# Using IoT and Cloud Based Analytics to Maximise HVAC Efficiency and Occupant Comfort and Safety

David Keightley, CEO Ecospectral Pty Ltd, Lachlan Birnie (Embedded Systems Engineer)
Unit 4/106 Mawson Place, Mawson, ACT 2607
David.Keightley@ecospectral.com.au
Lachlan.Birnie@ecospectral.com.au

## ABSTRACT

Sensing capabilities combined with data analytics is recognised as a powerful avenue to lower the cost of HVAC in buildings and to track system efficiency, system wear and repair scheduling. With new renewable energy supplies, battery storage systems and smart distributed electrical grids, HVAC systems need to respond to power load shedding and load shifting in highly flexible and more responsive ways that require additional information about customer needs and usage patterns.

Complementary data can contribute to significant HVAC flexibility and savings providing significant benefits to both customers and manufacturers. By tracking human activity along with energy, noise analysis and temperature within the building, facility managers and building occupants gain critical insight for planning, optimal space usage and behavioural changes resulting in happier safer occupants and significantly more efficient buildings.

This is accomplished by using existing and new sensors deployed throughout the building in a 3D mesh of sensing and control capabilities. Distributing intelligence throughout the building using new internet of things (IoT) technology, coupled with local open standard data and control formats and cloud based predictive analytics and artificial intelligence algorithms, the building HVAC system gains the ability to adapt to usage patterns, changes in usage patterns and equipment failure.

This paper describes that system architecture, an implementation approach and how it complements existing systems and provides knowledge to HVAC systems to satisfy both reduced energy consumption requirements, real time responsivity and occupant comfort and safety. As tolerance for $CO_2$ emissions approaches zero, this model offers significant gains for the HVAC industry to meet those goals.

## INTRODUCTION

HVAC is now responsible for approximately 60% of the energy consumed in buildings ranging from domestic through to large commercial and industrial buildings. We are now facing unpredictability in energy pricing putting fiscal planning at risk for buildings and infrastructure. It is becoming a matter of urgency to get our $CO_2$ emissions effectively to zero (or below) for our buildings. This means our HVAC systems must be more efficient.

Just putting sensors and wireless communication on our devices and labelling them part of the Internet of Things (IoT) is not going to solve the problem, in fact, it is likely to complicate the matter as marketing claims outstrip the reality of what can be delivered.

The same can be said for artificial intelligence and data analytics. Generic data analytics and cloud based AI processing must be highly focussed to achieve significant value and savings for buildings and cities. No industry knows this better than the HVAC industry as shown by publications referenced in this paper.

The architecture outlined in this paper is not driven by a specific industry. It is not designed to extend the relevance of any particular company or interest, instead it is derived to maximise knowledge and capability to multiple industries, including HVAC. It is an IoT architecture, but it is highly focused on signal capture and analysis. It is designed to capture how a building is used by occupants in real time and to provide predictive insight to systems, including HVAC, on how the building will be used in the future. There is a control component of the system model that can be used and integrated if desired.

## EXISTING HVAC MODELS

The HVAC industry has a strong history of R&D and made significant advances in efficiency whilst delivering the goals of air quality, temperature and comfort to building occupants. The sometimes-competing goals of comfort and health with savings in cost, energy and maintenance has driven intense development and research. A typical HVAC system includes a huge number of variables in a non-linear collection of systems and physical constraints.

Significant efforts in HVAC system research and development include simulation models as described in Crawley's [1] compilation of twenty building energy simulation models Winkelmann et al [2] using DOE-2 building energy analysis and many others. These simulations are based on physics and, like atmospheric or circuit simulation, run the models to examine behaviour. Analytic models are applied to individual components and subsystems and include work such as Wang et al [3] on cooling coil unit engineering model leading to significant control and efficiencies. Data driven model and computational intelligence and optimisation models have also been developed for HVAC optimisation including work by Katipamula et al. [4], Soyguder et al [5] and Wright et al [6]. Wright's work was of particular interest since it examined comfort levels and energy trade-offs. All of this work was primarily inwardly looking at the HVAC systems themselves for efficiency and reliability gains.

## SMART GRID INTEGRATION

The integration with Smart Grid systems is less advanced, but critical to moving forward with $CO_2$ reduction and reliability, but there is recent material and progress is significant. This includes recent publications by Hakima [7] and incentivisation at government levels DOE [8], corporate and individual office work levels Ratcliffe and Day [8]. While smart grid technology is being trialed and gradually implemented, the customer continues to be subject to fluctuating energy costs and grid limitations. Smart Grid technology, including smart metering is in a state of flux and while should be incorporated in plans, cannot be relied upon to return immediate benefits. At the commercial building level, the consumer is incentivised by cost of energy and fiscal mechanisms currently in place to reward the owner for participating in load shifting and shedding. Incentivising occupants is another matter and can be made part of a building management system and policies/practices of companies occupying the building.

Load shifting and shedding in response to grid needs and energy costs, smart grid or not, is critical for buildings meeting energy targets and realising cost benefits. An IoT system has the responsibility to provide the HVAC system, a key component of the potential cost savings and building occupants' comfort, the information it needs to achieve those goals, i.e. comfort and savings. Once again, an independent intelligent sensing and control system is well placed to provide this information through its knowledge base. Pre-charging a thermal mass during shoulder periods based on occupancy as well as other factors, such as pricing and weather, is a powerful practice for minimising peak load and peak charging HVAC related energy use. By using occupancy and fine grained delivery control, HVAC systems can pre-charge (heat or cool) only those areas that are likely to be occupied. Since those occupancy patterns will change day to day and hour to hour, predictive analytics on occupancy are critical to fine tuning. This approach also means that there are greater periods when the HVAC system can meet temperature and energy goals as well as maximise comfort goals. Effectively this is using IoT to assist in minimising relaxing comfort levels and enabling focused intelligent variable thresholding.

## PROPOSED COMPLEMENTARY APPROACH

As is described earlier in this paper, existing HVAC systems have incorporated significant energy saving smart capabilities and leading-edge research and development are moving ahead rapidly to further advance the state of the art. Smart Grid integration is still very much in development, but load shifting, relaxing of comfort constraints and thresholding are in use and now undergoing fine tuning. Computational approaches are a good way to reduce the complexities of nonlinear systems mathematical modelling, and offer good response and understanding.

Most current HVAC system R&D efforts fill a pie chart like the one shown in figure 1 where a slice has been deliberately left missing. These efforts focus on HVAC system data analysis in relation to system component and whole system modeling. Sensing and analytics have enabled discrete HVAC subsystem modeling as well as whole system analytics, resulting in significant savings in energy, failure prediction and system tuning.

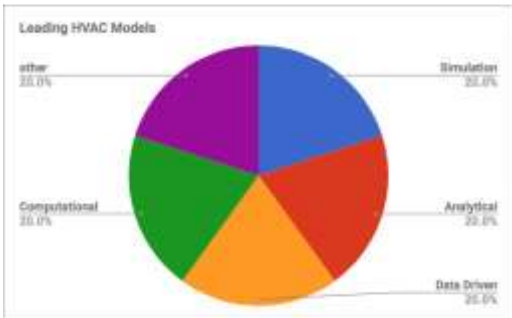


Fig. 1 *Major HVAC system models (graphic only, percentages not representative of actual usage).*

The "other" category is the one of interest in this paper and it is at least partially filled by IoT of a different nature than measuring mechanical system properties, that is occupancy patterns and related human behaviour characterisations, understanding and incentivisation. It is here that a complementary set of data can be used by HVAC systems to help drive $CO_2$ emissions to zero.

**Distributed Sensing**

Occupancy sensing is not a new technology, It has been used to build reactive lighting controls, security systems and primitive HVAC control for years, however it has been limited to controlling specific technologies including alarm systems, lighting, doors and HVAC. The control has involved real-time localised sensing. An intelligent array of wirelessly mesh connected sensors on every floor as part of an integrated architecture offers the ability to gain a clear understanding of how occupants, heat, light, sound and energy move through a building. Occupant behaviour and potential savings through analysis are the focus of this paper.

By balancing sensing, communication, control and intelligence, a 2-D array of sensors can be cost effectively deployed to provide detailed knowledge of occupancy patterns and other sensed variables in a building. A balanced system can be achieved by implementing a layered system modelled roughly on sensing, processing and control models found in nature. By distributing a low level of intelligence throughout the sensing leaves of the network, the system can make simple rules based decisions at the sensor nodes, communicate with neighbouring node, and pass key state information to the next level up in the system. This process is repeated using higher bandwidth and greater processing power resulting in a system that scales elegantly and maintains near real-time response capabilities.

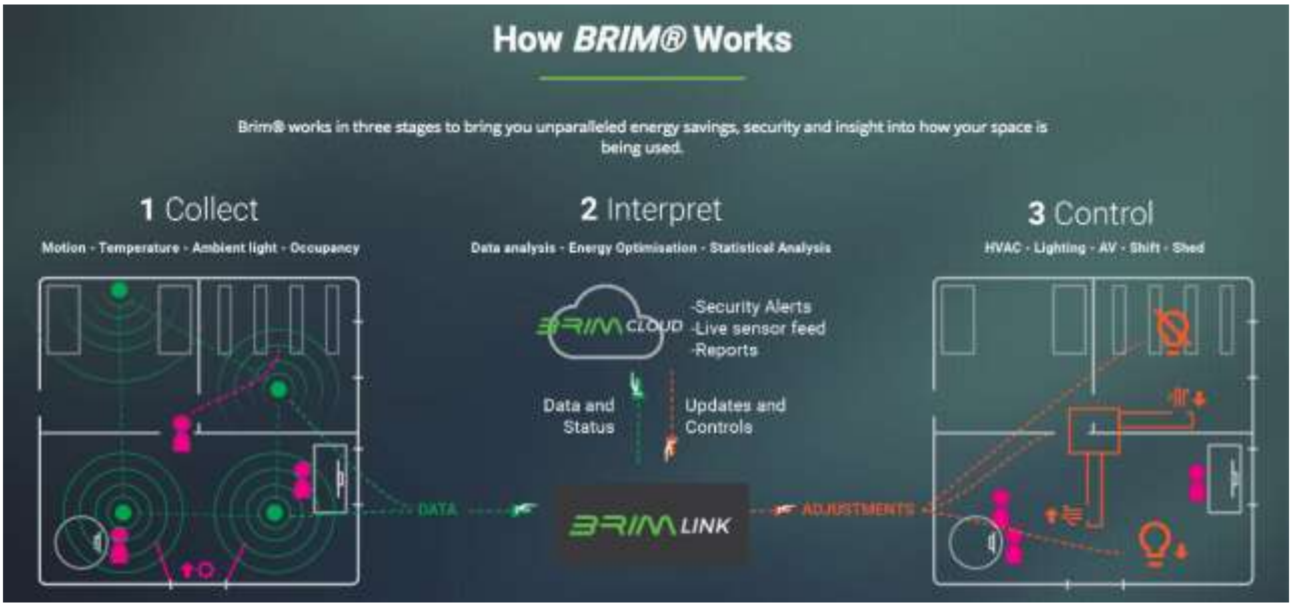


Fig. 2 *Layered System Model*

**Patterns and Prediction**

Start first by examining one floor of a building. Intelligent sensing nodes are distributed throughout the floor in individual offices, entry exit points and hallways. Since sensed motion is time stamped and passed to higher levels of the system, aggregating and processing hubs, then up to cloud based storage and analysis systems, the system is able to react locally to an event, but critically collect time of flight data and traffic density data between sensors and detailed occupancy patterns.

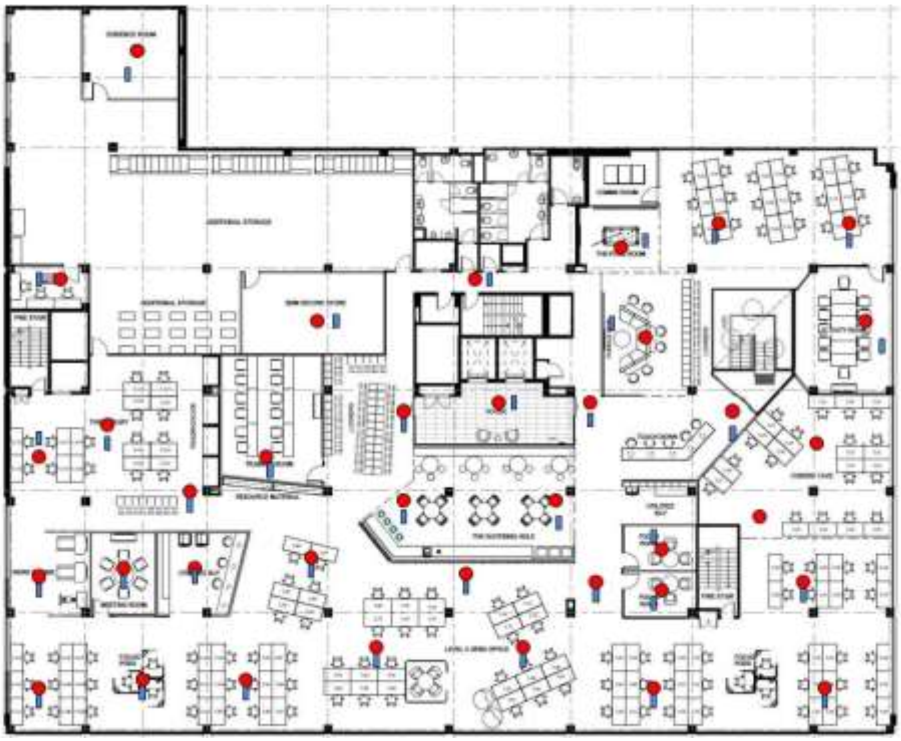

Fig. 3 *Example Sensor layout. The sensors are distributed to give excellent coverage and notification in doorways, hallways and work areas. Sensor numbers (density) can be increased or decreased to add finer resolution, however there is diminishing benefit as sensor ranges overlap and for most cases the ranges do not have to be contiguous.*

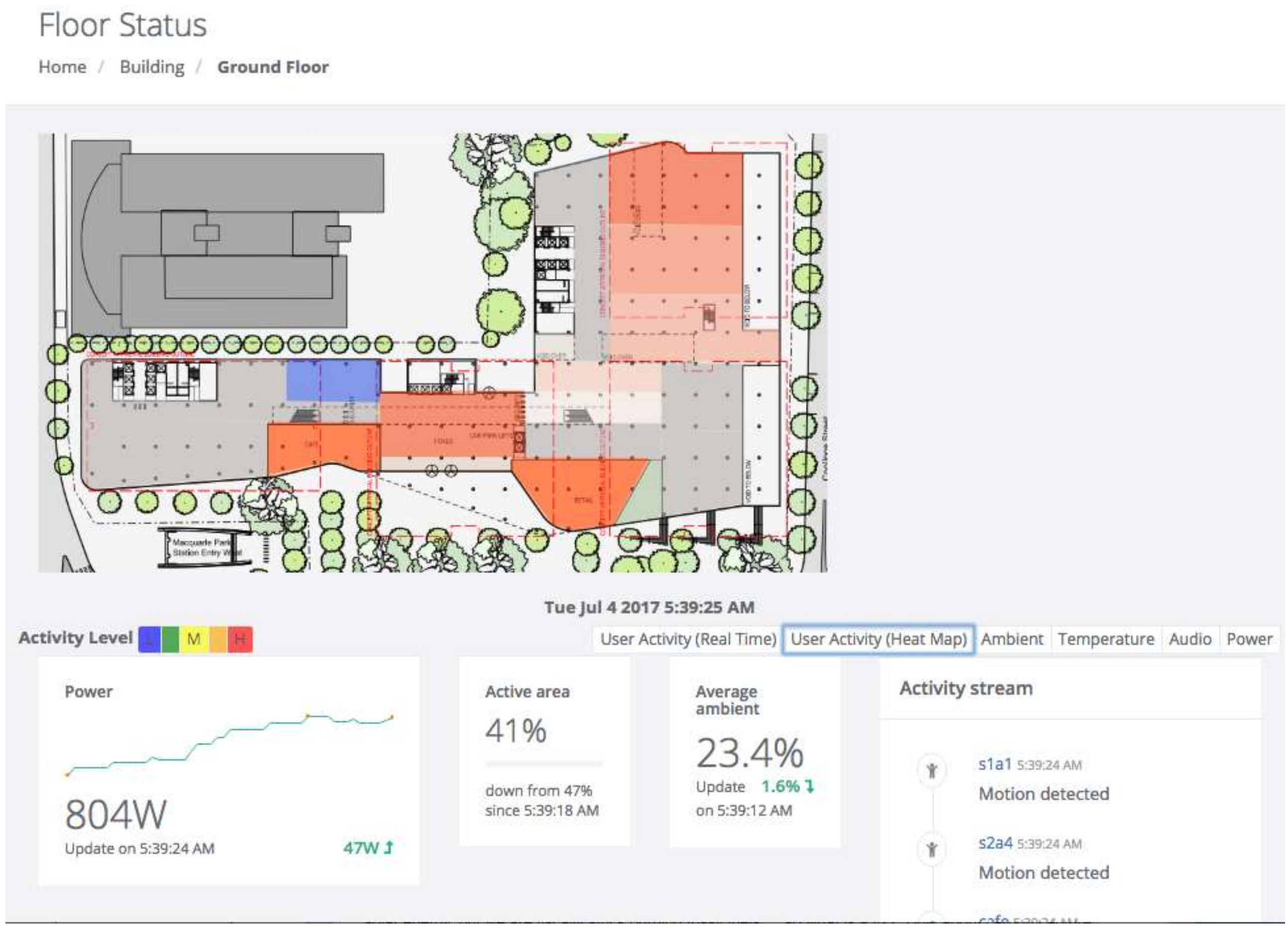


Fig. 4 *Usage heat maps per area. This feedback can be supplied to the HVAC control system to fine tune and minimise where air conditioning is used. This can be further refined*

**Integration into Existing and Future Solutions**

By taking a vendor and industry independent approach to understanding building occupancy and other data, a system becomes a cost effective component of a structure and not tied to lights or other potentially removed fixtures. Once the system is independent, the data can be collected optimally and in a unbiased fashion, thereby increasing the value to building subsystems including and critically HVAC as well as lighting, water, security and electricity.

For maximum value to integrators and HVAC suppliers, the system must use industry standard interfaces at all levels, from sensing and control through to APIs at cloud levels. Using standard APIs makes integration easier and should support both a cleaner more efficient architecture and one that's easier to protect from hacking and denial of service.

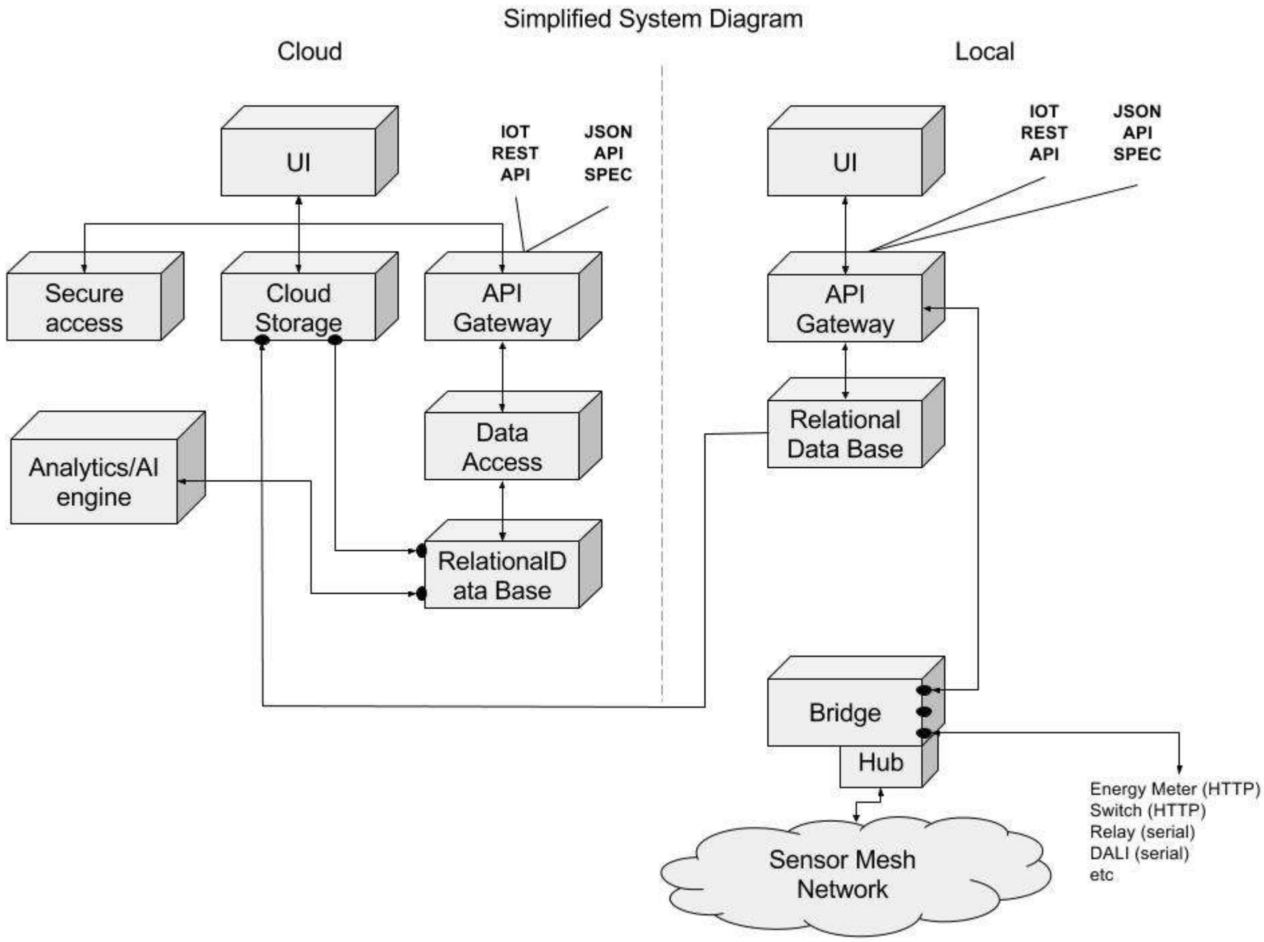


Fig. 5 *Simplified System Diagram. HVAC and BMS systems access to data through REST and JSON APIs in both cloud and in-building systems. This provides both data access, access to predictive analysis and fine grained (area/room/device level) control if desired.*

**Distributed Fine Grained Intelligence and Control**

The system architecture shown provides real time and delayed (5 minutes typical) access into motion information and physical events in the building. Not only does the system engineer and building manager now know what is likely to happen, but also what is happening. Real time in building access and control is the default capability, while delayed cloud access is the default capability to keep costs down. In case of any emergency or for critical energy related event such as smart grid load shed request or move to battery power, real-time access is available.

Consider the following scenario. The renewable smart-grid has predicted that power will decrease (weather and storage driven) at 0200 hrs. This system will inform the HVAC and power systems precisely where people are now and where they are most likely to be at 0200 hrs. If the building's HVAC and power systems are capable of fine grained control, then those parts of the building that are not needed can be shut down and those that are can have their services adjusted to meet the needs of the reduced power supply. Only those parts of the building that are occupied are serviced.

The system model supports fine grained control as well as fine grained sensing and analysis. The sensor mesh network is designed to be capable of control as well. By distributing inexpensive control capabilities to the sensor nodes, control can be performed precisely where it is needed. This control can be either split system HVAC control or VAV control. Maximum flexibility is gained if one distributes industry standard control interfaces to the lowest level of the system. This allows autonomous, semi-autonomous and fully controlled interfaces at the sensor level.

Fig. 6 A *sensor-controller configured at the lowest level to add semi-autonomous VAV control at the room level. The VAV can then react to local physical events including temperature, emergency, occupancy etc as well as be driven to participate in near real-time load shedding and shifting.*

**Benefits**

- By using a cloud connected IoT architecture, energy consumption/HVAC and service delivery is driven by and can be delivered to areas of the building that are or will be occupied
- Different rooms and area in a building can participate in load shedding and shifting to any degree. This highly flexible load shifting and shedding model using distributed intelligence and an IoT architecture. The customer may have one room that cannot participate directly next to one that can. By distributing a level of control to the lowest level a building can participate in real-time fine-grained load shedding and demand management.
- This architecture supports integration with HVAC systems at cloud level and local levels by providing an API to occupancy and other data (predicted and real-time) at both levels.
- The system model provides users with additional capabilities beyond optimising on occupancy patterns. For example, adding other sensing modalities and incorporating other web and cloud based information can further empower the HVAC system to contribute to conservation of energy.

- Flexible system model is not necessarily tied to existing infrastructure, but can be easily added to existing buildings or new build.
- Data and knowledge gained are useful for all building subsystems, emergency services and the system can be easily extended and integrated

## CONCLUSION

We have presented what we believe to be a missing piece in HVAC optimisation for building ranging from large office and industrial buildings through to residential solutions. This system model will work hand in hand with HVAC systems to optimise building for comfort and energy use. It is not "the" solution, but we believe a critical part in the complex puzzle of supplying HVAC in an environment where tolerance for $CO_2$ emissions is approaching 0. By understanding precisely how a building is used by people, HVAC services can be highly targeted both spatially and temporally. The data driven knowledge is complementary to existing system and component optimisation techniques and leaves room for significant expansion into further HVAC improvement and other building optimisation. In particular, using a fine-grained sensing and control approach with cloud level processing to optimise low level control settings can provide accurate data on candidate areas for energy savings, load shedding and shifting. If the infrastructure is in place for HVAC control at a fine-grained level, then there is significant potential for savings.

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