1 Contribution to objectives of the MOOI scheme

The B4B project contributes to realising the objectives of the MOOI theme 'built environment' by developing smart integrated user-friendly prototypes of affordable, modular, and scalable software plug-ins for utility buildings. These software plug-ins will be ready for further upscaling to the market in 2025 and will lead to:

(1) Less energy is wasted in installations' heating and cooling supply and the related CO_2 emissions. According to ECN (2016) the average energy consumption in office buildings is

- 17m ^{3} gas/m^2 and 60 kWh electricity/m^2.
- 1 m^3 of gas produces 1.89 kg of CO_2 emissions, 1 kWh of generated electricity produces 0.649 kg of CO_2
- Assuming 25% energy savings through smart controls and plug-ins saves 4.25 m^3 of gas and 15 kWh of electricity per m^2.
- This sums up to a total CO_2 reduction of 1.89x4.25+15x0.649=18 kg CO_2/m^2

With 24 million square meters of offices equipped with a BMS system (offices of more than 5000 m^2), the potential for CO_2 reduction is 0.4 million tonnes of CO_2 per year, equalling 5.7% of the total reduction required for the built environment. We still need to consider that part of the 23 million square meters of smaller offices will also need to switch to a BMS. In addition, there is also great potential in educational buildings, hospitals, shops, etc. The Netherlands has 460 million non-residential buildings (Climate Agreement, 2018). If these buildings have the same energy consumption per m^2 and 52% are equipped with a smart plug-in, then 4 million tonnes of CO_2 are saved in one go. That is more than half of the government's targets for the built environment. This highlights the enormous importance of BMS data-based energy diagnostic methods and plug-ins. This CO_2 reduction is obtained with very low investments per square meter (4EUR/m^2)

(2) Increase in end-user comfort, indoor air quality and user-friendliness of decentralised control systems. Ultimately, every technical solution stands or falls with its acceptance and correct use by the end user. Until now, it has rarely been included in research into fault diagnosis and control strategy, so the connection with user experience and acceptance by users is completely missing. Including it will, in addition to additional energy savings, lead to wider acceptance of smart control systems.

(3) Greater controllable energy flexibility that increases the use of self-produced renewable energy for heating and cooling and reduces system costs for transforming the built environment by 20-40%. By smart storage capacity management, local sustainable energy production can be increased by 40-50% (and fossil sources are reduced proportionally). A 90-95% increase is also mentioned, but the costs are still very high. This applies equally to photovoltaic cells and to storage in the ground in combination with geothermal energy. Assuming a modest OEM (Onsite Energy Matching) value of 40%, building self-consumption of approximately 15% is now increased to 40%. This means 25% less use of the grid by utilising the adjustable energy flexibility; high investments in grid reinforcement can be prevented or postponed.

3.2 Spin-off inside and outside the sector

We envision the following spin-off for the various stakeholders:

Building end-users:

- Improved user interfaces (WP3) will give building managers, tenants, and end-users a better understanding of how their building systems work, thereby increasing acceptance and confidence in using innovative solutions such as smart building control. The user interfaces provide improved decentralised control options to the end-user without sacrificing energy efficiency in the building.
- Smart Diagnostic Systems (WP1) will have a major role in ensuring comfort and indoor air quality. Indoor air quality is not visible, and the link with user-oriented interfaces will help to make this visible, thus improving the acceptance of the underlying controls, thus guaranteeing a healthier environment.

Building managers/building owners

- In general, what is of value to the end user is also of value to administrators and owners, if only because the number of complaints is greatly reduced. In the daily practice of building managers, much time is spent on solving indoor climate complaints, which costs money. Building managers and owners must invest in building management systems (BMS) for energy efficiency. This will be mandatory for almost all buildings of more than 5000 m^2 (power greater than 290 kW). By default, a BMS is usually not equipped with energy functionality. With the smart software plug-ins that are developed in B4B, much energy can be saved on an annual basis. However, this is only a small part of the story because the building owners/managers also have other interests in increasing the value of the smart plug-in (they have long known that their energy bill is negligible compared to other expenses such as salaries, maintenance, insurance, cleaning, etc.), because this will also:

- Reduce indoor environmental and comfort complaints; handling these costs takes much time for the administrator and facility manager.
- Reduce failure costs by getting a timely warning if a component is about to break or the energy control is not optimal.
- Reduce lost time by figuring out the origin of a problem in the installations or in the indoor climate.
- Enable planning of maintenance activities and management of energy bills on time.
- Enable monitoring of sustainability goals: Many owners and managers would like to achieve sustainability goals and can use the plug-in to aim for CO_2 reduction.
- Optimise building use and flexibility: by providing insight into the occupancy per room, for example, the thermostat and ventilation settings can be adjusted accordingly, resulting in energy savings.
- Building managers often wish to provide better insight into the operational aspects of complex installations.

Maintenance companies

- Maintenance companies that do remote management will also want to purchase the B4B products and use them in their new and current maintenance contracts. These products will allow them to monitor performance contracts and schedule maintenance work more efficiently and well ahead of time, thus generating a profit.
- The active participation of many of these stakeholders in all B4B meetings in the different work packages and exchanging ideas give us good faith that such a spin-off will be realised during the B4B project.

3.3 Publications and dissemination activities

Project deliverables in year 3

Del. No	Title
D2.01 |D2.02| D2.03	Report on modular energy model of the HVAC and electrical system, open-source energy demand and energy supply forecasting methods and algorithms including accuracy of predictions
D3.05	Comfort and occupancy data for Fault Detection and Diagnosis

Publications

Date	Title	Publisher
September 2023	Hicham Johra, Han Li, Flavia de Andrade Pereira, Kingsley Nweye, Lasitha Chamari, Zoltan Nagy (2023) IEA EBC Annex 81 – Data-driven smart buildings: Building-to-grid applications	IEA EBC Annex 81 – Data-driven smart buildings: Building-to-grid applications. 4-6 September Shanghai
October 2023	Lasitha Chamari; Ekaterina Petrova; Pieter Pauwels (2023). An End-to-End Implementation of a Service-Oriented Architecture for Data-Driven Smart Buildings	IEEE Access, Volume 11
July 2023	Yun Li, N Yorke-Smith, Tams Keviczky (2023) Robust Optimal Control with Inexact State Measurements and Adjustable Uncertainty Sets. IFAC-Papers Online	Proceedings of the 22nd IFAC World Congress, Yokohama, Japan, July 2023
December 2023	Yun Li, N Yorke-Smith, Tams Keviczky (2023) Unlocking Energy Flexibility From Thermal Inertia of Buildings: A Robust Optimization Approach	62nd IEEE Conference on Decision and Control (CDC 2023), Singapore, December 13-15, 2023, pp. 2555-2562.
June 2023	Srinivasan Gopalan, Hailin Zheng, Shalika S.W. Walker, Rick P. Kramer, Wim Zeiler (2023) Evaluation of the	Proceedings of Healthy Buildings 2023 Europe

Date	Title	Publisher
	performance of low-cost monitors for their use in fault detection and diagnosis	
June 2023	Karzan Mohammed, Vinayak Krishnan, Hailin Zheng, Shalika Walker, Rick Kramer, Wim Zeiler (2023) Low cost-effective measurements for schools	Proceedings of Healthy Buildings 2023 Europe
June 2023	Boogaard, Stefan, Cheung, Dave and Salcedo-Rahola, Tadeo-Baldiri (2023) "Building Energy Flexibility Assessment with Static Data."	2023 International Conference on Future Energy Solutions (FES), IEEE, 2023, pp. 1–4,
June 2023	Dols, Isa, and Salcedo-Rahola, Tadeo-Baldiri (2023) "From Energy Flexibility to Design Choice."	2023 International Conference on Future Energy Solutions (FES), IEEE, 2023, pp. 1–6
2024/2/1	Robbert Jan Dikken (Peutz) Lokale zonvoorspelling met hybrid AI op basis van beperkte weerdata	TVVL Magazine

Media

Date	Title	Title of journal, website etc.
2023/2/1	Brains4Buildings: Slimme, data-gedreven gebouwen (Martijn Kruijsse | HHS)	TVVL Magazine
2023/09/26	Brains4Buildings: Unlocking Flexibility with Near Real-time Buildings Models (Wouter Borsboom | TNO)	Flexcon 2023, Brussels
2023/10/1	Data security en privacy in smart buildings: "Mensen zijn de zwakste schakel" (Interview met Elena Chochanova en Tousif Rahman van TNO)	FHI Nieuwsbrief
2023/10/5	Want to make buildings more sustainable? Give them a brain!	Innovation Origins
2023/10/24	Slimme gebouwen helpen ons betere beslissingen te nemen (Interview met Karthik Gunderi | Deerns)	FHI Website
2023/11/8	Hoe met AI stappen maken in de Energiestransitie (Interview met Stefan Hoekstra en Joep van der Weijden van The Green Village)	FHI website

Presentations

Date	Presentor | Title	Event
2023/04/18	B4B Webinar #12: Dat Security (Johan de Wit | Siemens)	B4B webinar series
2023/06/14	B4B Webinar #13: Optimizing energy consumption and increasing energy flexibility of a nearly transparent building using MPC (Naveen Rajappa | TU Delft)	B4B webinar series
2023/09/19	Presentation by Shalika Walker	TVVL dag
2023/10/05	Huiskamer sessies B4B Smart Buildings with presentation by – Je GBS uit handen geven aan AI? Geen haar op mijn hoofd die daaraan denkt! (Stefan Hoeksta | The Green Village) – Gebruiker en gebouw als gelijkwaardige partners? Vera Lange / Wouter Sluis-Thiescheffer (HAN) – Fault Detection and Diagnosis (#FDD): wanneer is dit zinvol en waar is de business case? Laure Itard (TUD)	Smart Buildings Event (Building G 100)
2023/10/19	B4B Webinar #14: Reference Architecture (Lasitha Chamari | TU/e)	B4B webinar series
2023/11/15	"Brains for buildings Energy Systems" Joep van de Weijden en Stefan Hoekstra (The Green Village)	FHI Digitaal Gebouw van de Toekomst
2024/01/18	B4B Webinar #15: Fault experiments to generate data from living laboratory (Karzan Mohammed & Srinivasan Gopalan | TU/e)	B4B webinar series

Date	Presentor | Title	Event
2024/01/25	B4B Webinar #16: Harnessing UDMI Methodology to making buildings smarter (Ged Tyrell, Susan Gibson, Thomas Hynes | Tyrrell Building Technology)	B4B webinar series
2024/02/28	IEA Annex 81 | B4B online webinar "Scaling Adoption of Operational Intelligence to Energy Productivity in Smart Buildings"	B4B webinar series
2024/03/08	"From connected to Automated Buildings" Pieter Pauwels (TUe)	REHVA Expert Talks at Lighting Buildings