Indoor Climate as a Service: a digitalized approach to building performance management

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Abstract. Digitalization provides significant opportunities for innovation, new business models, and services for the building sector. This paper describes the implementation of a concept for providing “Indoor Climate as a Service”, based on a case study of digital transformation in a modern office building. This concept can accelerate the energy savings and reduce power demand in the existing building stock by implementing digitalization (sensors and actuation, together with data integration and analytics platform), and providing full incitements for energy investments at the same time as the contracted indoor climate is secured and verified using real-time data. The digital transformation included obtaining data from different sub-systems (climate control, IoT-devices and Space booking system etc.), applying the RealEstateCore ontology to organize the data, and the development of an IoT-Edge computing solution. A key objective of this study is to explore the types and quality of data (for example, from sensor signals) needed to implement the concept in a modern office building. Key indoor air quality and energy performance control parameters were analyzed with relevance to developing a robust business model. The results of the study demonstrate the significant potential of utilizing digital infrastructures for implementing Indoor Climate as a Service.

1. Introduction

While energy efficiency is a key element for smart buildings, the purpose of a smart building is to serve the needs of its occupants. Energy efficiency and load management need to be evaluated in the context of the quality of (building) services provided. The purpose of this study is to implement and evaluate the concept Indoor Climate as a Service (CaaS). It is a scalable business model for building performance management, designed to provide incentives for accelerating energy savings and reducing power demand in the existing building stock without compromising indoor climate quality (ICQ).

While this approach to building performance management is designed to be explicitly user-centric, it employs innovative digital tools and methodologies that have different levels of complexity, extending all the way to artificial intelligence. The utilization of these innovative technologies represents a veritable paradigm shift in building performance management, as well as powerful support in pursuing and achieving the United Nations’ sustainability goals (for example, SDG 3 Good Health, and SDG 7 Affordable and Clean Energy). This study and the concept of CaaS is a powerful tool for improving property management by implementing digitalization for (energy) optimization and long-term
verification of ICQ. Field studies have for instance, shown that an energy saving of 5–30% and improved indoor air quality can be achieved by applying artificial intelligence (AFDD) followed by corrections even if these are not done in real time [1].

This study was conducted at the state-owned Akademiska Hus (AH), one of the largest property management companies in Sweden, managing an area exceeding 3.3 million sq., one-third of which is accounted for by advanced lab environments for research and innovation. AH promotes a sustainable long-term development of university and college campuses and this study was carried out within the AH corporate strategy and goal of achieving carbon neutrality in building operation by 2025.

1.1. Indoor Climate as a Service (CaaS)

Until recently, the digitalization of HVAC services in buildings was mainly driven by the objective of reducing energy use, greenhouse gas emissions and costs. The concept of Indoor Climate as a Service (CaaS) focuses on delivering high quality indoor climate as the driving objective. Studies [2] have shown that indoor air quality has a direct impact on workers’ health and job performance.

CaaS builds on the use of an array of digital tools, including sensors for measuring and verification (of specified ICQ), development of a digital ecosystem, knowledge graphs for analysis, Edge-analytics, artificial intelligence for improved system optimization, as well as for enhanced monitoring.

CaaS is intended to provide added value by:

- Focusing on optimizing customer satisfaction and value, based on long-term, real-time verification of key contracted indoor climate parameters
- Utilizing big data technologies allowing the management of individual building performance to better synchronize with performance requirements for larger systems (e.g. building clusters, districts, cities).
- Being applicable for other buildings and scalable to larger real estate portfolios
- Considering the full range of indoor climate quality criteria, as needed
- Providing incentives for investments in quality management in buildings, including energy efficiency and load management (in compliance with existing energy contracts).

1.2. Objective and scope

This paper describes the implementation of a concept for providing Indoor Climate as a Service (CaaS), based on a case study of digital transformation in a modern office building. A key objective of this study is to explore the types and quality of data (for example, from sensor signals) needed for developing a robust business model. The implementation process is divided into four separate processes; (1) defining key ICQ parameters; (2) contracting a desired ICQ level; (3) developing a methodology for verification using real-time data; and (4) the final step the development of a methodology on how to create new insights by combining different data sources. Implementation or development of Big data technologies belong to future research and is in this study replaced by ad-hoc analysis of the streaming data. Key indoor air quality and energy performance control parameters were analyzed with relevance to developing a robust business model.

The aim of the paper is to contribution to future research in finding out the most cost effective and comprehensive way to implement the concept “Indoor Climate as a Service” in existing typical modern office buildings.

1.3. Indoor climate quality (ICQ)

The Indoor climate quality (ICQ) has to be defined in every implementation of CaaS. In this case study is the ICQ regulated in the non-legal agreement “Green lease” (Fastighetsägarnas Gröna avtal) between the tenant and AH and is stated as being the operative temperature (radiation temperature and air temperature). It is a very limited part of the whole spectra of Indoor environmental quality (IEQ). IEQ
covers the condition inside the building – air quality, visual environment, acoustic environment, thermal comfort – and their effects on occupants.

Due to limitations in the existing digital infrastructure; there are only sensors for the air temperature, but not the radiation temperature in every room, the verification of ICQ is simplified to only measuring the air temperature and the radiation temperature is neglected. It is neglected due to it is a building with a well-insulated climate shell with fewer cold bridges or surfaces. A consequence from that simplification is that the impact from cold windows is not considered.

1.4. Digitalization in building performance management.

Many existing buildings are already digitalized, to the extent that they rely on different types of automated systems for efficient operation. However, current building management systems are often a legacy from the process industry; they may utilize high-quality data, but typically only to optimize the performance of sub-systems and isolated processes. Data (sensor and actuators) are collected but is not analyzed or processed in a larger context. An essential step towards efficiency is making sense of the increasing amounts of data produced by different signals.

In line with current societal developments, even the “late-starter” real estate market needs to realize the importance of having access to and efficiently managing large quantities of high-quality data in pursuing and achieving successful operations. The implementation of digitalization (as the process of considering how to best apply digitized information – that is, the process of making analog information available in a digital format – to simplify specific operations [4]) has huge potential for realizing these hidden values.

We are experiencing a development that slowly breaks down the traditional boundaries between building management systems and traditional IT architectures, including different cloud solutions. Next-generation digital tools enable traditional building management systems to be integrated and operated at a higher system level, typically as eco-systems connected to a variety of control systems that utilize large and complex datasets (big data etc.).

2. Methodology

This paper describes the implementation of a concept for providing “Indoor Climate as a Service”, based on a case study of digital transformation in a modern office building. A key objective of this study is to explore the types and quality of data (for example, from sensor signals) needed to implement the concept in a modern office building.

Figure 1: The study case building at the campus of KTH Royal Institute of Technology.

The study was conducted as a case study of a 13,434 sq. meter office building on the campus of the KTH Royal Institute of Technology in Stockholm, see figure 1. The building is representative of a modern office building: it was built in 2005 with several technical systems for operating the building; an extensive building management system (BMS), an intelligent demand-control ventilation (DCV) system where the airflow can independently vary between different rooms, carbon- and temperature sensors in conference rooms, and energy meters throughout the building. Like all buildings on the KTH
Campus, the case study building is connected to a micro-grid on campus for district heating, cooling, and electricity supply. Akademiska Hus have a “Green lease” (Fastighetsägarnas gröna bilaga) contract with the only tenants within the building. The Green lease is a voluntary, non-legally binding agreement between AH and the tenant, detailing specific sustainable performance issues.

The implementation and the establishment of the concept including its activities are visualized in figure 2 below and explored and analyzed in this paper.

Figure 2: A partial scheme presenting the structure within the concept for providing Indoor Climate as a Service (CaaS).

The process of defining the Key parameters within the ICQ is visualized in the green section; the context of the contracted a level of ICQ visualized in the red section; the digital transformation for
verification of ICQ using streaming data in the yellow section. The grey section visualizes the activities with the methodology for building optimization including Big data technologies.

The development of Big data technologies e.g. data analytics or artificial intelligence belongs to futures research (white section) and is in this paper replaced by ad hoc analysis of the streaming data. Key indoor air quality and energy performance control parameters is analyzed with relevance to developing a robust business model.

3. Digital transformation
The digital transformation is merely a methodology for providing a contracted ICQ with a minimum amount of energy- and power demand in this specific user case. The following text explores the technical process connecting existing data sources (within the building or external data sources), the implementation of RealEstateCore ontology and the development of a digital IoT-Edge platform for organizing and start processing the data.

3.1. Cyber security
This digital transformation included the development of a Microsoft IoT-Edge solution within the building. Every campus, including KTH’s, has its own technical local area network protected by a firewall that uses Pulse secure with two-factor authentication for external access. An IT solution of high cyber security was developed within existing the firewalls in accordance with the regulations in the General Data Protection Regulation (GDPR). Classified data is stored on the IoT-Edge within the firewall and within the building, non-classified data is stored externally on the Microsoft Cloud and, if necessary, further exported to the IoT-Edge. The definition of classified and non-classified data is regulated in a specific contract between AH and the tenant, where classified data is not exposed to the Internet. Processing of Big data and the actuation (back to the BMS or DCV system) take place on and from the IoT-Edge.

3.2. RealEstateCore ontology (REC)
In this case study, the RealEstateCore ontology is utilized for data integration. RealEstateCore, which is described in more detail in the RealEstateCore ontology [5], is a common language that facilitates data-driven building control and the development of new services. In this case study, RealEstateCore version 3.1 has been tested and implemented in the building management and demand control ventilation system. It is the first version with an actuation module, with northbound and southbound message semantics for enacting actuations on systems. It gives an AH smart building system the ability to return a control signal back to the building management system (SAIA) and the demand control ventilation system (Lindinvent) in RealEstateCore format (“Feedback signal” in Figure 2).

Both the BMS and the DCV system communicate by Modbus TCP and are translated using IoT-Edge Modules, the “RealEstateCore” module in Figure 2. The modules are written in C# and can be configured to poll the source system at different intervals. The originated Tag list (building management- and the demand control ventilation system) is manually converted to the REC-Tag list.

3.3. Data sources
The digital transformation has a bottom-up approach, starting from the existing sensors and actuators within the building including external web services. Data sources connected to the target (a defined user case: measurements within the concept of CaaS) to be included in this digital transformation are:

- The building management system, (BMS), SAIA
- The demand control ventilation system (DCV), Lindinvent
- Space booking, the tenant’s system for managing space booking, Time edit
- Weather data including forecasting, SMHI
- Energy management system (EMS), Energiportalen
The building management system (BMS) is a computer-based system that monitors and controls the distribution of heating, cooling and electricity within the building. The quality of the streaming data was ensured by calibration or replacing several temperature- and CO2 sensors within the HVAC systems, every signals frequency had to be changes to 1-minute interval including the energy meters, the data export had to be changed from 60 to 1-minute interval by shifting (adding) the data exports from the energy management (EMS) to the BMS system. The BMS collects 726 signals (sensors and actuators) every minute.

The demand control ventilation system (DCV) automatically adjusts the airflow to the actual demand in every room. The exhaust air flow including the pressure balance are monitored and controlled within the BMS system. There is an ongoing modernization of the 15-year old DCV system: almost 50 % of the original version of the supply air duct are not connected to the climate system or the local area network within the building and no data is exported to the digital IoT platform. The transformation process ensuring the quality of the data included calibration or replacement of external CO2 sensors. The DCV system monitors and optimizes the airflow using data on a minute level from 2593 signals (based on approximately 50% of the supply air ducts within the building; 100 % of the exhaust air ducts are controlled and monitored within the BMS system). Together with the BMS, these signals are all mapped to the RealEstateCore ontology before being passed on to the analytics and infrastructure platform.

The space booking system, weather data system, and the energy management system (EMS) all use Open API for data exports every 60 minutes. The space booking system is the tenants’ external web service for coordinating scheduling and resource management. It collects data about bookings and reservations. Weather data contain weather forecast data for the next 10 days, based on forecast models, statistical adjustments and manual edits. The EMS is a web service with which to control the energy meters throughout AH. The energy data is stored on a server within the AH firewall and is exported to the Azure cloud service for the purpose of being visualized in a Power BI dashboard.

Acknowledgement within the digital transformation process.

- Access to data is vital in the digital transformation process. Difficulties exporting streaming data from existing legacy or contracts preventing data to be exported from external web services makes this, together with ensuring the data quality, a very time-consuming activity.
- Poor data quality and limited measurements; yet the sensor system in a BMS is design for building control purpose and not for the implementation of AI. There are e.g. no redundant measurements which increase the sensor faults: sensor faults could be accepted as a true value. As a result, sensor faults have strong impact overall automated fault detection and diagnosis (AFDD) accuracy and false alarm rate [3].
- Connecting the data sources to the Smart city. The time spent organizing the amount of heterogeneous data using the RealEstateCore ontology could be reduced by auto-generation of Tag-lists.

3.4. Digital platform.
This digital transformation included the development of a digital platform. The aim of this platform is to enable smarter build management through data-driven analysis and automation in a scalable, secure, and cost-efficient manner. By making previously isolated data sources available and understandable through the use of ontologies and open data formats, this solution can serve as a platform for ad-hoc exploration of data, enterprise reporting, machine learning, and the control of BMS.

A Microsoft Azure solution was developed by combining the potential of the cloud with security using an IoT-Edge solution to avoid exposing classified data outside the firewalls. See the structure of the digital IoT-edge platform in figure 2. This solution manages streaming data from five different source systems. Data from the building management system (BMS) and the demand control system (DCV) are extracted (according to the configuration specified in the two REC tag lists) using an IoT-Edge module running on an Edge Device physically located in the building. The BMS and the DCS
communicate via Modbus TCP and the data are translated using IoT-Edge Modules. The module’s function is to poll the source system according to the configuration specified in the REC tag list. The REC tag list differentiates between a “sensor” that represents a read operation and “actuators” that enable the writing of values back to the modbus registers. The importing of data from TimeEdit, SMHI and Energiportalen APIs is processed with a Data Factory that triggers every hour. This solution can enable future “AI” modules for processing big data to return a feedback value (an actuator) by routing “actuationRequests” to the “ModbusWrite”. The “ModbusWrite” module can be seen as the inverse of the “ModbusRead” module. It translates RealEstateCore formatted Json to Modbus requests that can be understood by the source system. The actuation commands are validated in the ModbusWrite Edge.

New experience from establishing and onboarding a digital IoT-edge platform; find a way to speed up the process for onboarding new data or systems to an existing platform using a specific ontology, include and automatize the anonymization of classified data in the export function of data, domain knowledge is crucial when addressing rules and intervals for the new signals to be send back to the BMS/DCV system.

3.5. Input data set.
The amount and the frequency of available data from the five different data sources are presented in Table 1 below. The available input data set is compared to the amount of data needed (to provide a robust business model) within the concept of CaaS.

Table 1: Available signals from five different data sources organized on a digital platform in comparison to the amount of data needed to provide a robust business model within the concept of CaaS.

| Data source   | Frequency (min) | Signals (sensor) | Signals (actuator) | Total data (24h) | Signals (sensor) | Signals (actuator) | Total data (24h) |
|---------------|-----------------|------------------|--------------------|------------------|------------------|--------------------|------------------|
| BMS (SAIA)    | 1               | 520              | 206                | 1 045 440        | 476              | 164                | 924 480          |
| DCV (Lindinv.)| 1               | 2202             | 391                | 3 733 920        | 2202             | 391                | 3 733 920        |
| Space booking | 60              | 1                | 0                  | 24               | 1                | 0                  | 24               |
| Weather data  | 60              | 19               | 0                  | 456              | 13               | 0                  | 456              |
| EMS (Energip.)| 60              | 22               | 0                  | 528              | 22               | 0                  | 528              |
| Summary       |                 |                  |                    | 4 780 344        |                  |                    | 4 659 384        |

The new digital IoT-Edge platform collects and organizes 4.78 million data points every 24 hours. Depending on the future process (for making use of data), up to 97 percent of the available signals could be relevant for future decision making within the concept of CaaS (97 percent of the signals are somehow connected to the target Energy efficiency and load management).

4. Conclusion
CaaS is a concept combining the interests of the customer; a good and verified indoor climate quality, with the interests of the stakeholders, in this case study Akademiska Hus; to accelerate the energy savings by providing full incitement for energy investments and implementing Big data technologies for building optimization. It is a business model with a great potential reducing the greenhouse gas emission while increase the focus of indoor environment quality.

In this case study is the ICQ defined and regulated as the radiation- and air temperature; a very limited part of the spectra of IEQ, but a good representative of what IEQ key parameters it is possible to verify based on existing digital infrastructure in a typical office building. This case study highlights the importance of the type of sensor; even with one sensor (temperature, pressure, state, presence) every five square meters, the existing digital infrastructure is insufficient when it comes to monitoring,
according to studies, two of the most important indoor key parameters within normal office conditions; the CO2- or the VOC-level [6].

A conclusion is that future implementation of CaaS cannot solely rely on existing digital infrastructure (sensors) and must be flexible to new sensors and data sources. The ability for upscaling opens great opportunities and great potential to expand to other services, such as space management (in the context of energy- and load management).

This study reveals the great potential in the streaming data based on existing digital infrastructure, but also the difficulties exporting the data to ensure the quality of the data. Yet the sensor system in a BMS is designed for control purpose and not for the implementation of AI. There are e.g. no redundant measurements which increases the sensor faults: sensor faults could be accepted as a true value. As a result, sensor faults have strong impact on overall automated fault detection and diagnosis (AFDD) accuracy and false alarm [3].

Combining streaming data from different sources opens great potential for optimization within systems that previously worked in isolation. However, ad-hoc analyses on the existing data-set (Table 1) does not reach beyond the expertise of a domain owner, in this case, an energy engineer, and Ad-hoc analyses would exclude the potential for Big data computing. Without any knowledge about future data processing (e.g. the implementation of different methodologies for processing of data), it is very difficult to evaluate the potential of the data. Studies have for instance shown that by implementing deep reinforcement learning (an under category of artificial intelligence), the amount of necessary sensors can be reduced to three, and till achieved 20 % in energy saving s in a large hot water system [7].

The potential in the digital transformation and in the data-set depends on several aspects:

- Future methodology for processing the streaming data
- The quality of the data
- The flexibility of the existing infrastructure (such as HVAC) to adapt to the new settings (from feedback signal).
- The ability to include more data sources (such as sensors or data sources)

The study has shown significant potential for implementing the CaaS concept in larger districts or even real estate portfolios. Future studies should analyze and evaluate the amount of signals needed for decision-making after implementing data analytics or artificial intelligence.

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