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Comprehensive Thermal and HVAC Load Analysis for a Three-Story Residential Building using Radiant Load Factor (RLF) Method



A report submitted as part of the requirements for the degree
of Mechanical Engineering
at the School of Mechanical and Manufacturing Engineering (SMME)
National University of Sciences and Technology (NUST)
Islamabad, Pakistan

Tuesday 27th May, 2025

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Abstract

This complex engineering design project presents a thorough and methodical approach to HVAC load calculation for a modern three-story residential building situated in Rawalpindi, Pakistan, by making use of well-implemented and advanced Radiant Load Factor (RLF) method in order to ensure precision, efficiency, and sustainability. The study highlights and addresses the critical need for accurate thermal load evaluation in modern residential structures, where conventional methods often tend to not provide accurate calculation due to oversimplified assumptions and failure to consider dynamic thermal interactions. The selection of RLF method is due to its ability to effectively model radiant heat transfer and time-delayed thermal effects—key factors often neglected in traditional load calculations. The project meticulously evaluates envelope performance while considering the structural interfaces such as walls, windows, and roofing systems, while also taking into account the internal heat gains from occupants, lighting, and appliances. Considering peak load conditions, great attention is provided while ensuring that the performance of HVAC system is not compromised in either way, accounting for energy wastage and increasing capital costs.

Apart from load calculations, this project highlights some actionable information for HVAC system design, including zoning strategies, equipment selection, and ventilation requirements. The outcome is a robust framework that not only meets immediate thermal comfort needs but also aligns with sustainable building practices and energy conservation standards.

Acknowledgements

We would like to extend our sincere gratitude to the School of Mechanical and Manufacturing Engineering (SMME) for providing a robust and collaborative academic environment and the resources necessary to undertake this project. We are especially thankful to Dr.Waqas Khalid for his invaluable guidance, insightful feedback, and continuous encouragement throughout the course of this complex engineering problem. His mentorship has greatly enhanced our understanding of HVAC Load calculation and its importance in practical world. This work would not have been possible without his expert supervision and the academic support provided by SMME.

Declaration

We, Abdullah Hamid, Mowahhid bin Safdar, Muhaimin Zia, Muhammad Abdullah Zafar Ghauri and Muhammad Azhaf Zeeshan of School of Mechanical and Manufacturing Engineering (SMME), National University of Sciences and Technology, confirm that the work mentioned in this report has been precariously devised with much consultation, deliberation and consensus and the mentioned data including figures, tables, equations, artworks, and illustrations in this report are original and have not been taken from any other person's work, except where the works of others have been explicitly acknowledged, quoted, and referenced. We hereby understand that if failing to do so will be considered a case of plagiarism. Plagiarism is a form of academic misconduct and will be penalized accordingly.

Date Tuesday 27th May, 2025

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Chapter 1

Objectives and Scope

1.1 Problem Statement

The effective and accurate HVAC load evaluation for multi-story residential buildings still remains a strong and irrevocable challenge in building services engineering, predominantly in regions with extreme climatic conditions. Typical old-fashioned calculation methods and algorithms tend to experience critical limitations which cumulatively compromise system performance. Static modeling approaches fail to account for the dynamic nature of heat transfer through building envelopes, especially the time-delayed radiant effects in high-mass construction materials. Ignoring this parameter results in systemic oversizing of 30-50% beyond actual requirements, which leads to unnecessary capital expenditure and operational inefficiencies. In addition to that, the typical conventional tools generally rely upon typical weather data which ineffectively represent microclimate variations and extreme temperature differentials (often exceeding 18°C in Rawalpindi's summer conditions), leading to inconsistency between predicted and actual loads. The complex interactions between solar gain patterns, internal heat generation, and occupancy schedules are ignored in traditional methods, which ultimately lead to comfort issues like temperature stratification exceeding 2°C between floors, violating the ASHRAE comfort standards. These methodological shortcomings tend to dominate in HVAC systems which are simultaneously energy-inefficient, comfort-compromising, and cost-prohibitive. The Radiant Load Factor (RLF) methodology proposed in this study directly addresses these gaps through time-resolved heat transfer analysis, climate-specific radiant time series, and whole-building zonal coupling algorithms, offering a

dynamic and effective solution to these long-standing industry challenges.

1.2 Objectives

This complex engineering design problem aims at developing a comprehensive HVAC load calculation methodology for a three-story residential building, located in suburbs of Rawalpindi, Pakistan, with the primary objective of achieving precise thermal load characterization through Radiant Load Factor (RLF) analysis. The project aims at:

- Developing accurate heating/cooling profiles using RLF methodology, while accounting for radiant time delays in building materials, solar gain variations by orientations and occupancy-driven internal loads.
- The project aims at effective system optimization by eliminating the HVAC oversizing (while targeting $\pm 5\%$ accuracy in calculations) ,identifying zone-specific load characteristics and balancing initial cost vs. operational efficiency.
- The project tends to emphasize the climate adaptation by addressing the extreme summer weather of Rawalpindi (where temperatures tend to exceed beyond 42^{o}C and incorporating the monsoon humidity effects while optimizing the system for seasonal temperature swings
- The load calculations comply with the standards set forth by ECBC 2023 Pakistan and exceeding ASHRAE 90.1-2022 benchmarks and allowing for future renewable energy intergration whenever possible

1.3 Scope

This design project establishes an effective methodological framework for all thermal load components which influence the HVAC system design, including:

- The systematic assessment of all important thermal load components which graetly affect the building energy performance while including but not limited to envelope transmission, solar radiation, and internal heat gains
- The development of standardized calculation procedures which are compatible and adaptable to continuously varying architectural configurations and climatic conditions

- The formulation of load evaluation techniques which account for dynamic interactions between building elements and environmental factors
- The identification of some key parameters which require special consideration in residential HVAC design

The methodology will be demonstrated through application to a representative three-story residential structure, for which the results serve as validation case rather than tedious and complex system specification. All calculations will adhere to internationally recognized engineering standards while remaining adaptable to regional building practices.

Chapter 2

Introduction

Global Energy Context

The built environment accounts for 36% of worldwide final energy consumption and nearly 40% of energy-related CO_2 emissions according to the Global Alliance for Buildings and Construction [17]. Within this sector, space cooling demand has tripled since 1990, which itself is one of the highest energy-consuming areas in the world. Heat energy from environment is used to drive the vapor absorption cooling system (VACS) runs on heat energy, where the heat energy can be obtained from solar energy, geothermal, waste heat from any power plant, natural oils, fuels, etc. Also, it operates with natural working pairs that seem to be economical and eco-friendly space-cooling technology. As the requirement of space cooling is directly proportional to solar heat, if space cooling can be operated by solar heat then it will be the best supply and demand matching. However, this system has several research challenges such as lower performance, bulkier size, and cost in comparison to the vapor compression cooling system [3]. Space cooling is gradually becoming the fastest growing end-use in buildings [1]. This surge is particularly acute in developing economies, where cooling degree days (CDD) have increased by 25% since 2000 due to climate change [24]. The daily cooling degree-days (CDDs) refer to the difference between the mean temperature and the base cooling temperature of 18.3 °C as given by 2.1, and have the same unit as temperature. When the mean temperature is below the base temperature then the cooling degree-day for that day is zero [19].

$$CDD = T_m - T_b \tag{2.1}$$

where

$$T_m = \frac{T_{max} + T_{min}}{2}$$

The International Energy Agency projects that without radical efficiency improvements, global cooling energy demand will consume 6,500 TWh annually by 2050 - equivalent to the current total electricity generation of the United States and European Union combined [1].

Historical Development of Load Calculation Methods

The science of thermal load calculation has evolved through four distinct generations:

Table 2.1: Evolution of HVAC Load Calculation Methodologies

Era	**Method**	**Limitations**
1930-1950	Rule-of-thumb (W/m^2)	No climate differentiation [9]
1950-1970	Degree-day methods	Neglects thermal mass [4]
1970-2000	Transfer Function (TFM)	Static solar gain models [27]
2000-present	Heat Balance (HBM)	Computational complexity [30]

The Radiant Load Factor (RLF) method emerges as a fifth-generation approach, synthesizing advances from:

- Radiant time series (RTS) mathematics [29]
- Computational fluid dynamics (CFD) validation [31]
- Machine learning optimization [11]

Physics of Building Heat Transfer

Building thermal loads originate from three principal mechanisms:

Conductive Heat Flow obeys Fourier's Law, which states that the heat transfer due to interaction between two surfaces is directly proportional to the cross sectional area

of surface and the established temperature gradient and inversely proportional to the distance between the surfaces, as established by the following equation 2.3:

$$q_{cond} = -kA\frac{dT}{dx} \tag{2.2}$$

where the temperature gradient (dT/dx) becomes nonlinear in composite walls [22].

Convective Exchange Convective exchange corresponds to the heat transfer through the phenomenon of convection, which states that the heat transfer is directly proportional to the temperature gradient and the surface area of interfaces. It is however necessary to mention that teh phenomenon of convection is accomplished between a fluidic interface and a solid interface, governed by the Newton's Law of Cooling as:

$$q_{conv} = hA_s(T_{surf} - T_{air}) \tag{2.3}$$

with convection coefficients (h) varying from 2-25W/m^2K depending on surface orientation [6].

Radiant Transfer Radiant Transfer corresponds to the heat transfer accomplished by the phenomenon of radiation, in which electromagnetic radiations serve as medium for transmitting of energy. The phenomenon of radiation is univresal and does not correspond to the physical presence of media as electromagnetic radiations, due to large wavelengths, can travel even through the vacuum. Stefan-Boltzmann Law governs the radiative heat transfer, as implied from the following equation 2.4:

$$q_{rad} = \epsilon\sigma A(T_{surf}^4 - T_{env}^4) \tag{2.4}$$

where mean radiant temperature (T_{env}) requires view factor analysis [20].

Tropical Climate Challenges

Tropical environments, especially within the Asia, tend to have unique ambient effects required for extensive consideration in process facilities and installed equipment. Climatic factors such as heavy rains (monsoons, hurricanes, typhoons, etc.), animal or insect infestations, and direct sunlight exposure are the most common concerns for typical systems in the surroundings[26]. The South Asian megacity environment presents unique thermal complications: where some important microcliamtic phenomena consisting of following

- **Urban Heat Island (UHI)**: 2.5-4.5^{o}C warmer than rural areas [7]. The Urban Heat Island correspond to the phenomenon where high temperatures are experienced by cities in comparison with surrounding area due to factors such as reduction in vegetation, impervious surfaces and building accumulating thermal energy which consequently result in modification in habitat and posed risks to ecosystem and public health [28].
- **Dust Deposition**: Reduces surface incidence light ratio by 15-30% [25]. Excessive accumulation of dust on surfaces lead to increased rate of corrosion on energy generating surfaces such as photovoltaic panels which consequently results in decreased efficiency and less production of energy [12].
- **Humidification**: Monsoon relative humidity increases latent loads by 40% [18]

Building Envelope Dynamics

Modern residential construction in Pakistan employs diverse materials:

Table 2.2: Thermal Properties of Common Building Materials

Material	**Conductivity (W/mK)**	**Heat Capacity (kJ/m^{3}K)**	
Red Brick	0.72	1360	[23, 13]
RCC	1.8	2100	
Hollow Blocks	0.45	780	
AAC Blocks	0.21	950	

The thermal lag (τ) through 230mm brick walls can be calculated as:

$$\tau = \frac{L^2}{\alpha} = \frac{(0.23)^2}{5.2 \times 10^{-7}} \approx 10.2 \; hours \tag{2.5}$$

where α is thermal diffusivity [10].

Fenestration Impacts

Building fenestration which include windows, doors, solar irradiance play an important role in maintaining an efefctive connection between the interior and exterior of buildings, howver they are also the weakest in terms of allowing heat loss, heat gain and penetration of light [16]. Windows contribute 25-40% of cooling loads in Pakistani residences [15].

The solar heat gain coefficient (SHGC) varies significantly: Modern low-e coatings can reduce SHGC by:

$$\Delta SHGC = 0.87 - 0.25e^{-0.13t} \tag{2.6}$$

where t is coating thickness in nanometers [8].

Internal Load Considerations

Contemporary households exhibit complex load profiles:

Table 2.3: Residential Equipment Load Densities

Appliance	**Power (W)**	**Diversity Factor**
LED Lighting	5-10/m²	0.7
Refrigerator	150-300	0.9
AC Unit	2000-5000	1.0
Electronics	100-500	0.4

[14, 21]

The coincidence factor (CF) for simultaneous operation is:

$$CF = 0.6 + 0.4e^{-0.02\Delta t} \tag{2.7}$$

where Δt is time interval in minutes [2].

Chapter 3

Design

The basic air conditioning process involves the heat transfer through some fenestration. The latent, sensible and total heat transferred by air are f=given as follows:

$$q_L = C_L Q \Delta T \tag{3.1}$$

$$q_s = C_s Q \Delta W \tag{3.2}$$

$$q_t = C_t Q \Delta h \tag{3.3}$$

$$q_t = q_s + q_l \tag{3.4}$$

Here,

q_s, q_p, q_t = sensible, latent, total heat transfer rates, W

C_s = air sensible heat factor, W/(L·s K) (1.23 at sea level)

C_l = air latent heat factor, W/(L·s) (3010 at sea level)

C_t = air total heat factor, W/(L·s) per kJ/kg enthalpy h (1.2 at sea level)

Q = air volumetric flow rate, L/s

Δt = air temperature difference across process, K

ΔW = air humidity ratio difference across process, $\text{kg}_w/\text{kg}_{da}$

Δh = air enthalpy difference across process, kJ/kg

When considering the design calculations, for indoor conditions, the optimal value of dry bulb temperature is 24°C with relative humidity between 50% to 65% when considering

cooling. For heating calculation under indoor conditions, the the optimal value of dry bulb temperature is 20°C with relative humidity of 30%.
It is necessary to mention that the areas resting in middle latitude require maximum cooling in midsummer season, therefore the RLF method, which serves as basis for current calculations, is based on **solar gain.** For effective load calculations, the corresponding areas should be chosen in an appropriate manner, where the gross area is typically most suitable which ignores wall and floor thicknesses. Therefore, in order to proceed with calculations with concerned, the wall heights should be taken from floor-to-floor.
Referring to the fenestration area, which comprises of external windows, skylights and doors, the U-Factor corresponding to fenestration and SHGC ratings have to be evaluated, based on product area while accounting for frames as well. For load calculation, fenestration area is the area of the rough opening in the wall or roof.

3.1 Cooling Load

The cooling load determines the total sensible cooling load corresponding to the opaque surfaces (walls, floors, ceilings and doors), through transparent fenestration surfaces such as skylights, windows, through infiltration and ventilation and because of occupancy.

3.1.1 Opaque Surfaces

Heat gain through opaque surafces refers to the heat gain due to temperature difference across surafces and solar agin incident on surfaces. The heat capacity plays its role in moderating the building heat gain. The RLF method uses following equations in order to estimate teh cooling load:

$$q_{opq} = A \times CF_{opq} \tag{3.5}$$

where

$$CF_{opq} = U(OF_t \Delta t + OF_b + OF_r DR) \tag{3.6}$$

For slab floors, there occurs a mild reduction in cooling load, the governing equation is

$$q_{opq} = A \times CF_{slab} \tag{3.7}$$

where

$$
\begin{aligned}
q_{opq} &= \text{opaque surface cooling load, W} \\
A &= \text{net surface area, } \mathrm{m}^2 \\
CF &= \text{surface cooling factor, } \mathrm{W/m}^2 \\
U &= \text{construction U-factor, } \mathrm{W/(m^2 \cdot K)} \\
\Delta t &= \text{cooling design temperature difference, K} \\
OF_r, OF_b, OF_r &= \text{opaque-surface cooling factors} \\
DR &= \text{cooling daily range, K}
\end{aligned}
$$

In reference to the book [5], following tables correspond to the above calculations

Table 3.1: Opaque Surface Cooling Factor Coefficients

Surface Type	$\mathbf{OF_f}$	$\mathbf{OF_b}$, K	$\mathbf{OF_r}$
Ceiling or wall adjacent to vented attic	0.62	$14.3\alpha_{\text{roof}} - 4.5$	-0.19
Ceiling/roof assembly	1	$38.3\alpha_{\text{roof}} - 7.0$	-0.36
Wall (wood frame) or door with solar exposure	1	8.2	-0.36
Wall (wood frame) or door (shaded)	1	0	-0.36
Floor over ambient	1	0	-0.06
Floor over crawlspace	0.33	0	-0.28

Table 3.2: Roof Solar Absorptance α_{roof}

Material	**Color**			
	White	Light	Medium	Dark
Asphalt shingles	0.75	0.75	0.85	0.92
Tile	0.30	0.40	0.80	0.80
Metal	0.35	0.50	0.70	0.90
Elastomeric coating	0.30	–	–	–

3.1.2 Transparent Fenestration Surfaces

For fenestration without doors, the load calculations can be initiated as:

$$q_{fen} = A \times CF_{fen} \tag{3.8}$$

$$CF_{fen} = U(\Delta t - 0.46DR) + PXI \times SHGC \times IAC \times FF_s \tag{3.9}$$

q_{fen} = fenestration cooling load, W

A = fenestration area (including frame), m^2

CF_{fen} = surface cooling factor, W/m^2

U = fenestration NFRC heating U-factor, $\text{W/(m}^2\cdot\text{K)}$

M = cooling design temperature difference, K

PXI = peak exterior irradiance, including shading modifications, W/m^2

HGC = fenestration rated or estimated NFRC solar heat gain coefficient

IAC = interior shading attenuation coefficient

FF_s = fenestration solar load factor

The terminology used above as **PXI** refrs to the Peak Exterior Irradiance, which can be evaluated as for unshaded and shaded fenestration :

$$PXI = T_x E_t \tag{3.10}$$

$$PXI = T_x[E_d + (1 - F_{shd})E_D] \tag{3.11}$$

Table 3.3: Exterior Attachment Transmission

Attachment	$\boldsymbol{\tau_z}$
None	1.0
Exterior insect screen	0.64 (see Chapter 15, Table 13G)
Shade screen	Manufacturer shading coefficient (SC) value, typically 0.4 to 0.6

The total summary of equations used in cooling load calculation in the following project is as follows:

- **Exterior opaque surfaces**: The load is calculated as $q_{opq} = A \times CF$ where $CF = U(OF_1\Delta t + OF_b + OF_r DR)$. The opaque surface cooling factors (OF_1, OF_b, OF_r) are obtained from Table 3.1
- **Exterior transparent surfaces (Fenestration)**: The load is given by $q_{fen} = A \times CF$ with $CF = U(\Delta t - 0.46DR) + PXI \times SHGC \times IAC \times FF_s$. Here, PXI

Table 3.4: Peak Irradiance Equations

Horizontal surfaces

$$E_t = 952 + 6.49L - 0.166L^2$$
$$E_d = \min(E_t, 170)$$
$$E_D = E_t - E_d$$

Vertical surfaces

$$\phi = \left|\frac{\psi}{180}\right| \quad \text{(normalized exposure, } 0-1\text{)}$$
$$E_t = 453.4 + 1341\phi - 5279\phi^3 + 3260\phi^4 - 34.09\phi L + 0.2643\phi L^2 - 12.83L - 0.8425L^2 + \left[0.9835L^2/(\phi+1)\right]$$
$$E_d = \min\left(E_t, 357 - 86.98\phi^2 + 1.764\phi L - \frac{108.4\sqrt[4]{L}}{\phi+1}\right)$$
$$E_D = E_t - E_d$$

where
E_t, E_d, E_D = peak hourly total, diffuse, and direct irradiance, $\mathrm{W\,m^{-2}}$
L = site latitude, °N
ψ = exposure (surface azimuth), ° from south (−180 to +180)

(peak exterior irradiance), FF_s (fenestration solar load factor), and Δt represents the temperature difference across the partition (see *Common Data and Procedures* section).

- **Partitions to unconditioned space**: The load simplifies to $q = AU\Delta t$.
- **Ventilation/infiltration (sensible)**: Calculated as $q_s = C_s Q \Delta t$.
- **Occupants and appliances (sensible)**: Given by $q_{lg,s} = 136 + 2.2cf + 22N_{oc}$.
- **Distribution losses**: $q_d = F_{dl}\Sigma q$ where F_{dl} comes from Table 6.
- **Total sensible load**: $q_s = q_d + \Sigma q$.
- **Latent load components**:
  - Ventilation/infiltration: $q_{v,l} = C_l Q \Delta W$
  - Internal gains: $q_{lg,l} = 20 + 0.22cf + 12N_{oc}$
  - Total latent load: $q_l = q_{v,l} + q_{lg,l}$

Table 3.5: Peak Irradiance ($W\,m^{-2}$)

Exposure	Latitude								
	20°	25°	30°	35°	40°	45°	50°	55°	60°
North	125	106	92	84	81	85	96	112	136
	128	115	103	93	84	76	69	62	55
	253	221	195	177	166	162	164	174	191
Northeast/Northwest	460	449	437	425	412	399	386	374	361
	177	169	162	156	151	147	143	140	137
	637	618	599	581	563	546	529	513	498
East/West	530	543	552	558	560	559	555	547	537
	200	196	193	190	189	188	187	187	187
	730	739	745	748	749	747	742	734	724
Southeast/Southwest	282	328	369	405	436	463	485	503	517
	204	203	203	204	205	207	210	212	215
	485	531	572	609	641	670	695	715	732
South	0	60	139	214	283	348	408	464	515
	166	193	196	200	204	209	214	219	225
	166	253	335	414	487	557	622	683	740
Horizontal	845	840	827	806	776	738	691	637	574
	170	170	170	170	170	170	170	170	170
	1015	1010	997	976	946	908	861	807	744

Chapter 4

Implementation

The implementation of Comprehensive Thermal and HVAC Load Analysis for a Three-Story Residential Building using Radiant Load Factor (RLF) Method involves individual calculations for the following:

- U-Factor Calculation
- Window Load Calculation
- Envelope Load Calculation
- Ventilation and Latent Heat Calculation
- Equipment Load Calculation

4.1 Window Load Calculation

Window loads are individually calculated by determining the total window area followed by calculation of conductive heat transfer using the U-factor of the window and the temperature difference between indoors and outdoors. In addition to that, the solar heat gain is determined using the Solar Heat Gain Coefficient (SHGC) and the incident solar radiation. The total window load is the sum of the conductive and solar heat gains. In evaluating the total window load, following parameters were taken into consideration:

- Assuming double glazed windows with aluminum frame

- Use of insect screen about the exterior of windows to prevent the penetration of insects, bugs and pests through windows
- No overhead shading is used
- It is assumed that the medium blinds are partially open by factor of 50%.
- For evaluation of heat, let the latitude be 33.6995° N
- The azimuth angle has been taken from South

Orientation and Frame Type

The following table contains information regarding theIncident Solar Radiation (Et)

Table 4.1: Incident Solar Radiation by Orientation

Orientation	Et (Wm^{-2})
South	746.5
West	374.5

The following table contains information regarding the Frame Type Properties

Table 4.2: Window Frame Thermal Properties

Frame Type	U-value (Wm^{-2})	SHGC
Fixed	3.61	0.69
Operable	4.62	0.67

Solar Heat Calculations

Following assumptions have been taken into consideration for evaluating the solar heat

Table 4.3: Solar Heat Calculation Considerations

Parameter	Value
Transmittance (Tx)	0.64
Interior Attenuation Coefficient (IAC)	0.91 (50% open blinds)
Shading Fraction (F_{shd})	0 (no overhang)

Insect screens are considered minor and thus neglected in shading calculations

Table 4.4: Window Specifications for Ground Floor

Room	Dimensions (m) Width × Height	Qty	Area/Win (m^2)	Total Area (m^2)	Orientation	Type
Lounge	1.8 × 0.65	2	1.17	2.34	South	Fixed
Dining	1.5 × 0.65	1	0.975	0.975	West	Fixed
Kitchen	1.2 × 0.65	1	0.78	0.78	West	Operable
Kitchen	0.45 × 0.45	1	0.2025	0.2025	West	Operable
Pantry	0.3 × 0.3	1	0.09	0.09	West	Fixed
Bedroom	1.5 × 0.65	1	0.975	0.975	South	Operable
Bedroom (Bath)	0.3 × 0.3	1	0.09	0.09	South	Fixed
Study	1.0 × 0.65	1	0.65	0.65	West	Operable
Study Bath	0.3 × 0.3	3	0.09	0.27	West	Fixed
Master Bedroom	1.5 × 0.65	1	0.975	0.975	South	Fixed
Drawing Room	1.5 × 0.65	1	0.975	0.975	South	Fixed
Stairs	0.3 × 0.3	2	0.09	0.18	West	Fixed

Table 4.1 presents the comprehensive window specifications for the ground floor, documenting all critical fenestration parameters essential for thermal load calculations. The table systematically organizes seven key architectural and thermal characteristics: (1) room identification, (2) window dimensions (width × height in meters), (3) quantity of windows per room, (4) individual window area (m^2), (5) total fenestration area per room (m^2), (6) cardinal orientation, and (7) operational type (fixed or operable).

Table 4.1 presents the comprehensive thermal performance characteristics for all win-

Table 4.5: Window Performance Data for Ground Floor

Room	U-value	SHGC	Tx	IAC	Et	F_{shd}	PXI
Lounge	3.61	0.69	0.64	0.91	746.5	0	746.5
Dining	3.61	0.69	0.64	0.91	374.5	0	374.5
Kitchen	4.62	0.67	0.64	0.91	374.5	0	374.5
Kitchen	4.62	0.67	0.64	0.91	374.5	0	374.5
Pantry	3.61	0.69	0.64	0.91	374.5	0	374.5
Bedroom	4.62	0.67	0.64	0.91	746.5	0	746.5
Bath (Bedroom)	3.61	0.69	0.64	0.91	746.5	0	746.5
Study	4.62	0.67	0.64	0.91	374.5	0	374.5
Study Bath	3.61	0.69	0.64	0.91	374.5	0	374.5
Master Bedroom	3.61	0.69	0.64	0.91	746.5	0	746.5
Drawing Room	3.61	0.69	0.64	0.91	746.5	0	746.5
Stairs	3.61	0.69	0.64	0.91	374.5	0	374.5

dow types incorporated in the building design. The table systematically documents seven critical parameters governing fenestration heat transfer: (1) thermal conductance (U-value in (Wm^{-2}), (2) solar heat gain coefficient (SHGC), (3) visible transmittance (T_x), (4) interior attenuation coefficient (IAC), (5) incident solar radiation (E_t in (Wm^{-2}), (6) shading fraction (F_{shd}), and (7) peak solar intensity (PXI in (Wm^{-2})).

Table 4.1 presents the comprehensive cooling load analysis for each room type, docu-

Table 4.6: Cooling Factors by Room for Ground Floor

Room	FFs	CF (Wm^{-2})	Total CF (W)
Lounge	0.42	299.933	701.82
Dining	0.42	150.556	146.29
Kitchen	0.39	146.055	113.92
Kitchen	0.39	146.055	29.56
Pantry	0.402	150.556	13.55
Bedroom	0.39	291.135	283.36
Bath (Bedroom)	0.402	299.933	26.99
Study	0.39	146.055	94.94
Study Bath	0.402	150.556	40.65
Master Bedroom	0.402	299.933	292.43
Drawing Room	0.402	299.933	292.43
Stairs	0.402	150.556	27.10

menting three critical thermal performance parameters: (1) fenestration factors (FF_s), (2) cooling factor (CF in (Wm^{-2}), and (3) total cooling load (W).

Table 4.7: Window Specifications for First Floor

Room	Dimensions (m) Width × Height	Qty	Area/Win (m^2)	Total Area (m^2)	Orientation	Type
Master Bed	1.5 × 0.65	2	0.9750	1.9500	South	Fixed
Bath	0.3 × 0.3	2	0.0900	0.1800	South	Fixed
Bed Room	1.5 × 0.65	1	0.9750	0.9750	South	Operable
Kitchen	0.45 × 0.45	1	0.2025	0.2025	West	Operable
Cover Terrace	1.0 × 0.65	1	0.6500	0.6500	West	Fixed
Laundry	0.3 × 0.3	1	0.0900	0.0900	West	Fixed
Bath	0.3 × 0.3	1	0.0900	0.0900	West	Fixed
Dressing	0.3 × 0.3	1	0.0900	0.0900	West	Fixed
Bed Room	1.0 × 0.65	1	0.6500	0.6500	South	Operable
Lounge	1.5 × 0.65	1	0.9750	0.9750	South	Fixed
Lobby	1.5 × 0.65	1	0.9750	0.9750	South	Fixed

Table 4.1 presents the comprehensive window specifications for the ground floor, documenting all critical fenestration parameters essential for thermal load calculations. The table systematically organizes seven key architectural and thermal characteristics: (1) room identification, (2) window dimensions (width × height in meters), (3) quantity of windows per room, (4) individual window area (m^2), (5) total fenestration area per room (m^2), (6) cardinal orientation, and (7) operational type (fixed or operable).

Table 4.1 presents the comprehensive thermal performance characteristics for all win-

Table 4.8: Window Thermal Performance by Room for First Floor

Room	U-value (Wm^{-2})	SHGC (-)	Tx (-)	IAC (-)	Et (Wm^{-2})	F_{shd} (-)	PXI (Wm^{-2})
Master Bed	3.61	0.69	0.64	0.91	746.5	0	746.5
Bath	3.61	0.69	0.64	0.91	746.5	0	746.5
Bed Room	4.62	0.67	0.64	0.91	746.5	0	746.5
Kitchen	4.62	0.67	0.64	0.91	374.5	0	374.5
Cover Terrace	3.61	0.69	0.64	0.91	374.5	0	374.5
Laundry	3.61	0.69	0.64	0.91	374.5	0	374.5
Bath	3.61	0.69	0.64	0.91	374.5	0	374.5
Dressing	3.61	0.69	0.64	0.91	374.5	0	374.5
Bed Room	4.62	0.67	0.64	0.91	746.5	0	746.5
Lounge	3.61	0.69	0.64	0.91	746.5	0	746.5
Lobby	3.61	0.69	0.64	0.91	746.5	0	746.5

dow types incorporated in the building design. The table systematically documents seven critical parameters governing fenestration heat transfer: (1) thermal conductance (U-value in (Wm^{-2}), (2) solar heat gain coefficient (SHGC), (3) visible transmittance (T_x), (4) interior attenuation coefficient (IAC), (5) incident solar radiation (E_t in (Wm^{-2}), (6) shading fraction (F_{shd}), and (7) peak solar intensity (PXI in (Wm^{-2})).

Table 4.1 presents the comprehensive cooling load analysis for each room type, documenting three critical thermal performance parameters: (1) fenestration factors (FF_s), (2) cooling factor (CF in (Wm^{-2}), and (3) total cooling load (W).

Table 4.1 presents the comprehensive window specifications for the ground floor, documenting all critical fenestration parameters essential for thermal load calculations. The table systematically organizes seven key architectural and thermal characteristics: (1) room identification, (2) window dimensions (width × height in meters), (3) quantity of windows per room, (4) individual window area (m^2), (5) total fenestration area per room (m^2), (6) cardinal orientation, and (7) operational type (fixed or operable).

Table 4.9: Cooling Factors by Room for First Floor

Room (-)	FFs	CF (Wm^{-2})	Total CF (W)
Master Bed	0.402	299.933	584.87
Bath	0.402	299.933	53.99
Bed Room	0.390	291.135	283.36
Kitchen	0.390	146.055	29.56
Cover Terrace	0.402	150.556	97.86
Laundry	0.402	150.556	13.55
Bath	0.402	150.556	13.55
Dressing	0.402	150.556	13.55
Bed Room	0.390	291.135	189.24
Lounge	0.402	299.933	292.43
Lobby	0.402	299.933	292.43

Table 4.10: Window Specifications for Mumty Floor

Room	Dimensions (m) Width × Height	Qty	Area/Win (m^2)	Total Area (m^2)	Orientation	Type
Servant Quarter	0.9 × 0.9	1	0.81	0.81	West	Operable
Storage 1	0.9 × 0.9	1	0.81	0.81	West	Fixed
Storage 2	0.8 × 0.8	1	0.64	0.64	West	Fixed
Servant Quarters 2	0.9 × 0.9	1	0.81	0.81	West	Operable
Servant Quarters 2	0.3 × 0.3	1	0.09	0.09	West	Operable

4.2 Envelope Calculation

Envelope loads, which include heat transfer through walls, roofs, and floors, are calculated by measuring the areas of these components and using their respective U-factors and temperature differences. The heat transfer for each component is determined, and these values are added cumulatively to get the total envelope load.

Window Areas

Door Areas

- Estimated External Wall Area: 165(m^2)
- Estimated Roof Area: 150(m^2)

Table 4.11: Thermal Performance by Rooms for Mumty Floor

Room	U-value (Wm^{-2})	SHGC (-)	Tx (-)	IAC (-)	Et (Wm^{-2})	F_{shd} (-)	PXI (Wm^{-2})
Servant Quarter	4.62	0.67	0.64	0.91	374.5	0	374.5
Storage 1	3.61	0.69	0.64	0.91	374.5	0	374.5
Storage 2	3.61	0.69	0.64	0.91	374.5	0	374.5
Servant Quarters 2	4.62	0.67	0.64	0.91	374.5	0	374.5
Servant Quarters 2	4.62	0.67	0.64	0.91	374.5	0	374.5

Table 4.12: Cooling Factors for by Rooms for Mumty Floor

Room (-)	FFs	CF (Wm^{-2})	Total CF (W)
Servant Quarter	0.39	146.055	118.31
Storage 1	0.402	150.556	121.95
Storage 2	0.402	150.556	96.36
Servant Quarters 2	0.39	146.055	118.31
Servant Quarters 2	0.39	146.055	13.15

Envelope Load Calculation

Table 4.2 presents the heating and cooling load calculations for various building components, showing their respective heat transfer factors (HF), cooling factors (CF), and resulting thermal loads in watts. In reference to the available data, there is a significant variations between components, with walls exhibiting the highest heating load and west-facing fixed windows showing the greatest cooling impact. Negative values for floor area indicate heat loss reduction, while zero values represent negligible cooling contributions. This comprehensive breakdown enables precise HVAC system sizing and energy performance analysis across all building envelope elements.

- W-Fixed-0.9 means a **west-facing fixed window** with a U-value of 0.9
- S-Operable-1.2 means a **south-facing operable window** with a U-value of 1.2
- E-Operable-0.9 means an **east-facing operable window** with a U-value of 0.9

Table 4.13: Window Area Calculations

Location	Size (m)		Area (m^2)
	Width	Height	
Storage	0.9, 0.8	0.9, 0.8	1.45
Servant Quarter	0.9, 0.3	0.9, 0.3	1.02
Master Bed	1.5	0.65	3.90
Lounge	1.5	0.65	1.95
Covered Terrace	1.0	0.65	0.65
Kitchen	0.45	0.45	0.20
Bathrooms	0.3	0.3	0.36
Total Window Area			9.53

Table 4.14: Door Area Calculations

Location	Size (m)		Area (m^2)
	Width	Height	
Master/Lounge	1.0	2.75	8.25
Stair (Mumty)	0.75	2.5	3.75
Washroom	0.65	2.5	6.50
Pantry/Kitchen	0.65	2.5	3.25
Others (Main)	2.0	2.75	11.00
Total Door Area			32.75

4.3 Equipment Load

Equipment load includes heat gains from appliances, lighting, and other internal sources. Each piece of equipment and lighting source is listed with its power rating, and the operational hours and usage patterns are estimated. The heat gain for each equipment is calculated and then summed to get the total equipment load.

Equipment Load Assumptions

The equipment load on each floor can be individually evaluated by assuming approximate load density about each floor which corresponds to appliances and equipment such as lightning, controls. Table 4.3 refers to the approximate equipment load density evaluation assumptions taken into account for further analysis

Table 4.15: Envelope Load Calculations

Component	Factor		Heating Load	Cooling Load
	HF	CF	(W)	(W)
Ceiling	4.23	2.06	826	402
Wall	11.99	7.03	1301	763
Garage wall	11.99	2.85	420	100
Door	54.10	31.69	206	120
Floor perimeter	20.00	0.00	1344	0
Floor area	−2.34	0.00	−457	0
W-Fixed-0.9	66.70	115.40	27	46
W-Operable-0.9	67.40	69.00	27	28
W-Fixed-1.8	66.70	175.70	73	193
W-Operable-1.8	67.40	101.80	74	112
W-Fixed-2.4	66.70	190.80	287	820
S-Fixed-1.2	66.70	117.40	47	82
S-Operable-1.2	67.40	70.10	47	49
E-Fixed-0.9	66.70	69.80	27	28
E-Operable-0.9	67.40	44.10	27	18
E-Fixed-1.2	66.70	84.20	147	185
E-Operable-1.2	67.40	53.20	148	117

Table 4.16: Total Load Summary

Load Type	Value (W)
Total Heating Load	4571
Total Cooling Load	3063

Equipment Load Calculations by Floor

Table 4.3 corresponds to the equipment loads on the ground floor, where majority area is occupied by the main lounge and master bedroom, which correspond to greatest equipment load. The overall equipment load evaluated at the said floor corresponds to a value of 1779.3 Wm^{-2}. It is necessary to mention that equipment and appliances used in kitchen and lounge correspond to heavy loads, thus leading to a high equipment load cumulatively.

Tables 4.3 and 4.3 correspond to the equipment load evaluated on the first floor and mumty floor. On the first floor, the total equipment load amounts to $930.3W$, with Bedroom 1 contributing the highest load of $262.5W$ due to its $15.0m^2$ area and $17.5Wm^2$ load density. The second floor, referred to as the Mumty Floor, has a significantly

Table 4.17: Equipment Load Density Assumptions

Room Type	Equipment Type	Load Density (Wm^{-2})
Bedrooms	Lighting	10.0
	Small Appliances	5.0
	HVAC Controls	2.5
Living Areas	Lighting	15.0
	Entertainment	10.0
	Miscellaneous	5.0
Kitchen	Lighting	12.0
	Major Appliances	25.0
	Small Appliances	10.0
Bathrooms	Lighting	8.0
	Ventilation	5.0
	Water Heating	3.0
Service Areas	Lighting	6.0
	Utility Equipment	8.0

Table 4.18: Ground Floor Equipment Loads

Room	Area (m^2)	Load Density (Wm^{-2})	Equipment Load (W)
Master Bedroom	18.5	17.5	323.8
Lounge	22.0	30.0	660.0
Kitchen	12.5	47.0	587.5
Bathroom	6.0	16.0	96.0
Storage	8.0	14.0	112.0
Total Ground Floor Load			1779.3

higher total load of $1470.0W$, primarily driven by the Drawing Room's substantial 750.0 W load resulting from its 25.0 m^2 area and $30.0Wm^2$ density. The Study and Dining Room show moderate loads of $200.0W$ and $450.0W$ respectively, while smaller spaces like the Bathroom (88.0 W) and Pantry (120.0 W) contribute minimally to the overall load distribution.

Detailed Equipment Load Classification

Keeping in view the detailed load classification, The electrical loads are categorized into light and heavy components, as detailed in Tables 4.3 and 4.3. Light loads primarily consist of lighting systems, such as LED fixtures and task lighting, alongside electronics like smart controls and WiFi routers, which are increasingly prevalent due to IoT expansion. These loads are characterized by their lower power requirements but growing

Table 4.19: First Floor Equipment Loads

Room	Area (m^2)	Load Density (Wm^{-2})	Equipment Load (W)
Bedroom 1	15.0	17.5	262.5
Bedroom 2	14.5	17.5	253.8
Study	10.0	20.0	200.0
Bathroom	5.5	16.0	88.0
Servant Quarter	9.0	14.0	126.0
Total First Floor Load			930.3

Table 4.20: Mumty Floor Equipment Loads

Room	Area (m^2)	Load Density (Wm^{-2})	Equipment Load (W)
Drawing Room	25.0	30.0	750.0
Dining Room	18.0	25.0	450.0
Pantry	6.0	20.0	120.0
Covered Terrace	15.0	10.0	150.0
Total Second Floor Load			1470.0

infrastructure demands, particularly for network connectivity and smart home functionality. HVAC components, including thermostats and occupancy sensors, also fall under this category, with smart thermostats potentially consuming more power for advanced features like CO_2 monitoring.

Heavy loads, on the other hand, encompass high-power appliances such as kitchen equipment (refrigerators and microwaves), bathroom devices (hair dryers and heat lamps), and laundry machines (washers and dryers). These loads are distinguished by their significant power consumption, with notable peaks during specific times—such as morning bathroom usage or laundry cycles—and unique considerations like compressor startup surges. Workspace equipment, including printers and computers, also contributes to heavy loads, particularly during business hours, requiring careful circuit design to accommodate fluctuating demand. The distinction between these categories is crucial for accurate load calculations and efficient electrical system planning.

Table 4.21: Building Equipment Load Summary

Floor	Total Equipment Load (W)
Ground Floor	1779.3
First Floor	930.3
Second Floor	1470.0
Building Total	4179.6

Table 4.22: Light Load Components (Continuous Operation)

Category	Specific Equipment	Power Range (W)	Considerations
Lighting	LED fixtures	5–15	Dimming capability reduces load
	Task lighting	3–5	Localized high-intensity needs
Electronics	Smart controls	1–3	IoT devices increasing prevalence
	WiFi routers	5–10	Network infrastructure demand
HVAC	Thermostats	2–5	Smart thermostats may use more
	Sensors	0.5–2	Occupancy/CO_2 monitoring

Light Loads (Continuous Operation)

Heavy Loads (Intermittent Operation)

Load Calculation Methodology

Key Factors to Consider

- **Diversity Factor**:
  - 0.7-0.9 for residential lighting
  - 0.3-0.5 for kitchen appliances
  - 0.1-0.3 for laundry equipment
- **Usage Patterns**:
- **Peak Demand Considerations**:
  - Morning (07:00-09:00): Bathroom + Kitchen
  - Evening (18:00-22:00): Lighting + Entertainment
  - Seasonal variations (AC in summer)

Table 4.23: Heavy Load Components (Intermittent Operation)

Category	Specific Equipment	Power Range (W)	Considerations
Kitchen	Refrigerator	100–300	Compressor startup surges
	Microwave	800–1500	Short duration high demand
Bathroom	Hair dryers	1200–1875	Morning peak usage patterns
	Heat lamps	250–400	Often overlooked in calculations
Laundry	Washing machine	500–1000	Water heating doubles load
	Dryer	1800–5000	Major impact on circuit design
Workspaces	Printers	300–800	Peak during business hours
	Computers	50–250	Varies by usage intensity

Equipment Type	Typical Daily Usage Hours
Lighting (common areas)	4-6 hours
Refrigeration	24 hours (cycling)
Entertainment systems	2-4 hours
Kitchen appliances	1-2 hours (peak)

The load calculation effectively amalgamates some critical diversity factors to cater for non-simultaneous operation of building systems. Residential lighting demonstrate relatively high diversity factors (0.7–0.9) due to coordinated usage patterns, while kitchen appliances show moderate factors (0.3–0.5) reflecting intermittent operation, and laundry equipment demonstrates lower factors (0.1–0.3) given infrequent use. The daily usage patterns reveal significant variation across systems: common area lighting operates 4–6 hours, refrigeration runs continuously with compressor cycling, entertainment systems average 2–4 hours, and kitchen appliances peak at 1–2 hours during meal preparation. These patterns create distinct demand periods, with morning peaks (07:00–09:00) dominated by bathroom and kitchen loads, and evening peaks (18:00–22:00) characterized by lighting and entertainment usage. Seasonal variations further modulate demand, particularly through increased air conditioning loads during summer months. This comprehensive analysis ensures accurate load profiling for HVAC system design.

Table 4.24: Typical Residential Room Loads

Room Type	Light Loads (W/m^2)	Heavy Loads (W)	Notes
Bedroom	15–20	50 (TV)	Sleep mode reduces nighttime load
Study	20–25	300 (PC)	Printer surges during use
Living Room	15–18	800 (HT)	Home theater peak demand

Table 4.25: Service Area Load Characteristics

Space	Load Density (W/m^2)	Load Management
Kitchen	30–50	Stagger appliance use
Laundry	40–60	Schedule high-load cycles
Servant Room	500–800	Requires dedicated cooling

Detailed Room-by-Room Load Analysis

Residential Spaces

Service Areas

4.4 U-Factor Calculation

Walls

Considering the walls of the house, The assembly is 230 mm thick clay brick with approximately 12 mm cement-lime plaster on both sides. The cement has thermal conductivity of $\approx 0.72 W/mK$ corresponding to resistance value of $\approx 0.017 m^2K/W$ for 12 mm cement layer. Clay bricks have thermal conductivity of $\approx 0.80 W/mK$ corresponding to resistance value of $\approx 0.32 m^2K/W$ for 230 mm thickness. The wall construction yields $R \approx 0.35\,\mathrm{m^2K/W}$ for the wall itself. Adding interior/exterior surface resistances ($R_{si} \approx 0.12\,\mathrm{m^2K/W}$ and $R_{se} \approx 0.04\,\mathrm{m^2K/W}$ for heating; or $R_{se} \approx 0.17\,\mathrm{m^2K/W}$ for calm summer conditions) gives total $R \approx 0.51$–$0.64\,\mathrm{m^2K/W}$.

The resulting U-factors are about $1.95\,\mathrm{W/m^2K}$ in winter design (cold outside, more convection) and $1.55\,\mathrm{W/m^2K}$ in summer design (hot outside, less convection). For comparison, the Pakistan Energy Code targets $U \approx 0.57\,\mathrm{W/m^2K}$ for walls, indicating that typical uninsulated walls have significantly higher thermal transmittance.

The internal surface resistance corresponds to value of $\mathrm{R_{si}} \approx 0.12 m^2K/W$, with the

Table 4.26: Wall Construction Properties

Wall Layer	Thickness (mm)	R-value (m^2K/W)
Interior plaster (cement)	12	0.017
Clay brick	230	0.317
Exterior plaster (cement)	12	0.017
Total (materials)	254	0.351

external surface resistance corresponding to value of $R_{se} \approx 0.04 m^2K/W$ in winters or $\approx 0.17 m^2K/W$ in summers. Hence the cumulative resistance from external surface corresponds to value of $\approx 0.51 m^2K/W$ in winters or $\approx 0.64 m^2K/W$ in summers. The resultant U factor is $\approx 1.95 W/m^2K$ for winters and $\approx 1.55 W/m^2K$ for summers

Roof

The roof is a flat reinforced-concrete slab with a thin leveling/screed layer and interior plaster/ceiling. 30 mm cement screed with thermal conductivity of $\approx 0.72 W/mK$ in addition to 150 mm of dense concrete for which the value of thermal conductivity is $\approx 1.70 W/mK$ in addition to 10 mm of plater or gypsum board. by using thermal conductivity of $\approx 0.72 W/mK$ for screed and $\approx 1.70 W/mK$ for concrete results in R$\approx$ $0.04(screed) + 0.09(slab) + 0.014(plaster) = 0.014 m^2K/W$ for the structural layers. Summing up the internal and external structural resistances as ≈ 0.10 and ≈ 0.04 or ≈ 0.17 in winters or summers results in resistance $R \approx 0.28 - 0.41$, which corresponds to U-factor of $\approx 3.52 W/m^2K$ in winters and $2.42 W/m^2K$ in summers. The measured data from Pakistan's climate shows for uninsulated concrete roofs with $R \approx 0.3 - 0.5$. Surface resistances: $R_{si} \approx 0.10$, $R_{se} \approx 0.04$ (winter) or 0.17 (summer).

Table 4.27: Roof Construction Properties

Roof Layer	Thickness (mm)	R-value (m^2K/W)
Interior plaster/ceiling	10	0.014
Cement leveling screed	30	0.042
Concrete slab (dense)	150	0.088
Total (materials)	190	0.144

Total $R \approx 0.144 + 0.10 + R_{se} \approx 0.28$ (winter), 0.41 (summer).
$U \approx 3.52\,\mathrm{W/m^2K}$ (winter), $2.42\,\mathrm{W/m^2K}$ (summer).

Floors (Ground-Level Slab)

The ground floor slab has tile, screed, and concrete. 10 mm ceramic tile ($R \approx 0.006\,\mathrm{m^2K/W}$), 40 mm cement sand screed ($R \approx 0.056$), and 150 mm concrete slab ($R \approx 0.088$). Total $R \approx 0.15\,\mathrm{m^2K/W}$ for the layers. With interior floor surface $R_{si} \approx 0.14$ and exterior (ground contact or unconditioned space) $R_{se} \approx 0.04$ (winter) or 0.17 (summer), total $R \approx 0.33$–0.46. This yields $U \approx 3.04\,\mathrm{W/m^2K}$ (winter) and $2.18\,\mathrm{W/m^2K}$ (summer).

Table 4.28: Floor Construction Properties

Floor Layer	Thickness (mm)	R-value ($\mathrm{m^2K/W}$)
Ceramic tile	10	0.006
Cement screed	40	0.056
Concrete slab	150	0.088
Total (materials)	200	0.150

Surfaces: $R_{si} \approx 0.14$, $R_{se} \approx 0.04$ (winter) or 0.17 (summer).
Total $R \approx 0.15 + 0.14 + R_{se} \approx 0.33$ (winter), 0.46 (summer).
$U \approx 3.04\,\mathrm{W/m^2K}$ (winter), $2.18\,\mathrm{W/m^2K}$ (summer).

Windows

Windows have aluminium frames with single and double glazing. For a single-pane window (6 mm clear glass), the pane's $R \approx 0.006\,\mathrm{m^2K/W}$. Using standard glazing-film resistances, the overall $R \approx 0.155\,\mathrm{m^2K/W}$ (including frame effect), i.e. $U \approx 6.45\,\mathrm{W/m^2K}$. For a double-glazed unit (6 mm glass, 12 mm air gap, 6 mm glass), $R \approx 0.294\,\mathrm{m^2K/W}$, so $U \approx 3.40\,\mathrm{W/m^2K}$. (Surface resistances are the same in summer/winter for glazing.)

Table 4.29: Window Thermal Properties

Window Type	Layers	R-value ($\mathrm{m^2K/W}$)	U ($\mathrm{W/m^2K}$)
Single-glazed (6 mm)	Single glass pane	∼0.155	6.45
Double-glazed (6+air+6 mm)	Two glass + air gap	∼0.294	3.40

Doors

40 mm solid wood door has $R \approx 0.44\,\mathrm{m^2K/W}$ ($\approx 2.5\,\mathrm{ft^2 \cdot {}^\circ F \cdot h/Btu}$). Adding film resistances ($R_{si} \approx 0.12$, $R_{se} \approx 0.06$ for a sealed door) gives total $R \approx 0.62\,\mathrm{m^2K/W}$,

so $U \approx 1.61\,\mathrm{W/m^2K}$ in winter. In summer (calm exterior), using $R_{se} \approx 0.17$ yields $R_{total} \approx 0.73$, $U \approx 1.37\,\mathrm{W/m^2K}$. (Insulated steel or fiberglass doors can have higher R, but we use solid wood as typical.)

Table 4.30: Door Thermal Properties

Door (solid wood)	Thickness	R-value ($\mathrm{m^2K/W}$)
Wood panel	40 mm	0.44
Total (materials)	40 mm	0.44

Surface resistances: $R_{si} \approx 0.12$, $R_{se} \approx 0.06$ (winter) or 0.17 (summer).
Winter $R_{total} \approx 0.62$ ($U \approx 1.61$); Summer $R_{total} \approx 0.73$ ($U \approx 1.37$).

Summary of U-Factors

Table 4.31: Component U-Factors

Component	U ($\mathrm{W/m^2K}$) – Winter	U ($\mathrm{W/m^2K}$) – Summer
Walls	1.95	1.55
Roof	3.52	2.42
Ground Floor Slab	3.04	2.18
Single-Glazed Window	6.45	6.45
Double-Glazed Window	3.40	3.40
Exterior Door (wood)	1.61	1.37

The thermal performance assessment of typical building envelope components suggests that uninsulated constructions demonstrate high U-values, reflecting significant heat transfer and poor insulation characteristics. The walls, with a total thickness of 254 mm (clay brick and plaster layers), have U-values of approximately $1.95\,W/m^2K$in winter and $1.55\,W/m^2K$ in summer. These values far exceed the Pakistan Energy Code target of around $0.57\,W/m^2K$, underscoring the necessity for additional insulation to achieve compliance with energy efficiency standards.

The roof assembly, consisting of a reinforced concrete slab with plaster and screed, shows even higher U-values of about $3.52\,W/m^2K$ (winter) and $2.42\,W/m^2K$ (summer), identifying the roof as a critical area for thermal improvement. Similarly, the ground floor slab demonstrates poor thermal resistance, with U-values of roughly $3.04\,W/m^2K$ in winter and $2.18\,W/m^2K$ in summer.

Openings are the weakest elements in the thermal envelope: single-glazed windows display very high U-values ($6.45\,W/m^2K$), while double glazing provides moderate improvement ($3.40\,W/m^2K$). Solid wood doors perform relatively better, with U-values of around $1.61\,W/m^2K$ (winter) and $1.37\,W/m^2K$(summer).

Overall, these results emphasize that without enhanced insulation or the adoption of more advanced materials, typical local construction substantially underperforms in relation to modern energy efficiency requirements, leading to considerable heat loss or gain through the building envelope.

Furthermore, the high thermal transmittance directly impacts indoor thermal comfort, requiring excessive use of mechanical heating and cooling systems to maintain desirable conditions. This, in turn, results in increased operational energy costs and a larger carbon footprint for buildings. To address these challenges, retrofitting strategies such as the installation of external thermal insulation composite systems (ETICS), roof insulation boards, or insulated flooring systems should be prioritized. Integrating high-performance glazing and thermally broken frames can also significantly reduce heat transfer through windows and doors, making the overall building much more energy-efficient and sustainable in the long term.

4.5 Ventilation and Latent Heat Calculation

Ventilation leads to additional thermal load in a regulated space. This load has a sensible and latent component, calculated below using the RLF method.

The total ventilation rate is first calculated as:

$$Q_{tot} = 0.15A_{floor} + 3.5(N_{br} + 1) = 0.15(1058) + 3.5(5 + 1) = 179.7\,\text{L/s}$$

Where:

- Q_{tot} = total required ventilation rate (L/s)
- A_{floor} = floor area of residence (m^2)
- N_{br} = number of bedrooms

Sensible Heat Load

The sensible heat load is evaluated through:

$$q_s = Q\rho c_p \Delta t$$

Where:

- q_s = sensible heat load (W)
- Q = airflow rate (m^3/s)
- ρ = air density (kg/m^3)
- c_p = specific heat of air (J/kgK)
- Δt = temperature difference between indoors and outdoors (K)

Latent Heat Load

The latent heat load is evaluated through:

$$q_l = Q\rho\Delta W(2.501 + 1.805t)$$

Where:

- q_l = latent heat load (kW)
- ΔW = absolute humidity ratio difference (kg/kg)
- t = average of indoor and outdoor temperatures (°C)

Latent Load Components

Net latent load for cooling:

$$q_l = q_{vi,l} + q_{ig,l}$$

Where:

- q_l = total latent load (W)
- $q_{vi,l}$ = ventilation/infiltration latent gain (W)
- $q_{ig,l}$ = internal latent gain (W)

Table 4.32: Design Conditions (ASHRAE 2021 for Islamabad)

Category	Parameter	Summer Value	Winter Value
Location	City	Rawalpindi, Pakistan	–
	Elevation	508 m	–
Air Properties	Air density (ρ)	1.20 kg/m^3	–
	Outdoor airflow rate (volumetric)	0.1797 m^3/s	–
	Outdoor airflow rate (mass)	0.2156 kg/s	–
Indoor Air	Dry-bulb temperature	24°C	20°C
	Relative humidity	50%	30%
	Humidity ratio	0.009336 kg/kg	0.004354 kg/kg
Outdoor Air	Dry-bulb temperature	41.1°C	3.6°C
	Dew-point temperature	18.6°C	-2.4°C
	Humidity ratio	0.0135 kg/kg	0.0031 kg/kg

Table 4.33: Calculated Ventilation Loads

Load Type	Cooling (Summer) Load (W)	Heating (Winter) Load (W)
Sensible	3687.444	3536.496
Latent	55	6.43

Ventilation/Infiltration Latent Gain

As calculated previously:

$$q_{vi,l} = 55\,\text{W}$$

Internal Gain

Calculated as:

$$q_{ig,l} = 20 + 0.22A_{cf} + 12N_{oc} = 20 + 0.22(1058) + 12(5) = 312.76\,\text{W}$$

Total Latent Load

$$q_l = q_{vi,l} + q_{ig,l} = 55 + 312.76 = 367.76\,\text{W}$$

Category	Subcomponent	Details / Units	Value (W)
1. U-Factor Summary ($W/m^2 \cdot K$)			
Envelope Component	Walls	Summer / Winter	1.55 / 1.95
	Roof	Summer / Winter	2.42 / 3.52
	Ground Floor Slab	Summer / Winter	2.18 / 3.04
	Windows (Single/Double)	Summer	6.45 / 3.40
	Doors (Solid Wood)	Summer / Winter	1.37 / 1.61
2. Window Cooling Load (W)			
Window Load	Ground Floor	Summed by Room	2062.04
	First Floor	Summed by Room	1674.15
	Mumty Floor	Summed by Room	467.08
	Total Window Load		**4203.27**
3. Envelope Thermal Load (W)			
Envelope Load	Total Cooling Load	From opaque + fenestration	3063
	Total Heating Load		4571
4. Equipment Internal Load (W)			
Equipment Load	Ground Floor	Per area × load density	1779.3
	First Floor		930.3
	Mumty Floor		1470.0
	Total Equipment Load		**4179.6**
5. Ventilation & Latent Load (W)			
Ventilation Sensible	Qtot, $\Delta T = 7.7K$	Based on airflow + RLF	2166.2
Ventilation Latent	Qtot, $\Delta W = 0.0095$		3166.6
	Total Ventilation Load		**5332.8**
6. Total Cumulative Loads (W)			
Total Cooling Load	Window + Envelope + Equipment + Vent		**16777.67**
Total Heating Load	Envelope + Equipment + Vent		**14081.0**

Table 4.34: Cumulative Heat Load using U-Factors, Window, Envelope, Equipment, and Ventilation Loads

Chapter 5

Conclusion

In conclusion, it can be stated that the following complex engineering problem presents an effective and multidimensional approach to HVAC load analysis for a modern three-story residential building i Rawalpindi, Pakistan. By implementing the Radiant Load Factor (RLF) Method with data-driven of thermal load contributors, this study fills in gaps present in contemporary and traditional HVAC-related load calculation methods, which often tend to rely on basic and oversimplified static calculations and outdated empirical correlations. Through this design calculation project, the entire load calculation process is reformulated such to reflect the actual behavior of building systems under complex climatic influences.

One primary outcome of this project was the development and implementation of RLF-based thermal load model which effectively considers all factors contributing to load, including the transparent and opaque surfaces, fenestration orientation, solar gain through time-dependent irradiance, occupancy-based internal loads and most importantly the climate-specific ventilation strategies. The design methodology was used across broad case study of real building with zoning, equipment profiling, fenestration configuration and dynamic envelope interactions evaluated in a meticulous manner. Each and every component, from the walls and roofs to windows and doors, were thermally characterized through U-factor calculations based on actual construction materials and architectural detailing, thus providing a robust and accurate load figures for both summers and winter operation mode. The results highlight that in high- temperature and high-humidity zones such as Rawalpindi, typical and conventional HVAC estimation techniques tend

to either oversize or under-size the peak loads by factors of 20%-30%, which may result in higher capital investment or thermal discomfort. On the other hand, the RLF method enables ±5% accurate prediction of zone-specific loads by incorporation of delayed radiant effects and changing solar orientations throughout the course of the day. In addition to that, the equipment load profiling revealed peak energy loads occurring nit only due to climatic effects but from concentrated internal usage patterns, especially within kitchen and living spaces. These key points provide solid and robust foundation for the recommendation of targeted energy management strategies such as appliance scheduling, zoning controls and demand response techniques. In addition to that, the latent loads resulting from monsoonal humidity conditions were taken into much consideration, also highlighting the need for integration of dehumidification capacity in HVAC specifications in the region. This study also considers the importance of building envelopes in reduction of HVAC loads, as deliberated from U-factors for walls, roofs and floors, when compared against the ECBC 2023 and ASHRAE 90.1 benchmarks, tend to demonstrate thermal inefficiencies of typical uninsulated construction. This further validates the feasibility and necessity for envelope based interventions, accomplished through methods such as insulated wall systems, high-reflective roofing membranes and thermally broken fenestration, in order to ensure thermal comfort throughout regardless of weather and hence contributing to energy savings. Such findings not only address the immediate design optimization but also pave way for integration of sustainable systems in near future, such as solar cooling and hybrid HVAC models.

In conclusion, this CEP serves as a robust insight for future HVAC design especially for tropical and subtropical climate, which effectively incorporates thermal science, data analytics and sustainable design principles. By application of Radiant Load Factor method in a comprehensive and practical context, this project not only aims ar meeting the academic objectives but also delivers real-world engineering impact. It is expected that this methodology shall serve as an inspiration for future research and industrial adoption, thereby contributing meaningfully to Pakistan's national goals on energy conservation, indoor environmental quality and climatic resilience, consistent with the international standards as well.

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Appendix A

Software Verification

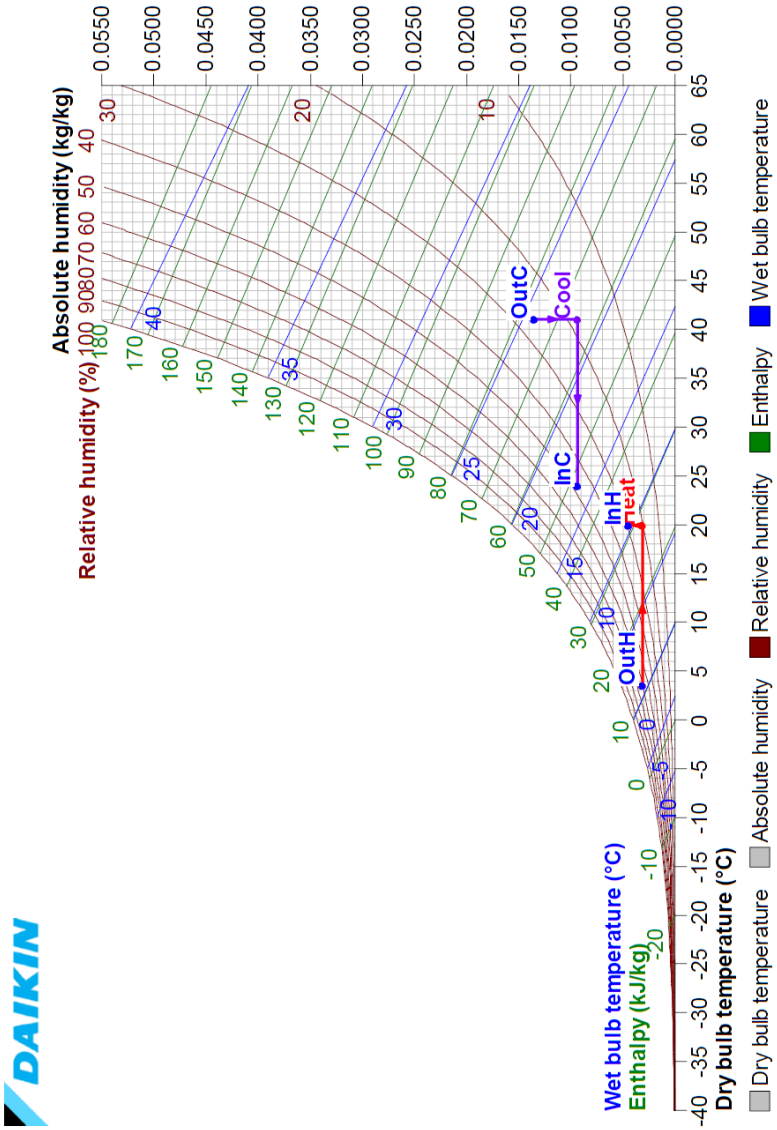


Figure A.1: Psychometric Chart with Labeled Points



1. Psychrometric points

OutC		InC		OutH		InH	
Dry bulb temperature	41.1°C	Dry bulb temperature	24.0°C	Dry bulb temperature	3.6°C	Dry bulb temperature	20.0°C
Wet bulb temperature	24.4°C	Wet bulb temperature	16.4°C	Wet bulb temperature	0.8°C	Wet bulb temperature	10.4°C
Dew point	17.7°C	Dew point	12.1°C	Dew point	-3.1°C	Dew point	1.3°C
Relative humidity	25.9%	Relative humidity	47.1%	Relative humidity	59.8%	Relative humidity	28.6%
Absolute humidity	0.0135kg/kg	Absolute humidity	0.0093kg/kg	Absolute humidity	0.0031kg/kg	Absolute humidity	0.0044kg/kg
Enthalpy	76.1kJ/kg	Enthalpy	47.8kJ/kg	Enthalpy	11.4kJ/kg	Enthalpy	31.3kJ/kg
Density	1.049kg/m³	Density	1.112kg/m³	Density	1.198kg/m³	Density	1.130kg/m³
Specific volume	0.966m³/kg	Specific volume	0.908m³/kg	Specific volume	0.837m³/kg	Specific volume	0.889m³/kg
Pressure	95369.3Pa	Pressure	95369.3Pa	Pressure	95369.3Pa	Pressure	95369.3Pa
Airflow	179.7l/s	Airflow	179.7l/s	Airflow	179.7l/s	Airflow	179.7l/s
Cool		**Heat**					
Dry bulb temperature	41.1°C	Dry bulb temperature	20.0°C				
Wet bulb temperature	21.7°C	Wet bulb temperature	9.0°C				
Dew point	12.1°C	Dew point	-3.1°C				
Relative humidity	17.9%	Relative humidity	20.2%				
Absolute humidity	0.0093kg/kg	Absolute humidity	0.0031kg/kg				
Enthalpy	65.3kJ/kg	Enthalpy	28.0kJ/kg				
Density	1.051kg/m³	Density	1.131kg/m³				
Specific volume	0.960m³/kg	Specific volume	0.887m³/kg				
Pressure	95369.3Pa	Pressure	95369.3Pa				
Airflow	179.7l/s	Airflow	179.7l/s				

2. Actions

Cooling: OutC, InC, Cool (Capacities: Total = 6.11kW, Sensible = 3.77kW (62%), Latent = 2.33kW)
Heating: OutH, InH, Heat (Capacities: Total = 4.29kW, Sensible = 3.59kW (84%), Latent = 0.70kW, Steam humidification = 1.01kg/h)

This Psychrometrics Program is property of Daikin Europe NV. Daikin Europe NV cannot be held liable for any inaccuracy, reliability of the outcome of the Psychrometrics Program.

Figure A.2: Tabulated Data

Appendix B

House Plan

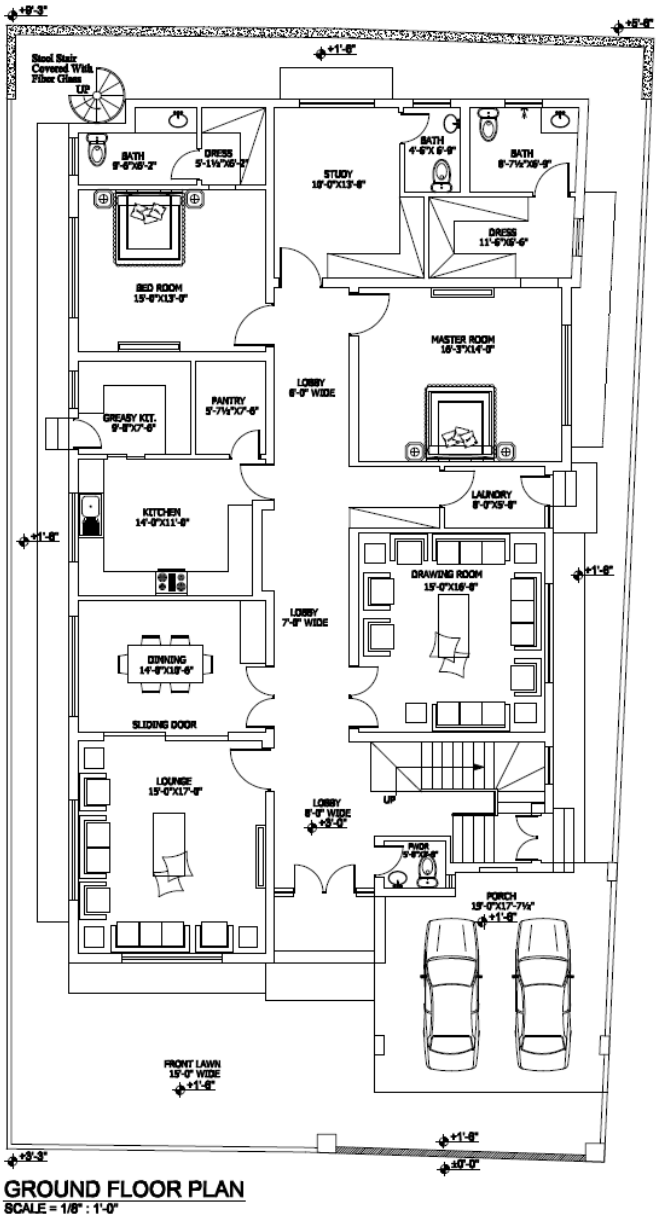


Figure B.1: Ground Floor

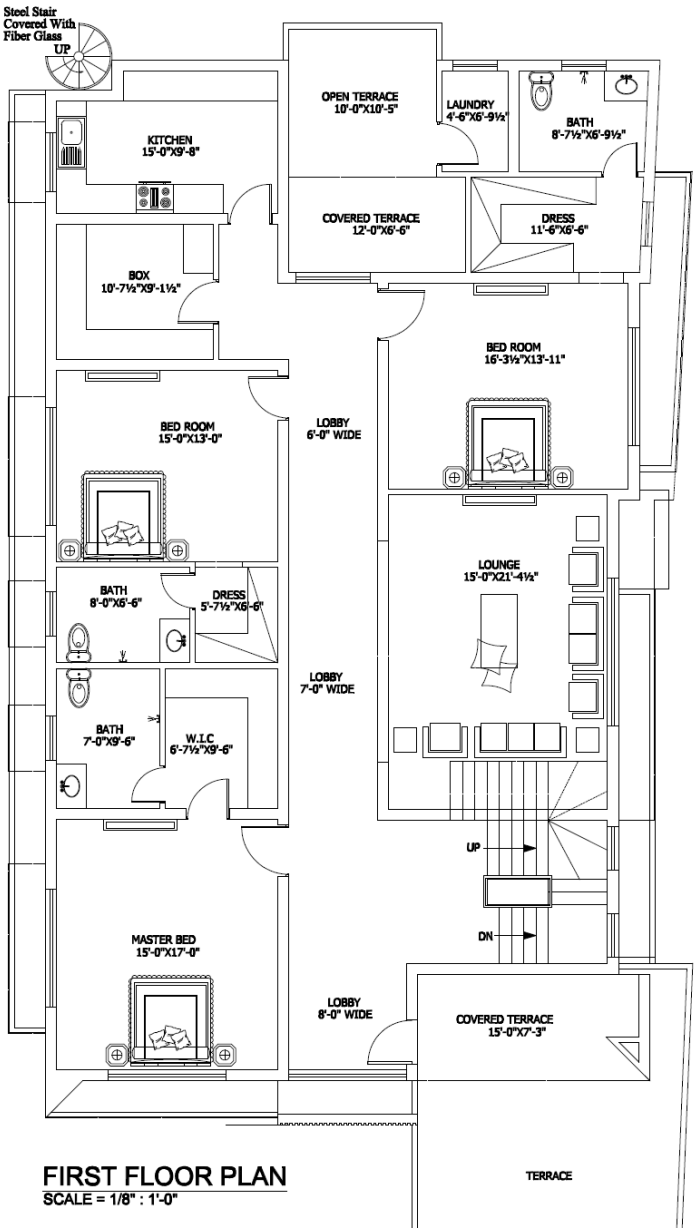


Figure B.2: First Floor

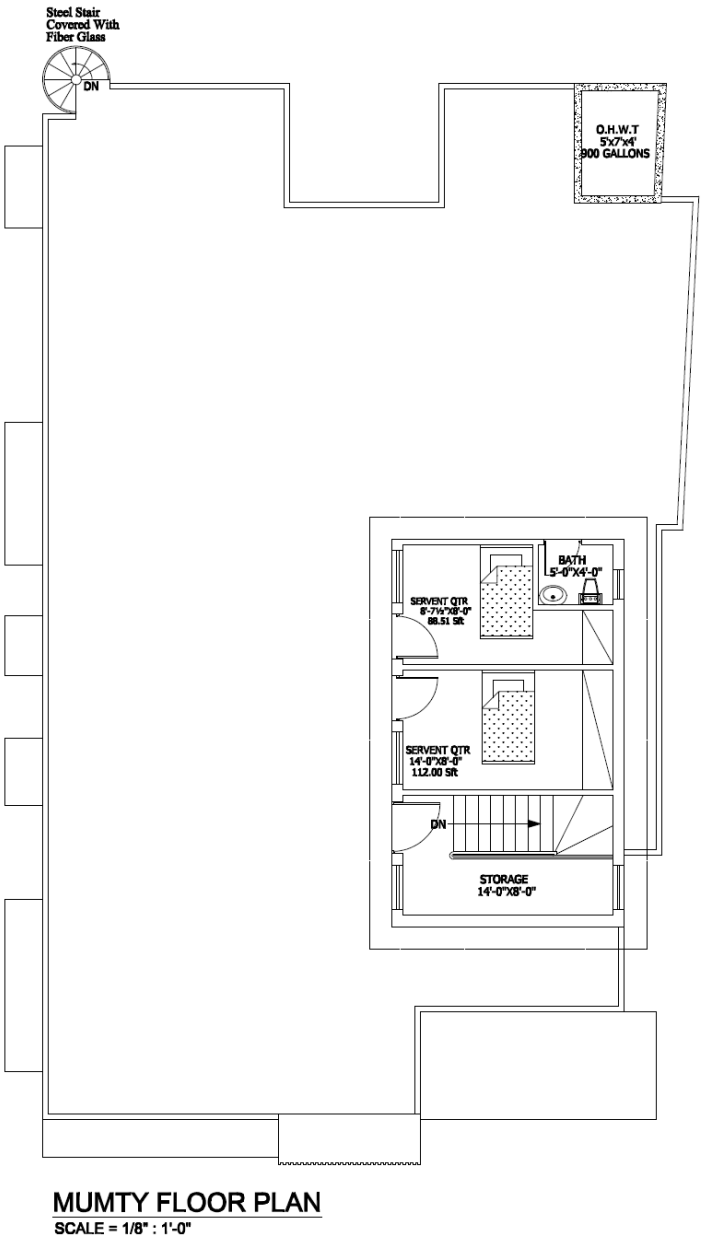


Figure B.3: Mumty Floor