

Energy Audit Report

2023/2024



JANUARY 1ST

T2 Company

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Executive Summary:

The HVAC report for the T2 commercial building presents a detailed analysis with practical recommendations for energy efficiency improvements. Here's a breakdown of the key aspects in simpler terms:

- Energy Savings Strategy:

The report suggests two main improvements: adding insulation and using a lighter roof colour.

These changes are like giving it a sun-friendly roof.

- Financial Impact:

The proposed upgrades could save a significant amount of energy, around 3558.112 kWh/year.

It's like turning off your lights for a long time and saving money on your energy bill.

The cost of making these changes would pay for itself in about 2.14 years.

- Occupant Comfort Boost:

Apart from saving money, these changes would make the workspace more comfortable.

It's like adjusting the thermostat at home to make it just right.

- Building Direction Consideration:

The report talks about the idea of changing the building's direction for even more energy savings.

However, it mentions that this could be tricky and expensive.

- Practical Solutions Focus:

The report emphasizes practical solutions like insulation and changing the roof colour.

It's like choosing the easiest and most effective ways to make your home more comfortable

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1.Introduction

In today's world, commercial buildings play an increasingly important role in our lives. They provide us with places to work, shop, and socialize. As such, it is essential that these buildings are comfortable and healthy for occupants. One of the most important factors in achieving this goal is the HVAC system.

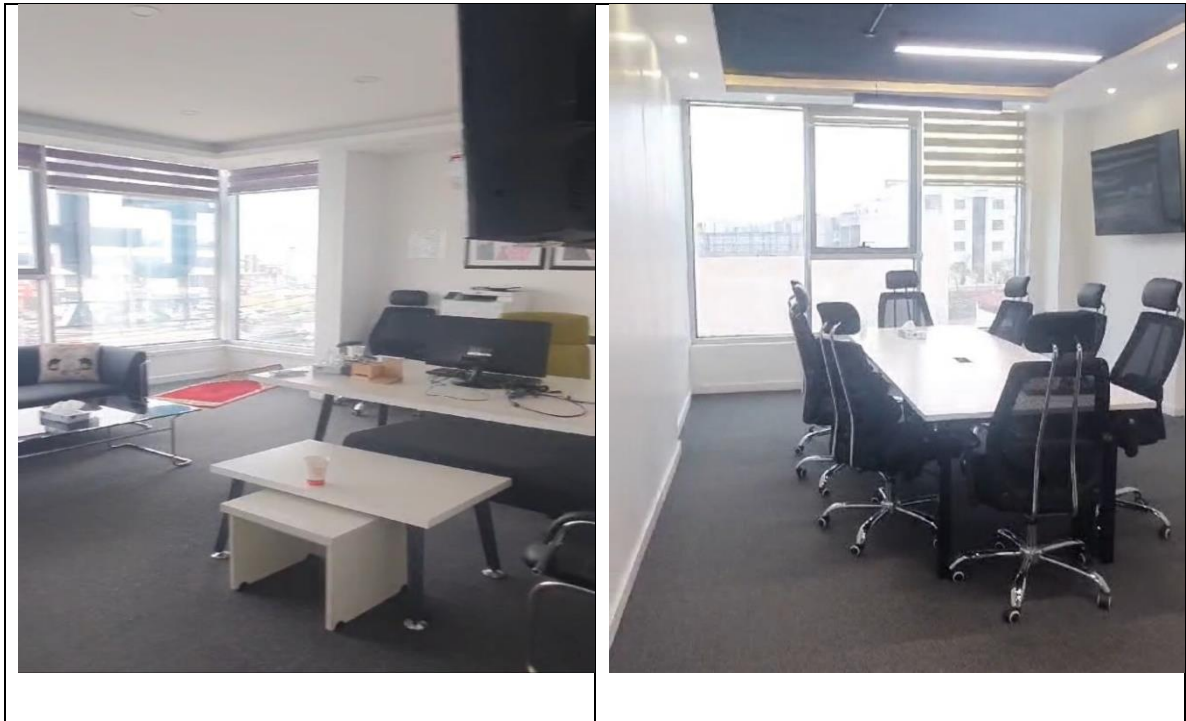
A well-designed HVAC system can provide a number of benefits for commercial buildings, including:

- Improved occupant comfort: A properly designed HVAC system will keep occupants cool in the summer and warm in the winter. This can lead to increased productivity and satisfaction.
- Improved indoor air quality: A good HVAC system will filter out pollutants and allergens from the air, creating a healthier environment for occupants.
- Reduced energy costs: An energy-efficient HVAC system can help to save money on energy bills.

1.1 Project Discription

The studied company is T2 which was established in city of Irbid in 2018 coinciding with the start of new technological era in various sectors.

The company on the 3rd floor of the main building, it consists rectangular plan area of $18.72 \times 12.18 \text{ m}^2$, which include 4 rooms (manger room , meeting room , main room and entrance room) , 1 kitchen and 1 bathroom. For the sake of our study, Friday and Saturday days (it is vacation on these days), and the daily work end time will be neglected since it has small energy consumption value compared on the working time.



(a)

(b)

Figure 1. Rooms of the company: (a) Manager room (b) Meeting room

Company Information

General information

Location : Irbid

Site Coordinates : 32°16'48"N 35°50'50"E

Company Physical Data

Dimensions (L x W x H) m : (18.72 x12.18x2.7) m

Capacity : 10-15 people.

Zoning

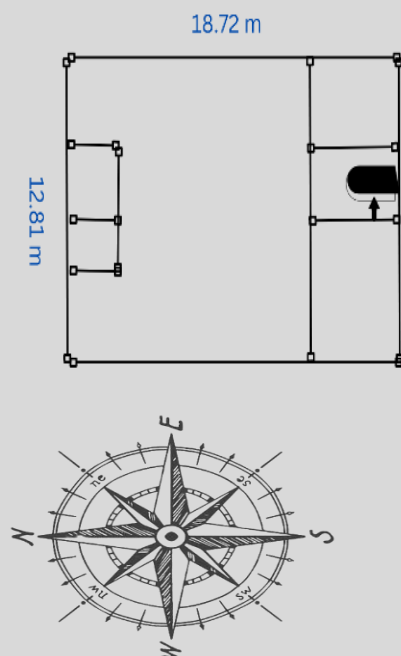
Company use : everyday (9 am – 6 pm)

Except Friday and Saturday .

Interior Lighting : LED + spot lights

HVAC / Air Circulation

Type : Mini-split Unit x 7



****Key performances of the Company:**

1) Energy Use Intensity (EUI):

Yearly Energy consumption = 85660 kWh/year

Total gross Area = 228 m²

$$\text{EUI} = \frac{\text{Yearly Energy consumption}}{\text{Total gross Area}} = \frac{85660}{228} = 375.7 \text{ kWh/year.m}^2$$

2) Energy per Capital (EPC):

of persons = 10-15 people

$$\text{EPC} = \frac{\text{Yearly Energy consumption}}{\text{\# Of people}} = \frac{85660}{15} = 5710 \text{ kWh/year. Person}$$

3) Benchmark

EUI (IN BTU/year. FT²) = 119.1

* ASHRAE Benchmark should be 52.9

So the company has a good potential of saving

2. Energy Audit methodology

The Energy audit procedure has been divided to 3 levels:

Level 1 (preliminary energy audit):

Data collection: Gathered past utility bills and weather data to analyse energy consumption trends over past year.

Company walkthrough: to count the area of the company, number of devices, number of occupancies

Getting more details from the employees.

Calculate and determined the necessary key performances.

Level 2 (Calculation and measurement):

Getting the necessary parameters, dimensions and data for installing them in HAP software to calculate heating loads, cooling loads, infiltration, etc..., after that we compare the output data with the current data,

Level 3 (Recommendations):

After the calculation we provide a list of recommendations for enhance the performance of the building condition in terms of heat loss, heat gain, energy consumption and financial wise.

2.1 Assumptions

* The overall heat transfer coefficient of the floor is the same as it for the partition wall (not the external wall) because the floor is not a ground floor it is a first floor.

* The glass was set to be the first glazing is 6mm blue-green reflective and the second glazing is 3mm clear (by comparing the existing glass with these data from internet).

* The minimum and maximum temperature of the unconditioned areas below the floor and next to the walls was set to be 5 C and 29 C, with an ambient of 1 C and 39 C respectively.

2.2 Areas

For windows:

3.59 m^2 , at the eastern side (12x windows).

1.28 m^2 , at the southern side (3x windows).

3.59 m^2 , at the southern side (1x window).

0.882 m^2 , at western side (1x window).

For door:

2 m^2 , at southern side (1x door).

For Walls (including the door +windows):

50.5 m^2 the total area for eastern side

32.9 the total area for southern side

50.5 m^2 the total area for western side

32.9 the total area for northern side

2.3 Weather

Design Parameters:

City Name	Irbid
Location	Jordan
Latitude	32.0
Deg. Longitude	-36.0
Deg. Elevation	773.0 m
Summer Design Dry-Bulb	35.0 °C
Summer Coincident Wet-Bulb	18.3 °C
Summer Daily Range	11.3
°K Winter Design Dry-Bulb	0.6 °C
Winter Design Wet-Bulb	-2.5 °C
Atmospheric Clearness Number	1.00
Average Ground Reflectance	0.20
Soil Conductivity	1.385
W/(m-°K) Local Time Zone (GMT +/- N hours)	-2.0 hours
Consider Daylight Savings Time	No
Simulation Weather Data	Irbid (Avg)
Current Data is	2001 ASHRAE
Handbook	

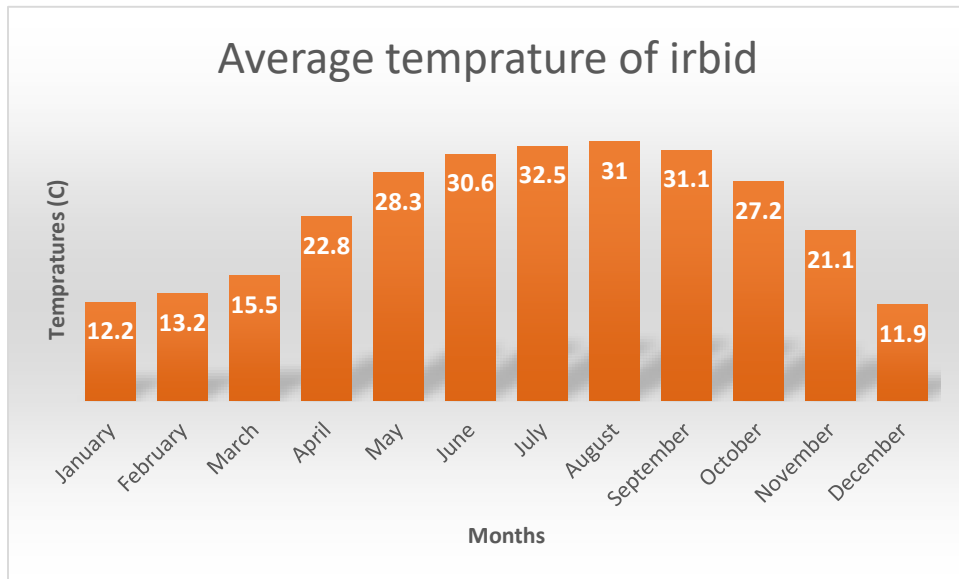


Figure 1 Average Temperature Vs months in Irbid

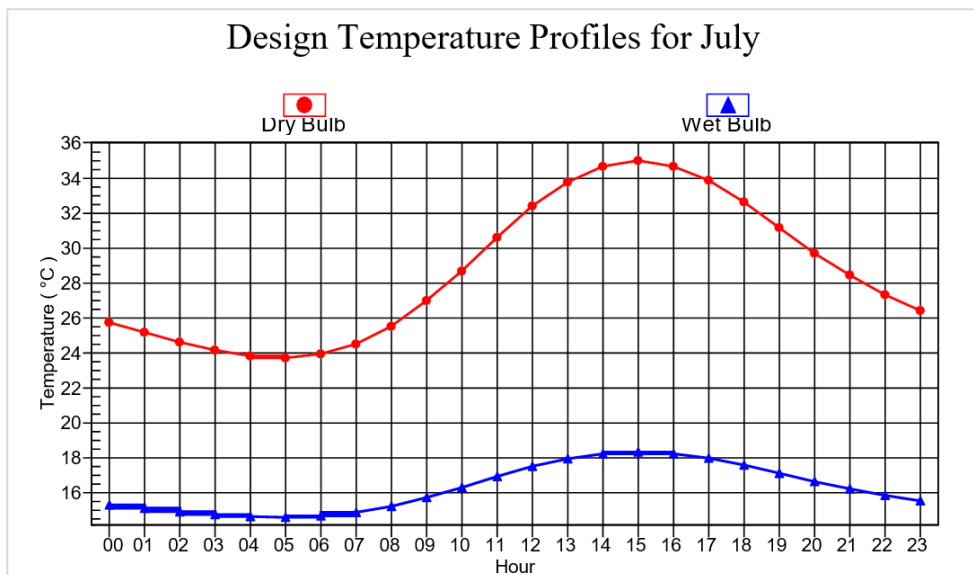


Figure 2 Hourly temperatures for JULY

The bar graph depicting the average temperatures for each month reveals distinct seasonal variations. December stands out as the coldest month, marked by the lowest average temperature, while July stands out as the warmest month with the highest average temperature. This valuable climatic data is sourced from ASHRAE, which serves as the foundation for the load calculations performed in HAP.

The second graph, illustrating temperatures over hours, provides a finer resolution of the daily temperature profile. The peak temperature is observed at 3 PM (15:00), indicating the warmest part of the day, while the minimum temperature occurs at midnight (00:00). These graphs not only showcase

the temperature extremes across different months but also pinpoint specific times of the day when the thermal loads on the building are most pronounced. The designed temperature data extracted from ASHRAE guides the load calculations, enabling accurate sizing and optimization of the HVAC system to ensure optimal comfort conditions within the building.

2.4 Building Design and Construction

HAP (Hourly Analysis Program) uses industry-standard methods for calculating thermal resistance (R) and overall heat transfer coefficient (U) in building components . The calculations are based on established principles of heat transfer in construction materials.

This section provides an in-depth look at the building envelope, covering walls, roofs, floors, and windows. It explores the types and materials used in construction, with a focus on layers in walls and essential specifications. Areas and specifications are defined for calculating thermal resistance and determining U-values. Similarly, window types are examined, and key parameters for U-value calculation are identified. The goal is to establish a fundamental understanding for subsequent thermal analysis and HVAC system design.

- **Walls types :**

- 1- Wall section

- 2- Wall partition

- **Calculation of Thermal Resistance (R):**

The thermal resistance of each layer (conduction) within a building component (a wall, roof, or floor) is determined using the formula:

$$R = \frac{d}{k}$$

Where:

- R is the thermal resistance,
- d is the thickness of the layer,
- k is the thermal conductivity of the material.

Layers: Inside to Outside	Thickness mm	Density kg/m³	Specific Ht. kJ/kg/K	R-Value m²·K/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
PLASTER	15.000	2000.0	0.90	0.01250	30.0
BLOCK	200.000	1400.0	0.84	0.22222	280.0
PLASTER	15.000	2000.0	0.90	0.01250	30.0
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	230.000			0.43	340.0

Overall U-Value: 2.344 W/m²/K

Figure 4 Wall section material layers

- **For wall section:**

Wall section, often referred to as an external wall, is constructed to provide insulation and protection against external weather conditions. For the thermal resistance for inside (R_{int}) and outside (R_{ext}) surfaces involves considering the convective heat transfer coefficients associated with the indoor and outdoor environments. The formula for surface resistance is :

$$R = \frac{1}{hA}$$

and A is the inside or outside surface areas. The convective heat transfer are influenced by factors such as the design temperature, surface temperature, and air properties , so if the outside surface temperature is equal to the inside temperature of the workspace the $R_{ext} = 0.05864 \text{ m}^2 \cdot \text{k}/\text{W}$, and if it is equal to the outside ambient temperature $R_{ext} = 0.12 \text{ m}^2 \cdot \text{k}/\text{W}$.

In plaster layer, $d = 15 \text{ mm}$, $k = 1.2 \text{ W/m.k}$:

$$R = \frac{d}{k} = \frac{0.015}{1.2} = 0.0125 \text{ m}^2 \cdot \text{k/W}$$

Similarly , In Block layer, $d = 200 \text{ mm}$, $k = 0.9 \text{ W/m.k}$:

$$R = \frac{d}{k} = \frac{0.2}{0.9} = 0.222 \text{ m}^2 \cdot \text{k/W}$$

Calculation of Overall Heat Transfer Coefficient (U):

HAP considers the thickness and thermal conductivity of each layer, summing up the resistances to obtain the total thermal resistance (R_{total}) for the component.

The overall heat transfer coefficient (U) is calculated using the formula:

$$U = \frac{1}{R_{\text{total}} + R_{\text{int}} + R_{\text{ext}}}$$

Where:

- U is the overall heat transfer coefficient,
- R_{total} is the total thermal resistance of the component,
- R_{int} and R_{ext} are the interior and exterior surface resistances, respectively.

$$U = \frac{1}{0.2472 + 0.12064 + 0.05864} = 2.344 \text{ W.k/m}^2$$

- For wall partition:

Wall Properties - [PARTITION WALL]

Wall Assembly Name: PARTITION WALL

Outside Surface Color: Light Absorptivity: 0.450

Layers: Inside to Outside	Thickness mm	Density kg/m³	Specific Ht. kJ/kg/K	R-Value m²·K/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12000	0.0
▶ PLASTER	15.000	2000.0	0.90	0.01250	30.0
BLOCK	200.000	1400.0	0.84	0.22220	280.0
Outside surface resistance	0.000	0.0	0.00	0.12000	0.0
Totals	215.000			0.47	310.0

Overall U-Value: 2.107 W/m²/K

Figure 5 Layers of partition wall

A wall partition is a separating structure between two adjacent spaces, often used to create distinct rooms within a building. For calculating the thermal resistance and overall heat transfer for the wall partition it will be the same procedure and same equations above , and the final answers are shown in figure 4 by HAP software.

- Roofs & ceiling :

Roof Properties - [ROOF SECTION]

Roof Assembly Name: ROOF SECTION

Outside Surface Color: Dark Absorptivity: 0.900

Layers: Inside to Outside	Thickness mm	Density kg/m³	Specific Ht. kJ/kg/K	R-Value m²·K/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
▶ PLASTER	15.000	2000.0	0.90	0.01250	30.0
RC SLAB	250.000	2300.0	0.92	0.14286	575.0
SCREED	50.000	2000.0	0.82	0.04167	100.0
SAND	50.000	1800.0	0.81	0.07143	90.0
CEMENT SAND	15.000	2000.0	0.84	0.01250	30.0
TILES	20.000	2450.0	0.90	0.01250	49.0
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	400.000			0.47	874.0

Overall U-Value: 2.115 W/m²/K

Figure 6 Roof section with information of its layers

At roof and ceiling section , the layers are illustrated comprehensively as shown in figure 5 , and as the same conduction and convection thermal resistance equations will be used with computing the overall heat transfer U .

- **Windows :**

There are three types of windows that exist in the entire workspace:

1- Window 1

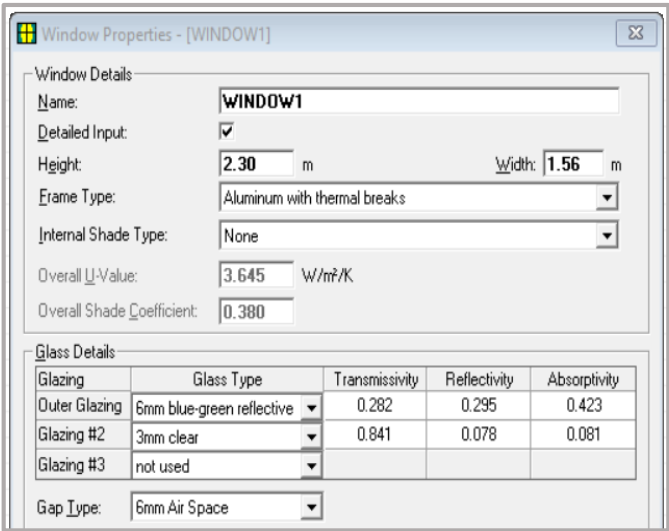


Figure 7 Specifications of Window 1

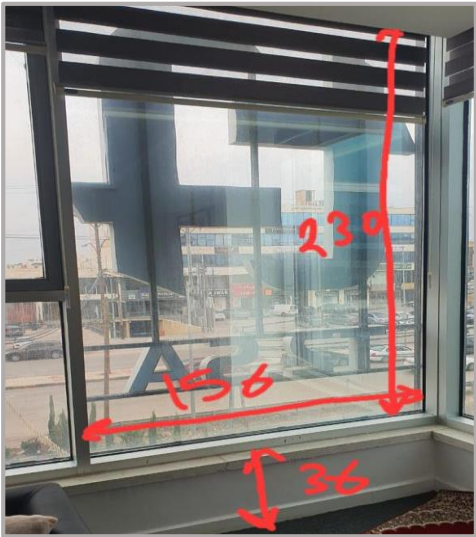


Figure 8 A picture of Window 1



Figure 9 Outer glass of Window 1

In the window analysis, Window Type 1, with dimensions H = 2.3 m and W = 1.56 m, was considered. The frame is of aluminum with thermal breaks. The outer glazing consists of 6mm blue green reflective glass with specified transmissivity, reflectivity, and absorptivity. The inner glazing is 3mm clear glass with its own set of specifications. A 6mm air gap separates the two glazing layers.

The overall shade coefficient is calculated by HAP based on the properties of the individual glazing layers and their configuration, accounting for factors such as solar radiation absorption, reflection, and transmission.

The overall shade coefficient (SC) for windows is determined by a combination of factors, including the properties of individual glazing layers, and the configuration of the window assembly.

$SC = \frac{SHGC}{0.86}$ represents a simplified relationship between the Overall Shade Coefficient (SC) and the Solar Heat Gain Coefficient (SHGC) which is a measure of how much solar heat is transmitted through a window, is typically determined through calculated based on the properties of the window components.

The U-value is derived from the thermal characteristics of each component and their arrangement calculated from equation of overall heat transfer coefficient (U).

2- Window 2

Glazing	Glass Type	Transmissivity	Reflectivity	Absorptivity
Outer Glazing	3mm clear	0.841	0.078	0.081
Glazing #2	not used			
Glazing #3	not used			

Gap Type: 6mm Air Space

Figure 10 Specifications of Window 2

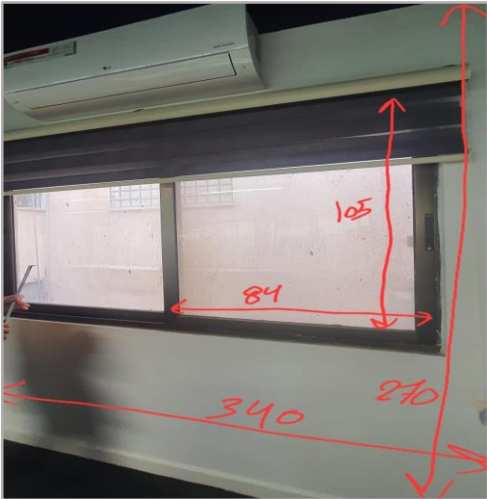


Figure 11 A picture of window 2

In the analysis of Window Type 2, characterized by dimensions $H = 1.05$ m and $W = 1.68$ m, an aluminum frame with thermal breaks was considered. The outer glazing is comprised of 3mm clear glass, as indicated in Figure 9, with specified transmissivity, reflectivity, and absorptivity.

According to HAP, the calculated U-value for this window is 6.208, while the overall shade coefficient is determined to be 0.881. Notably, the overall shade coefficient for Window Type 2 is higher than that of Window Type 1, which stands at 0.38, an increase in the Overall Shade Coefficient corresponds to an increase in the amount of solar heat that passes through the window. The U-value, is higher for Window Type 2, indicating a comparatively greater efficiency in transmitting heat.

3- Window 3

The screenshot shows the 'Window Properties - [WINDOW3]' window with the following details:

- Window Details:**
 - Name: WINDOW3
 - Detailed Input: ☒
 - Height: 1.22 m, Width: 3.15 m
 - Frame Type: Aluminum with thermal breaks
 - Internal Shade Type: None
 - Overall U-Value: 3.650 W/m²/K
 - Overall Shade Coefficient: 0.380
- Glass Details:**

Glazing	Glass Type	Transmissivity	Reflectivity	Absorptivity
Outer Glazing	6mm blue-green reflective	0.282	0.295	0.423
Glazing #2	3mm clear	0.841	0.078	0.081
Glazing #3	not used			
- Gap Type:** 6mm Air Space

Figure 12 Specification of window 3

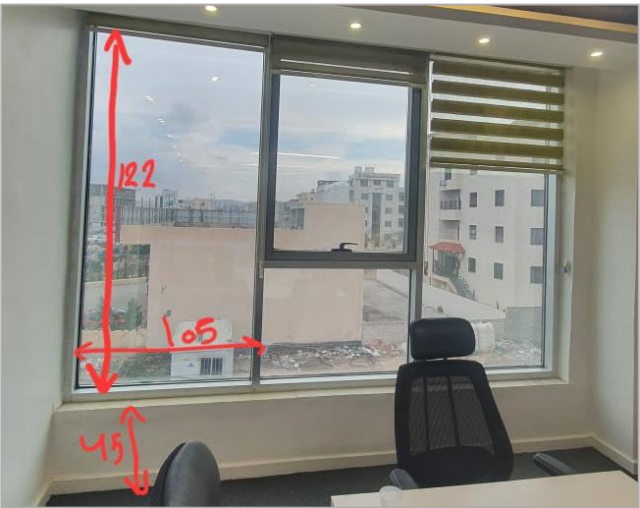


Figure 13 A picture of window 3

In the evaluation of Window Type 3, featuring dimensions $H = 1.22$ m and $W = 3.15$ m, an aluminum frame with thermal breaks was incorporated. The intricate details of the window, as depicted in the above figures, guided the HAP analysis. According to HAP results, the window exhibits a calculated U-value of 3.650 and an overall shade coefficient of 0.380.

2.5 Building load calculations

The building is organized into four distinct spaces:

- **The entrance** : a welcoming area that establishes the building's initial atmosphere.
- **The hall** : dedicated to IT-related work and fostering collaboration.
- **The manager's space** : strategically designed for effective administration.
- **The meeting room** : a dedicated area for group discussions and presentations.

Each space serves a specific function, contributing to the overall efficiency and functionality of the building. This division ensures that the design aligns with the varied needs of its occupants.

2.5.1 The Entrance



Figure 14 The entrance of the company

- General information

Space Properties - [ENTRANCE]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

Name: **ENTRANCE**

Floor Area: **14.0** m²

Avg Ceiling Height: **2.7** m

Building Weight: **341.8** kg/m²

Light ☐ Med. ☒ Heavy ☐

Figure 16 input parameters of entrance space

Space Properties - [ENTRANCE]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

Exposure	Roof Gross Area m²	Roof Slope (deg)	Skylight Quantity
1 H	14.0	0	0
2 not use			
3 not use			
4 not use			

Construction Types for Exposure: **1 (H)**

Roof: **ROOF SECTION**

Skylight: **(none)**

Figure 15 input parameters of Roof

Space Properties - [ENTRANCE]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

	Partition 1	Partition 2
	☐ Ceiling Partition ☒ Wall Partition	☒ Ceiling Partition ☐ Wall Partition
Area	8.4 m²	0.0 m²
U-Value	2.107	2.839 W/m²/K
Unconditioned Space Max Temp.	23.9 °C	23.9 °C
Ambient at Space Max Temp.	35.0 °C	35.0 °C
Unconditioned Space Min Temp.	23.9 °C	23.9 °C
Ambient at Space Min Temp.	12.8 °C	12.8 °C

Figure 17 input parameters of Wall partition

- Roof & floor Area : 14 m^2
- Height : 2.7 m
- Window type : No windows
- Wall : Horizontal exposure , Wall partition, 8.4 m^2

- External loads

TABLE 1.1.A. COMPONENT LOADS FOR SPACE " ENTRANCE " IN ZONE " Zone 1 "						
	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1700			HEATING DATA AT DES HTG		
	COOLING OA DB / WB 33.9 °C / 18.0 °C OCCUPIED T-STAT 23.9 °C			HEATING OA DB / WB 0.6 °C / -2.5 °C OCCUPIED T-STAT 21.1 °C		
		Sensible	Latent		Sensible	Latent
SPACE LOADS	Details	(W)	(W)	Details	(W)	(W)
Window & Skylight Solar Loads	0 m²	0	-	0 m²	-	-
Wall Transmission	0 m²	0	-	0 m²	0	-
Roof Transmission	14 m²	263	-	14 m²	609	-
Window Transmission	0 m²	0	-	0 m²	0	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	14 m²	-32	-	14 m²	180	-
Partitions	8 m²	0	-	8 m²	0	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	240 W	215	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	0 W	0	-	0	0	-
People	0	0	0	0	0	0
Infiltration	-	173	-41	-	475	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	619	-41	-	1264	0

• Design Heating Analysis for Entrance Space:

- In Winter (Design heating) :

- **Designed Dry Bulb Temperature:** Set at 0.6°C, during the coldest month (DES).

(Derived from regional climate data and standards)

- **Wet Bulb Temperature:** Established at -2.5°C.
- **Occupied Temperature:** Maintained at 21.1°C, this temperature represents the targeted indoor comfort level for occupants during the coldest month.
- **Data Source:** HAP obtains these temperature parameters from regional weather data, utilizing databases that provide comprehensive climatic information for the specific location of the building.

- **Sample of calculation**

For roof Transmission , $A = 14 \text{ m}^2$, $U = 2.115 \text{ W.k/m}^2$:

$$Q = U \times A \times \Delta T = 2.115 \times 14 \times (21.1 - 0.6) = 607 \text{ W}$$

At floor calculation , the HAP methodology to obtain conduction through floor:

When calculating transmission loads for floors above unconditioned regions, the temperature of the unconditioned region must be known. Temperature behavior in the unconditioned region is estimated with a simple linear model which defines the unconditioned space temperature as a function of the outdoor air temperature.

Together these four temperature inputs define the three sections of the space temperature profile:

1. When the outdoor air temperature is warmer than the "Ambient at Maximum Space Temperature", the unconditioned space temperature is equal to the "Unconditioned Space Maximum Temperature."
2. When the outdoor air temperature is colder than the "Ambient at Minimum Space Temperature", the unconditioned space temperature is equal to the "Unconditioned Space Minimum Temperature."

Space Properties - [ENTRANCE]	
General Internals Walls, Windows, Doors Roofs, Skylights Infiltration Floors Partitions	
Floor Type ☐ Floor Above Conditioned Space ☒ Floor Above Unconditioned Space ☐ Slab Floor On Grade ☐ Slab Floor Below Grade	
Floor Above Unconditioned Space Floor Area: 14.0 m² Total Floor U-value: 2.107 W/m²/K Unconditioned Space Max Temp.: 25.0 °C Ambient at Space Max Temp.: 38.0 °C Unconditioned Space Min Temp.: 15.0 °C Ambient at Space Min Temp.: 5.0 °C	

Figure 18 Floor space temperatures information

For Floor Transmission (above unconditioned space *figure 17*) , A= 14 m^2 , U= 2.107 $W.k/m^2$ (sensible):

$$Q = U \times A \times \Delta T = 2.107 \times 14 \times (21.1 - 15) = 179.9 W$$

- **In Summer (Design cooling) :**
- **Designed Dry Bulb Temperature:** Set at 33.9°C, during the hottest month (JULY).

(Derived from regional climate data and standards)
- **Wet Bulb Temperature:** Established at 18°C.
- **Occupied Temperature: Maintained at 23.9°C**, this temperature represents the targeted indoor comfort level for occupants during the hottest month.

- **Sample of calculation**

For roof Transmission , A= 14 m^2 , U= 2.115 $W.k/m^2$ (sensible):

$$Q = U \times A \times \Delta T = 2.115 \times 14 \times (23.9 - 15) = 263.5 W$$

For Floor Transmission (above unconditioned space *figure 5*) , A= 14 m^2 , U= 2.107 $W.k/m^2$ (sensible):

$$Q = U \times A \times \Delta T = 2.107 \times 14 \times (23.9 - 25) = -32.4 W$$

- Internal loads

The screenshot shows the 'Space Properties - [ENTRANCE]' dialog box with the 'Internals' tab selected. The 'Overhead Lighting' section is highlighted with a red box, showing 'Fixture Type' as 'Recessed, unvented', 'Wattage' as '240.0 Watts', and 'Ballast Multiplier' as '1.00'. The 'Task Lighting' section shows 'Wattage' as '0.00 W/m²'. The 'Electrical Equipment' section shows 'Wattage' as '0.00 W/m²'. The 'People' section shows 'Occupancy' as '0.0 People', 'Activity Level' as 'Office Work', 'Sensible' as '71.8 W/person', and 'Latent' as '60.1 W/person'. The 'Miscellaneous Loads' section shows 'Sensible' as '0 W' and 'Latent' as '0 W'.

Figure 19 Internal loads information

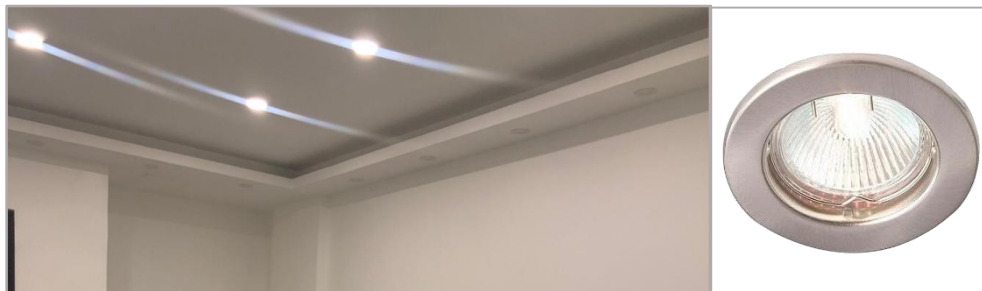


Figure 20 overhead lighting , Recessed unvented

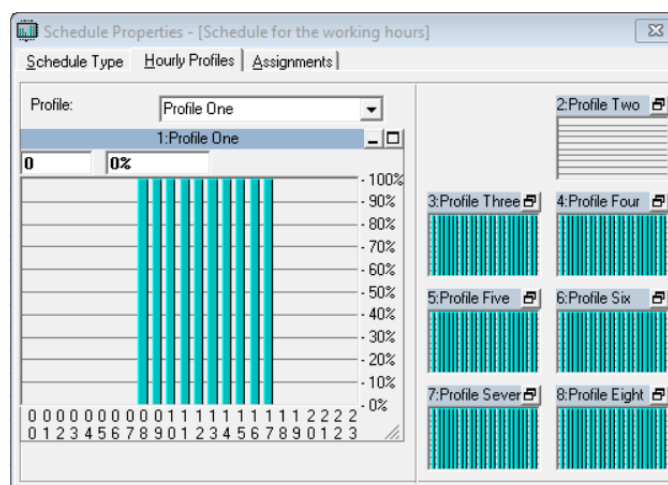


Figure 21 opening hours of lighting from 8 AM to 5 PM

Overhead lighting : Recessed unvented

Number: 24 lights , each 10 W

Overall power consumption : $10\text{ W} \times 24 = 240\text{ W} > \text{approximately } 214\text{ W}$ as sensible heat

Operating : From 8 AM to 5 PM.

Occupants : 0 people

2.5.2 The Hall

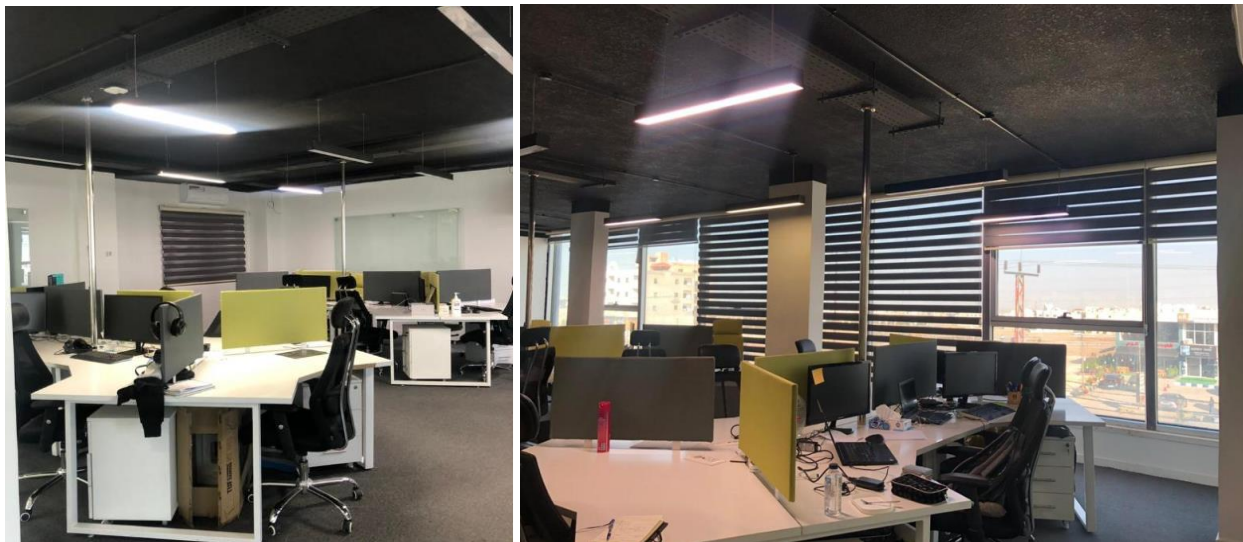


Figure 22 The hall space

- General information

-Roof & floor Area : 14 m^2

- Height : 2.7 m

- Window type : Eight from Windows 1 and One from Windows 2

- Window 1 area = $8 * 2.3 * 1.56 = 28.704\text{ m}^2$, Window 2 area = $1.68 * 1.05 = 1.764\text{ m}^2$

- Wall : Wall section , 33.7 m^2 and 9.2 m^2

Space Properties - [HALL]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

Exposure	Wall Gross Area m²	Window 1 Quantity	Window 2 Quantity	Door Quantity
1 E	33.7	8	0	0
2 W	9.2	0	1	0

Construction Types for Exposure: **2 (W)**

Wall: WALL SECTION

Window 1: WINDOW1

Figure 23 Input data for Hall space

TABLE 1.2.A. COMPONENT LOADS FOR SPACE " HALL " IN ZONE " Zone 1 "						
	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1700 COOLING OA DB / WB 33.9 °C / 18.0 °C OCCUPIED T-STAT 23.9 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C OCCUPIED T-STAT 21.1 °C		
		Sensible	Latent		Sensible	Latent
SPACE LOADS	Details	(W)	(W)	Details	(W)	(W)
Window & Skylight Solar Loads	30 m²	2386	-	30 m²	-	-
Wall Transmission	33 m²	853	-	33 m²	1419	-
Roof Transmission	160 m²	5584	-	160 m²	6957	-
Window Transmission	30 m²	1248	-	30 m²	2856	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	160 m²	532	-	160 m²	2873	-
Partitions	0 m²	0	-	0 m²	0	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	1130 W	1018	-	1130 W	0	-
Task Lighting	0 W	0	-	0 W	0	-
Electric Equipment	4500 W	3600	-	4500 W	0	-
People	12	671	721	12	0	0
Infiltration	-	264	-153	-	543	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0% / 0%	0	0
>> Total Zone Loads	-	16156	568	-	14648	0

- **Sample of calculations**

- **In Winter (Design heating) :**

- **Designed Dry Bulb Temperature:** Set at 0.6°C.
- **Wet Bulb Temperature:** -2.5°C.
- **Occupied Temperature: Maintained at 21.1°C.**

1. For Wall :

$$Q = U \times A \times \Delta T = 2.344 \times (33.7) \times (21.1 - 0.6) = 1619 \text{ W}$$

2. For Windows :

$$Q = U \times A \times \Delta T = 1.68 \times 1.05 \times 6.208 \times (21.1 - 0.6) + 8 \times 2.3 \times 1.56 \times 3.645 \times (21.1 - 0.6) = 2369.32 \text{ W}$$

3. Windows solar load :

The equation used in HAP to calculate solar heat gain through windows is:

$$Q_{\text{Solar}} = A \times \text{SHGC} \times \text{Solar Radiation}$$

Where:

- Q_{Solar} is the solar heat gain through the windows.
- A is the window area.

- **SHGC** is the Solar Heat Gain Coefficient, representing the fraction of solar radiation transmitted through the windows.
- **Solar Radiation** is the incident solar radiation on the windows.

4. Roof and floor calculations are identical for the equations and procedures of Entrance space , and the final answers are shown in table 1.2.A.

- **In Summer (Design cooling) :**

- **Designed Dry Bulb Temperature:** Set at 34.7°C.
- **Wet Bulb Temperature:** 18.2°C.
- **Occupied Temperature:** Maintained at 23.9°C.

5. For Wall :

$$Q = U \times A \times \Delta T = 2.344 \times (33.7) \times (34.7 - 23.9) = 853 \text{ W}$$

6. For Windows :

$$Q = U \times A \times \Delta T = 1.68 \times 1.05 \times 6.208 \times (34.7 - 23.9) + 8 \times 2.3 \times 1.56 \times 3.645 \times (34.7 - 23.9) = 1248.23 \text{ W}$$

7. Windows solar load :

The equation used in HAP to calculate solar heat gain through windows is:

$$Q_{solar} = A \times SHGC \times \text{Solar Radiation}$$

Where:

- Q_{solar} is the solar heat gain through the windows.
- A is the window area.
- SHGC is the Solar Heat Gain Coefficient, representing the fraction of solar radiation transmitted through the windows.
- Solar Radiation is the incident solar radiation on the windows.

8. Roof and floor calculations are identical for the equations and procedures of Entrance space , and the final answers are shown in table 2.

- Internal loads

The screenshot shows the 'Space Properties - [HALL]' dialog box with the 'Internals' tab selected. The dialog is organized into several sections with input fields and schedule buttons:

- Overhead Lighting:** Fixture Type (Free hanging), Wattage (1130.0 Watts), Ballast Multiplier (1.00), and a Schedule button set to 'Schedule for the workin'.
- Task Lighting:** Wattage (0.00 W/m²) and a Schedule button set to '(none)'.
- Electrical Equipment:** Wattage (3280 Watts) and a Schedule button set to 'Schedule for the workin'.
- People:** Occupancy (12.0 People), Activity Level (Office Work), Sensible (71.8 W/person), Latent (60.1 W/person), and a Schedule button set to 'Schedule for the working t'.
- Miscellaneous Loads:** Sensible (0 W), Latent (0 W), and two Schedule buttons both set to '(none)'.

Figure 24 input of internal load

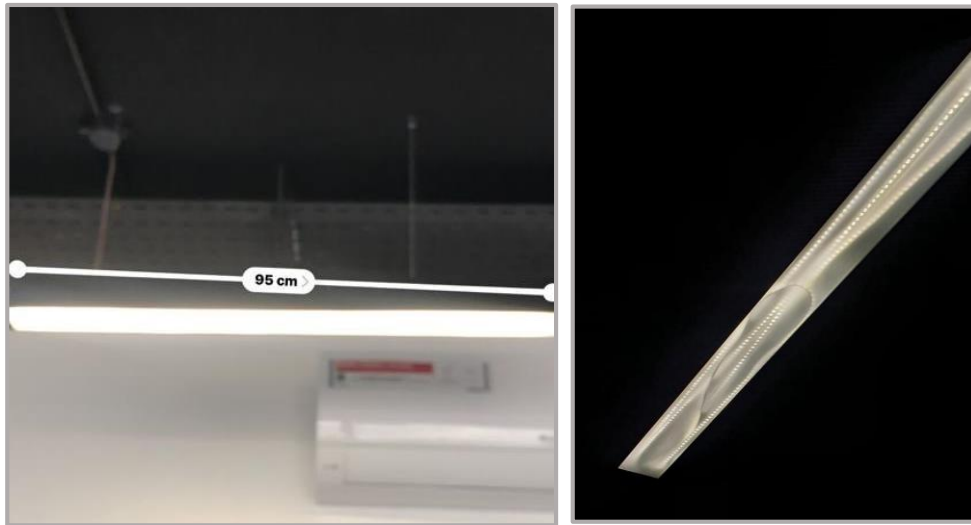


Figure 25 Hanging lighting

Overhead lighting : Free hanging

Number: 21 hanging lights , each approximately 54 W

Overall power consumption : $54 \text{ W} \times 21 = 1134 \text{ W} > \text{approximately } 1009 \text{ W}$ as sensible heat

Operating : From 8 AM to 5 PM.

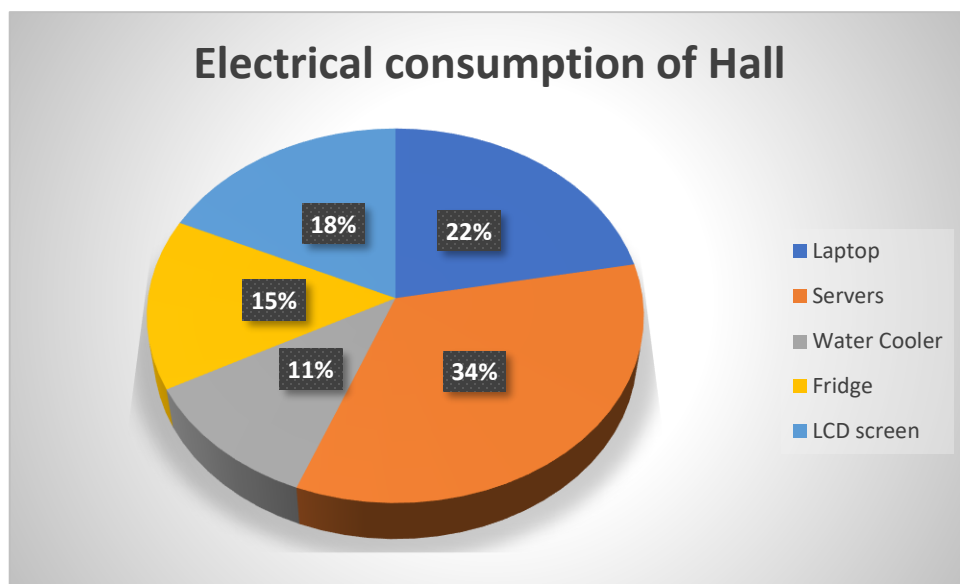
Occupants : Heat gain from people varies depending on the activity being performed in the space as shown in table 3 , the occupant mostly equal 12 people (workers).

Table 3 Heat gain from people

Activity Level	Sensible Heat Gain (BTU/h person)	Latent Heat Gain (BTU/h person)	Sensible Heat Gain (W person)	Latent Heat Gain (W/person)
Seated At Rest	230	120	67.4	35.2
Office Work	245	205	71.8	60.1
Sedentary Work	280	270	82.1	79.1
Medium Work	295	455	86.5	133.4
Heavy Work	525	925	153.9	271.1
Dancing	305	545	89.4	159.7
Athletics	710	1090	208.1	319.4

- Electrical equipment

Device name	Number of Devices	Operating Hours	Consumption in Watt	Total Consumption in Watt
Laptop	15	9H	65	975
Servers	2	24H	750	1500
Water Cooler	1	9H	500	500
Fridge	1	9H	500	650
LCD screen	2	9H	400	800
				4425



The electrical equipment consumption is entered into HAP with a schedule equal to the operating hours and then some of this will convert to sensible heat as shown in table 1.2 A .

As shown in the above figure , the consumption is mostly come from the server , which will contribute in increasing sensible cooling load.

Following the sample calculation of the load for the HALL, all the required numbers and data are presented in Table 1.2.A. This table serves as a comprehensive reference, detailing crucial parameters and values essential for the analysis of the Hall's thermal and energy performance.

2.5.3 The Manger room

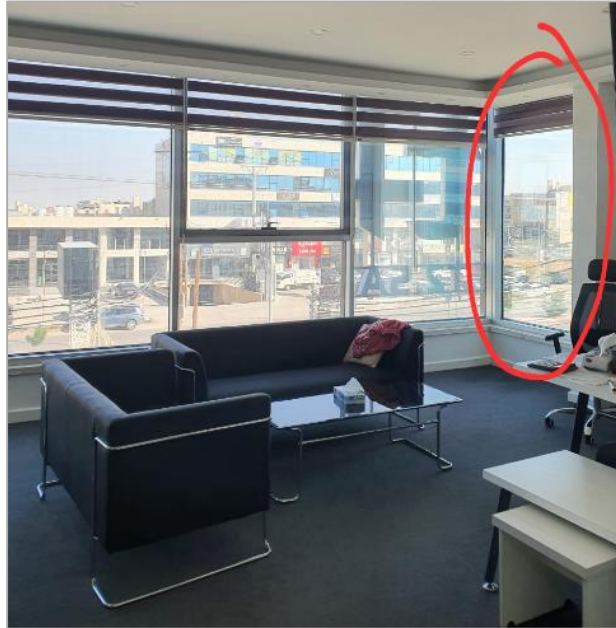


Figure 26 Manger Room

TABLE 1.3.A. COMPONENT LOADS FOR SPACE "MANAGER" IN ZONE "Zone 1"						
	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.7 °C / 18.2 °C OCCUPIED T-STAT 23.9 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C OCCUPIED T-STAT 21.1 °C		
		Sensible	Latent		Sensible	Latent
SPACE LOADS	Details	(W)	(W)	Details	(W)	(W)
Window & Skylight Solar Loads	14 m ²	793	-	14 m ²	-	-
Wall Transmission	14 m ²	424	-	14 m ²	572	-
Roof Transmission	27 m ²	1024	-	27 m ²	1191	-
Window Transmission	14 m ²	469	-	14 m ²	850	-
Skylight Transmission	0 m ²	0	-	0 m ²	0	-
Door Loads	0 m ²	0	-	0 m ²	0	-
Floor Transmission	27 m ²	99	-	27 m ²	180	-
Partitions	9 m ²	-8	-	9 m ²	116	-
Ceiling	0 m ²	0	-	0 m ²	0	-
Overhead Lighting	330 W	243	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	550 W	501	-	0	0	-
People	1	54	60	0	0	0
Infiltration	-	271	-81	-	945	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	3871	-21	-	3854	0

- **Input data**

Space Properties - [MANAGER]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

Name: **MANAGER**

Floor Area: **27.4** m²

Avg Ceiling Height: **2.7** m

Building Weight: **341.8** kg/m²

Light Med. Heavy

Figure 29 general information

Space Properties - [MANAGER]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

Exposure	Wall Gross Area m ²	Window 1 Quantity	Window 2 Quantity	Door Quantity
1 E	15.1	3	0	0
2 S	13.2	1	0	0

Construction Types for Exposure: **1 (E)**

Wall: **WALL SECTION**

Window 1: **WINDOW1**

Figure 28 wall and window types of manger room

Space Properties - [MANAGER]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

Overhead Lighting

Fixture Type: **Recessed, unvented**

Wattage: **330.0** Watts

Ballast Multiplier: **1.00**

Schedule: **Schedule for the workin**

Task Lighting

Wattage: **0.00** W/m²

Schedule: **(none)**

Electrical Equipment

Wattage: **550.0** Watts

Schedule: **Schedule for the workin**

People

Occupancy: **1.0** People

Activity Level: **Office Work**

Sensible: **71.8** W/person

Latent: **60.1** W/person

Schedule: **Schedule for the working**

Miscellaneous Loads

Sensible: **0** W

Schedule: **(none)**

Latent: **0** W

Schedule: **(none)**

Figure 27 Data input for internal loads

The manager's room has also been subjected to similar calculations that take into account both internal and exterior loads, in line with the calculations completed for the entrance and hall spaces. The approach used makes sure that all spatial assessments are comparable and consistent. All necessary information, including important parameters, has been thoroughly compiled in the table above. This tabular providing all the data needed for a comprehensive analysis of the energy and thermal dynamics unique to the manager's room.

2.5.4 The meeting room



Figure 30 The meeting room

TABLE 1.4.A. COMPONENT LOADS FOR SPACE " MEETING ROOM " IN ZONE " Zone 1 "						
	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1700 COOLING OA DB / WB 33.9 °C / 18.0 °C OCCUPIED T-STAT 23.9 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C OCCUPIED T-STAT 21.1 °C		
		Sensible	Latent		Sensible	Latent
SPACE LOADS	Details	(W)	(W)	Details	(W)	(W)
Window & Skylight Solar Loads	7 m ²	744	-	7 m ²	-	-
Wall Transmission	9 m ²	356	-	9 m ²	446	-
Roof Transmission	24 m ²	767	-	24 m ²	1061	-
Window Transmission	7 m ²	273	-	7 m ²	654	-
Skylight Transmission	0 m ²	0	-	0 m ²	0	-
Door Loads	0 m ²	0	-	0 m ²	0	-
Floor Transmission	24 m ²	82	-	24 m ²	160	-
Partitions	11 m ²	36	-	11 m ²	71	-
Ceiling	0 m ²	0	-	0 m ²	0	-
Overhead Lighting	410 W	368	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	100 W	92	-	0	0	-
People	3	165	180	0	0	0
Infiltration	-	206	-72	-	841	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	3089	108	-	3233	0

- **Input data**

Space Properties - [MEETING ROOM]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

Name: **MEETING ROOM**

Floor Area: **24.4** m²

Avg Ceiling Height: **2.7** m

Building Weight: **341.8** kg/m²

Light Med. Heavy

Figure 32 general information

Space Properties - [MEETING ROOM]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

	Wall	Window 1	Window 2	Door
Exposure	W			
Area m²	16.5			
Quantity	1	0	0	

Construction Types for Exposure: **1 (W)**

Wall WALL SECTION

Figure 31 wall and window types of meeting room

Space Properties - [MEETING ROOM]

General | Internals | Walls, Windows, Doors | Roofs, Skylights | Infiltration | Floors | Partitions

Overhead Lighting

Fixture Type: Free hanging

Wattage: **410.0** Watts

Ballast Multiplier: **1.00**

Schedule Schedule for the workin

Task Lighting

Wattage: **0.00** W/m²

Schedule (none)

Electrical Equipment

Wattage: **100.0** Watts

Schedule Schedule for the workin

People

Occupancy: **3.0** People

Activity Level: Office Work

Sensible: **71.8** W/person

Latent: **60.1** W/person

Schedule Schedule for the working h

Miscellaneous Loads

Sensible: **0** W

Schedule (none)

Latent: **0** W

Schedule (none)

Figure 33 Internal load of meeting room

The calculations for the meeting room were performed in a similar manner to the ones described above for the manager's room. The data obtained from these calculations is shown in the table above, which illustrates the breakdown of the loads of the meeting room. This methodology allows for a comprehensive understanding of the spatial distribution of the meeting room and provides a basis for comparing the different spaces within the building.

2.6 Ventilation

Ventilation is a crucial aspect of building design, aiming to maintain a healthy indoor environment. The needed ventilation is calculated based on factors such as space usage, floor area, and occupancy. It represents the volume of outdoor air required to ensure adequate dilution of indoor pollutants and maintain acceptable air quality for occupants.

1. Space Ventilation Analysis Table

Zone Name / Space Name	Mult.	Floor Area (m ²)	Maximum Occupants	Maximum Supply Air (L/s)	Required Outdoor Air (L/s/person)	Required Outdoor Air (L/(s·m ²))	Required Outdoor Air (L/s)	Required Outdoor Air (% of supply)	Uncorrected Outdoor Air (L/s)
Zone 1									
ENTRANCE	1	14.0	0.0	89.1	2.50	0.30	0.0	0.0	4.2
HALL	1	160.0	12.0	1651.2	2.50	0.30	0.0	0.0	78.0
MANAGER	1	27.4	1.0	406.0	2.50	0.30	0.0	0.0	10.7
MEETING ROOM	1	24.4	3.0	335.7	2.50	0.60	0.0	0.0	22.1
Totals (incl. Space Multipliers)				2482.0					115.1

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE (Continued)									
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)									
Occupancy Category	People Outdoor Air Rate		Area Outdoor Air Rate		Notes	Default Values			Air Class
	R_p		R_a			Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft ²	L/s·m ²		#/1000 ft ² or #/100 m ²	cfm/person	L/s·person	
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1

Figure 34 ASHREA 2010 std for Ventilation

1. Data Source:

In the case of office workspaces, the ventilation requirements have been specifically chosen based on ASHRAE standards. ASHRAE recommends a ventilation rate of 2.5 L/s (Liters per second) per person for office workspaces. This rate is in accordance with ASHRAE Standard 62.1-2010, which outlines guidelines for indoor air quality and ventilation.

The selection of 2.5 L/s/person as the ventilation rate for office workspaces ensures that the HVAC system provides an adequate supply of outdoor air to dilute contaminants and maintain a healthy environment for occupants

2. Maximum Supply Air:

The maximum supply air refers to the highest volume of conditioned air that the HVAC system can deliver to the designated spaces. It takes into account factors like the size of the space, the number of occupants, and ventilation requirements. This parameter ensures that the HVAC system is capable of meeting the specified ventilation needs.

2.7 Infiltration

The used method is LBL Model for Air Leakage:

COMPONENT	UNIT	PER AREA- PERIMETER	A LEAK (INCH^2)
SILL FOUNDATION-WALL	0.04	206.9	8.276
WALL-CEILING	0.07	206.9	14.483
WINDOW1 (12)	0.043	38.62	19.92
WINDOW FRAME1 – WALL (12)	0.019	38.62	8.8
WINDOW2 (2)	0.043	13.788	2.371
WINDOW FRAME2 – WALL (2)	0.019	13.788	1.0478
WINDOW3	0.086	9.5	0.817
WINDOW FRAME3 – WALL (1)	0.024	9.5	0.228
DOOR	0.114	21.5	2.451
DOOR FRAME-WALL	0.004	21.5	0.086
TOTAL			58.479

- **In winter**

($T_i=77F$, $T_o=35.6F$) , $v=0.289$ mile per minute , $a_s=0.047$, $a_w=0.0143$,

Volume of the company= 24155.2 ft^3 :

$$V = A_{leak} \sqrt{(a_s(T_i - T_o) + a_w v^2)}$$

$$V = 48959.1 \text{ ft}^3$$

$$ACH = \frac{V}{\text{volume of the company}} = 0.202$$

- **In summer**

($T_i=95F$, $T_o=77 F$) , $v=0.289$, $a_s=0.047$, $a_w=0.0143$):

$$V = 3229.55 \text{ ft}^3$$

$$ACH = 0.133$$

2.8 Zone Sizing Data

Table A : Zone Sizing Data

Zone Name	Maximum Cooling Sensible (kW)	Design Airflow (L/s)	Minimum Airflow (L/s)	Time of Peak Load	Maximum Heating Load (kW)	Zone Floor Area (m²)	Zone L/(s-m²)
Zone 1	23.74	2482	2482	Jul 1600	23	225.8	10.99

Table B :Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (kW)	Time of Load	Air Flow (L/s)	Heating Load (kW)	Floor Area (m²)	Space L/(s-m²)
Zone 1							
ENTRANCE	1	0.62	Jul 1700	89	1.264	14.0	6.36
HALL	1	16.15	Jul 1600	1651	14.648	160.0	10.32
MANAGER	1	3.87	Jul 1600	406	3.854	27.4	14.82
MEETING ROOM	1	3.1	Jul 1700	336	3.234	24.4	13.76

Table C. Air System Design Load Summary for HVAC SYSTEM

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.7 °C / 18.2 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	52 m ²	3921	-	52 m ²	-	-
Wall Transmission	27 m ²	726	-	27 m ²	1284	-
Roof Transmission	226 m ²	8423	-	226 m ²	9818	-
Window Transmission	52 m ²	2111	-	52 m ²	4811	-
Skylight Transmission	0 m ²	0	-	0 m ²	0	-
Door Loads	0 m ²	0	-	0 m ²	0	-
Floor Transmission	226 m ²	597	-	226 m ²	5454	-
Partitions	34 m ²	92	-	34 m ²	863	-
Ceiling	0 m ²	0	-	0 m ²	0	-
Overhead Lighting	2110 W	1881	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	5150 W	4708	-	0	0	-
People	16	872	961	0	0	0
Infiltration	-	403	-216	-	769	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	23735	746	-	22999	0
Zone Conditioning	-	25322	746	-	21953	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	2300 L/s	0	-	2300 L/s	0	-
Ventilation Load	115 L/s	1287	-729	115 L/s	2529	0
Supply Fan Load	2300 L/s	0	-	2300 L/s	0	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	26608	17	-	24483	0
Central Cooling Coil	-	26608	0	-	0	0
Central Heating Coil	-	0	-	-	24483	-
>> Total Conditioning	-	26608	0	-	24483	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		

After calculating the cooling and heating loads for each space in Zone 1, the total cooling load for the overall zone is determined to be 23.74 kW and for heating is 23 kW.

The table C from HAP indicates a Total System Loads of 26.608 kW or 7.58 Tons, representing the sum of system loads in both cooling and heating columns. These totals signify the net amount of heat that must either be removed (for cooling) or added (for heating) to maintain comfortable conditions in the zones. Additionally, the Total Conditioning value is calculated to be 24.483 kW or 6.97 Tons, which is the sum of all items in the coil load section of the output.

While Total Conditioning values should closely match corresponding Total System Loads values, slight differences may occur due to the iterative procedure used to determine system operating conditions.

3. Improving performance

To improve the performance of the system, first we must look at the original load sizing to compare the improved results with it.

The load calculations that show the original system size without improvement:

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.7 °C / 18.2 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	52 m²	3921	-	52 m²	-	-
Wall Transmission	27 m²	726	-	27 m²	1284	-
Roof Transmission	226 m²	8423	-	226 m²	9818	-
Window Transmission	52 m²	2111	-	52 m²	4811	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	226 m²	597	-	226 m²	5454	-
Partitions	34 m²	92	-	34 m²	863	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	2110 W	1881	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	5150 W	4708	-	0	0	-
People	16	872	961	0	0	0
Infiltration	-	403	-216	-	769	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	23735	746	-	22999	0
Zone Conditioning	-	25322	746	-	21953	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	2300 L/s	0	-	2300 L/s	0	-
Ventilation Load	115 L/s	1287	-729	115 L/s	2529	0
Supply Fan Load	2300 L/s	0	-	2300 L/s	0	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	26608	17	-	24483	0
Central Cooling Coil	-	26608	0	-	0	0
Central Heating Coil	-	0	-	-	24483	-
>> Total Conditioning	-	26608	0	-	24483	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		

The total cooling load was 26.608 KW, which is about 7.58 Tons of refrigeration. And the heating load was 24.483 KW which is 6.97 Tons.

The most effective area that consume the load is the “Hall”, because of it’s large area and it has a whole wall filled with windows in the eastern side, so this is the total load for this area alone:

TABLE 1.2.A. COMPONENT LOADS FOR SPACE " HALL " IN ZONE " Zone 1 "						
	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1700 COOLING OA DB / WB 33.9 °C / 18.0 °C OCCUPIED T-STAT 23.9 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C OCCUPIED T-STAT 21.1 °C		
		Sensible	Latent		Sensible	Latent
SPACE LOADS	Details	(W)	(W)	Details	(W)	(W)
Window & Skylight Solar Loads	30 m²	2321	-	30 m²	-	-
Wall Transmission	12 m²	367	-	12 m²	599	-
Roof Transmission	150 m²	6327	-	160 m²	6957	-
Window Transmission	30 m²	1198	-	30 m²	2856	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	160 m²	377	-	160 m²	3746	-
Partitions	0 m²	0	-	0 m²	0	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	1130 W	1018	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	4425 W	4100	-	0	0	-
People	12	671	721	0	0	0
Infiltration	-	264	-153	-	543	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	16643	568	-	14700	0

As seen that 4.75 Tons of cooling load and 4.18 Tons of heating load is just from this area, which is about 40% of the total load, so it is good to compare the improvement results on overall areas and see how this area is affected by the improvement.

First improvement: Adding an insulation of 100 mm thickness in the walls.

The first improve was to add an insulation material to decrease the overall heat transfer coefficient.

Wall Properties - [WALL SECTION]

Wall Assembly Name: **WALL SECTION**

Outside Surface Color: **Light** Absorptivity: **0.450**

Layers: Inside to Outside	Thickness mm	Density kg/m³	Specific Ht. kJ/kg/K	R-Value m²·K/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
plaster	15.000	2000.0	0.90	0.01250	30.0
insulation	100.000	30.0	0.45	3.33320	3.0
BLOCK	200.000	1400.0	0.84	0.22222	280.0
PLASTER	15.000	2000.0	0.90	0.01250	30.0
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	330.000			3.76	343.0

Overall U-Value: 0.266 W/m²/K

OK Cancel Help

A 100 mm thickness insulation material was added to the wall, so the overall heat transfer coefficient was reduced to 0.266 W/m²k. the results was positive.

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1500 COOLING OA DB / WB 35.0 °C / 18.3 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	52 m²	4108	-	52 m²	-	-
Wall Transmission	27 m²	68	-	27 m²	146	-
Roof Transmission	226 m²	7960	-	226 m²	9818	-
Window Transmission	52 m²	2133	-	52 m²	4811	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	226 m²	621	-	226 m²	5454	-
Partitions	34 m²	96	-	34 m²	863	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	2110 W	1864	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	5150 W	4674	-	0	0	-
People	16	851	961	0	0	0
Infiltration	-	416	-215	-	769	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	22790	746	-	21861	0
Zone Conditioning	-	24295	746	-	21140	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	2234 L/s	0	-	2234 L/s	0	-
Ventilation Load	115 L/s	1319	-727	115 L/s	2540	0
Supply Fan Load	2234 L/s	0	-	2234 L/s	0	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	25614	19	-	23680	0
Central Cooling Coil	-	25614	0	-	0	0
Central Heating Coil	-	0	-	-	23680	-
>> Total Conditioning	-	25614	0	-	23680	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		

- As seen that the cooling load reduced to 7.29 Tons, and the heating load 6.74 Tons. This improvement was done to reduce the losses that occurs due to conduction. For the “Hall” area:

TABLE 1.2.A. COMPONENT LOADS FOR SPACE " HALL " IN ZONE " Zone 1 "						
	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1700 COOLING OA DB / WB 33.9 °C / 18.0 °C OCCUPIED T-STAT 23.9 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C OCCUPIED T-STAT 21.1 °C		
		Sensible	Latent		Sensible	Latent
SPACE LOADS	Details	(W)	(W)	Details	(W)	(W)
Window & Skylight Solar Loads	30 m²	2386	-	30 m²	-	-
Wall Transmission	33 m²	853	-	33 m²	1419	-
Roof Transmission	160 m²	5584	-	160 m²	6957	-
Window Transmission	30 m²	1248	-	30 m²	2856	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	160 m²	532	-	160 m²	2873	-
Partitions	0 m²	0	-	0 m²	0	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	1130 W	1018	-	1130 W	0	-
Task Lighting	0 W	0	-	0 W	0	-
Electric Equipment	4500 W	3600	-	4500 W	0	-
People	12	671	721	12	0	0
Infiltration	-	264	-153	-	543	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0% / 0%	0	0
>> Total Zone Loads	-	16156	568	-	14648	0

The cooling load is now 4.59 Tons, and the heating load is 4.16 Tons.

Second improvement: Rotating the building 180 degrees.

This step the building was rotated 180 degrees, the west side comes to be east and vice-versa.

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1600			HEATING DATA AT DES HTG		
	COOLING OA DB / WB 34.7 °C / 18.2 °C			HEATING OA DB / WB 0.6 °C / -2.5 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	52 m²	5738	-	52 m²	-	-
Wall Transmission	27 m²	66	-	27 m²	146	-
Roof Transmission	226 m²	8423	-	226 m²	9818	-
Window Transmission	52 m²	2111	-	52 m²	4811	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	226 m²	597	-	226 m²	5454	-
Partitions	34 m²	92	-	34 m²	863	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	2110 W	1881	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	5150 W	4708	-	0	0	-
People	16	872	961	0	0	0
Infiltration	-	403	-215	-	769	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	24892	746	-	21861	0
Zone Conditioning	-	26019	746	-	21281	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	2402 L/s	0	-	2402 L/s	0	-
Ventilation Load	115 L/s	1271	-727	115 L/s	2546	0
Supply Fan Load	2402 L/s	0	-	2402 L/s	0	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	27290	19	-	23826	0
Central Cooling Coil	-	27290	0	-	0	0
Central Heating Coil	-	0	-	-	23826	-
>> Total Conditioning	-	27290	0	-	23826	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		

From the table, the cooling load was raised to 7.77 Tons, and the heating load is 6.78 Tons, the heating load was raised a little bit closer to be neglected. But for this step the results were negative, and the load was raised instead of lowered.

For this reason, the building rotated 90 degrees instead of 180 degrees, and the results were:

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.7 °C / 18.2 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	52 m²	2342	-	52 m²	-	-
Wall Transmission	27 m²	51	-	27 m²	146	-
Roof Transmission	226 m²	8423	-	226 m²	9818	-
Window Transmission	52 m²	2111	-	52 m²	4811	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	226 m²	597	-	226 m²	5454	-
Partitions	34 m²	92	-	34 m²	863	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	2110 W	1881	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	5150 W	4708	-	0	0	-
People	16	872	961	0	0	0
Infiltration	-	403	-216	-	769	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	21480	745	-	21861	0
Zone Conditioning	-	22652	745	-	21464	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	2106 L/s	0	-	2106 L/s	0	-
Ventilation Load	115 L/s	1275	-732	115 L/s	2547	0
Supply Fan Load	2106 L/s	0	-	2106 L/s	0	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	23927	13	-	24011	0
Central Cooling Coil	-	23927	0	-	0	0
Central Heating Coil	-	0	-	-	24011	-
>> Total Conditioning	-	23927	0	-	24011	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		

The results show that rotating the building 90 degrees (east to north side) reducing the cooling load from 7.29 Tons to 6.81 Tons, but the heating load was raised a little from 6.78 Tons to 6.84 Tons. This improvement is affecting the radiation heat transfer.

Third improvement: reducing the absorption of the roof by using a light roof color instead of dark color.

the color of the roof was dark, which indicates that the roof is absorbing a lot of radiation from the sun, so an improvement could be made to reduce the gained radiation.

After reducing the absorptivity from 0.9 to 0.45 as in the below figures:

Roof Properties - [ROOF SECTION]

Roof Assembly Name: **ROOF SECTION**

Outside Surface Color: **Dark** Absorptivity: **0.900**

Layers: Inside to Outside	Thickness mm	Density kg/m³	Specific Ht. kJ/kg/K	R-Value m²·K/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
PLASTER	15.000	2000.0	0.90	0.01250	30.0
RC SLAB	250.000	2300.0	0.92	0.14286	575.0
SCREED	50.000	2000.0	0.82	0.04167	100.0
SAND	50.000	1800.0	0.81	0.07143	90.0
CEMENT SAND	15.000	2000.0	0.84	0.01250	30.0
TILES	20.000	2450.0	0.90	0.01250	49.0
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	400.000			0.47	874.0

Overall U-Value: 2.115 W/m²/K

OK Cancel Help

Figure 35: The dark roof that has a 0.9 absorptivity

Roof Properties - [ROOF SECTION]

Roof Assembly Name: **ROOF SECTION**

Outside Surface Color: **Light** Absorptivity: **0.450**

Layers: Inside to Outside	Thickness mm	Density kg/m³	Specific Ht. kJ/kg/K	R-Value m²·K/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
PLASTER	15.000	2000.0	0.90	0.01250	30.0
RC SLAB	250.000	2300.0	0.92	0.14286	575.0
SCREED	50.000	2000.0	0.82	0.04167	100.0
SAND	50.000	1800.0	0.81	0.07143	90.0
CEMENT SAND	15.000	2000.0	0.84	0.01250	30.0
TILES	20.000	2450.0	0.90	0.01250	49.0
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	400.000			0.47	874.0

Overall U-Value: 2.115 W/m²/K

OK Cancel Help

Figure 36: The roof absorptivity after set to light

The results of this improvement are:

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1600 COOLING OA DB / WB 34.7 °C / 18.2 °C			HEATING DATA AT DES HTG HEATING OA DB / WB 0.6 °C / -2.5 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	52 m²	2342	-	52 m²	-	-
Wall Transmission	27 m²	51	-	27 m²	146	-
Roof Transmission	226 m²	4307	-	226 m²	9818	-
Window Transmission	52 m²	2111	-	52 m²	4811	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	0 m²	0	-	0 m²	0	-
Floor Transmission	226 m²	597	-	226 m²	5454	-
Partitions	34 m²	92	-	34 m²	863	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	2110 W	1881	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	5150 W	4708	-	0	0	-
People	16	872	961	0	0	0
Infiltration	-	403	-218	-	769	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	17364	744	-	21861	0
Zone Conditioning	-	18498	744	-	21180	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	1730 L/s	0	-	1730 L/s	0	-
Ventilation Load	115 L/s	1276	-736	115 L/s	2526	0
Supply Fan Load	1730 L/s	0	-	1730 L/s	0	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	19773	8	-	23706	0
Central Cooling Coil	-	19773	0	-	0	0
Central Heating Coil	-	0	-	-	23706	-
>> Total Conditioning	-	19773	0	-	23706	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		

The cooling load was reduced to 5.63 Tons, but the heating load is now 6.75 Tons, this is because that when the radiation absorbed by the roof is reduced a lot, at winter the heating load maybe will be increased or stay in the same range of load.

So, the average sizing of the system after these improvements is 7 Tons, instead of 10.5 Tons that is used now.

**note: all these improvements are cumulative improvements, which indicates that improvement two was done with existence of improvement one and so on.

4. Calculating Return-in-Investment

To make sure that the recommendations are feasible, they should have feasible study, it is as follows:

1) first improvement (Adding an insulation of 100 mm thickness in the walls):

- Old cooling: 7.58, old heating :6.79, cooling=0.29=1.019Kw= 1467.36 kWh/year
- New cooling:7.29, new heating :6.74, heating=0.05=0.1758Kw=253.152 kWh/year
- The cost of insulation material =7 JD/m²
- Total area of two walls (eastern and western sides)=101 m²
- Total cost of the installation of insulation material =101*7=707 JD

2) second improvement (Rotating the building 90 degrees):

- Old cooling:7.29, old heating:6.74, cooling=0.48=1.688 Kw=2430 kWh/year
- New cooling:6.81, new heating :6.84, heating=-0.1=-0.3516 Kw= -506.3 kWh/year

3) third improvement (reducing the absorption of the roof by using a light roof color instead of dark color):

- Old cooling:6.81, old heating:6.84, cooling=1.18=4.15 Kw= 1699 kWh/year
- New cooling:5.63, new heating :6.75, heating=0.090=0.3165 Kw=129.6 kWh/year
- The cost of the white paint =0.9 JD/m²
- Total area of the ceiling =228 m²
- Total cost=0.9*228=205

We will consider only the first and third improvements because it is hard to change the orientation of the company and will be costly if it is possible.

- Total saving=1467.36+253.152+1699+129.6=3558.112kWh
- Operating hours for a year (cooling or heating) =1440 hour
- Saving amount (0.12/kwh) =0.12*3558.112=427 JD /year.
- Total cost (First and the third improvements) =707+205=912 JD
- Payback period =(Total cost)/(saving amount)=912/427=2.14 years

If the owner of the building had chosen the right orientation (90 degree), he would have saved:

- Total saving=2430-506.3=1923.7 kWh/year
- Saving amount (0.12 JD/kwh) =0.12*1923.7=230 JD /year.

5. Discussion

The HVAC report for the T2 company provides a comprehensive analysis of the existing heating, ventilation, and air conditioning systems in the commercial building. The report is structured into three levels of energy audit, focusing on data collection, calculations, and recommendations for enhancing building performance.

The first level involves gathering utility bills, weather data, and conducting a walkthrough to understand the company's layout and occupancies. This initial stage sets the foundation for further analysis.

The second level delves into detailed calculations and measurements using HAP software. The report provides insights into wall construction, thermal resistance, and overall heat transfer coefficients (U-values) for both walls and windows. It highlights the significance of factors like convective heat transfer and thermal properties of different layers.

The third level presents recommendations based on the calculations from the previous level. Specific improvements, such as adding insulation to walls and using a lighter roof color, are suggested to enhance energy efficiency. The report evaluates the cost of these improvements and calculates potential savings in energy consumption.

The discussion can focus on the following key points:

- **Importance of HVAC Systems:** Emphasize the critical role of HVAC systems in ensuring occupant comfort, indoor air quality, and energy efficiency in commercial buildings.
- **Energy Efficiency Measures:** Discuss the proposed improvements, such as adding insulation and changing the roof color, and highlight how these measures can contribute to energy savings.
- **Financial Considerations:** Analyse the financial aspects, including the cost of improvements, potential savings, and the payback period. This provides a practical perspective for decision-makers.
- **Occupant Comfort:** Connect the proposed HVAC enhancements to the well-being and productivity of occupants. Improved thermal comfort and air quality contribute to a healthier work environment.
- **Feasibility of Recommendations:** Acknowledge the feasibility of the recommendations, considering factors like cost, practicality, and the potential impact on the building.
- **Alternative Solutions:** Discuss any alternative solutions or considerations that could further enhance energy efficiency or occupant comfort.

6. Conclusions

The HVAC report for the T2 company provides a comprehensive analysis:

- **Efficiency Gains:** Proposed HVAC upgrades offer tangible energy efficiency benefits.
- **Financial Feasibility:** Calculated savings and a 2.14-year payback period make improvements economically viable.
- **Occupant Impact:** Enhanced comfort and air quality contribute to a healthier work environment.
- **Strategic Importance:** Optimal building orientation could significantly impact energy savings.
- **Feasibility Constraints:** Challenges in changing building orientation highlight the importance of practical solutions.
- **Sustainability:** Proposed upgrades align with sustainable building practices