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Energy Audit of The Building Air-Conditioning System

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Abstract

Energy audit is one of the effective tools to identify potential of energy conservation and help to identify energy waste in a facility or system. In commercial office building like the Faculty of Mechanical Engineering (FME) Academic Building, its air-conditioning system (AC) alone consumed almost 72.55% of total monthly FME energy consumption for both of its Split unit and Central Cooling System. The objective of this study is to find the energy usage and billing of the AC at FME Academic building and finally to recommend the possible methods for energy conservation related to the system. This energy audit is done by conducting system observation, acquire data and information such as maintenance record, electrical usage, room condition and analyse system performance. During data collecting and observation few cause were found that lead to excess energy consumption for both systems that can be conserver in monetary term. For example, the VRV system that currently installed is expected to give saving of RM 65,900.78 annually in building operational costs.

Key words: *energy audit, air conditioning, building*

1. INTRODUCTION

In tropical base commercial building, air conditioning is one the most energy consumption due to the demand to meet the need of human comfort (Nasution & Hasan, 2006; Saidur, 2010). Many building systems are designed to operate at maximum load conditions. However, most building systems operate at their full load only for short periods of time. This often results in many systems operating inefficiently over long periods of time. Most such inefficient operations in buildings are encountered in air-conditioning systems that are normally sized to meet peak load conditions, these occur only for short periods during the normal day (Saidur, 2010). To increase the energy efficiency we need to know the energy usage for the system and pinpoint in the system for any possible energy saving. This can be done through energy analysis and audit (Elsadig, 2005; Jian, 2006; Nazari, 2008; Aziz & Sari, 2009). Albert Thumann's Handbook of Energy Audit defines it as to identify all the energy streams into the facility and the quantity energy used according to the discrete function. Energy audit is one of the most effective and comprehensive tools for energy management. It is the key to systematic approach of energy management. The main objective of the energy audit is to determine any possible opportunity for energy conservation of the audited system (Thumann & Younger, 2003; Rahman, 2009).

From energy audit, specific amount of energy take account of energy consumption of different component in the building, system or process to be reveal detail information needed. This process must be done accurately enough to identify and quantify the various forms of energy used and the purpose the energy used. This problem brings idea of the better use of the energy instead of fulfilling the need of the energy. In this matter energy analysis and energy audit becomes an essential tool for better energy management by giving a positive orientation not just the energy used and reduction but also good maintenance of the buildings or facility.

In this study only the analysis and audit of energy usage for air conditioning system will be focus on involving are two type of air conditioning system (split unit and central cooling system) used Faculty of Mechanical Engineering (FME) academic building. The objectives of the study are to find the energy usage for air conditioning system in the FME building, energy billings of air conditioning system and to conserve of energy for air conditioning system.

1.1 Type of Energy Audit

There are 4 level of energy audit (Thumann & Younger, 2003, PTM, 2006) :

a. Benchmarking

Benchmarking is by analysing the facility's historical energy use and performing a utility rate analysis to pinpoint any cost saving opportunities. In this stage any energy end used are being identifying as many as is reasonable. This overview audit is fine for small or budget-base organizations that want some quick tips on how they can reduce their energy usage and costs.

b. Walk-through audit

It the least cost by assesses building energy efficiency to identify simple and low-cost improvements and potential capital improvements for further study. Mostly it base on surveying and inspection to determine the maintenance and operating energy saving opportunity also collection of information to determine the need of further detailed audit.

c. Preliminary energy audit

Typical yet detail energy audit, this type of audit provide a more comprehensive analysis of the studied system not just energy usage analysis at previous walk through audit, but also includes more detailed energy calculations and financial analysis for proposed of energy efficiency measures. The financial analysis or Life Cycle Analysis allows the facility owner to understand the financial benefits installing energy efficient measures.

d. Detailed analysis audit

Further expansion from the previous levels of effort and is based on the audited representative's selection of measures to analyse further. This may include further refinement of an energy model or more extensive data collection. It know as capital intensive modification where it undertake field monitoring and engineering design which would lead to significant capital investment.

1.2 Measurement in Energy Audit

Energy Auditing involve with energy value, and this are gain from the measurement of audited system performance to plan for improvement later. This audit will be measure value such as condition of operation physical variable. There are two basic form of measurement that are relate to perform this energy audit (Thumann & Younger, 2003, PTM, 2006)

a. Energy consumption measurement.

By knowing the consumption of energy in the system audited, a study later can be done to know the cost related to the energy consumption. It can help to pinpointing area in the system that high energy consumption where the energy saving are highly recommended for the behavioral.

b. Energy efficiency measurement.

After the energy consumption measurement, comparison between the outputs to the input of the energy will determine whether the efficiency of the systems meet to the standard or requirement. This will give the reference to be considering either there are possible wastes of energy occurring or any energy conservation should be done for the system.

1.3 Energy Management with Air Conditioner (PTM, 2006)

Prevention is better that cure, in this matter energy wastage can be assume as disease in managing a building which it can lead to high maintenance and operational cost. So as the prevention a good energy management should applied to avoid high operational cost of the building occupied.

In energy audit there are three level of energy saving that can be achieve depending on to the priority by selecting the prefer ones, or by combining all the measure.

a. Zero cost measure

A good in-house maintenance is good way to start energy conservation, where it can help maintain system to perform efficiently for a long-term period. This can be achieved by emphasis on using existing equipment efficiency. The measures below are basically concentrated on measurement, control and maintenance of the air conditioning system:

Accurate temperature and humidity control
Prevent infiltration of warm air in the air conditioning spaces
Optimizing air flow of AHU units

b. Low cost measure

It represents a move towards technology for solution with a additional input from the related personal. The measures are low cost concentrated on the utility and process improvement within the system:
Improve the AHU heat transfer rate with low pressure drop design methods across ducting and coils.
Improve piping efficiency with lower loss piping design
Enthalpy Control (intake of ambient air instead of return air) depend on indoor air conditioning

c. High cost measure

This measure are usually emphasis on technology to achieve energy saving where such measure are need careful financial and technical analysis. New technologies are related to achieve this measure:

- Use renewable source of energy
- Efficient compressor and chiller
- Add number of cooling tower

1.4 Parameter in Air Conditioning (Malaysian Standard, 2001)

Conducting energy audit will refer to the energy used to perform the cooling for the system. These figures are influence by factor related with air conditioning such as the Coefficient of performance (COP). Another parameter that used to evaluate an air conditioning system performance is thermal comfort. It deals with the satisfaction of the occupant. According to the Malaysia Standard (MS) there are three factors that should be considered in thermal comfort for indoor air conditioning.

a. Relative humidity

It defines as the ratio of actual amount of moisture in the air at a temperature to the maximum amount air can hold at the temperature. It can be determine the dry and wet bulb reading and referring to the psychometric chart but this only applies at a constant pressure condition. Today, humidity value can be occupied by direct reading of a humidity reader. According to MS it should be maintain 55-70% where at high value of relative humidity will stimulate the growth of bacteria and condition area to be stuffy. While a lower relative humidity can cause dryness to skin leading to skin rash and excessive electrostatic charge in the occupant condition space.

b. Dry bulb temperature

The dry bulb temperature affects the relative humidity. In high relative humidity, require temperature will lower and vice versa for low relative humidity to achieve thermal comfort. From this understanding it is know that lower relative humidity will enhance the heat dissipation from the condition area. Recommended by MS for occupants feel thermally comfortable, the air temperature need to be 23-26°C but the minimum of temperature can be set to be 22°C. Then again the desire temperature are depends on the activity in the condition area.

c. Air velocity

Air velocity enhances heat transfer from condition area. Air velocity occurs due to the temperature difference of the air where it related to the density and relative humidity of the air. Cause by the pressure difference in the air, referring to the previous section the hotter the air the less dense with water vapor in the air and it will easily rise up will this is vice versa for cool air. This difference produces circular motion to the air and air velocity. Beside temperature difference, ventilation can also produce and increase the air velocity. Such ventilation is produce by either natural ventilation (eg. windows) or force ventilation (eg. AHU unit).

2. THEORETICAL CALCULATION

Referring to the energy audit requirement, the energy used by the system need to be determines. To perform this there are two forms measurement will be focus which is the energy used to operate air conditioning and cooling load of the system.

Heat that causes a change in temperature in an object is called sensible heat, while the heat that contribute to the cooling load by the moisture in the air is known as latent heat. To determine the energy we first need to determine the heat load are actually need to cool the condition area, where heat load is total of sensible heat and latent heat.

Total Heat Load = Sensible heat + Latent heat

$$= Qs + Ql \qquad (1)$$

Sensible heat is

$$Qs = m \times cp \times \Delta P \qquad (2)$$

where

Qs : sensible heat , kJ/s
m : mass flow rate, m/s
cp : specific heat, kJ/kg.K
ΔP : mix Air temperature + supply air temperature

To find mass flow rate of air

$$m = \rho \times Q \qquad (3)$$

where

ρ : air density, at the condition temperature,(kg/m^3)
Q : air volume flow (m^3/s)

Therefore, substituting Eq. 2 into 3

$$Qs = \rho \times Q \times cp \times \Delta P \qquad (4)$$

While for Latent Heat it is,

$$Ql = m_a \times \Delta h \qquad (5)$$

where

Δh : enthalpy difference, kJ/kg

Total enthalpy for this system is equivalent to the total heat enthalpy for partial water vapor and air. Where, for total enthalpy is known as:

$$h_m = h_a + w_v \times h_v \qquad (6)$$

where

h_m : enthalpy of air and vapor mixture, kJ/kg
h_a : enthalpy of air, kJ/kg
h_v : enthalpy of water vapor, kJ/kg
w_v : ratio of water vapor mass content to air mass content

The enthalpy can be calculated using the following formula:

$$\boldsymbol{h_a} = cp_{air} \times \boldsymbol{\Delta T} \qquad (7)$$

$$\boldsymbol{h_v} = cp_{vapor} \times \boldsymbol{\Delta T} + \boldsymbol{h_{fg}} + cp_{water} \times t_{dew} \qquad (8)$$

where

$cp_{water} \times t_{dew}$: enthalpy due saturated water, kJ/kg.K
$\boldsymbol{h_{fg}}$: enthalpy due to mixture of water and vapor,kJ/kg
$cp_{air} \times \boldsymbol{\Delta T}$: enthalpy due to saturated vapor, kJ/kg K

For t_{dew} is negligible compare to ΔT, so the water vapor enthalpy equation can be reduce to,

$$\boldsymbol{h_v} = cp_{vapor} \times \boldsymbol{\Delta T} + \boldsymbol{h_{fg}} \qquad (9)$$

Substituting Eq. 9 into 6

$$\boldsymbol{h_m} = [\![cp_{air} \times \boldsymbol{\Delta T} + w_v(cp]\!]_{vapor} \times \boldsymbol{\Delta T} + h_{fg}) \qquad (10)$$

Giving the for total enthalpy for cooling coil before and after in the AHU unit is

$$\boldsymbol{h_{m1}} = [\![cp_{air} \times \boldsymbol{\Delta T} + w_{v1}(cp]\!]_{vapor} \times \boldsymbol{\Delta T} + h_{fg}) \qquad (11)$$

$$\boldsymbol{h_{m2}} = [\![cp_{air} \times \boldsymbol{\Delta T} + w_{v2}(cp]\!]_{vapor} \times \boldsymbol{\Delta T} + h_{fg}) \qquad (12)$$

But in latent heat calculation, the heat load is neither due to humidification nor dehumidification. So heat load due to temperature difference is already cover in the sensible heat, where ΔT = 0. Giving that Eq. 11 and 12:

$$h_1 = w_{v1} \times h_{fg} \qquad (13)$$

$$h_2 = w_{v2} \times h_{fg} \qquad (14)$$

So for latent heat, substituting Eq. 3, Eq.13 and Eq.14 into Eq. 5:

$$Q_1 l = \rho \times Q \times \boldsymbol{h_1} fg \,(w_1 v2 - w_1 v1\,) \qquad (15)$$

Power consumption for the calculation can be calculated using the equation below for 1-Phase and 3-Phase current:

1-Phase Power = $\sqrt{1}$ (voltage)(current)(power factor)

3-Phase Power = $\sqrt{3}$ (voltage)(current)(power factor)

Both current and voltage consume by cooling tower and AHU unit can be measure at main switchboard at Cooling Tower room and AHU room.

Coefficients of performance (COP) define as the performance for air conditioning where for air conditioning it specifically referring to Coefficients of Performance Refrigerator (COP_R). The objective of refrigerating is to remove heat from the condition space (Ql) with a work is supply to the refrigerator heat engine $W_{net.in}$.

$$COP_R = \frac{Desire\ output}{Require\ input} = \frac{Q_l}{W_{net.in}} \quad (16)$$

$$COP_R = \frac{Total\ heat\ load}{Total\ electrical\ load} \quad (17)$$

Cooling tower performance is the percentage capability of the tower cooling. It is depends to environment condition. Where the top and the bottom water temperature of the cooling tower are taken into the calculation.

Cooling Tower performance:

$$= \frac{Random}{(Random + Approach)} \quad (18)$$

Where, substitute into Eq. 18:

Random = Top Water Temp − Bottom Water Temp

Approach = Bottom Water Temp − Environment Wet Bulb Temp

3. METHODOLOGY

3.1 Flow of Energy Audit

For this study, figure 1 show how the audit been done. Compare to conventional energy audit are done in a team of people from different expertise and involving larger area audited with more accuracy and higher cost. In this audit only air conditioning systems are be focus on.

3.2 Defining the Scope of Energy Audit

This study will be covering the evaluation of energy used for air conditioning system at all FME academic building (C23, C24 and C25). Taking the consideration of the use of air conditioning system in selected audited area during the sampling period is relevant as the average overall analysis for energy audit cover for the FME buildings.

3.3 On-Site Survey

Interview and Survey

To perform and complete the energy audit an interview and survey will be done to gain more knowledge and information about the audited system. The interview and survey conducted will be focusing to the operational and maintenance of the system. A possible survey of the occupant can also be done to determine whether the occupant comfortable with the current applied system management and the usage. Surveys will also being done for the monitor rooms for number of occupant and type of activity during data collecting. Some of the room might no be accessible due that an assumption will be made about the room and its usage capacity related to air conditioning system.

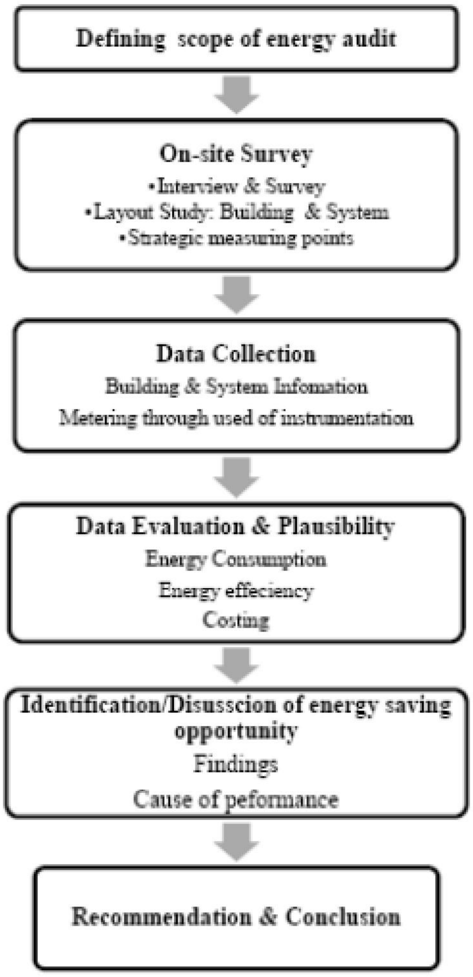

Figure 1. Flow chart of energy audit process

Study layout and information of the air conditioning system

To better understanding the air conditioning system used in these buildings, the layout of the building was obtain from office of asset and development (PHB) UTM. This information acquisition will cover information such as location and number AHU unit, size of the condition area, and specification of cooling tower, Spilt Unit, AHU unit installed in the FME building.

3.4 Data Collection

The data that are required to perform the audit are such temperature, airflow and humidity rearing in the occupant room. This will give the reading of heat load of condition area and also thermal comfort to be analysed later. Instrument such as Digital thermometer, humidity and air flow meter will be used for this occasion. To obtain power reading regarding the AHU, cooling tower, spit unit voltage clamp meter will be used. Since the is no specific meter regarding the usage of the air conditioning system alone, a sub-metering for the air conditioning system are needed to gain information of the power usage during the data acquisition.

3.5 Data Evaluation

Analysing of the data will be referring to the theoretical equation discuss in the section 2. Most of the calculation will lead to the total energy consumption and efficiency of the air conditioning system performance. This analysis of energy will then transfer to a cost related calculation for the system operational of the buildings.

4. RESULT AND DISCUSSION

4.1 Power Usage Distribution

Table 1 show all air conditioning component energy distribution involves in this audit where AHU set for 55.73% of the total component energy usage. Referring to Table 2 the detail distribution show the AHU compressor is the highest energy consumption. It is recommended, to apply energy saving for the system, energy conservation and system control should be focusing on the AHU compressor due to the finding of it performance and efficiency.

Table 1. AC system power usage distribution

Component Unit	kW	%
AHU Unit	58,161.29	55.73
Pump Cooling Tower	15,770.55	15.11
Fan Motor Cooling Tower	1,491.97	1.43
Split Unit	28,931.73	27.72

FME total power usages in this case are only referring only to 3 academic blocks C23, C24 and C25. Central cooling systems and its component consume almost 50% of the total power of air conditioning system where most of the energy used for the AHU. Taking November FME electrical usage as reference, it show that only less than 30% of total power used for other application beside air conditioning system. Clearly, that air conditioning system is the major consumer of FME electrical usage.

Table 2. Total power usage at FME November

Component Unit	Total Unit (kW)	Total Cost (RM)
Split Unit	28,931.73	9,026.65
AHU Compressor	39,069.72	12,189.75
AHU Fan	4,394.82	1,371.18
Pump Cooling Tower	15,770.55	4,920.41
Motor Fan Cooling Tower	1,491.97	465.49
FME Power Usage	119,193.00	37,188.22

4.2 Room Condition

The room conditions in the data show that most of the room having a temperature room between 22°C and 24°C. There also as low as 18°C at certain time of the day which is way below than it suppose to as instructed for all government building and set at by the thermostat. This condition leads to excessive power consumption of compressor for unnecessary cooling load in its total operational. In this case, it cause the room to overcool and also consume more energy as both of the compressor running for cooling instead a cut-off by the thermostat after exceeding its temperature setting which suppose to increase the room temperature to thermostat setting temperature by reducing compressor work load at the same room heat load naturally due time.

4.3 Overall AHU Unit Performance

Using eq. 17 the COP of AHU unit can be determine. Using total heat load and power usage the respected AHU unit. From the Table 4 it can see that although all the AHU unit are age more than 10 years but some of the AHU unit still capable of having COP more 3.0 which is more than what the set in the Malaysia Standard as see in Table 3.

4.4 Energy Saving Potential

The water cooling package unit (WCPU) AHU central cooling system workings principal are to meet the cooling need of the building not to specific to the need of the user. This is a clear sign of energy waste to a building if it is not occupied or cooling load require to the occupant. From observation during measure the room condition most of the occupant are not in the room especially lecturers room. It is estimated that almost 50% of the lecturer room are not occupied during a period of time.

Table 3. Recommended COP by MS

Cooling Capacity	Air Cooled	Water Cooled
< 19 kW	2.6	2.9
> 19 kW	2.7	2.9

Table 4. COP for AHU unit

BIL	Type	Model	Capacity	Power Usage	Room Condition			COP
				kW	kJ			
C23				A	I	J	K	
1	ACU	MYSS200B	20HP	21.32	25.16	32.53	57.69	2.18
2	ACU	MYSS200B	20HP	21.51	18.78	23.52	42.30	1.59
3	WCPU	WCP173	14.41TR	13.05	15.71	15.78	31.49	1.73
4	WCPU	WCP173	14.41TR	10.14	15.36	15.48	30.84	2.02
5	WCPU	WCP220	18.33TR	16.58	23.84	37.30	61.14	2.81
6	WCPU	WCP173	14.41TR	14.60	18.53	24.09	42.62	2.16
7	WCPU	WCP255	21.25TR	21.10	31.30	46.81	78.10	2.97
8	WCPU	WCP173	14.41TR	13.91	17.89	23.28	41.18	2.16
C24				A	I	J	K	
1	WCPU	WCP220	18.33TR	15.60	12.04	6.90	18.94	0.91
2	WCPU	WCP220	18.33TR	15.68	11.94	9.15	21.08	1.01
3	WCPU	WCP173	14.41TR	14.24	17.29	28.63	45.92	2.37
4	WCPU	WCP173	14.41TR	13.24	15.35	19.07	34.42	1.87
5	WCPU	WCP173	14.41TR	14.54	18.74	23.15	41.89	2.13
6	WCPU	WCP240	20.00TR	20.04	42.04	62.98	105.02	4.17
C25				A	I	J	K	
1	WCPU	WCP220	18.33TR	16.80	23.84	31.03	54.86	2.50
2	WCPU	WCP220	18.33TR	15.40	23.38	27.44	50.82	2.47
3	WCPU	WCP225	24.17TR	-	-	-	-	
4	WCPU	WCP290	21.25	-	-	-	-	
5	WCPU	WCP220	18.33TR	11.28	21.10	15.74	36.85	2.24
6	WCPU	WCP220	18.33TR	13.07	19.47	20.92	40.39	2.22
7	WCPU	WCP110	9.16TR	11.38	10.14	10.71	20.85	1.26

Starting from April 2012 all lecturer room will start using the new variable refrigerant volume (VRV) system to replace WCPU AHU of lecturer's room. Since the VRV System have not start operated yet, to perform energy audit of the system is impossible.

All assumption for this calculation made base on observation of it occupancy. Discussions with the installation contractor are made to have a better understand of the installed system principal and component. The new installed VRV system said to be better then the WCPU system for two reasons: energy saving potential and environment friendly.

Only 10 Unit of WCPU AHU units are taken into consideration for calculation that replace with the VRV system. The room capacity represents the numbers of lecturer that can be located in that room in one period of time. For VRV indoor unit, every lecturer room is installing with 1 indoor unit.

The Table 5 shows the usage of power usage for both systems. Although the total figure of the VRV System are higher then WCPU AHU unit, but occupancy of the room should be taken into consideration of the calculation.

Table 5. Comparison of WCPU and VRV system power consumption

Block	POWER USAGE		POWER USAGE (kW)		ROOM CAPACITY
	AHU	Cooling Tower	Outdoor Unit	Indoor Unit	
C23	13.05	30.96	20.37 Per Unit	0.03 Per Unit	24
	10.73				
	16.58				30
	14.60				
	21.10				29
	13.91				
C24	14.54	10.32			29
	20.04				
C25	11.28	10.32			26
	13.07				
Total (kW)	148.90	51.60	207.3	4.14	138
Total (RM)	46.46	16.10	64.68	1.29	

Due to its inverter compressor system, the VRV compressor will only produce the require amount of cooling loading and reduce the total operation power. Compare to the WCPU AHU unit, it operate to cool the entire room either its occupied or not. From the above understanding, total saving using the VRV system can be estimated. Assuming the operation of the system during only on working days annually and consider only half of the total occupant in the room at any particular time of the day.

Base from the calculation, the VRV system have the potential to give at least RM 65,900.78 of operational cost saving annually. Working load of the VRV system is base on the capacity used. During preliminary survey it is found out that most of the lecturer rooms are only occupied only by half of its full occupancy.

5. CONCLUSION

In this study, it is found that clearly air conditioning consumes the largest power in the FME building about 72.55% of its total energy usage. Due to this high demand on air conditioning alone, its believe that this is one of the system that should be look into for energy conservation.

The AHU Unit consumes the largest number of all air conditioning components. Most of the AHU are ready age more than 10 years and due to it most of the units are not perform well, where it needs constant maintenance. It would not just increase the operational cost of the system but also energy usages are not utilized to its maximum efficiency.

Some of the unit still have perform well but it consume larger number energy due to lack and broken control instrumentation such as thermostat and circuit timer which control the capacity of the air conditioning cooling load especially compressor which the biggest energy consumer in AHU. It is installing to cool the lecturer room in which most of the occupants are not at the room. This it another type of energy waste for cooling of less occupy space.

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