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Energy Performance Analysis of Terminal Building of Pokhara International Airport

BY

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A THESIS

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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
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The undersigned certify that they have read and recommended to the institute of engineering for acceptance, a thesis entitled '**Energy Performance Analysis of Terminal Building of Pokhara International Airport'** submitted by Praveen Acharya, in partial fulfillment of the requirements for the degree of Master of Science in Engineering in Renewable Energy Engineering.

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ABSTRACT

Heating and cooling are needed in a building to maintain a comfortable environment for the human living and working inside the building. Commercial building like airport needs space heating and cooling throughout the year to make as comfortable environment for the passengers and to maintain working temperature of different special equipment which is used inside the terminal building of an airport. Pokhara International airport is the third international airport of Nepal. It is an ICAO category 4D airport and consists of a single runway. The terminal building of Pokhara international airport serves as terminal for both domestic and international passengers. This study is about the energy consumption by space heating and cooling system installed in terminal building of Pokhara international airport. Heating and cooling system consumes almost 50 percent of the total energy consumption of the terminal building. Thus, the energy consumption of HVAC system of the terminal building must be optimized.

This study simulated the cooling and heating load of terminal building in Autodesk Revit which is 2277.03 kW and 1195.72 kW respectively. The study also conducted theoretical cooling load calculation with varying air change per hour to study the impact of fresh air load in the system. The cooling load at 2ACH, 1.5ACH and 0.7 ACH was 3243.58 kW, 2722.9 kW and 1889.81 kW respectively.

This study also simulated building energy use intensity in Autodesk Insight which is 495 kWh/m^2/yr.

Heat recovery calculation was also done in this study to see the opportunity to reduce energy consumption of the space heating and cooling system of the building which amounts to 123.48 kW.

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LIST OFABBREVIATIONS

AC	Air Condition
CAAN	Civil Aviation Authority of Nepal
PIA	Pokhara International Airport
PIACAO	Pokhara International Airport Civil Aviation Office
ICAO	International Civil Aviation Organization
TDO	Terminal duty Officers
VRF	Variable Refrigerant Flow
VRV	Variable Refrigerant Volume
DG	Diesel Generator
DB	Distribution Box
GF	Ground Floor
HVAC	Heating Ventilation and Air Conditioning
kVA	Kilo Volt Ampere
kVAR	Kilo Volt Ampere Reactive
kWh	Kilo Watt Hour
km	Kilo Meter
MVA	Mega Volt Ampere
NEA	Nepal Electricity Authority
NRs	Nepali Rupees

VIP	Very Important Person
HT	High Tension
LT	Low Tension
COP	coefficient of performance
SEER	Seasonal energy efficiency ratio
ACH	Air change per hour
BIM	Building Information Model

CHAPTER ONE: INTRODUCTION

1.1 Background

The international airport known as Pokhara International Airport is situated in the Nepalese region of Gandaki. It will eventually replace the former domestic airport, which is 3 km (1.9 mi) to the east of it. The airport, which is the third international airport in Nepal, officially opened for business on January 1, 2023, while STOL flights to Jomsom are being conducted out of the former airport. One million people are anticipated via the airport each year. The runway at Pokhara International Airport is designated 12-30 and measures 45 meters in width and 2500 meters in length, falling within the ICAO 4D Category. Runway 30 has an ILS System Precision Approach CAT-1 (PA1) facility, while Runway 12 has a Non-Precision Approach (NPA) facility. There are eight domestic parking lots and three international parking spots at the airport. The B737 series and other related aircraft types are anticipated to be among the most common kinds of aircraft using the airport. The airport's operation is anticipated to be historic since it will enable more flights, enhancing connectivity, and performing a significant part in the region's unparalleled economic development. Millions of passengers are expected to go through Pokhara International Airport every year due to a range of climate-related concerns. Establishing an atmosphere of comfort is essential if travelers are waiting at the airport. These airport buildings require a powerful air conditioning system that can provide a comfortable interior environment and precise air control of different zones. In order to keep people comfortable and prevent numerous machines and equipment connected to the airport from overheating, an air conditioner is necessary in airports.

An HVAC system based on a water-cooled chiller provides air conditioning for the terminal building of Pokhara International Airport. The main structure of Pokhara International Airport, the terminal building, is almost entirely covered by an HVAC system. It might be challenging to ascertain the variable refrigerant flow (VRF) system's true electricity usage and energy efficiency in buildings. Due to the intricate measurements needed, the process may be expensive. A number of variables, including operating mode, set point temperature, and climate, affect how well the VRF system performs (Qian et al., 2020).

The amount of energy used in refrigeration and air conditioning systems is dependent on a variety of factors, including ambient conditions, seasonal variations, operation and maintenance, and changes in load. Therefore, every one of these aspects must be considered as much as feasible in the performance evaluation. .(https://beeindia.gov.in/sites/default/files/4Ch9.pdf)

About 50% of a building's total energy usage is accounted for by its HVAC systems (Liu et al., 2015b). In contrast to split AC equipment, which permits a single interior and outdoor unit, an air-cooled chiller-based HVAC system employs an outdoor chiller to supply heated or cooled air via a duct system to nearly the whole building. The operating electricity consumption, peak heating/cooling load, and energy use intensity of Pokhara International Airport's terminal building are the subjects of this study. In addition to lowering energy consumption, proper building envelope systems increase the energy efficiency of the structure. It can save a significant amount of energy (Zhao et al., 2021). Reducing the operational electricity usage of HVAC systems is the focus of this research.

1.2 Problem Statement

The aviation sector contributes substantially to greenhouse gas emissions worldwide. Because airport terminal buildings use a lot of energy for lighting, ventilation, heating, air conditioning, and other building services, they account for a significant amount of this carbon footprint. Thus, it is essential to evaluate the Pokhara International Airport terminal building's energy performance and find ways to cut down on energy use and carbon emissions.

This thesis aims to analyze the energy performance of Pokhara International Airport's terminal building through an energy analysis. Energy data collecting, including fuel and power usage, as well as an evaluation of the building's envelope, HVAC system, lighting, and other energy-consuming systems are all part of the analysis. The thesis will also examine a number of energy-saving techniques, including HVAC systems.

The outcomes of this thesis will provide valuable insights into the energy performance of terminal building of Pokhara International airport and inform policymakers and airport operators on the best energy-efficient strategies to adopt. Furthermore, it will contribute to the development of sustainable aviation practices, which is critical for reducing the aviation industry's impact on the environment.

Figure 1.1: Night view of Terminal Building of Pokhara International Airport

1.3 Objectives

1.3.1 Main Objective

To study and analyze the energy performance of the Terminal building of Pokhara International airport in Pokhara, Nepal and ways to reduce energy consumption.

1.3.2 Specific Objectives

- Identify the energy consumption patterns and the sources of energy
- To simulate the HVAC load and energy use intensity of terminal building to analyse energy performance.
- To study the effect of fresh air intake on the performance of HVAC system of Terminal building.

1.4 Limitations

In this building energy analysis, it has been done only to analyze how much Heating and Cooling load can be reduced. This study has been done to analyze how much difference fresh air rate make to increase the energy efficiency of the building. And also conduct heat recovery calculation from exhaust air.

CHAPTER TWO: LITERATURE REVIEW

Building energy performance analysis is research that aims to increase a building's energy efficiency by identifying the variables that contribute most to energy consumption and suggesting energy-saving solutions. The goal of this study is to evaluate Pokhara International Airport's terminal building's energy efficiency. Early on in a building's life, low performance design can result in inefficient energy use and reduced thermal comfort. The goal of this study is to determine the energy-saving strategies that could be implemented without compromising thermal comfort by analyzing the medium-rise commercial building's greatest energy consumption factor. Energy modeling, which simulates various designs as energy-saving methods, is done by employing simulation tools to estimate the building's energy usage.

The transportation systems, HVAC, lighting, and air conditioning of terminal buildings consume a lot of energy. Huge volumes of spaces, frequently with uneven heat gains and huge glazing portions (like glass curtain walls) meant to bring in natural light and visually pleasing elements, are what define them. HVAC systems can use more energy than 40% of all electrical energy (Kotopouleas and Nikolopoulou, 2019).

Numerous studies have examined the energy analysis of airport terminal buildings in recent years. The main goals of these investigations have been to determine the patterns of energy consumption, assess the buildings' energy efficiency, and suggest energy-saving strategies.

In the current depleting global environmental condition, the energy at airport program of Bengaluru International Airport makes a vital contribution to sustainability and growth. All airports, regardless of size, have the capacity to adopt sustainable practices and save energy by managing it more effectively. At all levels, situational awareness, technological know-how, and comprehension of the influence on future generations would be the catalysts for change. (Reddy, 2014)

D'Antoni et al. (2019) examined the energy efficiency of the terminal building at Naples International Airport in Italy in different research. The building's energy usage trends were assessed by the writers using a combination of data analysis and energy simulation. They concluded that there was the greatest opportunity for energy savings in the building's envelope and lighting systems, and they suggested actions including installing energy-efficient lighting and enhancing insulation.

In research published in 2018, Yang et al. assessed Beijing Capital International Airport's Terminal 3's energy consumption trends and potential energy savings. The building's energy performance was assessed by the authors using an energy simulation, and they suggested a number of energy-saving strategies, including installing energy-efficient lighting, utilizing natural ventilation, and improving HVAC systems.

All things considered, these studies demonstrate how critical it is to carry out energy analysis on airport terminal buildings in order to pinpoint patterns of energy consumption, assess energy efficiency, and suggest energy-saving solutions. The studies also highlight how important it is to take into account the particular needs and difficulties faced by airport terminal buildings, such as the demand for continuous operation and high air quality, when analyzing and putting energy-saving measures into practice.

2.1 Energy Consumption pattern of Airport Terminal Building

The average energy usage of airport terminals is significantly higher than that of typical public buildings. Their intricate operational characteristics and spatial elements are the reason for this. The number of domestic and international airports in Nepal is growing quickly due to the country's ongoing development and urbanization, making now the ideal time to analyze the energy performance of terminal buildings and incorporate the findings of these analyses into both current and future airport terminal buildings.

Airport terminals are distinguished from traditional civil buildings by their incredibly tall, open spaces that are primarily covered by glazing systems. These structures have to manage a lot of passengers and run continuously for long periods of time. The total amount of energy used by HVAC systems is relatively significant. The 2017 Civil Aviation Bureau of China report, "Civil Airport Terminal Green Performance Investigation Report," revealed that the energy consumption, including cooling plants and terminal buildings, ranged from 129 to 281 kWh/(m2·a), with an average of 180 kWh/(m2·a). There is a significant potential for energy savings because, under similar climatic conditions, the highest energy consumption might be 50–100% higher than the average amount. Approximately 2.9 times as much energy is consumed on average than in non-airport areas.

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kWh/(m^2·a). There is a significant potential for energy savings because, under similar climatic conditions, the highest energy consumption might be 50–100% higher than the average amount. The average energy usage is 2.9 times higher than 61.96 kWh/(m^2·a) for public buildings outside of airports. The HVAC systems account for 41.2–62.9% of the airport's overall energy usage, with a range of 73.4–121.7 kWh/(m^2·a).

The total number of passengers and their flows have a substantial correlation with airport energy consumption. Numerous studies have been conducted on passenger flows at airports. Liu et al. used data from an on-site inquiry to mimic the dynamic distribution of travelers at airports. Their findings indicated that, in just 3.6% of the entire time, the passenger density surpassed the planned value.

The departure floor's maximum usage ratio was only 54.8–64.4%, and the primary air-cooling load's maximum actual demand (25 W/m^2) was noticeably lower than the design value (47 W/m^2). This indicates that airport HVAC systems can use a lot less energy if the amount of mechanical outdoor air can be changed in response to variations in actual occupancy rates.

Based on statistical data, the energy consumption of the civil aviation sector makes up around 8% of the energy consumption of the transportation sector as a whole. 94% of the energy consumed in the civil aviation sector is accounted for by aviation oil consumption, 3% is accounted for by airport energy consumption, 2% is accounted for by airline ground services energy consumption, and no more than 1% is accounted for by other civil aviation units' energy consumption. 2017 IOP Conf. Ser.: Earth Environ. Sci. 94 012134; Bo Li et al.

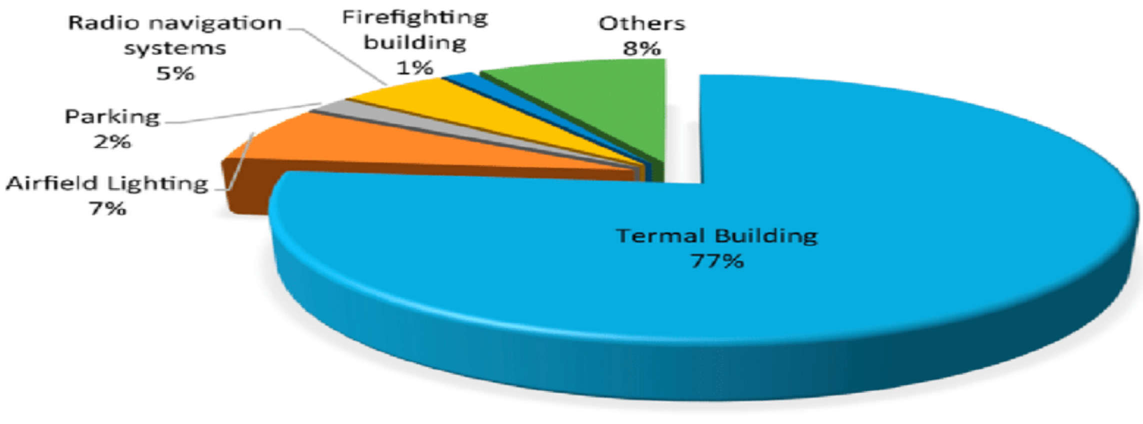

Figure 2.1: Distribution of energy consumption of an airport

2.2 Site location and Weather

The location is the Pokhara International Airport terminal building. Pokhara, the capital of Gandaki province and the hub of Nepal tourism, is a metropolitan city located in central Nepal with latitude and longitude coordinates of 28°16'0.8"N, 83°58'6.64"E. The city is situated at an elevation of about 822 meters on the shore of Phewa Lake. On May 4, 2013, Pokhara recorded its highest temperature of 38.5 °C (101.3 °F), whereas on January 13, 2012, it recorded its lowest temperature of 0.5 °C (32.9 °F). Figure 2.2 displays the monthly temperature variation in Pokhara.

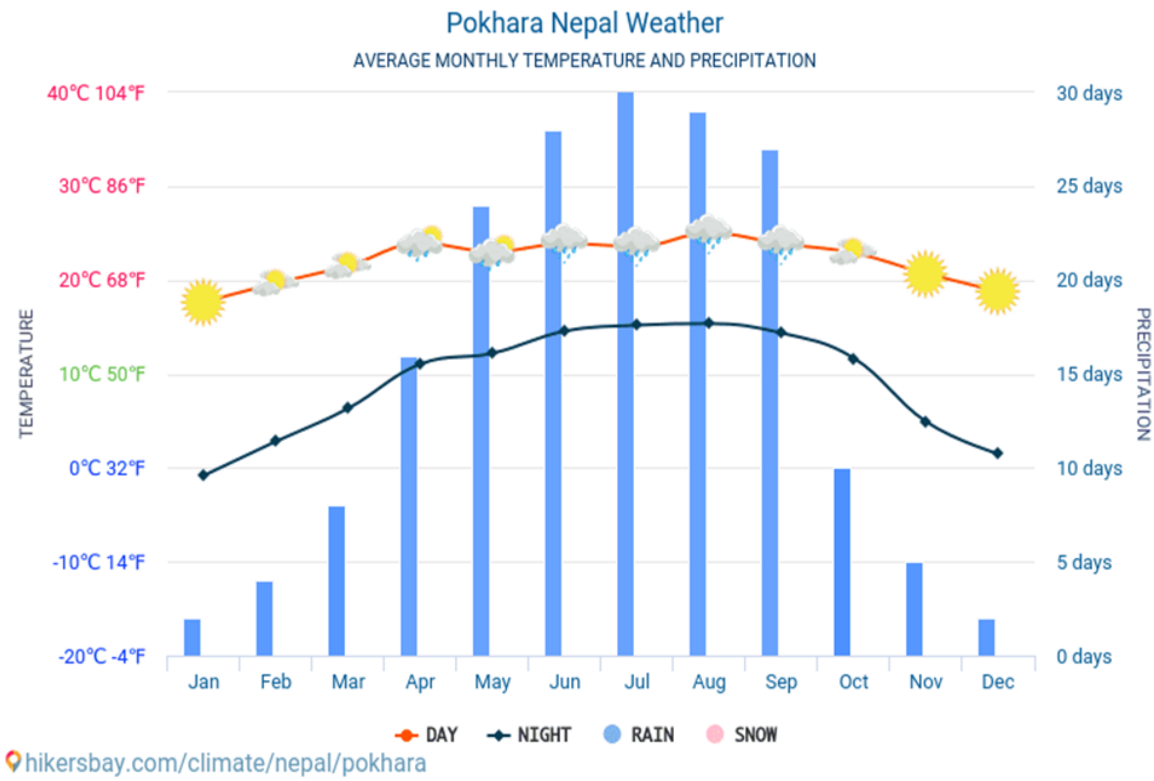

Figure 2.2: Monthly temperature variation of Pokhara (source: hikersbay.com)

The location of site is shown below in Figure 2.3

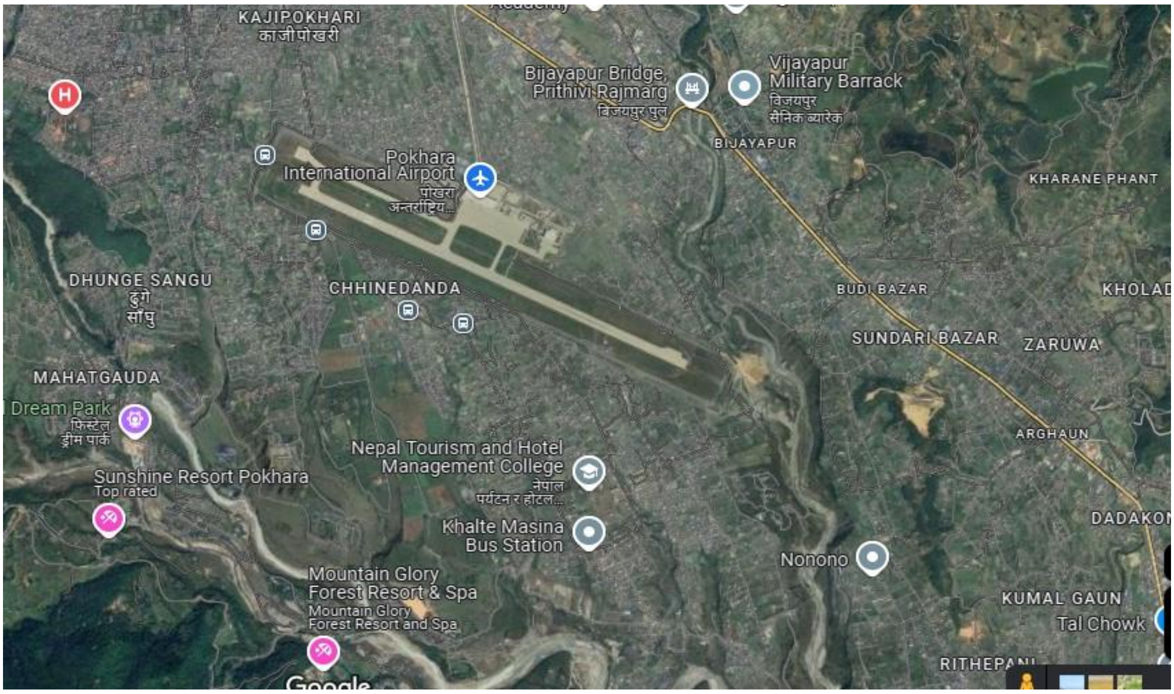

Figure 2.3: Location of Pokhara International Airport (source: Google maps)

2.3 HVAC and air conditioning systems

HVAC systems regulate temperature, humidity, and ventilation in buildings and automobiles, usually to keep the interior comfortable during adverse weather.

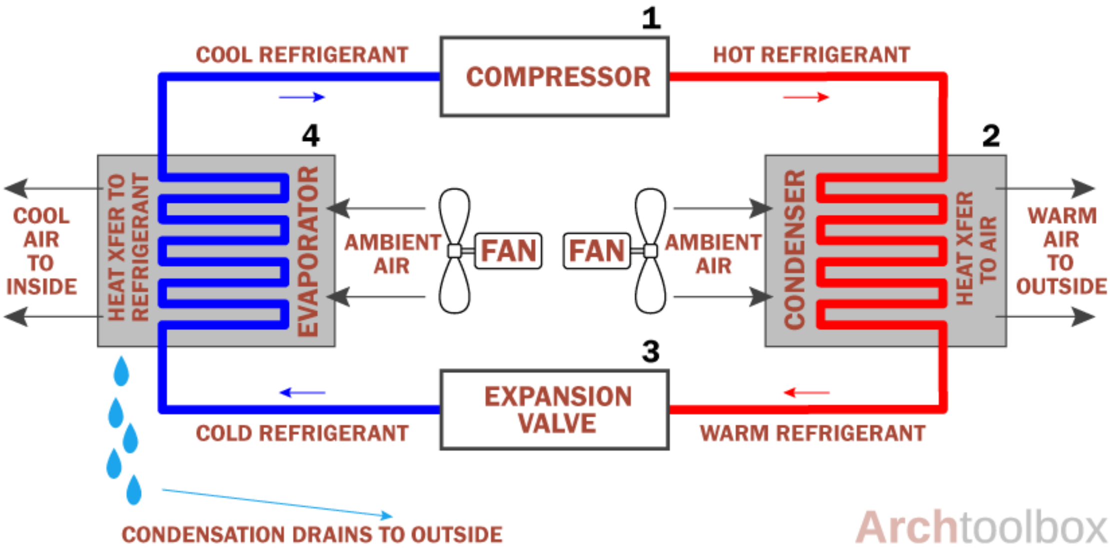

Figure 2.4: Working of an Air conditioning system (source: Archtoolbox.com)

Comfort levels for people vary depending on their psychological and physical well-being. From the perspective of the topic, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) provides the most appropriate definition, which reads as follows: human comfort is the state of mind that expresses satisfaction with the thermal environment. The factors that impact human comfort are

1. Temperature of effectiveness

2. The human body's generation and regulation of heat.

3. The body's loss of heat and moisture; and

4. The moisture content of the air

5. Air quality and amount

6. Motion of air

7. Surfaces that are hot or cold

8. Air Stratification

Effective Temperature: The three basic components that determine how warm or chilly a human body feels are as follows:

1. Air velocity.

2. Relative humidity; and

3. Dry bulb temperature

The effective temperature is used to assess the combined impact of these variables. It is described as an index that compiles the combined impacts on human health of air temperature, relative humidity, and air velocity. Effective temperate is expressed numerically as the temperature of saturated air at a speed of 5 to 8 m/min. saturated air, which generates clones or the same feeling of warmth as when the circumstances are met. The comfort chart presents the idea of effective temperature in a practical manner. The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) conducted study on a variety of subjects who were exposed to a wide range of environmental temperature, relative humidity, and air velocity. The results are shown in this chart. The wet bulb temperature is ordinates, and the dry bulb temperature is abscissa in the comfort chart.

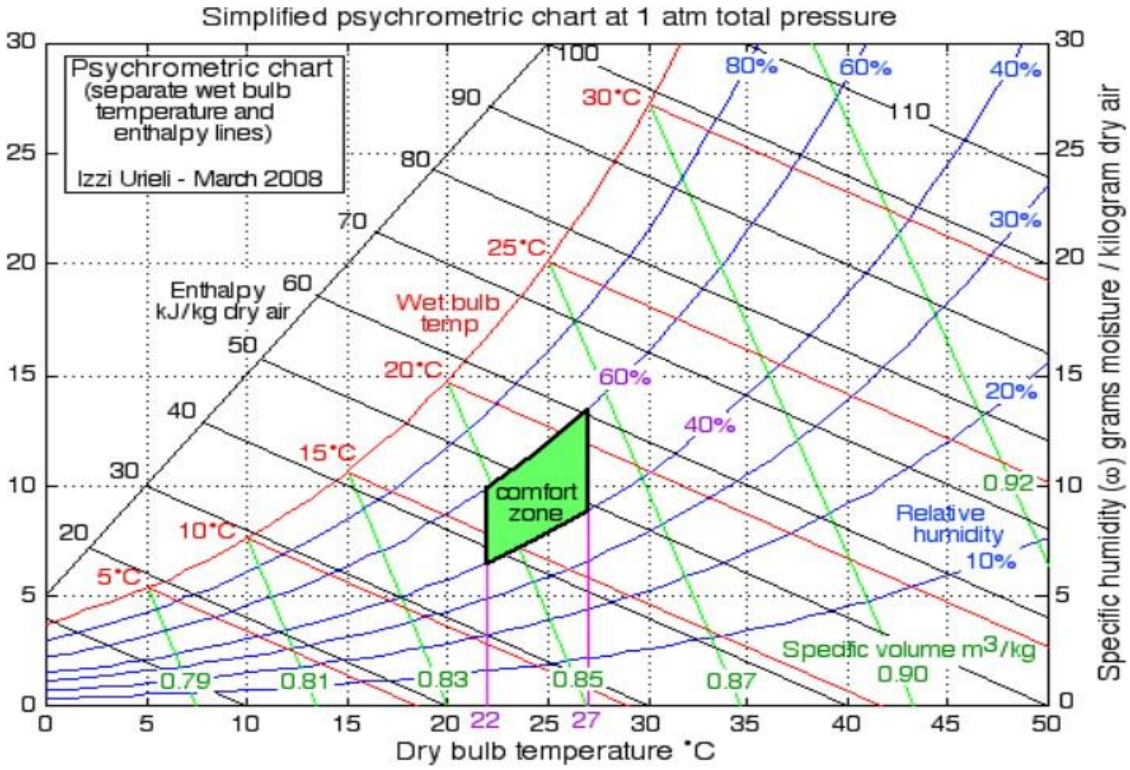

Figure 2.5: Simplified psychrometric chart at 1 atm total pressure (source: https://people.ohio.edu/com)

2.4 Ventilation

Through ventilation, air from the outside is brought into a building or space and distributed throughout. According to Etheridge & Sandberg (1996) and Awbi (2003), building ventilation generally aims to create clean air for breathing by extracting and dilution of pollutants that come from within the structure.

Three essential components make up building ventilation
The ventilation rate refers to the quantity and quality of outside air introduced into the room.

Airflow direction, which is the general direction of airflow in a building and should move from clean to filthy zones; and

Air distribution or airflow pattern: each area of the space should receive efficient air delivery from the outside, and each area should effectively remove the airborne contaminants produced there.

A building can be ventilated using three different techniques: mechanical, hybrid, or mixed mode ventilation.

2.4.1 Natural ventilation

Openings intended to let in natural forces, such breezes and the thermal buoyancy effect brought on by differences in the densities of the air inside and outside, allow outdoor air to enter structures. Examples of purpose-built apertures are windows, doors, trickling ventilators, solar chimneys, and wind towers. The natural ventilation of a building's interior is influenced by various factors such as climate, building design, and human activity.

2.4.2 Mechanical ventilation

Mechanical ventilation is powered by mechanical fans. Fans can be mounted in air ducts to feed or exhaust air from a room, or they can be mounted directly in windows or walls.

The type of mechanical ventilation used depends on the climate. For example, in warm and humid places, infiltration may need to be regulated or avoided to reduce interstitial condensation, which occurs when warm, humid air from within a structure infiltrate a wall, roof, or floor and meets a cold surface. A mechanical ventilation system with positive pressure is frequently employed in these situations. On the other hand, negative pressure ventilation is employed in cold areas to minimize interstitial condensation and prevent exfiltration. In rooms like bathrooms, kitchens, and toilets where pollutants are produced locally, the negative pressure system is frequently employed.

When a system operates under positive pressure, the air inside the room escapes through leaks in the envelope or other apertures. A negative pressure system creates negative pressure in the space and uses "sucking" air from outside to make up for it. A mechanical ventilation system that is considered balanced has had its exhausts and supplies of air evaluated and adjusted to ensure that they meet design requirements. It is possible to maintain a slightly positive or negative room pressure by using slightly varied supply or exhaust ventilation rates. For example, in a cold climate, 10% more air needs to be evacuated than supplied in order to create a slightly negative room pressure, which lowers the chance of interstitial condensation. In an airborne precaution room, it is standard procedure to keep the negative pressure in relation to the corridor at least 2.5 Pa in order to prevent infections.

2.4.3 Hybrid (mixed mode) ventilation.

Natural driving forces are what hybrid (mixed mode) ventilation uses to achieve the intended (design) flow rate. When the natural ventilation flow rate is too low, mechanical ventilation is used (Heiselberg & Bjørn, 2002).

Exhaust fans can be placed to boost room ventilation rates when natural ventilation alone isn't enough (with proper pre-testing and planning). However, caution must be exercised when using this straightforward hybrid (mixed mode) ventilation system. The fans should be positioned so that room air can exit via a wall or the roof and directly into the outdoors. The intended ventilation rate determines the size and quantity of exhaust fans, which need to be measured and tested before being used.

The usage of exhaust fans can present a number of issues, such as installation challenges (particularly with larger fans), noise (especially with high-power fans), fluctuating room temperature, and the need for a constant source of electricity. In the event that the room's conditions result in discomfort from heat, ceiling fans and spot cooling or heating systems may be incorporated.

2.4.4 Air change per hour (ACH)

Air changes per hour (AKA air change rate; commonly written as ACPH or ACH) is the frequency with which the full volume of air in a room or space is completely withdrawn and replenished in an hour. The number of times the air in a given area is changed per hour, assuming that the air is uniform or perfectly mixed, is known as the air changes per hour. According to theory, conditions pertaining to air age and pollution concentration are spatially equivalent when supply air is swiftly and uniformly mixed with the air that is already present in a space. This is known as perfectly mixed air.

Air in air distribution systems is often not uniformly or properly mixed. The ventilation techniques used and the enclosure's airflow efficiency define the precise percentage of air that is exchanged in a given amount of time. These systems range from a hypothetical system of perfect displacement, which removes and replaces all of the air in a room, to a short circuit flow, in which very little of the existing air is replaced. In a well-mixed ventilation scenario, the actual amount of air changed will be 63.2% after one hour and one ACH. To achieve equilibrium pressure, the amount of supply air entering the space and the amount of return air leaving the space must be equal.

In Imperial units:

$$ACH = \frac{60Q}{Vol}$$

where ACH stands for air changes per hour; higher values indicate increased ventilation In cubic feet per minute (cfm),

Q is the volumetric flow rate of air

Volume is equal to L ×W ×H in cubic feet

Measured in metric units:

$$ACH = \frac{3.6Q}{Vol}$$

Where

Vol is the space volume in cubic meters.

The volumetric flow demand is often expressed in cubic meters per hour when using metric measurements, for a specific room or building size and number of air changes per hour.

CHAPTER THREE: METHODOLOGY

The approach we take to solving a problem that comes up during research is known as the methodology of research. In order to address potential desired results, the difficulties must be designed into the standard framework using a methodical process. The main objective of this research is to study and analyze energy consumption pattern and ways to increase energy efficiency in the operation of terminal building of Pokhara international airport. Methodology is a systematic algorithm of how a research work is executed. In this study of energy analysis of terminal building of Pokhara International Airport, the first step is research design. Then the relevant literature review is carried out. Then the works of data collection, load calculation and energy simulation are done chronologically and with result the of this calculation, energy saving opportunities can be identified.

In this section, research methodology is developed for energy analysis of terminal building of Pokhara international airport. The main energy consumption factor for the terminal building is Heating, Ventilation and air conditioning system. It almost utilizes more than fifty percent of total energy consumption. This study focuses on the existing design energy consumption scenario of terminal building and the ways of reducing energy consumption by heating, ventilation and air conditioning system. The study also focuses on ways of recovering waste heat energy from the heating, ventilation and air conditioning system. The methodology is shown in figure 3.1

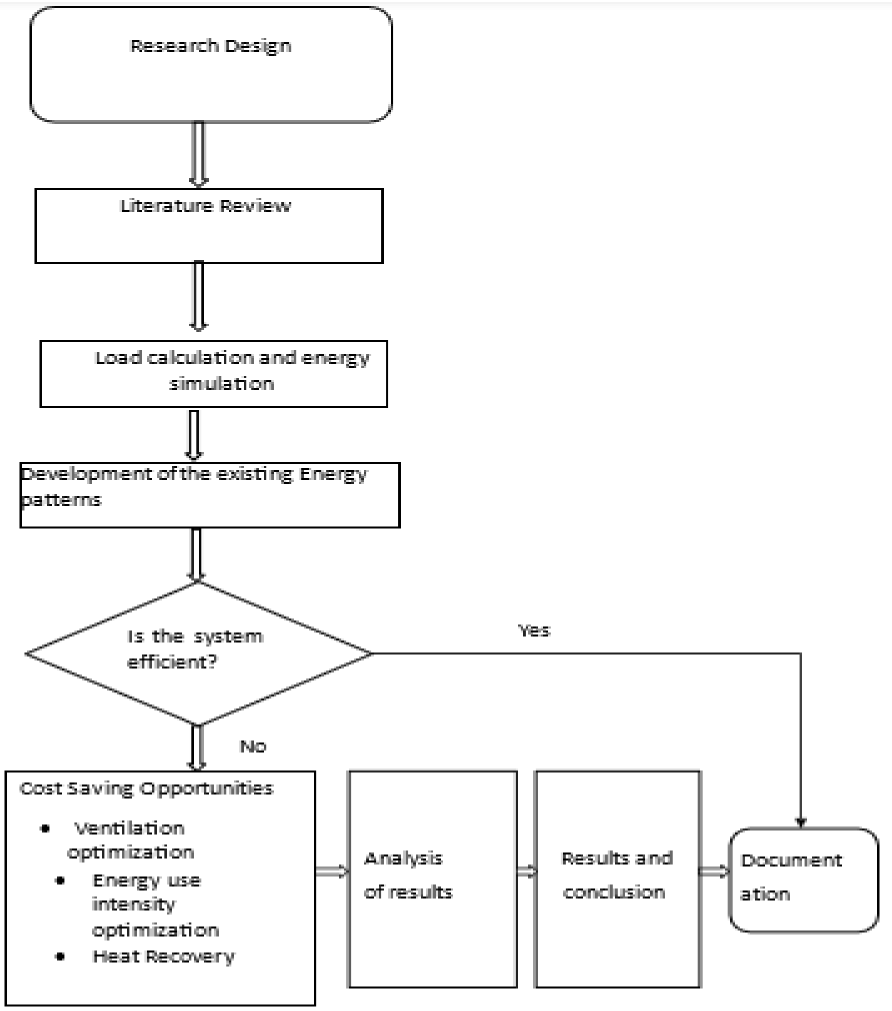

Figure 3.1: Research Framework

3.1 Research Design

The total approach used to address research issues is referred to as research design. A research design usually includes a description of the theories and models that underpin the project, the research question(s) that the project will address, a plan for obtaining information and data, and a plan for deriving conclusions from the data. Valid responses to research questions are produced by strong research designs; unreliable, inaccurate, or irrelevant replies are produced by poor designs.

3.2 Site

This study has been conducted in terminal building of Pokhara international airport, which is in Pokhara, capital of Gandaki province of Nepal. This airport is third international airport of Nepal. This airport is intended to act as a regional international airport. It has a single runway and one passenger terminal building which acts as terminal for both domestic and international terminal. It connects the mid-west part of Nepal to other places of Nepal.

3.3 Load Calculation

The total area of the building is 13503.39 square meter. The theoretical load calculation is done on the following basis

External walls, cooling load (cooling load coefficient) is formed by the roof of the heat transfer

$$Q = K_O * F_O * [(t_{lo} - t_{dl}) * C_a * C_p - t_n]$$

(From “Civil heating ventilation and air conditioning design" GB 50736 – 2012)

Where,

K_o = Heat transfer coefficient, W / (m^2 · °C)

F_o = Area of the external walls and roof, m^2

t_{lo} = Roof or wall temperature by cooling load calculated time value, °C

t_{dl} = Location correction coefficient envelope, °C

C_a = The outer surface of the heat value correction factor

C_p = An outer envelope surface of the solar radiation absorption coefficient of the correction value

t_n = Indoor temperature, °C

Exterior windows:

$$Q = F_{ch} * K_{ch} * CK_1 * CK_2[(t_{lc} + t_{d2}) - t_n]$$

(From “Civil heating ventilation and air conditioning design" GB 50736 – 2012)

Where,

K_{ch}= An outer window heat transfer coefficient, W / (m^2 · ℃)

F_{ch}= Outside the window area, m^2

t_{lc} = When the cooling load by calculating the temperature outside the window, ℃

t_{d2}= Cooling load of outer window is calculated by the temperature correction value

CK_1= External heat transfer coefficient of the correction value of the window frame of a different type

CK_2= There are facilities within the heat transfer coefficient of external window shading correction value

t_n= Indoor temperature, ℃

The inner envelope:

$$Q = K * F * (t_{ls} - t_n)$$

$$t_{ls} = t_w . p_j + \Delta t_{ls}$$

(From "Civil heating ventilation and air conditioning design" GB 50736 – 2012)

Where,

K= Heat transfer coefficient of the inner envelope, W / (m · ℃)

F= Area within the envelope, m^2

t_{ls}= Calculating an average temperature of the next room, ℃

t_n= Indoor temperature, ℃

$t_w . p_j$= Location average daily outdoor air design temperature is calculated, ℃

Δt_{ls}= Calculating an average next room temperature and the outdoor air-conditioning in summer calculation of the average temperature difference, ℃

The fresh air, permeation

$$Qr = Qs * CCL + Qq$$

$$Qs = n * Cr * q1$$

$$Qq = n * Cr * q2$$

(From “Civil heating ventilation and air conditioning design" GB 50736 – 2012)

where

Qr	Cooling load caused by body heat, W
Qs	Sensible heat cooling load, W
CCL	Human sensible heat cooling load factor
Qq	Latent heat cooling load, W
q1	Different working properties at room temperature
n	the number of air conditioning in the room, people
Cr	Clustering coefficient
q2	Each generates heat and latent heat, W

The illumination cooling load

$$Q = N * n_1 * C_{cl}$$

(From “Civil heating ventilation and air conditioning design" GB 50736 – 2012)

(incandescent and fluorescent lamp ballasts outside the air-conditioned room)

$$Q = (N_1 + N_2) * n_1 * C_{cl}$$

(From “Civil heating ventilation and air conditioning design" GB 50736 – 2012)

(surface mounted fluorescent lamp: air-conditioned room and then ballast installed)

$$Q = N_1 * n_1 * n_2 * C_{cl}$$

(From “Civil heating ventilation and air conditioning design" GB 50736 – 2012)

(concealed fluorescent: lamp in the ceiling safety glass)

Where,

N = Incandescent power, W

N_1 = Fluorescent lamp power, W

N_2 = The ballast power, and generally 20% of the fluorescent lamp power, W

n_1 = the proportion of the lamp while using coefficients, i.e. using a power installation when the power by

n_2 = Consider the glass reflection coefficient of the ventilation ceiling, when the fluorescent lamp cover with small holes, in the use of natural ventilation ceiling, 0.5-0.6 taken, without vent cap fluorescent lamp, depending on the roof ventilation is taken to be 0.6 to 0.8

C_{cl} = Cooling heat load factor formed by the illumination

The apparatus cooling load:

$$q = n_1 * n_2 * n_3 * n_4 * N \text{ (electrical equipment)}$$

$$q = 1000 * n_1 * n_2 * n_3 * \frac{N}{\eta} * C_{cl} \text{ (in process equipment and motor chamber)}$$

$$q = n_1 * n_2 * n_3 * N * C_{cl} \text{ (process equipment in the room only)}$$

$$q = n_1 * n_2 * n_3 * C_{cl} * \frac{N(1-\eta)}{\eta} \text{ (moto chamber only)}$$

(From “Civil heating ventilation and air conditioning design" GB 50736 – 2012)

Where,

N = Installation of electric power equipment, W
n_1= at the same time than using the coefficient, i.e., while using a power installation and the total installed power, generally 0.5 to 1.0

n_2= Installation coefficient, i.e. ratio of the maximum power and the actual consumption of the installed power is generally 0.7 to 0.9 preferably

n_3= the load factor, i.e. the average actual hours than the maximum design power and power consumption of the solid, and generally 0.4 to 0.5

n_4= Ventilation insulation coefficient

η= Motor efficiency, product samples by Richard, generally preferable 08 ~ 0.9

C_{cl}= Electrical equipment and appliances cold heat load factor

3.4 Building energy simulation

Building energy simulation of the terminal building of Pokhara international airport was done in Autodesk Revit and Insight. First, the building model was created in Autodesk Revit and collected information about the physical properties of the building was selected according to the options available on the Autodesk Revit. Necessary HVAC zones were created, and the load simulation was done. Then after the energy simulation was conducted in Autodesk Insight to simulate energy use intensity of the terminal building.

3.4.1 Autodesk Revit and Insight

Autodesk Revit and Autodesk Insight are Building information system software which can be used for heating and cooling load calculation or simulation. This software can also be used to design various HVAC systems. Autodesk can be used to generate the base model of the building with their physical and thermal properties and it can also use to analysis the building heating and cooling load and the area of energy consumption. Annual energy consumption of the building can be obtained from the Revit. Insight could use to perform Energy Use Intensity (EUI) of the building. Insight can also use to optimize the energy performance of the building and it assists to retrofit the exiting building to optimize building energy performance. Insight 360 facilitate visualization of the solar radiation on the surface to create new solar analysis workflow as well as PV energy generation. The analysis could use the power of the energy plus to produce the thermal heating and cooling loads in Revit Autodesk (Alba and Manana, 2016)

In this study, Autodesk Revit is used to make base model of the terminal building of the Pokhara International Airport by giving various input which were collected from site and default information present in Revit was used for heating and cooling load calculation. A screenshot of Revit default input is shown in figure 3.2

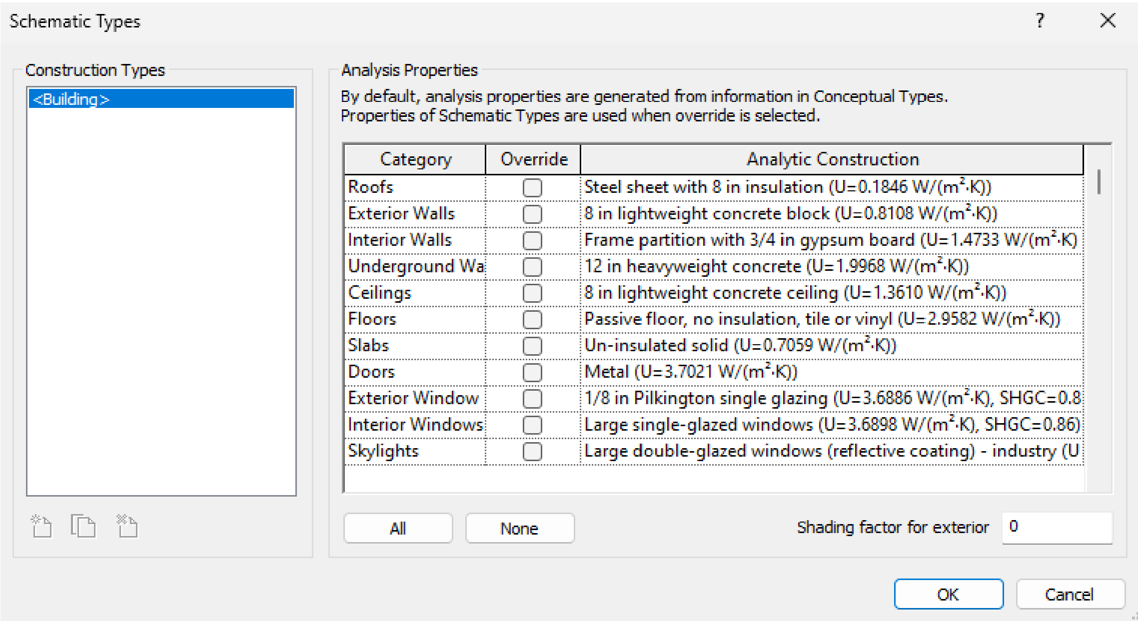

Figure 3.2: A screenshot of Revit settings

3.5 Air to Air heat recovery

Heat recovery is the process of extracting heat energy from the waste product. In this study, an opportunity was studied to recover heat from the exhaust air. Theoretical heat recovery from the exhaust was calculated. The recovered is exchanged with the supply air, thus reducing the overall energy consumption of HVAC system. The heat recovery is calculated on the basis of following formula:

$$Sensible\ heat\ recovery = CFM * 1.08 * \Delta t$$

(from CEDengineering.com)

Where,

CFM = the flow rate of air

Δt = the temperature difference of supply air and exhaust air

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Cooling load calculation and fresh air permeation

Cooling load calculation mainly depends on the envelope of the building, internal gains and fresh air permeation. Cooling load calculation of terminal building of Pokhara International Airport was done using radiant load calculation method.

Following design parameters were considered as shown in 4.1

Table 1.1: Design parameters (Source: Department of meteorology)

Air conditioning in summer outdoor dry bulb temperature °C	**Air conditioning in summer outdoor wet bulb temperature °C**	**Average daily temperature in summer air conditioning**
34.20	27.80	30.70
Outdoor summer average wind speed (m / s)	**Summer air-conditioning atmospheric transparency level**	**Summer atmospheric pressure (Pa)**
1.70	5	100400

Cooling load was calculated with different Air change per hour.

4.1.1 Cooling load with value of 2 ACH (Air change per Hour)

Cooling load of the terminal building with 2 Air change per hour is presented in the following Table 4.2

Table 4.2: Load calculation at 2 ACH (Air change per Hour)

Cooling Load(kW)	Fresh Air Cooling Load(kW)	Total Cooling Load (kW)
1160.86	**2082.72**	**3243.58**

From the table 4.2, we can see that fresh air cooling load amounts to **2082.72 kW** and total cooling load amounts to **3243.58** kW

4.1.2 Cooling load with value of 1.5 ACH (Air change per Hour)

Cooling load of the terminal building with 1.5 Air change per hour is presented in the following Table 4.3

Table 4.3: Load calculation at 1.5 ACH (Air change per Hour)

Cooling Load(kW)	**Fresh Air Cooling Load(kW)**	**Total Cooling Load (kW)**
1160.86	**1562.04**	**2722.90**

From the table 4.3, we can see that fresh air cooling load amounts to **1562.04 kW** and total cooling load amounts to **2722.9 kW**

4.1.3 Cooling load with value of 0.7 ACH (Air change per Hour)

Cooling load of the terminal building with 0.7 Air change per hour is presented in the following Table 4.4

Table 4.4: Load calculation at 0.7 ACH (Air change per Hour)

Cooling Load(kW)	**Fresh Air Cooling Load(kW)**	**Total Cooling Load (kW)**
1160.86	**728.95**	**1889.81**

From the above table we can see that fresh air cooling is **728.95 kW** and total cooling load amounts to **1889.81 kW**

4.2 HVAC load simulation

Building model of terminal building of Pokhara International Airport was created in Autodesk Revit by giving various information regarding the size, material and location of the building.

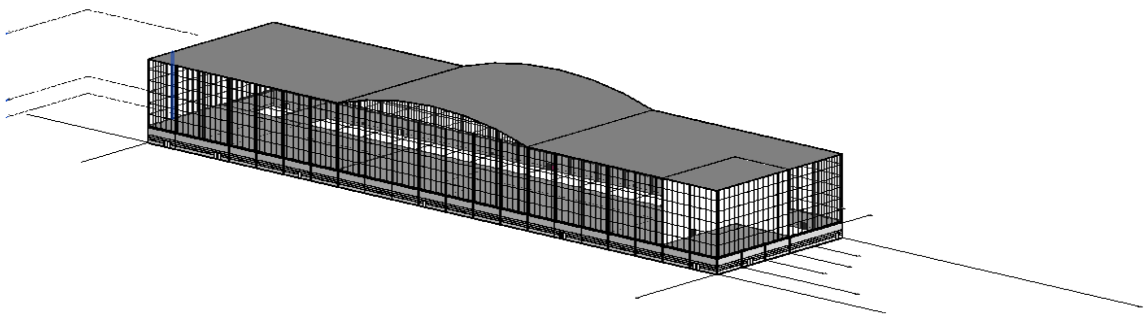

Figure 4.1: Building model created in AutoCAD Revit

After creating the model of the building, HVAC zones were created, and HVAC load calculation was simulated by using the software simulation feature.

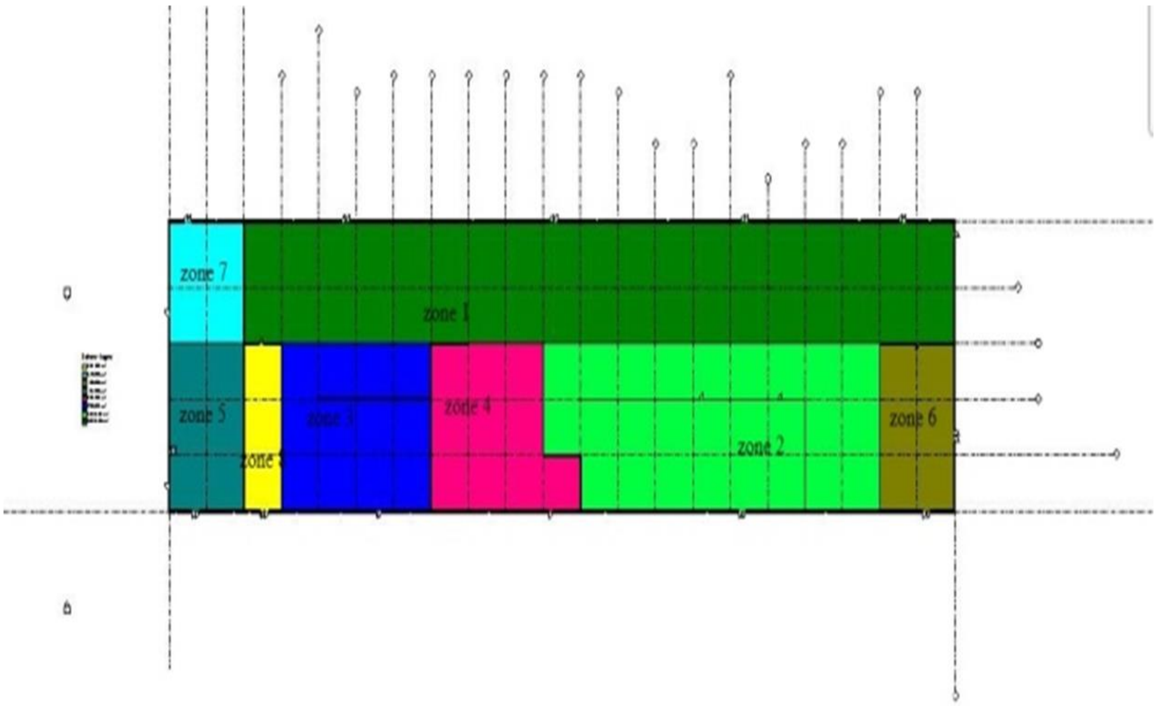

Figure 4.2: HVAC zones created in AutoCAD Revit

Table 4.5: Cooling Load simulation result in Autodesk Revit

No.	HVAC zone	Instant Sensible [KW]	Delayed Sensible [KW]	Latent [KW]	Total [KW]
1	zone 1	211.52	590.86	69.96	872.35
2	zone 2	131.96	368.62	43.64	544.23
3	zone 3	60.70	169.55	20.07	250.33
4	zone 4	50.58	141.30	16.73	208.62
5	zone 5	30.19	84.35	9.98	124.53
6	zone 6	30.169	84.27	9.97	124.42
7	zone 7	21.97	61.39	7.26	90.64
8	zone 8	15.00	41.91	4.96	61.87
	Total	**552.13**	**1542.28**	**182.61**	**2277.03**

From the above

Table 4.5, we can see that peak cooling load of terminal building is **2277.03 kW**

Table 4.6: Heating Load simulation result in AutoCAD Revit

No.	HVAC zone	Instant Sensible [KW]	Delayed Sensible [KW]	Latent [KW]	Total [KW]
1	zone 1	-284.35	-136.87	-36.86	-458.09
2	zone 2	-177.40	-85.39	-22.99	-285.79
3	zone 3	-81.59	-39.27	-10.57	-131.45

4	zone 4	-68.00	-32.73	-8.81	-109.55
5	zone 5	-40.59	-19.54	-5.26	-65.39
6	zone 6	-40.55	-19.52	-5.25	-65.33
7	zone 7	-29.54	-14.22	-3.83	-47.59
8	zone 8	-20.16	-9.70	-2.61	-32.49
	Total	**-742.23**	**-357.27**	**-96.21**	**-1195.72**

From the above Table 4.6, we can see that peak heating load of terminal building is **1195.72 kW**

4.3 Building energy simulation in Autodesk Insight

After creating building energy model in Autodesk Revit, building energy simulation was done in Autodesk Insight with the given building information, site location and other data. The energy use intensity of the terminal building of Pokhara International Airport 495kwh/m^2/yr. Figure 4.3 shows the output of energy simulation in Insight.

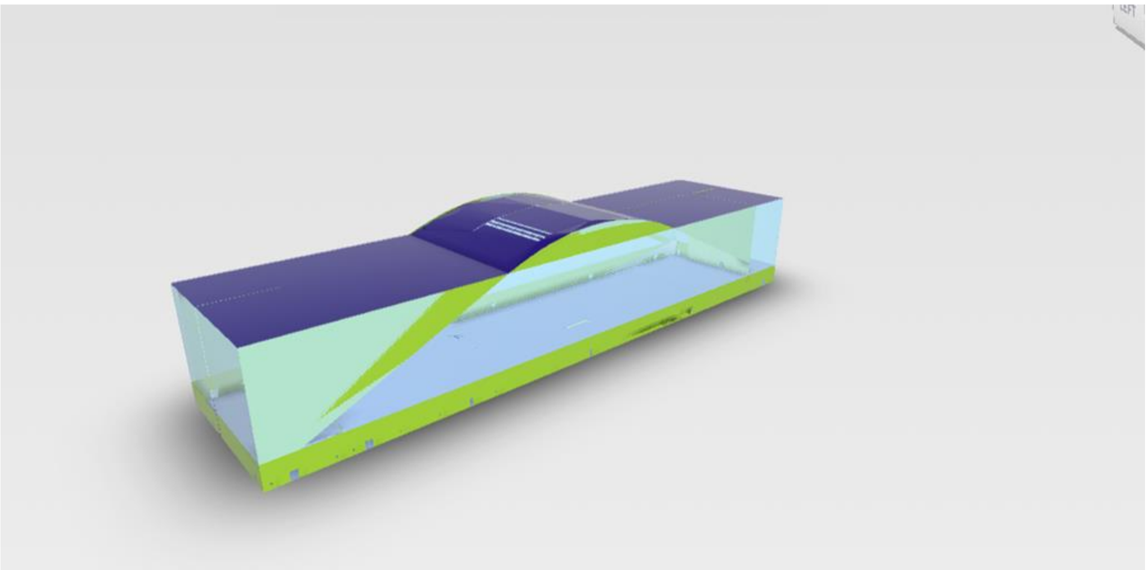

Figure 4.3: Energy model created by Autodesk Insight

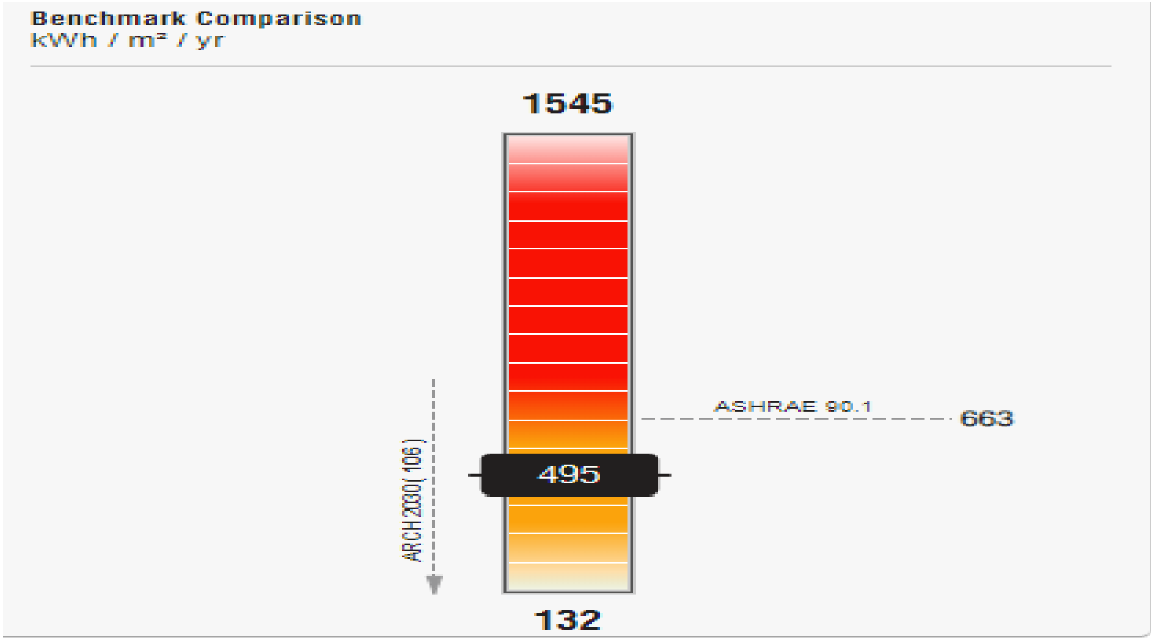

Figure 4.4: Benchmark comparison of Energy use intensity with ASHRAE 90.1

Figure 4.4 and 4.5 shows the energy use intensity of terminal building of Pokhara International Airport is 495kwh/m^2/yr. Which is efficient compared to ASHRAE 90.1 which is 663kwh/m^2/yr.

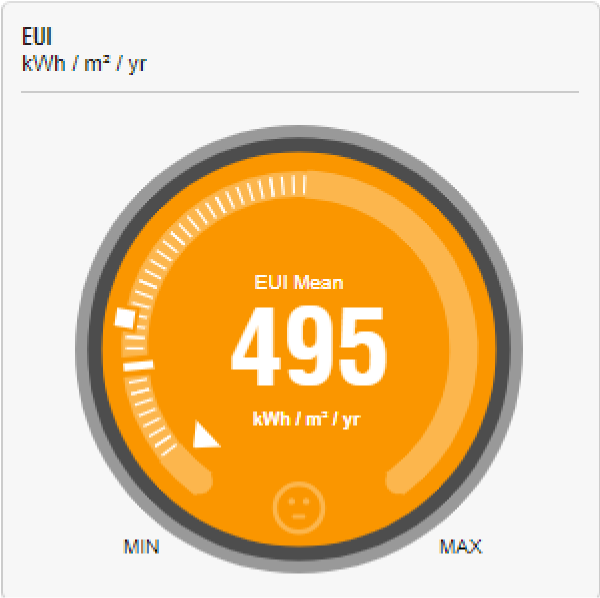

Figure 4.5: Energy use intensity of terminal building

4.4 Heat Recovery through air to air heat recovery

From the load calculation, we can see that fresh air load is significant, heat recovery can be of a significant important for saving energy.

Based on the fresh air requirement, the following heat recovery calculation has been done.

Table 4.7: Heat recovery calculation

CFM	**Q(Btu/hr.)**	**kW**	**Efficiency**	**Q(kW)**
30944.67	**601564.45**	**176.41**	**70%**	**123.48**

From the Table 4.7, we can see that 123.48 kW can be saved. This is almost 11% of total fresh air loads and almost 22% of the sensible load of the fresh air.

CHAPTER FIVE: CONCLUSIONS

5.1 Conclusion

The study conducted on the energy analysis of terminal building of Pokhara international airport was done smoothly. The study was mainly focused on the analysis of HVAC energy analysis and different factors affecting the energy consumption of HVAC system. According the load simulation done on Autodesk Revit, the cooling load of the terminal building is 2277.03 kW and subsequently the heating load of the terminal building is 1195.72 kW. The instant sensible cooling load is 552.13kW, delayed sensible cooling load is 1542.28 kW and latent cooling load is 182.61 kW. According instant sensible heating load is -742.23 kW, delayed sensible heating load is -357.27 kw and latent heating load is -96.21 kW. This load simulation shows that more energy is required for cooling than heating. Also due to high fresh air load sensible load is high

After the load analysis simulation of the HVAC system of the terminal building of Pokhara international airport was done, theoretical load calculation of the cooling load of the terminal building was conducted with varying air change per hour. The fresh air-cooling load at 2 air change per hour is 2082.72 kW, cooling load is 1160.86 kW and total cooling load is 32343.58 kW. At 1.5 air change per hour, the fresh air-cooling load is 1160.86 kW and total cooling load is 2722.9 kW. At 0.7 air change per hour, the fresh air-cooling load is 728.95 kW and total cooling load is 1889.81 kW. This shows that Air change per hour plays a important role in cooling load calculation and establishes that fact that increase in Air change per hour increase the overall cooling load of terminal building.

Building energy simulation was done in Autodesk Insight, the building energy use intensity of the terminal building of Pokhara international airport is 495 kWh/m^2/yr. Comparing this energy use intensity of terminal building of Pokhara international airport with ASHRAE 90.1, which is 663, the energy use intensity of terminal building is very efficient.

The CBECS report indicates the EUIs of 14 types of buildings. This research has been used 5000 measured data, it presents the survey results that the EUI of office buildings is 293.1kWh/$m2$ /yr., and Healthcare is 592.2kWh/$m2$ /yr., respectively. 55 However, Transportation buildings such as airports terminal, bus stations, train stations, subway stations, and ship berthing facilities are very different in terms of functionality and operational characteristics (Kim, Shin and Ahn, 2020)

The heat recovery calculation of the exhaust air was done and the room wise heat recovery has been calculated which amounts to 123.48 kW which is almost 11% of the total fresh air load of the building and almost 22% of the sensible load of the fresh air load of the terminal building.

5.2 Recommendations

The study concludes that fresh air load is very crucial in determining the cooling load in the terminal building of Pokhara international airport. The cooling load of HVAC system sharply rise with the rise in air change per hour. The standard ventilation rates should be formulated for the different sections of a terminal building for efficient selection of air change per hour according to the climatic conditions. Heat recovery system should be installed and utilized in terminal building of Pokhara International airport to recover the waste heat from exhaust air which can tap heat energy from waste exhaust air.

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Appendix I: **Cooling load with value of 2 ACH (Air change per Hour)**

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
1	101 Check-in office	1.36	4.51	5.87
2	102 International Passenger Arrivals Hall	71.48	140.19	211.67
3	103 Immigration waiting area	2.61	6.47	9.08
4	104 International passenger arrival hall	69.69	80.65	150.34
5	105 Unclaimed luggage	0.44	3.44	3.88
6	106 Staff security channel	2.25	7.02	9.26
7	107 Domestic passenger shuttle Hall	2.25	130.34	132.59
8	108 Domestic baggage reclaim hall	23.72	35.39	59.12
9	109 Galleria	7.38	22.61	29.99
10	110 International baggage reclaim hall, border	101.96	260.01	361.97
11	111 Domestic baggage sorting area	101.96	15.26	117.22
12	114 Office	1.17	2.98	4.15
13	115 Anti-terrorism emergency room	2.02	6.37	8.39
14	116 Alarm valve chamber	0.62	3.43	4.05

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
15	117 VIP area lobby	5.68	18.10	23.78
16	118 International flight boarding distal region	9.70	22.31	32.02
17	119 Security Center equipment room	6.49	8.48	14.97
18	120 Domestic VIP Room]	2.69	8.22	10.90
19	121 Exit border control	37.27	119.05	156.33
20	124 meet the media compartment	20.74	30.34	51.09
21	125 domestic VIP Room	2.74	9.36	12.09
22	126 Kokusai	3.86	7.05	10.91
23	128 International Joint Inspection District	8.64	7.57	16.21
24	129 female guard 7	1.62	5.45	7.07
25	130 M Guardian 7	1.33	3.83	5.16
26	133 Quarantine office	1.34	3.98	5.32
27	134 Luggage office	2.29	8.86	11.15
28	135 Distribution room	1.34	3.98	5.32
29	136 Quarantine office	1.34	3.98	5.32
30	137 International baggage sorting hall	12.91	19.60	32.51
31	139 M Guardian	2.05	3.92	5.98

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
32	140 M guard 3	2.60	6.37	8.97
33	141 Domestic baggage staging area	1.78	14.10	15.88
34	142 Female guard 1	1.37	4.82	6.19
35	144 M Wei 1	1.35	4.18	5.52
36	145 Domestic passenger screening area	55.20	117.39	172.59
37	146 M guard 2	1.35	4.19	5.54
38	147 Toilet 2	1.33	3.72	5.04
39	148 Shops	1.25	2.00	3.25
40	149 Children's rooms	0.98	2.41	3.39
41	151 Security channel	6.32	8.68	15.00
42	152 Domestic VIP Room	4.01	12.00	16.01
43	157 Media Release Lounge	3.52	8.10	11.62
44	158 Interdistribution between	6.92	33.62	40.54
45	160 Border Office	0.98	2.53	3.51
46	161 Room	1.38	4.99	6.37
47	162 Immigration Office	2.02	6.37	8.39
48	163 Room	1.76	1.78	3.55
49	164 Room	16.89	14.17	31.06

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
50	165 Substation control room	1.36	4.62	5.98
51	166 Room	1.39	5.10	6.48
52	168 Luggage inquiry	0.70	2.63	3.33
53	169 Unclaimed luggage	1.00	3.03	4.03
54	170 Female guard 3	1.40	5.35	6.74
55	171 Bathroom 6	1.25	2.00	3.26
56	173 Female guard 5	1.42	5.91	7.34
57	174 Quarantine office	1.32	3.63	4.95
58	176 Quarantine office	1.29	2.94	4.23
59	177 International baggage staging area	1.93	17.66	19.59
60	178 Room	9.70	13.39	23.09
61	179 Inter Security Operation Center	1.45	6.50	7.95
62	181 Clinic	1.36	4.58	5.94
63	182 Residues Wei	0.66	1.85	2.51
64	183 Border Office	1.43	6.00	7.42
65	184 Check-in space	1.31	3.40	4.71
66	185 Customs Office	0.98	2.42	3.40
67	186 female guard 4	1.36	4.54	5.90

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
68	187 luggage inquiry	1.32	3.63	4.95
69	188 customs houses	1.26	2.33	3.59
70	189 M guard 4	1.35	4.39	5.75
71	190 Border Office	1.39	5.11	6.50
72	191 center room between operations	1.31	3.35	4.66
73	192 center room between devices	6.41	6.56	12.96
74	193 broadcast studio	1.31	3.34	4.64
75	194 stowage compartment	0.70	2.74	3.45
76	195 Shops	1.62	3.87	5.50
77	4415 fire control room	1.36	4.61	5.97
78	4419 quarantine control room	1.28	2.79	4.07
79	4517 Border Office	2.05	1.78	3.83
80	4533 Police on duty houses	1.38	4.99	6.37
81	4534 [border control room]	1.38	4.99	6.37
82	4676 Wei	0.63	1.03	1.66
83	202 airline office	2.44	3.66	6.10
84	203 airline office	2.53	4.52	7.05
85	204 waiting area two compartments	11.85	21.23	33.07

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
86	205 seats near International Terminal	229.51	308.53	538.04
87	207 Galleria	13.13	19.00	32.12
88	208 Galleria	6.26	9.40	15.66
89	209 Restaurant (leasing)	13.29	21.12	34.41
90	210 Galleria	11.61	18.18	29.78
91	211 weak room	0.71	1.66	2.38
92	212 office	5.74	10.15	15.89
93	213 landside crew rest area	1.40	3.05	4.45
94	214 Boarding channel	19.25	25.94	45.19
95	215 Airside crew rest area	2.05	3.94	5.99
96	217 Isolation gallery	72.21	61.71	133.92
97	220 M guard 9	0.69	1.38	2.07
98	223 Prayer room	3.58	8.50	12.07
99	224 Smoking	1.29	1.66	2.95
100	225 female guard 9	1.06	1.50	2.56
101	227 International VVIP Terminal	4.67	12.17	16.84
102	230 office	1.35	2.35	3.70
103	235 office	10.23	19.19	29.42
104	237 security office	1.34	2.19	3.52

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
105	238 airline office	1.51	3.14	4.66
106	239 office	1.62	3.21	4.82
107	240 airline office	2.15	3.69	5.84
108	241 airline office	2.75	4.33	7.08
109	242 office	2.00	3.29	5.30
110	243 airline office	2.15	3.69	5.84
111	244 office	2.20	3.82	6.02
112	247 office	2.20	3.82	6.02
113	248 office	2.20	4.51	6.72
114	249 bathroom 8	2.45	5.24	7.69
115	250 toilet male guard 8	1.37	2.60	3.97
116	253 Customs Office	1.36	2.50	3.86
117	254 distribution chambers	1.36	2.50	3.86
118	255 security office	2.32	3.59	5.91
119	257 Weak engine room	1.33	2.15	3.48
120	258 Security office	2.04	3.73	5.76
121	261 Distribution room	2.04	2.06	4.10
122	1001 Channel staff	2.01	10.73	12.74
123	4722 VIP area	31.59	47.86	79.45
	Total	**1160.86**	**2082.72**	**3243.59**

Appendix II: **Cooling load with value of 1.5ACH (Air change per Hour)**

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
1	101 Check-in office	1.36	3.38	4.74
2	102 International Passenger Arrivals Hall	71.48	105.15	176.62
3	103 Immigration waiting area	2.61	4.86	7.47
4	104 International passenger arrival hall	69.69	60.49	130.18
5	105 Unclaimed luggage	0.44	2.58	3.02
6	106 Staff security channel	2.25	5.26	7.51
7	107 Domestic passenger shuttle Hall	2.25	97.76	100.00
8	108 Domestic baggage reclaim hall	23.72	26.55	50.27
9	109 Galleria	7.38	16.96	24.34
10	110 International baggage reclaim hall, border	101.96	195.01	296.97
11	111 Domestic baggage sorting area	101.96	11.45	113.41
12	114 Office	1.17	2.23	3.40
13	115 Anti-terrorism emergency room	2.02	4.78	6.80
14	116 Alarm valve chamber	0.62	2.57	3.19

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
15	117 VIP area lobby	5.68	13.58	19.26
16	118 International flight boarding distal region	9.70	16.73	26.44
17	119 Security Center equipment room	6.49	6.36	12.85
18	120 Domestic VIP Room]	2.69	6.16	8.85
19	121 Exit border control	37.27	89.29	126.56
20	124 meet the media compartment	20.74	22.76	43.50
21	125 domestic VIP Room	2.74	7.02	9.75
22	126 Kokusai	3.86	5.29	9.15
23	128 International Joint Inspection District	8.64	5.68	14.32
24	129 female guard 7	1.62	4.09	5.71
25	130 M Guardian 7	1.33	2.87	4.20
26	133 Quarantine office	1.34	2.99	4.32
27	134 Luggage office	2.29	6.65	8.94
28	135 Distribution room	1.34	2.99	4.32
29	136 Quarantine office	1.34	2.99	4.32
30	137 International baggage sorting hall	12.91	14.70	27.61
31	139 M Guardian	2.05	2.94	4.99

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
32	140 M guard 3	2.60	4.77	7.38
33	141 Domestic baggage staging area	1.78	10.58	12.35
34	142 Female guard 1	1.37	3.61	4.99
35	144 M Wei 1	1.35	3.13	4.48
36	145 Domestic passenger screening area	55.20	88.04	143.24
37	146 M guard 2	1.35	3.15	4.49
38	147 Toilet 2	1.33	2.79	4.11
39	148 Shops	1.25	1.50	2.75
40	149 Children's rooms	0.98	1.81	2.79
41	151 Security channel	6.32	6.51	12.83
42	152 Domestic VIP Room	4.01	9.00	13.01
43	157 Media Release Lounge	3.52	6.07	9.59
44	158 Interdistribution between	6.92	25.22	32.14
45	160 Border Office	0.98	1.89	2.88
46	161 Room	1.38	3.74	5.12
47	162 Immigration Office	2.02	4.78	6.80
48	163 Room	1.76	1.34	3.10
49	164 Room	16.89	10.63	27.52

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
50	165 Substation control room	1.36	3.46	4.83
51	166 Room	1.39	3.82	5.21
52	168 Luggage inquiry	0.70	1.97	2.67
53	169 Unclaimed luggage	1.00	2.27	3.27
54	170 Female guard 3	1.40	4.01	5.41
55	171 Bathroom 6	1.25	1.50	2.75
56	173 Female guard 5	1.42	4.44	5.86
57	174 Quarantine office	1.32	2.72	4.05
58	176 Quarantine office	1.29	2.21	3.50
59	177 International baggage staging area	1.93	13.24	15.18
60	178 Room	9.70	10.04	19.74
61	179 Inter Security Operation Center	1.45	4.88	6.32
62	181 Clinic	1.36	3.43	4.80
63	182 Residues Wei	0.66	1.39	2.05
64	183 Border Office	1.43	4.50	5.92
65	184 Check-in space	1.31	2.55	3.86
66	185 Customs Office	0.98	1.82	2.79
67	186 female guard 4	1.36	3.40	4.77

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
68	187 luggage inquiry	1.32	2.72	4.05
69	188 customs houses	1.26	1.75	3.01
70	189 M guard 4	1.35	3.29	4.65
71	190 Border Office	1.39	3.83	5.22
72	191 center room between operations	1.31	2.51	3.82
73	192 center room between devices	6.41	4.92	11.32
74	193 broadcast studio	1.31	2.50	3.81
75	194 stowage compartment	0.70	2.06	2.76
76	195 Shops	1.62	2.91	4.53
77	4415 fire control room	1.36	3.46	4.82
78	4419 quarantine control room	1.28	2.09	3.37
79	4517 Border Office	2.05	1.34	3.39
80	4533 Police on duty houses	1.38	3.74	5.12
81	4534 [border control room]	1.38	3.74	5.12
82	4676 Wei	0.63	0.77	1.40
83	202 airline office	2.44	2.74	5.18
84	203 airline office	2.53	3.39	5.92

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
85	204 waiting area two compartments	11.85	15.92	27.77
86	205 seats near International Terminal	229.51	231.40	460.90
87	207 Galleria	13.13	14.25	27.37
88	208 Galleria	6.26	7.05	13.31
89	209 Restaurant (leasing)	13.29	15.84	29.13
90	210 Galleria	11.61	13.63	25.24
91	211 weak room	0.71	1.25	1.96
92	212 office	5.74	7.61	13.35
93	213 landside crew rest area	1.40	2.29	3.69
94	214 Boarding channel	19.25	19.46	38.70
95	215 Airside crew rest area	2.05	2.95	5.01
96	217 Isolation gallery	72.21	46.28	118.50
97	220 M guard 9	0.69	1.04	1.73
98	223 Prayer room	3.58	6.37	9.95
99	224 Smoking	1.29	1.24	2.54
100	225 female guard 9	1.06	1.13	2.19
101	227 International VVIP Terminal	4.67	9.13	13.80
102	230 office	1.35	1.76	3.11

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
103	235 office	10.23	14.39	24.63
104	237 security office	1.34	1.64	2.98
105	238 airline office	1.51	2.36	3.87
106	239 office	1.62	2.41	4.02
107	240 airline office	2.15	2.76	4.92
108	241 airline office	2.75	3.25	6.00
109	242 office	2.00	2.47	4.47
110	243 airline office	2.15	2.76	4.92
111	244 office	2.20	2.86	5.07
112	247 office	2.20	2.86	5.07
113	248 office	2.20	3.39	5.59
114	249 bathroom 8	2.45	3.93	6.38
115	250 toilet male guard 8	1.37	1.95	3.32
116	253 Customs Office	1.36	1.88	3.23
117	254 distribution chamber	1.36	1.88	3.23
118	255 security office	2.32	2.69	5.01
119	257 Weak engine room	1.33	1.61	2.94
120	258 Security office	2.04	2.79	4.83
121	261 Distribution room	2.04	1.54	3.58
122	1001 Channel staff	2.01	8.05	10.06

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
123	4722 VIP area	31.59	35.90	67.48
	Total	**1160.86**	**1562.04**	**2722.91**

Appendix III: Cooling load with value of 0.7ACH (Air change per Hour)

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
1	101 Check-in office	1.36	1.58	2.94
2	102 International Passenger Arrivals Hall	71.48	49.07	120.55
3	103 Immigration waiting area	2.61	2.27	4.88
4	104 International passenger arrival hall	69.69	28.23	97.92
5	105 Unclaimed luggage	0.44	1.20	1.64
6	106 Staff security channel	2.25	2.46	4.70
7	107 Domestic passenger shuttle Hall	2.25	45.62	47.86
8	108 Domestic baggage reclaim hall	23.72	12.39	36.11
9	109 Galleria	7.38	7.91	15.30
10	110 International baggage reclaim hall, border	101.96	91.00	192.96
11	111 Domestic baggage sorting area	101.96	5.34	107.30
12	114 Office	1.17	1.04	2.21
13	115 Anti-terrorism emergency room	2.02	2.23	4.25
14	116 Alarm valve chamber	0.62	1.20	1.82

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
15	117 VIP area lobby	5.68	6.34	12.01
16	118 International flight boarding distal region	9.70	7.81	17.51
17	119 Security Center equipment room	6.49	2.97	9.46
18	120 Domestic VIP Room]	2.69	2.88	5.56
19	121 Exit border control	37.27	41.67	78.94
20	124 meet the media compartment	20.74	10.62	31.36
21	125 domestic VIP Room	2.74	3.28	6.01
22	126 Kokusai	3.86	2.47	6.33
23	128 International Joint Inspection District	8.64	2.65	11.29
24	129 female guard 7	1.62	1.91	3.53
25	130 M Guardian 7	1.33	1.34	2.67
26	133 Quarantine office	1.34	1.39	2.73
27	134 Luggage office	2.29	3.10	5.39
28	135 Distribution room	1.34	1.39	2.73
29	136 Quarantine office	1.34	1.39	2.73
30	137 International baggage sorting hall	12.91	6.86	19.77
31	139 M Guardian	2.05	1.37	3.42

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
32	140 M guard 3	2.60	2.23	4.83
33	141 Domestic baggage staging area	1.78	4.94	6.71
34	142 Female guard 1	1.37	1.69	3.06
35	144 M Wei 1	1.35	1.46	2.81
36	145 Domestic passenger screening area	55.20	41.09	96.29
37	146 M guard 2	1.35	1.47	2.81
38	147 Toilet 2	1.33	1.30	2.63
39	148 Shops	1.25	0.70	1.95
40	149 Children's rooms	0.98	0.84	1.82
41	151 Security channel	6.32	3.04	9.36
42	152 Domestic VIP Room	4.01	4.20	8.21
43	157 Media Release Lounge	3.52	2.83	6.35
44	158 Interdistribution between	6.92	11.77	18.69
45	160 Border Office	0.98	0.88	1.87
46	161 Room	1.38	1.75	3.13
47	162 Immigration Office	2.02	2.23	4.25
48	163 Room	1.76	0.62	2.39
49	164 Room	16.89	4.96	21.85

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
50	165 Substation control room	1.36	1.62	2.98
51	166 Room	1.39	1.78	3.17
52	168 Luggage inquiry	0.70	0.92	1.62
53	169 Unclaimed luggage	1.00	1.06	2.06
54	170 Female guard 3	1.40	1.87	3.27
55	171 Bathroom 6	1.25	0.70	1.95
56	173 Female guard 5	1.42	2.07	3.49
57	174 Quarantine office	1.32	1.27	2.59
58	176 Quarantine office	1.29	1.03	2.32
59	177 International baggage staging area	1.93	6.18	8.12
60	178 Room	9.70	4.69	14.39
61	179 Inter Security Operation Center	1.45	2.28	3.72
62	181 Clinic	1.36	1.60	2.97
63	182 Residues Wei	0.66	0.65	1.31
64	183 Border Office	1.43	2.10	3.52
65	184 Check-in space	1.31	1.19	2.50
66	185 Customs Office	0.98	0.85	1.83
67	186 female guard 4	1.36	1.59	2.95

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
68	187 luggage inquiry	1.32	1.27	2.59
69	188 customs houses	1.26	0.82	2.08
70	189 M guard 4	1.35	1.54	2.89
71	190 Border Office	1.39	1.79	3.17
72	191 center room between operations	1.31	1.17	2.48
73	192 center room between devices	6.41	2.29	8.70
74	193 broadcast studio	1.31	1.17	2.48
75	194 stowage compartment	0.70	0.96	1.66
76	195 Shops	1.62	1.36	2.98
77	4415 fire control room	1.36	1.61	2.98
78	4419 quarantine control room	1.28	0.98	2.26
79	4517 Border Office	2.05	0.62	2.68
80	4533 Police on duty houses	1.38	1.75	3.13
81	4534 [border control room]	1.38	1.75	3.13
82	4676 Wei	0.63	0.36	0.99
83	202 airline office	2.44	1.28	3.72
84	203 airline office	2.53	1.58	4.11

No	Room	Cooling Load (KW)	Fresh Air cooling Load (KW)	Total cooling Load (KW)
85	204 waiting area two compartments	11.85	7.43	19.28
86	205 seats near International Terminal	229.51	107.98	337.49
87	207 Galleria	13.13	6.65	19.77
88	208 Galleria	6.26	3.29	9.55
89	209 Restaurant (leasing)	13.29	7.39	20.68
90	210 Galleria	11.61	6.36	17.97
91	211 weak room	0.71	0.58	1.30
92	212 office	5.74	3.55	9.29
93	213 landside crew rest area	1.40	1.07	2.47
94	214 Boarding channel	19.25	9.08	28.33
95	215 Airside crew rest area	2.05	1.38	3.43
96	217 Isolation gallery	72.21	21.60	93.81
97	220 M guard 9	0.69	0.48	1.17
98	223 Prayer room	3.58	2.97	6.55
99	224 Smoking	1.29	0.58	1.87
100	225 female guard 9	1.06	0.53	1.59
101	227 International VVIP Terminal	4.67	4.26	8.93
102	230 office	1.35	0.82	2.17

103	235 office	10.23	6.72	16.95
104	237 security office	1.34	0.77	2.10
105	238 airline office	1.51	1.10	2.61
106	239 office	1.62	1.12	2.74
107	240 airline office	2.15	1.29	3.44
108	241 airline office	2.75	1.52	4.27
109	242 office	2.00	1.15	3.16
110	243 airline office	2.15	1.29	3.44
111	244 office	2.20	1.34	3.54
112	247 office	2.20	1.34	3.54
113	248 office	2.20	1.58	3.78
114	249 bathroom 8	2.45	1.84	4.28
115	250 toilet male guard 8	1.37	0.91	2.28
116	253 Customs Office	1.36	0.88	2.23
117	254 distribution chamber	1.36	0.88	2.23
118	255 security office	2.32	1.26	3.57
119	257 Weak engine room	1.33	0.75	2.08
120	258 Security office	2.04	1.30	3.34
121	261 Distribution room	2.04	0.72	2.76
122	1001 Channel staff	2.01	3.76	5.76
123	4722 VIP area	31.59	16.75	48.34
	Total	**1160.86**	**728.95**	**1889.82**

Appendix IV: Heat Recovery Calculation

No	Room	CFM	Q(Btu/hr.)	kw	Efficiency	Q(kW)
1	101 Check-in office	47.09	915.36	0.27	0.70	0.19
2	102 International Passenger Arrivals Hall	1412.60	27460.86	8.05	0.70	5.64
3	103 Immigration waiting area	94.17	1830.72	0.54	0.70	0.38
4	104 International passenger arrival hall	1765.74	34326.07	10.07	0.70	7.05
5	105 Unclaimed luggage	11.77	228.84	0.07	0.70	0.05
6	106 Staff security channel	47.09	915.36	0.27	0.70	0.19
7	107 Domestic passenger shuttle Hall	2207.18	42907.59	12.58	0.70	8.81
8	108 Domestic baggage reclaim hall	588.58	11442.02	3.36	0.70	2.35
9	109 Galleria	258.98	5034.49	1.48	0.70	1.03
10	110 International baggage reclaim hall, border	3531.49	68652.15	20.13	0.70	14.09
11	111 Domestic baggage sorting area	176.57	3432.61	1.01	0.70	0.70
12	114 Office	23.54	457.68	0.13	0.70	0.09

No	Room	CFM	Q(Btu/hr.)	kw	Efficiency	Q(kW)
13	115 Anti-terrorism emergency room	70.63	1373.04	0.40	0.70	0.28
14	116 Alarm valve chamber	0.00	0.00	0.00	0.70	0.00
15	117 VIP area lobby	94.17	1830.72	0.54	0.70	0.38
16	118 International flight boarding distal region	258.98	5034.49	1.48	0.70	1.03
17	119 Security Center equipment room	0.00	0.00	0.00	0.70	0.00
18	120 Domestic VIP Room]	94.17	1830.72	0.54	0.70	0.38
19	121 Exit border control	1177.16	22884.05	6.71	0.70	4.70
20	124 meet the media compartment	588.58	11442.02	3.36	0.70	2.35
21	125 domestic VIP Room	94.17	1830.72	0.54	0.70	0.38
22	126 Kokusai	47.09	915.36	0.27	0.70	0.19
23	128 International Joint Inspection District	235.43	4576.81	1.34	0.70	0.94
24	129 female guard 7	47.09	915.36	0.27	0.70	0.19
25	130 M Guardian 7	47.09	915.36	0.27	0.70	0.19
26	133 Quarantine office	47.09	915.36	0.27	0.70	0.19
27	134 Luggage office	47.09	915.36	0.27	0.70	0.19

No	Room	CFM	Q(Btu/hr.)	kw	Efficiency	Q(kW)
28	135 Distribution room	47.09	915.36	0.27	0.70	0.19
29	136 Quarantine office	47.09	915.36	0.27	0.70	0.19
30	137 International baggage sorting hall	235.43	4576.81	1.34	0.70	0.94
31	139 M Guardian	47.09	915.36	0.27	0.70	0.19
32	140 M guard 3	94.17	1830.72	0.54	0.70	0.38
33	141 Domestic baggage staging area	47.09	915.36	0.27	0.70	0.19
34	142 Female guard 1	47.09	915.36	0.27	0.70	0.19
35	144 M Wei 1	47.09	915.36	0.27	0.70	0.19
36	145 Domestic passenger screening area	1765.74	34326.07	10.07	0.70	7.05
37	146 M guard 2	47.09	915.36	0.27	0.70	0.19
38	147 Toilet 2	47.09	915.36	0.27	0.70	0.19
39	148 Shops	47.09	915.36	0.27	0.70	0.19
40	149 Children's rooms	35.31	686.52	0.20	0.70	0.14
41	151 Security channel	176.57	3432.61	1.01	0.70	0.70
42	152 Domestic VIP Room	141.26	2746.09	0.81	0.70	0.56
43	157 Media Release Lounge	132.43	2574.46	0.75	0.70	0.53
44	158 Interdistribution between	47.09	915.36	0.27	0.70	0.19

No	Room	CFM	Q(Btu/hr.)	kw	Efficiency	Q(kW)
45	160 Border Office	35.31	686.52	0.20	0.70	0.14
46	161 Room	47.09	915.36	0.27	0.70	0.19
47	162 Immigration Office	70.63	1373.04	0.40	0.70	0.28
48	163 Room	35.31	686.52	0.20	0.70	0.14
49	164 Room	47.09	915.36	0.27	0.70	0.19
50	165 Substation control room	47.09	915.36	0.27	0.70	0.19
51	166 Room	47.09	915.36	0.27	0.70	0.19
52	168 Luggage inquiry	23.54	457.68	0.13	0.70	0.09
53	169 Unclaimed luggage	11.77	228.84	0.07	0.70	0.05
54	170 Female guard 3	47.09	915.36	0.27	0.70	0.19
55	171 Bathroom 6	47.09	915.36	0.27	0.70	0.19
56	173 Female guard 5	47.09	915.36	0.27	0.70	0.19
57	174 Quarantine office	47.09	915.36	0.27	0.70	0.19
58	176 Quarantine office	47.09	915.36	0.27	0.70	0.19
59	177 International baggage staging area	47.09	915.36	0.27	0.70	0.19
60	178 Room	47.09	915.36	0.27	0.70	0.19
61	179 Inter Security Operation Center	47.09	915.36	0.27	0.70	0.19
62	181 Clinic	47.09	915.36	0.27	0.70	0.19

No	Room	CFM	Q(Btu/hr.)	kw	Efficiency	Q(kW)
63	182 Residues Wei	47.09	915.36	0.27	0.70	0.19
64	183 Border Office	47.09	915.36	0.27	0.70	0.19
65	184 Check-in space	47.09	915.36	0.27	0.70	0.19
66	185 Customs Office	35.31	686.52	0.20	0.70	0.14
67	186 female guard 4	47.09	915.36	0.27	0.70	0.19
68	187 luggage inquiry	47.09	915.36	0.27	0.70	0.19
69	188 customs houses	47.09	915.36	0.27	0.70	0.19
70	189 M guard 4	47.09	915.36	0.27	0.70	0.19
71	190 Border Office	47.09	915.36	0.27	0.70	0.19
72	191 center room between operations	47.09	915.36	0.27	0.70	0.19
73	192 center room between devices	0.00	0.00	0.00	0.70	0.00
74	193 broadcast studio	47.09	915.36	0.27	0.70	0.19
75	194 stowage compartment	23.54	457.68	0.13	0.70	0.09
76	195 Shops	58.86	1144.20	0.34	0.70	0.23
77	4415 fire control room	47.09	915.36	0.27	0.70	0.19
78	4419 quarantine control room	47.09	915.36	0.27	0.70	0.19
79	4517 Border Office	47.09	915.36	0.27	0.70	0.19

No	Room	CFM	Q(Btu/hr.)	kw	Efficiency	Q(kW)
80	4533 Police on duty houses	47.09	915.36	0.27	0.70	0.19
81	4534 [border control room]	47.09	915.36	0.27	0.70	0.19
82	4676 Wei	23.54	457.68	0.13	0.70	0.09
83	202 airline office	82.40	1601.88	0.47	0.70	0.33
84	203 airline office	82.40	1601.88	0.47	0.70	0.33
85	204 waiting area two compartments	412.01	8009.42	2.35	0.70	1.64
86	205 seats near International Terminal	7062.98	137304.30	40.27	0.70	28.19
87	207 Galleria	470.87	9153.62	2.68	0.70	1.88
88	208 Galleria	223.66	4347.97	1.28	0.70	0.89
89	209 Restaurant (leasing)	470.87	9153.62	2.68	0.70	1.88
90	210 Galleria	412.01	8009.42	2.35	0.70	1.64
91	211 weak room	23.54	457.68	0.13	0.70	0.09
92	212 office	176.57	3432.61	1.01	0.70	0.70
93	213 landside crew rest area	47.09	915.36	0.27	0.70	0.19
94	214 Boarding channel	470.87	9153.62	2.68	0.70	1.88
95	215 Airside crew rest area	70.63	1373.04	0.40	0.70	0.28
96	217 Isolation gallery	353.15	6865.21	2.01	0.70	1.41

No	Room	CFM	Q(Btu/hr.)	kw	Efficiency	Q(kW)
97	220 M guard 9	23.54	457.68	0.13	0.70	0.09
98	223 Prayer room	117.72	2288.40	0.67	0.70	0.47
99	224 Smoking	47.09	915.36	0.27	0.70	0.19
100	225 female guard 9	35.31	686.52	0.20	0.70	0.14
101	227 International VVIP Terminal	141.26	2746.09	0.81	0.70	0.56
102	230 office	47.09	915.36	0.27	0.70	0.19
103	235 office	353.15	6865.21	2.01	0.70	1.41
104	237 security office	47.09	915.36	0.27	0.70	0.19
105	238 airline office	47.09	915.36	0.27	0.70	0.19
106	239 office	47.09	915.36	0.27	0.70	0.19
107	240 airline office	70.63	1373.04	0.40	0.70	0.28
108	241 airline office	82.40	1601.88	0.47	0.70	0.33
109	242 office	70.63	1373.04	0.40	0.70	0.28
110	243 airline office	70.63	1373.04	0.40	0.70	0.28
111	244 office	70.63	1373.04	0.40	0.70	0.28
112	247 office	70.63	1373.04	0.40	0.70	0.28
113	248 office	82.40	1601.88	0.47	0.70	0.33
114	249 bathroom 8	82.40	1601.88	0.47	0.70	0.33
115	250 toilet male guard 8	47.09	915.36	0.27	0.70	0.19
116	253 Customs Office	47.09	915.36	0.27	0.70	0.19

No	Room	CFM	Q(Btu/hr.)	kw	Efficiency	Q(kW)
117	254 distribution chamber	47.09	915.36	0.27	0.70	0.19
118	255 security office	82.40	1601.88	0.47	0.70	0.33
119	257 Weak engine room	47.09	915.36	0.27	0.70	0.19
120	258 Security office	70.63	1373.04	0.40	0.70	0.28
121	261 Distribution room	47.09	915.36	0.27	0.70	0.19
122	1001 Channel staff	47.09	915.36	0.27	0.70	0.19
123	4722 VIP area	941.73	18307.24	5.37	0.70	3.76
Total						**123.49**

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Signed Ashish Agarwal

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