USING ENERGY MODELLING FOR CALCULATIONS OF ENERGY SAVINGS, PAYBACK AND RETURN ON INVESTMENT FOR A TYPICAL COMMERCIAL OFFICE BUILDING WITH IBT SYSTEMS

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ABSTRACT

This paper describes and focuses on the applications of a new range of smart building products, particularly Integrated Building Technology (IBT) systems, with the aim to demonstrate savings for improving energy efficiency and indoor environments in buildings. A typical commercial office space has been modelled via dynamic computer simulation software, considering scenarios of before and after the installation of IBT systems. This has then been compared against different building regulations and standards e.g. UK Building Regulation 2006 and ASHRAE 90.1. The study revealed 35% of energy savings per year, a payback period of nearly 1 year, and the return on investment (ROI) of approximately 65% using the IBT systems.

INTRODUCTION

The major energy consuming building stock includes residential, commercial, institutional, and public structures. It is a staggering fact that the buildings consume over 40% of the European Union's energy consumption. Looking at the figures in UK alone energy consumption in the buildings produces about half the nation's CO_2 emissions and many other environmentally damaging pollutants, which also contribute to global warming (UKGBC, 2013).

As a result, opportunities to minimise energy requirements through energy efficiency in buildings encompass building design, building materials, heating, cooling, lighting, and appliances. Annual delivered energy consumption in offices can range from under 100 to over 1000 kWh/m of treated floor area (ETSU, 2000). Although energy is used in buildings for the running of appliances and equipment, lighting and especially for heating and cooling needs i.e. HVAC services; the later are the most significant in terms of cost and environmental effect.

Figure 1 shows the energy consumption by sector in the UK in 2009. It can be easily seen that buildings account for about 40% of energy consumption amongst all other sectors and therefore, this indicates the importance of looking for energy reduction and saving potentials in the building sector, which is now also vital for meeting our CO_2 emission reduction targets for future.

In order to design a low energy building, a 3-stage approach is often adopted (Nicholls, 2002).

- Building Fabric and Insulation
- Active and Passive Systems
- Renewable Micro-generation

However, in order to maximise these energy savings, building systems should be effectively coordinated, thus that the building as a whole offers the best energy performance (Siemens, 2013).

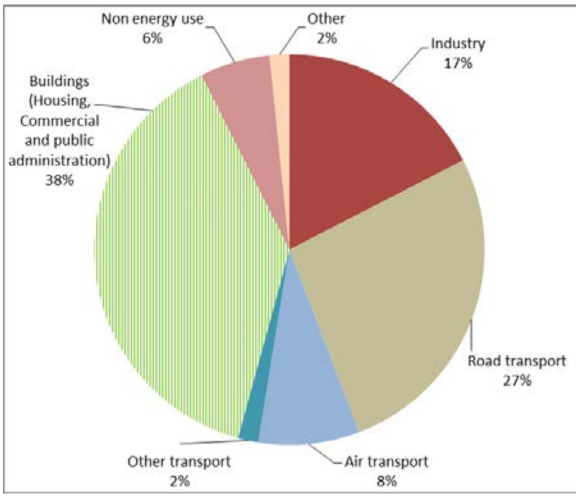

Figure 1 Final energy consumption by sector 2009 (UK, TWh) (DECC, 2011)

Looking at buildings today, lighting and heating loads have been identified as the top two major electricity-consuming necessities in the European Union as has been illustrated in Table 1 including other services considering the EU's commercial and residential sectors.

Table 1
Energy consumption in buildings in the EU (Halonen et al., 2010)

ENERGY CONSUMPTION IN BUILDINGS	% IN EU COMMERCIAL SECTOR	% IN EU DOMESTIC SECTOR
Cooling	4%	N/A
Lighting	**14%**	**11%**
Space Heating	**52%**	**57%**
Water Heating	9%	25%
Other	21%	7%
Total	100%	100%

The paper identifies IBT systems for commercial use and their distribution and benefits for achieving energy efficiency in commercial buildings.

Offices as building spaces have large number of people spending long hours, often performing difficult tasks, which require high levels of precision necessitate a particular attention. Considering the figures for the UK alone, about 10 million people work in office buildings that embody a massive capital investment as well as running costs (Schmertz, 1976), which stresses the importance of targeting such sector for improving energy efficiency.

The aim of this paper is to demonstrate the energy savings can be achieved through application of IBT in buildings and in this particular case, in a typical commercial office space. The study is also quantifying energy savings per year as well as payback periods and the return on investment for using such IBT systems.

IBT SYSTEMS

Building Energy Management System (BEMS)

It is now a known fact that poor control of heating, ventilation, cooling and lighting is responsible for excessive energy consumption in many buildings. Having better control over working area helps to produce consistently comfortable environment for building occupants. It is estimated that up to 90% of heating, ventilation and air conditioning building control systems are inadequate in some way, costing industry and commerce over £500 million (approximately €585 million) per year in additional energy costs. Used correctly, a BEMS can reduce total energy costs by 10% and increase comfort (Carbon Trust, 2007).

Several research projects have studied the use of BEMS data to simulate energy consumption in buildings and many studies have developed models incorporating BEMS data to support intelligent decision making processes in building controls. In 1988, Cumali group performed a study using simulation-assisted control in various buildings. Amongst them were three office buildings which had achieved electrical energy savings of about 20% (Cumali, 1988).

In a similar study by Dongmei zhou et al. (2011) in an office building, they demonstrated the effects of simulation-assisted building management and control on energy usage and reduction in a representative 14-story office building in San Jose, California with hot and dry climate. The building was modelled in a simulation software with 10% accuracy to the actual building data. Numerous temperature schedules and indoor temperature set points were created within the model and the most energy efficient temperature schedule was identified. This was followed by an application of a few energy saving strategies e.g. "pre-cooling the environment during lunch time and as a result lower the chiller's runtime at the peak energy use time period, to start temperature set back as the occupancy rates fall in the building and finally to slowly reduce the temperature set-point in the morning until the occupant body temperatures reach the body comfort level of 98.6°F (37°C)". Overall, they found out that using the above strategies, a 2.25% energy reduction in the mentioned case study building can be achieved.

The payback period for the $90,480 (approximately €67,250 in January 2013) investment on their proposed system is 11.4 years which can be hardly justified in most construction projects. It is worth mentioning that they recommended using a system of monitoring the occupancy levels via radio frequency identification cards in future studies, which can result in more energy savings (Zhou et al., 2011).

Although the two studies presented are to a large extent based on similar principles and additionally better facilities are used in the more recent study. It can be noted that a significant difference between the energy savings in these studies exists, 20% reduction in the 1988 study versus 2.25% reduction in the 2011 study. This can be largely attributed to the improved standards of buildings and more stringent regulations which have been put in place after a decade.

Integrated Building Technology (IBT)

IBT is generally referred to a single intelligent building management platform, which connects and coordinates all building systems such as lighting, HVAC, AV in an integrated approach. Having a core integrated system allows for increased data and information sharing between different sensors and building systems which can result in better functionality of all systems. It usually functions through a control panel via a software platform. The seamless management software ties every room and every zone in every separate environment as defined by designer or user. (Crestron, 2012)

While the capabilities of IBT are immense, in this paper we have focused on only the Energy aspects.

IBT allows remote user control of all systems within a building from any location in the world. The control mechanisms in every room allow for increased occupant comfort and productivity (i.e. HVAC, lighting, schedulding, etc.) with maximum energy efficiency. Monitoring equipment included but not limited to daylight sensors, fire sensors, occupancy sensors, temperature sensors and security cameras. The measured data from these sensors can then enable the BEMS or operator to monitor, manage and control the building.

Energy savings through IBT are achieved through time based scheduling or temperature set points for individual zones which are further enhanced by various monitoring sensors as mentioned above. Users are able to override the BEMS command via touch screen panels, web browser or other smart devices. Occupants and facilities managers can track the real-time and historical rate of energy and water consumption within the building, enabling them to understand and act upon any disadvantageous in usage ha Incorporating bits or patterns.

IBT is a modular solution which makes this technology highly flexible for different budgets and building types. An IBT connected building can be made up of small installations up to large complex systems. IBT is suitable for both new construction, retrofit or exisiting buildings as it does not require major construction work. It keeps building occupants and facility managers informed of each and every room's conditions in real-time. An example of IBT integrated scenario has been given below:

"When a meeting is scheduled, IBT enables you to automatically 'wake up' the room prior to the start of a presentation. After the meeting, our occupancy sensors detect when a room is vacant and automatically powers down energy-consuming devices. In case of no show, the building automatically turns off all systems and allows the meeting room to be booked by others." (Crestron, 2012)

In the study, IBT is used in a way to demonstrate savings through operational energy within the investigated building.

METHODOLOGY

Diversity Factor (DF)

The factor represents the percentage reduction of electricity usage hours for that particular space and function (e.g. 0.6 means a space will only be consuming 60% of energy for that particular space within a typical working hours). The study uses DF from the manufacturing company of the IBT products in the simulation model to utilise the calculations based on factors such as a typical working hours/usage hours and/or installed load/running load.

Building Simulation (BS)

Building simulation is the process of using a computer platform to build a virtual replica of a building. In layman's terms, the building is built in pieces on a computer and a simulation is performed taking that building through the weather of an entire year. In a way, building simulation is a way to quantitatively predict the future and thus has considerable value. Building simulation is commonly divided into two categories: Load Design and Energy Analysis. In the study, BS is used for predicting the operational energy pattern of a typical commercial office space.

In this study, the aim is to investigate the impact can be made by the applications of IBT systems in office building spaces and therefore, whether considering the higher standards of building regulations using the relatively new IBT systems could somewhat shed light on how much energy can be saved and to what extend the payback period of IBT systems as opposed to other BEMS technology is different.

A typical commercial office space has been modelled and the respective layout has been shown in Figures 2 and 3. The building is a single floor office building with a total area of 1020 m .

Figure 2 Typical office space layout

The simulation process has been aimed to identify the energy use and the usage patterns with and without the IBT systems for a typical year. DesignBuilder software has been chosen in this case (version 2.2.5.004 used with the calculation engine of EnergyPlus version 4.0) because it is a dynamic simulation package considering the research goals and suitability for inputting diversity factors in the simulation data (BEAU, 2012 and Crestron, 2010).

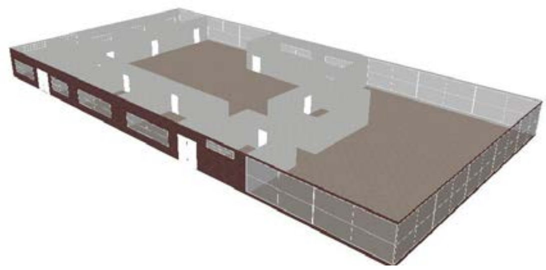

Figure 3 Computer model generated by DesignBuilder

The simulation has been carried out with and without the IBT systems to allow for comparison and evaluation of energy savings. Various scenarios from the simulations were then compared and analysed with different building standards e.g. Building Regulation 2006 and ASHRAE 90.1. In this study, all IBT systems have been chosen from a range of products from a single manufacturer in order to create the best integration between all systems and to create a realistic scenario/case for a typical commercial office. In order to create an accurate simulation model, the following data has been taken into account: occupancy rates, lighting, heating, DHW (domestic hot water) and appliances based on the 2006 UK Part L building regulations. Moreover, the simulation results have been compared against the UK Department of Energy and Climate Change (DECC, 2011 and CIBSE, 2008) electricity and fossil-thermal benchmark values for a typical office category.

Based on the Part-L non-domestic UK building regulations 2006, the external u-value for the building has been taken as 0.35 W/m K in the simulation model. Likewise, u-value for ground floor and flat roof has been used as 0.25 W/m K, airtightness value of 0.5 ac/h (ODPM, 2006).
Furthermore, the benchmark for a typical office building is: electricity 95 KWh/m and fossil-thermal benchmark of 120 KWh/m (CIBSE, 2008).
In the study, typical office hours is scheduled for operation between 8 am to 6 pm with a gap of 1 hour at lunch time from noon to 1 pm. The same profiles have been used for most zones in the model with the exception of bathrooms, storage spaces and electrical rooms where no gap was considered. In contrast, conference room had a shorter working schedule of 9 am to 12 pm and 1 pm to 6 pm.
Based on the recommended comfort criteria for office buildings including heating and cooling, temperature set points have been considered accordingly with CIBSE guidelines as shown in Table 2 (CIBSE, 2006).

Table 2
Temperature set points for different area of the office space (CIBSE, 2006)

ROOM TYPE	HEATING SET POINT	COOLING SET POINT
Typical Offices / Open Plan	22°C	24°C
Kitchen / Toilet	20°C	N/A
Meeting Rooms	22°C	24°C
Print / IT Rooms	20°C	23°C
Reception	20°C	23°C

Any other assumptions in this project have been based on the National Calculation Methodology (NCM) provided by the Building Research Establishment (BRE).
Moreover, diversity factors were analysed for various spaces in the modelled office space for simulating the effect of using the IBT systems that has been shown in Table 3.

Table 3
Diversity factors for office areas controlled by IBT systems

ROOM	DIVERSITY FACTOR
Reception	0.8
Conference Room	0.4
Printing & Scanning centre	0.8
Bathroom Male	0.4
Kitchen	0.6
Room 1	0.5
Room 1 (2)	0.5
Meeting Room	0.2
Open Plan Office	0.7
Bathroom Female	0.4
Storage	0.1
Electrical Room	0.1

The diversity factors have been supplied by the manufacturer of IBT products. The following points are important in terms of understanding the way diversity factors act in the simulation model.

- Diversity Factors can be explained as (typical working hours/usage hours) or (installed load/running load).
- The load is time dependent as well as being dependent upon equipment characteristics. The diversity factor recognises that the whole load does not equal to the sum of its parts due to this time interdependence (i.e. diverseness).
- When the maximum demand of a supply is being assessed, it is not sufficient to simply add together the ratings of all electrical equipment that could be connected to that supply. If this is done, a figure somewhat higher than the true maximum demand will be produced. This is because it is unlikely that all the electrical equipment on a supply will be used simultaneously.
- The concept of being able to de-rate a potential maximum load to an actual maximum demand is known as the application of a diversity factor.
- 0.7 or 70% diversity means that the device in question operates at its nominal or maximum load level 70% of the time that it is connected and turned on.
- If everything (all electrical equipment) was running at full load at the same time the diversity factor would be equal to One (1).

Four different simulation scenarios have been considered and compared in this study.

A) A base case with the Part L non-domestic UK building regulations (2006).
B) Part L non-domestic UK building regulations (2006) with adapted factors.
C) A base case with ASHRAE 90.1 (2009).
D) ASHRAE 90.1 with adapted factors.

Lighting Sensitivity Analysis

List of smart devices used in a typical office space as follows (Crestron, 2012):

- Automation processor & software
- Fluorescent dimmer
- High voltage switch
- 50 watt power supply
- Automation control
- Distribution hub
- Distribution block
- Light & motion detector

For full details and information about quantity of each device, refer to the ROI calculation in Table 5.

Life Cycle Analysis

In this study, the Return on Investment (ROI) analysis is currently not including Life Cycle Analysis (LCA) for IBT systems; therefore this is considered as one of the limitations to the work carried out.

Table 4
Energy simulation comparison between base case –Building Reg 2006 & ASHRAE 90.1 as well as percentage difference in energy consumption (+ve indicates more energy consumption and –ve indicates energy savings)

BUILDING STANDARDS	APPLIANCES (ELECTRICITY)	LIGHTING (ELECTRICITY)	HEATING (GAS)	CHILLER (ELECTRICITY)	DHW (GAS)
Building Reg 2006	132052.6	103052.8	13098.7	41831.1	6652.5
Building Reg 2006 with factor	70540.5	75481.8	20017.6	24656.5	6652.5
Energy Reduction with Factor (IBT)	-87.2%	-36.5%	+52.8%	-69.7%	0.0%
ASHRAE 90.1	132052.6	190932.6	7384.0	63652.1	6652.5
ASHRAE 90.1 with Factor	70540.5	125645.6	10983.0	35889.6	6652.5
Energy Savings with Factor (IBT)	-87.2%	-52.0%	+48.7%	-77.4%	0.0%

RESULTS AND DISCUSSION

Study Findings

Figure 4 and Table 4 show the amount of electricity usage for all different scenarios, with and without IBT systems (i.e. with and without diversity factors). It can be easily noticed that after the installation of IBT systems, total energy consumption has been reduced by a noticeable amount e.g. in Case A from approximately 300,000 KWh/year to just under 200,000 KWh/year in Case B and from approximately 400,000 KWh/year in Case C to 250,000 KWh/year in Case D. Moreover, even though in both building regulation scenarios the overall consumption has decreased, not all energy consuming measures have followed the same trend. For instance, energy consumption for domestic hot water (DHW) has remained constant, which can be explained by the fact that there are no IBT measures, which had a control on this particular measure.

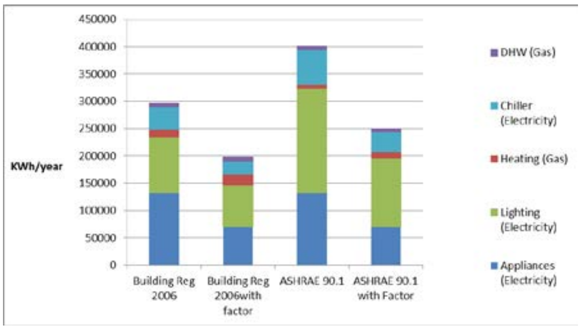

Figure 4 Electricity usage by four different scenarios

Furthermore, unexpectedly a significant increase in energy usage in heating energy consumption can be seen in contrast with the overall energy reduction trend. The respective increase in heating consumption with IBT systems for Cases B & D has been by approximately 50%. This trend can be explained by the reduction in lighting usage as a heat-generating factor in the building, which has resulted in a higher working load on the heating system. Another trend worth mentioning is the drastic reduction of 70-77% in cooling loads due to the reduction in heat generation by lighting.

Value for Money/Return on Investment (ROI)

Cost of installations for each device has been obtained from commercial suppliers, in this case from Crestron, and as can be seen in Table 5, the total price of IBT devices, which have been used in this study, are £21,399.00 excluding VAT, (Crestron, 2012).

ROI calculations have been based on the energy consumption figures from the building simulation results for both the case of 2006 UK Building Regulations and ASHRAE 90.1. Electricity has been assumed as the energy source for all building systems except for space heating and domestic hot water that were gas supplied. Standard electricity rate of 14 pence/kWh and standard gas rate of 4.64 as year 2012 rates. As stated by Energy Saving Trust (EST), this has been the basis for energy costs and savings (EST, 2012).

As a result, total cost savings per year under the UK Building Regulations 2006 and ASHRAE 90.1 equated respectively to £13,907 and £21,135. Therefore, considering the total investment costs of £21,399, a payback period of approximately 1.54 years and ROI of 65% have been achieved for 2006 UK Building Regulations. The respective values under ASHRAE 90.1 have been derived approximately as 1.01 years and 98.8%.

Challenges and Barriers

There are various costs involved in installing this cutting-edge technology ranging from planning and design process, deployment and user training. Nevertheless, the most important barrier may be the capital costs particularly in smaller commercial buildings. In the meantime, there are currently no financial incentives or policies in the UK to facilitate uptake of this type of technology and therefore their adoption rate is still unknown as a form of an independent study. On the other hand, Green

Building Initiative by the European Commission (EC) is a key driver behind IBT system and currently signed up by companies such as Siemens.

Knowledge of Technology

Rapid advancement in the field of building controls and automation has resulted in increasing complexity of this technology. For instance, "a designer or technician for this type of system needs to know the hardware and software of the control system, as well as all relevant codes and standards related to HVAC, fire alarms, security, lighting control, elevator control, etc." (Brown 1998, cited in Advanced Sensors and Controls for Building Applications: Market Assessment and Potential R&D Pathways). Therefore, problems may arise due to the lack of knowledge or experience at different levels from system designer to operator to building occupant. For example; poor integration and ineffective placement of sensors as well as shortfall in programme specifications may result in total system malfunction or at least energy performance of lower than expected.

Supporting more demonstration projects in order to show the capabilities of IBT would be a good way to increase the industry's awareness of this technology and to transfer the knowledge. Similarly, performing long-term post occupancy evaluation of projects of this nature can increase the industry's confidence in IBT. The best current example of integration of IBT systems (known as Smart Control for Building Systems by Siemens) could perhaps be the recently unveiled urban development centre by Siemens, known as 'The Crystal' in London (Siemens, 2013).

Table 5
Energy savings and ROI calculations in relation to the IBT systems in the typical office space

ITEM NUMBER	QTY	DESCRIPTION	UNIT PRICE	TOTAL PRICE
DIN-AP2	1	DIN Rail 2-Series Automation Processor	£1,056.00	£1,056.00
DIN-4DIMFLV4	9	DIN Rail 0-10V Fluorescent Dimmer	£531.00	£4,779.00
DIN-8SW8	7	DIN Rail High-Voltage Switch	£278.00	£1,946.00
DIN-PWS50	4	DIN Rail 50 Watt Cresnet Power Supply	£202.00	£808.00
DIN-2MC2	22	DIN Rail Motor Control	£384.00	£8,448.00
DIN-HUB	1	DIN Rail Distribution Hub	£288.00	£288.00
DIN-BLOCK	1	DIN Rail Distribution Block	£144.00	£144.00
CH-LMD1	15	Light & Motion Detector 1	£204.00	£3,060.00
C2NI-CB-W-T KIT	6	Cameo Keypad International Version, White, Textured	£145.00	£870.00
SW-FUSION-EM	1	Energy Management Software		
	1	Row custom DIN pre-assembled enclosure RCBO to module inputs, MCB to circuit outputs. Fully wired.		
	1	Row custom DIN pre-assembled enclosure RCBO to module inputs, MCB to circuit outputs. Fully wired.		
	1	Row custom DIN pre-assembled enclosure RCBO to module inputs, MCB to circuit outputs. Fully wired.		
	1	Row custom DIN pre-assembled enclosure RCBO to module inputs, MCB to circuit outputs. Fully wired.		
Quote Total (Ex VAT)				£21,399.00
Grand Total (Ex VAT)				£21,399.00

CONCLUSION

The project demonstrates the possibilities of energy savings with the use and application of Integrated Building Technology (IBT) systems. The analyses were further elaborated by calculating the Return on Investment (ROI) for the installed systems for a typical commercial office building in London, UK. Energy modelling and simulation have been carried out to justify the energy usage of various components in the case study.

The findings from the study have demonstrated that the installed IBT systems in this case will save approximately 35% of energy per year further reducing the operational costs of the building. The payback period identified in this project is just about 1 year on the investment cost (i.e. ROI is approx. 65%).

The research can recommend further investigation in IBT systems using real-time energy monitoring rather than using diversity factors. This approach would provide results that are more accurate and a spreadsheet of results, which can also help to check the accuracy of model per week or per month. This can hence be considered as a future continuation of this project. Moreover, an online ROI calculator can be developed in a more robust form that will be useful for Crestron and their clientele usage.

Furthermore, the project will continue with more rigorous analysis of ROI by including LCA for IBT systems, which can be utilised in building environments.

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