



**TRIBHUWAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS**

THESIS NO: M-24-MSMDE-2018/2020

**Design, Simulation, and Analysis of an Air-Conditioning System:
A Case Study of the Proposed Aerospace Building of Pulchowk
Engineering Campus in the Context of Nepal**

by

Sudin Bhujju Shrestha

**A THESIS
SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND
AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE IN ENGINEERING IN
MECHANICAL SYSTEMS DESIGN AND ENGINEERING**

**DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
LALITPUR, NEPAL**

JULY, 2020

COPYRIGHT

The author has agreed that the library, Department of Mechanical and Aerospace Engineering, Pulchowk Campus, Institute of Engineering may make this thesis freely available for readers. Moreover, the author has agreed that permission for extensive copying of this thesis for the scholarly purposes may be granted by the professor(s) who supervised the project work recorded herein or, in their absence, the Head of the Department wherein the thesis was done. It is understood that the recognition will be given to the author of this thesis and the Department of Mechanical and Aerospace Engineering, Pulchowk Campus, Institute of Engineering in any use of the material of this thesis. Copying, publication, or other uses of this thesis for financial gain without the approval of the Department of Mechanical and Aerospace Engineering, Pulchowk Campus, Institute of Engineering, and the author's written permission is prohibited.

Request for permission to copy or to make any other use of the material in this report in whole or in part should be addressed to:

Head

Department of Mechanical and Aerospace Engineering

Pulchowk Campus, Institute of Engineering

Lalitpur, Katmandu

Nepal

TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled “**Design, Simulation, and Analysis of an Air-Conditioning System: A Case Study of the Proposed Aerospace Building of Pulchowk Engineering Campus in the Context of Nepal**” submitted by Sudin Bhuj Shrestha, in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Systems Design and Engineering.

Associate Prof. Dr. Nawraj Bhattarai
Supervisor

Department of Mechanical and Aerospace Engineering

Mr. Hari Bahadur Dura
Supervisor

Department of Mechanical and Aerospace Engineering

Prof. Dr. Bivek Baral
External Examiner

Department of Mechanical Engineering
School of Engineering, Kathamandu University

Committee Chairperson,
Head of Department

Department of Mechanical and Aerospace Engineering

Date: July, 2020

ABSTRACT

Optimization of energy consumption has been on the limelight from the beginning of this 21st century, with more than half of the energy being spent on controlling the indoor atmospheric conditions. Taking into account that the field of Heating, Ventilation, and Air-conditioning (HVAC) is in its preliminary developing stage in Nepal, researches associated with HVAC system optimization is only starting to germinate with detailed HVAC optimization studies being implied only in major HVAC projects. Commercially available software is available for that however, they only do so much in predicting the load not so much on how that load will affect the temperature distribution with respect to time and space. At such Computational fluid dynamics (CFD) can be a very effective tool in simulating the steady and unsteady temperature distributions. The present work focuses on design, simulation, and analysis of an air conditioning system best suited for the auditorium hall of the proposed Aerospace building of the Pulchowk Engineering Campus. Considering the fact, that the climate of Kathmandu is of subtropical type, the cooling loads were calculated for summer months from March to October via various methods implying Cooling Load Temperature Differences (CLTD), Hourly Analysis Program (HAP) and Autodesk Revit MEP. Consequently, the loads were estimated to be 9.87 Tons, 8.52 Tons, and 9.487 Tons respectively. Simulations were then performed in Fluent ANSYS for boundary conditions meeting the requirements of the weather data for 8, 9, 10 and 11 Tons of air-conditioning system setups which led to the conclusion that for desired design temperature of 21.5°C, 10 Tons had the best performance in terms of the average of kWh used per hour for comfortable condition as well as the total energy consumed.

ACKNOWLEDGEMENT

The completion of any task would be incomplete without mentioning those people who made it possible by their immense support and encouragement throughout the research work. First and foremost, I would like to express my heartfelt gratitude to my extremely devoted supervisors Prof. Dr. Nawraj Bhattarai Department of Mechanical and Aerospace Engineering, Pulchowk Engineering Campus, and Ass. Prof. Hari Bahadur Dura, Department of Mechanical and Aerospace Engineering, Pulchowk Engineering Campus whose continuous help, stimulating suggestions and encouragement helped me throughout the research and even during writing this thesis.

Sincere gratitude to the department for permitting to do the necessary research work, and commence this thesis. I also acknowledge with a sense of deep appreciation to Ass. Prof. Kamal Darlami, Department of Mechanical and Aerospace Engineering Pulchowk Engineering Campus. I, from the core of my heart, would like to thank my classmates/seniors, Mr. Navien Thapa, Mr. Hemanta Dulal, Mr. Milan Adhikari, Mr. Sanjiv Poudel, Mr. Sandip Thakur and Mr. Rojesh Man Shikhrakar for their valuable suggestions for improvement and help throughout.

I would also like to take a moment to thank my seniors Ms. Asbina Baral and Mr. Krishna Kumar Yadav for providing me technical and moral support during the making of this research also for all their help, support, interest, encouragement and valuable hints. I owe deep respect to my family for their support, guidance, affection, and critical comments throughout my journey. Last but not the least, it is my honor to thank my friends Mr. Milan Adhikari, Mr. Suwarna Thapa, Mr. Sunav Dahal and Ms. Neliya Shakya who has assisted me immensely in this journey.

Finally, I would like to appreciate every individual directly or indirectly involved in the completion of my research.

Thank you, everyone.

TABLE OF CONTENTS

COPYRIGHT.....	I
ABSTRACT.....	III
ACKNOWLEDGEMENT.....	IV
LIST OF TABLES	VIII
LIST OF FIGURES	IX
LIST OF ABBREVIATIONS	X
CHAPTER ONE: INTRODUCTION.....	1
1.1 Background	1
1.2 Objectives	2
1.2.1 General Objective	2
1.2.2 Specific Objectives	2
1.4 Scope of Work	3
CHAPTER TWO : REVIEW OF LITERATURE.....	4
2.1 Heat gain and cooling load	4
2.2 Significance of load calculation of an HVAC system	5
2.3 Thermal lag or time lag.....	6
2.4 Heat gain and cooling load calculation methods	7
2.4.1 Conduction Transfer Function Model.....	7
2.4.2 Heat Balance Method.....	10
2.4.3 Radiant time-series method.....	12
2.4.4 Cooling Load Temperature Difference (CLTD).....	13
2.5 Comparison of the calculation methods.....	15
2.6 Types of air conditioning systems installations	17
2.6.1 Self-contained	17
2.6.2 Split Systems.....	17
2.6.3 Central refrigeration system.....	18
2.7 Computational fluid dynamics (CFD)	20
2.7.1 Pre-processor.....	20

2.7.2 Solver	21
2.8 Governing equations	22
2.8.1 Navier-Stokes Equation	22
2.8.2 K-Epsilon Model.....	22
2.9 CFD in HVAC designing.....	24
CHAPTER THREE : RESEARCH METHODOLOGY.....	25
3.1 Literature Review.....	27
3.2 Data Generation	27
3.2.1 Description of the space.....	27
3.2.2 Weather Statistics.....	27
3.3 Load calculation methods	30
3.3.1 Cooling Load Temperature Difference (CLTD).....	30
3.3.2 Carrier’s Hourly Analysis Program (HAP).....	34
3.3.3 Autodesk Revit MEP	34
3.3.4 Considerations made for the calculations	35
3.3.6 Considerations made for the simulation	36
3.4 CFD Analysis and Mesh Independence Study.....	37
3.4.1 Geometry Modelling.....	37
3.4.2 Mesh Development and Mesh Independence	39
CHAPTER FOUR : RESULTS AND DISCUSSION	40
4.1 Load calculated by CLTD Excel Solver	40
4.2 Load calculated by HAP	41
4.3 Load calculated by Revit MEP	42
4.4 CFD Results	43
4.5 Energy Analysis	45
CHAPTER FIVE : CONCLUSIONS AND RECOMMENDATION.....	49
5.1 Conclusions.....	49
5.1 Recommendations.....	49

REFERENCES.....	50
PUBLICATIONS.....	54
APPENDIX A : CLASSIFICATION OF DIFFERENT SURFACES.....	55
APPENDIX B : CALCULATION OF INFILTRATION.....	58
APPENDIX C : INTERNAL LOAD CALCULATION	59
APPENDIX D : RETURN VENT SIZING.....	60
APPENDIX E : INLET VENT CALCULATION	61
APPENDIX F : CALCULATED LOAD DATA.....	62
APPENDIX G : TEMPERATURE DISTRIBUTION CONTOURS.....	64
APPENDIX H : ENERGY USAGE DATA.....	68
APPENDIX I : INTERPOLATED SCL VALUE OF GLASS FOR 27°	
LATTITUDE.....	70
APPENDIX J : INTERPOLATED CLTD VALUES OF WALLS FOR 27°	
LATTITUDE.....	72
APPENDIX K : INTERPOLATED CLTD VALUES OF ROOF FOR 27°	
LATTITUDE.....	80
APPENDIX L : CLTD EXCEL SOLVER.....	81

LIST OF TABLES

Table 2-1: Iteration to calculate the heat gain through a surface using TFM model	9
Table 2-2: CLTD/SCL/CLF method.....	14
Table 2-3: Categorization of types of the air conditioning system	19
Table 3-1: Information related to the targeted space	27
Table 3-2: Design parameters for the Kathmandu Valley (ASHRAE, 1993).....	28
Table 3-3 : Monthly temperature pattern for Kathmandu Valley (ASHRAE, 1993) ..	28
Table 3-4: Design conditions for Kathmandu valley by ISHRAE (ISHRAE, 2019) ..	29
Table 3-5: Specifications of A/C chosen for the simulation.....	35
Table 3-6: Positioning of A/C vents	38
Table 4-1: Maximum load through internal sources.....	40
Table 4-2: Load calculated by Revit MEP.....	42
Table A-1: Material assumptions and classification for wall	55
Table A-2: Material assumption and selection of the type of roof	55
Table A-3: Material assumptions for floor	56
Table A-4: Window material, type of glass assumption and zone classification	56
Table A-5: Material assumptions for windows and door.....	57
Table B-1: Assumptions to calculate the infiltration (ASHRAE, 2005)	58
Table C-1: Assumptions to calculate internal loads	59
Table D-1: Sizing of return vents (Engineering ToolBox, 2010)	60
Table D-2: Calculations for the return vent	60
Table E-1: Inlet air velocity calculation.....	61
Table E-2: Calculations for the temperature of inlet vent air	61
Table F-1: Load through external sources	62
Table F-2: Monthly load calculated using CLTD Excel Solver (Btu/hr)	62
Table F-3: Load comparison of hourly temp. data, Assum.1 and Assum.2 (Btu/hr)...	63
Table F-4: Monthly load calculated using HAP (Btu/hr)	63
Table H-1: kWh used per hour of thermal comfort condition (Monthly Avg.).....	68
Table H-2: kWh used per hour of thermal comfort condition on average total.....	68
Table H-3: Total kWh consumed (Monthly Avg.)	69
Table H-4: Total kWh consumed on average total	69

LIST OF FIGURES

Figure 2.1: Time lag over the day (Gut, et al., 1993)	6
Figure 2.2: Pattern of the first iteration and the final solution. (Reddy, et al., 2017)....	9
Figure 2.3. Graphical representation of the heat balance. (McQuiston, et al., 2005) ..	10
Figure 2.4: Errors associated with CLTD/SCL/CLF (Spitler & F.C. McQuiston, 1993)	16
Figure 3.1: Research Methodology Flowchart.....	26
Figure 3.2 Monthly temperature pattern for Kathmandu (ASHRAE, 2019).....	29
Figure 3.3: Geometric model produced in SolidWorks	38
Figure 3.4: Mesh independence	39
Figure 3.5: Mesh developed.....	39
Figure 4.1: External load trends.....	40
Figure 4.2: Monthly load pattern (CLTD Excel Solver).....	41
Figure 4.3: Monthly load pattern (HAP).....	42
Figure 4.4: 8 Tons A/C performance	43
Figure 4.5: 9, 10, 11 Tons A/C performance	44
Figure 4.6: Temperature increase curves	45
Figure 4.7: kWh used per hour of thermal comfort condition (Monthly Avg.) for various desired inside temp (22.5°C, 22°C and 21.5°C)	46
Figure 4.8: Total kWh consumed (Monthly Avg.) for various desired inside temp (22.5°C, 22°C and 21.5°C)	47
Figure 4.9: Energy consumed and average kWh used per hour for comfort condition	48
Figure D.1: Relationship between the CFM and the return vent sizing.....	60
Figure G.1: Temperature distribution of 8 Ton A/C after 30 mins (lengthwise top, breadthwise bottom).....	64
Figure G.2: Temperature distribution of 9 Ton A/C after 30 mins (lengthwise top, breadthwise bottom).....	65
Figure G.3: Temperature distribution of 10 Ton A/C after 30 mins (lengthwise top, breadthwise bottom).....	66
Figure G.4: Temperature distribution of 11 Ton A/C after 30 mins (lengthwise top, breadthwise bottom).....	67

LIST OF ABBREVIATIONS

°C	Degree Celsius
°F	Degree Fahrenheit
A/C	Air conditioner
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ATF	Conduction Transfer Function
BIM	Building Information Modelling
BTU	British Thermal Unit
CAD	Computer Aided Designing
CFD	Computational Fluid Dynamics
CFM	Cubic Feet per Minute
CLF	Cooling Load Factor
CLTD	Cooling Load Temperature Difference
CM	Centimetre
CO ₂	Carbon dioxide
DBT	Dry Bulb Temperature
E	East
ELA	Effective leakage area
F	Feet
HAP	Hourly Analysis Program
HBM	Heat Balance Method
HOF	Handbook of Fundamentals
HR	Hour
HVAC	Heating, Ventilation and Air-Conditioning
IN	Inch
ISHRAE	Indian Society of Heating, Refrigerating and Air Conditioning Engineers
J	Joule
K	Degree Kelvin
KJ	Kilo Joule
KTM	Kathmandu
L	Litre
Lb.	Pound

M	Meter
MCWB	Mean Coincident Wet Bulb Temperature
MIN	Minute
MPH	Miles per hour
N	North
NE	North East
NW	North West
RH	Relative Humidity
RTSM	Root
S	South
S	Second
SCL	Solar Cooling Load
SE	South East
SW	South West
TFM	Transfer Function Method
TJ	Tera Joule
VRF	Variable Refrigerant Flow
W	Watt
W	West
WAC	Window Air Conditioner
WBT	Wet Bulb Temperature

CHAPTER ONE : INTRODUCTION

With the exponential growth in the pace of economy and technology, comes the demand for more energy to fuel the thriving development. The supply of energy in this 21st century faces complications to keep up with the demand. Distinctly, the peak load period shows that building energy consumption reaches 40% of the total energy consumption in the world. Out of which HVAC systems in buildings consume about 60% to 70% of total electricity consumption in some countries (Zhou, et al., 2017) and contribute over 30% of the CO₂ emissions (Yanga, et al., 2014). This increasing demand for energy in building usage stimulates the search for higher yet efficient and low-emission energy production and usage methods. (Deng, et al., 2011).

With the increase in demand, the task of maintaining an indoor climate with reduced energy use is becoming more and more tedious, thus giving birth to better methods of re-evaluating the current method of handling of the current energy crisis(Akande and Adebamowo, 2010).

1.1 Background

Located at 27°41'N 85°21'E and an elevation of 1338m Kathmandu Valley is located in the Warm Temperate Zone (1,200-2,300m). Parts of the valley at lower elevation have a humid subtropical climate, while parts of the valley at higher elevation have a subtropical highland climate. The average summer temperature is 28-30°C (82-86°F) while the average winter temperature is 10.1°C (50.2°F) in the valley (Department of Hydrology and Meteorology, 2012) (World Metrological Organization, 2013). While the highest temperature in summer reaches about 32.5°C in July and the lowest reaches about -2°C (ISHRAE, 2019).

Because of this type of climatic condition, Kathmandu valley in general faces about 8 months of summer (March to October) and 4 months of winter (November to February). Moreover, in this type of climatic condition, the cooling load during the summer days are much higher than the heating load during the winter. As a result, the HVAC systems installed in the valley are designed to prioritize the summer cooling load conditions. Considering the pace of urbanization and development the number of HVAC system installations is increasing more are more not only in the commercial buildings but also in the residential settlements as well. In Kathmandu valley alone, the energy demand of the residential sector was found to be about 7,500 TJ in 2013 with an increasing rate of

4% per annum. About 4% of the total energy utilized in a modern city house in the country is for space heating and cooling (Rajbhandari & Nakarmi, 2014).

HVAC is the total study of the systems which regulates, controls, and maintains the required atmospheric condition of an indoor or vehicular environment for human comfort, industrial purposes, commercial buildings, food processing, and inventory irrespective of external conditions (Khurmi & Gupta, 1987). Every element every system associated with controlling the indoor climatic conditions is a sub-branch of HVAC.

HVAC has become an integrated asset of residential, commercial, and industrial buildings which includes sensitive areas such as labs, hospitals, and even mobile vehicles such as cars, trains, airplanes, ships. The commercial Air Conditioning system that we see in simple terms works on the vapor-compression cycle, where the heat is absorbed in the evaporator i.e. the targeted area to be cooled and heat is rejected at the compressor. Basically, air is blown toward the evaporator whereby the heat present in the air is absorbed by the refrigerant. As a result, the temperature of the airdrops and is then convected out toward the targeted area i.e. this system works on the forced-convection system.

1.2 Objectives

1.2.1 General Objective

To perform design, simulation, and analysis of the Air-Conditioning system required for the auditorium hall of the proposed Aerospace building at Pulchowk Engineering Campus.

1.2.2 Specific Objectives

- i. To calculate the load requirement of space using the CLTD/SCL/CLF method, HAP and Autodesk Revit MEP of the space-based on summer cooling load conditions.
- ii. To develop CAD geometry of the auditorium hall in SolidWorks and use the geometry to perform individual transient CFD simulation of the respective space for different month load scenarios.
- iii. To analyze the results obtained from the simulation and identify the time-dependent performances under different load conditions.
- iv. To analyze the performance of different capacities of the Air Conditioning system based on the energy used.

1.4 Scope of Work

There have been previous studies in the past related to designing an HVAC system in Nepal. Most of them are associated with what capacity of the HVAC system is required, what type of HVAC system is best suited, what will be the long-term energy cost, maintenance, load calculation, etc. Some studies are based on combining two or more systems to create a hybrid system that is capable of sufficing the HVAC needs. Despite the effectiveness of CFD in the field of HVAC, CFD is still very new to the Nepalese science society. It all boils down to the fact that the immense amount of computational resources required for CFD calculations which are not readily accessible to all here. Consequently, the application of CFD in HVAC is only limitedly applied to large commercial HVAC projects in which access to computational resources is possible. By the tool of CFD, it is possible to simulate the operation of an HVAC system at various intervals of time. CFD analysis can be a very effective tool to identify the exact performance of an HVAC system thus allowing to identify to what extent it is viable to undersize or oversize to achieve a balance between performance and cost.

This research is a case study focused on calculating the cooling load inside the auditorium hall of the proposed Aerospace building of the Pulchowk Engineering Campus with various methods and evaluating the time-dependent performance of the HVAC system using CFD and comparing the results with respect to the aspect of energy.

CHAPTER TWO : REVIEW OF LITERATURE

2.1 Heat gain and cooling load

The undifferentiated heat flow into space is generally described as 'heat gain', i.e. the amount of heat flowing in the space by any source that is capable of generating and transferring heat into space is considered as 'heat gain'. The general methods through which significant heat is transferred in space are as following (ASHRAE, 1980):-

- a) Solar load through glazing which maybe windows or open vents.
- b) Heat conducted through walls exposed to exterior surroundings and roof.
- c) Head conducted through internal partitions, ceiling, and floor.
- d) The heat generated by the sources inside which may be the occupants, lights, electrical or electronic appliances, or any other heat-generating sources.
- e) Heat loads that are infiltrated into the system as a result of unwanted ventilation.

The portion of heat gain that contributes to increasing the air temperature(only) to uncomfortable conditions at a given point in time is called the cooling load. In other words, cooling load is the quantity of heat that must be removed from a building to maintain comfort conditions for the occupants.

In terms of the sources of generation there are specifically 2 types of heat gains: -

- a) **Sensible heat gain:** Sensible heat gain is the load that is added directly to the system without changing the moisture content of the system which may be transferred through any mediums: conduction convection and radiation.
- b) **Latent heat gain:** Consider the level of moisture in the space is changed because of sources such as evaporation inside. If a constant humidity indoor environment is to be maintained, an equal amount of water vapor must be condensed out of the system at a rate equal to the rate at which the water vapor is being added in the space. The amount of energy equivalent to the rate of condensation times the latent heat of condensation gives the latent heat gain.

The cooling load is the fundamental basis for designing the HVAC system. The following are the types of loads based on designing of an HVAC system (Grondzik, 2007):-

- a) **Block load:** It is the overall diversified load used to size the HVAC system which is based on the assumption that not all zones peak at the same moment. It is the

maximum load that the AHU needs to detect and handle also called the refrigeration load which is less than the sum of the peak loads.

- b) **Coincident load:** A load which occurs coincidentally with some other load. Eg. the latent load being coincident with the sensible load.
- c) **Design load:** The highest, reasonable, and possible load likely to be faced. It is not the maximum value that may or may not occur, rather it is the maximum load that occurs for a reasonable amount of time to affect the design cost consideration.
- d) **Diversified load:** Different major loads do not have peak value simultaneously. In such fashion, the diversified load is also used to describe loads caused by the sources that operate at a capacity below the maximum performance levels at all times. The diverse spread of load patterns over the day must be accounted for places where the temperature must be kept under control at all times such as labs.
- e) **Dynamic load:** Those loads whose value changes step by step with respect to time.
- f) **Instantaneous load:** It is the load observed over a definite period, usually one hour.
- g) **Peak load:** It is the maximum possible coincident load.

2.2 Significance of load calculation of an HVAC system

For a given space, the heating or cooling load produced can be affected by multiple factors. Setting up an HVAC system is time-consuming as well as costly. Also, once it is set up, the flexibility to modify the performance of the system is very tedious. Thus, the preliminary calculation must be made before had to estimate the required system to be set up. Other than for economic assistance, load calculations help us to attain the following objectives (ASHRAE, 1980):-

- a) Deduce necessary data for HVAC system design and component selections.
- b) Provide data for evaluation of the optimal undersizing of the system.
- c) Allow analysis of partial loads faced by the HVAC system.

2.3 Thermal lag or time lag

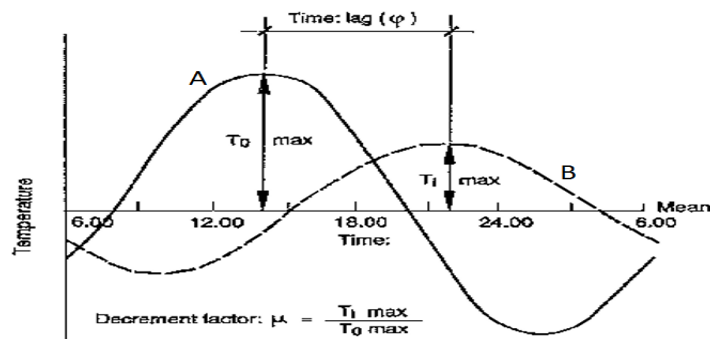


Figure 2.1: Time lag over the day (Gut, et al., 1993)

In the cooling process, the rate of heat received (heat gain) is not equal to the heat removed (cooling load) from a space or building i.e. the actual load is always, below the peak total instantaneous heat gain in the system. At all time, portions of the heat gain are immediately convected away as well as some are drawn/absorbed by the furnishings and building structure such as roof, walls, and floors through radiation. The heat stored in furnishings and structures then heats the room air through convection after a delayed time. This is the time lag effect (Musa, 2010). Time lag is defined as the time difference between the occurrence of peak outer surface temperature and the occurrence peak inner surface temperature (Gut, et al., 1993). The greatest challenge in estimating the maximum load is to estimate when the maximum load will take place. The reason is that the discrete element loads are diversified and often peak at different times. For example, the heat transfer through the roof and window are converse to each other. Roof load is maximum in the late afternoon and window load is maximum in the east-facing morning side. Conversely, the value reverses at opposite times of the day. Figure 2.1 depicted above shows a rough estimation of how thermal/time lag plays onto the heat gain onto a zone. Curve A shows the load on the exterior walls which is higher during the beginning of the day while Curve B indicates the heat that is conducted through the walls which are high during the latter part of the day. This delay in the transfer of heat into space is the time lag. The greatness of the time lag effect greatly relies on the physical properties of the materials.

2.4 Heat gain and cooling load calculation methods

2.4.1 Conduction Transfer Function Model

Before devising the CLTD method for cooling load calculation, a study was performed to derive a method for arranging walls and roofs with respect to their thermal properties, specifically the time lag effect they produce. A set of conduction transfer function (CTF) coefficients were produced which covered a range of construction materials (Harris & McQuiston, 1988). In total 42 groups of roofs and 41 groups of walls were produced with a set of CTF coefficients allocated to each group. Correlations were then produced to related the grouped walls and roofs based on principle material, R-value, mass placement with respect to insulation, the material with which the principle material is combined, and availability of suspended ceiling (in the case of roofs). The CTF coefficients were then used in the CTF equation to estimate the heat gain or loss. The 1-D conductive heat gain (or loss) $\dot{Q}_{cond,t}$ at time t hour through the roof and walls is determined using the conduction transfer function (CTF) model (Harris & McQuiston, 1988) i.e.

$$\dot{Q}_{cond,t} = - \sum_{n \geq 1} d_n \dot{Q}_{cond,t-n\Delta t} + A \left(\sum_{n \geq 0} b_n T_{os,t-n\Delta t} - T_i \sum_{n \geq 0} C_n \right) \quad 2.1$$

$$T_{os} = T_o + \frac{(\alpha \cdot I_t)}{h_o} + \frac{(\varepsilon \cdot F)}{h_o} \quad 2.2$$

where,

T_o = Outside air temperature

α = Absorptance of surface

I_t = Total radiation incident on the surface

h_o = Outside convective and radiative heat transfer coefficient

ε = Emittance of the surface

F = Difference between the long-wavelength radiation incident on the surface from the sky and the radiation emitted by a black body at outdoor air temperature.

A = Area of roof or wall, m^2 (ft^2)

Δt = time step of 1 hour

$T_{os,t}$ = sol-air temperature of the outside surface at time t, this is taken as the external thermal boundary condition

$b_n, c_n, d_n =$ CTF coefficients provided by (Harris & McQuiston, 1988)

In the steady-state limit, that is, when $\dot{Q}_{cond,t}$, T_{os} , and T_i are all constant, the above equation becomes,

$$\dot{Q}_{cond,t} \sum_{n \geq 0} d_n = +A(T_{os} \sum_{n \geq 0} b_n - T_i \sum_{n \geq 0} C_n) \quad 2.3$$

where $d_0 = 1$,

$$\text{since, } \dot{Q}_{cond} = AU(T_{os} - T_i) \quad 2.4$$

Comparing the above two equation we get,

$$\sum_{n \geq 0} b_n = \sum_{n \geq 0} C_n \quad 2.5$$

$$\text{and, } U = \frac{\sum_{n \geq 0} C_n}{\sum_{n \geq 0} b_n} \quad 2.6$$

The indoor temperature T_i is the indoor thermal boundary condition. Basically, the initial value $Q_{cond,t} = 0$ is unidentified; its value is independent and is iterated over a sufficient time of diurnal cycles (a few days to a week) until the pattern becomes periodic/steady and the accuracy is of the desired value. Numerical values of the CTF coefficients of different construction materials have been recalculated with time steps of 1 hour which are available at (ASHRAE, 1997). The method of iteration is discussed as follows:-

- i. Identify T_i, T_{sol}
- ii. For the corresponding structure, I identify all values of $b_n, \sum C_n$, and d_n .
- iii. Arrange a table as above.
- iv. Set initially $Q_{cond,t} = 0$ for $t > 1$.
- v. The results in the successive days are shown in the successive column.
- vi. Note the three initial rows for $t = -k, -(k-1), \dots -2, -1, 0$ correspond to the calculations for the previous repetitive day, and so the entries are shown in italics.
- vii. For the first ($Q_{cond,t}/A$) entry at $t=1$, the value is calculated as,

$$\begin{aligned} X = \frac{\dot{Q}_{cond,1}}{A} &= \frac{d_1 \cdot \dot{Q}_{cond,1-1}}{A} + \frac{d_2 \cdot \dot{Q}_{cond,1-2}}{A} + \frac{d_{k-1} \cdot \dot{Q}_{cond,1-(k-1)}}{A} \\ &+ \frac{d_k \cdot \dot{Q}_{cond,k}}{A} + b_0 \cdot T_{os,1-0} + b_1 \cdot T_{os,1-1} + b_{k-1} \cdot T_{os,1-(k-1)} \quad 2.7 \\ &+ b_k \cdot T_{os,1-k} + T_i \cdot \sum_{n \geq 0} C_n \end{aligned}$$

viii. To initiate the second-day calculations, the conductive gains for the last k hours of the previous day are copied into the first k rows of the column corresponding to the second day and so on.

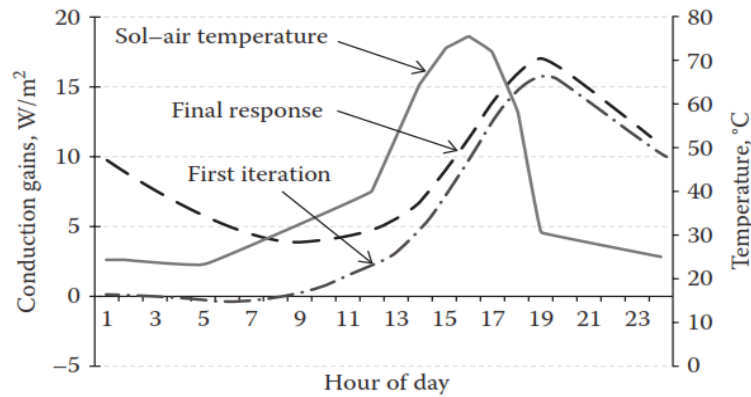


Figure 2.2: Pattern of the first iteration and the final solution. (Reddy, et al., 2017)

- ix. As the number of the iteration is increased to continue for more days, it comes to notice that the diurnal pattern being stabilized as in figure 2.2 below.
- x. After the heat gains are calculated for each type of wall for different hours equivalent cooling loads can be calculated by multiplying various weighing factors if present.
- xi. The CLTD/SCL/CLF values are then calculated by dividing the hourly cooling load per square foot for the surface by the overall U-value of that surface.

Table 2-1: Iteration to calculate the heat gain through a surface using TFM model

t (hour)	$T_{os,t}$	$Q_{cond,t}/A$	$Q_{cond,t+24}/A$	$Q_{cond,t+48}/A$	....
$-k$..	0	..	$Y2$	$Y3$
$-(k-1)$..	0	..	$Y2$	$Y3$
..	..	0	..	..	..
-1	..	0	$Y1$	..	..
0	..	0	$Z1$	..	..
1	..	X	..	..	..
..
23	..	$Y1$	$Y2$	$Y3$	..
24	..	$Z1$	$Y2$	$Y3$	..

2.4.2 Heat Balance Method

The general principle followed by this method is that flow of energy in each zone is balanced. It implies the energy balance equations for the zone air inside and the inner and outer surfaces of each wall, roof, and floor (McQuiston, et al., 2005). Consider an enclosed system with four walls, a roof, and a floor. Heat transfer is taking place through the windows, walls, and the roof as well as internal heat being produced via internal elements. The heat balances on both inner and outer surfaces an individual wall or roof are demonstrated in figure 2.3 below.

The heat balance on the j exterior surface and interior surface at time θ are represented

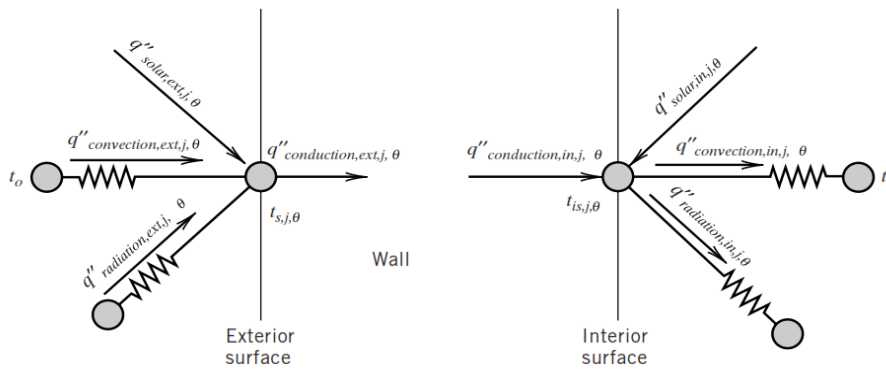


Figure 2.3. Graphical representation of the heat balance. (McQuiston, et al., 2005)

conceptually by the equations below (McQuiston, et al., 2005).

$$q''_{conduction,ext,j,\theta} = q''_{solar,ext,j,\theta} + q''_{convection,ext,j,\theta} + q''_{radiation,ext,j,\theta} \quad 2.8$$

$$q''_{conduction,in,j,\theta} = q''_{solar,in,j,\theta} + q''_{convection,in,j,\theta} + q''_{radiation,in,j,\theta} \quad 2.9$$

where,

$q''_{conduction,ext \text{ or } in,j,\theta}$ = conduction heat flux, Btu/hrft² or W/m²

$q''_{solar,ext \text{ or } in,j,\theta}$ = absorbed heat flux

$q''_{convection,ext \text{ or } in,j,\theta}$ = convection heat flux

$q''_{radiation,ext \text{ or } in,j,\theta}$ = Thermal radiation heat flux

$q''_{conduction,ext \text{ or } in,j,\theta} \neq q''_{conduction,in,j,\theta}$ (steady-state heat transfer condition) doesn't occur.

also,

$$\begin{aligned}
q''_{conduction,ext,j,\theta} &= -Y_o t_{is,j,\theta} - \sum_{n=1}^{N_y} Y_n t_{is,j,\theta-n\delta} + X_o t_{es,j,\theta} \\
&+ \sum_{n=1}^{N_x} X_n t_{es,j,\theta-n\delta} + \sum_{n=1}^{N_q} \Phi_n q''_{conduction,ext,j,\theta-n\delta}
\end{aligned} \tag{2.10}$$

$$\begin{aligned}
q''_{conduction,in,j,\theta} &= -Z_o t_{is,j,\theta} - \sum_{n=1}^{N_y} Z_n t_{is,j,\theta-n\delta} + Y_o t_{es,j,\theta} \\
&+ \sum_{n=1}^{N_y} Y_n t_{es,j,\theta-n\delta} + \sum_{n=1}^{N_q} \Phi_n q''_{conduction,in,j,\theta-n\delta}
\end{aligned} \tag{2.11}$$

$$q''_{solar,ext,j,\theta} = \alpha G_t \tag{2.12}$$

$$q''_{convection,ext,j,\theta} = h_c (t_o - t_{os,j,\theta}) \tag{2.13}$$

$$q''_{radiation,ext,j,\theta} = \varepsilon \sigma [F_{s-g} (t_g^4 - t_{es,j,\theta}^4) + F_{s-sky} (t_{sky}^4 - t_{es,j,\theta}^4)] \tag{2.14}$$

where,

Y_n, X_n and Z_n = ‘cross’, ‘exterior’ or ‘interior’ CTF coefficient,

, Btu/hrft²F or W/m²K

$T_{is,j,\theta}$ and $T_{es,j,\theta}$ = Interior and exterior surface temperature, °F or °C

Φ_n = Flux coefficient dimensionless

α = Solar absorptivity

G_t = Total solar irradiation incident on the surface, Btu/hrft² or W/m²

(calculated by ASHRAE clear sky model)

h_c = Convection coefficient

$t_{os,j,\theta}$ = Outside surface temperature on the jth surface on time t_θ .

ε = Surface long-wavelength emissivity

σ = Stefan-Boltzmann constant

F_{s-g} and F_{s-sky} = View factor, surface to ground and surface to sky

t_g and t_{sky} = Ground temperature and sky temperature

$t_{es,j,\theta}$ = Exterior surface temperature on jth surface on time t_θ

Similar is adopted in the case of the interior surface. The basic methodology of iteration is similar to the CTF method which is explained below: -

- i. During calculation, at one time level of the iteration, the values of exterior and interior surface temperatures unknown and must be identified coincidentally with the surface heat balance.
- ii. When the calculation begins, previous values of surface temperature and heat fluxes are unknown. Thus, necessary assumptions must be made for past values for initiating the calculation and then iterated on a foremost day. For the second day, the values of the first day are used, and so on, until a steady periodic stable value is reached.
- iii. CTF coefficients are calculated by the load calculation program itself provided on the ASHRAE website.

2.4.3 Radiant time-series method

The radiant time series method (RTSM) is uncomplicated than the heat balance method. The RTSM method makes several simplifications to the heat balance method such as there is no internal or external heat balance rather it is assumed all the surface are effectively at the zone air temperature and facilitates the use of single convection coefficients, radiation coefficients as well as fixed surface conductance independent of surface temperature, sky temperature, etc (Spitler, et al., 1997). The storage and release of energy by the surfaces are approximated with predetermined zone response values. The procedure of calculation is as follows: -

i. Determination of exterior boundary conditions

$$q''_{convection,ext,j,\theta} = h_c(t_e - t_{os,j,\theta}) \quad 2.15$$

$$t_e = t_o + \frac{\alpha G_t}{h_o} - \frac{\varepsilon \delta R}{h_o} \quad 2.16$$

where,

h_o = Combined exterior convection and radiation coefficients.
Btu/hrft²F or W/m²K

δR = Difference between thermal radiation incident on the surface from the sky and surroundings and the radiation emitted by a blackbody at outdoor air temperature.
Btu/hrft² or W/m²

ii. Conduction heat gains

$$q''_{conduction,in,j,\theta} = \sum_{n=0}^{23} Y_{pn} (t_{e,j,\theta-n\delta} - t_{rc}) \quad 2.17$$

where,

Y_{pn} = nth response factor, Btu/hrft²F or W/m²K

$t_{e,j,\theta-n\delta}$ = Sol-air temperature, n hours ago, F or C

t_{rc} = Presumed constant room air temperature, F or C

iii. Application of radiant time series

RTSM predicts the cooling load utilizing a radiant time series. Similar to the conduction transfer function in which present and past values of sol-air temperature periodic response factors are used to estimate the load transfer iteratively, the coefficients of radiant time series are also used to in this method to estimate the load using the current and past values heat transfer iteratively:

$$\dot{q}_{\theta,CL} = r_0 \dot{q}_{\theta} + r_1 \dot{q}_{\theta-\delta} + r_2 \dot{q}_{\theta-2\delta} \dots \dots r_{23} \dot{q}_{\theta-23\delta} \quad 2.18$$

where,

$\dot{q}_{\theta,CL}$ = Cooling load at the current hour, Btu/hr or W

$\dot{q}_{\theta-n\delta}$ = Heat gain n hours ago, Btu/hr or W

r_n = nth radiant time factor

Radiant time factors are calculated using the heat balance model. Assuming, all the surfaces have adiabatic properties, the heat balance model is repeated for a single hour every 24 hours. The cooling load is iterated until a steady periodic pattern is retrieved. (Spitler, et al., 1997).

2.4.4 Cooling Load Temperature Difference (CLTD)

The CLTD takes into consideration of the thermal lag in the heat convecting through the surface, also the lag due to the radiation emitted from the inner wall surface to internal elements which vary with time-dependent system heat gain, the massiveness of the structure, and the geophysical location. The CLTD, SCL, and CLF data were calculated using the transfer function method. The production of the table values using the CLTD/SCL/CLF method comes with the cost of accuracy as data for every type of structure cannot be developed. Considering the number of months, and the number of latitudes initially the total classification of 41 walls and 42 roofs were done. However, a much more practical usable version of the CLTD tables described in GRP 158

(ASHRAE 1979) is based on (Rudoy & Duran, 1975). In their work, they computed cooling loads for 10 and 16 types of roofs and walls respectively. These cooling loads corresponded to the heat gain under standard circumstances: latitude of 40°N, July 21st date, the maximum outside temperature of 95°F, 21°F daily range, and 78°F inner design temperature. They also provided latitude and month correction factor to use with other conditions of latitude and month. Later on however separate tables for latitude 24°N, 36°N, and 48°N were devised preventing the need for latitude and month correction factor. the entire process of cooling load calculation is summarized in table 2-2.

Table 2-2: CLTD/SCL/CLF method

Type	S.N.	Load source	Equation
E X T E R N A L	1.	Roof	$\dot{q}_{\theta 1} = UA(CLTD)_{corr\theta}$ $(CLTD)_{corr\theta} = [(CLTD * K) + (78 - t_i) + (t_{om} - 85)] * f$ $t_{om} = t_o - \frac{DR}{2}$
	2.	Partition walls and floor	$\dot{q}_{\theta 2} = UA(t_o - t_r)$
	3.	Solar gain through glass	$\dot{q}_{\theta 2} = A(SC)(SCL)_{\theta}$
	4.	Conductive heat gain through glass	$\dot{q}_{\theta 3} = UA(t_o - t_r)$
I N T E R N A L	5.	People	$\dot{q}_{\theta s4} = N(\text{Sensible heat gain})(CLF)$ $\dot{q}_{\theta L4} = N(\text{Latent heat gain})$ $\dot{q}_{\theta 4} = \dot{q}_{\theta s4} + \dot{q}_{\theta L4}$
	6.	Lights	$\dot{q}_{\theta 5} = N(BF)(W)(CLF)$
	7.	Equipment	$\dot{q}_{\theta 6} = N(UF)(W)(CLF)$
	8.	Ventilation and infiltration air load estimation	$\dot{q}_{\theta s7} = \dot{m}(Cp)(t_o - t_r)$ $\dot{q}_{\theta 17} = \dot{m}(h_g)(W_1 - W_2)$ $\dot{q}_{\theta 7} = \dot{q}_{\theta s7} + \dot{q}_{\theta 17}$ $\dot{V} = A_{leak} \sqrt{a_s(t_o - t_r) + a_w v^2}$

2.5 Comparison of the calculation methods

Among all the ASHRAE HOFs published, only the 1993 and 1997 editions contained a proper comparison of the TFM and the CLTD/SCL/CLF in which the load calculated using the CLTD/SCL/CLF method overestimated the load by 6.5% compared to TFM method (Mao, et al., 2018).

(Joudi, et al., 2005) tallied the cooling loads predicted by the TFM and the CLTD/SCL/CLF method against their measured data. Their experimental setup consisted of a test zone located in Baqubah, Iraq, at 33.3°N latitude and 44.1° E longitude. The characteristics were: medium-weight construction, an A/C installed for a constant 26°C. Cooling loads were calculated for 4 dates of 21st from May to September using the TFM and the CLTD/SCL/CLF methods. It was found that the variation among the calculated and estimated loads was 33%. However, since the comparison was done only for a single system, their study should be taken as a reference instead of deriving conclusions.

(Rees, et al., 1998) carried out a quantitative analysis of ASHRAE and the U.K. cooling load calculation method. Compared to the HBM, it was found that RTSM tends to predicted higher value of peak cooling loads in cases comprising of zones with a greater quantity of glazing. The differences were as much as 37%. While on other cases RTSM and HBM were relatable.

(Rees, et al., 2000a) performed a qualitative comparison of the HBM and the RTSM method. They concluded that the HBM method was better in simulating the physical heat being transferred.

(Mao, et al., 2018) compared the HBM method to the simpler RTS, TFM, and CLTD/SCL/CLF method and found that even though they reduce the calculation period, the results they produce are considered accurate. However, the shortcomings of these methods are the factors and coefficients that they use. In contrast to all the other methods which assume temperature pattern to be generally uniform throughout the day, the HBM allows the possibility of a temperature variation in cooling load calculations. They concluded that the accuracy was in the order of HBM, RTSM, TFM, and CLTD/SCL/CLF method.

Out of all the methods available HBM, RTSM, and TFM method are two-stepped methods wherein first, the heat gains are calculated, and then the heat gains are then converted to cooling loads. The heat gains are calculated iteratively for each element.

The addition of the various constants and factors in each method adds to the complication of the calculation.

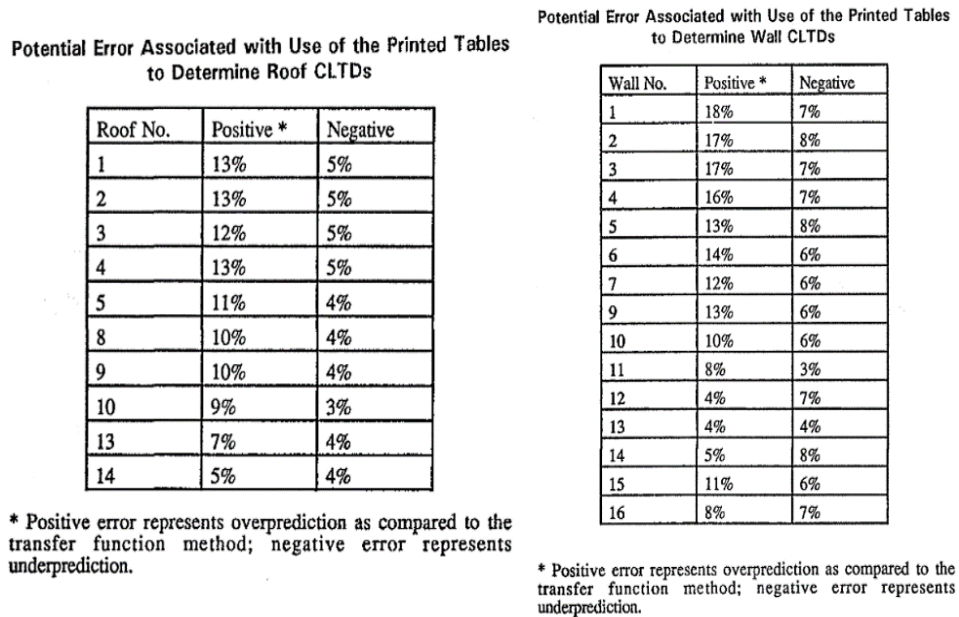


Figure 2.4: Errors associated with CLTD/SCL/CLF (Spitler & F.C. McQuiston, 1993)

In summary, the previous studies that have been conducted comparing the differences between the methods of calculation mostly state that HBM performs better. For the rest, however, because of the variation in the test environments or the disparity of the data used in different studies definite ranking put forward researches can only be taken as references rather than conclusions. While any method theoretically can be used by hand, using a spreadsheet, or a computer program, the heat balance method is best done in a standalone computer program because of the tedious and complicated nature of it and the required data associated with it. Comparatively, RTSM and TFM method are capable of being used for use in a spreadsheet (McQuiston, et al., 2005), yet all the factors/constants coefficients and details about the test environment must be known for the results to be accurate. On the other hand, as the CLTD/SCL/CLF method is developed out of the TFM method because of which the iteration part of the calculation is avoided. Due to the availability of the predetermined value which is capable of representing most cases, for the resource available CLTD/SCL/CLF method can produce decently accurate results.

2.6 Types of air conditioning systems installations

2.6.1 Self-contained

The simplest example of a self-contained AC is the window AC which consists of an outer casing that houses a compressor that is hermetically sealed (NPTEL, 2020). The evaporator and condenser are also within the housing. For the movement of air, there are two fans. One for pushing air out i.e. on the condenser side another for inside i.e. on the evaporator side, yet both the fans are mounted on the same motor. These sorts of window air conditioning units are installed in an open window. WACs are available in capacities from 5000 and 16,000Btu/h (0.4–1.3 Tons). A WAC is installed either in a window or a framed wall opening (Bansal, 2015).

2.6.2 Split Systems

The basic construction of a split air conditioning system is such that they are divided into two separate entities. The inside unit i.e. inside the conditioned space houses the expansion valve, evaporator coil, and the inside blower fan. The outside unit i.e. which lies outside in the environment houses the compressor, condenser, and outside blower fan. The two units connected by ducts. Split systems are further classified into mini-split and the central system.

i. Mini-split (ductless) system and multi-split system

A mini-split system is a ductless system that can supply conditioned and heated air to a single of a building. (Mitsubishi Electric US. Inc, 2013). While multi-split systems are capable of up sufficing the needs of up to 8 zones from a single outdoor unit. Commercially available single-zone mini-split systems have a cooling capacity of 9,000 to 36,000Btu (9,500–38,000kJ) per hour while multi-split systems have higher capacities of up to 60,000 Btu's (Hundy, et al., 2008).

ii. Variable refrigerant flow (VRF) systems

A variable refrigerant flow (VRF) systems is a form of large multi-split system that is capable of varying the flow of refrigerant to evaporator units placed in different indoor zones based on demand, which makes it possible for numerous indoor fan coil units to be in connection to an individual outdoor unit (Baral, 2019). It is not a separate kind of air conditioning setup rather a new technology developed in the sector of HVAC. The outdoor unit comprises one or multiple inverter-driven compressors i.e. the speed of their

operation can be changed by altering the frequency of the current being supplied (Hai, et al., 2006). As the speed of the compressor directly affects the amount of refrigerant being delivered (Jin-Long & LinT.-J.Yeh, 2007). Each indoor fan coil unit has the measuring control device that is handled by the indoor unit, or by the outdoor unit. If demanded by the indoor unit, the outdoor unit then spools up the right amount of refrigerant to fulfill the demand (Sivaraman, 2019). Out of all HVAC systems, VRF systems are becoming more and more popular for heating and cooling as they have higher performance characteristics in partial load situations, providing independent zone conditioning, and maintenance easiness (Lin, et al., 2016). However, the VRF system has its drawbacks too. VRF can provide certain Tons/KW of thermal load only. the outdoor unit of the VRF system has a capacity from 3.5KW to 88KW, while the indoor unit has capacities from 1.5KW to 25 KW for both heating and cooling (Baral, 2019).

2.6.3 Central refrigeration system

The operation of the central air-conditioning system is primarily done in high-demand large-scale buildings where it is necessary to maintain a constant indoor climate throughout the year (Zhang, et al., 2019). Central air conditioning systems compared to others are much more capable of handling larger areas with very low fluctuation and response time. The principle element in this system is the air handling unit (AHU). Air handling units are the primary elements of the central refrigeration system. It also does the task of mixing purified outside air with return air after which follows the necessary psychometric processes. Central refrigeration systems are used in places where capacities such as 100,000CFM (50 m³/s) are required (Elnaggar & Alnahhal, 2019). The central system consists only of a single common pair of return and supply air ducts called plenum which begins at AHU, the primary plenum then branches out to serve to multiple rooms all being delivered by the same entity. The AHU and the control mechanism are placed in an isolated location sometimes termed as AHU room (Ahmed, et al., 2007).

(Tomoyuki Nanami, 2013) described it as a system that can provide conditioning to multiple zones in a building using a single air-conditioning unit. Each room is provided with a controller which is individually able to control the temperature of that particular room. The advantages and disadvantages of types of air conditioning system setups are described in table 2-3 below.

Table 2-3: Categorization of types of the air conditioning system

A/C type Criteria	Window unit (self- contained)	Mini-split (ductless) system	Multi-split system	Central Air conditioning system
Cost	Low	Low	High	Very high
Capacity	Low	Low but greater than (1)	High	Higher
Response time	High for a small room; low if applied to a larger one	Higher than (1)	High	High
Maintenance	Difficult as the units are installed sealed in the window and removal is tedious	Easier than (1) as only one unit can be separately maintained at a time	Easier compared to multiple mini-split systems	Maintenances are generally large scale and costly
Application area	Household purpose	Household purpose, small-scaled commercial purpose	Small scaled commercial purpose	Large scale commercial purpose
No. of zones able to handle	1	1	Multiple up to 8	Multiple than (3)
Flexibility to modify/upgrade	None	None but addition systems can be installed if necessary	Flexible	Flexible but costly
Noise associated	High	low	Low	low

2.7 Computational fluid dynamics (CFD)

Computational Fluid Dynamics is the science that studies the systems involving fluid flow and all the aspects/ properties associated with it employing computer-based simulation. The implementation of CFD stretches over a range of commercial and non-commercial areas such as aerodynamics, hydrodynamics, thermodynamics, turbomachinery, chemical process engineering, HVAC, hydrology, and oceanography, meteorology, biomedical engineering, etc. (Versteeg & Malalasekera, 1995). There are numerous advantages of CFD over the experimental approach to designing of fluid systems such as decreasing the lead times and costs in designing, applicable to controlled experiments which are tedious or even impractical to be performed in reality, ability to examine systems which risky to operate beyond their rated limits and virtually unlimited level of details in the solution generated.

The target of CFD is to understand what is happening physically at each moment of the fluid flow, around and within designated objects which are caused as a result of events such as dissipation, diffusion, convection, shock waves, slip surfaces, boundary layers, and turbulence (Lomax, et al., 1999).

CFD can be assumed as a group of computational methodologies used to solve various equations governing fluid flow and for the application of it, it is essential to decide what the physical assumptions are and related equations are to be used to solve the problem (H & Milovan, 2002). The fundamental ground CFD however is the Navier–Stokes equations, which can be defined as the governing equation for fluid flows.

With the advancement of computer science and the widespread availability of advances, computer machines with powerful processing capabilities incorporating effective algorithms and detailly complex pre and post-processing facilities have enabled the use of commercial CFD codes to solve rather complex fluid problems which were near to impossible if done by manual hand calculations. All CFD software generally includes three parts: pre-processor, solver and post-processor, the initial two being more important are explained below (Versteeg & Malalasekera, 1995):-

2.7.1 Pre-processor

Pre-processing consists of providing input parameters of a fluid flow system to a CFD program. The activities involved in this stage are:

- i. Defining the geometry of flow problem: the computational domain.

- ii. Grid generation i.e. it is the sub-division of the target computational domain into small and fine, non-overlapping sub-domains: grid/ mesh of cells/ control volumes/ elements.
- iii. Selecting the physical and/or chemical phenomena that involve the flow problem and need to be modeled.
- iv. Definition of fluid properties.
- v. Definition of the boundary conditions.

The solution of the flow equation (velocity, pressure, temperature, etc.) is defined at nodes in every cell. The accuracy of the solution is directly proportional to the number of cells in the grid i.e. greater is the quantity of cells better is the solution accuracy however that comes as a trade-off due to the consumption of larger time.

2.7.2 Solver

The numerical solution techniques are divided based on the method of discretization of the partial differential equation that governs the fluid flow: finite difference, finite element, and spectral methods. In general, all the methods perform the following steps:

- i. Approximation of the unknown flow variables utilizing simple representation functions.
- ii. Solvable algebraic equations are produced by discretizing i.e. by substitution of the approximations into the governing flow equations.
- iii. The solution of the algebraic equations.

The discretization methods are explained in brief below.

- i. Finite difference methods:** Finite difference methods produces point samples at the node points of a grid of co-ordinate lines which are then used to describe the flow problem variables.
- ii. Finite Element Method:** This method utilize simple piecewise functions (e.g. linear or quadratic) to explain the differences in flow parameters.
- iii. Spectral Methods:** This method assumes the unknowns employing truncated Fourier series or series of Chebyshev polynomials.

The finite volume method is a special case finite difference formulation. It is used as the principle discretization method in major commercially available CFD software such as PHOENICS, FLUENT, FLOW3D, and STAR-CD. The numerical algorithm consists of the following steps:

- i. The governing equations of flow are integrated over the control volumes of the computational domain.
- ii. Discretization includes the substituting of multiple finite-difference approximations in the integral equation for the representation of flow phenomenons(convection, diffusion, etc). The integral equations are converted into a system of algebraic equations.
- iii. Algebraic equations are then solved by an iterative method.

2.8 Governing equations

2.8.1 Navier-Stokes Equation

The governing equations for three-dimensional, steady, turbulent, and incompressible flow with heat transfer are the continuity equation, the energy equation, and the N–S equation (momentum equation).

Continuity equation:-

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \quad 2.19$$

Momentum equation (N-S equation):-

$$\frac{\partial u}{\partial t} + u \cdot \nabla u = \nu \nabla^2 u - \frac{1}{\rho} \nabla p + \rho g \quad 2.20$$

Energy equation:-

$$\frac{\partial}{\partial t} \left(\rho \left(e + \frac{V^2}{2} \right) \right) + \nabla \cdot \left(\rho \left(e + \frac{V^2}{2} \right) \cdot V \right) + \nabla \cdot (pV) - \text{viscous force} + \nabla \cdot (\dot{q}) = 0 \quad 2.21$$

where,

u, v, w = Velocity of fluid in X, Y, and Z direction.

ρ, μ, ∇, p = Density, coefficient of viscosity, divergence, pressure

2.8.2 K-Epsilon Model

The K-epsilon model is predominantly preferred as the goto turbulence model. It is a two-equation model consisting of transport equations (representing turbulent behavior of the flow to consider for previous effects like convection and diffusion of turbulent energy) in which the first transported variable being the turbulent kinetic energy (k) and second transported variable being the rate of dissipation of turbulent kinetic energy (ϵ). The fundamental principle is that the turbulent viscosity is isotropic i.e. the ratio between

Reynolds stress to the mean rate of deformations is constant and independent of directions. The equation to calculate the turbulent kinetic energy k , and dissipation ε are as follows (Versteeg & Malalasekera, 2007):-

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\frac{\mu_t}{\sigma_k} \cdot \frac{\partial k}{\partial x_j} \right] + 2\mu_t \cdot E_{ij} \cdot E_{ij} - \rho \varepsilon \quad 2.22$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\frac{\mu_t}{\sigma_\varepsilon} \cdot \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \cdot \frac{\varepsilon}{k} \cdot 2\mu_t \cdot E_{ij} \cdot E_{ij} - \rho \cdot C_{2\varepsilon} \cdot \frac{\varepsilon^2}{k} \quad 2.23$$

Rate of change of k or ε + Transport of k or ε by convection = Transport of k or ε by diffusion + Rate of production of k or ε - Rate of the destruction of k or ε
where,

u_i =represents velocity component in the corresponding direction

E_{ij} = represents the component of the rate of deformation

μ_t = represents eddy viscosity

$$\mu_t = \rho \cdot C_\mu \cdot \frac{k^2}{\varepsilon}$$

$C_\mu, \sigma_\varepsilon, C_{1\varepsilon}, C_{2\varepsilon} = 0.09, 1.00, 1.300, 1.44, 1.92$, which are adjustable constants.

(Versteeg & Malalasekera, 2007).

2.9 CFD in HVAC designing

CFD has been adopted as a key tool for the overall optimization of the operation of AC systems. (Chow & Lin, 1999) performed simulations using EXACT3 CFD to analyze the operation of split-type air conditioners considering the increasing temperature in the condensing units and reported results produced by CFD are accurate with respect to the stack effect on the performance of the A/C operating at different floors of the building.

(Chow, et al., 2000) studied on the performance of the re-entrant shapes using CFD techniques and concluded that compared to I and L shaped, T-shaped re-entrant had the better energy operation where the outdoor condenser is placed on.

(X.R, et al., 2017) analyzed the feasibility and energy saving property of clean air conditioning in clean operation chambers in a hospital where airflow distribution was simulated using the CFD software Airpak 3.0 while Fluent software was used to post-process the wind speeds of the operating area. It was found that an increase of the air supply area and return air inlets can increase the area of unidirectional flow regions of the main flow regions and avoid indoor vortexes and turbidity in the operating area. The application of a secondary air return system in summers can reduce energy consumption (X.R, et al., 2017).

(Sharma, 2017) studied how the location of supply air and return air vents affect the indoor air temperature and the velocity of air moving in the space. CFD simulations were performed onto geometries with varying positions of supply and return vents. It was found that the indoor temperature and velocity are changed according to the placement of supply air diffusers.

(Kumar & Bartaria, 2018) studied how the positioning of A/C units can affect the thermal comfort conditions and found that that the arrangement of the A/C units placed on walls facing each compared to the A/C units placed on the same wall took lower time to delivery comfort temperature conditions even though the airflow rate from the A/C units in both the case were identical.

CHAPTER THREE : RESEARCH METHODOLOGY

The preliminary stage of any HVAC system designing is the estimation of the load. For this, there are many methods of load calculations implemented by many computer-based software. These commercially available software have features such as estimating the cooling and heating load, infiltration, recommending the capacity depending upon the type of HVAC system, estimating load patterns throughout the day, etc. Some software are also able to estimate energy usage but they do so by generalizing the usage pattern throughout the day. Having said that, these software only do so much in predicting the load not so much on how that load will affect the temperature distribution with respect to time and space. Yet, designing an HVAC system required much more than only knowing the value of loads. Knowledge about optimum positioning of the inlet and outlet vents, temperature profile across space, presence of short-circuiting of the airflow, location of the hottest and coldest region, the local velocity of air, throw and spread of the inlet air, size of the stagnation zones, etc. are equally important topics. The most important question, however, is: How long will it take to reach the desired temperature?

In short, the load calculation software are unable to provide qualitative data related to the performance HVAC system. It is possible to calculate all the above-mentioned parameters mathematically but the entire process is extremely tedious. At such the option is the experimental method or analytical method. Experimentally testing of an HVAC system is not possible contributing to multiple factors such as uniqueness of each HVAC system, cost, time, the scale of the experiment, etc. The only remaining option thus is the analytical method. For this, one of the primary analytical methods of the HVAC system study is CFD analysis. There are several advantages of CFD over experimental approaches such as reduction of lead times and costs in designing, conducting multiple controlled experiments which are difficult or impossible to perform, the ability to operate beyond their normal performance limits, and practically unlimited level of detail of result. CFD analysis can be a very effective tool in simulating the steady and unsteady temperature distributions. It can precisely calculate the time-dependent performance of the HVAC system under various load scenarios. Unlike the load calculating software which generalizes the operation of the HVAC system, the energy analysis done using CFD is much more accurate.

The methodology of this research comprises two significant parts: mathematical load calculations and analytical CFD analysis. Initially, preliminary data related to the geometry, material of the structure, size, location, weather data, etc. are determined. These data are used in the mathematical load calculation as well as the analytical CFD analysis. The cooling loads are calculated using manually developed CLTD Excel Solver, HAP (TFM) method, and Autodesk Revit MEP (RTSM) method. The total loads calculated are compared to verify if they are within 10% of the average value. Simultaneously, geometry and mesh for the CFD simulations are also developed. The physical boundary conditions are set up using the initial available data. Simulations are then performed for a range of different capacities of the A/C system depending upon the value of the cooling load estimated by different cooling load calculation methods. The results from the simulation are then used to produce a time-dependent performance analysis of the different capacities of A/C systems which is then together with the calculated load is used to perform the energy analysis. The methodological approach carried out in this research is depicted in figure 3.1 below.

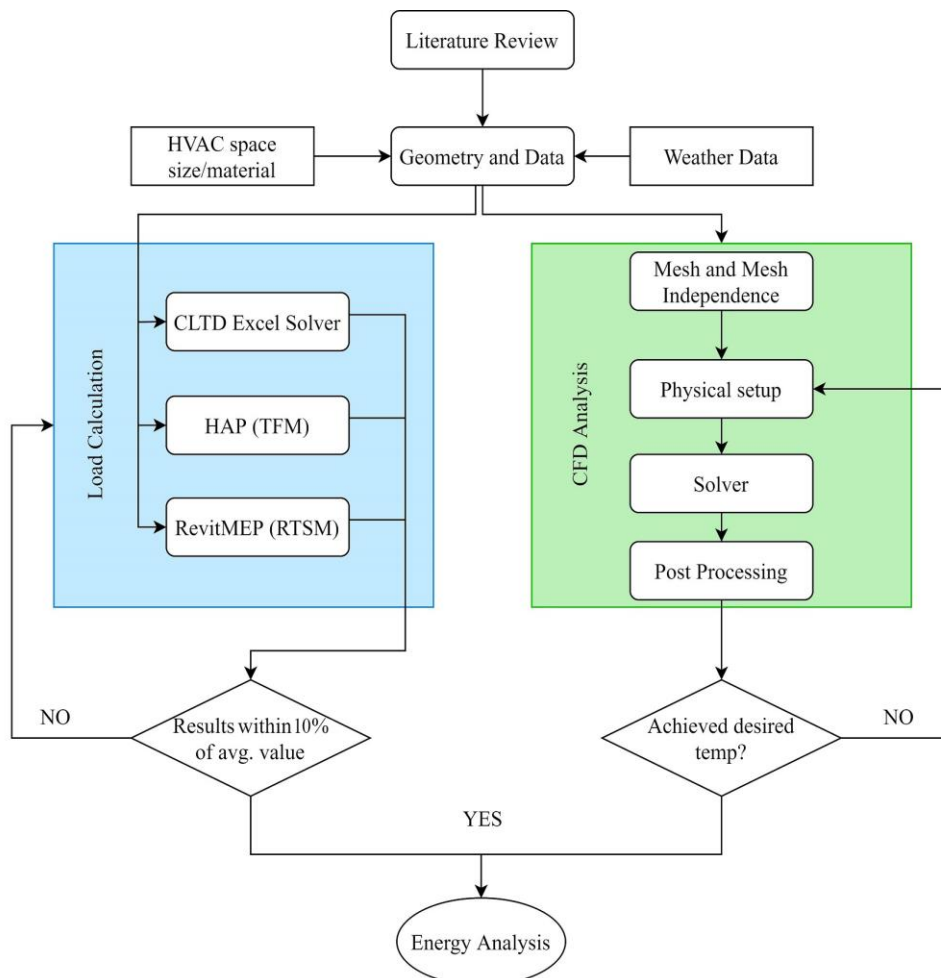


Figure 3.1: Research Methodology Flowchart

3.1 Literature Review

Reviewing the articles and journal papers provide insights into the degree up to which any work or researches or studies are put forth by scholars from the past to the present. The literature related to this research has been already discussed above.

3.2 Data Generation

3.2.1 Description of the space

Since the development of the Aerospace building of the Pulchowk Engineering Campus is in the preliminary phase, there are very little data associated with what the final hall will look like. What is currently available are initial CAD drawings from which data such as locations of the hall, size, minimum and maximum height, etc. are obtained. Some of the information available are enlisted in Table 3-1 below.

Table 3-1: Information related to the targeted space

S.N.	Element	Value
1.	Floor area	3585.0ft ²
2.	Floor size	68.1ft×49.2ft
3.	Roof area	3596.4 ft ²
4.	Roof exposure	NW
5.	Roof slope	5°
6.	Average ceiling height	25.3ft
7.	Location of Partition	SW side
8.	Location of hall	NE side of the building
9.	Longer Side	NE, SW
10.	Shorter side	NW, SE
11.	Floor location of the hall	2 nd floor
12.	Total number of floors occupied	2 nd and 3 rd
13.	Probable location of window placement	NW and NE side.
14.	Door width	5ft

3.2.2 Weather Statistics

The weather data essential for the calculations of the cooling loads are prerecord by (ASHRAE, 1993) and (ISHRAE, 2019). These sources have the design temperature data as well as the monthly weather data of Nepal. The essential data used in this research are enlisted below in table 3-2 to 3-4.

Table 3-2: Design parameters for the Kathmandu Valley (ASHRAE, 1993)

Weather properties			
Data available			
Location	KTM valley	Summer design DBT	89°F 31.67°C
Required indoor temp	71°F 21.67 °C	Summer co-incident WBT	78°F 25.56 °C
Elevation	4388ft	Summer daily range	25°F 13.89°C
Latitude	27.7 deg	Winter design DBT	33.0°F 0.56°C
Longitude	-85.2 deg	Winter co-incident WBT	27.3°F -2.78°C
Data assumed			
Criteria	Temperature	Remarks	
Ambient space max temp	89°F 31.67°C	Design summer DBT	
Unconditioned space max temp	80°F 26.67°C	Assumed to be 5°C lower than design summer DBT	
Ambient space min temp	51.7°F 10.39°C	Min winter temp	
Unconditioned space min temp	59.69°F 15.94°C	Assumed to be 5°C higher than min Jan winter WBT	
Average wind speed	5.6kmph	Satellite data recorded from Jan 2015 to December 2019 (weatheronline ltd., 2019)	

Table 3-3: Monthly temperature pattern(°F) for Kathmandu Valley (ASHRAE, 1993)

Month	Max DBT	Min DBT	Max WBT	Min WBT
Jan	77.2	52.2	70.6	51.7
Feb	79.2	54.2	71.6	53.7
Mar	82.4	57.4	74.8	56.9
Apr	83.6	58.6	75.0	58.1
May	86.0	61.0	76.0	60.5
Jun	88.0	63.0	78.0	62.5
Jul	89.0	64.0	78.0	63.5
Aug	89.0	64.0	78.0	63.5
Sep	87.0	62.0	77.0	61.5
Oct	84.8	59.8	75.8	59.3
Nov	80.6	55.6	73.8	55.1
Dec	78.2	53.2	71.8	52.7

Table 3-4: Design conditions for Kathmandu valley by ISHRAE (ISHRAE, 2019)

Design Conditions							
Heating DBT		Cooling DB/MCWBT					
99.6%	99%	0.4%		1%		2%	
2	3	30	26	29.4	25	28.7	25

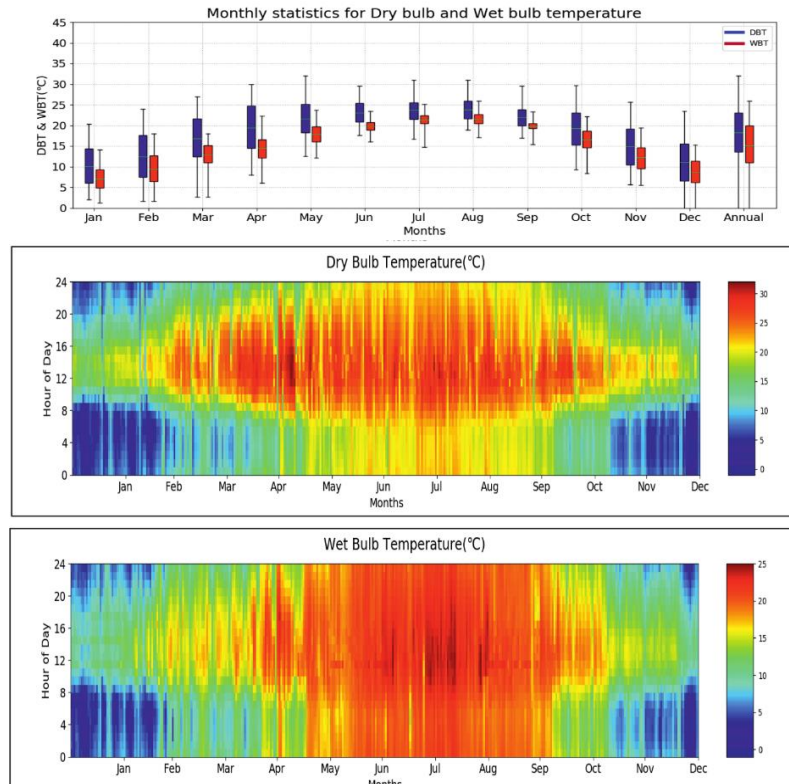


Figure 3.2: Monthly temperature pattern for Kathmandu (ISHRAE, 2019)

While comparing the weather statistics as well as the design temperatures provided by the two sources we can see that even though the data were provided 26 years apart, there is very little difference between the two. The summer design temperature provided by (ASHRAE, 1993) is 31.67°C while the one provided by (ISHRAE, 2019) is 30°C (for 0.4% confidence level) which is very close. Also, the winter design temperature provided by (ASHRAE, 1993) is 0.56°C while the one provided by (ISHRAE, 2019) is 2°C (for 99.6% confidence level) which is very also very close. Because in this study one of the methods used to calculate the cooling load calculation is done using Carrier's Hourly Analysis Program (HAP using weather data from (ASHRAE, 1993), the CLTD method used is also based on the same weather data for consistency.

3.3 Load calculation methods

3.3.1 Cooling Load Temperature Difference (CLTD)

For the application of the CLTD method an Excel Solver was made (included in Appendix E), in which users were to input various data and statistics and gives the option to choose inputs such as wall type, roof type, zone type, etc. Because the CLTD/SLC/CLF table for the 27° is not available, they were iterated using the tables available for latitude 24°, 36°, and 48° (ASHRAE, 1997). The iterated data are listed in Appendix F, G and H. The features of the Excel solver developed are as follows: -

a) Input

- i. Dimensions.
- ii. Design outdoor temperature, indoor temperature, and daily range.
- iii. The number of occupancies.
- iv. Area, type, and resistance of walls, roof, partitions, and door.
- v. Area, type, and shading coefficient of glass in each direction.
- vi. Current supply and voltage supply in the space.
- vii. CFM of Infiltration.
- viii. Overhead lightening load per sqft.

b) Output

- i. Load per occupant and due to all occupancy.
- ii. Total CFM flow inside the space (including the ones due to A/C)
- iii. Heat transfer on each direction of the wall, roof, and window on each hour from 9:00 to 18:00.
- iv. Maximum individual external load and the hour at which it occurs.
- v. Maximum individual internal loads.
- vi. The total load in the space.

In general, the calculation proceeds as follows (Spitler & F.C. McQuiston, 1993):-

a) External cooling load estimation:-

i. For external walls and roofs:-

$$\dot{q}_{\theta 1} = UA(CLTD)_{\text{corr}\theta} \quad 3.1$$

The tabulated CLTD values are calculated for the following assumptions (ASHRAE, 1980):-

- Dark flat surface roof
- Indoor temperature of 78⁰F
- Outdoor maximum temperature of 95⁰F with an outdoor mean temperature of 85⁰F and the outdoor daily range of 21⁰F
- Solar radiation typical of 40⁰N latitude on July 21
- Without and with suspended ceiling, but no attic fans or return air ducts in the suspended ceiling space.
- Inside surface resistance of $R = 0.333 \text{ ft}^2 \cdot \text{°F} \cdot \text{hr/Btu}$

For cases other than above correction is required in CLTD which is given by:-

$$(CLTD)_{\text{corr}\theta} = [(CLTD * K) + (78 - t_i) + (t_{om} - 85)] * f, \text{ for } \text{°F} \quad 3.2$$

$$t_{om} = t_o - \frac{DR}{2} \quad 3.3$$

where,

U= Overall heat transfer coefficient, Btu/(hr-ft²-°F) or W/(m²-°C)

A= Area, ft² or m²

CLTD_{corrθ} = Corrected CLTD which gives the temperature difference equating to the cooling load at temp θ, °F or °C

CLTD = Tabular CLTD, °F

t_i, t_{om} = Actual inside and mean outside design dry bulb temperature, °F or °C

DR = Daily range, °F or °C

K = Colour adjustment factor, 1 if dark colored or light in an industrial area, 0.83 if permanently medium colored (rural area), 0.65 if permanently light-colored (rural area) (ASHRAE, 1980)

f= Factor for attic fan and or ducts, 1 if no attic or ducts, 0.75 if positive ventilation. (ASHRAE, 1980)

ii. For internal partition walls and floor:-

$$\dot{q}_{\theta 2} = UA(t_o - t_r) \quad 3.4$$

where,

U = Design heat transfer coefficient for windows, Btu/(hrft²°F) or W/(m²°C).

A = Area, ft² or m²

t_o = Temperature in adjacent space or exterior environment, °F or °C

t_r = Inside design temperature (constant) in conditioned space, °F or °C

iii. For solar gain through the glass:-

$$\dot{q}_{\theta 2} = A(SC)(SCL)_{\theta} \quad 3.5$$

where,

A = Area, ft² or m²

SC = Shading coefficient (internal shade)

SCL_{θ} = Solar cooling load factor Btu/(hr-ft²-°F) or W/(m²-°C)

Again the SCL accounts for the thermal response (lag) mentioned above

iv. For conductive heat gain through the glass:-

$$\dot{q}_{\theta 3} = UA(t_o - t_r) \quad 3.6$$

where,

U = Design heat transfer coefficient for windows, Btu/(hrft²°F) or W/(m²°C).

A = Area, ft² or m²

t_o = Temperature in adjacent space or exterior environment, °F or °C

t_r = Inside design temperature (constant) in conditioned space, °F or °C

b) Internal Cooling load estimation:-

i. People:-

$$\dot{q}_{\theta s4} = N(\text{Sensible heat gain})(CLF) \quad 3.7$$

$$\dot{q}_{\theta L4} = N(\text{Latent heat gain}) \quad 3.8$$

$$\dot{q}_{\theta 4} = \dot{q}_{\theta s4} + \dot{q}_{\theta L4} \quad 3.9$$

where,

$\dot{q}_{\theta s4}$ = Sensible load

$\dot{q}_{\theta L4}$ = Latent load

N = number of Occupancy.

CLF = cooling load factor, by the hour of occupancy.

ii. Lights:-

$$\dot{q}_{\theta 5} = N(BF)(W)(CLF) \quad 3.10$$

where,

N = number of lights in space.

BF = Ballast factor, 1.0 for incandescent bulb and 1.2 for fluorescent light

W = Watts input from electrical plans or lighting fixture data Btu/hr

CLF = cooling load factor, by the hour of usage

iii. Equipment:-

$$\dot{q}_{\theta 6} = N(UF)(W)(CLF) \quad 3.11$$

where,

N = number of lights in space.

BF = Usage factor

W = Electrical loads or lighting fixture, Watt or Btu/hr

CLF = cooling load factor, by the hour of usage.

iv. Ventilation and infiltration air load estimation:-

$$\dot{q}_{\theta s7} = \dot{m}(Cp)(t_o - t_r) \quad 3.12$$

$$\dot{q}_{\theta l7} = \dot{m}(h_g)(W_1 - W_2) \quad 3.13$$

$$\dot{q}_{\theta 7} = \dot{q}_{\theta s7} + \dot{q}_{\theta l7} \quad 3.14$$

where,

$\dot{q}_{\theta s7}$ = Sensible heat load

$\dot{q}_{\theta l7}$ = Latent heat load

\dot{m} = Mass flow rate of ventilation/infiltration air, kg/sec or lb/hr

C_p = Specific heat of air at constant pressure, J/kg or Btu/lb

t_o = Temperature in adjacent space or exterior environment, °F or °C

t_r = Inside design temperature (constant) in conditioned space, °F or °C

h_g = latent heat of vaporization, J/kg or Btu/lb

$W_1 - W_2$ = Difference of specific humidity, g/kg or oz/lb

Infiltration rate is calculated as:-

$$\dot{V} = A_{leak} \sqrt{a_s(t_o - t_r) + a_w v^2} \quad 3.15$$

where,

A_{leak} = Effective leakage (ELA) of building, cm^2 or in^2

a_s = Stack coefficient (McQuiston, et al., 2005), $[(L/s)^2/(cm^4.K)]$ or $[(ft^3/min)^2/in^4.°F]$

t_o = Temperature in adjacent space or exterior environment, °F or °C

t_r = Inside design temperature (constant) in conditioned space, °F or °C

a_w = Wind coefficient from table (McQuiston, et al., 2005),

$[(L/s)^2/(cm^4 \cdot (m/s)^2)]$ or $[(ft^3/min)^2/in^4 \cdot (mph)^2]$

v = Wind speed, m/s or mph

3.3.2 Carrier's Hourly Analysis Program (HAP)

Carrier's Hourly Analysis Program (HAP). HAP is a commercial computer-based program that is employed in designing HVAC systems. This software uses the transfer function method for its calculation purpose (Carrier Corporation, 2016). It is used for estimating design cooling and heating loads particularly for the sizing of the elements of an HVAC system. In general, the tasks that it performs are as follows:

- i. Calculates the design cooling and heating loads.
- ii. Determines required airflow rates.
- iii. Sizing of cooling/heating coils and air circulation fans.
- iv. Calculate the annual energy usage and costs associated with it.
- v. Produce tabulated and graphical reports of hourly, daily, monthly, and annual data.

3.3.3 Autodesk Revit MEP

Autodesk Revit MEP is a BIM (Building Information Modelling) software developed by Autodesk for engineers associated with various disciplines such as architecture, landscape, structure, mechanics, electric, and plumbing (MEP). It can be used for designing building structures in 3D, annotate the model with 2D drafting elements, thus helping to organize and trace the building's lifecycle, from initial drawing concept to constructed structures and further in life maintenance and/or demolition. For building cooling load calculation RevitMEP uses the much accurate radiant time series method (RTSM). It streamlines the designing process by facilitating the use of a single model which are compatible with multiple programs for different design elements such as building element energy analysis, structural analytical modeling, ventilation or air-conditioning ducting, electric wiring, etc.

3.3.4 Considerations made for the calculations

The targeted area of installation is an auditorium hall i.e. a single zone system. The target zone is small and costly for setting up a central air-conditioning system. In the case of a split air-conditioning system, because of the presence of only one zone and for simplicity of simulation, a simple mini-split (ductless) system is chosen rather than a multi-zone system or VAR air conditioning system. It can be observed that the specifications of A/C depending upon the capacities are more or less similar to each other. Out of all, for the process of simulation, the models chosen to specify the simulation parameters are mentioned in Table 3-5 below.

Table 3-5: Specifications of A/C chosen for the simulation

Brand	Model	Capacity (Tons)	CFM	Cooling Range (°C)	Dimension (mm)	Watts
LG	VM242H6	2.041	741.6	18~48	998*330*210	2010
LG	VM122H6	1.083	441.4	18~48	837*302*189	1095

3.3.5 Selection of the type of HVAC system for the calculations

The development of the proposed building is currently in the preliminary phase, as a result, there are very little data available to calculate the load. For the calculation of the loads, specific data are required related to material, heat generation elements, atmospheric conditions, infiltration, etc. Due to unavailability, assumptions had to be made which are enlisted in Appendices A and B. Also, to find out the load caused due to the internal components such as occupancy, electrical appliances, lighting, etc. the CLF factor is essential. The CLF factor is based on the number of hours spent/turned on after entry into space by occupants, usage of the electrical appliances or lights, and also the type of zone. The assumptions of type of zone can be made vaguely by assuming what kind of interior space it will most likely become. But the estimation of total time usage or occupants staying inside is very vague and making assumptions can lead to very inaccurate results. Thus, for the calculations of internal elements, in particular, the CLF factor is ignored and rather it is assumed that the internal elements give out a maximum load all the time while in use. The assumptions associated with internal loads are enlisted in Appendix C.

3.3.6 Considerations made for the simulation

The ambient temperature was assumed to be the maximum temperature provided by the weather data with respect to the months. The initial temperature of the space was assumed to be that of the ambient when no air conditioning system is turned on.

The wall boundary conditions were set up based on the type of material and the weather conditions. The radiation boundary condition was chosen for the walls assuming that the outer surface of the wall is in equal temperature as the ambient. For representing the heat generation through occupants inside the auditorium, heat generation markers of diameter 30cm were placed equidistant to each other (a total of 52 markers) and heat flux of 100 occupants are assumed (350Btu/hr per person) to be produced from them.

For the return vent (outlet-vent) boundary condition was chosen in with non-existent backflow pressure and backflow temperature of ambient temperature. The sizing of the return vents was based on (Engineering ToolBox, 2010) which gives the minimum size of return vent that should be placed inside the conditioned zone for the given total CFM of the HVAC system. The article provides return vents sizing for CFM of 100 to 1355. By observing the data it was found that the size of return vent varied linearly to the CFM of the HVAC system thus, the sizing of the required system was also interpolated linearly which is shown in Appendix D.

For the inlet air, the velocity inlet boundary condition was chosen. If we divide the flow rate CFM by the opening size of the vents we can identify the inlet flow velocity. For that, the size of the inlet vents for 2 and 1 Tons A/C was assumed to be the same size as 900mm*100mm. The flow velocity of the A/C of different capacities is calculated and mentioned in Appendix D.

The temperatures of the inlet of different A/C systems enlisted in Appendix D are calculated mathematically using the simple heat equation mentioned below.

$$\dot{Q} = \dot{m}C_p (T_o - T_d) \quad 3.16$$

where,

Q= Rate of extraction of heat i.e. the cooling capacity of A/C.

m=Mass flow rate (can be calculated using the flow rate mentioned in the table above and density of air i.e. 1.225 kg/m³)

T_o, T_d= Outside design temp and temp of the air exiting A/C vents.

C_p=Specific heat capacity of air at constant pressure. (Assumed 1.006 kJ/kg K)

Note:- It is assumed that the air to be dry because simulating 2 phase mixture is very complex, lack of availability of data related to relative humidity, and the fact that the value of the sensible load is much higher than latent load.

The viscosity model was chosen to be a standard epsilon model. Turbulent flows are universal in CFD and are notably affected by the existence of walls, especially in the viscosity-affected regions which have large gradients in the solution variables. A precise portrayal of the near-wall region governs a successful estimation of wall-bounded turbulent flows. Because our area of interest is inside the zone rather than the near-wall reasons, the inside zone is the area of fully developed turbulence as a result mature turbulence models such as k-epsilon are wise to be used which is used particularly in the simulations of this research. Second-order upwind scheme was chosen for discretization with the 4th order accuracy for the calculations to be performed.

3.4 CFD Analysis and Mesh Independence Study

3.4.1 Geometry Modelling

The geometry was developed based on the reference plan of the auditorium hall of the proposed Aerospace building of the Pulchowk Engineering Campus obtained from the department. AutoCAD and SolidWorks both were used to develop the geometry to be used later in mesh development. The door is located on the leftmost side of the South-West side. The podium for the presenter is assumed to be on the SE side and the attendees are assumed to sit on the NW side facing the southeast side. It is assumed that there is a total of 13 tires of 1m length and 0.15 height steps and a 1.8m length disable friendly tire at the front as well where the attendees will remain sit. The windows are only permitted on the North-East and the North-West walls. On the North-West walls, there are 2 windows equidistant to each other and the end walls which are 1m above the floor. While on the North-East side there are 3 windows again equidistant to each other and the end walls which are 1m above the wall. All the windows are of the same size i.e. (2.45m×1.82m). The door is located at the South-West side sized (1.6m*2.44m). The inlet vents are placed 1m below the ceiling and equidistant to each other to allow sufficient uniform air mixing. The number and position of the A/C were determined as mentioned in table 3-6 below.

Table 3-6: Positioning of A/C vents

S.N.	Capacity	SW	NW	NE	SE
1.	8 Tons	2×2 Tons		2×2 Tons	
2.	9 Tons	2×2 Tons	1×1 Tons	2×2 Tons	
3.	10 Tons	2×2 Tons	1×2 Tons	2×2 Tons	
4.	11 Tons	2×2 Tons	1×2 Tons	2×2 Tons	1×1 Tons

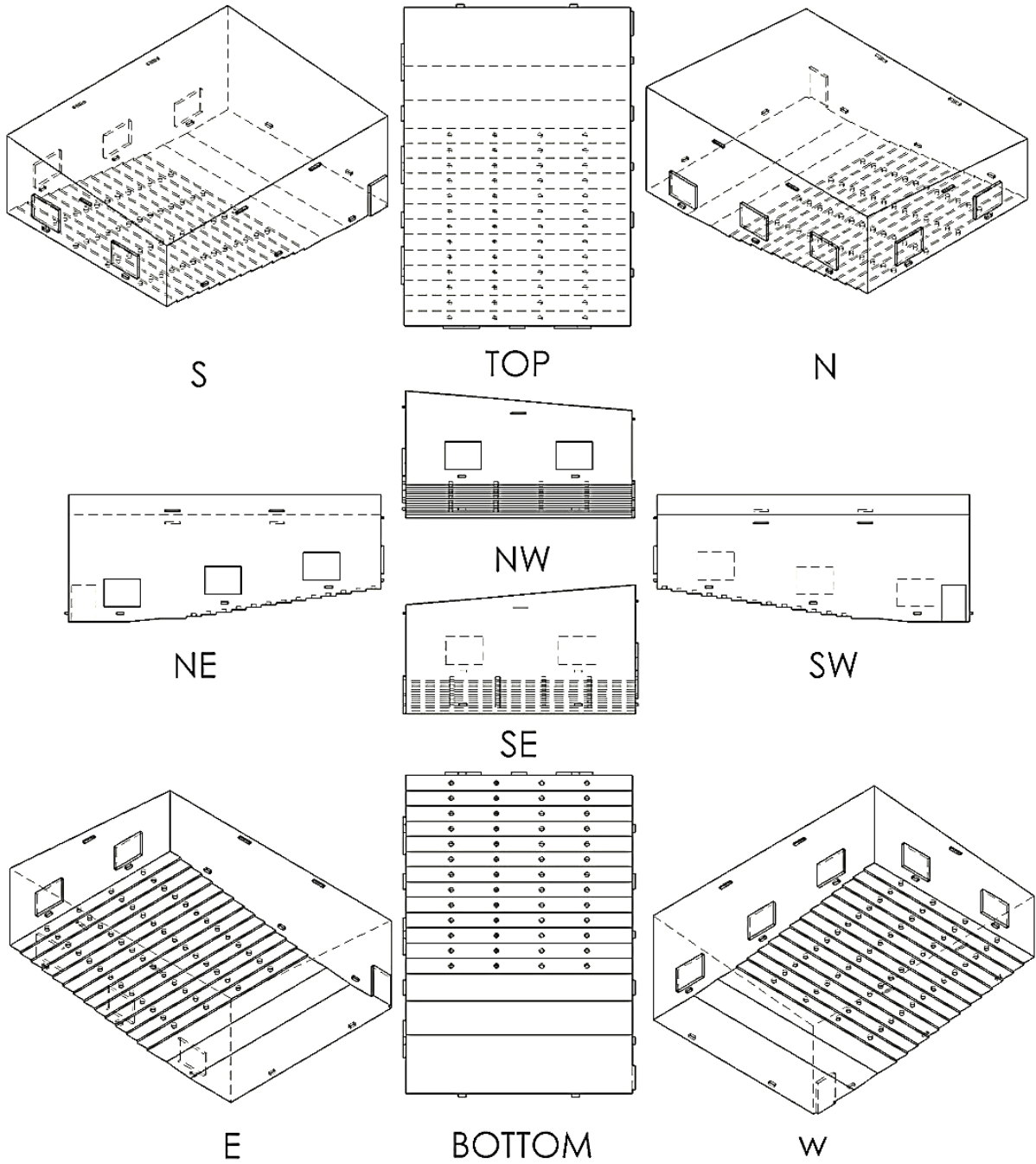


Figure 3.3: Geometric model produced in SolidWorks

3.4.2 Mesh Development and Mesh Independence

The mesh for the simulation was made using ANSYS Fluent meshing tool. Meshes ranging from cell no. 71,170 to 1,289,265 were used and while comparing the average volume temperature of the space after 40mins of run time for 10 ton A/C configuration following results were found shown in figure 3.4 below. Since the deviation of the result (i.e. 0.32) between the largest and smallest mesh used was very small, the mesh having 152,573 no. of cells was chosen for further processing.

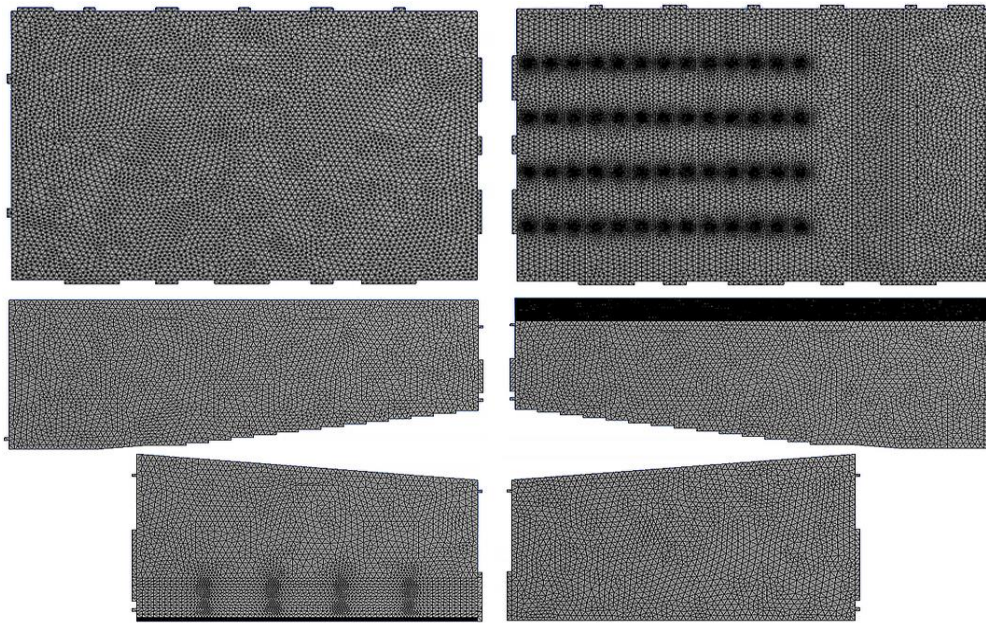


Figure 3.5: Mesh developed

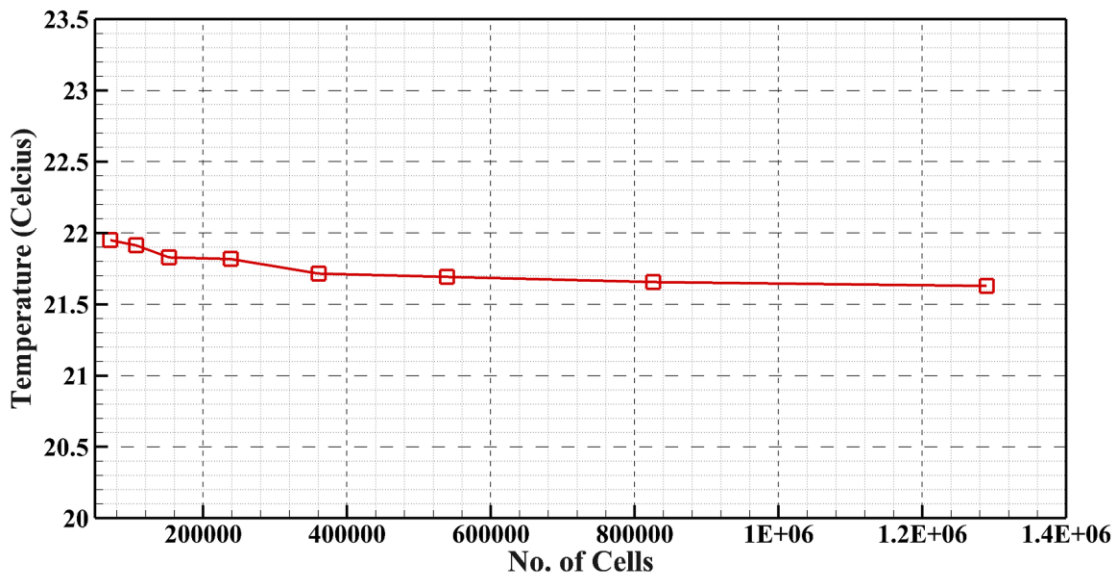


Figure 3.4: Mesh independence

CHAPTER FOUR : RESULTS AND DISCUSSION

The calculation of the load includes primarily two types of loads; internal and external loads (mentioned in table 2-2). As explained in section 3.3.3, the calculation of internal loads was calculated to be constant (except infiltration and floor load varies in CLTD and HAP but constant for Revit MEP). The external loads calculated through different methods are explained in section 4.1. The internal load elements and their calculated value are depicted in table 4-1.

Table 4-1: Maximum load through internal sources

S.N	Internal Element loads (Btu/hr)	
1.	Load through infiltration	1816.93
2.	Floor	15155.00
3.	Overhead lighting load	11037.35
4.	Internal appliance load	2402.34
5.	Partition load	1343.83
6.	Occupancy load	35000

4.1 Load calculated by CLTD Excel Solver

By using the CLTD method the maximum load for the July and August month was calculated to be 9.87 Tons at 5 pm. If we use the maximum and minimum temperature of each month from the weather data and use it into the Excel Solver, we can get the peak load condition for each month. The breakdown of individual external loads, as well as monthly load calculated, is shown in figures 4.1 and 4.2 below.

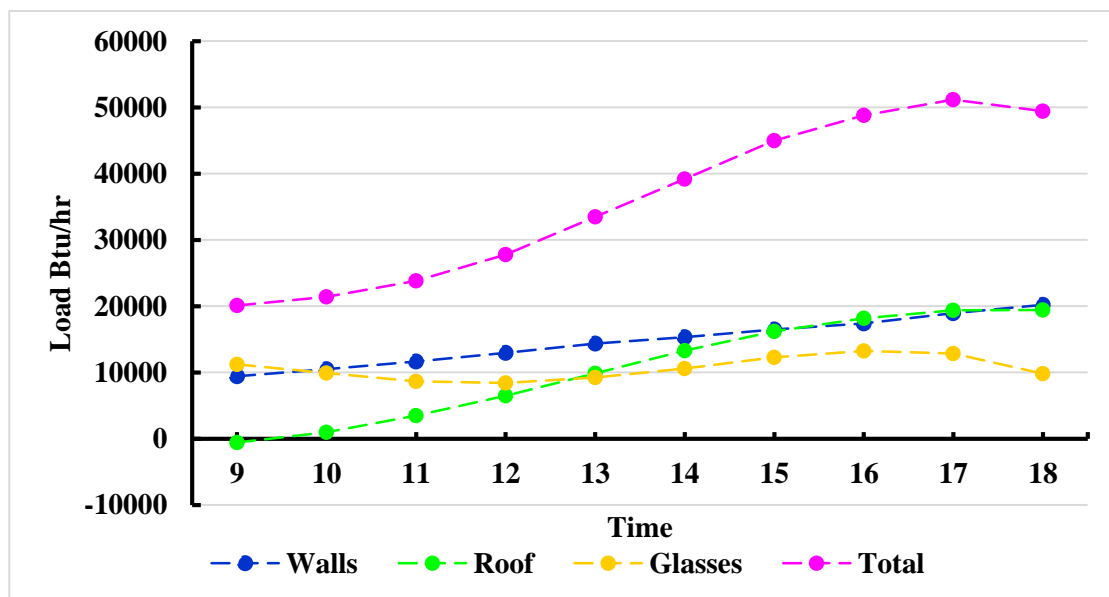


Figure 4.1: External load trends

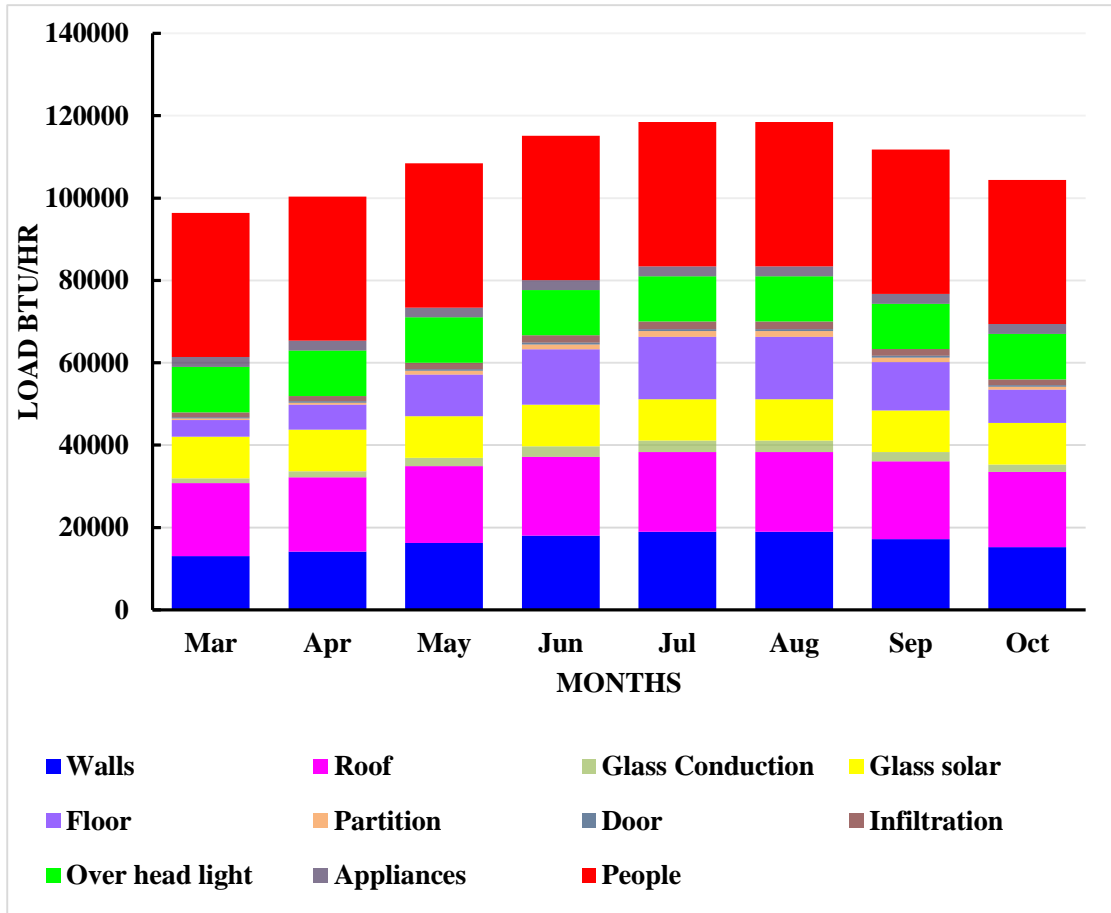


Figure 4.2: Monthly load pattern (CLTD Excel Solver)

4.2 Load calculated by HAP

Unlike the CLTD which calculates on the assumption that the temperature is uniform throughout the day. HAP takes into consideration of the hourly varying temperature data through the day for calculation. By using HAP it was calculated that the peak load of 8.52 Tons occurs in July at 5 pm. To produce peak data using HAP and compare it to CLTD, necessary assumptions are made in the hourly temperature data. The assumptions are enlisted below.

Assumption 1: The peak design temp is reached at the peak load time i.e. 5 pm of July,

Assumption 2: The peak design temp occurs throughout the day as in CLTD in July.

The maximum load calculated by HAP using Assump:1 and Assump:2 were 8.7 Tons and 9.1 Tons both at 5 pm of July respectively. The breakdown of individual external loads as well as the monthly load calculated is shown in figure 4.3 below. (Note that HAP doesn't provide the freedom of getting hourly load data as in the CLTD Excel Solver)

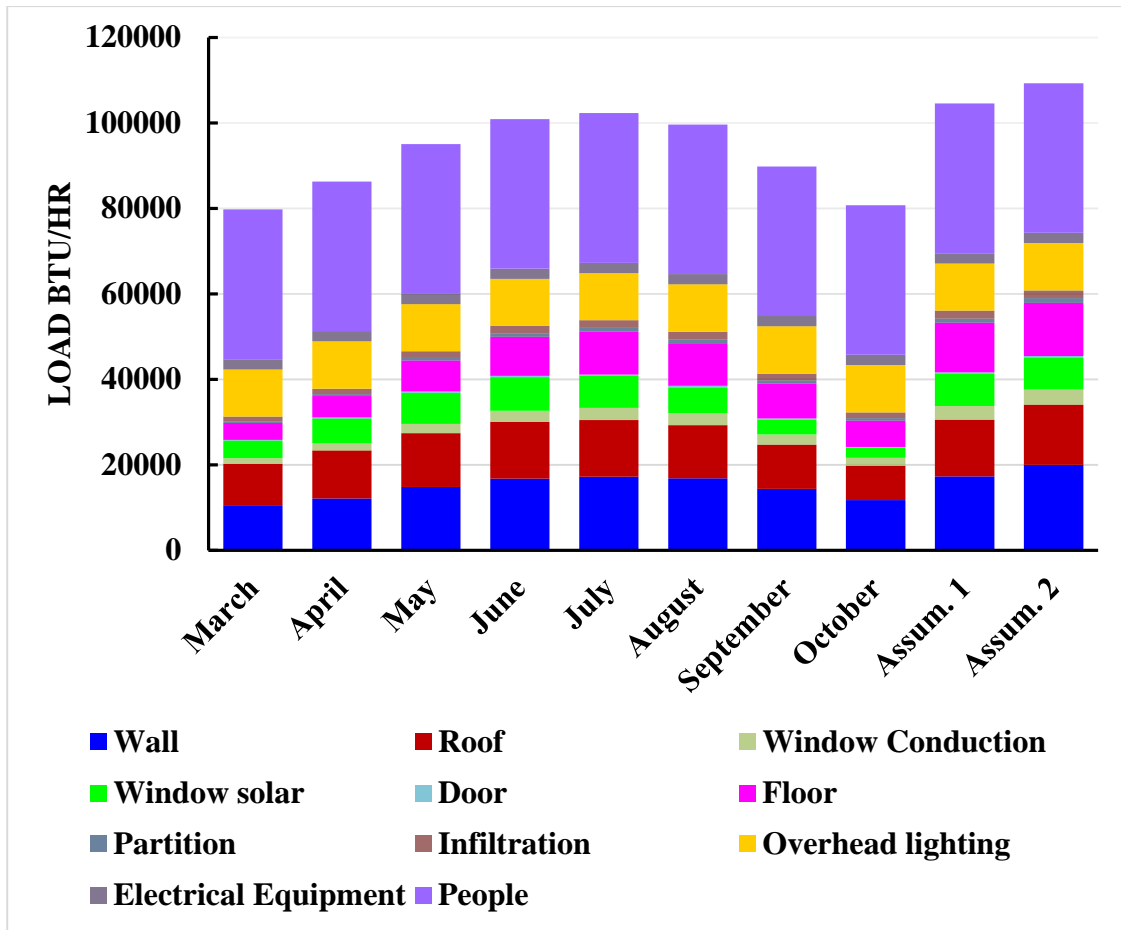


Figure 4.3: Monthly load pattern (HAP)

4.3 Load calculated by Revit MEP

Unlike the above two methods which have the freedom of providing monthly as well as hourly load data, Revit MEP is designed such that only the necessary design maximum load can be obtained. The external loads from walls (including partition), windows, door, and roof calculated using RevitMEP have been shown below. Together with the internal elements i.e. infiltration, floor, overhead lighting load, Internal appliance load, occupancy load from table 4-1, the total load adds up to 9.487 Tons which occurs at 5 pm of July.

Table 4-2: Load calculated by Revit MEP

S.N.	Elements	Loads (Btu/hr)
1.	Walls (including partition)	18,109.40
2.	Windows	13,382.10
3.	Door	41.5
4.	Roof	16,907.31
Total		48,440.31

4.4 CFD Results

The simulations were performed for various A/C Ton configurations for March to October. For assisting the simulation as well as the analysis, it was assumed that the human comfort conditions to begin below 23.5°C and final desired inner targeted temperature conditions to be multiple one; being 22.5°C, 22°C, and 21.5°C.

Considering the response time, in all cases of desired inner temperature, it was found that the performance ranged from the highest A/C configuration i.e. 11 Tons to cool the quickest while the 8 Tons to be the slowest, which was obvious. The 8 Ton A/C configuration was not able to cool down the temperature of the space to 21.5°C. The 8 Ton A/C configuration suffered significant performance loss in July and August being able to drop the temperature to the human comfort range only after the 30-40 minute mark, yet never able to attain the 21.5°C. However, in other months overall it can drop the temperature to the human comfort range within 15-25 minutes.

On the contrary, the 11 ton A/C configuration seemed to perform very well in July and August. It was able to drop the temperature to human comfort levels in 15-20 minutes.

The temperature distribution contours of the auditorium hall for different configurations of A/C after 30 mins of operation is shown in Appendix G. The figure 4.4 and 4.5 shows the temperature drop curve for 8, 9, 10 and 11 Tons A/C for various months.

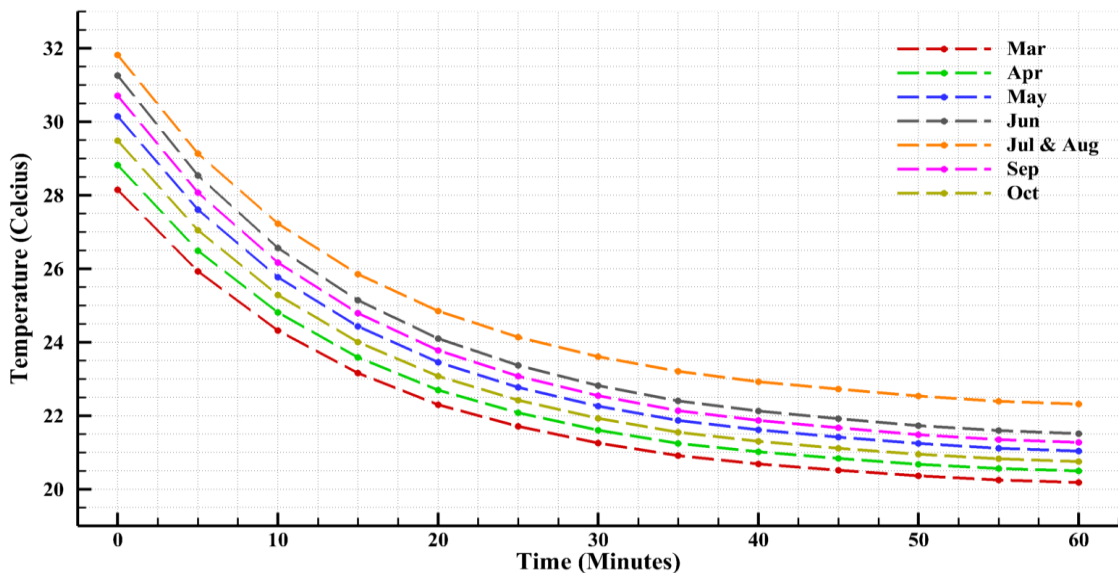


Figure 4.4: 8 Tons A/C performance

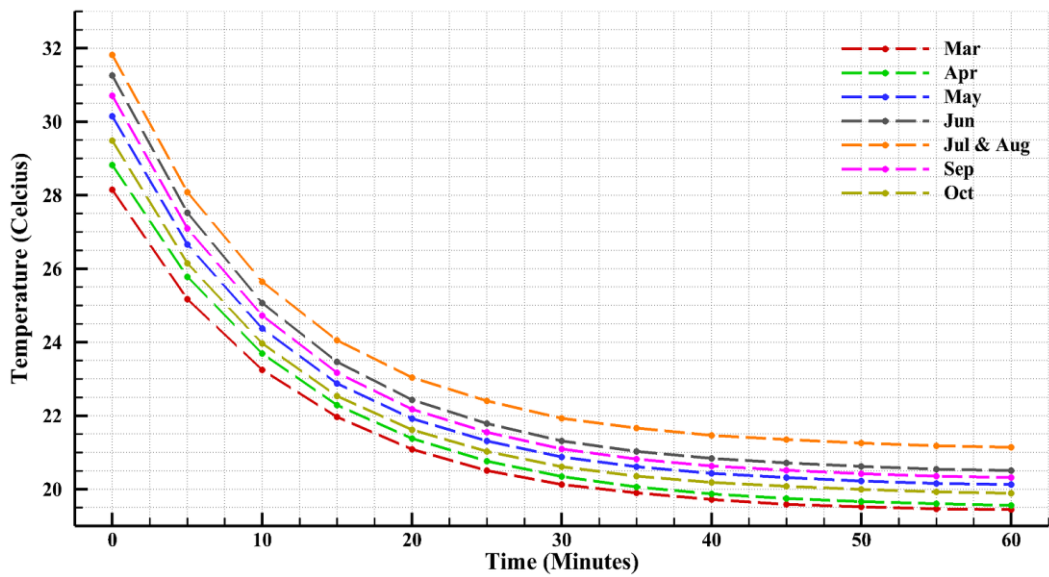
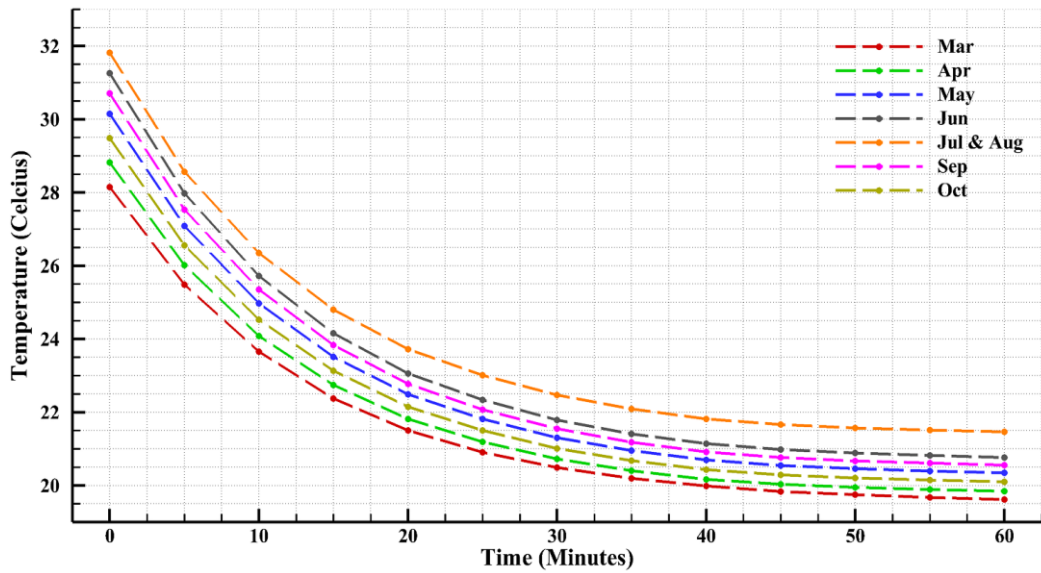
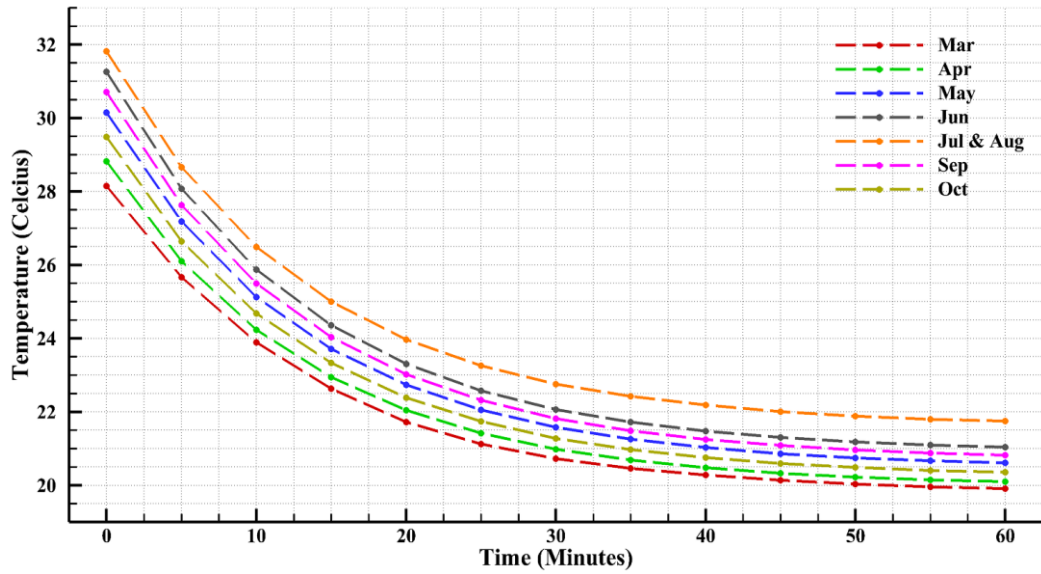


Figure 4.5: 9, 10, 11 Tons A/C performance

4.5 Energy Analysis

Simulations were also performed to evaluate how fast did the temperature increase from the desired temperature to the temperatures beyond human comfort conditions for different months which is shown in figure 4.6. For this, the same geometry, and boundary configurations were used but the boundary conditions of A/C inlet vents were turned off.

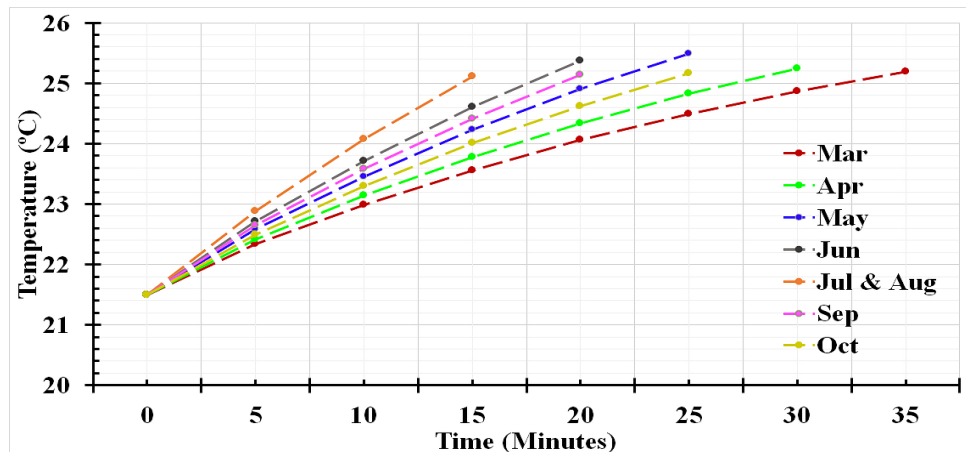


Figure 4.6: Temperature increase curves

Assuming that the A/C is to be turned on 8 hours a day from March to October and the A/C cut-off thermostat temperature (the temperature at which A/C turns back on once the temperature starts to increase again) to be 23.5°C, by using the temperature drop curves of each A/C configurations and the temperature increase curves of each month it was possible to calculate the total time the A/C would be turned on each day and month, consequently to calculate the total energy consumed for various cases of desired inner targeted temperature (22.5°C, 22°C, and 21.5°C).

If we consider average kWh used per hour of thermal comfort condition as well as the total energy consumed to be the performance criteria; it was found that in the case of 22.5°C (desired inside temperature), the performance was in the order of 8, 10, 11 and 9 Tons. In the case of 22°C (desired inside temperature), the performance was in the order of 8, 11, 10, and 9 Tons. While in the case of 21.°C (desired inside temperature), the performance was in the order of 10, 11, 9, and 8 Tons.

The monthly pattern of kWh used per hour of thermal comfort condition and total kWh consumed for various desired inside temp (22.5°C, 22°C, and 21.5°C) is shown in figure 4.7 and figure 4.8 below while figure 4.9 depicts the overall average of these data.

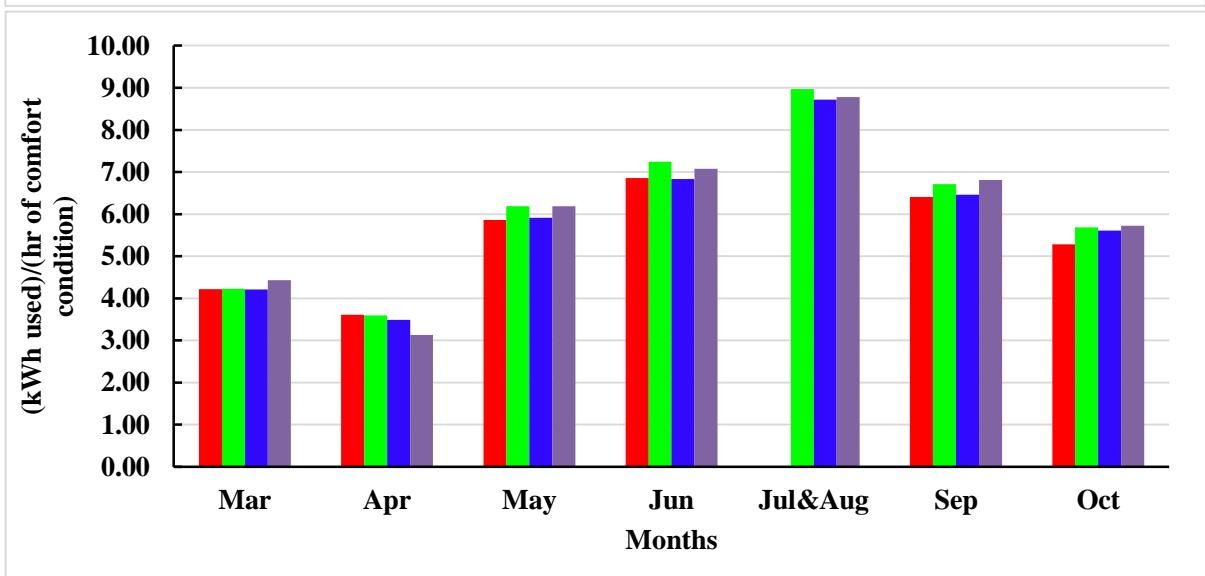
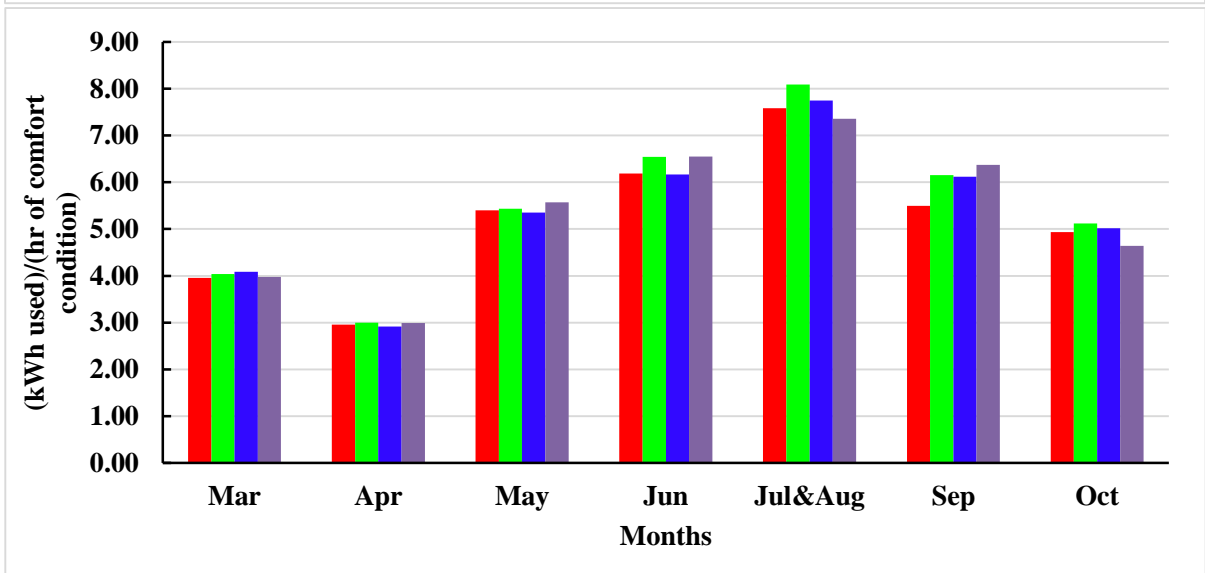
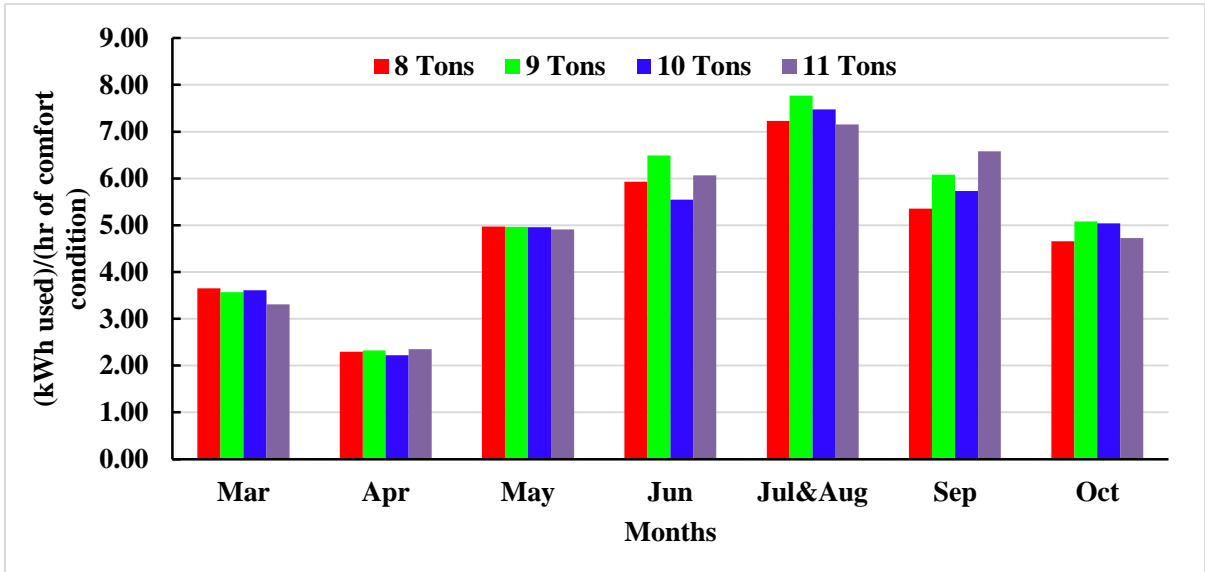


Figure 4.7: kWh used per hour of thermal comfort condition (Monthly Avg.) for various desired inside temp (22.5°C, 22°C and 21.5°C)

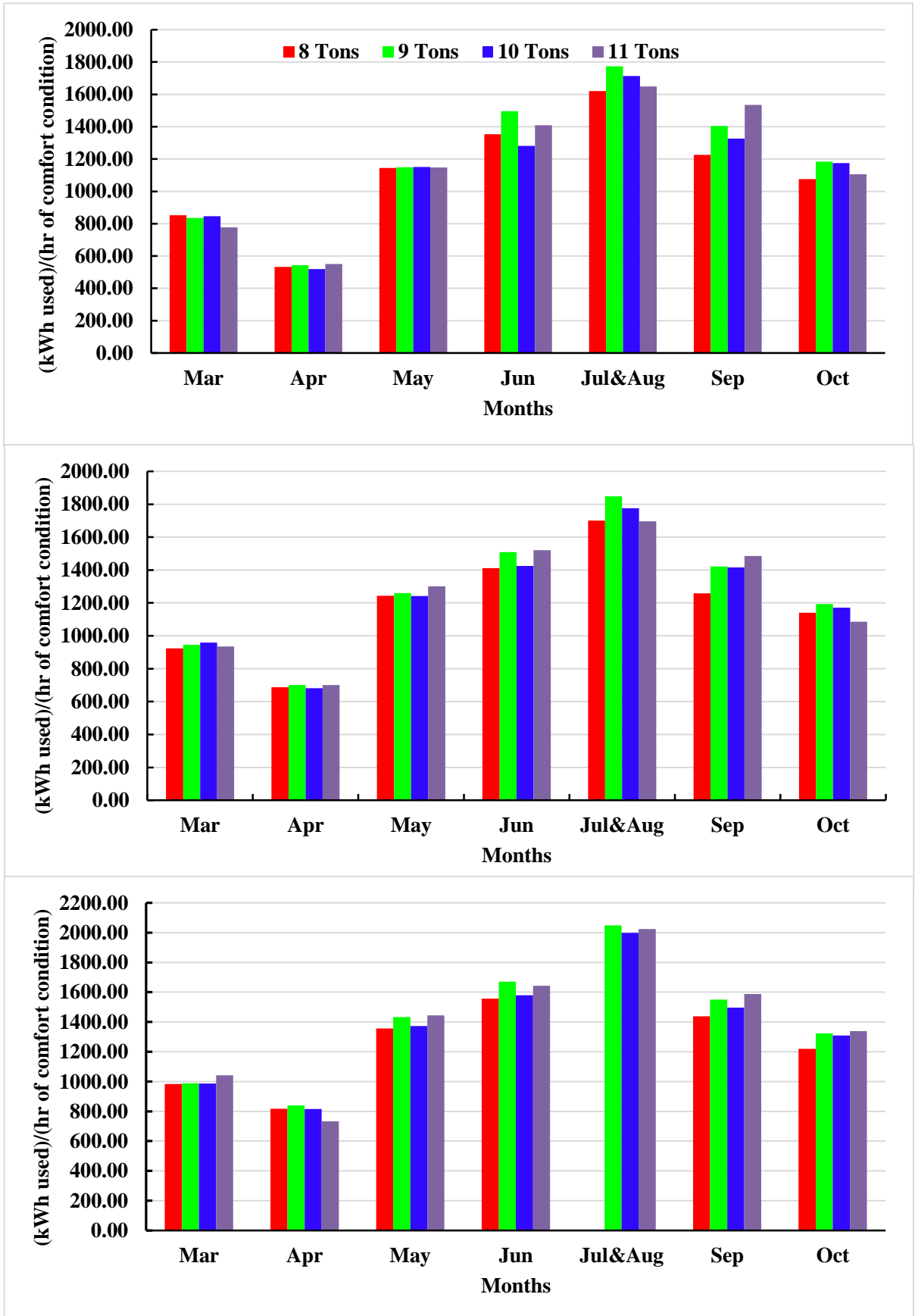


Figure 4.8: Total kWh consumed (Monthly Avg.) for various desired inside temp (22.5°C, 22°C and 21.5°C)

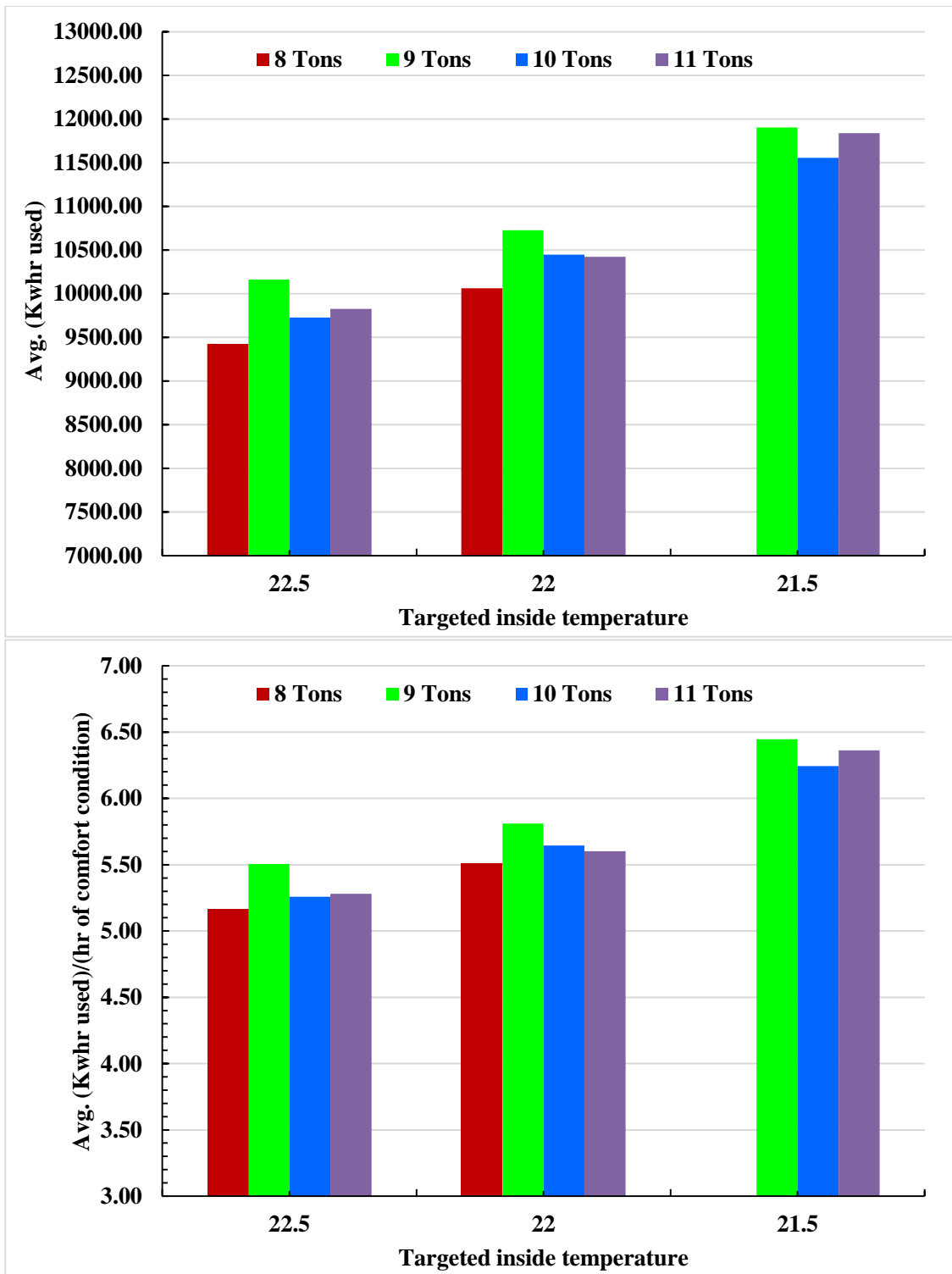


Figure 4.9: Energy consumed and average kWh used per hour for comfort condition

The detailed data of average kWh used per hour of thermal comfort condition as well as the total energy consumed for different desired final inside temperatures of the graphs above is shown in Appendix H.

CHAPTER FIVE : CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

The entire process of design, simulation, and analysis of an air-conditioning system was successfully carried out for the proposed aerospace building of the Pulchowk Engineering Campus in this research. With respect to the modern construction standards, weather data as well as proposed design plans, necessary considerations were made for the materials, occupancies, possible infiltration, etc. The total design maximum cooling was calculated to be about 9.87, 8.52 and 9.487 Tons using ASHRAE recognized CLTD, TFM(HAP), and RTSM(Revit MEP) methods. By analyzing the sources of cooling load, it was found that even though the area roof is about 75% of the area of the total wall surfaces the amount of heat transfer in both cases is almost similar. Thus, one of the minor conclusions obtained was that it is effective to insulate the roof than to insulate the walls. The simulations performed in ANSYS Fluent for 8, 9, 10, and 11 Tons revealed the primary conclusions of this research. Considering the time required to attain the desired design temperature to be the criteria that define the performance, in all cases the 11 Tons A/C configuration tends to be superior followed by 10, 9, and 8 Tons. Nevertheless, considering average kWh used per hour for comfortable conditions as well as the total energy consumed for cooling to be the criteria that define performance and choosing the desired design temperature to be 22.5°C the performance was in the order of 8, 10, 11 and 9 Tons. On the contrary, choosing the desired design temperature to be 22°C the performance was in the order of 8, 11, 10, and 9 Tons. However, if the desired design temperature was chosen to be 21.5°C, the performance was in the order of 10, 11, 9, and 8 Tons.

5.1 Recommendations

This research has its limitations which provide opportunities for future studies to refine and narrow the scope. The following are some areas that can be incorporated to widen the scope of this thesis work.

- i. Inclusion of and on the effect of humidity as well as the 2 phase nature of water vapor in the air onto the behavior of load and temperature pattern.
- ii. Study as well as simulate the winter load behaviors.
- iii. Effect of variable placement of inlet and outlet vents.
- iv. Heat storage behavior of the internal elements.

REFERENCES

- Ahmed, S. S., Majid, M. S., Novia, H. & Rahman, H. A., 2007. Fuzzy logic based energy saving technique for a central air conditioning system. *Energy*, p. 1222–1234.
- ASHRAE, 1980. *Cooling and Heating Load Calculation Manual*. Washington, D.C. : U.S. Department of Housing and Urban Development .
- ASHRAE, 1993. *ASHRAE Handbook: Fundamentals*. s.l.:ASHRAE, 1993.
- ASHRAE, 1997. *ASHRAE Handbook: Fundamentals*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- ASHRAE, 2005. *Handbook of Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- Bansal, P., 2015. High efficiency novel window air conditioner. *Applied Energy*, pp. 311-320.
- Baral, A., 2019. *Design and Analysis of Hybrid Solar Thermal and Variable Refrigerant Flow System for Space Conditioning: A Case Study of Hall in Dhunche*. s.l.:Proceedings of IOE Graduate Conference.
- Carrier Corporation, 2016. *Hourly Analysis Program Quick Reference Guide*. s.l.:s.n.
- Chow, T. & Lin, Z., 1999. Prediction of on-coil temperature of condensers installed at tall building re-entrant. *Applied Thermal Engineering*, pp. 117-132.
- Chow, T., Lin, Z. & Wang, Q., 2000. Effect of building re-entrant shape on performance of air-cooled. *Energy and Buildings*, p. 143–152.
- Deng, J., Wang, R. & Han, G., 2011. A review of thermally activated cooling technologies for combined cooling, heating and power systems.. *Progress in Energy and Combustion Science* 37, pp. 172-203.
- Department of Hydrology and Meteorology, 2012. *Normals From 1981-2010*, s.l.: Department of Hydrology and Meteorology, Ministry of Environment, Science and Technology, Government of Nepal.
- Elnaggar, M. & Alnahhal, M., 2019. *Central Air Conditioning: Systems*. s.l.:IntechOpen. Engineering ToolBox, 2010. [Online] Available at: https://www.engineeringtoolbox.com/air-return-intakes-sizes-capacities-d_1592.html [Accessed 05 Jan 2020].
- Grondzik, W. T., 2007. *Air-Conditioning System Design Manual*. Atlanta: ASHRAE.

- Gut, P., Ackerknecht, D. & ILE, S. K. f. A. T. a. I., 1993. *Climate responsive building*. St. Gallen, Switzerland: SKAT.
- Hai, X., Jun, S., Hang, Z. & Bin, T., 2006. Design and Research of the Digital VRV MultiConnected Units With Three Pipes Type Heat. *International Refrigeration and Air Conditioning Conference*.
- Harris, S. & McQuiston, F., 1988. *A Study to Categorize Walls and Roofs on the Basis Of thermal Response*. Ottawa, s.n.
- H, F. J. & Milovan, P., 2002. *Computational Methods for Fluid Dynamics*. s.l.:Springer-Verlag.
- Hundy, G. F., Trott, A. R. & Welch, T. C., 2008. *Refrigeration and Air-Conditioning*. s.l.:Butterworth-Heinemann.
- ISHRAE, 2019. *Nepal Weather Data 2019*. s.l.:Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE).
- Jin-Long & LinT.-J.Yeh, 2007. Identification and control of multi-evaporator air-conditioning systems. *International Journal of Refrigeration*, pp. 1374-1385.
- Joudi, K.A. & Al-Badree, A., 2005. Comparison of cooling load calculation methods by TFM, CLTD and TETD with experimental measurements. *Al-fateh Journal* .
- Khurmi, R. & Gupta, J., 1987. *A Textbook of Refrigeration and Air Conditioning*. s.l.:S. CHAND.
- Kumar, A. & Bartaria, V. N., 2018. CFD Analysis of Room with Air Conditioner By Using Ansys Workbench. *Journal of Emerging Technologies and Innovative Research (JETIR)*, Volume 5(Issue 7), pp. 99-104.
- Lin, B. et al., 2016. Investigation of winter indoor thermal environment and heating demand of urban residential buildings in China's hot summer – Cold winter climate region. *Building and Environment*, pp. 9-18.
- Lomax, H., Pulliam, T. H. & Zingg, D. W., 1999. *Fundamentals of Computational Fluid Dynamics*. s.l.:University of Toronto Institute for Aerospace Studies.
- Mao, C., Baltazar, J.-C. & Haberl, J. S., 2018. Comparison of ASHRAE Peak Cooling Load Calculation Methods. *Science and Technology for the Built Environment*.
- McQuiston, F. C., Parker, J. D. & Spitler, J. D., 2005. *Heating, Ventilating, and Air Conditioning Analysis and Design*. s.l.:John Wiley & Sons, Inc..
- Mitsubishi Electric US. Inc, 2013. *M-Series Contractor Guide*. [Online] Available at: <http://mitsubishipro.com>

- Musa, M. F. B., 2010. *Building Energy Analysis Using Cooling Load Factor/Cooling Load Temperature Difference (CLF/CLTD) Method*, s.l.: University Malaysia Pahang. NPTEL, 2020. [Online] Available at: <https://nptel.ac.in/content/storage2/courses/112105129/R&AC%20Web%20files/R&AC%20Lecture%202/Hyperlinks/Hermetic%20compressors.htm>
- Rajbhandari, U. S. & Nakarmi, A. M., 2014. Energy Consumption and Scenario Analysis of Residential Sector Using Optimization Model – A Case of Kathmandu Valley. *Proceedings of IOE Graduate Conference*, pp. 476-483.
- Reddy, T. A., Kreider, J. F., Curtiss, P. S. & Rabl, A., 2017. *Heating and Cooling of Building*. s.l.: Taylor & Francis Group, LLC.
- Rees, S. J., Spitler, J. D., Davies, M. G. & Haves, P., 2000a. Qualitative Comparison of North American and U.K. Cooling Load Calculation Methods. *HVAC&R RESEARCH*, pp. 75-98.
- Rees, S. J., Spitler, J. D. & Haves, P., 1998. Quantitative comparison of North American and U.K. cooling load calculation procedures-results. *ASHRAE Transactions*, pp. 47-61.
- Rudoy, W. & Duran, F., 1975. Development of an improved cooling load calculation method. *ASHRAE Transactions* , pp. 19-69.
- Sharma, P. M. K., 2017. Simulation of Thermal Environment of a Conditioned Space at Different Air Supply Conditions by CFD Analysis. *ANUSANDHAN- AISECT University Journal*, pp. 51-55.
- Sivaraman, D. I., 2019. *HVAC Principles and Systems*. s.l.: Dr Ilango Sivaraman, 2019.
- Spitler, J. D., Fisher, D. E. & Pedersen, C. O., 1997. The Radiant Time Series Cooling Load Calculation Procedure. *ASHRAE Transactions*, p. 503–515.
- Spitler, J. & F.C. McQuiston, 1993. The CLTD/SCL/CLF Cooling Load Calculation Method. *ASHRAE Transactions*, pp. 183-192.
- Spitler, J. & F.C. McQuiston, 1993. THE CLTD/SCL/CLF COOLING LOAD CALCULATION METHOD. *ASHRAE Transactions*, pp. 183-192.
- Tomoyuki Nanami, K., 2013. United States, Patent No. US 8,369,995 B2.
- Versteeg, H. K. & Malalasekera, W., 1995. *An introduction to Computational Fluid Dynamics: The Finite Volume Method*. Essex CM20 2JE, England: Longman Scientific & Technical.
- Versteeg, H. K. & Malalasekera, W., 2007. *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*. s.l.: Pearson Education Limited.

- weatheronline ltd., 2019. *weatheronline.co.uk*. [Online]
Available at: weatheronline.co.uk
- World Metrological Organization, 2013. *World Weather Information Service-Kathmandu*, s.l.: s.n.
- X.R, D., Y.Y, G. & Y.Y, C., 2017. Design and Simulation of an Air Conditioning Project in a Hospital Based on Computational Fluid Dynamics. *Archives of Civil Engineering* , pp. 23-38.
- Yanga, L., Yana, H. & Lam, J. C., 2014. Thermal comfort and building energy consumption implications – A review. *Applied Energy*, pp. 164-173.
- Zhang, Z., Zhang, Y. & A. K., 2019 . Thermal comfort of people in a super high-rise building with central air-conditioning system in the hot-humid area of China. *Energy & Buildings*.
- Zhou, C.-Y.et al., 2017. Study on the relationship between thermal comfort and air conditioning energy consumption in different cities.. *Journal of Computers*, pp. 135-145.

PUBLICATIONS

Bhaju Shrestha, S., Bahadur Dura, H., & Bhattarai, N. (2020). Design, Simulation and Analysis of an Air-Conditioning System: A Case Study of the Proposed Aerospace Building of Pulchowk Engineering Campus in the Context of Nepal. *IOE Graduate Conference, 2020-Summer*, 8.

APPENDIX A : CLASSIFICATION OF DIFFERENT SURFACES

Table A-1: Material assumptions and classification for wall

Wall and partition material assumptions			
Materials	Thickness	R-value (hrft²F/Btu)	Remarks
E0 Inside surface resistance	0	0.685	(ASHRAE, 1997)
B5 R-3 board insulation	1	3.33	(ASHRAE, 1997)
E2 Slag & Stone	0.5 in	0.05	(ASHRAE, 1997)
C4 4-in common brick	4 in	0.79365	(ASHRAE, 1997)
A2 4-in face brick	4 in	0.43290	(ASHRAE, 1997)
A0 Outside surface resistance	0	0.33	(ASHRAE, 1997)
Total		5.621	
Wall classification			
Criteria	Assumption	Remark	
Mass location	Mass outside the insulation	Insulation is located at the inside most part	
Primary material	C4 4-in common brick	From the table above	
Secondary material	A2 4-in face brick	From the table above	
Wall type	12	(ASHRAE, 1997)	

Table A-2: Material assumption and selection of the type of roof

Roof material assumption			
Materials	Thickness	R-value (hrft²F/Btu)	Remarks
Inside surface	0	0.685	(ASHRAE, 1997)
Acoustic Tiles	0.5 in	1.79	(ASHRAE, 1997)
Air space	0	0.91	(ASHRAE, 1997)
R-10 batt insulation	3.5	10.0	(ASHRAE, 1997)
4-in HW concrete block	4 in	0.70922	(ASHRAE, 1997)
Slag & Stone	0.5 in	0.05	(ASHRAE, 1997)
Outside surface	0	0.333	(ASHRAE, 1997)
Total		14.48	
Roof classification			
Criteria	Assumption	Remark	
Mass location	Mass outside the insulation	Insulation is located at the inner most part	
Suspended ceiling	Present	Assumed present for lightening structures and acoustic purposes	
Primary material	C12, HW Concrete 4in		
Roof type	4	(ASHRAE, 1997)	

Table A-3: Material assumptions for floor

Floor material assumption			
Materials	Thickness	R-value (hrft²F/Btu)	Remarks
Inside surface (above floor)	0	0.685	(ASHRAE, 1997)
4 –in HW concrete block	4 in	0.709	(ASHRAE, 1997)
Slag and stone	0.5 in	0.05	(ASHRAE, 1997)
Inside surface (floor below)	0	0.685	(ASHRAE, 1997)
Total		2.129	

Table A-4: Window material, type of glass assumption and zone classification

Window material assumption				
Materials	Thickness	K-value (hrftF/Btu)	R-value (hrft²F/Btu)	Remarks
Inside surface	0		0.685	(ASHRAE, 1997)
Glass (3mm glass)	0.00984 ft	2.1249	0.02091	(ASHRAE, 1997)
Outside surface	0		0.333	(ASHRAE, 1997)
Total			1.03891	
Window glass property assumption				
Particular	Value	Remarks		
Type of glazing		Glazing assumed to be double-pane clear		
Shading coefficient	0.6	Average of 0.62 (venetian) and 0.58 (light blinds)		
Zone type to use with SCL for glass				
Criteria	Assumption	Remark		
Location	Middle floor of a multi-storey building	Known from the design plan		
No of walls having a window	2	NE and NW side		
Floor-type	Concrete	-		
Floor covering	Carpet	-		
Partition type	Concrete block	-		
Inside shade available	Full coverage	Curtains or Venetian providing full coverage		
Zone type	C	(ASHRAE, 1997)		

Table A-5: Material assumptions for windows and door

Door material assumption				
Material	Thickness	K-value (hrftF/Btu)	R-value (hrft²F/Btu)	Remark
Inside surface	0		0.685	(ASHRAE, 1997)
Door (5cm thick)	0.0164 ft	24.02194	0.39406	(ASHRAE, 1997)
Outside surface	0		0.333	(ASHRAE, 1997)
Total			1.41206	

APPENDIX B : CALCULATION OF INFILTRATION

Table B-1: Assumptions to calculate the infiltration (ASHRAE, 2005)

Data for effective leakage area		Best estimate	Value	Leakage area (ft ²)
Window casement not weather stripped		0.023 (in ² /ft ²)	5 windows of size 6×8ft i.e. 240ft ²	5.52
Double door not weather stripped		0.16 (in ² /ft ²)	1 door of size 5×8ft i.e. 40ft ²	6.4
Masonry wall window frame no caulking		0.093 (in ² /ft ²)	5 windows of size 6×8ft i.e. 240ft ²	22.32
Masonry wall window frame no caulking		0.072 (in ² /ft ²)	1 door of size 5×8ft i.e. 40ft ²	2.88
Air conditioner		3.7 (in ² /unit)	5 units on average	18.5
Ductwork (return vent) Unsealed and without a vapour barrier		3.7 (in ² /unit)	10 units	37
Total ELA				92.62 ft ²
Average wind speed		5.6kmph	From table 3.1 (weatheronline ltd., 2019)	
Stack coefficient		0.000435 (L/s) ² /cm ⁴ .k	For 3 stories building with light local shielding; few obstructions such as few trees or small buildings (Reddy, et al., 2017)	
Wind coefficient		0.000382 (L/s) ² /(m/s) ² .cm ⁴		
Infiltration using the formula $\dot{V} = A_{leak} \sqrt{a_s(t_o - t_r) + a_w v^2}$		91.9301 CFM		

APPENDIX C : INTERNAL LOAD CALCULATION

Table C-1: Assumptions to calculate internal loads

Occupancy load		
Number of occupancies	100	
Latent heat	120 Btu/hr/person	(ASHRAE, 1997)
Sensible heat	130 Btu/hr/person	(ASHRAE, 1997)
Total	35000 Btu/hr	
Overhead lightening load		
Fixture type	Recessed, unvented	(ASHRAE, 1997)
Wattage	0.9 W/ft ²	(ASHRAE, 1997)
Ballast factor	1	(ASHRAE, 1997)
Total roof area available	3596.4 ft ²	
Total	11037.35 Btu/hr	
Electrical appliance load	It is assumed that 20% of the total wattage of the electrical appliances is wasted as heat energy. Assuming that the current supply is 16A and 220V the total heat generated 704 watts i.e. 2400.64 Btu/hr	(ASHRAE, 1997)
Total internal load	48437.99 Btu/hr	

APPENDIX D : RETURN VENT SIZING

Table D-1: Sizing of return vents (Engineering ToolBox, 2010)

Flow rate (CFM)	C.S recommended return vent size (in ²)	Flow rate (CFM)	C.S recommended return vent size (in ²)	Flow rate (CFM)	C.S recommended return vent size (in ²)
100	40	220	84	485	180
120	48	260	96	490	192
125	50	260	96	660	240
145	56	300	120	665	240
155	60	305	112	795	288
155	60	320	120	830	300
180	70	325	120	1015	360
190	72	390	144	1160	420
215	80	400	150	1355	480

Table D-2: Calculations for the return vent

S.N.	Cooling load (Tons)	A/C arrangement number		Flow rate CFM	Interpolated value of return vent size (in ²)
		1 Ton	2 ton		
1.	8		4	2966.4	1053.74
3.	9	1	4	3407.8	1209.57
5.	10		5	3708	1315.55
7.	11	1	5	4149.4	1471.38

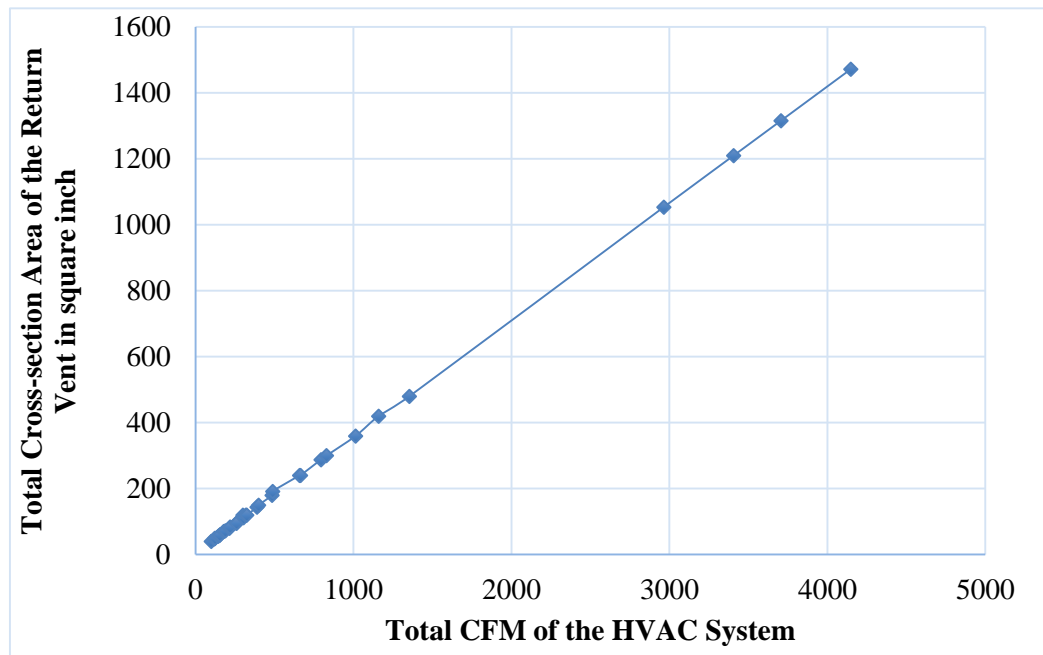


Figure D.1: Relationship between the CFM and the return vent sizing

APPENDIX E : INLET VENT CALCULATION

Table E-1: Inlet air velocity calculation

S.N.	Capacity	Area(mm)	Flow rate		Velocity (m ² /s)
			CFM	m ³ /s	
1.	1.083 Tons	900*100	441.4	0.208317604	2.31464005
3.	2.041 Tons	1000*100	741.6	0.349996229	3.49996229

Table E-2: Calculations for the temperature of inlet vent air

Capacity	Tons	1.083	2.041
Volume Flow rate	CFM	441.4	741.6
	m³/s	0.208	0.35
Mass flow rate (kg/s)		0.255	0.429
Temp. of air entering (°C)		31.67	31.67
Temp. of air exiting (°C)		16.83	15.03

APPENDIX F : CALCULATED LOAD DATA

The load calculated using CLTD Excel Solver is shown in table F-1 and table F-2.

Table F-1: Load through external sources

CLTD/SCL/CLF method								
External Element loads (Btu/hr)								
Load on the walls					Load on roof	Solar load on the glass		Conduction load glass
Facing	NE	SE	SW	NW	Horizontal	NE	NW	NE&NW
Area	1775 ft ²	1292 ft ²	740 ft ²	1197 ft ²	3596.4 ft ²	144 ft ²	96 ft ²	240 ft ²
9:00	3552.52	2241.06	1283.58	2342.47	-558.83	9439.20	1670.4	120.60
10:00	4420.92	2643.30	1250.67	2182.75	993.48	7430.4	1886.4	603.02
11:00	5131.42	3160.46	1250.67	2129.51	3477.18	5313.60	2016	1326.63
12:00	5762.98	3735.10	1250.67	2182.75	6457.62	4471.2	2116.8	1809.05
13:00	6394.54	4252.26	1382.32	2342.47	9872.71	4233.6	2462.4	2532.66
14:00	6710.32	4539.58	1513.97	2555.42	13287.80	3996	3830.4	2773.87
15:00	7026.10	4826.89	1810.18	2821.61	16206.15	3672	5601.6	3015.08
16:00	7026.10	5056.75	2106.39	3194.27	18193.11	3261.6	6955.2	3015.08
17:00	7341.88	5229.14	2534.25	3833.13	19372.87	2764.8	7329.6	2773.87
18:00	7341.88	5229.14	2962.11	4684.93	19434.97	2008.8	5256	2532.66

Table F-2: Monthly load calculated using CLTD Excel Solver (Btu/hr)

Element	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Walls	13062.86	14131.14	16267.70	18048.17	18938.40	18938.40	17157.93	15199.42
Roof	17733.63	18031.67	18627.76	19124.50	19372.87	19372.87	18876.13	18329.72
Glass Conduction	1181.91	1471.36	2050.25	2532.66	2773.87	2773.87	2291.46	1760.80
Glass solar	10094.40	10094.40	10094.40	10094.40	10094.40	10094.40	10094.40	10094.40
Floor	4041.33	6062.00	10103.33	13471.11	15155.00	15155.00	11787.22	8082.67
Partition	358.36	537.53	895.89	1194.52	1343.84	1343.84	1045.21	716.71
Door	322.93	356.93	424.91	481.57	509.89	509.89	453.24	390.92
Infiltration	1150.73	1271.86	1514.11	1716.00	1816.94	1816.94	1615.06	1392.99
Overhead light	11037.35	11037.35	11037.35	11037.35	11037.35	11037.35	11037.35	11037.35
Appliances	2400.64	2400.64	2400.64	2400.64	2400.64	2400.64	2400.64	2400.64
People	35000.00	35000.00	35000.00	35000.00	35000.00	35000.00	35000.00	35000.00
Total	96384.14	100394.88	108416.36	115100.92	118443.20	118443.20	111758.64	104405.62

The load calculated using HAP is shown in table F-3 and table F-4.

Table F-3: Load comparison of hourly temp. data, Assum.1 and Assum.2 (Btu/hr)

Element	Hourly temp. data		Assum.1		Assum.2	
NE Wall	6514		6531		7495	
SE Wall	4680		4692		5394	
NW Wall	3704		3716		4366	
SW Wall	2379		2386		2788	
Total	17277		17325		20043	
Roof	13226		13228		14081	
Window	Solar	Transfer	Solar	Transfer	Solar	Transfer
NE window	3332	1716	3332	1954	3332	2086
NW window	4102	1144	4102	1303	4102	1390
Total	7434	2860	7434	3257	7434	3476
Sub-Total	10294		10691		10910	
Door	350		399		426	
Floor	10004		11580		12450	
Partition	887		1027		1104	
Infiltration	1816.93		1816.93		1816.93	
Overhead lighting	11037.35		11037.35		11037.35	
Electrical Equipment	2400.64		2400.64		2400.64	
People	35000		35000		35000	
Total	102292.92		104504.92		109268.92	

Table F-4: Monthly load calculated using HAP (Btu/hr)

Element	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Assum.1	Assum.2
Wall	10556	12146	14868	16760	17277	16866	14397	11804	17325	20043
Roof	9665	11254	12565	13255	13226	12427	10334	7971	13228	14081
Window Conduction	1335	1612	2166	2628	2860	2860	2397	1889	3257	3476
Window solar	4127	5882	7297	7897	7434	5967	3452	2321	7434	7434
Door	163	197	265	322	350	350	294	231	399	426
Floor	3952	5052	7253	9087	10004	10004	8170	6153	11580	12450
Partition	350	448	643	806	887	887	724	546	1027	1104
Infiltration	1150.72	1271.85	1514.11	1715.99	1816.93	1816.93	1615.05	1392.98	1816.93	1816.93
Overhead lighting	11037.35	11037.35	11037.35	11037.35	11037.35	11037.35	11037.35	11037.35	11037.35	11037.35
Electrical Equipment	2400.64	2400.64	2400.64	2400.64	2400.64	2400.64	2400.64	2400.64	2400.64	2400.64
People	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000
Total	79736.72	86300.84	95009.10	100908.98	102292.92	99615.92	89821.04	80745.97	104504.92	109268.92

APPENDIX G : TEMPERATURE DISTRIBUTION CONTOURS

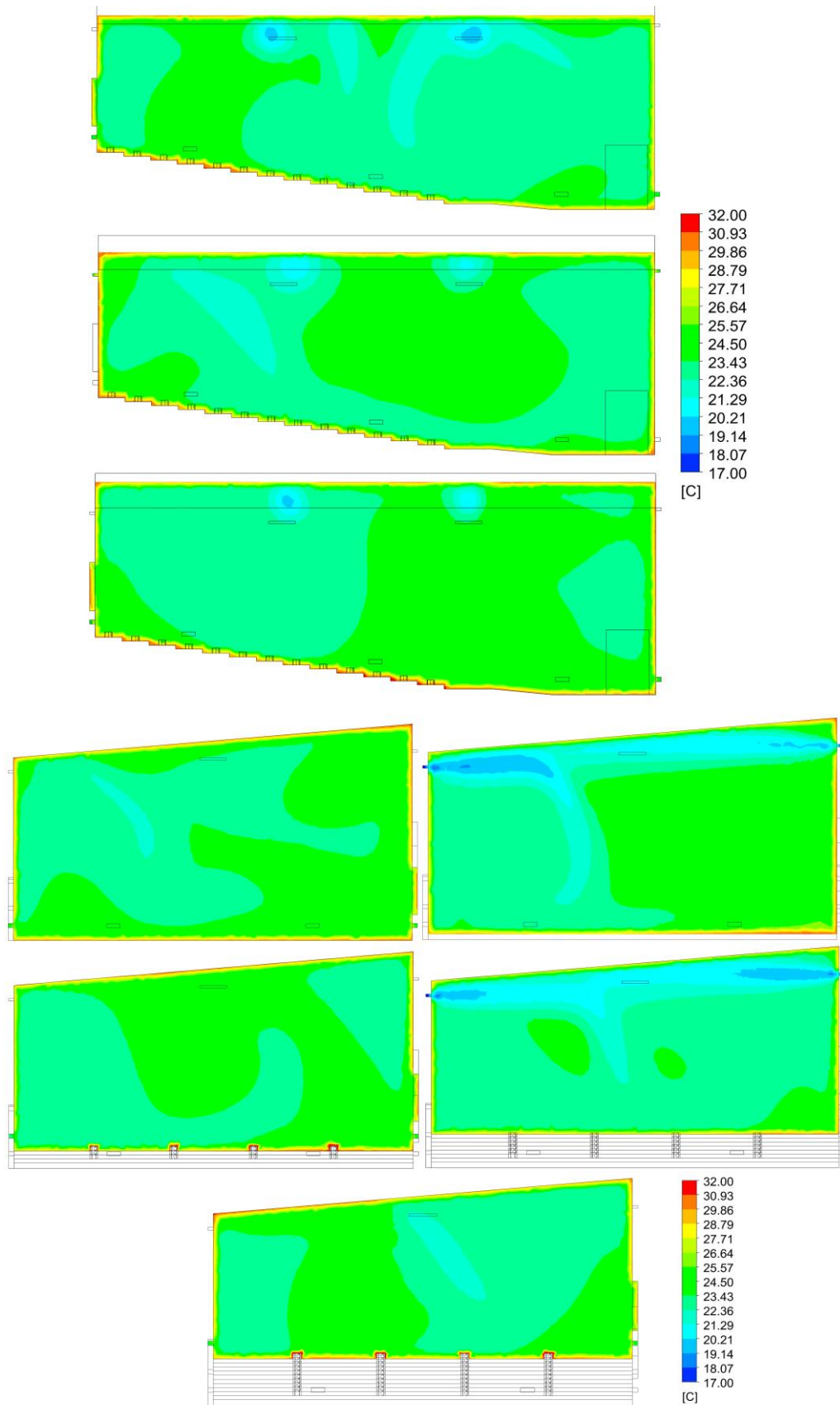


Figure G.1: Temperature distribution of 8 Ton A/C after 30 mins (lengthwise top, breadthwise bottom)

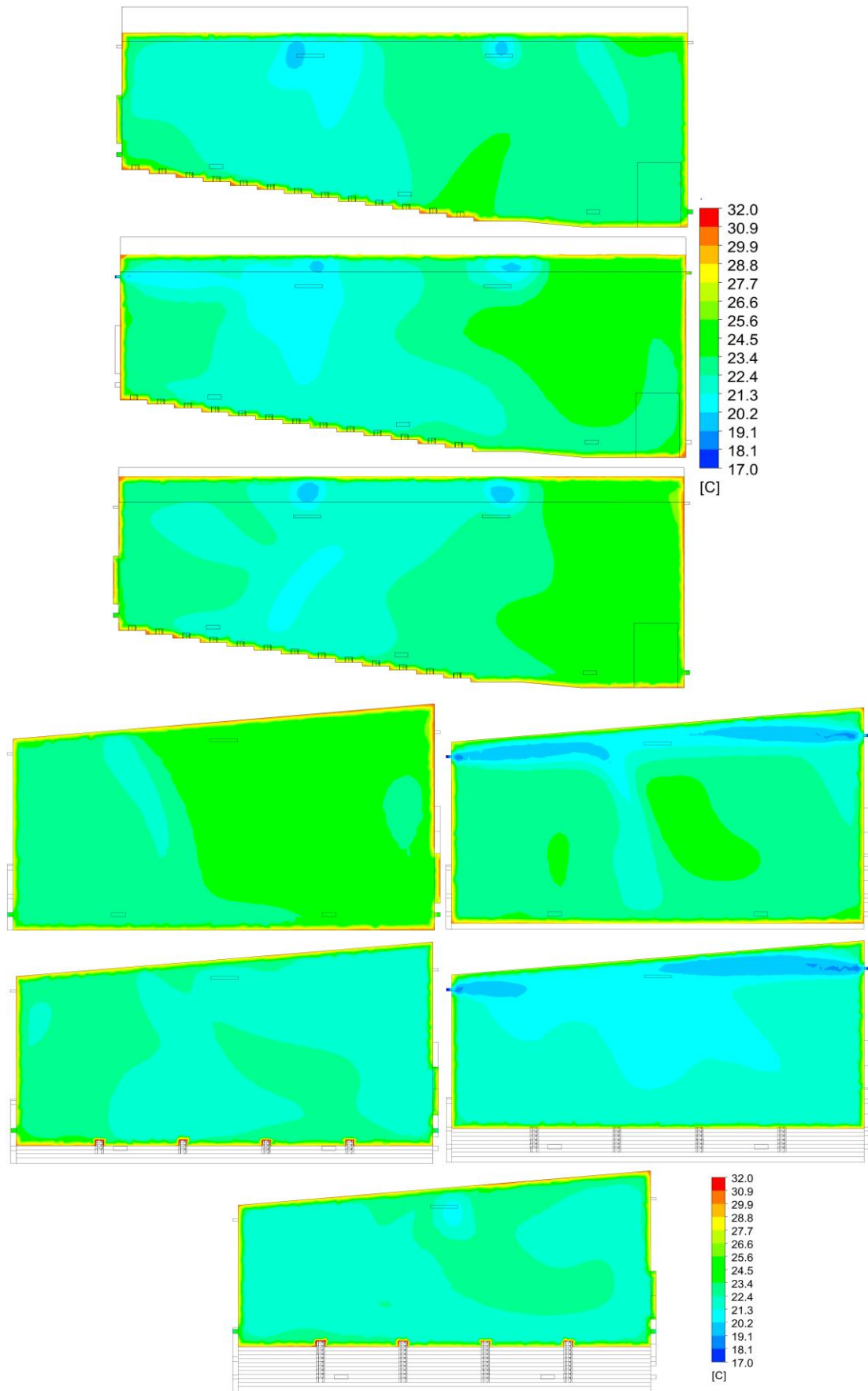


Figure G.2: Temperature distribution of 9 Ton A/C after 30 mins (lengthwise top, breadthwise bottom)

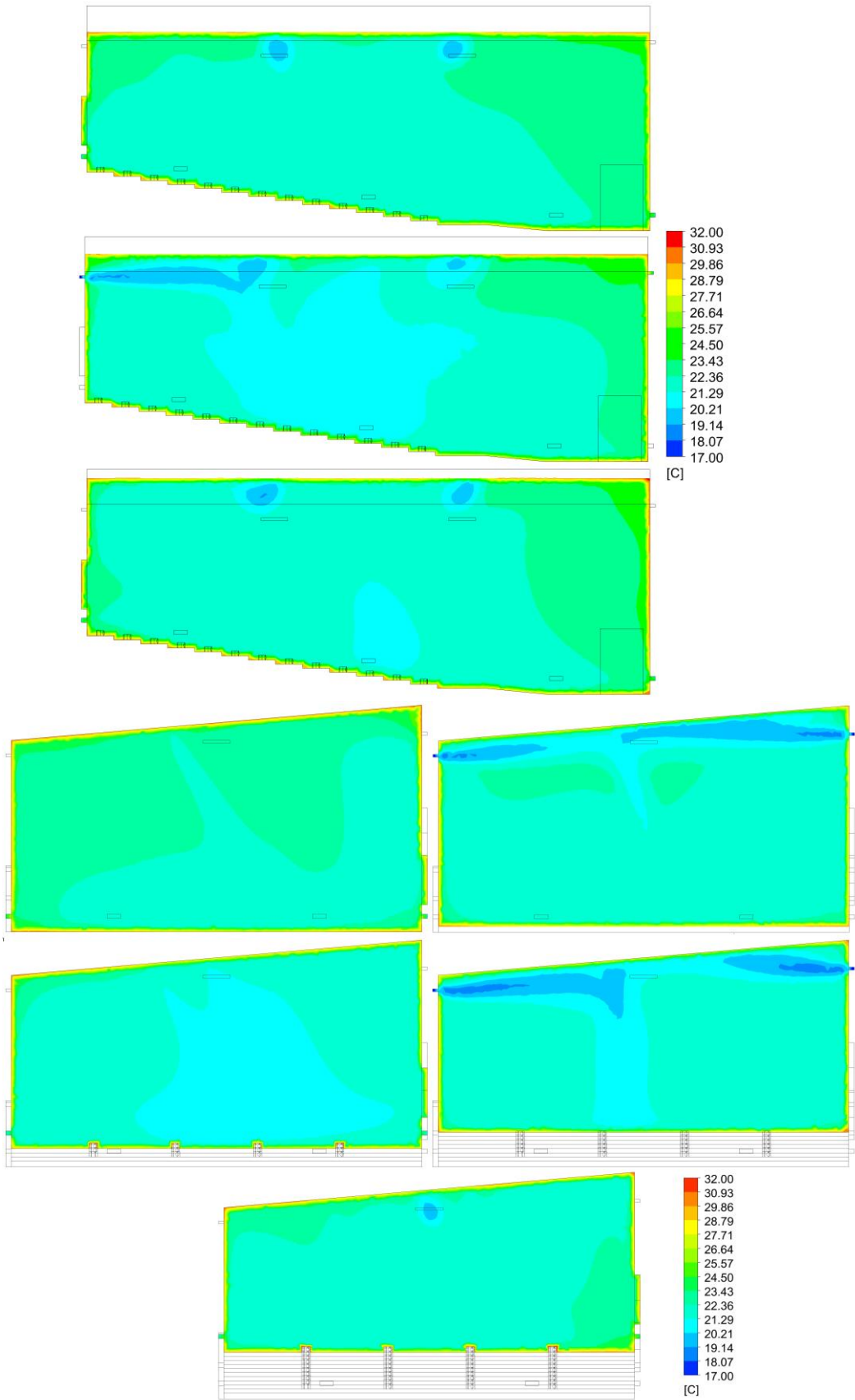


Figure G.3: Temperature distribution of 10 Ton A/C after 30 mins (lengthwise top, breadthwise bottom)

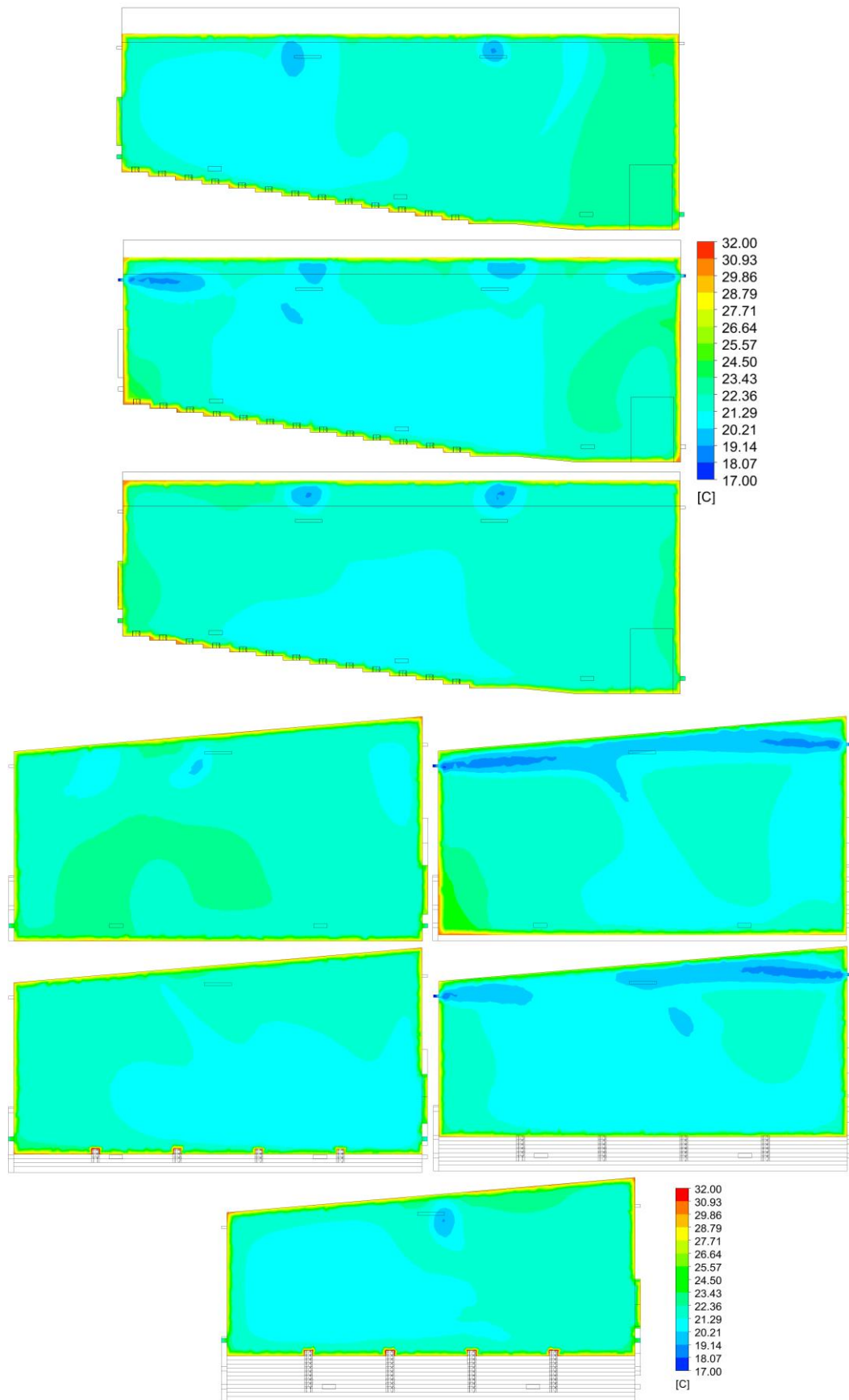


Figure G.4: Temperature distribution of 11 Ton A/C after 30 mins (lengthwise top, breadthwise bottom)

APPENDIX H : ENERGY USAGE DATA

Table H-1: kWh used per hour of thermal comfort condition (Monthly Avg.)

Desired Temp	A/C Capacity in Tons	Mar	Apr	May	Jun	Jul & Aug	Sep	Oct
22.5°C	8	3.65	2.30	4.97	5.93	7.23	5.35	4.66
	9	3.57	2.32	4.96	6.49	7.77	6.08	5.08
	10	3.61	2.22	4.96	5.55	7.48	5.73	5.04
	11	3.31	2.35	4.91	6.07	7.15	6.58	4.73
22°C	8	3.96	2.96	5.40	6.19	7.58	5.50	4.93
	9	4.04	3.00	5.44	6.55	8.09	6.15	5.12
	10	4.09	2.91	5.35	6.17	7.75	6.12	5.02
	11	3.98	2.99	5.57	6.55	7.36	6.37	4.64
21.5°C	8	4.21	3.61	5.86	6.85		6.40	5.28
	9	4.22	3.60	6.18	7.25	8.97	6.71	5.68
	10	4.21	3.49	5.91	6.84	8.72	6.46	5.61
	11	4.43	3.13	6.19	7.07	8.78	6.81	5.72

Table H-2: kWh used per hour of thermal comfort condition on average total

Desired Temp Tons	22.5°C	22°C	21.5°C
8 Tons	5.17	5.51	
9 Tons	5.50	5.81	6.45
10 Tons	5.26	5.64	6.24
11 Tons	5.28	5.60	6.36

Table H-3: Total kWh consumed (Monthly Avg.)

Desired Temp	A/C Capacity in Tons	Mar	Apr	May	Jun	Jul & Aug	Sep	Oct
22.5°C	8	852.19	532.71	1144.98	1352.90	1620.42	1225.42	1076.28
	9	835.03	542.38	1149.98	1496.21	1773.83	1405.23	1184.06
	10	846.94	518.92	1150.62	1281.31	1713.69	1326.52	1174.93
	11	777.78	550.48	1147.23	1408.67	1649.42	1534.71	1105.84
22°C	8	923.00	686.93	1242.70	1410.83	1699.90	1257.82	1139.90
	9	945.17	701.03	1259.83	1508.99	1848.13	1421.39	1192.79
	10	958.33	681.40	1242.41	1425.06	1775.86	1416.19	1170.48
	11	935.42	700.95	1300.77	1521.26	1696.48	1485.26	1085.94
21.5°C	8	983.11	817.81	1356.07	1556.13		1437.20	1220.06
	9	988.59	839.77	1433.38	1670.47	2047.81	1550.46	1324.18
	10	986.69	815.01	1372.48	1579.18	1997.78	1496.51	1308.88
	11	1041.99	733.42	1444.30	1642.62	2024.09	1587.44	1338.84

Table H-4: Total kWh consumed on average total

Desired Temp Tons	22.5°C	22°C	21.5°C
8 Tons	9425.33	10060.98	
9 Tons	10160.55	10725.46	11902.49
10 Tons	9726.63	10445.57	11554.31
11 Tons	9823.53	10422.57	11836.80

(Note: The data for 8 Ton for 21.5°C for July and August month is not available as this A/C configuration is unable to achieve this temperature)

APPENDIX I : INTERPOLATED SCL VALUE OF GLASS FOR 27° LATITUDE

		Time																							
Zone type A	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	0	0	0	0	0	20.5	33.5	34	35	37.5	39.8	41.5	41.8	39.8	37.5	37.3	40.5	33	11.3	6	3	1	1	0
	NE	0	0	0	0	0	60.3	125	147	138	107	73	56	48	43.3	37.8	32	25.3	14.8	6.25	3	1.25	1	0	0
	E	0	0	0	0	0	64.3	143	179	181	154	107	67.8	54	45.8	39.8	33	25.3	14.8	6.25	3	1.25	1	0	0
	SE	0	0	0	0	0	30	78	109	121	115	92	65.8	52	45	38.5	32.5	25.5	14.8	6.25	3	1.25	1	0	0
	s	0	0	0	0	0	5.75	15.5	23.3	31.5	39.5	47.5	52.3	52	47	40.8	33.5	25.3	15	6.25	3	1.25	1	0	0
	SW	0	0	0	0	0	5.75	15.5	23.3	30	35	38.8	45.8	68.3	96.5	118	125	111	67.8	26	12.8	6.5	3.25	1.25	1
	W	1	0	0	0	0	5.75	15.5	23.3	30	35	38.8	40.8	66.8	116	160	187	186	126	46.3	22	11.3	5.25	3	1.25
	NW	1	0	0	0	0	5.75	15.5	23.3	30	35	38.8	40.8	48.3	76.3	115	146	156	111	40	19.5	9.25	5	2	1
	hor	0	0	0	0	0	12.5	57.8	115	170	217	251	269	271	256	224	177	117	57	25	12.3	6.25	3	1.25	1

		Time																							
Zone type B	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	2	2	1	1	1	17.3	28.8	30.3	31.3	34.5	36.8	38.8	39.5	38.8	36.5	37.3	39.8	33.5	15.8	10	7	5	4	3
	NE	2	1	1	1	1	52.3	106	126	122	99.8	73.8	60	53.8	49	43.5	37.8	30.8	20.5	12	9	6	5	3	3
	E	2	2	1	1	1	55	121	153	159	142	105	74.3	63	55	48	41	33.3	22.8	13.3	10	7	5	4	3
	SE	2	1.25	1	1	1	26.3	66.5	93.5	106	103	86.3	66.3	55.8	49.8	44.3	38	30.8	21	12.5	8.5	6.25	4.25	3.25	2.25
	S	1.25	1.25	1	1	0.25	5.5	13.3	20.3	27.3	35	42.3	47	48	44.8	40	34.3	27.8	18.8	10.8	7.5	5.5	4.25	3.25	2.25
	SW	5.25	3.25	3	2.25	1.25	5.75	13.5	20.3	26.3	31	35	41.3	61.3	86.3	105	112	103	68.8	35.5	23.8	16.3	11.8	8.75	6.5
	W	7.25	6	4.25	3.25	2.25	6.75	14.5	21.3	27	32	35	37.8	60.8	102	141	165	168	122	57.8	38.3	26.8	18.5	13.5	10.3
	NW	6	5	4	3	2	6.5	14.3	21	27	31.8	35	37.8	44.8	69.3	102	129	140	106	48.3	32	22	16	11	8
	hor	8	6	4.25	3.25	3	13	50.3	98.5	147	190	223	242	249	242	218	181	132	80.5	50.8	35.5	25.3	19	14	10.3

		Time																							
Zone type C	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	5	5	4	4	3.75	20.3	29.5	29.3	29.3	31.8	34.5	35.8	35.8	34.8	33.5	34.3	37	31.8	14	10.8	8.75	7.75	6.75	6
	NE	7.75	6.75	6	5.75	5	55.3	105	118	109	86	61.5	51.8	49	46.3	42.5	37.8	32	23.3	16	13.8	11.8	10.8	9.75	8.75
	E	9	8	7.25	7	6	59	120	144	144	123	88.3	62	56	51.3	47	42.3	35.5	26.8	19.3	16.3	14.3	13	11.3	10.3
	SE	7.25	6.5	6.25	5.25	4.25	29.5	67.3	89.3	97.5	91.8	75.3	56.5	49	45.3	41.3	37	31.3	22.5	15.8	12.8	11.5	10.5	9.5	8.25
	S	4.5	4.5	3.5	3.25	3.25	7.75	14.8	20.5	26.5	33	39.3	43.3	43.3	39.8	35.3	30.5	25.5	16.8	11	8.75	7.75	6.75	5.75	5.5
	SW	10.8	9.75	8.5	7.5	7.25	11	17.8	23.5	28.3	32	34.3	40.3	59	81.8	98	102	91.5	58.3	28	21.5	18	15	13.8	11.8
	W	15.3	14.3	12.3	11.3	10.3	13.8	20.5	25.5	30.3	34	36	37.8	59.8	98.8	132	153	151	103	44.3	31.8	26.5	22.5	19.5	17.3
	NW	12.8	11.8	10	9	8	12.5	19.3	24.3	29	32.8	35	36.8	42.8	66.5	97.3	121	127	91.3	36.3	26.8	21.8	18.8	15.8	14
	hor	24	21.3	19	17	15.3	24.3	59.3	103	145	180	207	222	225	216	194	160	117	73.5	51.5	43.3	38	33.3	30	27

		Time																							
Zone type D	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	8	7.75	6.75	6	5.75	18	25.8	25.5	26.5	28.5	30.8	32.5	32.8	32.8	32.5	32.8	35.3	30.5	17	14.8	12.8	11.8	10	9
	NE	11.8	10.8	9.75	8.75	7.75	47	86.3	98.3	93.3	77.3	60	52.8	50.8	48.3	45.3	41.5	36.5	29	22.8	20.5	17.8	15.8	14.8	12.8
	E	14.3	13	11.3	10.3	9.25	50.8	99	119	122	109	83.3	64.3	59.3	56.3	52.3	47.3	41.5	33.8	27.3	24.3	21.3	19.3	17.3	16
	SE	11.5	10.5	9.5	8.5	7.5	27	56	74.5	81.8	79.8	68.3	55	49.3	46.8	43.8	39.8	34.8	27.8	22	19	17	15.8	13.8	12.8
	S	6.75	6.75	5.75	5.5	4.5	8	13.8	18.5	23.3	28.5	34	38	38.3	36.3	33.3	30	25.8	20	14.5	12.3	11.3	10	9	8
	SW	16.3	15	13	11.8	10.8	13.3	18.8	22.8	26.5	29.5	31.5	36.8	52	69.8	84.3	88.8	82.3	57.8	34.3	29	25.5	22.5	20.3	18.3
	W	23.5	21.3	19.3	17.3	15.3	17.8	22.5	26.3	29.3	32.3	34	36	53	84	112	130	131	96	51.3	42.8	36.8	32.5	29.5	26.5
	NW	19.5	17.8	15.8	14	12.8	15.3	20	24	27.8	30.8	32.8	34	39.3	58.5	83.3	103	109	83	42.8	34.8	29.8	26.8	23.8	21.8
	hor	36.3	33	30	27	24	30.5	56.8	91	124	154	177	192	198	195	181	156	124	89.8	71.3	62.3	56	50.3	45.3	40.3

APPENDIX J : INTERPOLATED CLTD VALUES OF WALLS FOR 27° LATITUDE

		Time																							
Wall 1	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	1	0	-1	-2	-3	-2	5.5	13	16	17	19	22	26	28	30	31	33	33	27	17	11	7	5	3
	NE	1	0	-1	-2	-3	0.3	19	40	50	51	46	37	31	30	30	30	28	24	18	13	10	7	5	3
	E	1	0	-1	-2	-3	0.3	20	45	60	63	59	48	36	32	31	30	28	24	19	13	10	7	5	3
	SE	1	0	-1	-2	-3	-2	9.3	27	40	46	48	45	38	33	31	30	27	24	18	13	10	7	5	3
	S	1	0	-1	-2	-3	-3	-1	3.3	8.3	14	21	28	33	35	35	33	28	24	19	13	9.3	7	4.3	3
	SW	1.3	0	0.5	1	1.8	1.8	0.8	3.3	8	13	17	22	31	43	54	60	61	54	38	21	12	8	5	3
	W	2	0.3	-0	1	1	2	0.8	3.3	8	13	17	22	27	42	59	73	80	76	54	28	14	9	5.3	3
	NW	2	0	0.5	1	1	1.8	0.8	3.3	8	13	17	22	27	35	48	60	68	67	50	26	13	8	5	3

		Time																							
Wall 2	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	5	3	2	0	-1	-2	-1	2.3	7	11	14	17	20	23	25	28	30	31	31	29	23	17	12	8
	NE	5	3	2	0	-1	-2	0.3	9.8	24	36	43	44	41	37	33	32	31	29	26	22	18	14	10	7
	E	5	3	2	0	-1	-2	0.5	11	27	43	53	55	52	44	38	35	32	30	27	23	18	14	10	8
	SE	5	3	2	0	-1	-2	-1	4.8	15	27	37	42	43	40	37	34	32	30	26	22	18	14	10	7.3
	S	5	3	1.3	0	-1	-2	-2	-1	1.3	4.5	9	15	22	27	31	33	32	30	27	23	18	14	10	7.3
	SW	6.3	4	2	1	-1	-2	-2	-1	1.3	5	9	13	18	25	34	44	52	56	54	46	34	23	16	10
	W	8	5	2.3	1	0	-1	-2	-1	1.3	5	9	13	17	23	33	46	59	69	72	62	46	31	20	12
NW	7	4	2	1	-1	-1	-2	-1	1.3	5	9	13	17	22	29	38	49	58	61	55	41	28	18	12	

Time																									
Wall 3	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	7.8	5	3.8	2	1	0	1.3	5	7.8	11	13	16	19	21	24	26	28	29	29	26	21	17	13	10
	NE	7	5	3	2	0.8	0	4.5	15	25	34	37	37	35	34	32	32	31	29	26	22	19	15	12	9
	E	7	5	3.3	2	1	0	5.5	17	30	40	46	46	43	40	37	35	33	30	27	23	19	16	12	10
	SE	7	5	3.3	2	0.3	0	2.5	8.8	18	26	33	36	37	36	34	33	32	30	27	23	19	15	12	9.3
	S	7.3	5	3.3	1.3	0.3	-1	-1	0.3	2.3	5.5	10	15	21	25	28	29	29	28	25	21	18	15	12	9.3
	SW	10	7.3	5.3	3.3	1.3	0.3	0	1	3	6	9	13	18	25	34	42	48	50	47	39	31	24	19	14
	W	13	9.3	6.3	4	2	1	0.3	1.3	3.3	6	9	13	17	24	34	46	56	62	60	51	40	31	23	17
	NW	12	8	6	4	2	1	0	1	3	6	9	13	17	22	29	38	47	53	53	45	35	27	21	16

Time																									
Wall 4	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	12	8	6	4	2	0.8	0	0	3	5.8	9.5	12	15	18	21	23	26	28	29	29	28	24	20	15
	NE	10	7	5	3	2	0	0	3.3	11	20	29	35	38	38	36	34	33	32	30	27	24	20	16	13
	E	10	8	5	3.3	2	1	0	3.3	12	23	35	44	47	46	43	40	37	34	32	28	25	21	17	13
	SE	10	7.3	5	3	2	0.3	0	1.3	5.8	14	22	30	35	37	37	37	34	33	31	28	24	20	16	13
	S	10	7.3	5	3	2	0	-1	-1	-1	1.3	4.3	8	13	18	23	27	29	30	29	27	23	20	17	13
	SW	16	11	7.3	5	3	1	0	-1	0	1.3	4	7.3	11	16	22	30	39	45	49	49	44	36	28	22
	W	20	14	9.3	6.3	4	2	0	0	0	2	4.3	7.3	11	15	21	30	41	52	60	62	57	47	37	28
NW	18	13	9	6	3	1	0	0	0	2	4	7.3	11	15	20	26	35	44	51	53	50	42	33	19	

Time																									
Wall 5	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	13	11	8.8	6.8	5	3	2	3	5	6.8	9.5	12	14	16	19	21	23	25	26	27	25	22	19	16
	NE	13	11	8	6.8	5	3	3	6.3	13	20	26	30	32	32	31	31	31	31	29	27	24	21	18	16
	E	14	11	9	7	5	4	3.3	6.5	14	23	32	37	39	39	37	36	35	33	31	29	26	22	19	16
	SE	13	10	8.3	6.3	5	3.3	2.3	4.3	8.5	15	21	26	30	32	32	32	31	31	29	27	25	22	19	16
	S	12	9.5	7.5	6.3	4.3	3	2	1.3	1.3	3.3	5.5	8	13	16	20	23	25	26	25	24	22	19	17	15
	SW	19	16	12	9.5	7.3	5.3	3.3	3	3.3	4	5.3	8	11	15	21	27	34	40	43	42	38	32	28	23
	W	23	19	15	12	9.3	7	5	4	4	4.3	6.3	8.3	11	15	20	28	37	45	51	52	48	42	35	29
	NW	21	17	14	11	8	6	4	3	3	4	6	8	11	14	19	24	31	39	44	45	42	37	31	26

Time																									
Wall 6	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	14	12	9.8	8	6.8	5	4	5	6	7.8	9.5	11	13	15	17	20	22	23	25	25	23	21	19	16
	NE	14	12	10	8	7	5	5.3	8.3	14	20	25	28	28	29	29	29	30	29	28	26	24	22	19	17
	E	15	13	11	9	7	6	6	9.5	16	23	30	34	35	35	34	34	33	32	30	28	26	23	20	18
	SE	14	12	10	8.3	7	5.3	4.3	6.5	11	15	20	24	28	29	30	29	29	29	28	26	24	22	19	17
	S	13	11	8.5	7.5	5.5	4.3	3.3	3.3	3.3	4.3	5.8	9	12	16	18	21	23	23	23	23	21	18	17	15
	SW	20	17	15	12	9.5	7.3	6.3	5.3	5.3	6	7.3	9	11	16	20	26	31	36	38	37	34	30	27	23
	W	24	21	17	14	12	9.3	8	7	6.3	7	8	10	12	15	20	27	35	42	46	46	43	38	33	29
NW	22	19	16	13	11	8	7	6	6	6	7.3	9	11	14	18	23	30	36	40	41	38	34	29	25	

Time																									
Wall 7	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	14	12	11	9	7.8	6.8	6.8	7	8.8	9.5	11	12	14	15	17	19	20	22	23	22	21	19	17	16
	NE	16	14	12	11	9	8	9	12	17	21	24	25	26	26	27	27	28	27	26	25	23	21	19	17
	E	17	15	13	11	10	9	9.5	14	20	25	29	31	31	31	31	31	30	30	28	27	25	23	21	19
	SE	16	14	12	10	9.3	7.3	7.5	9.5	14	17	21	23	25	26	26	27	27	27	26	24	23	21	19	17
	S	13	11	9.8	8.5	7.5	6.3	5.5	5.3	5.5	6.5	7.8	10	13	16	18	19	20	21	21	20	18	17	16	14
	SW	20	18	16	14	12	10	8.5	8.3	8.3	8.5	9.3	11	13	17	21	25	29	32	33	31	29	27	24	22
	W	24	21	19	16	14	12	11	10	10	10	11	12	14	17	22	28	34	39	41	39	36	33	30	27
	NW	21	19	17	15	13	11	9.8	9	9	9	10	11	13	16	20	24	29	33	36	35	32	29	26	24

Time																									
Wall 8	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	19	16	14	11	9	7	5	4	4	4.8	5.8	7.8	9.5	12	14	16	18	21	23	24	25	25	23	21
	NE	18	16	13	11	9	7	5	4.3	6	9.3	15	20	25	28	29	30	30	30	30	30	28	26	24	21
	E	19	17	14	12	9.3	7.3	6	5	6.3	11	18	25	31	34	36	36	36	35	34	32	30	28	25	22
	SE	19	16	13	11	9.3	7.3	5.3	4.3	4.3	6.5	11	16	21	25	29	30	31	30	30	30	28	26	24	22
	S	16	14	12	9.5	8.3	6.3	4.5	3.3	2.3	2.3	3.3	4.3	6.5	9.3	13	16	19	22	24	24	24	23	21	19
	SW	27	23	19	16	13	10	8.3	6.3	4.3	4.3	4.3	5.3	7	9.3	12	17	22	28	33	37	39	38	35	31
	W	34	29	24	19	16	13	10	8	6.3	5.3	5.3	6	7.3	9.3	12	16	22	30	37	44	47	47	44	39
NW	30	25	21	18	14	11	9	7	5	5	5	6	7	9	12	15	20	25	32	37	40	41	38	34	

Time																									
Wall 9	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	18	16	14	12	9.8	7.8	5.8	4.8	4.8	5.5	6.5	7.8	9.5	12	14	16	18	20	22	24	24	24	22	21
	NE	19	16	14	12	9	7.8	5.8	5.8	6.8	11	16	20	24	27	29	30	30	30	30	29	28	26	24	21
	E	20	17	15	12	10	8	6	5.8	7.8	12	18	25	30	33	35	35	36	35	33	32	30	28	25	23
	SE	19	16	13	11	9.3	7.3	6	5	5.8	8	12	17	21	25	27	29	30	30	30	29	28	26	24	22
	S	16	15	13	10	8.3	6.3	5.3	4	3	3	3.3	4.3	6.5	10	13	16	19	22	23	24	23	22	21	18
	SW	27	23	20	16	13	11	8.3	7	5	5	5	6	7	9.3	12	17	22	27	33	36	37	36	34	30
	W	33	29	24	20	17	14	11	8.8	7	6	6	6.8	8	10	13	17	23	30	37	43	45	44	41	38
NW	29	25	22	18	15	12	9.8	7.8	5.8	5.8	5.8	6	7.8	9.8	12	16	20	26	31	37	39	38	36	33	

Time																									
Wall 10	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	17	16	14	13	11	9.3	7.5	7.3	7.3	7.3	8.3	9.3	10	12	14	15	17	18	20	21	22	21	20	19
	NE	19	17	15	13	11	10	9	8.3	10	14	17	21	23	25	26	26	27	27	27	26	26	24	23	21
	E	21	19	17	14	12	11	9.3	9.3	11	15	19	25	28	30	31	31	31	31	31	30	29	27	25	23
	SE	19	17	15	13	12	9.5	8.3	7.5	8.5	11	14	18	20	23	25	26	27	27	27	27	26	24	23	21
	S	15	14	13	11	9.3	8	6.8	5.8	4.8	4.8	5.5	6	8.3	11	14	16	18	20	21	21	21	20	19	18
	SW	25	22	20	17	15	13	12	9.5	8.3	8.3	8.3	8.5	9.5	11	14	18	21	26	30	32	33	32	30	27
	W	30	27	24	21	19	16	14	12	11	10	10	10	11	12	15	18	23	29	34	38	39	38	36	34
NW	27	24	21	19	17	14	12	11	9	9	9	9	10	12	14	17	20	25	29	33	34	34	32	30	

Time																										
Wall 11	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
	N	17	16	14	13	11	9.3	8.3	7.3	7.3	8	8.3	9.3	10	12	14	15	16	18	19	21	21	21	20	18	
	NE	20	18	16	15	13	12	11	9.8	12	14	17	20	22	24	25	25	26	26	26	26	26	25	24	23	21
	E	21	19	18	16	14	13	12	11	13	16	20	24	27	29	30	30	30	30	30	30	29	28	26	25	23
	SE	19	18	16	14	13	11	10	9.3	10	12	15	17	20	22	24	25	25	25	26	25	25	24	22	21	
	S	15	14	13	12	11	9.3	8.3	7.3	6.3	6.3	6.5	7.5	8.8	11	13	15	17	18	19	19	19	19	18	16	
	SW	24	22	20	18	16	14	12	11	10	10	9.3	10	11	12	15	18	21	24	28	30	30	29	27	26	
	W	29	26	24	22	20	18	16	14	13	12	12	12	12	13	15	18	22	27	32	36	36	36	34	32	
	NW	26	24	22	20	18	16	14	13	11	11	11	11	12	13	14	17	20	24	28	31	32	31	30	28	

Time																										
Wall 12	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
	N	16	15	14	13	12	11	9.8	8.8	8.8	9.5	9.5	11	12	13	14	15	16	17	19	19	20	19	18	17	
	NE	19	18	17	16	14	13	12	12	13	16	18	20	22	23	24	24	25	25	25	25	25	24	23	22	21
	E	21	20	18	17	15	14	13	13	15	17	20	24	26	28	28	29	29	29	29	29	28	27	26	24	23
	SE	19	18	16	15	13	12	11	11	11	13	15	18	20	21	23	24	24	24	24	24	24	24	23	22	21
	S	15	14	13	12	11	9.5	8.5	7.5	7.3	7.3	7.3	8.3	9.5	11	13	15	16	17	18	18	18	18	17	16	
	SW	23	21	20	18	17	15	13	12	11	11	11	11	12	13	15	18	21	24	26	28	28	28	26	24	
	W	28	26	24	22	20	18	17	15	14	14	13	13	14	15	16	19	23	27	31	34	34	33	32	30	
	NW	24	23	21	20	18	16	15	14	13	12	12	12	13	14	15	17	20	24	27	29	29	29	28	26	

Time																									
Wall 13	Facin g	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	17	15	14	13	12	11	9.8	9	9	9.8	9.8	9.8	11	11	12	15	15	17	17	19	19	20	18	18
	NE	20	18	17	16	15	12	12	12	13	16	18	19	22	23	24	24	25	25	26	25	25	23	22	21
	E	21	19	18	16	15	14	13	14	15	18	21	24	26	27	27	28	28	28	28	28	26	25	25	22
	SE	19	18	17	15	14	13	12	11	12	14	16	19	21	22	23	22	24	23	24	22	23	22	21	20
	S	14	14	13	11	11	9.8	9.5	8.5	7.5	8.3	8.5	9.5	11	13	14	15	17	17	17	17	17	16	16	15
	SW	22	20	19	18	16	16	14	13	12	12	12	12	12	14	16	19	22	24	27	28	28	27	24	23
	W	27	25	23	22	20	18	16	15	14	13	13	13	14	15	16	19	23	27	31	33	33	32	31	29
	NW	24	23	21	20	17	17	15	13	12	12	12	12	13	13	14	16	19	22	27	29	30	29	28	27

Time																									
Wall 14	Facin g	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	17	16	15	14	13	12	11	11	10	10	11	11	12	12	13	14	15	16	17	18	18	18	18	17
	NE	20	19	18	17	16	15	14	13	14	15	17	19	21	22	22	23	24	24	24	24	24	23	22	21
	E	22	21	20	19	17	16	15	15	15	17	19	22	24	25	26	26	27	27	27	27	26	25	24	23
	SE	20	19	18	17	16	15	14	13	13	14	15	17	19	20	21	22	22	23	23	23	23	23	22	21
	S	15	14	13	13	12	11	9.8	9.8	8.8	8.8	8.8	8.8	9.8	11	12	13	15	16	17	17	17	17	16	16
	SW	23	22	21	19	18	17	16	15	14	13	13	13	13	14	15	17	19	21	23	25	26	25	25	24
	W	27	26	24	23	21	20	19	17	16	16	15	15	15	15	16	18	21	24	27	22	23	23	23	22
	NW	24	23	22	21	19	18	17	16	15	14	14	14	14	14	15	17	19	21	24	26	27	27	27	26

Time																									
Wall 15	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	21	19	17	15	13	11	9	7.8	6.8	6	6	6.8	7.8	8.8	11	13	15	17	19	21	22	23	23	22
	NE	22	20	18	16	14	11	9.8	8	7	8.3	11	14	18	22	24	26	27	28	29	29	29	28	26	24
	E	24	22	19	17	14	12	10	9	8	9.3	12	17	21	26	29	31	32	33	33	33	32	30	29	26
	SE	23	21	18	16	13	11	9.3	8	7.3	7.3	8.5	12	15	18	21	24	26	27	28	28	28	27	26	25
	S	19	17	15	14	12	9.8	8.5	6.5	5.5	4.3	4.3	4.3	5.5	6.8	9	11	15	17	19	21	21	22	22	21
	SW	30	27	25	22	19	16	14	11	9.3	7.5	6.5	6.3	6.3	7.3	9.3	12	16	20	24	28	32	33	33	32
	W	37	34	30	27	23	20	16	14	11	9.3	8.3	8	8	9	10	12	16	21	26	32	37	40	41	40
NW	33	30	27	24	21	18	15	12	10	8	7	7	7	8	9	12	15	19	23	28	32	35	36	35	

Time																									
Wall 16	Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	N	20	18	17	15	14	12	11	9	8	7.8	7.8	7.8	8.8	9.8	11	13	14	16	17	19	20	21	21	21
	NE	22	21	19	17	15	13	12	10	10	10	12	15	18	21	23	24	26	26	27	27	27	26	25	24
	E	24	22	20	18	16	14	12	11	10	11	14	17	21	24	27	29	30	30	31	31	30	29	28	26
	SE	22	21	19	17	15	13	11	10	9.3	9.3	11	13	15	18	20	22	24	25	26	26	26	26	25	24
	S	18	17	15	14	13	11	9.5	8.5	6.5	6.3	5.5	5.5	6.5	7.8	9	11	14	16	18	19	20	20	20	19
	SW	28	26	24	22	20	18	16	14	12	10	9.3	8.5	8.5	9.3	10	13	16	19	23	26	29	30	30	29
	W	34	32	29	27	24	21	18	16	14	12	11	10	10	11	11	13	16	20	25	30	33	36	36	36
NW	30	28	26	24	21	19	17	14	12	11	10	9	9	10	11	12	15	18	22	26	29	31	32	32	

APPENDIX K : INTERPOLATED CLTD VALUES OF ROOF FOR 27° LATTITUDE

Roof Number	Time																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	1	4	5	6	6	2	10	27	44	62	76	86	92	92	86	74	59	40	24	14	8	4	2
2	2	0	-1	2	3	3	3	2	15	31	48	64	77	86	90	89	82	70	54	37	24	14	8	5
3	12	8	5	2	0	-2	-2	3	12	23	35	47	59	68	74	77	74	68	58	47	37	29	22	16
4	16	11	6	3	0	-2	-3	-4	-1	6	16	28	41	55	67	75	80	80	76	67	55	44	33	23
5	21	16	12	8	5	3	1	1	4	11	20	30	42	52	61	68	71	70	66	59	50	41	33	27
8	28	24	20	17	14	11	9	9	10	14	20	27	35	43	49	54	58	58	56	52	47	42	37	32
9	31	25	20	16	12	9	6	4	3	6	11	18	26	36	46	54	61	65	66	63	58	51	44	37
10	36	31	27	22	19	15	12	9	8	8	11	16	22	30	37	45	52	56	59	59	56	52	47	41
13	34	31	28	25	22	20	17	16	15	16	19	23	28	33	38	43	47	49	50	49	46	43	40	37
14	34	32	30	27	25	23	21	19	19	19	21	24	27	32	36	40	43	45	46	45	44	42	39	37

APPENDIX L : CLTD EXCEL SOLVER

Name of Project:		Aerospace hall					Address:		Pulchowk																
Space Used For:		Auditorium					Design Engineer:																		
Calculation For:							Peak Load at:							electric load											
Space Details(All Dimensions in Feet):														Current											
length:	68	Breadth:	49	Height:	30	Volume:	99960						Voltage												
Design Condition(All units in FPS system):							CFM(Outdoor Air):							Power											
	DBT	WBT	%RH			Number of People:		100	Type of Work	Sitting in Theatre-Day			20% heat conversion												
Outside	89	78	50			CFM for People:		5	No. of ACH	0.420120048			CFM due to infiltration												
Inside	71	59.24	50			CFM for area:		0.06	Load Per Person	350			total CFM without A/C												
Difference	18					CFM:		699.92			Ti		71	A/C ton used											
Eq. Temperature Correction factor:									Total load due to people		35000		Daily Range		25	A/C CFM 400CFM/ton									
For Wall and Roof Load									Total load due to Appliances in watts		704		Tom		76.5	total CFM									
Wall CLTD																									
Facing	Area, ft2	Resistance	Wall Type	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	walls	non-CLTD										
N	0			0	0	0	0	0	0	0	0	0	0	N											
NE	1775	5.621	Wall12	3552.52	4420.92	5131.42	5762.98	6394.54	6710.32	7026.10	7026.10	7341.88	7341.88	NE	5684.04										
E	0			0	0	0	0	0	0	0	0	0	0	E											
SE	1292	5.621	Wall12	2241.06	2643.30	3160.46	3735.10	4252.26	4539.58	4826.89	5056.75	5229.14	5229.14	SE	3833.12										
S	0			0	0	0	0	0	0	0	0	0	0	S											
SW	740	5.621	Wall12	1283.57	1250.66	1250.66	1250.66	1382.31	1513.96	1810.17	2106.38	2534.24	2962.10	SW	2369.68										
W	0													W											
NW	1197	5.621	Wall12	2342.46	2182.75	2129.51	2182.75	2342.46	2555.41	2821.60	3194.27	3833.12	4684.93	NW	4137.34										
Total				9419.68	10497.64	11672.07	12931.50	14371.59	15319.29	16484.78	17383.51	18938.40	20218.06												
Roof CLTD																									
Name	Area, ft2	Resistance	Roof Type	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	roof	CLTD										
Roof	3596.4	14.48	4	-558.83	993.48	3477.18	6457.62	9872.71	13287.80	16206.15	18193.11	19372.87	19434.96	roof	4470.66										
glass conduction load																									
	area	resistance																							
	240	0.995	120.60	603.01	1326.63	1809.04	2532.66	2773.86	3015.07	3015.07	2773.86	2532.66													
Glass Solar load																									
Facing	Area, ft2	SC	Glass Type	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	Window	CLTD										
N	0			0	0	0	0	0	0	0	0	0	0	N											
NE	144	0.6	Type C	9439.2	7430.4	5313.6	4471.2	4233.6	3996	3672	3261.6	2764.8	2008.8	NE	2605.02513										
E			Type C	0	0	0	0	0	0	0	0	0	0	E											
SE			Type C	0	0	0	0	0	0	0	0	0	0	SE											
S			Type C	0	0	0	0	0	0	0	0	0	0	S											
SW			Type C	0	0	0	0	0	0	0	0	0	0	SW											
W			Type C	0	0	0	0	0	0	0	0	0	0	W											
NW	96	0.6	Type C	1670.4	1886.4	2016	2116.8	2462.4	3830.4	5601.6	6955.2	7329.6	5256	NW	1736.68342										
Total				11109.6	9316.8	7329.6	6588	6696	7826.4	9273.6	10216.8	10094.4	7264.8												
Total														20091.0	21410.93	23805.49	27786.17	33472.97	39207.36	44979.61	48808.50	51179.54	49450.49	total external	24836.5665

load due to infiltration						Overhead lighting load				
Infiltration rate (CFM)	Infiltration rate (M3/s)	Cp air assumed to be constant	Out door max temp (celcius)	Designed desired temp (celcius)	Load due to infiltration (KW)	Load due to infiltration (BTU/hr)	(Watt) Heat per sq ft of roof	(BTU/hr) Heat per sq ft of roof	Roof area	Total
91.9301	0.043386176	1.003	31.666	21.666	0.530899285	1811.502685	0.9	3.069	3596.4	11037.35

Conduction door load				
Area	Resistance	Outdoor max temp	Designed desired temp	load from door
40	1.41206	89	71	509.8933473

floor load				
Floor area	Total floor U value	Unconditioned space max temp	Dsigned desired temp	Load from floor
3585	2.129	80	71	15155.00235

Total	118443.203
Total Cooling Load(in TR)	9.870266918

Partition load				
Partition area	Resistance	Unconditioned space max temp	Designed desired temp	Load from floor
839.3	5.621	80	71	1343.836

Conduction window load for NON-CLTD				
Area	Resistance	Outdoor max temp (design temp)	Designed desired temp	Load from door
240	0.995	89	71	4341.709

Non-CLTD	92100.2266
In Tons	7.67501888

