# PROGRESSING FROM INTELLIGENT TO SMART BUILDINGS

*A.H.Buckman,*

*Energy Researcher,*
*Department of*
*Mechanical*
*Engineering,*
*The University of*
*Sheffield,*
*UK*

*M.Mayfield,*

Visiting Professor of
Civil Engineering,
The Department of
Civil and Structural
Engineering,
The University of
Sheffield,
UK

Director,
ARUP,
UK

*R.Meijer,*

Information Commons
Manager,
The Information
Commons,
The University of
Sheffield,
UK

*S.B.M.Beck*

Professor of Mechanical
Engineering,
The Department of
Mechanical
Engineering, The
University of Sheffield,
UK

## ABSTRACT

This paper addresses the issue of the misunderstandings surrounding the terms *intelligent* and *smart* when applied to modern buildings. The terms have increasingly been used interchangeably which has led to confusion for designers, researchers and clients.

The authors propose that utilising the increasingly available information as a tool to forewarn the building control systems, rather than reacting to stimuli, can allow adaptability and a distinction between Intelligent and Smart Buildings. A case study building in Sheffield is used as a simple example of using enterprise systems to manipulate zoning of a building at predicted occupancy levels.

The results suggest that this example of information utilisation enables efficient energy and resource distribution whilst maintaining the functional value of the building and the ability for occupants to have a choice of their own environment.

## INTRODUCTION

A view of non-domestic building progression is that it can be measured through three drivers:

1. Energy and Efficiency
2. Comfort and Satisfaction
3. Longevity

Each is used here in its broadest sense and encompasses a number of contemporary terms such as energy effectiveness and well-being. With significant operating costs and “a shifting culture towards value rather than cost” (Clements-Croome 2011), longevity accounts for the financial cost of the building.

Over the past three decades, intelligent building research has evolved from definitions relating to full control of their own environment (Stubbings 1986), to being holistically “responsive to the requirements of occupants, organisations and society” (Clements-Croome 2011). The development in definition reflects the changing requirements and expectations of a building when related to the drivers mentioned previously. The change has been, for the better part, positive and can be seen as a useful progression. However, the rapid advancement of technology and research has resulted in confusion around the meaning of *intelligence* with views ranging from vernacular architecture to the most technically advanced modern buildings.

Recent research into concepts such as intelligent agent controllers (Callaghan, Clarke et al. 2009), enterprise integration and novel methods for control has provided an opportunity to define upper bounds to intelligent buildings and clarify a definition of the increasingly used term Smart Building. The increasing amount of information available to building researchers, designers, operators and occupants is at the heart of the concept, with adaptability being fundamental.

This paper will use the case study of a non-domestic building in Sheffield, which would be categorized as *intelligent*, to show how the operation could be improved, by assessing energy usage data and applying methods through which information could be used differently in order to reduce energy usage whilst increasing comfort levels, without removing occupant control.

## WHAT IS A SMART BUILDING?

Control within non-domestic buildings is a largely contested and well researched area. Buildings which are largely manually controlled can perform very well when appropriately designed for a specific context, *providing that the occupants use them in the way that the building was designed for.* Automated buildings tend to be designed to the theoretical climatic conditions, occupancy and use. Both are susceptible to decreases in performance during change of occupancy, use or climatic conditions. Smart Buildings reconcile both human control and automation in order to achieve the drivers for buildings progression. This can be achieved through the effective utilisation of the wealth of information that can be gathered from a building.

Forewarned is forearmed. *Smart buildings* make use of available information to provide a building which is adaptable to short medium and long term change. The information is acquired through the integration of intelligence, enterprise, control systems and materials and construction (see Figure 1) to create a building that is a single system, adaptable to both the function of the building and the needs of the occupants (Buckman, Mayfield et al. 2013).

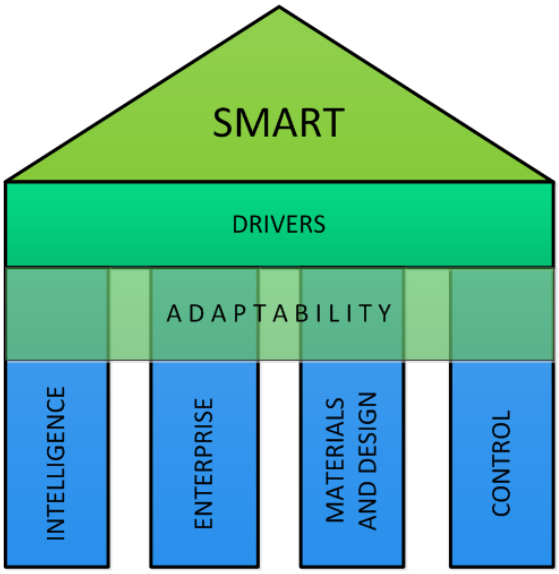

**FIGURE 1 - DIAGRAMATIC REPRESENTATION OF A SMART BUILDING (BUCKMAN, MAYFIELD ET AL. 2013)**

The four aspects shown here are seen to be existing methods through which building development has been achieved in the past:

1. the methods by which building operation information is gathered and responded to (intelligence),
2. the interaction between the occupants and the building (control),
3. the buildings physical form (materials and construction) and
4. the methods by which building use information is collected and used to improve occupant performance (enterprise)

The following case study will show a new way to approach building design to endeavour to make these aspects adaptable.

## CASE STUDY

The Information Commons, shown in Figure 2, is a multi-award winning Sheffield University building in the UK. The building could be categorised as intelligent and has an H level energy performance certificate classification.

**FIGURE 2 - THE INFORMATION COMMONS, SHEFFIELD, UK**

## BACKGROUND

When opened in April 2007 the Information Commons (IC) was seen as a unique, leading environment which provides a flexible space to facilitate learning. The building is seven storeys high with an atrium space rising through floors 1-4. The numerous, flexible spaces available for silent and quiet study are supplemented by a number of bookable small rooms and seminar rooms, as well as spaces for permanent staff offices. Besides these spaces, the building operates as The University's largest (by area) library. The building reaches capacity during most term time dates, which is testament to its effectiveness. It is open 24 hours a day, 364 days per year and is run predominantly upon electricity. The electricity-reliant building is likely to become more common in the future due to decentralised energy production and electrification of power supplies (Kyle, Clarke et al. 2010; HM Government 2011).

The building has an online room booking system for staff and students, a computer booking system for students only, as well as methods through which occupancy and the distribution of computer users can be measured.

Although the function of the building has been fulfilled, the open, flexible nature has come at a cost of inflexible energy consumption. The users of the building generate a lot of heat by nature of its function and so cooling is the primary use of electricity. This cooling is achieved via a single air blast cooler running constantly, and two chillers which are used when required. The other primary electricity use is for small power, including computing, lighting and services.

Each floor has between 3 (ground floor) and 6 (first floor) zones apart from floors 5 and 6 which are single zones. Each zone is served by a single air conditioning unit which supplies air to the zone through numerous floor grates, containing low powered fans.

## RESULTS AND DISCUSSION

### ENERGY CONSUMPTION

Four weeks have been chosen to represent key points in the academic year as shown in Table 1. The electricity metering intervals in the building are half-hourly. Figure 3 shows a visual representation of the building energy consumption over these four weeks and it can be seen that there are peak times of power consumption which occasionally breaches 200kWh, but the apparent base load power consumption, which occurs for the majority of the period, is between 80 and 120kWh. The increase from base load energy is likely to be caused be the use of small power from the plug systems and lighting, whereas the base load energy will be used for maintaining a constant comfortable environment throughout the building.

**TABLE 1 - REPRESENTATIVE DATES FOR DATA**

| # | Week Comparison | Represents |
|---|---|---|
| **1** | 3rd–9th October 2011 | Beginning of Term |
| **2** | 24th-30th October 2011 | Mid Term |
| **3** | 26th December 2011 – 1st January 2012 | Holiday Period |
| **4** | 16th-22nd January 2012 | Exam Period |

**TABLE 2 - KEY FOR FIGURE 3**

| kWh | Energy Consumption |
|---|---|
| 0 | Minimum |
| 40 | Low |
| 80 | Medium |
| 120 | High |
| 160 | Very High |
| 200 | Maximum |

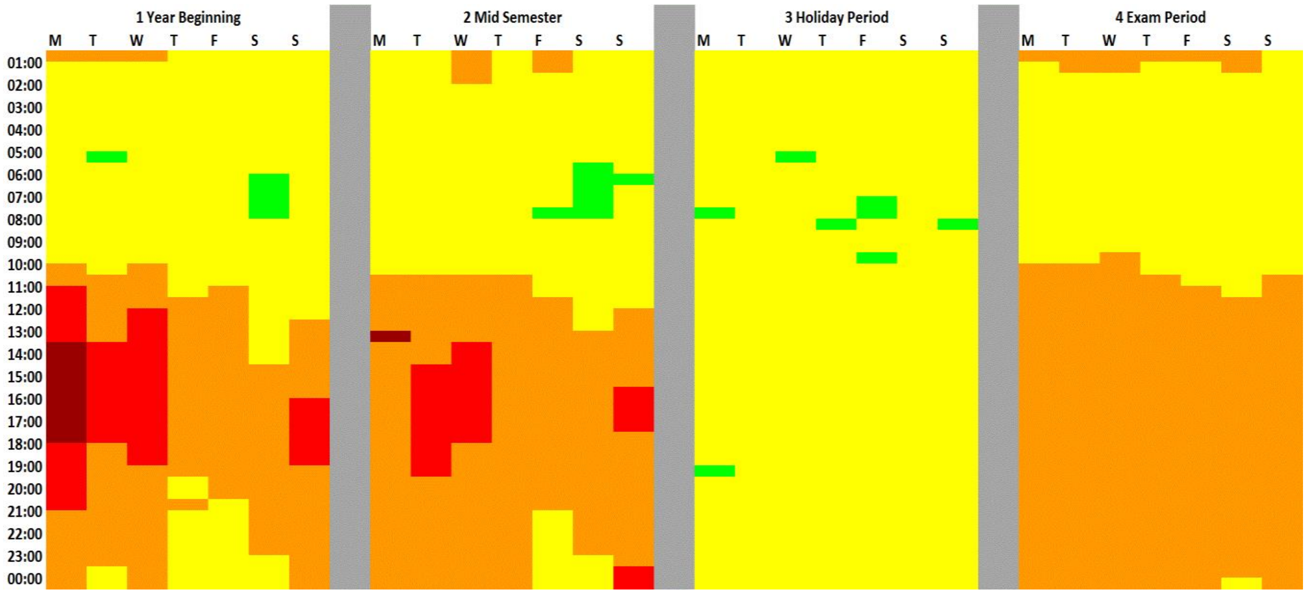

FIGURE 3 - VISUAL REPRESENTATION OF ENERGY CONSUMPTION WITHIN THE INFORMATION COMMONS

## OCCUPANCY VS ELECTRICITY CONSUMPTION

Figure 4 shows a visual representation of the occupancy within the IC during the 2011/12 academic year. The occupancy and weather data intervals are hourly. Table 3 shows the classifications related to the maximum occupancy percentage of the building capacity.

The areas that are most intriguing in Figure 4 are the sub optimal times where the building has less than 600 occupants, with the capacity for over double this. Quite often, especially in the holiday periods and early mornings (throughout the year between 03:00 and 06:00) there are less than 100 occupants, yet the building is still required to be mechanically regulated to comfortable conditions.

TABLE 3 - KEY FOR FIGURE 4

| **Minimum Occupancy** | **Maximum Percentage of Capacity** | **Classification** |
|---|---|---|
| 0 | 46 | Suboptimal |
| 600 | 69 | Optimal |
| 900 | 81 | Busy |
| 1050 | 92 | Full |
| 1200 | 100 | Overfull |
| 1300 | | Dangerous |

The relatively high energy use within the IC towards midnight compared to other suboptimal times is illustrative of the number of people remaining in the IC in the evenings, since the levels are often only a little below optimal, alongside the

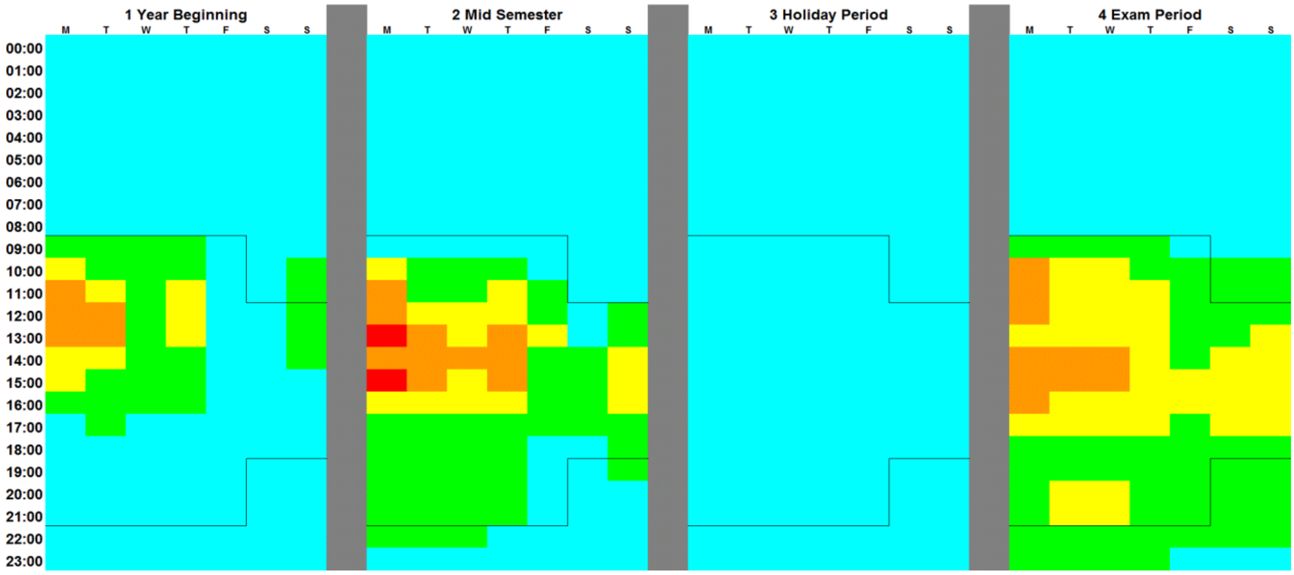

FIGURE 4 - VISUAL REPRESENTATION OF OCCUPANCY LEVELS WITHIN THE INFORMATION COMMONS

varying functions at different time of day. For example, in mid semester, at midnight, a relatively high proportion of occupants will be utilising the computer and printing facilities to complete assignments. This can go some way to explaining the high energy usage on the Sunday night. This suggestion is further enforced by the average stay time on Sunday October 30th increasing from 20 minutes for those leaving between 8am and 9am, to 3 hours 49 minutes for those leaving between 11pm and 12pm.

A Smart Building will endeavour to reduce the base load energy consumption and thus target more consistent energy consumption per occupant whilst maintaining functionality and occupant comfort. **Error! Reference source not found.** shows the current correlation between occupancy and energy usage per occupant hour over the four days shown in table 1. The average energy consumption per occupant-hour, when the building is "optimal" or above, during these four days is 0.72kWh person$^{-1}$ hour$^{-1}$. In contrast, the average for "below optimal" energy usage is 3.34kWh person$^{-1}$ hour$^{-1}$; near a factor of 5 higher. However, the building is suboptimal 70% of the time, and therefore, as an example, if the energy consumption per occupant-hour was reduced by half when in suboptimal occupancy states, the energy saved would be 31% of the total building energy consumption over the four days used. This will be primarily due to inefficient use of space and resources in the building. Using information more effectively can enable building space and resources to be used more effectively in suboptimal time periods.

TABLE 4 - KEY FOR FIGURE 5

| kWh per Occupant Hour |
|---|
| 🟦 <0.3 |
| 🟩 0.3-1 |
| 🟨 1-3 |
| 🟧 3-10 |
| 🟥 10-30 |
| 🟫 30-100 |
| ⬛ >100 |

## APPLYING SMART CONCEPTS

An example of how higher levels of building space and resource efficiency can be achieved through a combination of enterprise system integration, real time displays and occupant feedback is provided below.

Part of the value of the IC is the ability for occupants to have a choice of location, hence the reason for optimal occupancy being between 45% and 70% of capacity. Therefore, when the building has only 200 occupants, it would be useful to have approximately 1/3 of the building operational.

Further value in the IC is added through its multifunctional use capabilities, with silent study areas, group working areas and quiet zones as examples. In order to enable this distribution of uses to be maintained, occupants would need to be informed as to where the location of the zones. This would be achieved through real time screens at the entrance to the IC, as well as screens within each area of the building.

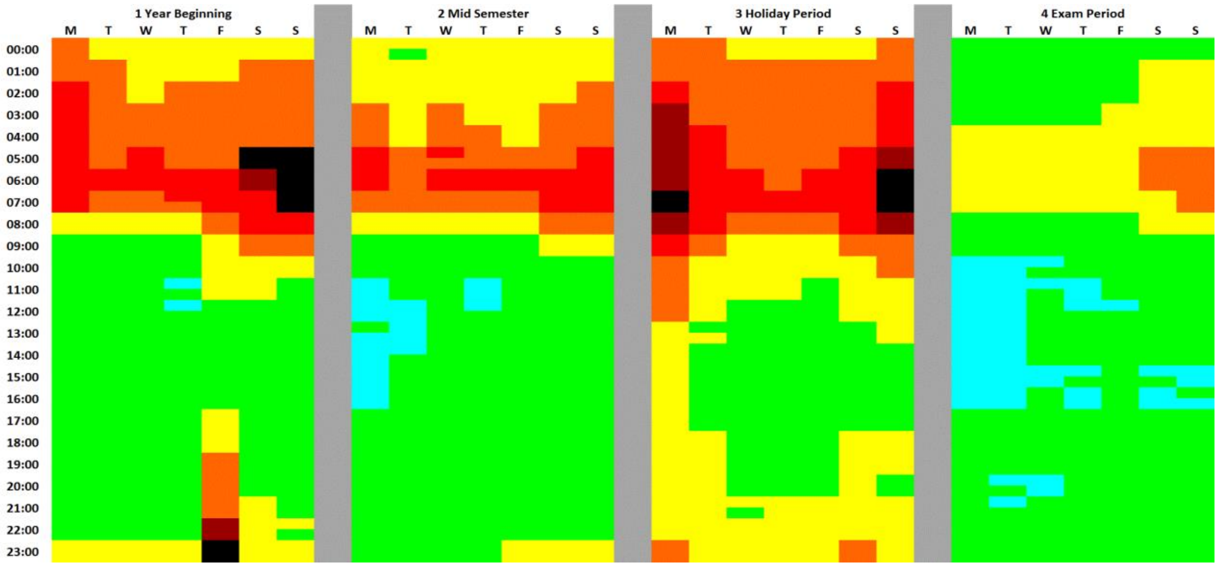

FIGURE 5 - VISUAL REPRESENTATION OF ENERGY USED PER OCCUPANT HOUR WITHIN THE INFORMATION COMMONS

The IC has 7 floors and assuming that these are flexible spaces which can adapt to the needs of the occupants, each floor can be utilised when the occupancy requires it, in order to meet the minimum occupancy levels of 70% capacity, as based upon current optimal levels. Table 5 shows the number of floors that are required to be available for different occupancies and the corresponding number of hours within the 4 weeks discussed that the building could satisfy the occupancy criteria to have only the respective number of floors operational.

**TABLE 5 - MAXIMUM PERMITTABLE CAPACITY TO ALLOW MAINTENANCE OF CHOICE AVAILABLE TO OCCUPANTS**

| Floors Open | Capacity | Max Allowable Occupancy | Hours occupancy criteria are satisfied |
|---|---|---|---|
| **7 floors** | 1300 | 900 | 132 |
| **6 floors** | 1114 | 771 | 46 |
| **5 floors** | 929 | 643 | 30 |
| **4 floors** | 743 | 514 | 50 |
| **3 floors** | 557 | 386 | 63 |
| **2 floors** | 371 | 257 | 106 |
| **1 floor** | 186 | 129 | 245 |

In the building the floors would not necessarily need to signify the usable zones here we will treat it as such. When implemented the new spread of occupancy classifications would be as in Figure 6. It can be seen that, compared to Figure 4, space is utilised far more efficiently, whilst maintaining the value of the IC.

Table 6 shows estimated theoretical maximum energy savings possible using this concept. A number of assumptions have been made to estimate this value, the two most important being:

- The baseline energy is assumed to be the minimum electricity consumption value over the entire year (180kW), and is therefore assumed to be unaffected by the occupancy of the building and solely dependent on the area of the building that is operational.
- It is assumed that the building zones are functionally flexible and use baseline energy equally.

**TABLE 6 - MAXIMUM THEORETICAL ENERGY SAVINGS OVER THE 4 WEEKS**

| | |
|---|---|
| **Baseline energy use (original)** | 120960 kWh |
| **Baseline energy use (with smart concept)** | 56469 kWh |
| **Total building energy use in the 4 selected weeks** | 156491 kWh |
| **Maximum energy saving potential** | 41.2% |

The actual savings are likely to be lower than the figure in Table 6 due to, among other reasons:

- Dedicated functional zones that are operational at all times
- The assigning of larger discrete blocks of time in which zones are closed, rather than half hour iterations
- Interactions between operational and non-operational zones

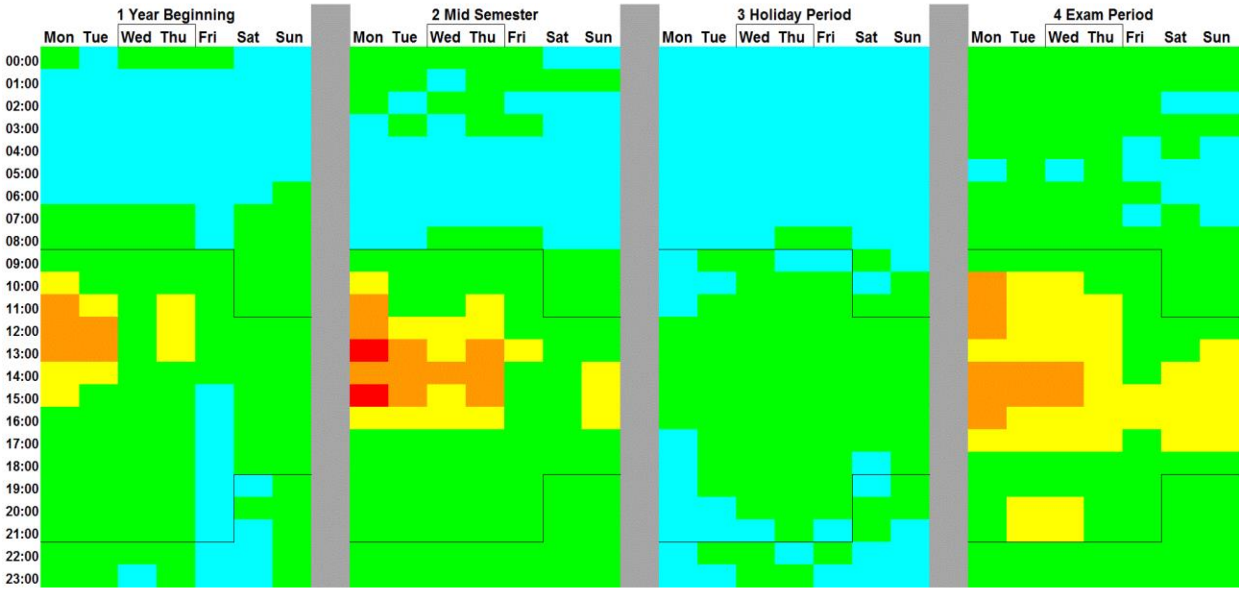

FIGURE 6 - UPDATED OCCUPANCY DIAGRAM WHEN BUILDING ZONES ARE SHUT DOWN CORRELATING TO EXPECTED OCCUPANCY LEVELS

However, by designing a building to be adaptable and implementing smart principles, the reduction in energy consumption will be significant and achieved without compromising the comfort of the occupants.

Integrating enterprise into the building operating system would allow for an individual to specify a computer and preferred comfort variables in order to be allocated a computer that is in the currently occupied zones of the building. A similar method could be achieved with room bookings. Enterprise integration could also allow the building to adapt the mechanical services needed in a room based upon the occupancy levels and intended use.

The ability to tailor information to specific occupants would also be possible and useful for both the comfort and energy use within the building. Informing an occupant that their preferred location is likely to be cooler than usual due to the predicted weather conditions may encourage the occupant to adapt themselves and therefore negate the need for excess mechanical heating, whilst improving comfort. This information can be conveyed using smart devices, computers and social networking sites in order to reach the desired audience.

## CONCLUSIONS

Although it needs to be acknowledged that The IC is a relatively unusual example of a building with highly variable rates of occupancy usage, it serves as an example as to how the utilisation of information before an event has occurred can increase energy efficiency whilst maintaining occupant comfort, rather than the building operator, the building systems or the building occupants having to react in order to rectify the energy waste or discomfort within a building.

The design of both interior and external aspects of a building, alongside the flexibility of the building enterprise systems, will impact upon the effectiveness of the concept; the more flexible the functions are in a particular zone, and the fewer rooms that are required to be open at all times, the higher the potential savings will be.

The occupants still control their own comfort but with the benefit of being informed, showing that choice does not need to be to the detriment of energy efficiency.

## ACKNOWLEDGEMENTS

This research was funded by the UK Energy Research Council (UKERC) and conducted as part of the E-Futures DTC at The University of Sheffield.

## REFERENCES

Buckman, A. H., M. Mayfield, et al. (2013). What is a Smart Building?, The University of Sheffield.

Callaghan, V., G. Clarke, et al. (2009). "Some socio-technical aspects of intelligent buildings and pervasive computing research." Intelligent Buildings International **1**(1): 56-74.

Clements-Croome, D. (2011). "Editorial." Intelligent Buildings International **3**(4): 221-222.

Clements-Croome, D. (2011). "Sustainable intelligent builldings for people: A review." Intelligent Buildings International **3**(2): 67-86.

HM Government (2011). The Carbon Plan: Delivering our low carbon future, Department of Energy and Climate Change.

Kyle, P., L. Clarke, et al. (2010). "Climate policy and the long-term evolution of the U.S. buildings sector." Energy Journal **31**(2): 145-172.

Stubbings, M. (1986). "Intelligent Buildings." Contracts.