Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 142 (2017) 3088–3095

Energy Procedia

www.elsevier.com/locate/procedia

9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK

Technological Advancement of Energy Management Facility of Institutional Buildings: A Case Study

Zakia Afroz[a*], *Gary Higgins*[a], *Tania Urmee*[a], *GM Shafiullah*[a]

[a]School of Engineering and Information Technology, Murdoch University, WA-6150, Australia

Abstract

An efficient energy management system in commercial/institutional buildings can reduce energy consumption and operational cost and provide a comfortable and healthy indoor environment. However, without incorporating energy-efficient technologies and analysing the resulting performance the building energy management system may not provide effective control over energy consumption and the indoor environmental conditions. To verify system performance, it is necessary to study the building energy efficiency, examine building indoor environment and investigate existing operational strategies. This can eventually give the actual energy scenario of the building exploring problems existing within the system and opportunities for further upgrade paths that are both technologically and economically sustainable. To get the actual scenario of building energy management facilities, an institutional building of Murdoch University, Australia that incorporated state of the art technologies in the last two decades will be studied in this paper. Through this case study analysis salient information is revealed that will bring benefits to the energy management personnel as well as researchers in this area.

Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.

Keywords: Energy Management System (EMS); Energy Consumption; Indoor environment; Institutional Building.

1. Introduction

Efficient energy management strategies can play an important role in controlling and monitoring energy usage as well as improving building indoor environment in commercial and institutional buildings. Research shows that implementing efficient energy management strategies can lead to 5-15% energy savings in existing buildings [1]. This significant percentage of energy saving opportunity has heightened attention among policymakers and researchers with a view toward increasing energy efficiency and reducing GHG emissions in buildings [2, 3].

The technology of building energy management system (BEMS) is getting sophisticated with time enabling better control over energy consumption, healthy and comfortable indoor environments and reducing operational cost [4].

Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy .
10.1016/j.egypro.2017.12.449

Heating, ventilation and air-conditioning (HVAC) system controlled by BEMS is a major contributor to energy consumption in commercial and institutional buildings. Historically HVAC systems were used to maintain the satisfactory thermal comfort level inside the building, lately the need for providing visual comfort to the occupants and preserving indoor air quality has increased especially with the revolution of technology [5]. This competing requirement of HVAC system demands effective and efficient operation to improve the energy efficiency, thermal and visual comfort level and indoor air quality.

In fact, a potential for energy savings resides in the use, control and interaction of appliances and domestic devices, in order to get their maximum efficiency during normal operation [6]. And the contribution of energy management system (EMS) in this regard is unescapable. However, BEMS are often incorrectly regarded as a fit and forget system. An efficient BEMS can turn into an inefficient one without a routine basis maintenance and upgrade [7]. Therefore, it is the demand of efficient EMS to upgrade after reasonable time interval to maintain consistent performance [1]. This technological advancement of BEMS must comply with Energy Management Control (EMC) legislation and more importantly, keep pace with any modifications to the building structure. To evaluate the effectiveness of any EMS and its existing strategies, it is very important to study the performance of energy consumption, examine building indoor environment and investigate existing operation strategies. However, building energy performance and indoor environmental condition depends on building specific information such as geographic location, building type, size, age, occupancy schedule, operation and maintenance, energy sources, utility rate structure, building fabric, service systems, etc [7]. Therefore, this information can guide in future for optimal retrofit solutions or upgradation opportunities. One of the good ways of collecting this information is performing preliminary case study. Through case study analysis it is possible to evaluate if the operation results are satisfying design expectations and to identify opportunities to improve the energy efficiency that will lead to sustainable building energy consumption [8, 9].

Murdoch University Energy Management system established in 1974 has been upgraded on need basis with efficient equipment and advanced control system to ensure efficient performance and to maintain economically viable operational cost. This research will study the EMS of this University to understand the chronological development of building energy management technology and its application to energy management facilities in institutional buildings. The aim of this study is to identify if there is any scope for improving the performance of the existing HVAC system and the energy efficiency of the study building that is technologically and economically sustainable. To achieve the goal this study will collect the building specific information, investigate the operational strategy of AHU of the study building, gather information about operation, maintenance and upgradation history of the energy management facility of University, examine the strategy of existing HVAC control system and identify problems existing within the system. Based on preliminary case study analysis some possible upgradation opportunities will be revealed in this study that are apparently technologically and economically sustainable. These opportunities will be assessed in further studies to quantify the economic and indoor environmental benefits. The benefits achieved through resulting upgradation of the EMS of Murdoch University will be also quantified in further studies through data analysis to determine the economic and environmental outcome of applied technology.

2. Methodology of investigation

The methodology of investigation has been selected and developed based on the aim of this case study. This study performed a survey of the energy management system of an institutional building facility through a process of studying necessary documents, reviewing the Building Management system via the Graphical User Interface (GUI) and performing walk through audit of the energy management facility. The flow chart as shown in Figure 1 depicts the consecutive approaches to achieve the goals.

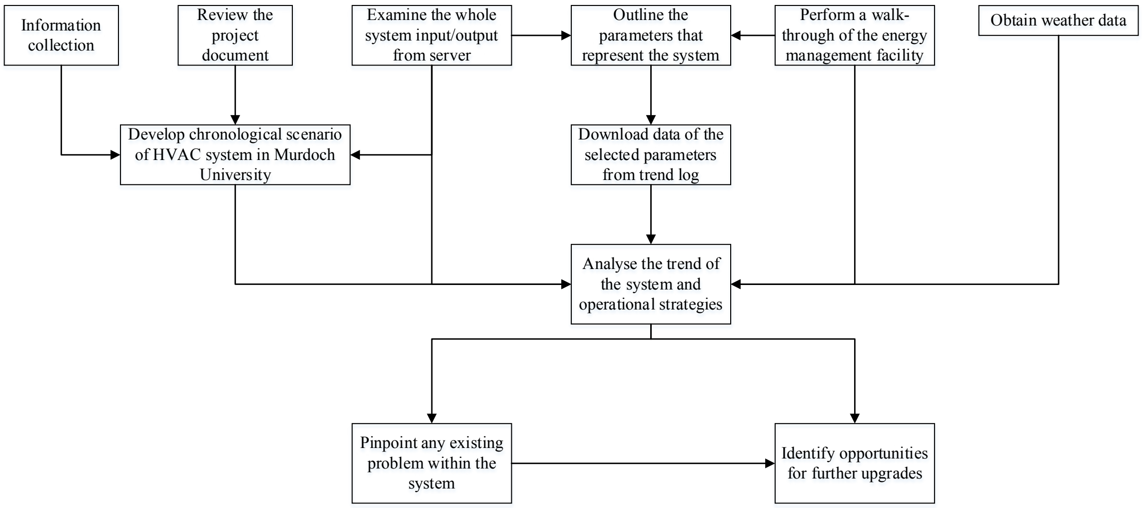

Figure 1: Flowchart showing methodology of investigation

3. Outcomes of investigation

The investigation provided in depth information of the study building, operational strategies of AHUs, present energy management control system, historical background of the energy management facility, problems existing within the system and opportunities to improve the performance of HVAC system. This information is portrayed in the following subsections:

3.1. Building Description

To verify any existing problems with the HVAC control system, this research focuses on current Energy Management Facility of Murdoch University as a case study. The Murdoch University Library North building has been selected for the preliminary case study analysis. The test building, as shown in Fig. 2, is a multi-storey 5873 m^2 Gross Floor Area, 3853 m^2 Useable Floor Area building comprising four levels with different activity schedules.

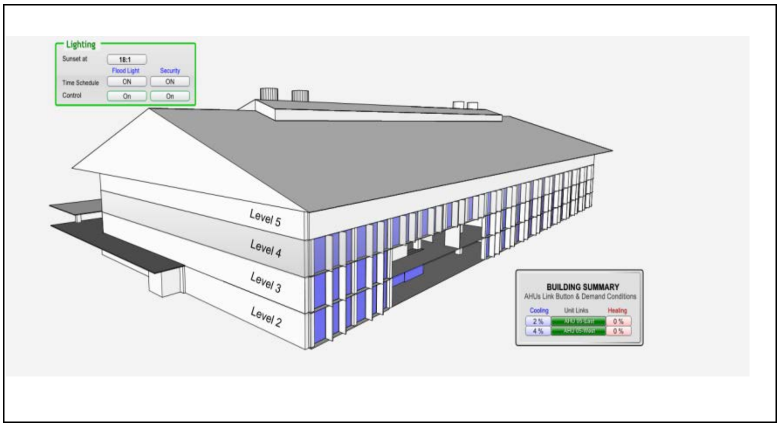

Fig. 2: The Murdoch University Library North Building

The Table 1 provides detailed information about the building configuration and occupancy working schedule. Note this building has no level 1.

Table 1: Building configuration and occupancy working schedule

Level	2	3	4	5	Total
Gross Floor Area (m^2)	1468	1468	1468	1,1468	5873
Building Wall / Construction / Thickness	North, East and west elevation concrete retaining wall 230mm, with 50mm cavity and North – 92mm blockwork, East and West 200mm blockwork. South elevation approximately ½ elevation area 100mm blockwork with 250mm cavity. ½ elevation area 48 single glazed anodised aluminium framed windows – no thermal break	North elevation floor-ceiling single glazed “shopfront” type windows. North Elevation fully solar shaded by ambulatory roof West Elevation 190mm Block work. East elevation 190mm Blockwork – 50mm cavity -92mm blockwork - 50mm cavity – 190mm blockwork. South Elevation as level 2	North Elevation fully solar shaded by ambulatory roof. North elevation as South Elevation level 2 West Elevation 190mm Block work. East elevation 190mm Blockwork. East elevation party wall with B351. South Elevation as level 2	Gable end metal sheet roofing fixed to metal purlins with 50mm anti con insulation. Ventilated ridge and eaves	
Height	3.45m FFL slab to slab	3.45m FFL slab to slab	3.45m FFL slab to slab	Ventilated loft space	
Occupant Time Schedule	24/7	Weekday: 8am-11pm Weekand:10am-5pm	Weekday: 8am- 5:pm	Plant and storage	

3.2. Operational Strategies of AHUs in Study Building

The library building is served by a variable air volume air conditioning system. The building consists of two air handling units (east and west) in total. These air handling units are controlled by the building management system (BMS) facilities through time scheduling. Each air handling unit (AHU) as shown in Figure 3 is equipped with one centrifugal return air fan modulating return air, an exhaust air and an outside air intake dampers, an automatic time switch operated dry media roll filter, one centrifugal supply air fan, two banks of cooling coils and two banks of heating coils. Air is supplied from AHU to variable air volume (VAV) boxes through two ducts: perimeter and centre. There are sixty-two VAV boxes in total located in the ceiling space of the three floors. The electronic VAV controller of each VAV box contains a single blade damper. When the temperature in any particular zone falls below the thermostat set-point, the electronic VAV controller on the corresponding VAV box modulates the damper, thus reducing the air flow to the zone until equilibrium is achieved. The system is capable of modulating through the full range of 0% to 100% air flow.

Control of all zones in the central zone of the building is maintained by VAV box alone and the supply air is controlled to a fixed temperature which is set via an algorithm that looks at the status of all VAV box loads.

In view of the higher degree of fluctuation in the load on the perimeter zones, the control units for the perimeter zones are fitted with resistive electric reheat banks on the discharge from the units. These reheat banks are controlled via the corresponding VAV controller.

The control program for AHU has been designed in such a way that several control strategies can be implemented. When ambient conditions are conducive, it becomes more economical to use a high percentage of outside air and a low percentage of return air. Therefore, in this situation, economy air cycle turns on. This economy air cycle can operate in conditions dependent on the call for cooling or heating and corresponding ambient conditions. In addition to the economy cycle, each conditioner includes a warm up cycle and a night purge cycle.

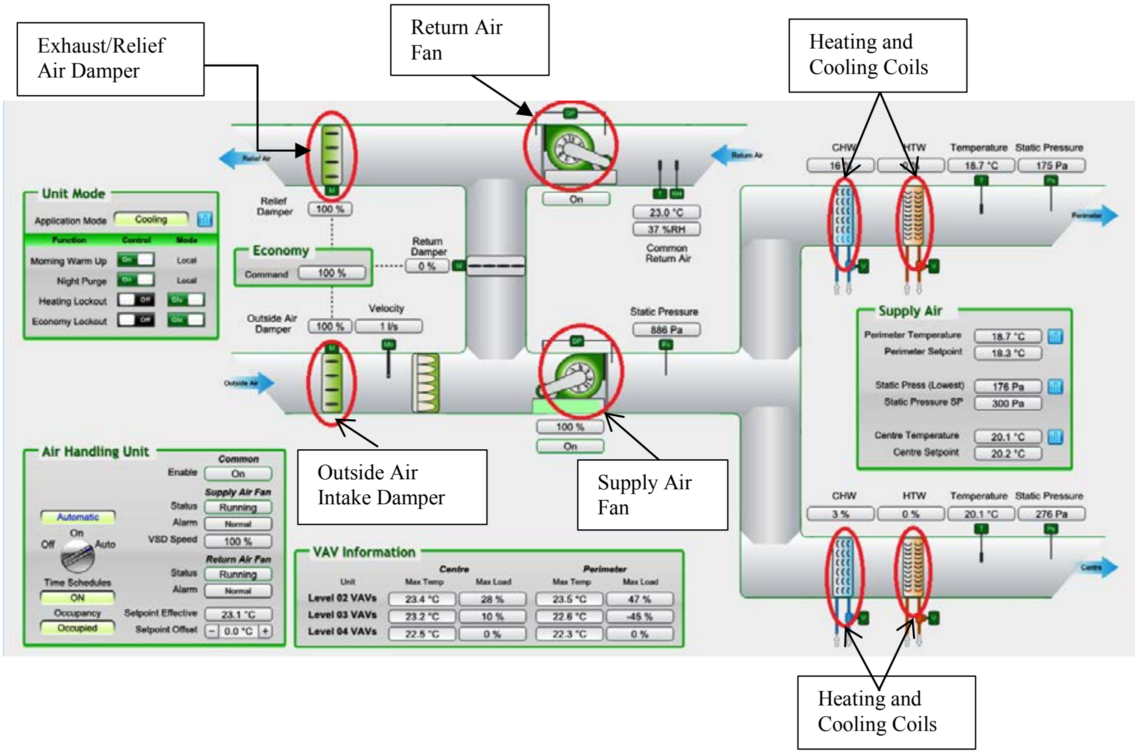

Figure 3: Schematic of AHU

3.3. Chronological development

The building management system of Murdoch University has been upgraded chronologically and many obsolete product lines have been replaced time to time to comply with EMC legislation and to minimize the risk of failure from older components of the system. The Table 2 gives a brief list of major installed equipment, modification of control systems and the outcome achieved through this upgradation.

Table 2: Chronological development of building management system of Murdoch University

Year	Control System	Installation of primary equipment /system upgradation	Purpose of upgrade	Benefits achieved
1974	Pneumatic	Original system controls		
1991	Installed building management software I/NET	TAC Pacific EMS Direct Digital Control system upgrade	To facilitate more reliable and flexible programmable control via algorithms and PID loops	• Improved reliability and additional control features such as time-scheduling, more accurate control over space temperature. • Provided a powerful data gathering mechanism.
1992		• One 2.2 MWr centrifugal water cooled glycol chiller • Underground ice tank farm for thermal storage with a capacity of 10,000 kWh • A cooling tower	To add extra capacity to cope with demand	• Higher Coefficient of System Performance in comparison to existing centrifugal chillers

1999		• Two 1.1MWr Trane air cooled screw chillers	To improve efficiency at low demand e.g winter season	• Gave consistency in flow temperatures • Improved efficiency
2004		• One 2.5 MWr Centrifugal Chiller • A cooling tower	To add Extra capacity to cope with demand	Improved efficiency
2007		Variable Speed Drive (VSD)	To provide incremental control over air volumes	• Improved efficiency • Improved temperature control and air quality
2010		One 4.4 MWr Trane Chiller	To meet the cooling load for the extended portion of the campus.	• Improved efficiency • Satisfied demand
2011		Some mechanical works to AHU's – Louvres etc.	In need of refurbishment of mechanical components at end of life.	• Provided lost functionality • Improved efficiency
2013		Boiler upgradation after 40 years	After 40 years' reliability and performance issues were apparent	• Lowered gas consumption • Improved reliability
2014	Upgraded from I/NET to SBO (StruxureWare Building Operation)	Energy metering has been installed on all chillers, secondary chilled water pump and gas fired boilers.	Some of the obsolete controllers of DDC did not comply with current EMC legislation.	This allowed the analysis of seasonal chiller performance and chiller staging them to be optimised for system efficiency.
		Several buildings have been subdivided	• To improve the communications response, reduce risk of a failed board and allow an upgrade path in more manageable chunks. • To transmit global variables reliably	• Improved communication response • Reliable global variable transmission has enabled global set-point such as variable Master Temperature Set Point dependant on ambient conditions.
			• Upgraded to SBO to enable consistency in trend logging across similar types of equipment. .	• Superior trend logging capabilities • Enabled data for use in historical analytics, fault finding, and efficiency initiatives. • Enabled implementation of best practice algorithms • Enhanced programming features and GUI • Improved customer satisfaction due to better thermal comfort, indoor air quality and fault management response.
2015		Addition of pressurisation and vacuum de-aeration systems to campus chilled water reticulation enabling conversion from an open head system to a closed system.	• To reduce Chilled Water (CHW) starvation at the extremities of the network on high CHW demands. • To reduce corrosion in the system • To reduce air entrainment in the system due to marginal positive head on high demand days.	• Reduced cavitation at secondary and primary chiller pumps. • Increased heat exchange efficiency at chiller evaporators and AHU coils.
2016				Improvement in system performance due to continuous commissioning
2017		IAQ sensors	Identify VOC levels	Expected benefits are to identify VOC levels and dilute with a higher percentage of outside air thus improving indoor air quality.

3.4. Existing AHU control system

The current HVAC system of the study building is operated and controlled by the Energy Management Facility of Murdoch University by using SBO system. The following steps are followed to provide the necessary inputs to the system.

(i) The system looks at outside air enthalpy and compares it with indoor air enthalpy to define the operational strategy of AHU;
(ii) AHU supply temperature set point is determined by the load of VAV box;
(iii) System air pressure is maintained and dependent on the time-schedule of each floor.

3.5. Problems existing within the system

- Difficulty in establishing the mapping between input and output variables of the current HVAC system due to physical constraints.
- Large differences in heat load in different spaces although air is passing through a common duct for those spaces. This is vastly different from the original open plan design intent.
- After modifications to certain spaces at the studied institutional building, the newly created spaces were serviced by the existing HVAC system with mostly minor modifications to plant. However, the system response was not modelled and the resulting performance has not been analysed.

3.6. Opportunities Identified

Based on preliminary survey of the energy management facility of Murdoch University following opportunities have been identified that can improve the performance of the HVAC system by optimizing energy efficiency, and building indoor thermal comfort level and IAQ:

- Some of the key factors e.g. CO_2 concentration, VOC affecting the building indoor air quality and occupants' comfort can be integrated with the current EMC system to improve the system reliability.
- Building indoor environmental conditions and energy consumed by HVAC system can be predicted to use them in Model Predictive Control (MPC) system.
- MPC system can be integrated with the existing Proportional Integral Derivative (PID) controller for improving the performance of the Building Automation System (BAS).

4. Conclusion

It is very important to get an insight about the historical background of the energy management system of a building facility and current operational strategies and controlling method of AHUs to investigate the effectiveness of this system and to explore further upgradation opportunities. This study undertaken a preliminary case study analysis in an institutional building and revealed how the studied EMS and its control have been upgraded chronologically to cope with EMC legislation, technological revolution, to meet concurrent increasing heating and cooling load and to improve operational strategy. This has eventually delivered better control over building indoor environment and energy consumption. Still there are some problems existing within the studied system that have been revealed though this investigation and further improvement opportunities have been discovered. The outcome of resulting upgradation and the improvement opportunities identified through this case study analysis will be quantified in further studies in terms of economic and building indoor environmental benefits.

References

[1] M. R. Brambley, D. Hansen, P. Haves, D. Holmberg, S. McDonald, K. Roth, *et al.*, "Advanced sensors and controls for building applications: Market assessment and potential R&D pathways," *Pacific Northwest National Laboratory,* 2005.

[2] G. Trencher, V. Castán Broto, T. Takagi, Z. Sprigings, Y. Nishida, and M. Yarime, "Innovative policy practices to advance building energy efficiency and retrofitting: Approaches, impacts and challenges in ten C40 cities," *Environmental Science & Policy,* vol. 66,

pp. 353-365, 12// 2016.

[3] M. Mardookhy, R. Sawhney, S. Ji, X. Zhu, and W. Zhou, "A study of energy efficiency in residential buildings in Knoxville, Tennessee," *Journal of Cleaner Production,* vol. 85, pp. 241-249, 2014.

[4] T. Nikolaou, D. Kolokotsa, and G. Stavrakakis, "Review on methodologies for energy benchmarking, rating and classification of buildings," *Advances in Building Energy Research,* vol. 5, pp. 53-70, 2011.

[5] P. H. Shaikh, N. B. M. Nor, P. Nallagownden, I. Elamvazuthi, and T. Ibrahim, "A review on optimized control systems for building energy and comfort management of smart sustainable buildings," *Renewable and Sustainable Energy Reviews,* vol. 34, pp. 409-429, 6// 2014.

[6] M. J. Kofler, C. Reinisch, and W. Kastner, "A semantic representation of energy-related information in future smart homes," *Energy and Buildings,* vol. 47, pp. 169-179, 2012.

[7] Z. Ma, P. Cooper, D. Daly, and L. Ledo, "Existing building retrofits: Methodology and state-of-the-art," *Energy and Buildings,* vol. 55, pp. 889-902, 2012/12/01/ 2012.

[8] L. Johannsdottir, B. Davidsdottir, M. E. Goodsite, and S. Olafsson, "Insurers' role in enhancing development and utilization of environmentally sound technologies: a case study of Nordic insurers," *Journal of Cleaner Production,* vol. 65, pp. 526-538, 2/15/ 2014.

[9] Y. Huang, J.-l. Niu, and T.-m. Chung, "Energy and carbon emission payback analysis for energy-efficient retrofitting in buildings—Overhang shading option," *Energy and Buildings,* vol. 44, pp. 94-103, 1// 2012.