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Cooling Load Estimation of Auditorium by CLTD Method and its Comparison with HAP and TRACE Software

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Abstract- **Heating ventilation and air conditioning (HVAC) system is required to provide comfort conditions such as humidity, temperature and other environment parameters for occupants and machines. The necessity of design of such system is increasing day by day. To install air conditioning system for comfortable environment it is mandatory to estimate the total cooling load of building. Cooling load temperature difference (CLTD), radiant time series (RTS) and total equivalent temperature difference (TEDF) are different methods to calculate the total cooling load. In this study we explained CLTD method to calculate cooling load of an auditorium. The design of Auditorium is developed by AutoCAD software. Total cooling load of auditorium is calculated by CLTD method and results are validated with hourly analysis program (HAP) and Trace 700 software.**

Index Terms-- **Heating ventilation and air conditioning (HVAC), cooling load temperature difference (CLTD), total equivalent temperature difference (TEDF), radiant time series (RTS), hourly analysis program (HAP) and Trace 700.**

I.INTRODUCTION

Cooling load is basically the rate at which heat would need to be removed from the space in order to bring the space at desired comfort conditions by air conditioning and refrigeration equipment's. Comfort conditions are the first priority nowadays for occupants, indoor products, and different processes and for machines. Therefore, it is necessary to calculate the cooling load to install a HVAC system that provides the desired comfort conditions to buildings like offices, halls, homes, industries and laboratories etc. Cooling load is the rate at which both sensible and latent heat must be removed from space to maintain the desired comfort conditions. These are main components of cooling load. Sensible heat gain occurs when there is a direct addition of heat to the enclosed space and causes its air temperature to rise and Latent heat gain is associated with rise of moisture to the air of enclosed space.

The total cooling load of building is divided into external and internal cooling loads. External cooling load is the load due to conduction of heat through building envelopes i.e. walls, roof, floor, windows, and doors. Internal cooling load is the load generated by occupants, electrical lights and appliances.

Adnan Shariah et al. [1] calculate the heating/cooling load of residential buildings for three different climatic regions in Jorden. This study analyzed the insulation effect of building. Combinations of wall and ceiling insulation that were considered for analysis are no insulation, only ceiling insulation, only wall insulation and both wall and ceiling insulation. Tousif Ahmed [2] developed a computer program for calculation of cooling load in C# .NET (C Sharp dot NET) programming language tool. To test the results of the developed software, cooling load of room is calculated by that software and "TRACE 700" and results are compared. Yonas Mitiku Degu [3] calculated the cooling load of Hibir Boat. This study explained the air conditioning unit selection to deliver conditioned air to the rooms and meeting hall of Hibir Boat to meet the occupant's comfort conditions.

E. Bellos et. al. [4] calculated the heating and cooling load of building by using TRNSYS and EQUEST software. Other parameters such as infiltration rate, building orientation, Insulation thickness and windows area of building were also analyzed and comparison were made between the results of both software. Ujjwal Kumar Sen et. al. [5] explained CLTD method for cooling and heating load calculation. Total cooling load and total dehumidifier air of a classroom was calculated for both summer and monsoon season. It is also observed that there is deviation in solar air temperature for different orientation of surfaces. Azhar Kareem Mohammed et. al. [6] compared the total cooling load results of two storeys building calculated by CLTD method using ASHRAE standards and by HAP software.

Rutvik Lathia and Jaymin Mistry [7] calculated the tonnage capacity of 1000 seats auditorium by CLTD method and designed efficient emission free HVAC system for that auditorium. Ujjwal Kumar Sen et. al. [8] explained different methods of cooling load calculations. Cooling load of examination office is calculated by CLTD method and results obtained were compared with Elite CHVAC software. Saifullah Zaphar and Tekletsadik Sheworke [9] developed a computer program to calculate the cooling load of buildings. To develop this software programming language has been done in Visual Basic 6.0 and Microsoft Access has been used to create the data base. A cooling load of hall was calculated by this software and also by HAP v4.90 and results are compared for testing and validation.

Er. Prashant Sharma and Prof. Dr. J. P. Yadav [10] developed a generalize computer program to calculate the cooling load of multi-storeys buildings in C++. Total Equivalent Temperature

Difference (TETD) method was explained for heating/cooling load calculation of air conditioning building. Fahad Al Harbi et. al. [11] calculated the total cooling load of AlFahad Mosque located at Unaizah in Qassim Region Saudi Arabi (K.S.A.) by both E20 sheet manually and HAP software. Results of cooling load calculation obtained by both ways were compared. Hasan Oktay et. al. [12] compared cooling load calculation results of CLTD method and TETD method for buildings envelope.

II. METHODOLOGY

The methodology shown in FIGURE 1 as given below;

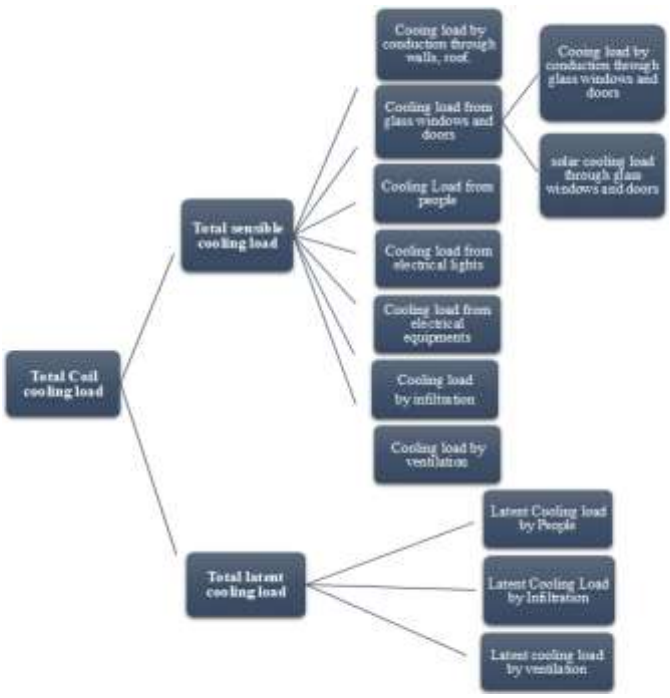

FIGURE 1: METHODOLOGY

III. CLTD METHOD TO CALCULATE COOLING LOAD

Following equation obtained are used to calculate the cooling load of buildings by CLTD method,

A. HEAT GAIN DUE TO CONDUCTION THROUGH WALLS, ROOF, GLASS WINDOWS AND DOORS

Heat gain by conduction through walls, roof, glass windows and doors can be calculated by following relation,

$$Q = U * A * CLTD \quad (1)$$

Here "A" represents area of the wall, roof, window or door, "U" represents the overall heat transfer coefficient and it is calculated by,

$$U = \frac{1}{\Sigma R} \quad (2)$$

Here, "R" is the resistance to the heat transfer. ΣR is equal to sum of resistance for conduction, convection and radiation. "$CLTD$" is the cooling load temperature difference and it can be calculated as,

$$CLTD_{Corrected} = [CLTD + (78 - T_r) + (T_m - 85)] \quad (3)$$

The value of $CLTD$ can be determined from ASHRAE table, "T_r" is Indoor room temperature and "T_m" is Mean outdoor temperature. "T_m" can be calculated by following relation,

$$T_m = T_{max} - (Daily\ Range)/2 \quad (4)$$

B. SOLAR HEAT GAIN THROUGH WINDOWS AND DOORS

The relation for solar heat gain through glass windows and doors can be given as,

$$Q_{Glass\ Solar} = A * SC * SCL \quad (5)$$

Here, $Q_{Glass\ Solar}$ represents solar transmission load through the glass, "A" is the area of window or door, "SC" is Shading coefficient and "SCL" represents Solar Cooling Load Factor.

C. HEAT GAIN FROM PEOPLE

Occupants produce both sensible and latent heat gain according to their activity level. The heat gain from occupants is based on the average number of people that are expected to be present in a conditioned space. The heat gain from occupants or people can be calculated from following formula,

$$Q_{Sensible} = N * QS * (CLF) \quad (6)$$

$$Q_{Latent} = N * QL \quad (7)$$

Here, "N" is number of people in space, "Q_S" and "Q_L" are Sensible heat gain and Latent heat gain from occupants respectively and "CLF" is cooling load factor.

D. HEAT GAIN FROM ELECTRICAL LIGHTS

Light emitting elements are primary source of heat. Sensible cooling load from lightening can be calculated by following relation,

$$Q = 3.41 * W * F_{UT} * F_{SA} * CLF \quad (8)$$

Here, "W" represents Watts input from electrical lighting plan or lighting load data, "F_{UT}" is Lighting use factor that is ratio of time the light will be in use, "F_{SA}" is special ballast allowance factor and "CLF" is Cooling Load Factor and 3.41 is conversion factor from watt(W) to "Btu/hr".

E. HEAT GAIN FROM ELECTRICAL EQUIPMENTS

Electrical equipments and appliances have effect on cooling load. The heat gain from electrical equipments and appliances can be calculated by following equations,

$$Q_{Sensible} = Q_{in} * Fu * Fr * CLF \quad (9)$$

$$Q_{Latent} = Q_{in} * Fu \quad (10)$$

Here, "Q_{in}" is rated energy input from appliances, "Fu" is Usage factor, "Fr" is Radiation factor and "CLF" is Cooling Load Factor, by hour of occupancy.

F. HEAT GAIN FROM INFILTRATION

Infiltration can be defined as, leakage of outside air in the building structure through window cracks and opening of doors. Space cooling load due to heat gain from infiltration can be calculated by following equations,

$$Q_{Sensible} = 1.08 * CFM * (To - Ti) \quad (11)$$

$$Q_{Latent} = 0.7 * CFM * (\omega_0 - \omega_i) \quad (12)$$

Here, To, Ti is outside and inside dry bulb temperature respectively and ωo, ωi is outside and inside humidity ratio respectively. "CFM" is Infiltration air flow rate and it is given as

CFM = (Volume of space*ACH)/60 m3/min

"ACH" is air changes rate.

G. HEAT GAIN FROM VENTILATION

Ventilation air is supplied to the conditioned space with the intensions to minimize odour, smoke concentration, Carbon dioxide and other undesired gases so that the freshness of air could be maintained. Coil cooling load due to heat gain from ventilation can be calculated by following equations,

$$Q_{Sensible} = 1.08 * CFM * (To - Ti) \quad (13)$$

$$Q_{Latent} = 0.7 * CFM * (\omega_0 - \omega_i) \quad (14)$$

where "To" is outside dry bulb temperature and "Ti" is the dry bulb temperature of air leaving the cooling coil, "ω_0" is outside humidity ratio and "ω_i" is Humidity ratio of air leaving the cooling coil. "CFM" is the ventilation air rate.

H. TOTAL LOAD

Total Space cooling loads is equal to total space sensible heat gain plus total space latent heat gain. It does not include ventilation load. This is also called Room Total Load.

$$Total\ Space\ Cooling\ Load = Q_{ROOF} + Q_{Roof} + Q_{Walls} + Q_{Windows} + Q_{People} + Q_{Lights} + Q_{Appliances} + Q_{Infiltration} \quad (15)$$

$$Total\ coil\ cooling\ load = Total\ Space\ cooling\ Loads + Ventilation\ Load. \quad (16)$$

Total coil cooling load is also called Gross Total Load.

I. AUDITORIUM DESIGN PLAN AND LOCATION

AutoCAD is one of the main Computer Aided Design (CAD) software tool used for design of different mechanical components and in construction industry. The Auditorium design is made in AutoCAD software.

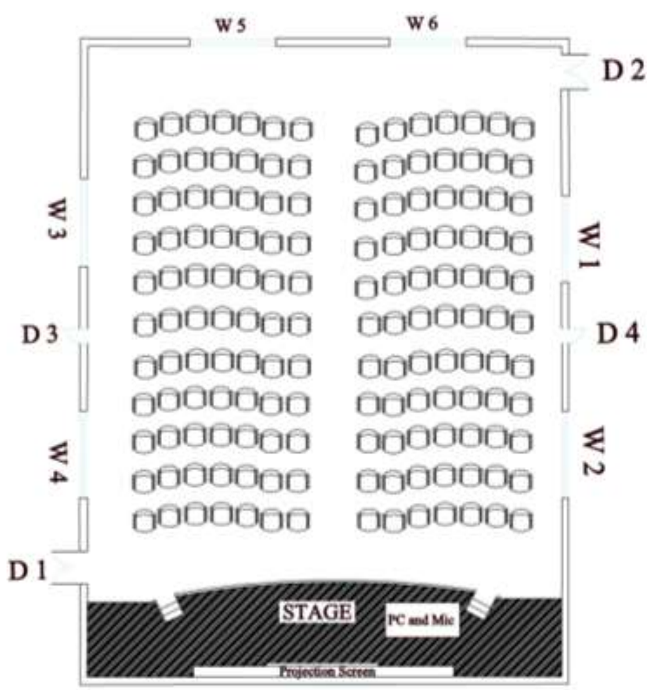

FIGURE 2: AUDITORIUM DESIGN

TABLE 1
THERMAL CONDITIONS FOR AUDITORIUM

Thermal Condition	Value
Outdoor dry-bulb temperature (°F)	107.9
Indoor dry-bulb temperature (°F)	95
Outdoor wet-bulb temperature (°F)	84.58
Daily Range	22.9
Outside relative humidity	61%
Inside relative humidity	55%
Wind velocity (mph)	10

IV. BUILDING DIMENSIONS

Auditorium is placed in Sargodha (Pakistan) at Latitude 32.07° N and longitude 72.7°E. Auditorium has place of 154 occupants. Floor area of auditorium is 4000ft^2.

TABLE II
BUILDING CONDITIONS FOR AUDITORIUM

Type	Area (ft^2)	Material
Roof	4000	Flat roof constructed of 4inch LW concreate, 3inch insulation, steel decking, Acoustic tile (suspended ceiling).
South & North wall	1343.6	Walls constructed of 4inch face brick, 1inch stucco siding, 1inch insulation and 3/4inch gypsum or plaster.
East & West wall	900	Same material
Window	23	Uncoated double glazed clear (1/4inch thick, air space) window, fixed, Aluminum with thermal break
Door (D1, D2)	33.6	--
Door (D3, D4)	16.8	--

V. TOTAL SPACE COOLING LOADS

The row indicated by yellow color indicates the peak space load by CLTD method in the day and the result is given in TABLE III.

VI. SOFTWARE ANALYSIS - HAP SOFTWARE

HAP (Hourly Analysis Program) is a computer tool developed by Carrier. It helps engineers and energy analysists for energy analysis and designing of HVAC system for commercial buildings. HAP estimates design cooling and heating loads for commercial buildings in order to determine required sizes for HVAC system components. HAP software window does not contain Sargodha city of Pakistan. Therefore, Karachi is selected and all the calculations are done in the month of July from 9:00AM to 5:00PM.

Following are the steps for calculation of heating/cooling load by HAP software, 1. Insert Schedule properties for occupancy, people, appliances, thermostat in HAP software, 2. Insert Wall, roof, window and door properties for building. 3. Insert Weather properties for location. 4. Inserting space properties for roof, walls, number of doors and doors and windows in the walls, infiltration and other internal properties for lighting, equipment and people.

VII. TRACE SOFTWARE

Trace is another window-based computer program used to calculate heating/cooling load of buildings. Trace software does not contain Pakistan weather therefore we import Karachi Weather from weather file and calculate the cooling load of auditorium. Select a weather profile of that city in which building is located. Define all templates according to building design. Enter room parameters. Define the system, assigning the room to the system. Calculate the results for cooling load of building.

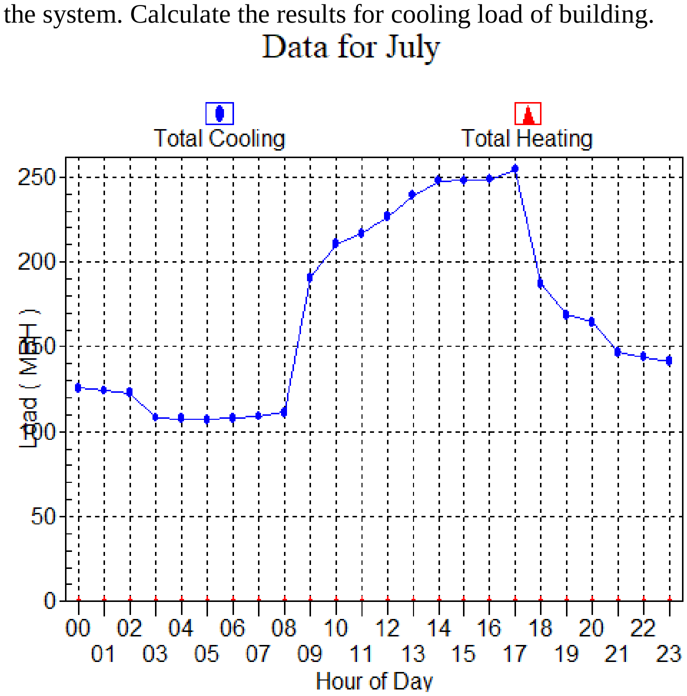

FIGURE 3: HOURLY COOLING LOAD OF AUDITORIUM BY HAP SOFTWARE

VIII. CONCLUSION

To conclude the cooling load of Auditorium located in Sargodha by using HAP and TRACE Software and compared the results. It is observed that total cooling load of Auditorium calculated from CLTD method is 20.7TR and from HAP (see Fig. 4) and TRACE software (see FIGURE 4) is 21.2TR at 17:00 hours. By hand calculation it is found that each T.R can cover 17.95m^2 floor areas while from HAP it is fond that each T.R can cover 17.52m^2 of floor area. The results obtained from CLTD and software is almost same, the difference in results is because of approximation. Differences between the results of HAP and TRACE software are within a 10% range is shown in FIGURE 5 and FIGURE 6 respectively.

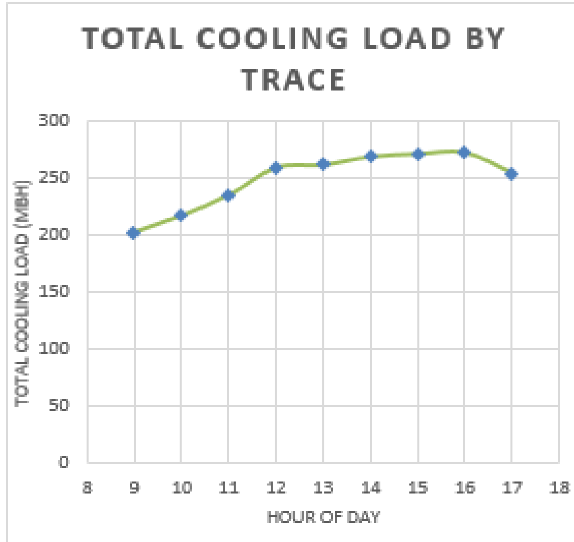

FIGURE 4: HOURLY COOLING LOAD OF AUDITORIUM BY TRACE SOFTWARE

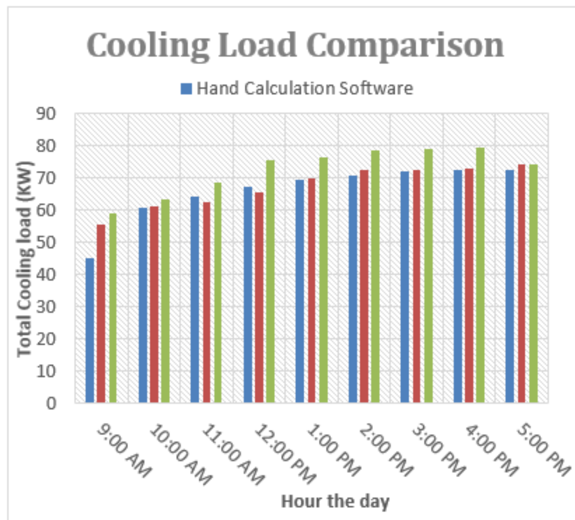

FIGURE 5: COOLING LOAD COMPARISON BY ANALYSIS AND BY SOFTWARE

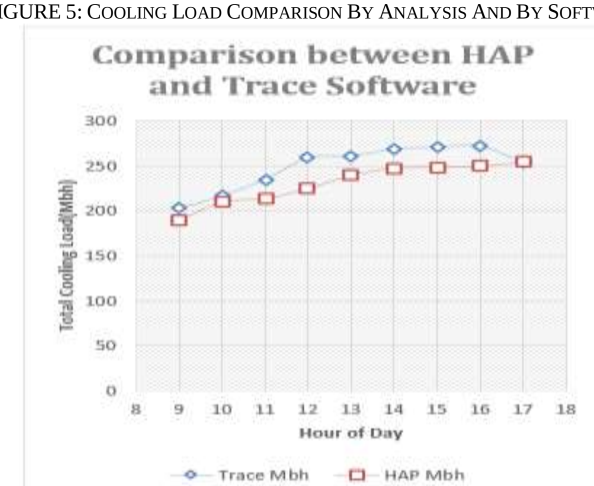

FIGURE 6: COMPARISON BETWEEN HAP SOFTWARE AND TRACE SOFTWARE RESULTS OF TOTAL HOURLY COOLING LOAD.

APPENDIX

The HAP Report for Auditorium Cooling Load and other simulation with different parameters are given in TABLE III and TABLE IV and the summary is given in FIGURE 7 and FIGURE 8.

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TABLE III:
TOTAL SPACE COOLING LOAD EMPIRICAL CALCULATION

Time	Q_{Roof} (Btu/hr)	Q_{Wall} (Btu/hr)	$Q_{Window\ Conduction}$ (Btu/hr)	$Q_{Window\ Solar\ Trans.}$ (Btu/hr)	$Q_{Door\ Conduction}$ (Btu/hr)	$Q_{Door\ Solar\ Trans.}$ (Btu/hr)	$Q_{sensible\ People}$ (BTU/hr)	$Q_{latent\ People}$ (BTU/hr)	Q_{lights} (BTU/hr)	$Q_{Sensible\ Appliances}$ (BTU/hr)	$Q_{Infiltration\ Sensible}$ (BTU/hr)	$Q_{Infiltration\ latent}$ (BTU/hr)	Space total Sensible load	Space total latent load	Total Space Cooling load
9:00 AM	3037.5	3444.2	-152.1	8085.4	-111.1	2653.5	0	18480	0	0	10668.6	39513.6	27626.0	57993.6	85619.6
10:00 AM	7004.8	5140.0	21.7	8756.1	15.8	3265.9	23023	18480	21605.7	1839.6	10668.6	39513.6	81341.3	57993.6	139334.9
11:00 AM	10972.2	7370.6	282.5	7526.5	206.3	3878.2	26565	18480	24486.5	2122.7	10668.6	39513.6	94079.4	57993.6	152073
12:00 AM	14939.5	9443.2	456.4	6445.9	333.3	4286.5	28690.2	18480	25926.9	2292.5	10668.6	39513.6	103483.3	57993.6	161476.9
1:00 PM	17915.1	11707.3	717.2	5887.0	523.9	4245.6	30107	18480	26791.1	2405.7	10668.6	39513.6	110968.8	57993.6	168962.4
2:00 PM	20146.7	13813.4	804.1	5216.4	587.4	3837.4	31523.8	18480	27079.2	2518.9	10668.6	39513.6	116196.1	57993.6	174189.7
3:00 PM	21138.5	16367.5	891.1	4433.9	650.9	3225.0	32232.2	18480	27367.2	2575.5	10668.6	39513.6	119550.7	57993.6	177544.3
4:00 PM	20890.6	18748.0	891.1	3763.2	650.9	2776.0	32940.6	18480	27367.2	2632.1	10668.6	39513.6	121328.5	57993.6	179322.1
5:00 PM	19402.8	20682.9	804.1	3316.1	587.4	2571.9	33649	18480	27655.3	2688.7	10668.6	39513.6	122027.0	57993.6	180020.6

TABLE IV:
TOTAL COIL COOLING LOAD BY HAND CALCULATION

Time	Space total Sensible load (BTU/hr)	Space total latent load (BTU/hr)	Total Space load (BTU/hr)	$Q_{Ventilation\ Sensible}$ (BTU/hr)	$Q_{Ventilation\ latent}$ (BTU/hr)	Total coil Sensible load (BTU/hr)	Total coil latent load (BTU/hr)	Total coil cooling load (BTU/hr)
9:00 AM	27626.0	57993.6	85619.6	14669.42	54331.2	42295.42	112324.8	154620.2
10:00 AM	81341.3	57993.6	139334.9	14669.42	54331.2	96010.72	112324.8	208335.5
11:00 AM	94079.4	57993.6	152073	14669.42	54331.2	108748.8	112324.8	221073.6
12:00 AM	103483.3	57993.6	161476.9	14669.42	54331.2	118152.7	112324.8	230477.5
1:00 PM	110968.8	57993.6	168962.4	14669.42	54331.2	125638.2	112324.8	237963
2:00 PM	116196.1	57993.6	174189.7	14669.42	54331.2	130865.5	112324.8	243190.3
3:00 PM	119550.7	57993.6	177544.3	14669.42	54331.2	134220.1	112324.8	246544.9
4:00 PM	121328.5	57993.6	179322.1	14669.42	54331.2	135997.9	112324.8	248322.7
5:00 PM	122027.0	57993.6	180020.6	14669.42	54331.2	136696.4	112324.8	249021.2

Air System Sizing Summary for Auditorium terminal unit

Project Name: Auditorium Report	11/22/2020
Prepared by: Naveed Gull	10:08PM

Air System Information

Air System Name	Auditorium terminal unit		Number of zones	1	
Equipment Class	SPLT AHU		Floor Area	4000.0	ft²
Air System Type	SZCAV		Location	Sargodha, Pakistan	

Sizing Calculation Information

Calculation Months	Jul to Jul	Zone CFM Sizing	Sum of space airflow rates
Sizing Data	Calculated	Space CFM Sizing	Individual peak space loads

Central Cooling Coil Sizing Data

Total coil load	21.2	Tons	Load occurs at	Jul 1700	
Total coil load	254.3	MBH	OA DB / WB	107.9 / 84.2	°F
Sensible coil load	161.9	MBH	Entering DB / WB	79.7 / 68.5	°F
Coil CFM at Jul 1700	7094	CFM	Leaving DB / WB	58.0 / 57.1	°F
Max block CFM	7094	CFM	Coil ADP	55.6	°F
Sum of peak zone CFM	7094	CFM	Bypass Factor	0.100	
Sensible heat ratio	0.637		Resulting RH	60	%
ft²/Ton	188.8		Design supply temp.	58.0	°F
BTU/(hr-ft²)	63.6		Zone T-stat Check	1 of 1	OK
Water flow @ 10.0 °F rise	N/A		Max zone temperature deviation	0.0	°F

Supply Fan Sizing Data

Actual max CFM	7094	CFM	Fan motor BHP	0.00	BHP
Standard CFM	6913	CFM	Fan motor kW	0.00	kW
Actual max CFM/ft²	1.77	CFM/ft²	Fan static	0.00	in wg

Outdoor Ventilation Air Data

Design airflow CFM	1010	CFM	CFM/person	6.56	CFM/person
CFM/ft²	0.25	CFM/ft²			

FIGURE 7: AIR SYSTEM SIZING SUMMARY

Design Cooling Load Summary

By Trane
System selection for Auditorium
Sargodha

System - System - 001
Zone - Room - 001

Coil Location - Zone

Coil Peak Calculation Time: July, hour 17
Ambient DB/WB/HR: 108 / 85 / 151

COOLING COIL LOAD INFORMATION

Load Component	Sensible Btu/h	Latent Btu/h	Total Btu/h	Percent of Total
Solar Gain	6,198		6,198	2.4%
Glass Transmission	4,600		4,600	1.8%
Wall Transmission	32,803		32,803	12.9%
Roof Transmission	18,945		18,945	7.4%
Floor Transmission	0		0	0.0%
Adj Floor Transmission	0		0.00	0.0%
Partition Transmission	0		0	0.0%
Net Ceiling Load	0		0	0.0%
Lighting	16,006		16,006	6.3%
People	13,653	6,468	20,121	7.9%
Misc. Equipment Loads	849	0	849	0.3%
Cooling Infiltration	24,305	39,797	64,102	25.2%
Sub-Total ==>	117,359	46,265	163,624	64.2%
Ventilation Load	33,420	54,721	88,141	34.6%
Exhaust Heat	-1,390	0	-1,390	-0.5%
Supply Fan Load	465		465	0.2%
Return Fan Load	0		0	0.0%
Net Duct Heat Pickup	0		0	0.0%
Wall Load to Plenum	0		0	0.0%
Roof Load to Plenum	0		0	0.0%
Adj Floor to Plenum	0		0	0.0%
Lighting Load to Plenum	4,001		4,001	1.6%
Misc. Equip. Load to Plenum	0	0	0	0.0%
Glass Transmission to Plenum	0		0	0.0%
Glass Solar to Plenum	0		0	0.0%
Over/Under Sizing	0		0	0.0%
Reheat at Design	0	0	0	0.0%
Underfloor Sup Heat Pickup	0		0	0.0%
Supply Air Leakage	0	0	0	0.0%
Total Cooling Loads	153,855	100,987	254,842	100.0 %

COOLING COIL SELECTION

Coil Selection Parameters	
Coil Entering Air (DB / WB)	83.3 / 69.2 °F
Coil Entering Humidity Ratio	85.79 gr/lb
Coil Leaving Air (DB / WB)	47.8 / 47.6 °F
Coil Leaving Humidity Ratio	49.14 gr/lb
Coil Sensible Load	153.86 MBh
Coil Total Load	254.84 MBh
Cooling Supply Air Temperature	47.89 °F
Total Cooling Airflow	3,923.89 Cfm
Resulting Room Relative Humidity	50.06 %

General Engineering Checks

Total Cooling Load	21.2 ton
Area / Load	188.35 ft²/ton
Total Floor Area	4,000 ft²
Cooling Airflow	0.98 cfm/ft²
Airflow / Load	184.77 cfm/ton
Percent Outdoor Air	23.5 %
Cooling Load Methodology	CLTD-CLF (ASHRAE TFM)

Project Name: System selection for Auditorium
Dataset Name: FINALLAST.TRC

TRACE® 700 v6.2.4 calculated at 08:24 PM on 11/22/2020
Alternative - 1 Design Cooling Load Report Page 1 of 1

FIGURE 8: HOURLY ANALYSIS PROGRAM V4.90