Visual Analytics for Energy Monitoring in the context of Building Management

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***Abstract*—Building management systems (BMS) provide monitoring and control of most large-building assets (heating, ventilation, air conditioning, lighting, security systems, and so on). With the recent advancement of the Internet of Things and data management systems, BMS must gather and manage increasingly detailed data coming from a greater number and diversity of sources. The availability of such data should help building managers optimise the energy consumption of buildings. However, current BMS don't allow efficient visualisation of such data, which means that even if the data is available, it is not used to its full potential. In this paper, we describe a prototype BMS interface providing interactive visualisations of traditional building data (temperature, energy consumption), as well as more novel data (comfort feedback from occupants and live occupancy). We evaluate this prototype by first showing how it could be used to plan a long-term energy saving strategy, and then in a feedback session involving facility managers at a university.**

***Index Terms*—building management, visualisation, energy consumption, visual analytics**

I. Introduction

Building and facility managers are in charge of the monitoring and maintenance of large facilities, like university campuses, hospital or office buildings. With the rise of Artificial Intelligence, the evolution of the data management system and also the development of the Internet of Things, their role has changed and has greater potential to focus on energy efficiency [34]. In modern buildings, thousands of sensors continuously produce data. These data are then centralised by the Building Management System (BMS), which stores the data and allows it to be visualised to help building managers in day-to-day monitoring but also in the planning of long-term energy savings strategies.

However, to date BMS do not take full advantage of this increasing amount of data and don't provide effective visualisation [36]. By combining data from different sources, visualisation has the potential to give building managers an understanding of buildings' operation with a higher resolution.

This is a classic data analysis problem that could be tackled by visual analytics, which is defined as the combination of automated analysis techniques and interactive visualisation to improve the understanding and the use of large datasets for decision-making [17]. In this paper, we propose to apply such techniques to this specific problem and present a prototype system that proposes different interactive visualisations aimed at helping building managers.

In our research, interviews and observations of facility managers at a large university campus provided the requirements that led to the design of these visualisations. We first evaluated the system by showing how it could be used in the planning of an energy saving strategy based on live occupancy data. Then, we conducted a feedback session with building managers of the same university. They found our visualisation easy to understand and helpful as it allows them to draw new insights about their buildings' operations and efficiency.

II. Motivation

We followed an Activity Centred Design process [20]. It consists of involving real end-users throughout the design and development phases, and understanding their tasks and their environments.

The role of Facility Managers is to make sure that buildings are operating well and efficiently without compromising occupants' comfort. To have a better understanding of how they complete these objectives, we performed several interviews with facility managers from a large university. In this particular case, the facility managers need to make sure that staff can conduct teaching and research effectively. For example, if a researcher needs to use an electron microscope, they will make sure that the building has the capacity to fit and service it, and that the building operation won't have any impact on the sensitive instruments.

The facility management division of the university is divided into three subdivisions: Monitoring and maintenance, Project

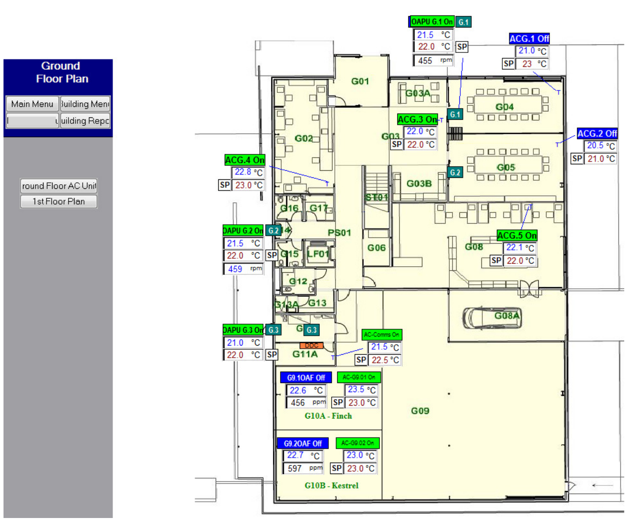

Fig. 1. Screenshot of the current BMS system of the university. This page provides monitoring information regarding the AC units of a building using a map-based visualisation.

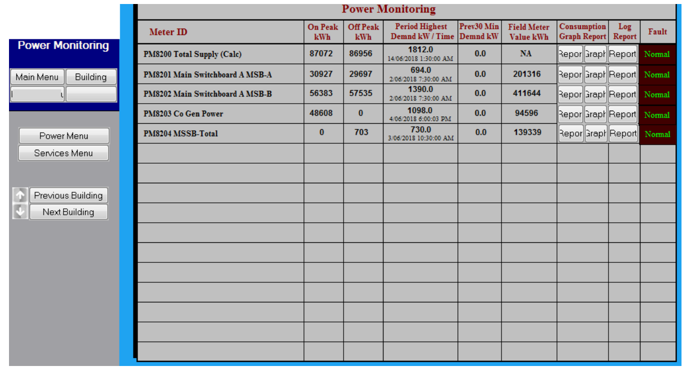

Fig. 2. Screenshot of the current BMS system of the university. This page provides monitoring information regarding the power meters of a building using a table.

delivery, and Planning. While the first one needs to be very reactive and work on day-to-day issues, the second and the third need to have a global understanding of the buildings and to have a long-term vision in order to, for example, plan future energy-saving strategies and cope with changing occupancy and use.

The monitoring of the Heating Ventilation and Air Conditioning (HVAC), lighting and security systems is done by the Building Management System (BMS). It can be considered as the brain of the building, it collects all the data coming from these systems and other sensors, centralises these data and allows facility managers to act on them. However, in our interviews with facility managers it became apparent that they considered the BMS interface as being overly complicated, and that it does not allow easy visualisation and analysis of historical data.

Large volumes of historical data about building behaviours are then stored but rarely used. Nevertheless, facility managers admitted that such data could be useful. Historical data could be used to understand the building operation, which could then inform the design and planning of buildings and be used to optimise the performance of the building both in space utilisation and energy efficiency. It could also be used to predict its future behaviour (e.g. a plant failure, or future energy consumption). Typically, when asked for information about the operation of a building, the facility managers create a summary of the energy consumption of one building by downloading the raw data from the BMS and then they visualise the results in Excel spreadsheets.

The current BMS makes accessing data for generally inquiry very difficult, for example, the facility managers would like to be able to easily be able to take a detailed look at the operation of specific assets and spot operational inefficiencies, but currently do not do this regularly as it is far from a casual undertaking. During one interview, we asked them to demonstrate their current process for downloading such data. When having a look at the data with one of them, we spotted a period where the boiler and the chiller for a specific building were functioning at the same time. Such operation is not rational and should be investigated - the fact it became apparent through such casual inspection raises concerns that the current difficulty of accessing the data is hiding many such problems.

In addition to interviews, one facility manager took us on site to see the entire HVAC system of one building and showed us the different assets: the AC units, the physical controllers, and the plants (boiler and chiller). This helped us a great deal in understanding the overall process and showed us the importance of the context. The users confirmed this during interviews, as they told us that they prefer using map-based visualisation with data overlays (See Figure 1) to Excel spreadsheets which lacked visual information and contextual data (See Figure 2).

Finally, the comfort of occupants is a concern for facility managers, especially in a university in which students and researchers are required to work in rooms for long hours. However, for now, the only data collected that is relevant to comfort is the inside temperature of rooms. Thus, there is no account of the variation of comfort across individual occupants. One occupant could feel comfortable at 20°, but another could feel chilly. It also doesn't take into account that in a big room the temperature at the location of the sensor could be very different from the temperature at another location of the room, such as just near the window. To take all of that information into account would mean to improve communication with occupants, to allow them to send feedback regarding their comfort. It is possible in the university for the administrative staff to send requests regarding heating and cooling comfort to facility managers. However, it is for now mainly used for maintenance requests and is far from a finely-grained census.

III. Related Work

Researchers believe that building automation systems (BAS) will become more and more "intelligent" in the coming years [34]. This is due to hardware evolution which allows facility managers to install more sensors that collect more—and different types of—information. But it is also driven by the development of new algorithms and data structures to manage and analyze big volumes of data coming from these sensors. Gerrish *et al.* support the idea that the main factor driving this change is the use of Building Information Modelling (BIM) as a tool for building management [15]. BIM is a collaborative technology which brings together different information regarding a building (such as the 3D model, design requirements, material characteristics, etc.) useful during its lifecycle [24]. For now, it is mainly used in the design and construction of buildings, however, it can be used to efficiently compute and predict building energy performance. This change means that new visualisations and interfaces should be provided to allow building managers to work effectively with these potentially complex data models.

However, there is little research that explores the general design of such interfaces and visualisations. Rather, existing work mostly focuses on specific tasks, for example: asset management, and how the use of 3D visualisation could ease identification and provide better contextual information [27], [31], or on how to use virtual reality to improve realism [11]. Others focused on visualisation for monitoring sensor data. Again, researchers explored the use of 3D which should help operators understand the data in the physical geometry and context of the building, and thus gain better situational awareness. Hsieh and Lu compared the use of 3D contextual visualisation (3D building model overlaid with sensor data) with non-contextual visualisation (2D scatterplot and bar charts) for a sensor monitoring task [16]. They showed that the 3D contextual visualisation led to better performance. However, the authors didn't test the use of 2D contextual visualisation. By contrast, Yang and Ergan compared tabular, 2D and 3D contextual visualisation for a sensor monitoring task and showed that the use of 2D and 3D visualisation improved completion time and accuracy compared to tabular only representation of the data, but no differences were found between 2D and 3D visualisations [36]. Attar *et al.* argued that using a 3D model should be better for visualisation as it allows the visualisation of values, for example, through surface shading to highlight room features, which should provide better contextual information to the building manager [3]. McNamara et al. focused on the use of 3D to visualise a summary of sensors data (gas detector, HVAC system and occupants' trajectory) [22]. They explained how, additionally to an event quiltmap, it was used to discover patterns of gas contamination. One example of a more complete visualisation for FM is *Thermoostat* presented by Sangunetti et al. [28]. The system is based on Participatory Thermal Sensing (PTS), which means that in addition to sensors, the system visualises qualitative feedback from occupants. It provides a good understanding of the relative comfort of occupants in each building. This information is visualised in a table and a summary is visualised through an overlay of the 2D floorplan.

While visualisation for building management has not been thoroughly explored, more focus has been put on visualisation of energy consumption. This has been considered as an efficient way of making people aware of their own consumption [1], and thus, motivating them to adopt energy saving behaviours [33]. Studies focused on developing the guidelines to create such visualisations: it should be updated frequently, over a long period, and it should also be clear and appealing (thanks to the use of contextual visualisation like floorplans). Furthermore, the visualisation should allow comparison between periods, appliances and specific goals. Finally, visualisation should allow people to spot patterns and link the consumption to their own habits [4], [5], [14], [26], [35]. Most of the proposed visualisations focused on "smart home" applications. Chiang *et al.* compared different visualisations (Numerical, Analogue and Ambient) in a difference spotting task [7] and showed that Numerical visualisation led to better response time and accuracy. Masoodian *et al.* proposed a new visualisation that brings together pie-charts, time series and contextual information to provide a better understanding of energy consumption to the user [21]. Monigatti *et al.* proposed a meter visualisation which provides present and past values [23]. Finally, Ellegard and Palm proposed a more complex visualisation which consists of a visual diary of household consumption, and that allows occupants to understand better their temporal use of energy [12]. Adding interaction to such a visualisation can improve user engagement, as shown by Costanza *et al.* in their paper [9]. In addition to energy consumption visualisation, users were able to annotate the visualisation and simulate different scenarios.

Other visualisation systems focused on energy consumption of more complex buildings like university campuses or office buildings, which requires support for a much greater volume of data [18]. Timm and Deal evaluated the efficacy of a central energy dashboard in a campus [32]. The dashboard provided information regarding the present and past consumption, and a comparison with a previous period, and was visible by everyone in the campus. It led to a decrease of 7-10% of energy consumption and was used by facility managers to assess the impact of energy saving strategies. Kim *et al.* proposed a more complex visualisation composed of a geographical map which overlaid real-time consumption using color for each building and time-series graphs for temporal consumption [19]. Soni and Lee provided similar information in their visualisation but with a higher resolution as they overlaid the information on floorplans [29]. Instead of overlaying energy usage on the floorplans, Attar *et al.* chose to overlay data that is more meaningful for the user, such as air temperature [2]. This choice is beneficial for building managers, as well as occupants themselves, as it has a direct meaning for them. Another way to better engage people is to allow interaction with the visualisation. Spence *et al.* went in that direction with their collaborative energy visualisation for the workplace [30].

Fig. 3. The home view of our proposed visualisation system provides a campus map that allows users to select a building

Fig. 4. Screenshot of the building view, it provides a link to the energy and comfort dashboard for each room. It also displays the position and status of the HVAC assets. By clicking on an asset, the user can display specific information (Status, Inside temperature and Set Points in the case of HVAC)

Users could annotate visualisation and were provided a virtual space to discuss energy related issues. The use of the system led to a decrease in energy use and a better engagement from users on energy issues.

To sum up, the use of visualisation for Facility Management has been investigated mostly for specific tasks (Assets management and sensors monitoring), but not with a global approach to integrating large volumes of heterogeneous data to ease daily building management while also considering the planning of energy saving strategies. The closest example of such system is Thermoostat, however we go one step further by adding occupancy data to occupant feedback and we show how this helps the design of one energy saving strategy. Our visualisation is based upon the different guidelines regarding energy consumption visualisation enacted in the literature. It uses clear and appealing visualisation, is based on time-series and contextual floorplan visualisation and allows comparison with previous periods. Our research is starting to explore the use of 3D for such visualisations, however, because it is not clear how it impacts the understanding of the situation, we chose not to use it in the system described and evaluated here.

IV. Prototype

Following the Activity-Centred Design process, we use the interviews and observations performed with building managers to lead the design of several visualisations which are integrated into one prototype. It was implemented in HTML+CSS and JavaScript and used real data provided by the building managers of the university.

A. Data Management

Our prototype can manage different types of data:

- Sensors data: These are physical measures provided to the BMS by sensors placed in fixed locations in the buildings. The sensor measure temperature, energy consumption, chiller and boiler demand, etc. Each sensor is linked in the system to a room or a group of rooms.
- Location data: These are the live position of occupants in the building, providing real-time occupancy data for each room. Because GPS is not available for indoor location, an additional system needed to be installed. We choose the Honeywell Vector Occupant App solution [1] which consists of bluetooth beacons that triangulate smartphones that have the specific application installed. For the purpose of another project, the solution was installed in one building as part of a trial, so the data was available only for that one facility.
- Comfort feedback data: These are subjective feedback sent by occupants of the building about inside temperature. The data is a 5-points rating that goes from cold to hot. This functionality was provided by the Honeywell Vector Occupant App solution, which allows us to attach a precise location to each piece of feedback.
- Timeschedule data: These concerned mostly classrooms, and consist of the schedule of classes for each room.

B. visualisation

Interviews and observations showed that even if the current BMS already gathers most of these data, they are not visualized efficiently. We implemented visualisation that combines different data sources and provides building managers with new understanding of how the building operates.

First, a campus map allows the users to choose the building they want to visualize (Figure 3). It leads to a floorplan of the selected building with the possibility to switch between floors if necessary (Figure 4). The floorplan provides links to both energy and comfort dashboards, it also displays each sensors' position on the floorplan. Users can click sensors to display a tooltip with the current state and a plot of previous value (Figure 4).

The energy dashboard consists of a summary of different information regarding a specific room (Figure 5). It provides energy consumption for the current month, with a comparison with the same month of the previous year and a particular consumption target (Figure 5-a). It also provides a summary of the comfort feedback sent by the occupants for this room, with the specific number of negative feedback, and the evolution of the amount of negative feedback compared to the same month the year before (Figure 5-b). Both displays are complementary

[1] https://buildingsolutions.honeywell.com/en-US/solutions/Vector

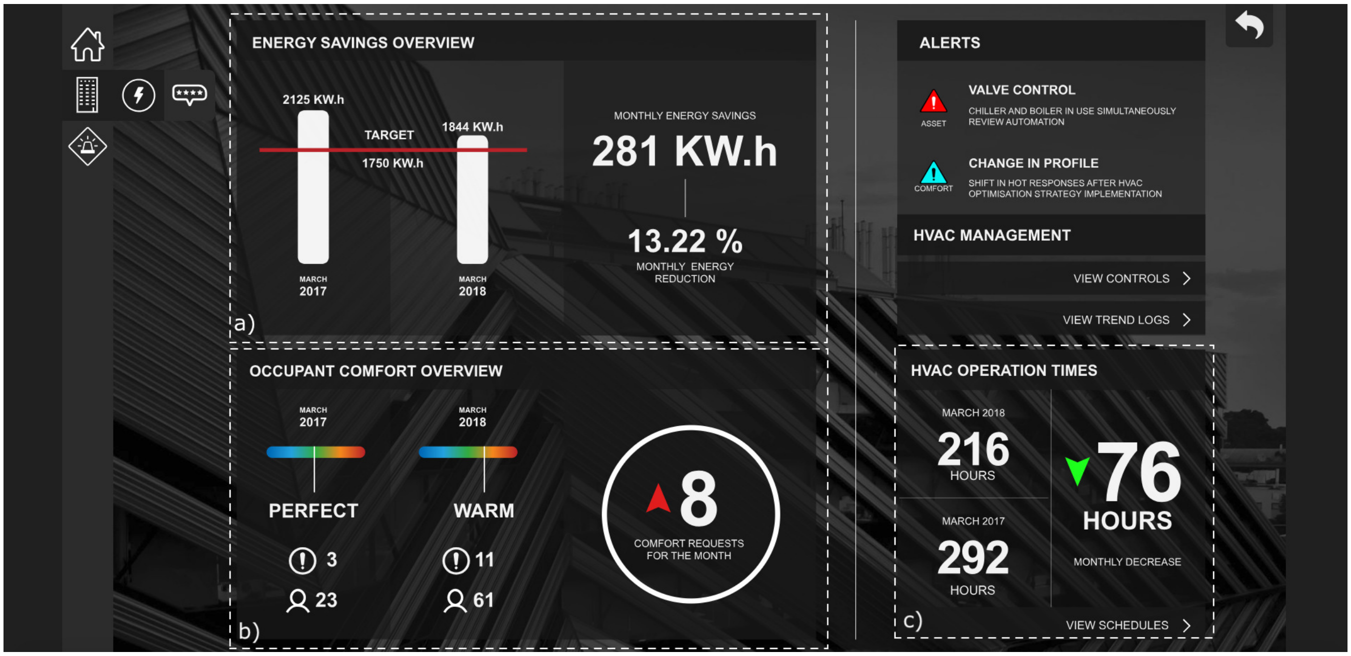

Fig. 5. Screenshot of the energy dashboard. It provides, for one room, an overview of the energy consumption (a), the comfort level (b) and the HVAC operation times (c). Dashed lines added for illustration purpose.

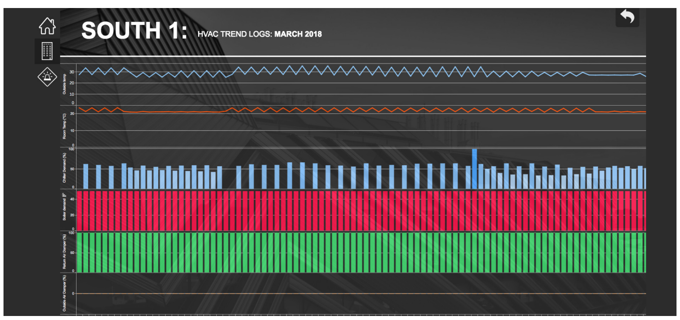

Fig. 6. Screenshot of the trend log which provides a visualisation of the time evolution of technical parameters

as they allow users to understand the impact of energy savings on occupants comfort. In that case, a saving of 13.22% of energy led to an increase of 8 negative feedbacks. It is then the building managers role to understand if there is a causality link and to act on it. Finally, It displays different technical information: alerts, access to HVAC control and data regarding the HVAC system, and a summary of its operation period with access to its schedule (Figure 5-c). Again, the main information (i.e. the HVAC operation time) is clearly presented here to provide an overall understanding of the situation to building managers. In this case, the saving of energy is probably due to the decrease of the operation time of the HVAC system for this room. However, it is also probably the cause of the increase in negative feedback.

By clicking on ”View Trend Logs” on the energy dashboard, users can visualise time series of different technical variables specific to the room (Figure 6). In this case, it shows inside and outside temperatures, and the boiler, chiller and air damper demands. By hovering on the visualisation, users can access the detailed value. The information is presented in parallel to help users understand the effect of the different pieces of technical equipment and the outside temperature on the inside temperature, and more generally on the occupants' comfort. By clicking on ”View Schedule”, users have access to the HVAC operation schedule (Figure 7). It showed for the current week, the period the room had been conditioned and the room occupancy (fully occupied, less than 50% and empty). Occupancy, in that case, is calculated using Honeywell Vector Occupant App data if available and time schedule else. This schedule allows users to understand in which period the room is conditioned while not used, but also when it is conditioned and under-used. Such findings could then enable the building manager to relocate a specific meeting or class, which will require less energy to conditioned.

The second dashboard provided by our prototype is the comfort dashboard which provides a monthly overview of comfort feedback provided by occupants (Figure 8). On the left of the screen, the distribution of each feedback is displayed for the month, which in this case show that most feedback is positive. However, there is a fair amount of Cold/Hot feedback. On the right, the indoor location distribution of comfort is displayed on a floor map. The temperature at different locations of a large room, like the one in this example, can significantly vary, and even if the temperature measurement by the sensors matches the setpoint, location far from the sensor can differ by several degrees. Such visualisation helps building managers understand the thermal behaviour of the room and modify the HVAC operation to provide better thermal comfort, like change

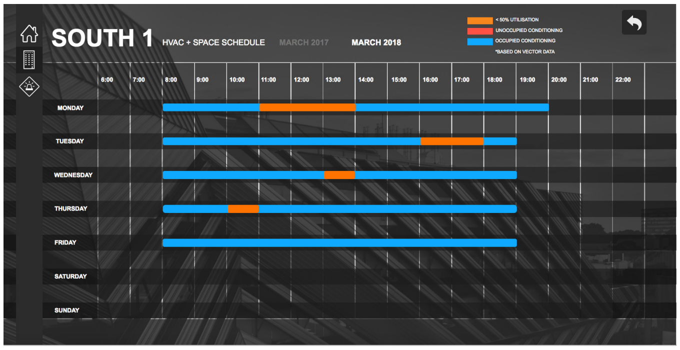

Fig. 7. Screenshot of the HVAC schedule which provides a visualisation of the operation time of the HVAC as a function of the occupancy of the rooms

a setpoint or add or remove an AC unit. For example, here we can notice that cold feedback come from people located close to AC units, which means that the setpoint may need to be raised up. It is possible to display this distribution for a shorter period using the slider at the bottom left; the white circles separate the different weeks.

The different visualisations presented in this section are not new. However, the demonstration of how they can be used in the context of building management is, and this is the contribution of this paper.

V. Evaluation

The evaluation of our system was done in two steps. As a first step, we explain how our system could be used to plan an energy saving strategy. Then, we did a feedback session with the facility managers interviewed previously during which we showed them our prototype.

A. Planning and monitoring of an energy strategy

Additionally to daily monitoring of buildings behaviour, building managers are in charge of the planning of long-term strategy for buildings operation. To do that, they need to understand the current behaviour of the building, which measure is influenced by which actions and to be able to compare the building performance before and after the start of a strategy. These can be done using our prototype.

Using our prototype, we looked at the HVAC operation schedule of a lecture theatre combined with the class schedule. We noticed that it was conditioned during a period when it was not used (Figure 9-green). We talked about this with the university building managers who explained that it would not be possible to condition a room when it was used as it would put too much pressure on the system to fully reconditioned a room in a hot/cold day, and it would be very slow (Figure 9-blue). After discussion, we concluded that if such a solution was not possible. It would be however possible to adopt a more effective strategy that would take into account HVAC system capacity and occupant comfort, as the dynamic setpoint strategy (Figure 9-orange) [10].

The Dynamic setpoint strategy consists of bringing setpoint closer to outside temperature when the room is unoccupied. It leads to energy savings since to condition a room to a temperature closer to the outside temperature requires less energy. Setpoints can be chosen manually by building managers, in that case, ”unoccupied” setpoints shouldn’t be too far from the ”occupied” one, else it could take time for the inside temperature to reach the appropriate setpoint when the room is occupied, and thus be uncomfortable. It is also possible to let the BMS chooses the ”unoccupied” setpoint, in that case, it can take into account outside temperature, thermal characteristics of the room, and subsequent planned occupation to select the optimal setpoint which saves as much energy as possible without compromising comfort.

Using simulations, Dobbs and Hencey showed that such strategy could lead to 27% energy savings. However, the ”unoccupied” setpoints should be chosen carefully to avoid uncomfortable rooms [10]. They also simulated the use of a predictive HVAC control strategy which predicts occupation using a stochastic model to precondition rooms before their use. It leads to fewer savings (19%), but is more comfortable for occupants.

After the implementation of any strategies mentioned above, our prototype would allow building managers to monitor their efficiency easily. Comparisons of energy consumption and HVAC operation time with the same month the previous year could give a rough idea of the savings. The trend logs would provide more insights into how the strategy affects the operation of the different assets (Chiller, Boiler, etc.). Finally, the impact on occupants’ comfort could also be monitored thanks to comfort feedback. Building managers can see if the implementation of a strategy lead to more negative feedback than the same month the year before, and adjust it consequently.

B. Feedback from experts

A one-hour feedback session was done with three facility managers from the university. First, we presented the different functionalities of the prototype. Then we discussed around 3 topics:

- What do you think about the usability of the prototype
- How the presented visualisations could help you in your tasks
- How could you improve the presented visualisations

a) Usability: Overall, the three facility managers were positive regarding the usability of the prototype. They found the interface easy to understand. It seemed clear how to activate the different functionalities. The dashboards were not overloaded with information, and the visualisations were easy to understand. However, They commented that the navigation to a specific building on the campus could be confusing for someone who doesn’t know the position of each building and that a search field could be helpful. They also found the meaning of the two icons that lead to the dashboards not obvious enough.

b) Functionalities: They found that the presented visualisations could be very helpful in some of their tasks. The summary provided by the energy dashboard allows a

Fig. 8. Screenshot of the comfort dashboard which provides a summary of the comfort feedback sent by occupants

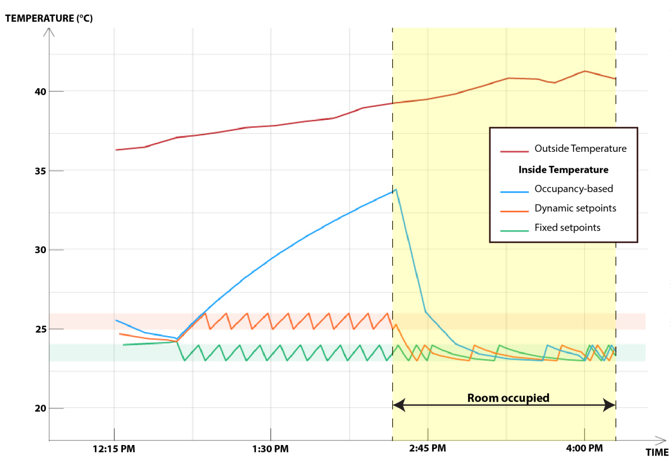

Fig. 9. Impact of the HVAC strategy on the inside temperature in function of the outside temperature. The blue curve represents an occupancy-based strategy, the orange one the dynamic setpoints strategy and the green one the fixes setpoints strategy.

straightforward assessment of the performance of a building. However, they found that visualisations of comparison were not consistent, which could be confusing, some are absolute and other relative. Maybe we should present both at the same time. They liked the trend log and the fact that its layout (several charts in one column) allows a natural association between the different measures and see causality between them. They would like to be able to rearrange their order, as some are more useful in some contexts and not in others. They also liked the HVAC schedule, one of them admitted that he never thought of looking at the HVAC operation in function of the occupancy of rooms (by using schedules and the booking system); but that it could be helpful to spot opportunities to optimise HVAC operation. Finally, regarding the comfort dashboard, all the three of them thought that it could be beneficial for space management. They also believed that it would be good to help guide maintenance work and to help operators spot technical issues when they notice specific patterns. For example, when a room always receives negative feedbacks, it may hide a technical problem with the HVAC system. However, they found that they would need to be able to get a little more details regarding the feedback, like the time and the inside temperature at the time of the feedback.

c) Improvement: Finally, they made lots of valuable comments about what could be improved in our interactive visualisations. First, they suggested we add real-time "monitoring" information regarding building on the campus map. For example, to display for each building the number of activated alarms, it could allow the operator to grasp important information very quickly. Then, on the main page of the energy dashboard, they would like to be able to customise and dig into details of the consumption. For example, to compare the current week with the previous one, or the current month with a specific month, while now, be default the comparison is done only with the same month of the last year. They also suggested that information regarding factors that could influence energy consumption should be added, like average outside temperature during the day.. The same request for customisation was expressed for the trend log; operators should be able to apply different filters directly to the data, and finally to be able to export the visualisation to an image format.

VI. Conclusion

In this paper, we presented a prototype of a building management system which takes advantage of a multitude of data coming from different sources to provide insights regarding energy efficiency and occupants' comfort. The design was driven and evaluated by interviews with building managers of a major university. Feedback sessions with expert users showed that the designed visualisations were easily understandable for them and could be quite useful in their current tasks. By combining different data sources, it provided them with insights that are difficult to get with current tool. It also showed how new types of data could be used to provide a better understanding of occupants' comfort.

We next plan to explore two different directions. The first one is the use of 3D visualisation as it has already been envisioned in the literature [2], [16], [36]. 3D visualisations of buildings with information overlaid on top of it could provide better situational awareness to building managers and help them to monitor the building but also to assist with planning. In addition, we will explore the use of immersive technologies (e.g. Virtual and Augmented reality, wall-sized displays) and how immersive analytics could be beneficial in such contexts [6]. The use of immersive technologies has already been shown to be beneficial for monitoring in other contexts, like road traffic management [25] but also for visualisation of abstract data [8]. Augmented reality could also be useful for building managers to display various data in-situ when they are in the field, as has been envisioned by Ens *et al.* [13].

The second direction we will explore is the use of machine learning to predict the inside temperature of a specific room as a function of the different parameters that have an influence on it, like outside temperature and occupancy. Such prediction would help us find the appropriate setpoint to apply in any situation in order to optimise energy consumption without affecting occupants' comfort. Such prediction was previously done using a thermal model of buildings [10], however, the complexity of such a model makes it difficult to fully realise, which leads to imprecision. Using machine learning with historical data would probably be more accurate and allow a better optimization.

The two directions are of course very linked with each other. More optimization will lead to more complex automation done by the BMS, however, building managers have to make sure that decisions taken by the BMS go in the right direction. Well designed visualisation should provide such understanding, and thus, keep building managers in the loop.

VII. Acknowledgment

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