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PREFACE

This is the second 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 concisely overviews our activities and results in the second year. For more information, visit our website or contact us at contact@brains4buildings.org.

Utrecht, May 25, 2023.

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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 environment 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.

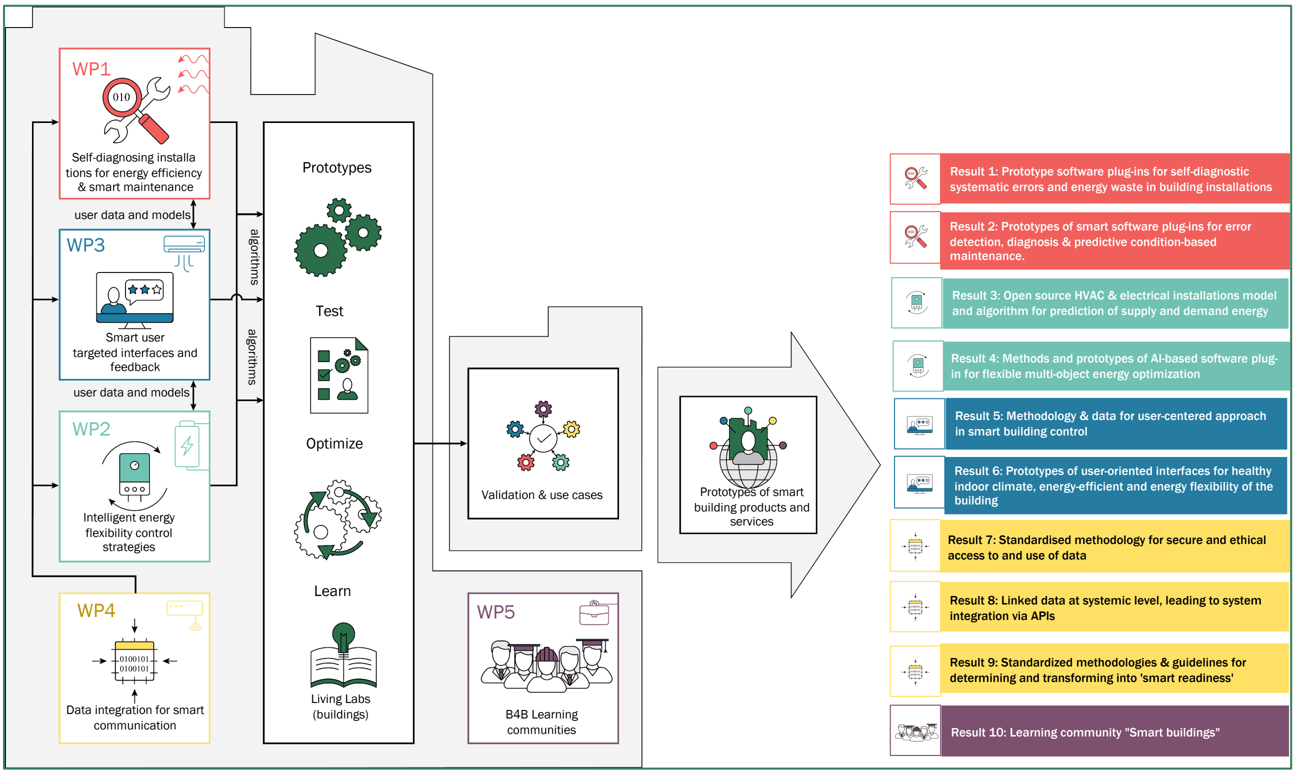

Figure 2: Five work packages organised around livings labs & use/validation cases leading to 10 tangible results.

- 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, to energy-flexible buildings and to 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, which means that it is not only about cost optimisation but also aimed at optimising 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 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 and 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.

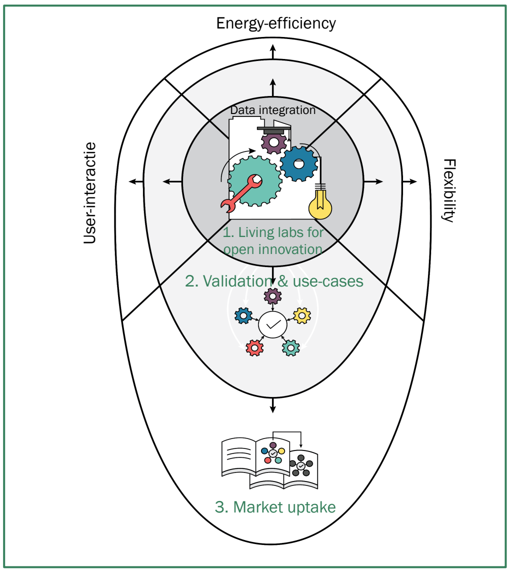

Figure 3: Collaboration around three circles: living labs (circle 1), use & validation cases (circle 2) & potential users & market parties (circle 3).

1.5 Project partners

Figure 4: Overview of project partners

2 ACTIVITIES AND RESULTS FOR YEAR 2

2.1 Summary of highlights in Year 2

The project activities are organised around living labs. These are education and office buildings currently in use for which historical and current data are available and can be used for small-scale testing to collect data for further development of methods and algorithms. Figure 5 provides an overview of the buildings used as living labs and the tests already executed or planned for the coming period.

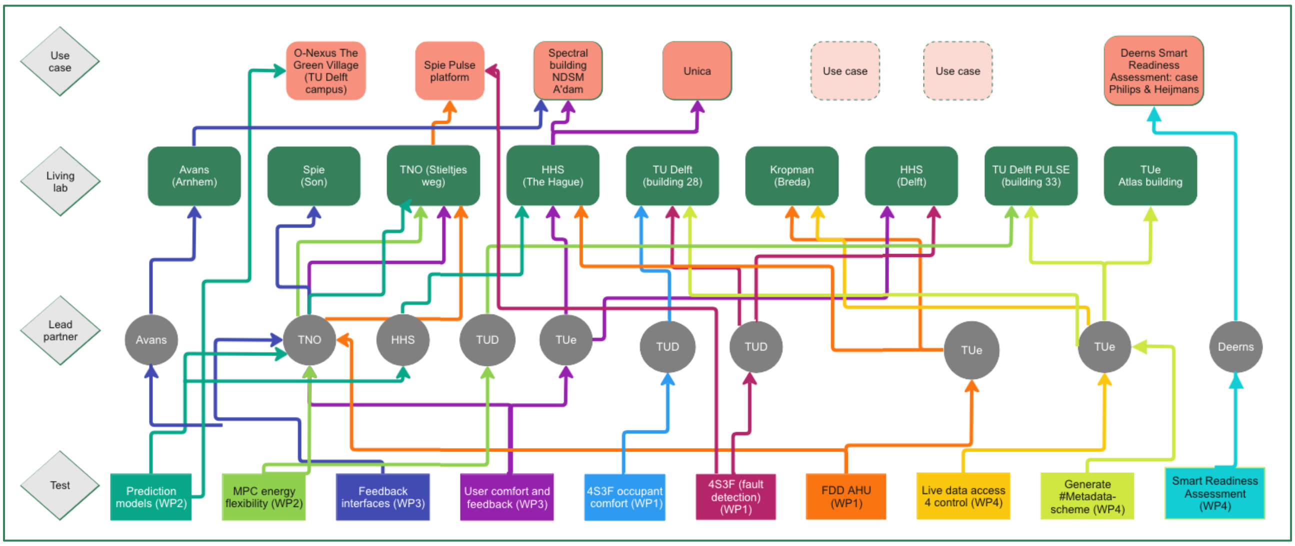

Figure 5: Overview tests executed and planned in the living labs and the identified use- and validation cases.

The activities around these living labs and use cases have already resulted in the first proofs-of-concept of systems and methods that will be further validated and developed in the project's second half. This includes a first proof-of-concept of an automated diagnostic system for fault detection and diagnosis in building installations, a smart readiness assessment tool, a comprehensive framework for asset owners and other stakeholders to set up robust digital strategies and a #GenerateMyMetaDataScheme 5-step procedure to create a BRICK schema starting from data sets from a BMS provider.

The activities in the second year also provided valuable insights for delineating prototyping development in years 3 and 4 of the projects. This includes insights on positions and spatial granularity of sensing networks enabling the detection of the most important faults and most useful methods to increase user-centeredness in buildings.

A large amount of valuable monitoring data was gathered and analysed, which is the key starting point for further developing proofs-of-concept of methods and software plug-ins in years 3 and 4. In parallel, use- and validation cases were defined (and more will be defined in the next year) in which industry partners will test these proofs-of-concept for their scale-up potential.

Broader awareness of smart buildings has occurred through various presentations, publications and media outlets. Furthermore, advocacy on the topic by the DGBC through www.platformduurzamehuisvesting.nl and De Gideons www.gideonstribe.nl raised awareness on the topic with companies and politicians. Together with TVVL, DGBC has ensured transparency and clarity concerning one of the preconditions for smart buildings, namely by developing a protocol on how to measure the actual energy consumption of a building (See www.weii.nl).

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

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

Activities in year 2 focussed on further developing, extending, and implementing the 4S3F method in the living labs building 28 at TU Delft campus, the Kropman building and testing a first simple DBN (Diagnostic Bayesian Network) model for air handling units (AHU) for implementation in the Pulse platform of Spie.

Experiences with these tests revealed that diagnostic models must include knowledge of HVAC systems; relying solely on Machine Learning (Black box) approaches is impossible. This shows the importance/relevance of applying the 4S3F method and developing DBN models. Experiments resulted in a first proof-of-concept of an automated diagnostic system for fault detection and diagnosis in Air Handling Units for further testing and validation in other buildings in the coming period. The proof-of-concept is a good starting point for the scalable software plug-ins we want to deliver by the end of the project.

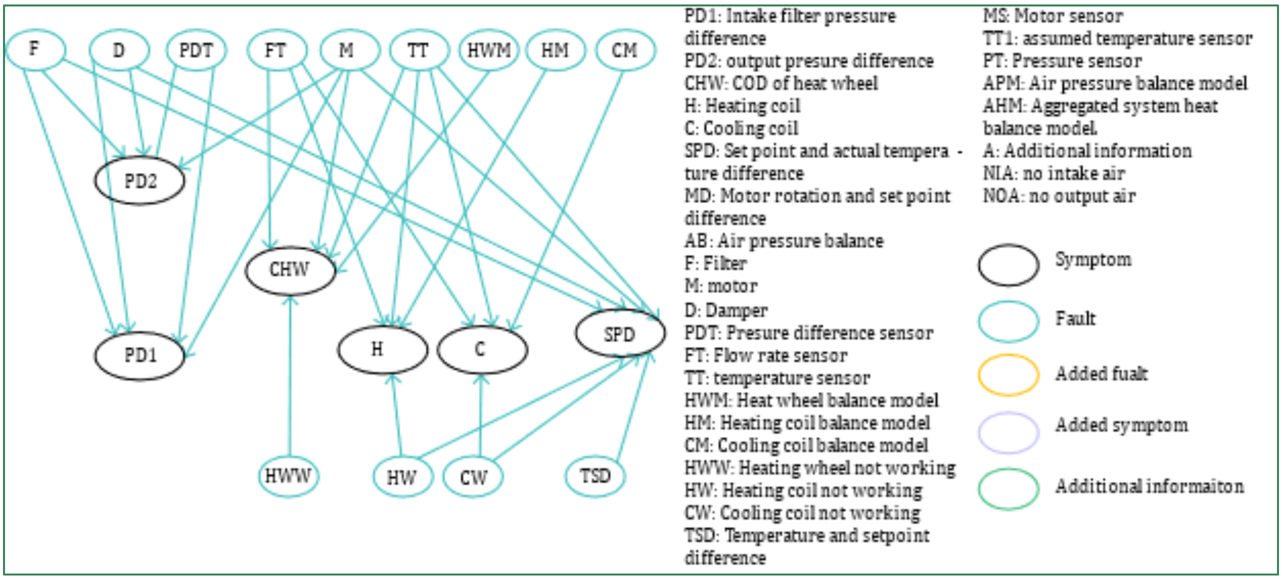

Figure 6: Application of the 4S3F method to a standard air handling unit and the corresponding DBN model

Figure 6 shows a complete diagnostic Bayesian network of a standard AHU. It shows the relationship between possible faults in the system (the blue circles), and symptoms observed when the fault appears (the black circles). For instance, a measured strange value of PD2, the output pressure difference, may come from a clogged filter F, a wrong position of the damper D, a broken pressure difference meter PDT, or a motor failure. This network is programmed in Python; the data from the sensors is first converted to 'symptom present' or 'symptom absent' and fed to the Bayesian network, which then calculates the probability that the symptom is caused by one or the other fault.

In the proof-of-concept, different aggregation levels and sensor-rich and sensor-poor settings are tested on Building 28, and the effect of prior and conditional probabilities on the results. The tests will be validated with the log data from maintenance in year 3. A part of the DBN was implemented in their AHU in collaboration with SPIE. An approach was tested to integrate occupant behaviour into the Bayesian network of HVAC systems, based on a Driver-Need-Action-System approach, and tested at the TU Delft living lab (Building 28).

Result 2: Prototypes of smart software plug-ins for error detection, diagnosis & predictive condition-based maintenance

Activities in year 2 focused on several topics. TU/e focussed on setting up the experiments at the living lab study at Kropman Breda and collecting data over a full heating and cooling season. This included (see Figure 7) i) introducing faults to analyse the energy impact of faults (re-commissioning), ii) testing of various types of sensors, iii) occupant surveys and iv) data logging.

An EnergyPlus building simulation model was developed for the Pareto-LEAN approach to determine the energy impact of faults. Figure 8 provides preliminary analysis results showing the faults' heating and cooling season ranking based on their contribution to energy consumption and the first delineation of errors to focus on the remainder of the project. These collected data are an important starting point for work in the coming year in developing proof-of-concept of scalable plug-ins. TU/e and Kropman will use the collected data to test different machine-learning algorithms. Meanwhile, Cloud Energy Optimizer is evaluating different ML algorithms for their buildings supported by ArtEnergy.

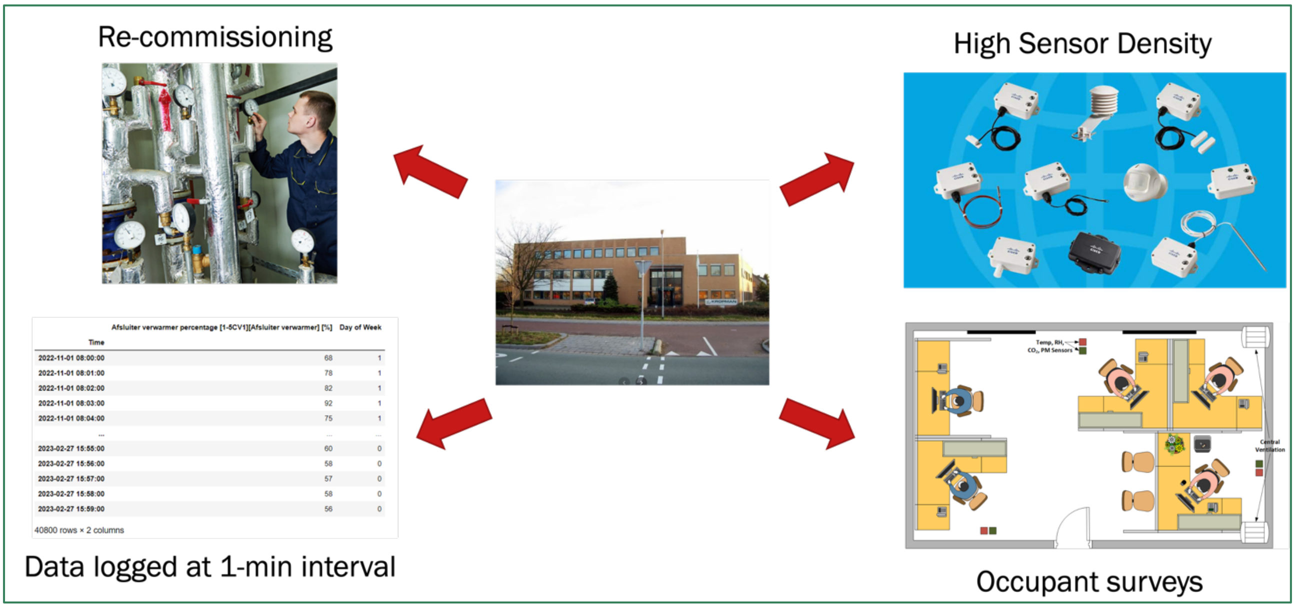

Figure 7: Set-up of the living lab test at the Kropman building in Breda.

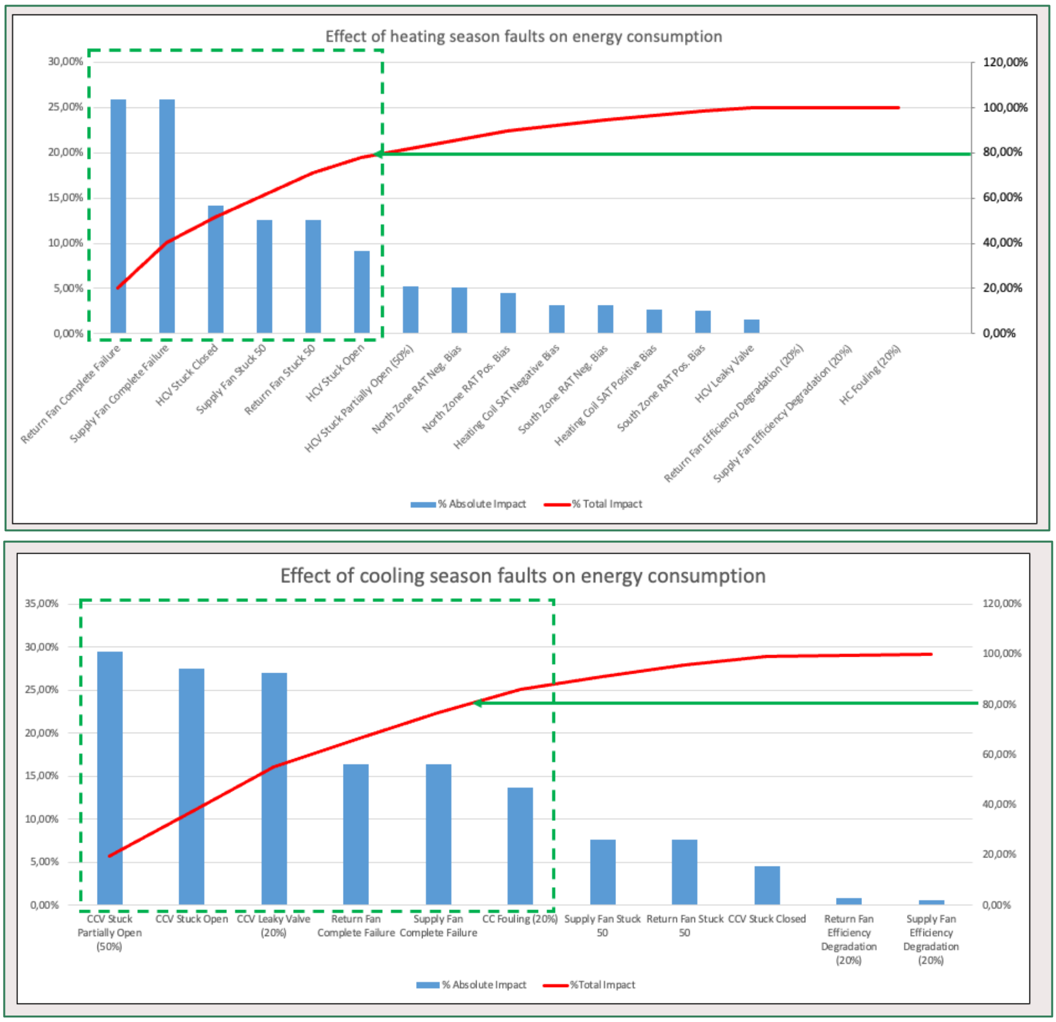

Figure 8: Pareto-LEAN Analysis: Preliminary Results with data from the Kropman building.

The living lab experiment also tested different sensor types. TU/e and Sensing360 collaborated with Kropman to investigate vibration sensors in the Living Lab Kropman Breda in the air handling unit. Moreover, it has been studied what sensors are necessary at what positions to detect the most important faults. These tests provide inputs for developing scalable and affordable fault detection and predictive maintenance plug-ins.

TNO used 12 months of data from the TNO building at the Stieltjesweg in Delft to develop further the virtual sensing and model tracking technology based on physics-based models of the AHU and the chiller in combination with a physical model of the building. The outcome of the virtual sensors can be used as an input for the fault diagnosis. Next to the physical approach, TNO is working on a data-driven approach in which boundaries, rule-based and ML will help to detect the symptoms. In cooperation with SPIE, TNO works on the relation matrix between symptoms and faults (see Figure 9)

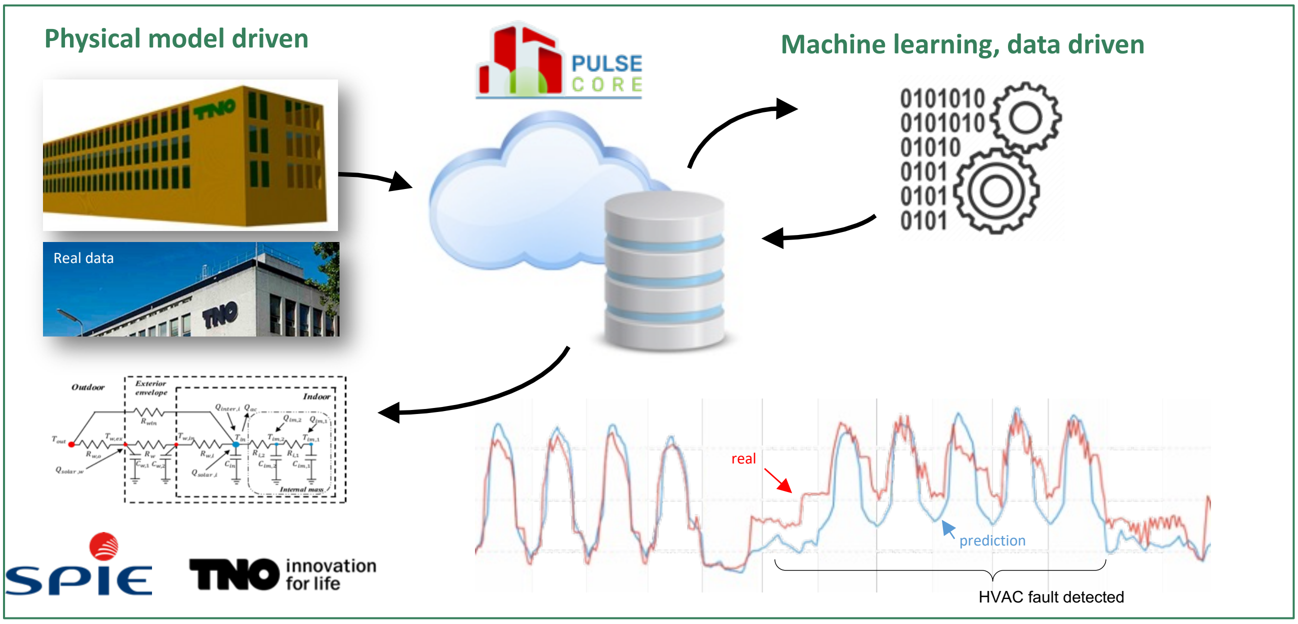

Figure 9: Outline of the work by TNO and Spie on the use of physical and data-driven models for fault detection

Peutz researched modelling buildings and the use of sensor data. An alpha version was developed for the first test in which Peutz uses the output of a BMS system from an office. They also investigate ways to automate the modelling of different building topologies so that aspects can be parameterised more efficiently as an essential towards scalability of the application in real-world situations.

DYSECO evaluated the commercially available platform Waylay for implementing Bayesian networks for fault detection and diagnosis under dynamic climate conditions. The outcome is that fundamental simplifications in the existing platform limit the functionality and uptake of the AFDD modules developed within the B4B project. Hence, DYSECO has started to develop a new platform based on open-source Python libraries to guarantee compatibility with AFDD plugins to be developed.

DWA works on automated detecting sensor anomalies in multi-sensor networks by applying unsupervised and supervised machine learning algorithms. They furthermore worked on "Occupant as a sensor", in which data from 47 multi-sensors and app requests were gathered at the DWA office in Gouda over 18 months.

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 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 the energy flexibility. The method was tested with the information from the EPA-U reports from 3 buildings (1 living lab of B4B and 2 from the portfolio of Rijksvastgoedbedrijf) (see Figure 10).

	THUAS (Delft)				Hanzevast investments				KNMI De Bilt			
	α (s)	*β (s)*	*A(J)*	*Δ (W)*	*α (s)*	*β (s)*	*A(J)*	*Δ (W)*	*α (s)*	*β (s)*	*A(J)*	*Δ (W)*
Insulation	7.0	7.0	7.0	7.0	5.0	5.0	5.0	5.0	6.0	6.0	6.0	6.0
Thermal inertia building services	5.5	8.2	8.0	8.1	8.3	2.9	4.2	6.6	9.2	3.5	2.7	4.6
Thermal inertia construction	6.0	8.4	8.4	8.4	6.2	8.3	8.3	8.3	5.6	8.0	8.0	8.0
Heating	6.8	8.1	7.0	6.8	9.1	5.8	7.1	9.1	3.3	4.4	2.2	3.3
Cooling	5.4	8.3	5.2	5.2	2.2	4.7	3.3	3.3	5.3	9.9	6.1	5.4
Warm water	8.5	8.4	5.1	7.8	4.9	3.9	3.9	3.9	7.7	8.0	6.0	6.0
Control strategy	3.8	6.3	3.8	8.8	1.3	1.9	1.3	1.9	0.6	2.5	0.6	0.6
Storage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	0.0
Building type	7.0	7.0	8.0	6.0	8.0	7.0	8.0	8.0	8.0	7.0	8.0	8.0
Outside temperature	10.0	10.0	10.0	6.0	4.0	9.6	4.0	4.0	10.0	10.0	10.0	6.0
Radiation	7.5	7.5	7.5	7.5	10.0	10.0	10.0	10.0	7.5	7.5	7.5	7.5
Total rating	**6.1**	**7.4**	**6.4**	**6.5**	**5.4**	**5.4**	**5.0**	**5.5**	**5.7**	**6.2**	**5.3**	**5.0**
Potential	**6.7**	**7.9**	**6.9**	**7.1**	**5.8**	**5.8**	**5.5**	**6.0**	**6.3**	**6.6**	**5.7**	**5.5**

Figure 10: Result of assessing the impact of different building parameters on four flexibility indicators for three buildings. α ((Time): The time it takes from the start of the response to the maximum response. β (Time): The total amount of time during which the consumption is reduced. A (Energy): The total decrease in energy demand during the response. B (Energy): The total increase in energy consumption – also called rebound.

Project partners have developed and tested several models. These models will be used later to test the flexibility of buildings (thermal inertia, installations).

TNO developed a hybrid building model and physical-based component models for an air handling unit (including separate models for the fan, the heat recovery wheel, and the heating and cooling coil), for a chiller, for induction units, for PV supply and application of these models in the living lab TNO Stieltjesweg in Delft. The component models are integrated into the hybrid building model.

HHS has been developing a building model using the open-source Modelica language. The test model of a simple residential house with a heat pump and ventilation system has been created using the IBPSA library IDEAS. The open-source software OpenModelica has been used to run the simulations.

Windesheim developed a grey model relating CO2 and occupation. Windesheim designed and implemented a Bluetooth presence detection and CO2-concentration measurement device, collected data about ventilation, CO2 concentration and occupancy amongst 23 rooms in 3 buildings and obtained sufficient informed consent to measure in 6 rooms. Over 500k data points were collected in 6 rooms between October 10 and November 2, 2022, of which 3 rooms ultimately had enough data for proper analysis. These data were used to develop the grey-box model (Data and models are available through GitHub).

O-Nexus developed proof-of-concept of a model to harvest the energy flexibility buildings offer and applied this to energy management in homes. The next step is to continue these experiments by setting up a use case for flexibility in an SME building at The Green Village, including a thermal buffer, heat pump and PV panels.

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. By considering continuous control input for heating/cooling devices, TUD proposed a new design framework for energy flexibility assessment and control for buildings. With the proposed approach, the flexibility potential of buildings can be quantitively assessed, and the energy flexibility can be exploited via demand response requests for solving grid congestion problems without violating indoor comfort constraints (see **Error! Reference source not found.** for an example of one of the simulation results). Furthermore, possibilities were explored to test control algorithms in the living labs. As these are existing buildings currently in operation and that cannot stop operation during the test period, logistics are complex and require thorough preparation.

In the co-creation centre in the green village, a Model Predicitive Control algorithm was developed and tested by TUDelft for the optimal control of solar blinds together with the loading and discharging of PCM batteries in the ventilation system, showing a very interesting saving potential in comparison with rule-based control (RBC) (see Figure 11).

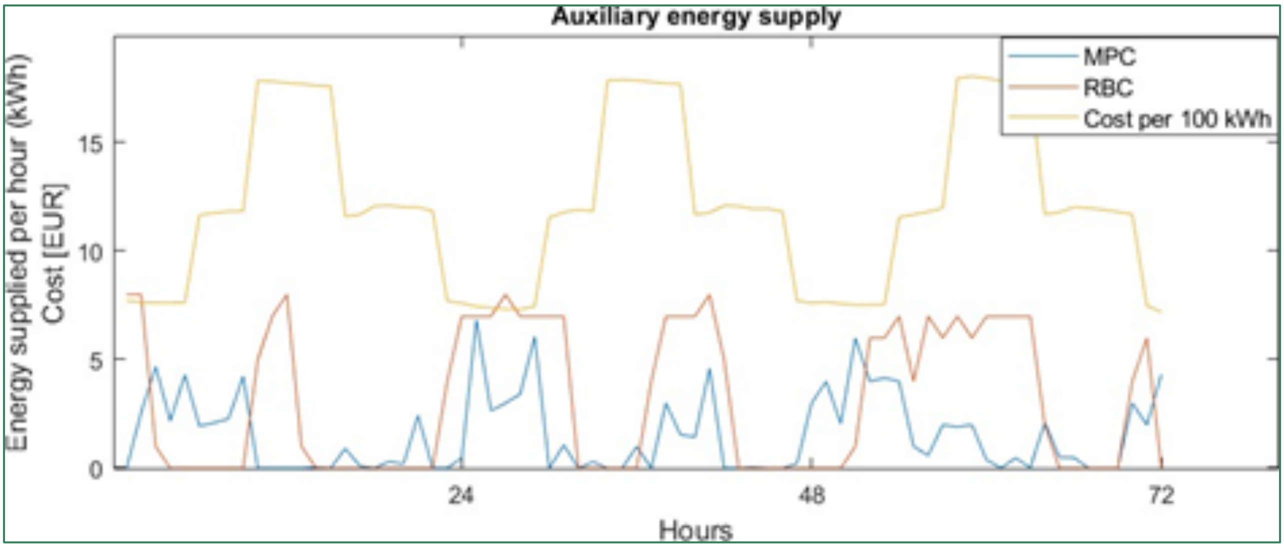

Figure 11: Energy use when using MPC (blue) and RBC (red), given a certain cost function (yellow)

2.4 WP 3: Smart user-targeted interfaces and feedback

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

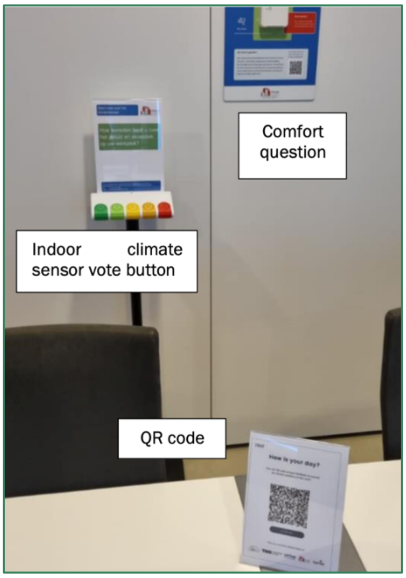

Figure 12: Set-up of the experiment at the office of Spie

TNO, Spie, Unica and TU Delft finalised the deliverable on "Method of determining the real-time comfort and health level of buildings". This report includes results on developing a tool that continuously gathers feedback on the perceived comfort level of office users in a minimal nuisance manner. One of the most important aspects was determining a strategy to trigger and motivate people to provide their momentary perceived comfort. A pilot study was conducted in an office of SPIE in which user feedback was gathered with self-standing vote boxes and QR codes placed on room tables. The most important findings included: 1) placing the vote button directly in the workspace and 2) using a vote button connected to a touchscreen.

OfficeVitae, TNO en TU Delft worked on further developing feedback dashboard displays and filters for building inspectors to view indoor label data according to location and time. These three parties are also working on the strategy and initial implementation of a smart notification system to inform building inspectors when label scores fall below target levels. This is being tested and refined at the TNO living lab at the Leeghwaterstraat in Delft.

TNO, HAN, TU/e, Spie and DGBC developed a method to determine relevant feedback to help office users better understand control strategies of climate systems. This method was tested in 5 office buildings, and 37 participants were recruited to demonstrate how the method works and gather the first information. Results from these experiments are input for the development and redesign of interfaces. The results were presented in deliverables 3.04.

TNO finished the literature review on existing user behaviour models, made an analysis of which of the existing models would be the best option to use in the hybrid models to be used in WP1 and WP2 and started the evaluation of the models that were chosen, based on the data of the living lab TNO Stieltjesweg. The results were presented in deliverable 3.08.

Furthermore, different partners worked on collecting data on comfort and occupancy for FDD systems:

– TU/e, Unica and HHS collected data in the HHS living lab in The Hague, including collecting data pilot testing of a self-reporting app to gather data related to personal thermal comfort, air quality and variables influencing thermal comfort. Other partners in the consortium already use the developed app.

– Apta Technologies used the data collected in the platform developed by Unica for the HHS in The Hague living lab to conduct data analysis in the living lab based on existing behaviour modelling techniques. The result will be fed into the work in FDD in WP 1.
– Avans using machine learning techniques to predict human well-being in buildings. The main insights were that features like thermal comfort, humidity, and air quality have the most impact on human satisfaction without taking active/passive feedback into account.

The results are a good starting point for prototyping data-driven user-oriented interfaces in result 6 in year 3 and 4.

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

HAN started investigating the user requirements regarding building climate. Results were included in a report (Deliverable 3.09) which shows a model in which two different user types - occupants and facility managers- are positioned to the building and its climate and regulatory systems that resulted in a first list of requirements that can be used as a starting point for the redesign of interfaces.

Spectral started developing a Beta application and integrating it into the internal tooling deployed by Spectral for usability testing and facilitating the activation of the realised version with the user cohort at use case building they have identified.

2.5 WP 4: Data integration for smart communication

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

TNO and TU/e created a privacy, ethics, and security framework. Where the earlier deliverable focused much on ethics and privacy regulations, work in the second year focused particularly on security measures. The activities established an overview of security threats and mitigation strategies, used as a starting point for a #hackmybuilding experiment that TNO and RVB conducted. The research resulted in a comprehensive framework, incorporating data privacy, security and ethics and serving as a means for asset owners and other stakeholders to set up robust digital strategies to withstand the increasing cyber-physical threats on their digital and physical systems (see Figure 13).

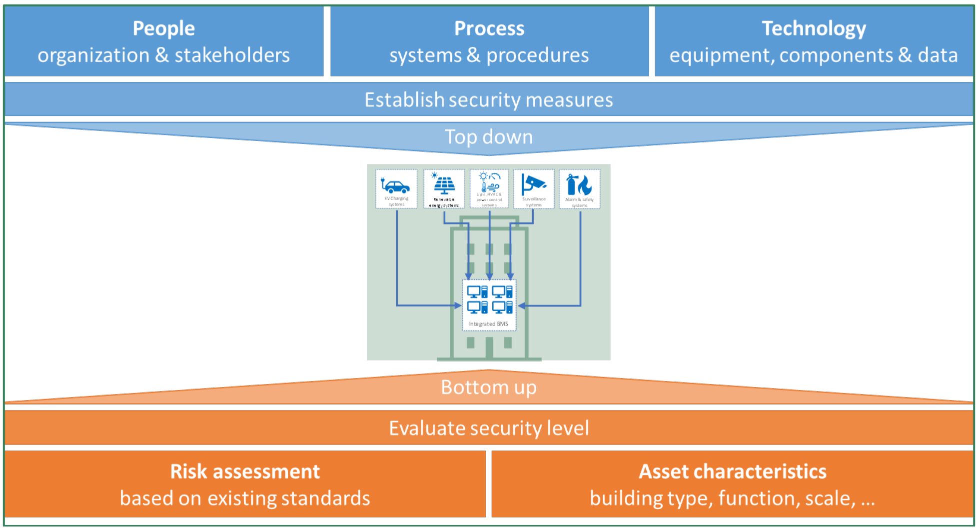

Figure 13: The Privacy, Security, and Ethics Framework to guide asset-owners and stakeholders.

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

Activities included (1) investigating the overall structure of the reference system architecture for smart buildings based on literature and known best practices and (2) technical implementations and development to make this reference architecture happen in living labs and reference sites. TU/e published the first report with a proposal for a reference system architecture for data integration in smart buildings, outlined in Figure 14.

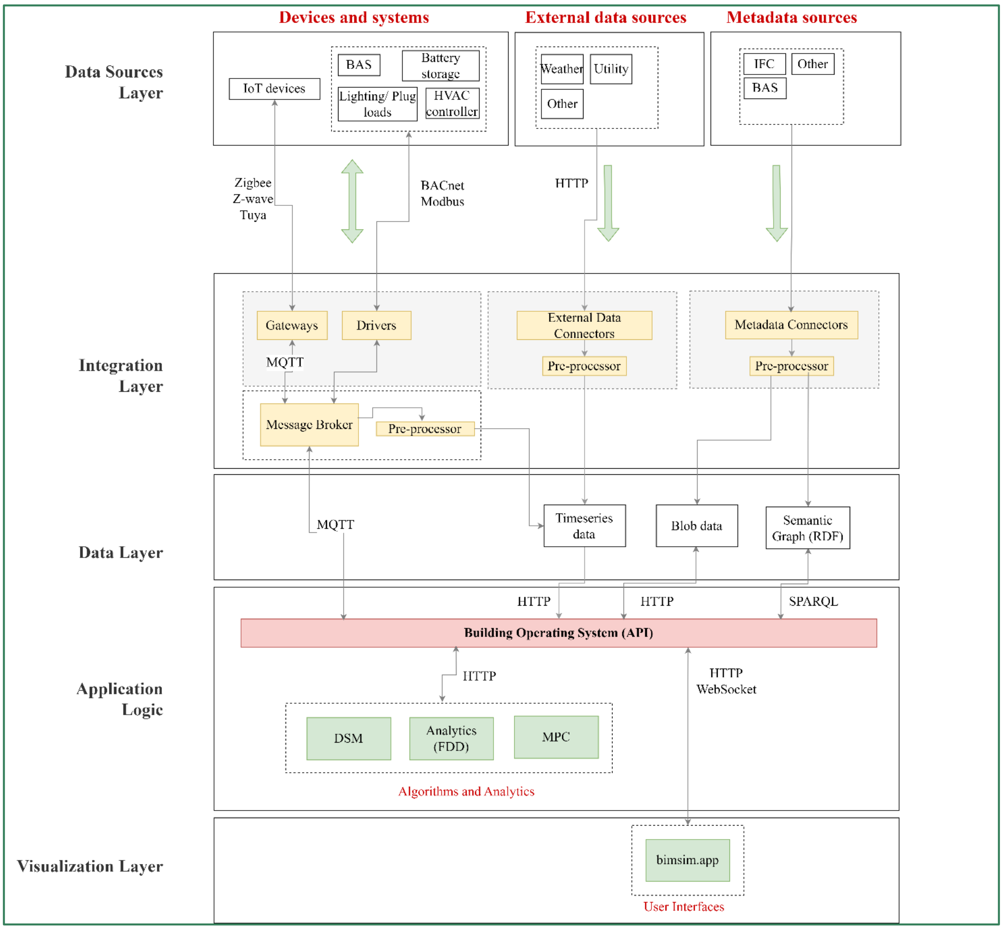

Figure 14: Proposed reference architecture for smart buildings.

Experiments initiated in connection with the creation of a reference system architecture in the living labs included:

- #GenerateMyMetadataSchema experiment (TUD and TU/e Living Labs): This experiment investigates 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 it measures). This leads to a 5-step procedure to create a BRICK schema starting from data sets from a BMS provider. This has been tested successfully for TUDelft and TU Eindhoven cases.

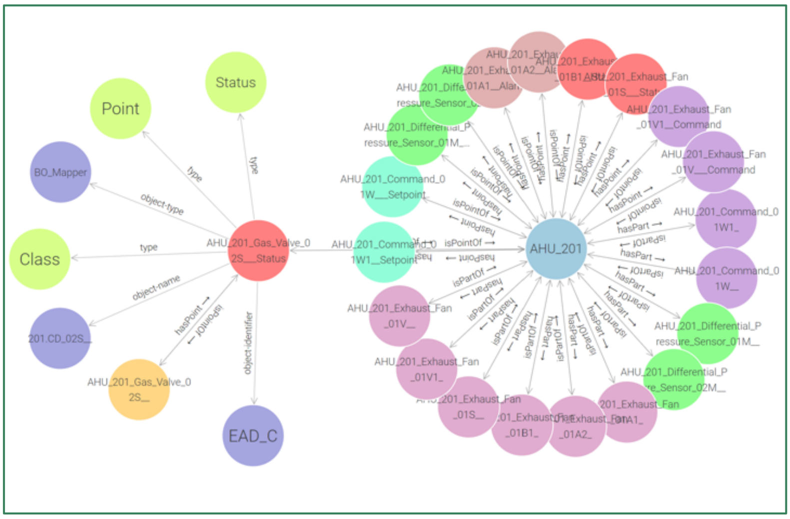

Figure 15: Example of metadata generated for an Air Handling Unit

- #RealTimeDataAccess experiment (Kropman Living Lab/use case lab): In this experiment, it is investigated to what extent data can be tracked in real-time using the available system architecture (and what is real-time even? How many minutes?) to detect faults (FDD algorithms WP1) then and potentially intervene in the building (Model-Predictive Control – MPC).

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

Deerns, supported by Heijmans and Philips Real Estate, NEN, WE, RVB, and TU/e developed a Smart Buildings Assessment procedure. The procedure includes:

- Excel spreadsheet with all questions to be answered to evaluate/calculate the smart readiness of a building, using a custom selection of parameters as devised within B4B (Deerns). This assessment differs from the SRI assessment, yet it is closely related.
- A guideline document with explanations behind the terms and questions used.
- A PowerPoint presentation that explains the procedure.

Based on the assessment, a building is scored according to 6 criteria, as shown Figure 15. It can then be evaluated which measures can be taken to increase the smartness of the building, thereby focusing on its energy systems.

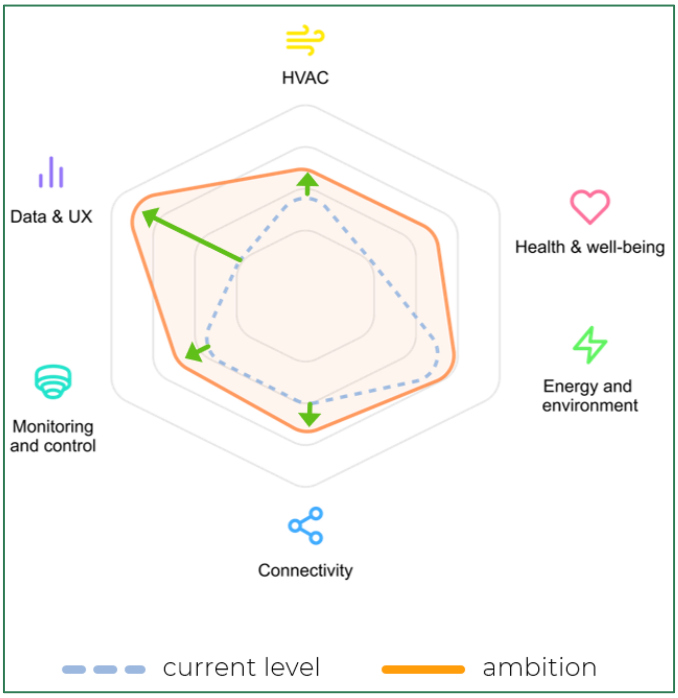

Figure 16: Example of Smart Building Assessment score

2.6 WP 5: Learning Community

Result 10: Learning community "Smart buildings"

We had another 3 consortium meetings in which consortium partners met (attendance between 60-70 participants) to discuss progress within the project. Various workshops were organised to exchange and further develop ideas and good practices on specific topics.

We continued with our monthly online Brains4Buildings webinars, 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. Post-covid participation had declined, but 25-50 people still attended each webinar and dozens viewed the recording. Most participants come from outside the project, and we already received several requests from other partners to give a lecture. This way, we gradually build a broader (international) learning community and an online repository of "smart building" topics. The full webinar slides and recordings list can be found on our website.

TU Delft started by building a knowledge platform. This platform needs to evolve into a repository with information for different target groups:

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

The open knowledge platform offers "introductory knowledge" and "quick wins" as well as "in-depth" knowledge on various topics (see screenshot below). The knowledge platform_is now partly filled but not yet accessible to the broader group. To that end, the platform must be further filled and guide specific target groups.

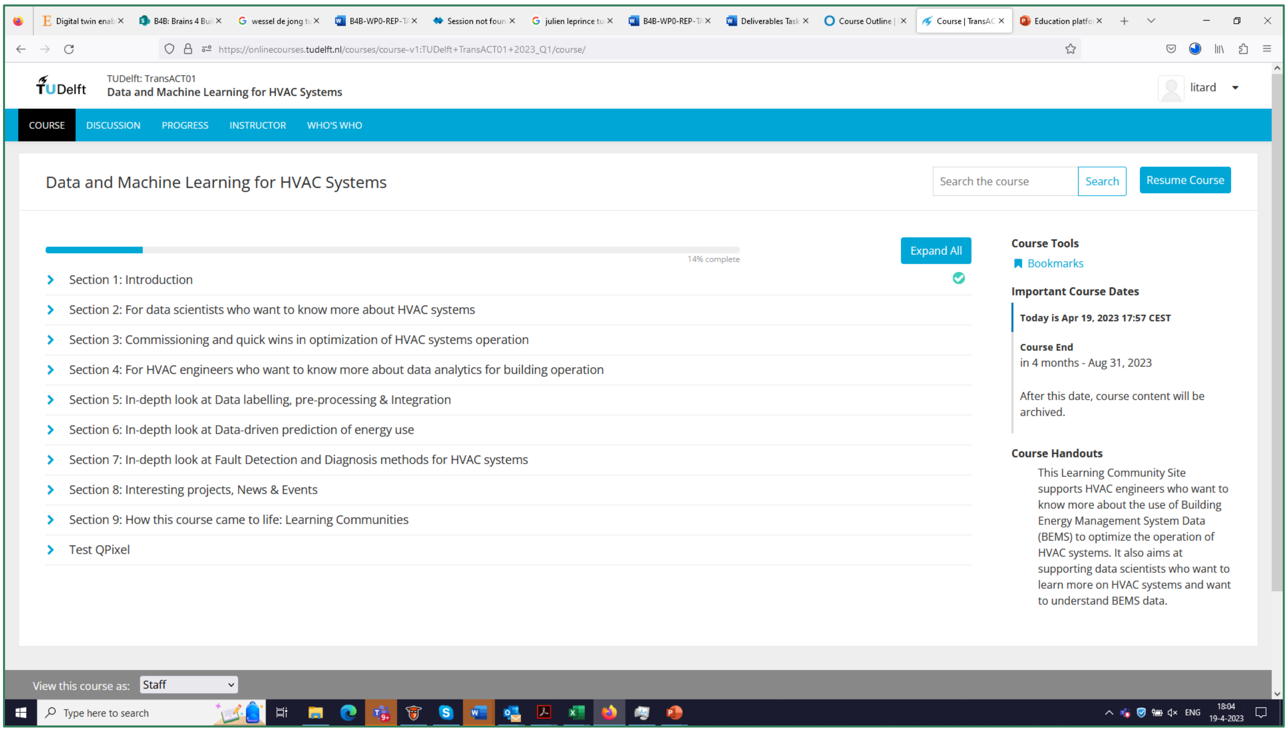

Figure 17: Screenshot of the knowledge platform.

The DGBC and TU Delft developed a plan to develop a learning track for 3 different target groups:

- Facility managers: focus on indoor climate, comfort complaints, operational costs
- Building managers: linked to Paris Proof activities of the DGBC with a focus on the business case for smart buildings and quick wins.
- Installers: linked to "Bespaar Samen" a challenge to make 10,000 buildings more energy efficient.

This learning track aims to raise awareness and provide practical guidance. The learning track takes a step-by-step approach by organising 4-6 meetings/workshops in which participants can bring data of their own building(s) and in which, in each meeting/workshop, a different subject is covered e.g. (1) analysing data, (2) assessing comfort complaints, (3) data security, (4) Business cases etc. Participants that want to dive deeper will be referred to the knowledge platform.

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. This still needs 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 a lot of 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 to plan maintenance activities and manage the energy bill on time.
- Enable to monitor 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 2

Del. No	Title
D3.01	Report on method for monitoring and collecting real-time subjective comfort data
D3.02	Report on method to assess occupants' comfort and health
D3.03 |D3.06	Report on end-user requirements for fault detection and diagnosis control systems and interfaces + End-user requirements for energy flexibility control systems and interfaces
D3.04	Report on insight of what feedback to the user will help user acceptance, reduce complaints and increase energy saving
D3.08	User profiles for use in hybrid models
D3.09	Report on requirements for the re-design of interfaces for O-nexus, Unica and Spectral
D4.02	Data test set for internal research purposes
D4.04	Guidelines to make every building "smart", incl. specification of the Smart Readiness Indicator
D4.05	Privacy, ethics, and security framework with a view to increasing market acceptance and innovation
D4.06	Reference system architecture for data integration in smart buildings

Publications in year 2

Date	Title	Publisher
Yun Li, Neil Yorke-Smith, and Tamas Keviczky (2023)	Unlocking Energy Flexibility from Thermal Inertia of Buildings: A Robust Optimization Approach. Submitted to IEEE Conference on Decision and Control 2023, Under Review.	IEEE Conference on Decision and Control 2023
Yun Li, Neil Yorke-Smith, and Tamas Keviczky (2023)	Robust Optimal Control with Inexact State Measurements and Adjustable Uncertainty Sets. Accepted to the 2023 IFAC World Congress, Yokohama, Japan	IFAC world congress 2023 (9-14 July 2023)
Vera Lange (2022)	Creatieve onderzoeksmethoden verhelderen gebruikersperspectief	Website HAN
Chorius, Misscha (2022)	Energiezuinig gedrag bevorderen in kantoorgebouwen	Website HAN
Chamari, L., Petrova, E., Pauwels, P., van der Weijden, J., Boonstra, L. & Hoekstra, S., 30 Mar 2023,	Metadata Schema Generation for Data-driven Smart Buildings	Proceedings of the 11th Linked Data in Architecture and Construction Workshop .

Date	Title	Publisher
Chamari, L., Petrova, E. & Pauwels, P., 20 Mar 2023	Extensible real-time data acquisition and management for IoT enabled smart buildings.	Proceedings of the 2023 European Conference on Computing in Construction.
Spiekman, Marleen; te Duits, Noa; Lange, Vera; Jeurens, Jasper; Sluis-Thiescheffer, Wouter (2023)	Methodology to develop interfaces to help office users better understand control strategies of climate systems (abstract submitted)	Healthy Building Conference 2023
Xiang Xie, Jorge Merino, Nicola Moretti, Pieter Pauwel, Janet Yoon Chang, Ajith Parlikad (2023)	Digital twin enabled fault detection and diagnosis process for building HVAC systems	Automation in Construction Volume 146, February 2023, 104695
Wisse, K. (2023)	Comfort apps: hoe vaak gebruiken we ze?	TVVL magazine Nr 1 February 2023
Stephen White et al. (2023)	International Energy Agency: A Data Sharing Guideline for Buildings and HVAC Systems	IEA Annex 81
Zeiler, W. (2022)	Brains for Buildings to achieve Net Zero. In A. Sayigh (editor), *Achieving Building Comfort by Natural Means*	Achieving Building Comfort by Natural Means redactie, Vol. Innovative Renewable Energy, blz. 1-2. Springer Nature.
Wisse, K. (2022)	Evaluatie klimaatklasse A in de praktijk	TVVL magazine Nr 6 December 2022
Dikken, Robbert Jan (2022)	Gebouwen als dynamische component in het energienet	Peutz website (11-6-2022)
Zeiler, W. (2022)	Energieflexibiliteit opschalen metdatagestuurde slimme gebouwen: Internationaal project IEA Annex 81.	September 2022, 30-34, VVplus
Chitkara, S., van den Brink, A. H. T. M., Walker, S. S. W. & Zeiler, W., (2022)	An early prototype for fault detection and diagnosis of Air-Handling Units	Proceedings Clima 2022. p. 1-8 p.

Media in year 2

Date	Title	Title of journal, website etc.
2023/03/27	The B4B Project aims to develop scalable and modular solutions that save 20-30% of energy (interview met Mirjam Harmelink | TUD)	Build Up
2023/03/05	Thema Smart Building: Overspoeld door data (interview met Laure Itard | TUD)	Property NL

Presentations in year 2

Date	Presentor | Title	Event
2023/04/06	B4B Webinar #12: Securing Operational Technology (OT): New Kid on the Block or Familiar Risk? A wake-up call for one of the biggest threats for the future (Johan de Wit | Siemens)	B4B webinar series
2023/03/27	Rick Kramer (| De energiesystemen van gebouwen worden te complex)	ABB relatiesdag | Leusden
2023/03/16	B4B Webinar #11: Experiences with user feedback in a living lab environment (Sander van der Harst | Unica & Frans Joosstens | HHS)	B4B webinar series
2023/02/16	B4B Webinar #10: Security. Privacy and Ethics in Smart Buildings (Elena Chochanova, Tousif Rahman | TNO)	B4B webinar series
2023/02/06	Mirjam Harmelink | Brains 4 Building's Energy Systems	TKI Urban Energy Consortium podium | Utrecht
2023/01/12	B4B Webinar #9: Comfort apps in smart buildings, do we use them and what's their effectiveness (Kees Wisse | DWA)	B4B webinar series
2022/11/29	Mirjam Harmelink | Brains 4 Building's Energy Systems	Paris Proof congres (DGBC) | | Rotterdam
2022/11/13	B4B Webinar #8: Prescriptive, predictive and preventive maintenance of rotating assets (Eric van Genuchten | Sensing 360)	B4B webinar series
2022/11/08	Niels de Jong Cloud Energy Optimiser | Slim samen besparen	FHI Digitaal Gebouw
2022/10/13	B4B Webinar #7: Setting up a living lab (Jan Willem Dubbeldam | Kropman)	B4B webinar series
2022/09/15	B4B Webinar #6: FDD of the low Δ T syndrome (Anand Thamban | TU/e)	B4B webinar series
2022/06/16	B4B Webinar #5: Monitoring Heat Pump performances (Dave Baas | Renor)	B4B webinar series
2022/05/19	B4B Webinar #4: Energy transition requires adaptive buildings (Niels de Jong | Cloud Energy Optimizer)	B4B webinar series