Theoretical and Numerical Audit of Energy Consumption in an Existing Building under the Environmental Conditions of Pakistan

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Abstract: Energy efficiency and conservation are more important to people and the consumption of energy in buildings is one of the core aspects of energy utilization in buildings. The energy audit is an effective method for identifying opportunities for improvement, optimization, and energy conservation. In this paper, an energy audit of an existing building is presented both theoretically and numerically under the environmental conditions of Pakistan. Research efforts emphasized the identification of energy consumption in the current and retrofitted form of a Mosque located at The University of Lahore, Pakistan. To initiate the energy audit, detailed CAD drawings were obtained from the authority concerned. The thermal load calculations were carried out theoretically using energy balance techniques whilst numerically using HAP software and the obtained results were compared for validation. Thermal loads calculated theoretically and numerically were 42.7 tons and 43.7 tons, respectively and it was found that the thermal load calculations determined using both methods were in good agreement. To minimize energy consumption, insulation was added to the walls, roof, and glass. The thermal load calculation results obtained after introducing insulations were 31.02 tons theoretically and 29.7 tons numerically. After comparing the results, it was found that a significant reduction in energy consumption i.e., approx. 30% could be done with minor modifications in the suggested parameters of the existing building.

Keywords: Energy Audit, Load Calculations, HVAC, HAP Software, AutoCAD

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1. Introduction

HVAC&R is an acronym for heating, ventilating, air conditioning, and refrigerating. The combination of cycles in this normally embraced term is equal to the commonly used term air conditioning which is used everywhere, from small houses and shops to high-rise buildings, and has different layouts, heating, and cooling capacities. Air conditioning is a joint cycle that executes numerous functions concurrently such as regulating the air to the designated space, provision of cooling and warming from the source plant, regulating the temperature, stickiness, air development, level of sound, air tidiness, and weight differential in a space within their optimal ranges for the comfort of the tenants of the designated space 0. A/C-R is being utilized in many stationery and mobile applications to give comfort to users. Above 20% of fuel and energy in vehicles and buildings respectively is consumed by A/C-R. It is used in the transport industry, especially in trailers that have the lowest COP i.e., 1.5 as compared to other refrigeration systems. So, any enhancement in the efficiency of such a system will have a positive global impact 0. To meet the demands for thermal comfort and indoor air quality, heating, ventilation, and air conditioning (HVAC) systems have been employed to enable the heating, cooling, and ventilation of buildings. Early in the 20th century, HVAC systems began to develop, and they have continued to improve till the present when different types of HVAC systems are widely utilized in commercial residential and industrial buildings. However, for HVAC systems to operate properly, significant energy consumption is needed. In Europe and the US, the building industry makes up around 30% of all energy usage. Thus, HVAC systems use around 5% of the energy in a commercial building for heating, 12% for ventilation, and 14% for cooling. One of the major issues HVAC engineers are dealing with is the utilization of energy-efficient systems while maintaining the high standards for thermal comfort and indoor air quality of buildings. The trend of HVAC nowadays is toward system optimization and the evaluation of several approaches to meet energy goals 0.

In this regard, Hourly Analysis Program (HAP), is a computer tool that aids engineers in designing cooling systems for commercial use. It performs two functions. Firstly, it can be used to design systems and assess loads. Secondly, it can be employed for the estimation of energy costs and energy-based simulation which provides hourly energy simulation for the analysis of energy demands. This tool is available as two similar, but unique products and provides similar system design abilities along with attributes of energy analysis 0.

Exclusively, the HAP program implements the following functions:

1. Computes design heating and cooling loads for coils, spaces, and zones of the HVAC system.
2. Calculates airflow rates for different zones/spaces and the system.
3. Determines the size of heating and cooling coils.
4. Estimates the size of air circulation fans, boilers, and chillers.

Keeping in view the latest trends, Shira et al 0 analyzed energy consumption in buildings using HAP software and carried out their research work at the Polytechnic University of Tirana. Based on ISO 16790:2008; the international standard of thermal performance and energy use, they presented various mathematical models of thermal calculations. Furthermore, Mohsen et al 0 conducted a trial work on a scale model to examine characteristic ventilation conditions in and around rectangular-shaped structures. The trials stress the significance of associating a light well with outside space at ground level. Their results demonstrate a corresponding connection between opening size and ventilation rate. They also examined the stream designs around a gathering of structures, as being influenced by wind speed. For the assessment of the solace conditions in the rooms, Maqsood et al 0 determined Fanger Predicted Mean Vote as a component of dry bulb temperature, wet-bulb temperature, airspeed, and mean brilliant temperature for every hour and recorded it during the tests. All surrounding climate segments are shown for the test time frame to assess the presence of the evaporative cooling techniques utilized in the test house.

Al-Sulaiman and Zubair 0 completed an overview of private energy utilization in the eastern region of Saudi Arabia from August 1989 to July 1990, to give data concerning private electrical energy utilization designs. According to their obtained results, about 75% of the electrical energy utilization was utilized for space cooling. They also audited the support records of a significant air-conditioning administrative organization and concluded that countless air-conditioning unit issues are because of the neighborhood's dust-loaded, destructive, and high-encompassing temperatures and climate conditions. Similarly, a design approach based on a modeled building and simulation software was developed by Rahmouni et al, 0. They selected an office building for testing and investigated five efficiency parameters in three different climatic conditions in Algeria. They reported that the optimal parameters' combination has a considerable effect on CO_2 emission and the energy saving of buildings. According to their obtained results, they witnessed a rise of 31% and 41% in cold and hot climate conditions, respectively.

Tauseef et al 0 reported research efforts to emphasize the identification of factors that are causing high energy consumption in an existing structure. They simulated the actual operation conditions, assessed the cooling load of the building by using HAP software, and suggested retrofitting measures to minimize energy utilization. It is recommended that substantial energy savings can be attained with minor modifications to the existing structure. They claim that they saved 28.6% of energy by implementing various techniques of retrofitting. In addition to that, Maryadi et al 0 used HAP software to calculate the cooling load. They demonstrated the use of various glass types in buildings and showed that changing the glass types greatly affects the cooling load calculation and electricity consumption. This is because the thickness and the brightness of the glass transmitted different heat. In the same way, Osama et al 0 evaluated the heat and cooling load of a dormitory building with five climate conditions using HAP software. They designed and simulated the PV systems, and thermal solar at the same time for the same building and concluded their work with a systematic comparative analysis of five conventional systems and solar systems. The obtained results showed that the electrical systems and thermal systems achieved 100% and 29% non-renewable energy savings respectively.

Most energy conservation applications are carried out to protect the environment, save money, and most frequently, resource conservation. From the literature review, it has been observed that an energy audit of a building is one of the most thorough approaches for examining energy consumption and waste in buildings. This paper aims to perform an energy audit and identify the factors that could be optimized by introducing a few modifications that can contribute to minimizing the energy utilization of the existing building. This work will present both the manual and HAP software load calculations of the chosen building with and without introducing the insulations in the roof, walls, and windows and then compare the obtained results.

2. Methodology

2.1 The Mosque Plan and Location

There is no building existing in front or behind the mosque which means that the sides of the building are directly open to the atmosphere.

Location:

Building Location: University of Lahore Mosque, Lahore.

Latitude: 31.4606° North

Longitude: 74.2438° East

Google map location GPRS: The University of Lahore, Lahore 54000

https://goo.gl/maps/3uYRPMAEDeDwXYhk9

The floor plan of the mosque is shown in Fig. 1, while the dimensions of the floor, windows & doors, along with thermal conditions are enlisted in Table 1.

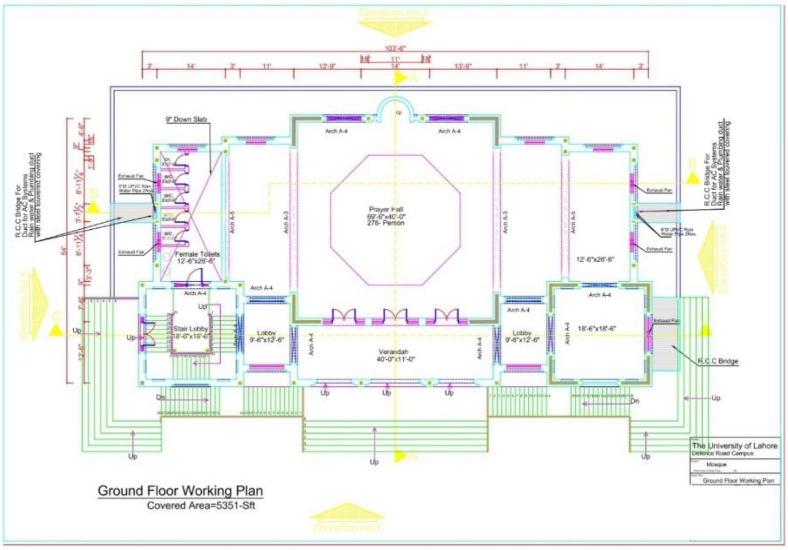

Fig. 1. The floor plan layout.

Table 1. Dimensions of floor, windows, doors, and thermal conditions of the location.

<table>
<tr><td colspan="7">Floor Dimensions</td></tr>
<tr><td>Floor</td><td>Width (ft)</td><td>Length (ft)</td><td>Height (ft)</td><td>Area (ft^2)</td><td>Volume (ft^3)</td><td>Material</td></tr>
<tr><td>Ground</td><td>69.5</td><td>40</td><td>14</td><td>2780</td><td>38920</td><td>Brick, Plaster, Insulation</td></tr>
<tr><td colspan="7">Windows & Doors Dimensions</td></tr>
<tr><td>Type</td><td>Width (ft)</td><td>Length (ft)</td><td>Area (ft^2)</td><td colspan="2">Material</td><td>Quantity</td></tr>
<tr><td>Windows</td><td>10</td><td>7</td><td>70</td><td colspan="2">Medium Dark Glass</td><td>07</td></tr>
<tr><td>Windows</td><td>5</td><td>3</td><td>15</td><td colspan="2">Medium Dark Glass</td><td>02</td></tr>
<tr><td>Doors</td><td>4.28</td><td>8.6</td><td>36.8</td><td colspan="2">Wood</td><td>03</td></tr>
<tr><td colspan="7">Thermal Conditions</td></tr>
<tr><td>Condition</td><td colspan="2">Dry Bulb Temperature (ºF)</td><td colspan="2">Wet Bulb Temperature (ºF)</td><td>Relative Humidity (%)</td><td>Humidity Ratio (g/Ib)</td></tr>
</table>

Outside	115	78	82	80
Inside	81.5	68.6	44	40
Difference	33.5	---------		

2.2 Load Calculations Using Theoretical Method

The calculations of cooling load for air conditioning framework configuration are fundamentally used to decide the volume flow rate of the air system, and the huge loads of refrigeration needed for the system. It gives contributions to the system to choose ideal plan options. Load calculations using manual and software methodologies are done by the existing plan (without insulation) and suggested insulations used in roofs, windows, and walls. Heat loads were calculated based on the methods outlined in the ASHRAE Handbook of Fundamentals. Design heat transmission coefficients used for cooling loads should be obtained from the Plant Structures Branch and should reflect the actual materials to be specified. The following equations were used for computing the space cooling load due to the heat gained.

1. ***Lighting Load***

$$Q_s = 3.41 \text{ x } qw \text{ x } CLF \text{ x } BF$$

2. ***People Load***

$$Q_s = q_s \text{ x } No. of\ people \text{ x } CLF$$

The latent heat gain from people is,

$$Q_L = q_L \text{ x } No. of\ people$$

3. ***Doors Load***

$$Q_s = U \times A \times CLTD$$

Ventilation Load; sensible and latent loads

$$Q_s = 1.1 \text{ x } (T_o - T_r) \text{ x } CFM$$

$$Q_L = 0.68 \text{ x } (W_o - W_i) \text{ x } CFM$$

4. ***Equipment Heat Gain***

$$Total\ Sensible\ Load = No. of\ fans \times Watts/fan$$

5. ***Conduction through Roof***

$$Q_s = U \times A \times CLTD$$

6. Conduction through Walls and Windows

$$Q_s = U \times A \times \Delta T$$

2.3 Load Calculations using HAP Software

HAP software is used to calculate the heating and cooling load of commercial structures, which helps to decide the size of components required for the HVAC system. This software also specifies the required information for choosing equipment. A few important factors such as HVAC equipment, environmental conditions, and building information; must be known before performing design calculations. The data collection includes studying the needs of the HVAC system, evaluating building usage, and extracting information from the building plans.

The details of weather required during calculations include the values of humidity, solar radiation, and temperature variation the building encounters throughout the year. The weather conditions play a vital role in load calculations. Lahore city is chosen from the weather database of the software to define the weather details. After adding the weather details of the selected city, the next step is to define the facilities; which comprises the definition of doors, windows, exterior walls, and ceilings. Load calculations of the facility are performed for both with and without insulation.

3. Results & Discussions

Manual load is calculated for the existing building and with proposed modifications, i.e., without insulation and with suggested insulations. The subsequent sections presented the evaluated results obtained by using the equations mentioned in the methodology section and HAP software respectively.

3.1 Manual Calculations without Insulation

1. Lighting Load

The specifics of the lighting loads in each room are gathered from the calculation of the actual lighting loads.

$$Q_s = 3.41 \text{ x } qw \text{ x } CLF \text{ x } BF \tag{1}$$

where,

Q_s = Sensible cooling load in Btu/hr

qw = Total Wattage of Lamps; 52 lights each of 12 watts = 624 watts

CLF = 1.0

BF = Blast factor = 1.30; Table 4.1 ASHRAE GRP – 158

$$Q_s = 3.41 \text{ x } 624 \text{ x } 1 \text{ x } 1.30 = 2766.2 \; Btu/hr$$

2. People Load

The sensible heat gain from people is,

$$Q_s = q_s \text{ x } No.of\ people \text{ x } CLF \quad (2)$$

where

The values of sensible and latent heat gain are taken for "seated, very light work" i.e., q_s = 140 watts and q_L = 480 Btu/h at 78 °F DB. After converting the values for 80 °F DB, sensible heat gain is decreased by 8%, and latent heat gain is increased by 8% of the actual values.

q_s = Sensible heat gain per person = 128.8 watts = 477.4 Btu/h; (1 watt = 3.41 Btu/h)
Table 4.5 ASHRAE GRP – 158

CLF = Cooling Load Factor = 0.30; Table 4.6 ASHRAE GRP – 158

$$Q_s = 477.4 \text{ x } 278 \text{ x } 0.30 = 39815 \; Btu/hr$$

The latent heat gain from people is,

$$Q_L = q_L \text{ x } No.of\ people \quad (3)$$

$$Q_L = 518.4 \text{ x } 278 = 144115 \; Btu/hr$$

where

q_L = Latent heat gain per person = 518.4 Btu/h; Table 4.5 ASHRAE GRP - 158

3. Doors Load

The conduction through the door is,

$$Q_s = U \text{ x } A \text{ x } CLTD \quad (4)$$

where

U = 0.42 Btu/hr/ft^2/F; Table 3.6 ASHRAE GRP - 158

A = 110.4 sq. ft

CLTD = 115 – 81.5 = 33.5 F

$$Q_s = 0.42 \times 110.4 \times 33.5 = 1553.33 \; Btu/h$$

4. Ventilation Load

The detail of the Ventilation Load is,

$$Q_s = 1.1 \text{ x } (T_o - T_r) \text{ x } CFM \quad (5)$$

$$Q_L = 0.68 \text{ x } (W_o - W_i) \text{ x } CFM \quad (6)$$

where

T_o = Design outside ambient temperature = 115 F

T_r = Room design temperature = 81.5 F

CFM = Rate requirement of ventilation = 1669 CFM
W_o = Air humidity ratio (Outside) 82%
W_i = Air humidity ratio (Room) 44%

$$Q_s = 1.1 \text{ x } (115 - 81.5) \text{ x } 1669 = 61502.65\ Btu/h$$

$$Q_L = 0.68 \text{ x } (82 - 44) \text{ x } 1669 = 43127\ Btu/h$$

5. Equipment Heat Gain

The detail of the equipment heat gain is,
Number of Fans = 27; Each Fan is 80 Watts

$$\text{Total Sensible Load} = 27 \times 80 = 2160 \text{ watts} = 7365\ Btu/h \quad (7)$$

6. Conduction through Roof

The conduction through the rooftop is

$$Q_s = U \times A \times CLTD \quad (8)$$

where
U = 0.3 Btu/hr/ft^2/F
A = 2780 sq. ft
CLTD = 115 F

$$Q_s = 0.3 \times 2780 \times 115 = 95910\ Btu/h$$

7. Conduction through Walls

The conduction through the shaded wall is,

$$Q_s = U \times A \times \Delta T \quad (9)$$

where
U = 0.308 Btu/hr/ft^2/F Table 3.2F ASHRAE GRP - 158
A = 973 sq. ft (N and S)
A = 560 sq. ft (E and W)
ΔT = 115 – 81.5 = 33.5 F

$$Q_s(N \text{ and } S) = 10039.41\ Btu/h$$

$$Q_s(E \text{ and } W) = 5778.08\ Btu/h$$

8. Conduction through Windows

The conduction through windows is

$$Q_s = U \times A \times \Delta T \quad (10)$$

where

U = 1.098 Btu/hr/ft^2/F

ΔT = 115 – 81.5 = 33.5 F

Number of windows (N & S) = 7

A = 70 sq. ft x 7 = 490 sq. ft (N & S)

Number of windows (E & W) = 2

A = 15 sq. ft x 2 = 30 sq. ft (E & W)

$$Q_s(N\ and\ S) = 18023.67\ Btu/h$$

$$Q_s(E\ and\ W) = 1103.49\ Btu/h$$

Overall Sensible Load = 278802 Btu/hr

Overall Latent Load = 187242 Btu/hr

Overall Load = 466044 Btu/hr = 38.837 Tons

Safety Factor 10% = 42.721 Tons

3.2 Manual Calculations with Insulation

1. Lighting Load

Lighting load is calculated by using Eq. 1.

$$Q_s = 2766.2\ Btu/hr$$

2. People Load

People load is calculated by using Eq. 2.

$$Q_s = 39815\ Btu/hr$$

The latent heat gains from people by using Eq. 3 is,

$$Q_L = 144115\ Btu/hr$$

3. Doors Load

The conduction through the door is calculated by using Eq. 4 where,

U = 0.30 Btu/hr/ft^2/F

A = 110.4 sq. ft

CLTD = 115 – 81.5 = 33.5 F

$$Q_s = 0.30 \times 110.4 \times 33.5 = 1109.5\ Btu/h$$

4. Ventilation Load

Ventilation load is calculated by using Eq. 5 & 6.

$$Q_s = 61502.65\ Btu/h$$

$$Q_L = 43127\ Btu/h$$

5. Equipment Heat Gain

The equipment heat gain is the same as calculated in the previous section by using Eq. 7.

$$\text{Total Sensible Load } = 7365\ Btu/h$$

6. Conduction through Roof

The conduction through the rooftop is calculated by using Eq. 8 where,

U = 0.025 Btu/hr/ft^2/F

A = 2780 sq. ft

CLTD = 115 F

$$Q_s = 0.025 \times 2780 \times 115 = 7992.5\ Btu/h$$

7. Conduction through Walls

The conduction through shaded walls is calculated by using Eq. 9 where,

U = 0.098 Btu/hr/ft^2/F

A = 973 sq. ft (N and S)

A = 560 sq. ft (E and W)

ΔT = 115 – 81.5 = 33.5 F

$$Q_s(N\ and\ S) = 3194.35\ Btu/h$$

$$Q_s(E\ and\ W) = 1838.48\ Btu/h$$

8. Conduction through Windows

The conduction through windows is calculated by using Eq. 10 where,

U = 0.588 Btu/hr/ft^2/F

ΔT = 115 – 81.5 = 33.5 F

Number of windows (N & S) = 7

A = 70 sq. ft x 7 = 490 sq. ft (N & S)

Number of windows (E & W) = 2

A = 15 sq. ft x 2 = 30 sq. ft (E & W)

$$Q_s(N\ and\ S) = 9652.02\ Btu/h$$

$$Q_s(E\ and\ W)\ =\ 590.94\ Btu/h$$

Over all Sensible Load	= 151103 Btu/hr
Over all Latent Load	= 187242 Btu/hr
Overall Load	= 338345 Btu/hr = 28.195 Tons
Safety Factor 10%	= 31.02 Tons

It has been observed that manual calculations showed a thermal load of 42.72 tons without insulations and 31.02 tons by adding insulations to the roof, walls, and windows. For validation of the obtained results, the thermal load is also calculated by HAP software and is described in the next section.

3.3 Load Calculations using HAP Software

Load calculations using HAP software under existing conditions that is, without insulation are shown in Table 2 and Table 3 respectively. Similarly, load calculations with suggested insulation conditions are presented in Table 4 and Table 5.

Table 2. Load calculations without insulation conditions (Air System Sizing Summary).

Air System Sizing Summary for MOSQUE			
Air System Information			
Air System Name	MOSQUE	Number of Zones	1
Equipment Class	SPLT AHU	Floor Area	2814.0 ft^2
Air System Type	SZCAV	Location	LAHORE, Pakistan
Sizing Calculation Information			
Calculation Month	Jan to Dec	Zone CFM Sizing	The sum of space airflow rate
Sizing Data	Calculated	Space CFM Sizing	Individual peak space loads
Central Cooling Coil Sizing Data			
Total Coil Load	43.7 Tons	Load occur at	Jun 1500
Total Coil Load	524.9 MBH	OA DB / WB	108.0 / 86.0 °F
Sensible Coil Load	345.0 MBH	Entering DB / WB	72.0 / 62.7 °F
Coil CFM at Jun 1500	16129 CFM	Leaving DB / WB	51.7 / 50.9 °F
Max Block CFM	16129 CFM	Coil ADP	49.4 °F
The sum of peak zone CFM	16129 CFM	Bypass Factor	0.100
Sensible heat ratio	0.657	Resulting RH	60 %
CFM/Ton	368.7	Design supply temp.	58.0 °F
ft^2/Ton	64.3	Zone T-stat Check	1 of 1 OK
BTU/(hr. ft^2)	186.5	Max zone temperature	0.0 °F

		deviation	
Water flow @ 10.0 °F rise	N/A		
Central Heating Coil Sizing Data			
Max coil load	165.1 MBH	Load occurs at	Jan 0600
Coil CFM at Jan 0600	16129 CFM	BTU/(hr. ft^2)	58.7
Max coil CFM	16129 CFM	Ent. DB / Lvg DB	52.1 / 61.9 °F
Water flow @ 20.0 °F drop	N/A		
Supply Fan Sizing Data			
Actual Max CFM	16129 CFM	Fan motor BHP	0.00 BHP
Standard CFM	15718 CFM	Fan motor kW	0.00 kW
Actual Max CFM/ ft^2	5.73 CFM/ ft^2	Fan static	0.00 in wg
Outdoor Ventilation Air Data			
Design airflow CFM	1669 CFM	CFM/person	5.56 CFM/person
CFM/ ft^2	0.59 CFM/ ft^2		

Table 3. Load calculations without insulation conditions (Zone Sizing Summary).

Zone Sizing Summary for MOSQUE			
Air System Information			
Air System Name	MOSQUE	Number of Zones	1
Equipment Class	SPLT AHU	Floor Area	2814.0 ft^2
Air System Type	SZCAV	Location	LAHORE, Pakistan
Sizing Calculation Information			
Calculation Month	Jan to Dec	Zone CFM Sizing	The sum of space airflow rate
Sizing Data	Calculated	Space CFM Sizing	Individual peak space loads

Zone Terminal Sizing Data

Zone Name	Design Supply Airflow (CFM)	Minimum Supply Airflow (CFM)	Zone CFM/ ft^2	Reheat Coil Load (MBH)	Reheat Coil Water gpm @ 20.0 °F	Zone Htg Unit Coil Load (MBH)	Zone Htg Unit Water gpm @ 20.0 °F	Mixing Box Fan Airflow (CFM)
Zone 1	16129	16129	5.73	0.0	-	0.0	-	0

Zone Peak Sensible Loads

Zone Name	Zone Cooling Sensible (MBH)	Time of Peak Sensible Cooling Load	Zone Heating Load (MBH)	Zone Floor Area (ft^2)
Zone 1	152.8	Jun 1500	16.6	2814.0

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (MBH)	Time of Peak Sensible - Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft^2)	Space CFM/ ft^2
Zone 1							
GF Prayer Hall	1	152.8	Jun 1500	16129	16.6	2814.0	5.73

Table 4. Load calculations under suggested insulation conditions (Air System Sizing Summary).

Air System Sizing Summary for MOSQUE			
Air System Information			
Air System Name	MOSQUE	Number of Zones	1
Equipment Class	SPLT AHU	Floor Area	2814.0 ft^2
Air System Type	SZCAV	Location	LAHORE, Pakistan
Sizing Calculation Information			
Calculation Month	Jan to Dec	Zone CFM Sizing	The sum of space airflow rate
Sizing Data	Calculated	Space CFM Sizing	Individual peak space loads
Central Cooling Coil Sizing Data			
Total Coil Load	29.7 Tons	Load occur at	Jun 1500
Total Coil Load	356.5 MBH	OA DB / WB	108.0 / 86.0 °F
Sensible Coil Load	200.9 MBH	Entering DB / WB	83.8 / 71.9 °F
Coil CFM at Jun 1500	7321 CFM	Leaving DB / WB	57.7 / 56.8 °F
Max Block CFM	7321 CFM	Coil ADP	54.8 °F
The sum of peak zone CFM	7321 CFM	Bypass Factor	0.100
Sensible heat ratio	0.564	Resulting RH	60 %
CFM/Ton	246.7	Design supply temp.	58.0 °F
ft^2/Ton	94.7	Zone T-stat Check	0 of 1 OK
BTU/(hr. ft^2)	126.7	Max zone temperature deviation	0.2 °F
Water flow @ 10.0 °F rise	N/A		
Central Heating Coil Sizing Data			
Max coil load	72.5 MBH	Load occurs at	Dec Htg
Coil CFM at Jan 0600	7321 CFM	BTU/(hr. ft^2)	25.8
Max coil CFM	7321 CFM	Ent. DB / Lvg DB	62.6 / 72.0 °F
Water flow @ 20.0 °F drop	N/A		
Supply Fan Sizing Data			
Actual Max CFM	7321 CFM	Fan motor BHP	0.00 BHP
Standard CFM	7135 CFM	Fan motor kW	0.00 kW

Actual Max CFM/ ft^2	2.60 CFM/ ft^2	Fan static	0.00 in wg
Outdoor Ventilation Air Data			
Design airflow CFM	1669 CFM	CFM/person	5.56 CFM/person
CFM/ ft^2	0.59 CFM/ ft^2		

Table 5. Load calculations under suggested insulation conditions (Zone Sizing Summary).

Zone Sizing Summary for MOSQUE			
Air System Information			
Air System Name	MOSQUE	Number of Zones	1
Equipment Class	SPLT AHU	Floor Area	2814.0 ft^2
Air System Type	SZCAV	Location	LAHORE, Pakistan
Sizing Calculation Information			
Calculation Month	Jan to Dec	Zone CFM Sizing	The sum of space airflow rate
Sizing Data	Calculated	Space CFM Sizing	Individual peak space loads

Zone Terminal Sizing Data

Zone Name	Design Supply Airflow (CFM)	Minimum Supply Airflow (CFM)	Zone CFM/ ft^2	Reheat Coil Load (MBH)	Reheat Coil Water gpm @ 20.0 °F	Zone Htg Unit Coil Load (MBH)	Zone Htg Unit Water gpm @ 20.0 °F	Mixing Box Fan Airflow (CFM)
Zone 1	7321	7321	2.60	0.0	-	0.0	-	0

Zone Peak Sensible Loads

Zone Name	Zone Cooling Sensible (MBH)	Time of Peak Sensible Cooling Load	Zone Heating Load (MBH)	Zone Floor Area (ft^2)
Zone 1	131.0	Jun 1500	15.6	2814.0

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (MBH)	Time of Peak Sensible - Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft^2)	Space CFM/ ft^2
Zone 1							
GF Prayer Hall	1	131.0	Jun 1500	7321	15.6	2814.0	2.60

3.4 Comparative Analysis of Results

To analyze the impact of insulations in the suggested factors i.e., roof, walls, and windows; a comparison of load calculations with and without insulations is presented in Table 6.

Table 6. Comparison of results obtained with and without insulations

HAP Software				
	Without Insulation		**With Insulation**	
Overall Load	43.7 Tons		29.7 Tons	
Manual Calculations				
Calculated Parameters	**Without Insulation**		**With Insulation**	
	Sensible (Btu/h)	**Latent (Btu/h)**	**Sensible (Btu/h)**	**Latent (Btu/h)**
Lights	2766.2	-	2766.2	-
People	39815	144115	39815	144115
Doors	1553.33	-	1109.5	-
Ventilation Load	61502.65	43127	61502.65	43127
Equipment Heat Gain	7365	-	7365	-
Roof	95910	-	7992.5	-
Walls (N and S)	10039.41	-	3194.35	-
Walls (E and W)	5778.08	-	1838.48	-
Walls (N and S)	18023.67	-	9652.02	-
Walls (E and W)	1103.49	-	590.94	-
Total Load	**278802**	**187242**	**151103**	**187242**
Overall Load	466044 Btu/hr = 38.837 Tons		338345 Btu/hr = 28.195 Tons	
Safety Factor 10%	**42.721 Tons**		**31.02 Tons**	

From Table 6 and Fig. 2, it has been seen that without insulation conditions, the cooling load obtained using the manual method and HAP software is 42.72 tons and 43.7 tons respectively, while with suggested insulation conditions, the cooling load obtained using the manual method and HAP software is 31.02 tons and 29.7 tons respectively. The graphical representation of load calculations using HAP software and manual working is shown in Fig. 2.

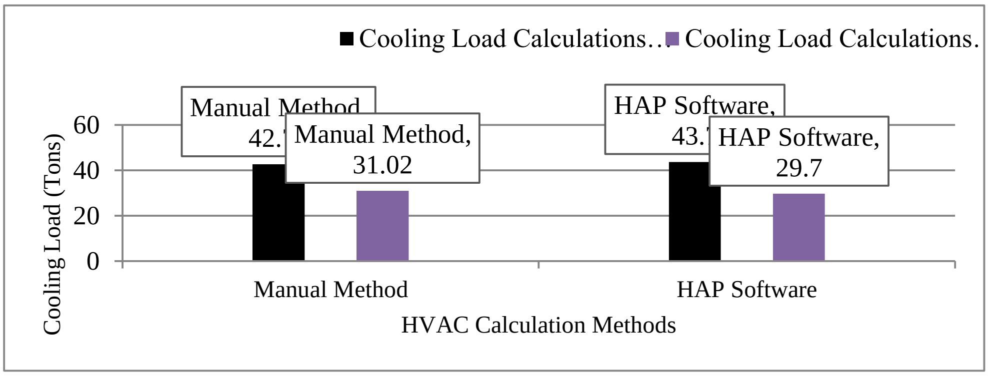

Fig. 2. Comparison of load calculation methods (Manual Method and HAP Software).

4. Conclusion

The research effort emphasizes identifying the patterns of energy consumption for a Mosque located at The University of Lahore, Pakistan. Initially, load calculations are carried out without insulation conditions and a comparative study of manually obtained results with HAP software has been made. Building envelope retrofitting is implemented and insulation is proposed in doors, roofs, walls, and windows respectively. The load calculations are then performed again with insulation conditions using both the manual method and HAP software. The cooling load obtained without insulation using the manual method and HAP software is 42.72 tons and 43.7 tons respectively, however, the cooling load obtained with suggested insulation using the manual method and HAP software is 31.02 tons and 29.7 tons respectively. It has been witnessed that approx. 30% energy utilization can be minimized by introducing minor modifications to the existing building plan. The way forward of this study includes the improvisation of comfort, energy efficiency, and sustainability of the building by implementing lighting and renewable energy retrofitting techniques.

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