Buildings Energy Simulation Using Energy Express: A Case Study on Sub-tropical Central Queensland University (CQU) Buildings

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ABSTRACT

The strategies of buildings energy management can be developed through energy audit, analysis and simulation. Currently, different end-users of CQU buildings such as heating, ventilating and air conditioning (HVAC) units, electrical appliances, etc do not take full advantage of local sub-tropical climatic conditions. Therefore, climate-responsive strategies need to be implemented in order to take full advantage of the positive climate attribute of sub-tropical climate regarding efficient energy management and conservation measures. This study is conducted on a three-story library building of CQU. HVAC systems were selected for practical operational energy conservation measures (ECM) to take advantages of hot and humid subtropical climate. A baseline energy consumption profile of the building is simulated using building energy simulation software called Energy Express (EE). The simulated results are then validated with energy audit and on-site metered data. The means to utilize environmental conditions to improve building energy efficiency is investigated. Variable air volume (VAV) system as an energy conservation option is investigated and compared with existing constant air volume (CAV) system. This study found that about 12% energy savings could be achieved by replacing CAV system with VAV system as an option for energy retrofitting, and hence recommended to CQU management for consideration.

Keywords: Building energy, hot-humid climate, energy conservation, energy simulation, variable air volume system.

1. INTRODUCTION

The building sector consumes about 28% of the overall energy consumption of a nation [1]. Within the building sector, office buildings consumes highest energy compared to other types of buildings since the modern advent of computers and other office equipments increased the internal heat gains in most offices. HAVC systems itself is responsible for up to 60% of the total building energy consumption for controlling heat gain and maintaining indoor air quality depending on the building type [2-4]. Building owners under any climatic conditions are required to introduce an appropriate energy management system for optimum and efficient use of energy in buildings. Not only it reduces the building energy consumption and expenditure but also it ensures friendly and sustainable environment by reducing emissions of greenhouse gases [5]. High cost of energy and its associated peak-demand charge necessitates an immediate step of energy conservation and peak load demand control of buildings.

Effective HVAC control strategies should be developed for efficient energy management. Energy savings of approximately 30% can be achieved through introducing proper ECM in existing building without compromising the indoor comfort [5, 6]. The speed and reliability

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of today's computers and the availability of suitable energy simulation softwares with optimization techniques has given us opportunity to take the advantages of thermal design of buildings for energy conservation decision making purposes. Chirarattananon and Taweekun, using DOE-2 simulation program, reported that the whole building retrofit is more cost effective than adopting individual options [7]. Philip and Chow, using Trace 600 simulation program, reported that about 17% energy savings could be achieved through introducing three ECMs [8]. Al-Homoud [9] reported that up to15% energy savings could be achieved in large office buildings in hot and humid climate.

According to Commercial Buildings Energy Code of Melbourne, about 65% of electrical energy is used for space conditioning in Australia [10]. Rockhampton is more hot and humid area than any other location in Queensland. Australian Bureau of Meteorology records show that in 2005 Rockhampton had hottest temperature in this region over 37 years. This clearly indicates that the HVAC system of a building in this region has a huge potential for energy savings. Development of strategies for a cost effective and efficient energy management is thus very important.

The aim of this study was to investigate whether the energy consumption can be reduced by delineating appropriate HVAC control strategies that can be incorporated with building management system (BMS). An energy audit is conducted following the procedures of Australian/ New Zealand standard AS/NZS 3598:2000 to identify the areas of largest energy saving potential. Then energy consumption profile is simulated using Energy Express software and validated with on-site metered data. The VAV system as an ECM is evaluated and discussed.

2. BUILDING AND HVAC DESCRIPTION

The library building of CQU was selected as a model for this study. It was built in 1978. The library is a three-story building of 10.5 m high from plinth level and each level height is 3.5m. Typical floor plan lay out of case study building is shown in Figure 1. It has a total fully air conditioned floor area of approximately 5400 m^2, number of occupants about 1000 per day. The air conditioned areas includes an archive room, seven computerized conference rooms, eleven office rooms, six discussion rooms, two large book shelf areas and two general on-line computer browsing areas. The library is rectangular in shape and has standard construction with light weight concrete aggregate single glazed brick 130mm walls, light weight 2×15 mm^2 gypsum board with 100 mm cavity brick, suspended type 15mm gypsum board ceiling tiles and east, west, north, south facing conventional glazing windows. The lighting system serving the building is mainly of regular 36 Watt double fluorescent lamps. The operating schedule of the facility is from 8:00 am to 8:00 pm on Monday to Thursdays, from 8:00 am to 5:00 pm on Friday and from 9:00 am to 2:00 pm on Saturday. The HVAC system used in the building is constant air volume (CAV) system with 11 fan coil units (FCUs) and five direct expansion (DX) package units serving the different zones of the building. The cooling of the building is provided by two parallel reciprocating water cooled chillers, rated cooling capacity of each chillier is 660 kW. All the chillers and five DX package units are controlled by building management system (BMS) in accordance of the cooling demand of different zones. Each chillier has coupled with a compressor, four fan motors and one chillier pump motors. Fresh air is supplied to the building through insulated fresh air duct, which are connected directly to the FCUs. A total of nine axial type fresh air fans are employed to bring in the fresh air from the external facade of the building. Each floor has separate thermostat control. All the conditioned zones in the building have set points between 23 and 25°C for summer and 21 and 22°C for winter. All FCUs are controlled by schedules and after 5:30 pm it is set closed for some floors which usually become unoccupied after that time but cooling is continued through substantial areas for avoiding from mold growth on books.

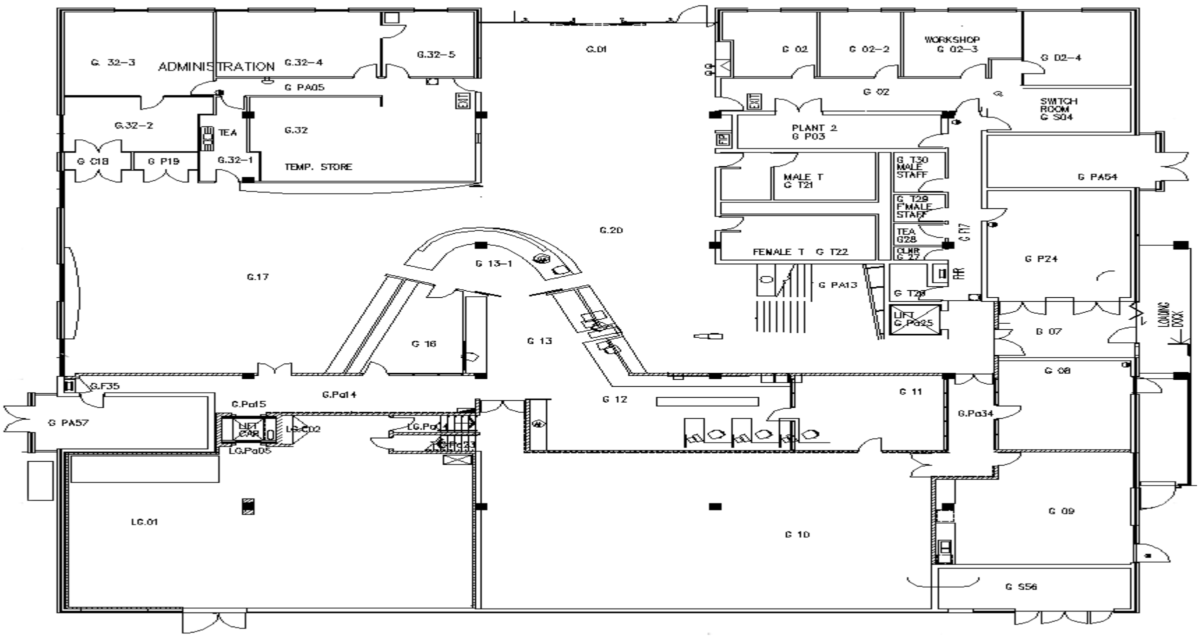

Figure 1: Floor plan lay out of CQU library building

3. ENERGY AUDIT AND ANALYSIS

Each zone of the building was physically investigated in order to obtain information about the building lighting, equipment and occupancy. The building architectural and engineering drawings along with operating manual were reviewed for the purpose of getting details of building envelope's thermal characteristics. Details of the building physical and operational characteristics were taken from the building description. The equipment used in the library includes personal computers, small and large printers, Xerox machines, and few scanners. The procedures of Australian/New Zealand standard AS/NZS 3598:2000 were used for calculating equipment and lighting power densities. For each zone of the building, the total number of equipment and lighting fixtures was counted by Remote Space Management section of the Division of Facilities Management (DFM) of CQU. The occupants flow rate was observed for few weeks. Lighting and equipment power densities along with people density at different floors of the library are shown in Table 1.

Table: 1: Details of lighting, equipment and people in case study (library) building

Floor name	Lighting + Equipment power density average (W/m^2)	Air-conditioning power density average (W/m^2)	Number of people Per 100 m^2
Ground	20	33	15
First floor	24	31	18
Second floor	20	30	16

Information about HVAC systems, FCU's and chillers were collected from design data, equipment tags, as well as the information provided by the building maintenance personnel.

Energy consumption data were taken from the utility bills and Smart Meter (installed in the library building) data. Data were also collected from Ergon Energy (a local Power Company), since CQU main campus energy is recorded from a central meter. Historical annual energy consumption profile was determined from the central metered data. Figure 2 shows energy consumption profile for 2004 and 2005.It can be seen from Figure 2 that there is a variation in monthly electric energy use due to seasonal weather effects and during winter months, electrical energy use was lower due to lower outside air temperatures.

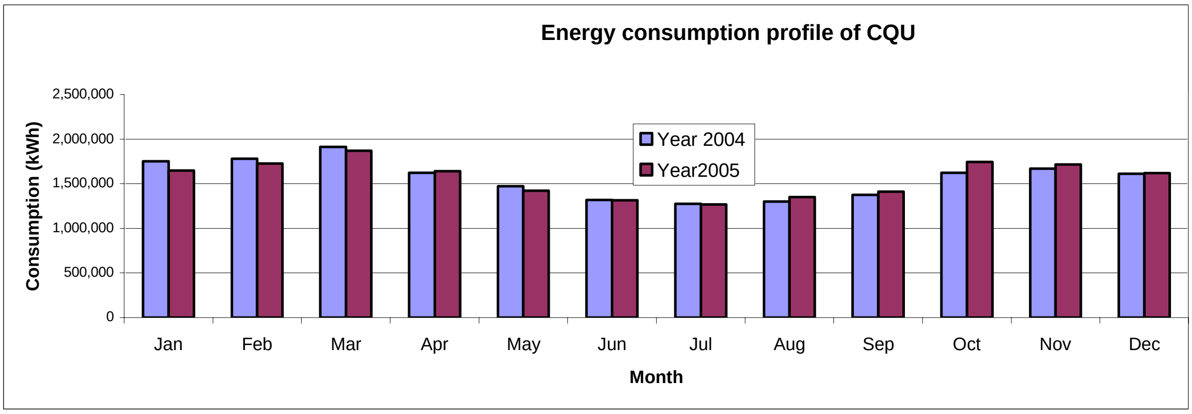

Figure 2: Energy consumption profile of CQU campus buildings

The breakdown of energy consumption of HVAC, lights and other equipment is shown in Figure 3. The HVAC system in the library building had the greatest potential for energy saving as it consumes approximately 61% of the total building energy use. The reason for this is the large internal load in the form of people in the conference rooms, reading rooms, web browsing area and huge collection of books. The control strategy of energy management for the library building is aimed to determine its energy savings potential. The cooling plants and fan coil units were studied. The energy audit identified the major energy consumers as well as areas where retrofits could be made to obtain energy savings.

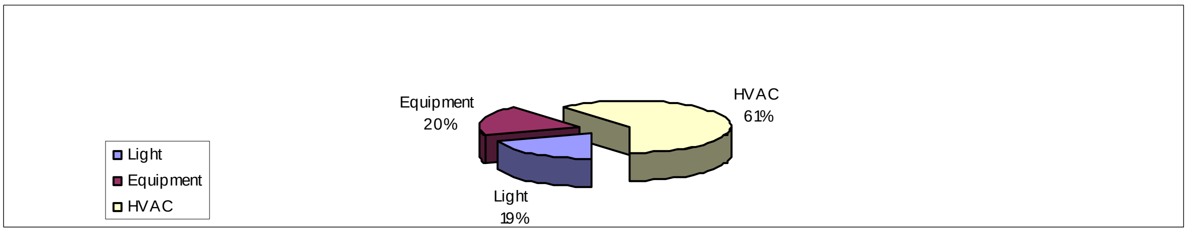

Figure 3: Energy consumption breakdown of library building of CQU

4. SIMULATION AND MODEL VALIDATION

Energy Express (EE), a building's energy simulation software developed by CSIRO, Australia, for prioritizing Australasian climatic condition, was used in this study for simulating energy consumption. EE was first released in 2005. A base case model was developed using the constructional record/physical data, energy audit and some assumptions from built-in library of EE. Rockhampton weather data was used as input parameters into the simulation program. Different indoor set point temperatures for winter and summer months were separately used. Schedules of people, lighting and equipment operations were adjusted and different infiltration rates were introduced into the simulation. Figure 4 compares baseline daily energy consumption predicted by EE and the corresponding on-site (actual) metered data for mid April to mid May 2006. Monthly energy consumption has been simulated because whole year data is not available yet for model validation for the case study building. The simulation results show that energy simulation predicts the energy use pattern of the building fairly well. The results show less than 10% difference between baseline model and on-site (actual) metered data in any day and overall difference is about 7%. These results can be considered realistically accepted in the field of building operational parameters.

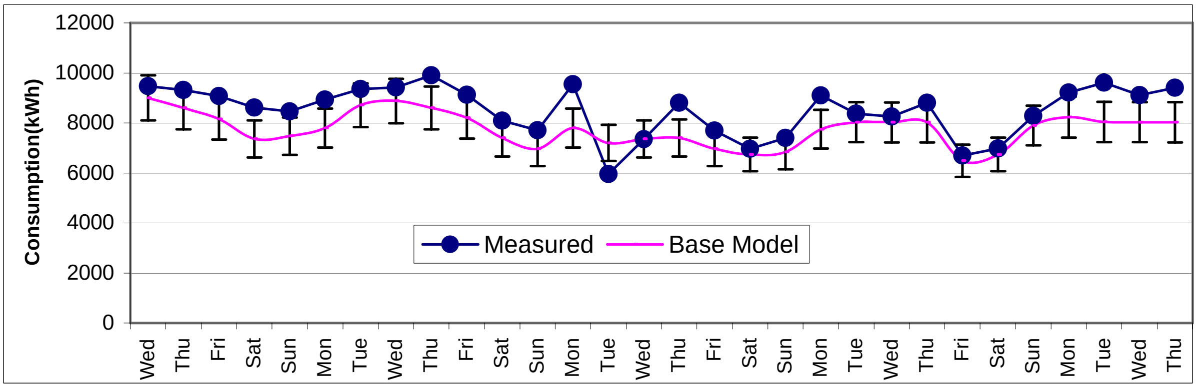

Figure 4: Comparison of baseline model prediction and on-site metered data

5. CONSERVATION MEASURE AND COMPARISON

A variable air volume (VAV) energy conservation measure was assessed since library building's occupant load varies instantaneously time to time. Consequently, VAV system was considered as a potential candidate although VAV as energy conservation measures requires major financial investment for its implementation. It can be implemented through system renovation or retrofitting to the library building. VAV systems provide a variable amount of supply air conditioned at a constant temperature to meet thermal loads in particular spaces on thermostat settings. The supply air volume can be controlled and modulated using various techniques such as outlet dampers, inlet vanes and variable speed drives. Variable speed drive fans were assumed in the VAV systems using the simulation program, necessary rezoning was considered on the ground, first and second floors of the building. The simulation results of the new system arrangement (VAV system) are shown in Figure 5. On an average, 11.8% reduction in energy consumption was achieved for this test case. VAV system is preferable for office and institutional building but not for sophisticated buildings such as hospital, research laboratory where precise humidity is essential.

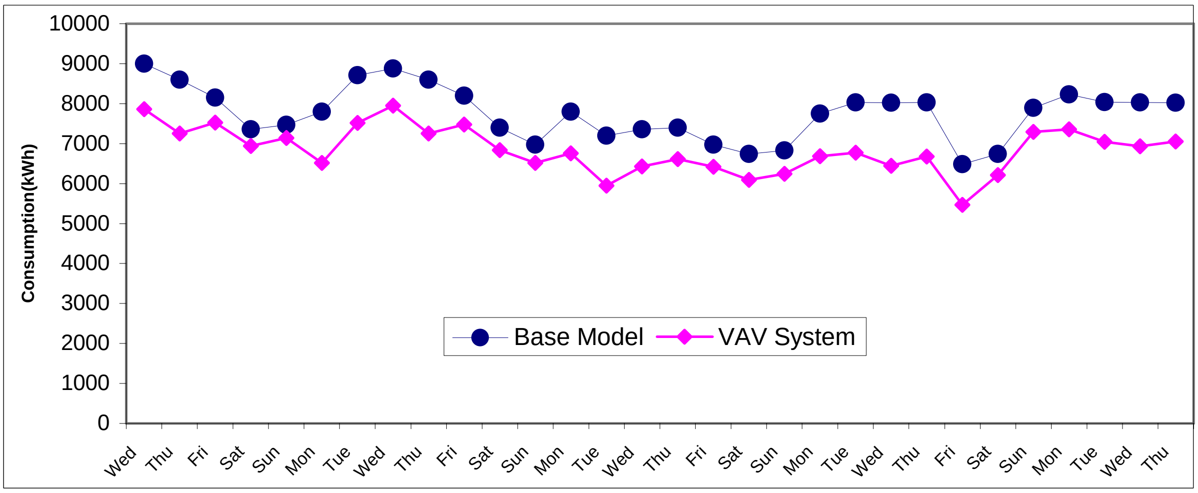

Figure 5: Energy savings with VAV system in comparison with CAV system

6. CONCLUSIONS AND RECOMMENDATIONS

A baseline model of building energy consumption profile has been developed using Energy Express and validated against on-site metered data. Energy audit has been conducted to identify potential areas of energy savings. The HVAC system in the library building in hot-humid climate like Rockhampton has a great potential for energy saving as it consumes approximately 2/3rd of total building energy use. The VAV system as an option for energy conservation measures over CAV system has been assessed. The simulated results show that about 11.8% energy savings could be achieved annually by replacing CAV system with VAV system in HVAC units. It can be strongly recommended that a VAV system is implemented when system renovation takes place in such existing buildings and should be considered for similar office buildings where load demand and weather changes drastically in summer or mid winter in subtropical regions.

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