O 37. STUDY OF DIFFERENT BUILDING RETROFITTING TECHNOLOGIES ON ENERGY SAVINGS

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ABSTRACT: Retrofitting building envelope and heating ventilation and air conditioning plants, is crucial to reduce energy consumption. This research work deals with a building where an underfloor heating system, water radiators, and natural ventilation are the main systems used to maintain comfort condition throughout the majority of the building areas. This work involved developing a 3D model relating to building architecture, structure, occupancy & heating ventilation and air conditioning (HVAC) plants operation. Different energy retrofit technologies such as building envelope, lighting, heating, cooling and ventilation, as well as the use of solar energy were analysed. The objective of this research work was to develop a methodology that start by comparing various energy retrofit technologies and then continues to identify the most suitable in terms of energy savings and cost of investment. Result of the analysis on selected best retrofit technology shows that a reduce cost of investment in 15% was obtained compare to other technologies. Furthermore, electricity consumption savings and heat released can vary between 20 and 30% on monthly basis.

Keywords*: Energy Efficiency, Building Retrofitting, Building Energy Simulation, Cost of Investment*

INTRODUCTION

Environmental concerns and the recent increase in energy costs open the door for innovative techniques to reduce energy consumptions. Buildings account for about 40% of the energy consumption in the European Union (EU) [1]. Energy Efficiency Directive was formally adopted by the Council of Ministers and European Parliament in October 2012. The main objective of the Directive is to promote the improvement of the energy performance of buildings within the EU through cost-effective measures [2].

The aim of an energy retrofit is to improve energy efficiency by implementing the most optimal mix of technologies at a reasonable investment. Energy retrofits of existing buildings are important because buildings tend to undergo system degradation, change in use, and unexpected faults over time. It is well known that the efficiency of buildings and their equipment degrades over their service life, and even faster when they are not maintained appropriately. Building components can also under-perform when they are not properly designed or installed.

In 2008, the Royal Institute of British Architects (RIBA) and the Chartered Institution of Building Services Engineers (CIBSE) launched CarbonBuzz, a free online platform allowing practices to share and publish building energy consumption data anonymously [3]. It enables designers to compare predicted and actual energy use for their projects, whilst also allowing for comparison against benchmarks and data supplied by other participating practices. In particular, Hamilton et al. [4] compared the predicted and actual electricity consumption in three building sectors: schools, general offices and university buildings. They demonstrated that the measured electricity demands are approximately 60–70% higher than predicted in both schools and general offices, and over 85% higher than predicted in university campuses. The European research group Ecofys for EURIMA [5], conducted long-term research on the efficiency and economy of different retrofit methods, based on various climate conditions across different countries in Europe and put forward the most appropriate energy-saving technologies for particular regions. Their results analysis focused on energy-saving methods for building envelope only. Griffith et al [6] selected 4820 measured data points based on real investigation and calculated some technologies' greatest energy-saving potential. They concluded that U.S. commercial buildings could achieve 43% energy savings. The research took into account the energy savings possible for buildings and the economic impact of each energy-saving technology. Chidiaca et al [7] established three basic building models according to survey data on nine typical office buildings in Canada and studied the efficiency and application of some retrofit methods.

They calculated the payback and efficiency of retrofit methods applied in different climate zones. Mills et al. [8], has shown that improving existing buildings will yield median energy savings of 16% in the United States.

The main objectives of this research works included: firstly the development of a methodology for increasing the accuracy of energy model capable of reducing the gap between predicted and real energy consumption. Secondly, different energy retrofit technologies such the replacement of lighting and motors was explored. In addition, the time of the heat pump system was analysed. The estimated total annual saving related to the proposed energy retrofit solutions was determined.

The layout of this paper is as follow: Section II presents the two levels of the calibration methodology. Section III, gives an overview of the demonstration building and HVAC plants. Section IV describes the building simulation for comparing various energy retrofit technologies to identify the most suitable in terms of energy savings and cost of investment. Finally, Section V provides a conclusion with future research works.

OVERVIEW OF CALIBRATION METHODOLOGY

In our calibration methodology, input parameters are specified by an analyst and used by energy simulation programs to reproduce a building's thermal processes, while outputs are energy performances simulated by energy simulation programs, given certain input parameters. Two levels of calibration are performed and use a combination of building, system and measurement data.

Building energy models were developed using EnergyPlus Version 8.2 [2]. The adequacy of this calibration was evaluated against the ASHRAE Guideline 14 [9].

Figure 1 shows the procedure for model calibration and identification of energy savings opportunities and is composed by the first and second level of calibration. Finally, detail analysis related to building calibration methodology and result analysis can be found in Mustafaraj et. al [10].

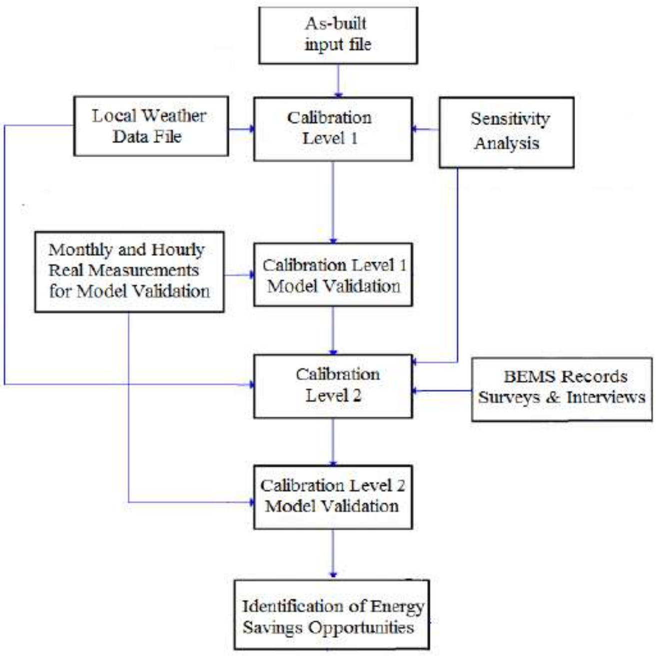

Fig. 1. Algorithm for model calibration and energy saving opportunities [10]

Overview of Building and HVAC plants

The Environmental Research Institute (ERI) building in Cork is a three-storey 4500 m^2 research building containing offices, computer laboratories, wet laboratories, a clean room and controlled temperature rooms. Figure 2 shows a 3-D view generated with DesignBuilder [11] using design documents.

The building is a reinforced concrete structure providing high levels of thermal mass to allow for natural and mechanical ventilation with night cooling as required. The build-up of the floors, roof, external facades, internal partitions and windows were constructed from as-built structural drawings. The build-up thermal properties were taken from CIBSE [12] and ASHRAE [13].

Fig. 2. ERI building 3-D view of design model [10, 11]

Apart some areas of the building that occupy the central core of the building space (such as WCs, cold rooms, clean rooms and stores) which are mechanically ventilated by five air handling units (AHUs), the rest of the building is naturally ventilated. Figure 3 is a schematics overview of the HVAC system. The building is heated by an underfloor heating system that is primarily supplied by a geothermal heat pump that taps into a water supply fed from a culvert running adjacent to a nearby river. For more detail about the building structure and description of HVAC system refer to Mustafaraj et. al [10]. Finally, total annual building electricity consumption is 221,225kWhr.

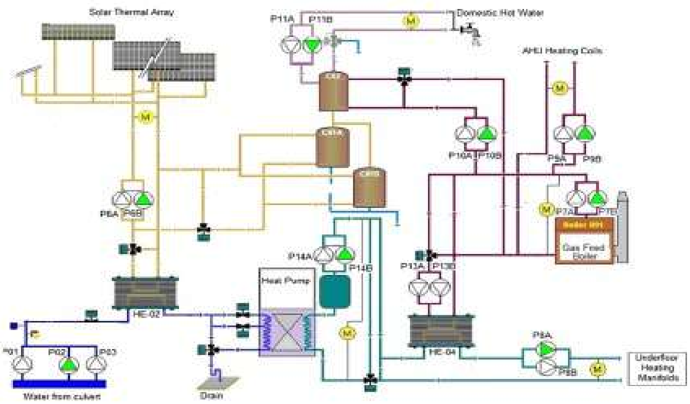

Fig. 3. Schematic of the HVAC system [10]

Analysis of Results

After completing the calibration process (see G. Mustafaraj et al. [10]), reductions in energy consumption was made by implementing a certain number of energy retrofit technologies. The energy retrofit technologies includes: modifying the time schedule of the heat pump, replacement with high efficiency lighting & occupancy sensors, substituting old motors with high efficiency motors, installation of variable speed drivers on water pump and high efficiency air conditioning systems. Cost of investment was used as a key constraint of the study and selection of energy retrofit solutions was limited to total investment of €3000.

Other energy retrofit technologies such as building external insulation, variable speed drivers and solar panels were investigated, but the cost of investment for applying these technologies was deemed to be high. Three energy retrofit technologies were identified. The total cost savings were calculated based on the average cost electricity in Ireland that was fixed at 0.18 €/kWhr. The result of the analysis on the implementation of the proposed inventions is outlined below.

Time schedule heat pump modification

The floor material structure is a concrete base and has a thickness of 70 cm. Therefore, each floor presents a slow thermal response. The duration during which the heat pump is turned "ON" can vary between 6 to 12 hours and depends on the weather conditions. This is managed by the Building Management System (BMS) technician, who based on his experience and weather forecast conditions decides in advance how many hours it will be turned "ON" during the following week. Consequently, the "ON"/"OFF" time schedule of the heat pump (which supplies 80% of heat to the building), is not regulated efficiently because is not based on real weather condition and the thermal behaviour of the building. Its electricity consumption is higher compared to what is required to provide optimal thermal conditions throughout the building.
Alternatively, the present research analysis used EnergyPlus to turn the heat pump "ON" and "OFF" based on the real thermal behaviour of the building and weather condition supplied by the weather data file. Results have shown that the time required to keep heat pump "ON" varies from 4 to 8 hours at night time in order to maintain satisfactory comfort conditions inside the building. Consequently, less time is required compared to that managed by the technician on the BEMS (from 6 to 12 hours).
Figure 4 presents the heat pump's measured and EnergyPlus model output monthly electricity consumption. It was verified that energy savings can vary between 20 and 27% on monthly basis.

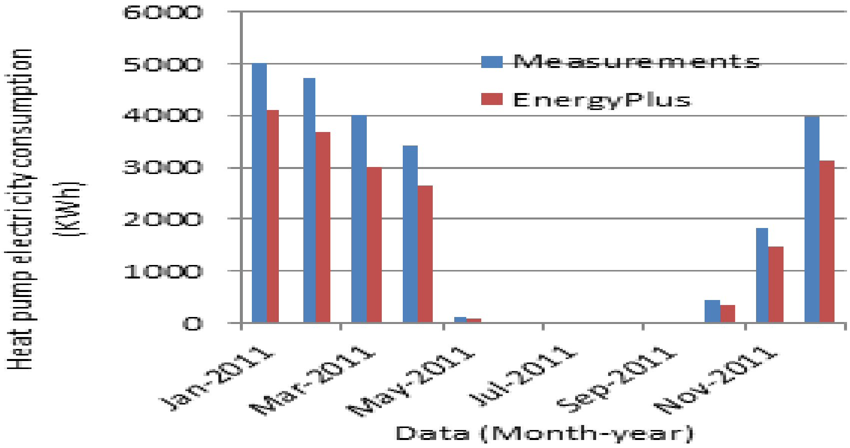

Fig. 4. Monthly comparison of electricity consumption between manual (Measurement) and automatic (EnergyPlus) control of the heat pump

Finally, total electricity savings were calculated to be 5050 kWhr/yr (i.e. corresponding to a total savings of 290€/yr). The payback period is immediate because there is no cost on investment for implementing this energy retrofit technology.

Lighting efficiency improvements & luminosity sensor

The existing lighting in the building was analysed and we recommend the replacement of standard efficiency lamps with high-efficiency lamps. Furthermore, luminosity sensors were installed with the aim of adjusting the intensity of artificial lighting based on the intensity of natural lighting. Thereby, electricity savings can be obtained by installing luminosity sensors. Table 1 presents the results analysis (on yearly based) obtained in EnergyPlus by replacing the existing standard lamps with high efficiency lamps and luminosity sensors. The energy savings from high-efficiency lighting also includes a savings of 2200 kWhr/yr due to the reduced heat load on the air-conditioning system. Table 2 shows the costs and payback for spot relamping and group relamping program which also includes the cost of luminosity sensors

Table 1. Energy Use and Energy Cost Comparison: Standard Lamps vs. High-efficiency Lamps with luminosity sensors

Number of Lamps in building	Present Lighting			Proposed Lighting with Luminosity sensors		
	Lamp Type/ Wattage (W)	Total energy used (kWhr/yr)	Total energy cost (€/yr)	Lamp Type/ Wattage (W)	Total energy saved (kWhr/yr)	Total cost savings (€/yr)
100	CF40	14304	2574	HF34	2436	438.48
27	CF35	15546	2798	HF60	2109	379.62
9	IL100	2470	444	CMF27	903	162.54
7	IL75	3656	658	CMF13	1222	219.96
10	MV400	34212	6158	HMV325	3657	658.26
	Totals	70188	12632	Totals	10327	1858.86

Table 2. Comparison of implementation cost and simple payback period for spot and group relamping

Proposed Lamp Type	Spot Relamping		Group Relamping	
	Implemetation Cost	Simple Payback Period	Implemetation Cost (with rebate)	Simple Payback Period
HF34	265	0.6	452	1.1
HF60	110	0.3	350	0.9
HMV325	505	0.8	1077	1.7
CMF13	143	0.7	137	0.7
CMF27	123	0.8	114	0.7
Totals	1146	0.6	2130	1.2

Figure 5 presents a monthly comparison between electricity consumption obtained by the EnergyPlus model simulation data for high efficiency lamps against that obtained from real measurements taken from standard lamps actually installed in the building. Finally, total energy savings by spot relamping of standard lighting with high efficiency lighting was estimated to be 1858€/yr, with an average payback period of 6 months.

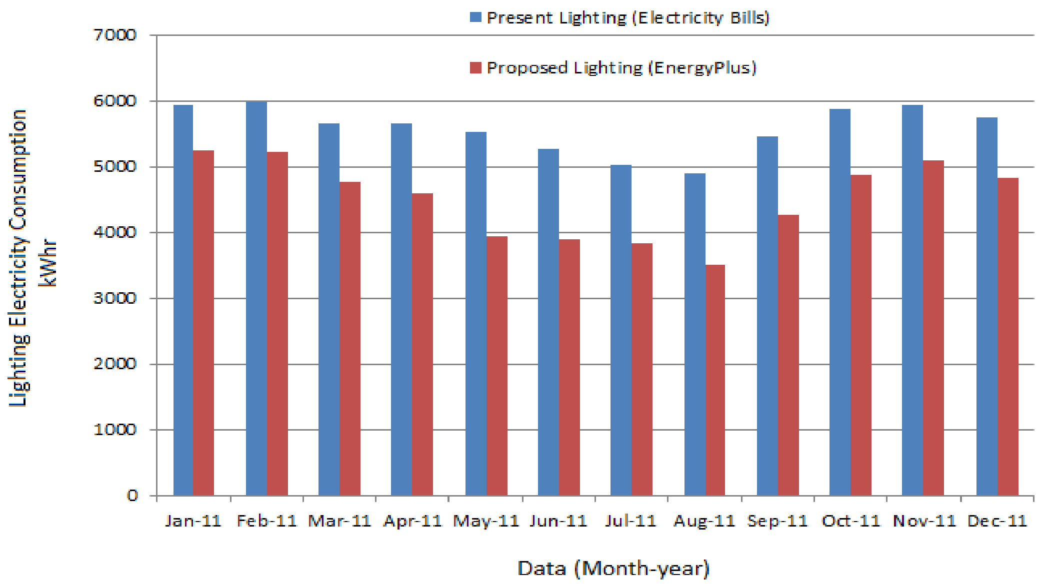

Fig. 5. Monthly present lighting v proposed lighting electricity consumption

High efficiency motors

The operating efficiency of electric motors has been improved in recent years. Depending on the horsepower rating, the operating efficiency of high-efficiency motors can be from 1-10 percent higher than the operating efficiency of standard motors. The audit analysis inventoried the motors at this facility and determined that it would be cost-effective to replace 14 of the 19 motors with high efficiency as the existing motors failed. For very small motors or seldom-used motors, the simple payback period is too high to make replacement cost-effective. Table 3 presents the results analysis (on yearly based) obtained in EnergyPlus by replacing the existing standard motors with high efficiency motors.

Table 3. High efficiency motors: Summary of savings and costs

kW	Number of motors	Motor Efficiency		Energy Savings (kWhr/yr)	Energy Cost Savings (€/yr)	Implementation Cost (including rebate)	Simple Payback period
		Standard	High				
3.73	2	0.839	0.89	1936	348.48	174	0.4
5	3	0.886	0.923	3649	656.82	378	0.5
7	4	0.901	0.931	4012	722.16	752	0.6
10	1	0.908	0.934	1643	295.74	286	0.7
			Totals	11240	2023.2	1590	0.6

Figure 6 presents a monthly comparison of electricity consumption between standard motors and high efficiency motors. Total energy savings estimated by replacing standard motors with high efficiency motors is 2023€/yr, while the average payback period was approximately 6 months.

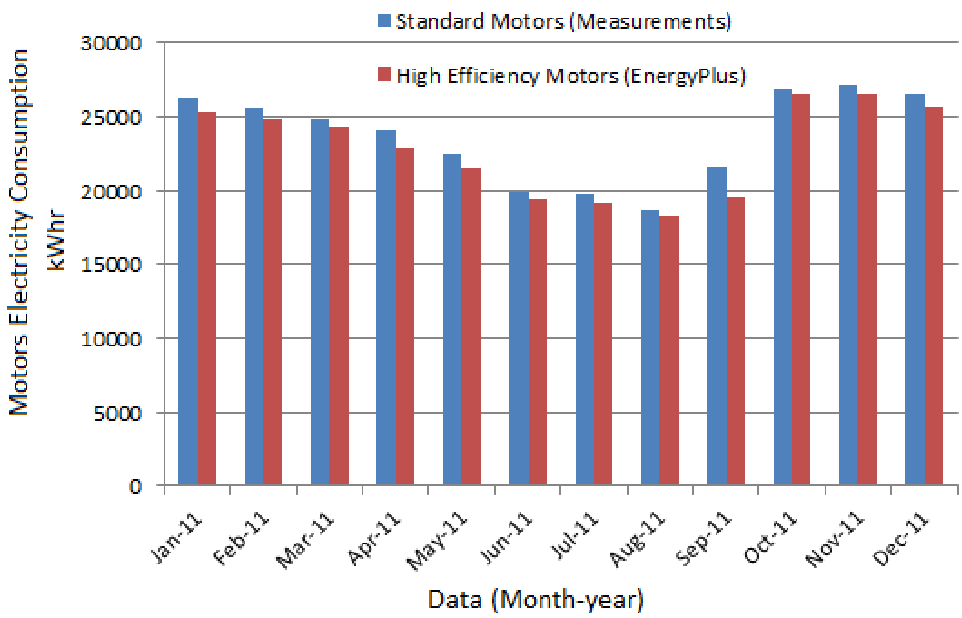

Fig. 6. Monthly standard motors v high efficiency motors electricity consumption

Table 4 summarizes the energy retrofit recommendation obtained. Changing the heat pump time schedule from manual to automatic based on the real thermal behavior of the building was estimated to provide a saving of around €290 per year without any cost of implementation and the payback is immediate. Replacement of lighting and motors with more efficient alternatives, could provide potential cost savings of €3881 but would include an implementation cost of €2736. Finally, it was estimated that the implementation of the recommended measures could provide an annual electricity savings of 22,117kWhr corresponding to projected cost saving of €4170.

Table 4. Energy Retrofit Technologies: Summary of Savings and Costs

Description of Energy Retrofit Technologies	Potential Savings (€/yr)	Implementation Cost (€)	Simple Payback Period (yrs)	Energy Savings (kWhr/yr)	Demand Reduction (kW)
Process Improvements					
1. Time schedule Heat Pump Modification	290	0	Immediate	5050	0
2. Replacement with High Efficiency Lighting	1858	1146	0.6	10327	0.241
3. Replacement with High Efficiency Motors	2023	1590	0.6	11240	1.757

CONCLUSIONS

This research work presents firstly a brief overview of the calibration process developed in previous research work [10]. Using a previously validated energy model that complies with ASHRAE guidelines [9], three different types of energy retrofit technologies were investigated. Secondly, the time schedule of the heat pump was modified based on real thermal behavior of the building where the potential energy saving was calculated to be 5050 kWhr/yr with a potential cost savings of €290. Thirdly, the proposed replacement of standard lighting with high efficiency lighting incorporating luminosity sensors would deliver a potential of €1858 which includes a smple payback period of 6 months. In this scenario, the cost of implementation was calculated to be €1146. Fourthly, the replace of standard motors with high efficiency motors was estimated to result in potential cost savings of €2023.
The total electricity saving on early basis subject to implement of recommended solutions was estimated to be 22,117 kWhr corresponding to approximately 10% of the total building electricity consumption per year. The findings of this research illustrate the importance of using an accurate and calibrated building energy model. This allows energy auditors, building owners and ESCOs (Energy Service Companies) to compare technologies and approaches, estimate the potential savings and the potential return on investment period prior to actual installation of optimal energy retrofit solutions. Finally, future research could explore the extension of the developed approach to other types of buildings including commercial facilities.

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