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Energy Efficiency Calculation and Air Handling Unit Design Based on Cooling Load Capacity at MASTEK Mosque

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Abstract. The rate of development growth in Indonesia has resulted in an increase of energy demand. In addition, most power generation systems still use fossil fuels of nearly 50%, in other words this fuel can run out within the next 18 years. The electricity needs in the building come from the use of lighting, computers, office equipment, heating, ventilation, air conditioning and also air conditioning systems (AHU). This paper aims to investigate energy efficiency based on cooling load capacity to reduce energy use and design an air conditioning system. A well-designed HVAC system will have a great impact on indoor air conditions. Room comfortability will be realized throughout the year and also the outside environment if cared for properly according to the procedures of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Handbook of Fundamentals. Mastek Mosque required 167,151,241 Btu/h. The ducting design for central air conditioning systems uses 12 x 8 pipes for the main ducting and 10 x 6 for the ducting suction with 12 nozzles and 10 x 6 and 10 x 8 return ducting sizes. This system has the advantages of efficient, silent cooling and increased comfort for prayer.

1. Introduction

The rate of development growth in Indonesia has resulted in an increase of energy demand. Electrical energy is the most energy needed in almost all development sectors, this is indicated by the rate of industrial growth where everything requires electrical energy. In addition, most power generation systems still use fossil fuels of nearly 50%, in other words this fuel can run out within the next 18 years. On the other hand, the government has a target that 95% of Indonesia's territory will have electricity by 2025. Several alternatives have emerged as power plants such as DSSC [1], Photovoltaic [2], Wind Turbine [3], Water Turbine [4], etc.

In a multi-storey building alternative power generation is one way to reduce environmental impact. In addition to creating alternative power plants, reducing energy consumption in buildings is an option as well as increasing economic benefits. The electricity needs in the building come from the use of lighting, computers, office equipment, heating, ventilation, air conditioning and also air conditioning systems (AHU). Consumption is about 44% of total commercial use. Limited use of air cooling can lower energy consumption. The air conditioning system is one way to reduce electricity consumption.

The most widely used method of air conditioning systems is to use a single air conditioning source. R P Shean has conducted research on air conditioning systems in high rise buildings by controlling the use of cooling, the use of this control can save 17% of the load on electricity usage [5]. The air conditioning process can be affected by several conditions such as humidity, fans to circulate cold air, ducting system and also the cooling load generated from a room [6]. In addition, the efficiency of the cooling system can reduce energy consumption, the energy consumption of the cooling system needs to be calculated beforehand [7]. Air cooling products that have several good dehumidification features are already on the market. The requirement for dehumidification by fresh air introduced into a room is a major problem in this new system. This external air dehumidification load needs to be taken into account to design a heating, ventilation and air conditioning (HVAC) system [8]. Increasing air volume can increase humidity in certain climates. According to the standard revision of 62-1989, the requirements for the average relative humidity (RH) of the occupied room are ≤60% and for RH for the period of empty space is ≤70%. However, this requirement is not submitted for public review because according to existing standards recommending RH between 30-60%, this requirement needs to be met in areas with high humidity levels [9].

In designing AHU energy consumption is strongly influenced by several things such as climatic conditions, geographical conditions, enthalpy, relative humidity, wet bulb temperature, dry bulb temperature [10]. In the design process, it is necessary to pay attention to climatic geographic conditions in the application of AHU and cooling load analysis. Therefore, there is a need in detail to investigate the effects of all aspects. This paper aims to investigate energy efficiency based on cooling load capacity to reduce energy use and design an air conditioning system at the MASTEK mosque, Sebelas Maret University.

2. Method

2.1. Mosque Dimension and Location

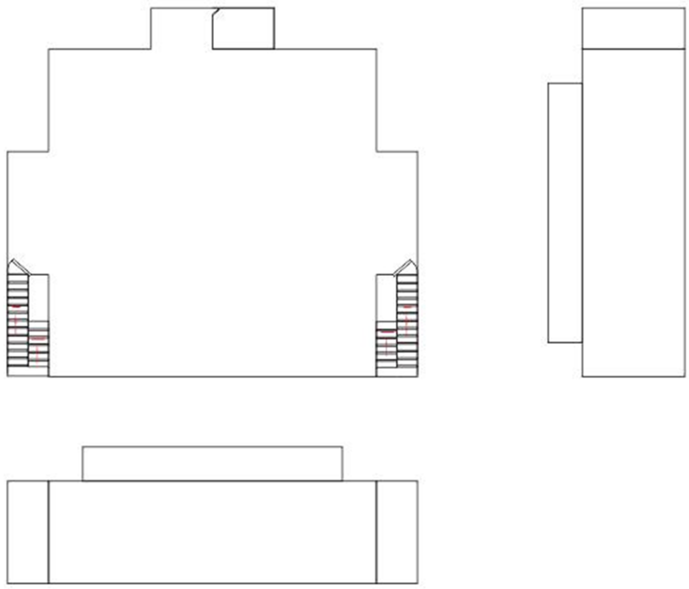

Figure 1. Mosque design

Mastek Mosque is located in the Sebelas Maret University area of Surakarta at coordinates 7°34'0″ NL 110°49'0″ EL with the mosque design as shown in Figure 1. The average speed of the wind that blows in this area is 4 knots with average temperature 31 °C. Table 1 explains the dimensions, materials and number of windows and doors at the Mastek mosque as well as the environmental conditions shown in Table 2.

Table 1. Mosque dimensions

Type	Area (ft^2)	Materials	Quantity (Location)
Main Floor	1359.634	Brick, Ceramics, Plaster	
Windows	23.710	Glass	4 (South)
	24.210		2 (North)
	24.840		4 (East)
	2.690		2 (West)
Doors	26.900	Glass, Frame Al.	2 (East)

Table 2. Thermal Conditions

Condition	Temperature (°F)	Relative Humidity
Outside	87.8	80%
Inside	68	50%

2.2. Heating, Ventilation and Air Conditioning (HVAC)
A well-designed HVAC system will have a great impact on indoor air conditions. Room comfortability will be realized throughout the year and also the outside environment if cared for properly [11]. This energy calculation is carried out to determine the performance of the air conditioning system by evaluating its energy conversion [7]. Equipment in HVAC (Heating, Ventilation, Air-Conditioning) systems using a chiller is recommended to meet the minimum efficiency and criteria.

2.3. Air Handling Unit (AHU)
Psychometric diagrams are of particular concern in the air handling unit system planning process. Air Handling Unit (AHU) is a unit that functions to condition and channel air into the room air distribution system. The air that passes through the AHU is conditioned by temperature, humidity, number of particles, pressure, amount of flow so that the conditions for achieving room conditions can be achieved [12].

2.4. Cooling Load Calculations
The calculation of the cooling load in the air conditioning system is used to determine the airflow rate and the cooling load required with an optimal design. Cooling loads are divided into two categories, which is external cooling loads and internal cooling loads. External loads come from heat gain entering from the exterior walls, partition walls, interior doors, infiltration and roofs. Meanwhile, internal cooling loads are latent and sensible heat that comes out of several conditions originating from people, electric lights, equipment and appliances.

Heat load is calculated according to the procedures of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Handbook of Fundamentals. The heat transmittance coefficient in the building which affects the cooling load is selected according to the actual material. Cooling load calculation using the Transfer Function Method (TFM). First, heat loss from exterior walls, roofs, and floors is calculated using conduction transfer function coefficient; and the solar and internal heat gains are calculated.

3. Result and Discussion
The calculation of the cooling load in the Mastek Mosque building takes into account the overall heat transfer coefficient based on each material in the time period of 1.00 PM (GMT + 7). The room load

generated from the lights and speakers is 210 watts and 400 watts, respectively, with 7 lamps and 4 speakers. In the building wall area, there are several sections of cooling, which is glass, concrete, roof, floor, celling, and infiltration.

3.1. Glass and Wall

Cooling factor = Area large × sun gain × factor

Table 3. Cooling load on glass and wall

Glass/ Wall Side	Area Large (sq ft)	Sun Gain (Btu/h sq ft)	Factor	Sensible Load (Btu/h)	Ref.
Glass - South	94.84	14	1.00	1327.76	Sun Gain (Table 15) Factor (Table 16) [12]
Glass - North	48.42	11	1.00	532.62	
Glass - West	5.38	14	1.00	75.32	
Glass- East	150.64	14	1.00	2108.96	
Wall - South	317.638	4	0.52	660.68	Sun Gain (Table 19) Factor (Table 21) [12]
Wall- North	364.979	4	0.52	759.156	
Wall- West	445.894	8	0.52	1854.902	
Wall- East	300.634	10	0.52	1563.297	
Wall Extend	1126.742	14	1	1577.388	

3.2. Roof, Floor and Celling

Cooling factor = Area large × temperature different × factor

Table 4. Cooling load on roof, floor and celling

Type	Area Large (sq ft)	Temp. Diff. (°F)	Factor	Sensible Load (Btu/h)	Ref.
Roof	1359.634	10.8	0.31	14684.3572	Factor (Table 29) [12]
Floor	1359.634	5.8	0.25	1971.4693	
Celling	1359.634	5.8	0.20	1577.1700	

3.3. Infiltration

Table 5. Cooling load on infiltration

Type	CFM	Temp. Diff. (°F)	U Factor	Sensible Load (Btu/h)	Ref.
Infiltration	10003.2	10.8	1.08	14684.3572	Factor (Table 45) [12]

3.4. Internal Heat

Table 6. Cooling load on internal heat

Type	Sum	Power (watt)	Factor	Internal Heat (Btu/h)	Sensible Load (Btu/h)	Ref.
People (active)	209			215	449935	Table 48
Lamp	7	210	1.25	3.4	892.5	Table 49 [12]
Speaker	4	400		3.4	1360	

3.5. Room Sensible Heat (RSH)

Room Sensible Heat (RSH) is obtained from the calculation of the amount of sensible heat $\sum q_{sensible}$= 99804.46 Btu/h multiplied by a factor of 102% so that the value of obtained is 101806.53 Btu/h. In this design process it is assumed that there is a leak in the ducting area of 5% of the RSH [12]. So, RSHS is 5% times RSH to be 5090.02 Btu/ h. so that the total sensible heat becomes 106890,551 Btu/h.

3.6. Latent Heat

Latent heat consists of several parts, namely the latent load of people, infiltration and space. The latent load of people is 49115 Btu/h and the infiltration is 7150.81 Btu/h with an assumption factor 0.66 and CFM refers to table 45 in the ASHRAE Handbook. As for the latent load value of the room as in the calculation below:

$$RLH = \sum q_{\text{latent}} \times 102\ \%$$
$$= 56265{,}81 \text{ Btu/h} \times 102\ \%$$
$$= 57391{,}13 \text{ Btu/h}$$

As in the design of room sensible heat, it is assumed that there is a ducting leak which causes the latent load to increase by 5% to 60,260.69 Btu/h. Based on the calculations that have been done, the total cooling load is 167,151,241 Btu/h. There is a difference with the calculation according to the market, which is 65,430 Btu/h. In addition, it can be analyzed that the air temperature exits the cooling system and enters the room using a Psychrometric diagram.

3.7. Psychrometric Diagram

A comfortable room must meet the right t_{adp}. To find out the t_{adp} value, it is necessary to do an analysis using a psychometric diagram with data outside the temperature of 31 °C, RH 80%, the assumed room temperature is 25 °C, RH 50% with a mixture temperature of 28 °C obtained from the calculation of Qc = Qh of the assumption of m and c constant.

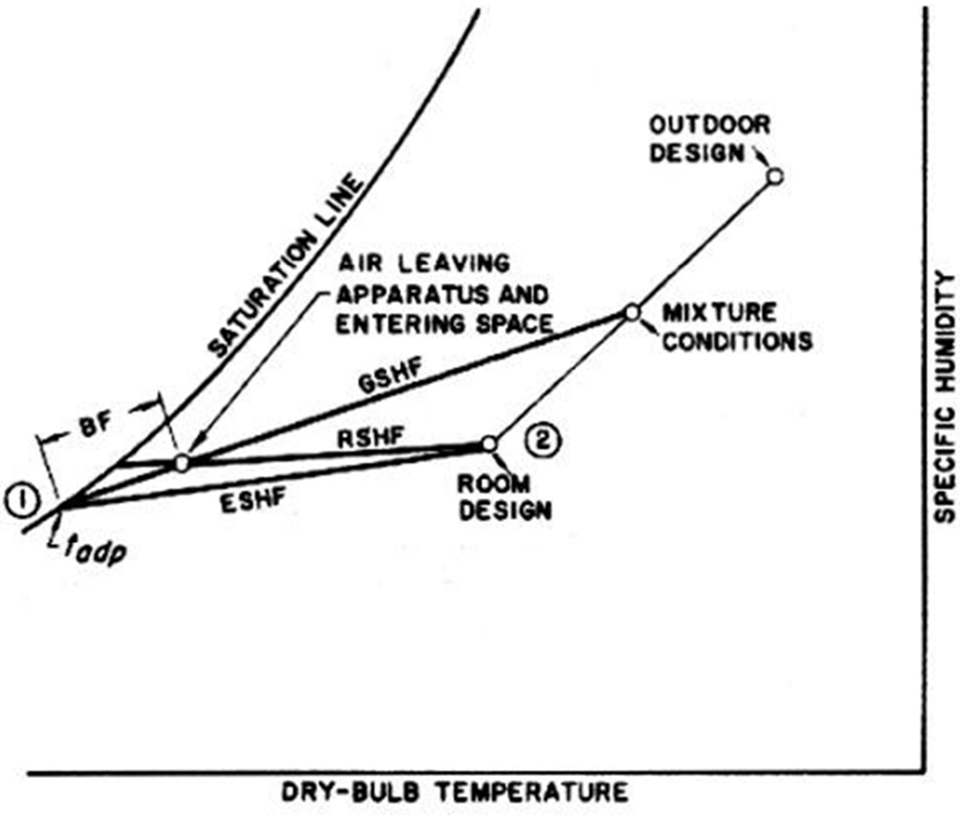

Figure 2. Analysis diagram

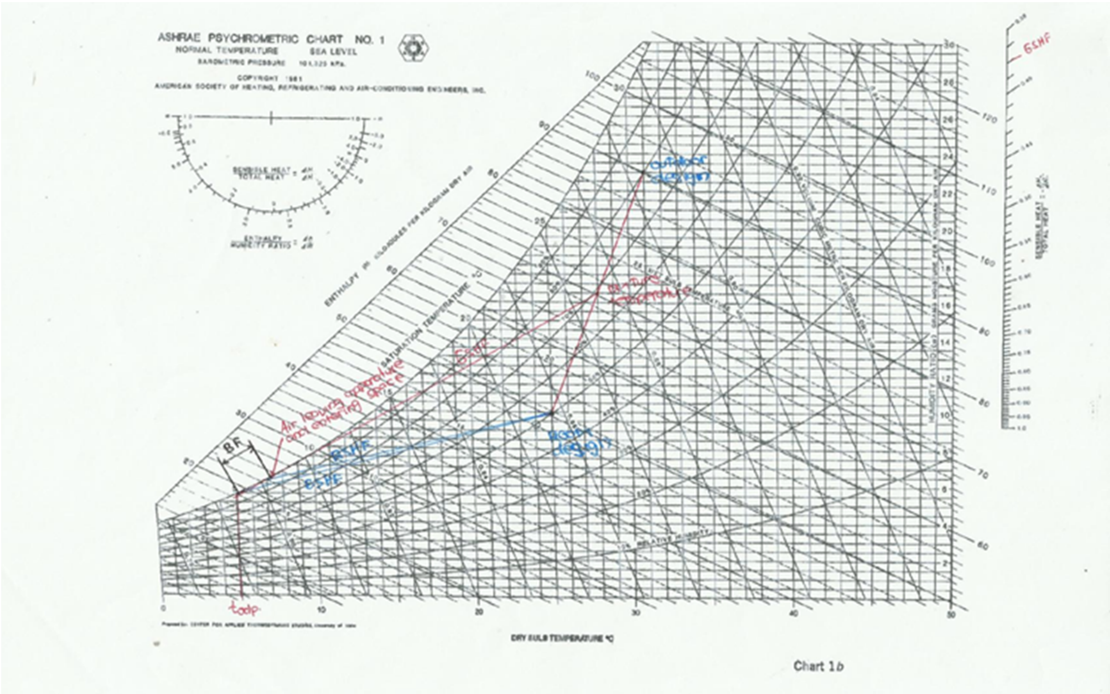

Figure 3. Psychrometric Analysis

The value of Room Sensible Heat Factor is 0.64, Outdoor Air Sensible Heat is 1101.32, Outdoor Air Latent Heat is 7367.5, Outdoor Air Total Heat is 19068.82. So that the effective sensible heat factor value is 0.63. After obtaining this value, it can be applied to a psychometric diagram as shown in Figure 3.Based on the picture above, the t_{adp} value = 5 °C and the temperature of the air outlet system of 7.3 °C with the Grand Sensible Heat Factor (GSHF) is 0.38.

3.8. Air Handling Unit Design

After obtaining the value from the cooling load capacity calculation, an air conditioning system with a central AC system can be designed. The design of the air conditioning system with central AC needs to take into account the size of the ducting, with the size of the Mastek Mosque room, the ducting size is 4 m x 4 m with 3 lines, the distance between the lines is 3.68 m and the distance between the nozzles is 2.85 m. Based on Table 7 on the ASHRAE Handbook [12] with Total Air Quality, it can be determined that the maximum speed of ducting is 1500 fpm. So it can be seen that the ducting supply size and ducting return size are shown in Table 7 with the assumption that in the ducting return size the maximum ducting speed is 20% of the entry speed.

Table 7. Ducting Supply Size

Duct Section	Air Quality (cfm)	CFM	Duct Area	Maximum Ducting Speed	Ducting Size (inch)
1 & 4	1003.2	100 %	100 %	1500.0	12 × 8
5 & 8	668.8	67 %	73.5 %	1360.5	14 × 6
9 & 12	334.4	33 %	41 %	1219.5	10 × 6
2,3,6,7,10,11	150.0	15 %	21.5 %	1048.0	10 × 6
Return 1	1003.2	50%	36%	1200.0	10 × 6
Return 2	668.8	50%	61%	1088.4	12 × 8

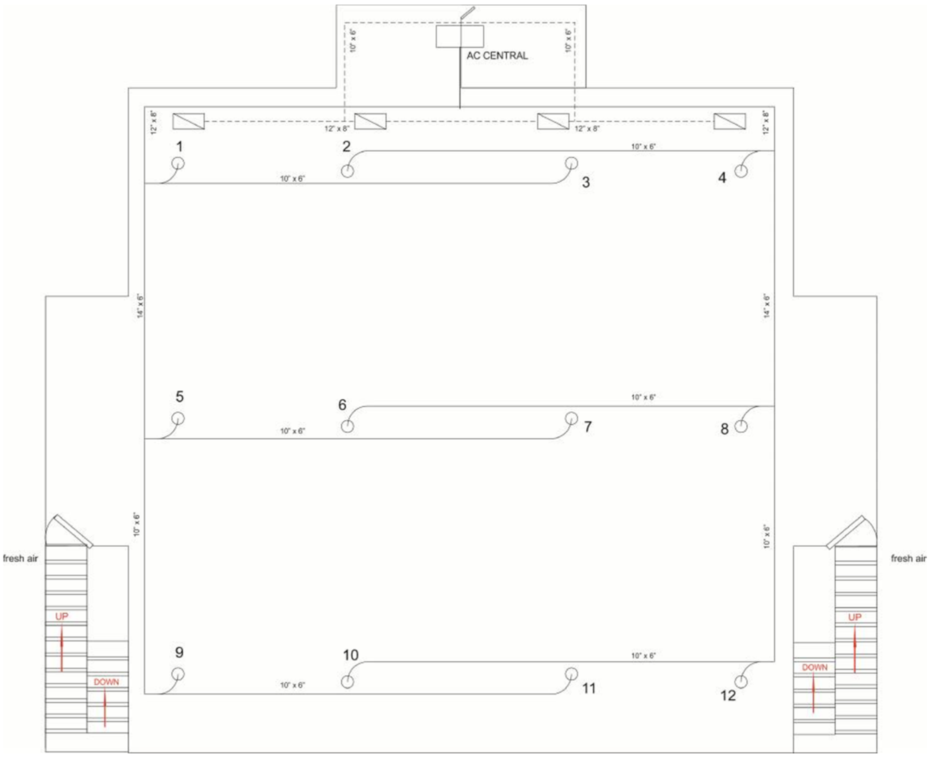

Figure 4. Design of Air Handling Unit and Ducting Size Air Conditioning Central

4. Conclusion

Mastek Mosque required 167,151,241 Btu/h by using the manual calculation method based on the ASHRAE Handbook. This calculation is much different from the market's calculation, which is 65,430 Btu/h. Thus, in this study, a re-assessment was carried out in determining the air conditioning system. Centralized air conditioning system is an option. This system has the advantages of efficient, silent cooling and increased comfort for prayer. The ducting design for central air conditioning systems uses 12 x 8 pipes for the main ducting and 10 x 6 for the ducting suction with 12 nozzles and 10 x 6 and 10 x 8 return ducting sizes.

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