University College Dublin

School of Mechanical & Materials Engineering

MEEN10050 Energy Engineering - Spring 2022

Group Assignment

Heating Energy Requirements for a Room over 7 Consecutive Days

by

Group 101

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Abstract

The study of the Heat Transfer from through the walls of this room was conducted to better understand the effect of Heat Transfer between the inside and outside of a building. The study includes altercations, such as greater and lesser ACH (Air Changes per Hour), and additional insulation, to calculate the effect of the changes.

The room was measured for this project and the details about conductivity were gathered from various reliable sources. The outdoor temperature was determined using a sin function to imitate the fluctuating temperature of a seven-day cycle. Calculations were performed using a spreadsheet as to allow future changes if necessary. Furthermore, this permitted easy access to graphs of the data.

Using this calculated data, the amount of energy (number of radiators) required to maintain 21 across the seven-day period was determined. On the 30th hour it required 338.8673 amount of heating to maintain the indoor temperature. The majority of heat loss was determined to be due to the ventilation system (60.07%).

Introduction

1.1 Introduction

This is a report calculating the energy required to maintain a 21.0°C room temperature in a single room with three walls exposed to variations in external ambient air temperature over the course of 7 days given a vent that cause the air to change at a steady rate of 1.5 Air Changes per Hour (ACH). This report will determine how many and how powerful radiators in this room must be to maintain the internal temperature.

The external temperature is calculated given a sin formula to imitate the rising and falling temperatures of a day night cycles over 7 days.

Additionally, this report will calculate the Heat Transfer to the outside of the wall given specific altercations (namely if the vent causes the air to change at 0.75ACH, and 3ACH, and if there were an additional layer of insulation (100mm thick) added to the internal surface of the wall).

Methodology: The approach to the problem regarding

Results and Analysis: Interpretation of the findings from the methodology

Conclusions: Highlighting key findings and their significance

Reference: Sources

Appendix A: Contributions to the project

Appendix B: Sustainable Development Goals

1.2 Assumptions

1. That the indoor air temperature is maintained 21.0°C throughout the analysis.
2. That room occupants and appliances contribute an average energy input of 12.0 W/m^2 (watts per m^2 of room floor area).
3. That steady state heat transfer conditions apply during each individual hour of the week but that the magnitude of the rate of heat loss through the walls and windows may change from hour to hour.
4. That heat transfer effects through the floor, ceiling and other interior walls of the room will be ignored, this is a vast simplification resulting in less realistic computed results.
5. That heat storage effects in the materials or the fabric of building are ignored. This too is a significant simplification; this is to allow for one-dimensional steady state heat transfer to occur.
6. That radiation heat transfer effects are absent. This is also a vast simplification that results in less accurate results
7. That the 3 walls ($3*2.4\ m^2 + 4*2.4\ m^2 + 4*2.4\ m^2$) on the exterior have no corners and act as one wall ($11*2.4m^2$), therefore the exterior and interior surface area are equal as though it were one long wall.
8. That the electric radiators do not supply heat until it is required to maintain the 21.0°C internal air temperature and maintain the temperature exactly.
9. That heaters turn on when internal heat gain doesn't cover heat lost
10. That the air density in the interior is the same as the exterior (air that enters through the ventilation system).

11. That the heat transfer coefficient of convection on the surface of the wall outdoors h_o = 34.0 W/m^{2}K and the heat transfer coefficient of convection on the surface of the wall on the interior h_i = 8.29 W/m^{2}K.
12. The skirting board was excluded from calculations to keep the calculations simple. This of course produces less accurate results although the exclusion of the skirting board only causes minor inaccuracies as the effect it would have on heat transfer is minimal.
13. That the window frame is assumed to be around the edge of the window with the same area.
14. That the window cannot be opened.

Methodology

Calculate the energy input required to maintain the 21°C interior temperature given the fluctuating exterior temperature. This input will be granted in the form of radiators within the room and the number and power of these radiators is to be determined.

2.1 Room and Building Description

2.1.1 Walls

The room which was built in 2006 as an extension to the building constructed in 1990, has a length of 4.00m, a breadth of 3.00m and a height of 2.40m.

The external wall is constructed of 5 layers covering an area of 24.02 m^2:

Internal Surface: Dry Wall (Plaster)

Leaf 1: Standard Block Wall

Insulation: King Span Insulation

Leaf 2: Standard Block Wall

External Surface: External Render (Plaster)

Table 2.1: Calculation of the Resistance of each layer of the wall

Wall Calculations						
Materials	Conductivity	Resistivity	Thickness	Area (m^2)	Resistance (Per m^2)	Resistance
Internal Plaster(Dry Wall)	0.2500	4.0000	0.0180	24.0200	0.0720	0.0030
Leaf 1	0.8000	1.2500	0.1000	24.0200	0.1250	0.0052
Insulation	0.0250	40.0000	0.1000	24.0200	4.0000	0.1665
Leaf 2	0.8000	1.2500	0.1000	24.0200	0.1250	0.0052
External Plaster	0.5000	2.0000	0.0180	24.0200	0.0360	0.0015
Wall						
	Conv Coeff (h)				Total Wall Res	0.1814
Inside Air	8.2900			24.0200	0.1206	0.0050
Outside Air	34.0000			24.0200	0.0294	0.0012
					Total Res	0.1877
					U-Value	0.2218

The Resistivity was calculated using the formula

$$\frac{1}{k} = \rho$$ **Formula 2.1:** Resistivity

Where:

ρ = Resistivity of the component

k = Conductivity of the component

Resistance per square metre (K/W*m^2) is calculated by thickness/conductivity $\Delta x/k$

The formula for this table is Resistance

$$\frac{\Delta x}{A*k} = R_{comp}$$ **Formula 2.2:** Resistance

Where:

R_{comp} = the resistance of the component

Δ x = The thickness of the component

A = The area of the component

k = Conductivity of the component

Internal Plaster and External Plaster conductivities (k values) were found in Manzllo *et al*. (2008)

Leaf 1 and Leaf 2conductivities (k values) found in Mark (2012)

Insulation conductivity (k value) sourced from (Kingspan.com, 2021)

2.1.2 Window

There is a window which occupies 1.9285 m^2 and its frame which occupies 0.4515 m^2 collectively covering 2.38 m^2 of the exterior wall.

Internal (0.004m) - Low Emissivity Pane

Air cavity (0.016m) - Air Insulation

External (0.004m) - Single Pane (1.25 K*m/W)

Window Frame (PVC) (0.072m) - Window Frame

Table 2.2: Calculation of the Resistance of each layer of the Window

Window Calculations						
Materials	**Conductivity**	**Resistivity**	**Thickness**	**Area(m^2)**	**Resistance Per m^2**	**Resistance**
Internal (Low E)			0.0040	1.9285	0.3267	0.1694
Air Cavity			0.0160	1.9285	0.1700	0.0882
External (Single Pane)	0.8000	1.2500	0.0040	1.9285	0.0050	0.0026
Window						
	Conv Coeff				**Total Window Res**	0.2602
Inside Air	4.2000			1.9285	0.2381	0.1235
Outside Air	34.0000			1.9285	0.0294	0.0153
					Total Res	0.3989
					U-Value	1.3000

Table 2.3: Calculation of the Resistance of each layer of the Window Frame

Window Frame (PVC) Calculations						
Materials	Conv Coeff	Resistivity	Thickness	Area(m^2)	Resistance Per m^2	Resistance
Window Frame (PVC)			0.0720	0.4515	0.5153	1.1413
Inside Air	8.2900			0.4515	0.1206	0.2672
Outside Air	34.0000			0.4515	0.0294	0.0651
					Window Frame (PVC)	
					Total Res	1.4736
					U-Value	1.5030

The value or resistance per m^2 of an air cavity was found in (Ohio.edu 2008).

Conductivity (k value) of the external pane was found by (Nuclearpower.com, 2022).

The Resistivity was calculated using the formula as above

Resistance per square metre ($K/W*m^2$) is calculated by thickness/conductivity ($\Delta x/k$)

The U value of the window alone = 1.3 was taken from (Neuffer.de, 2022).

As such for the values in the table relating to the internal Low Emissivity Pane, the values were calculated in reverse order. The Value for resistance per m^2 was calculated using the two other values of resistance per m^2 in the window. The formula used is

$$\frac{1}{U} - \left(\frac{R_{cavity}}{A} + \frac{R_{glass}}{A}\right) = \frac{R_{low\ e}}{A}$$ **Formula 2.3:** U value

Where:

U = u value of the window frame
R_{cavity} = The resistance of the air cavity
R_{glass} = The resistance of the glass pane
$R_{low\ e}$ = The resistance of the low-e glass

2.1.3 Visual Representation

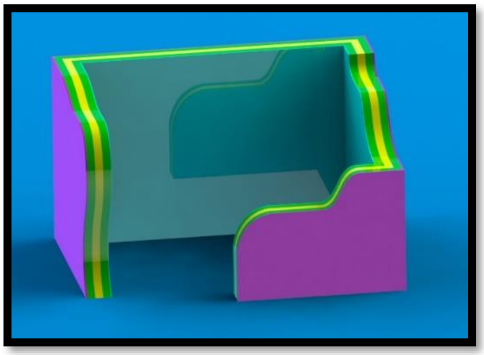


Figure 2.1 Walls of Room in Question

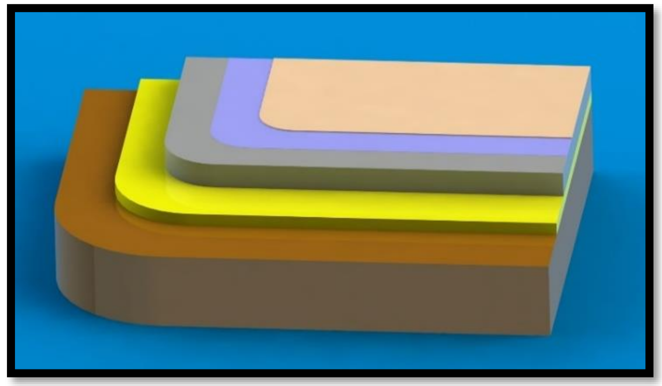


Figure 2.2 Layers of External Walls

Figure 2.3: Window

Figure 2.4: Cross section of window

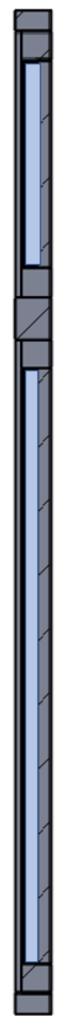


Figure 2.5: Bedroom walls

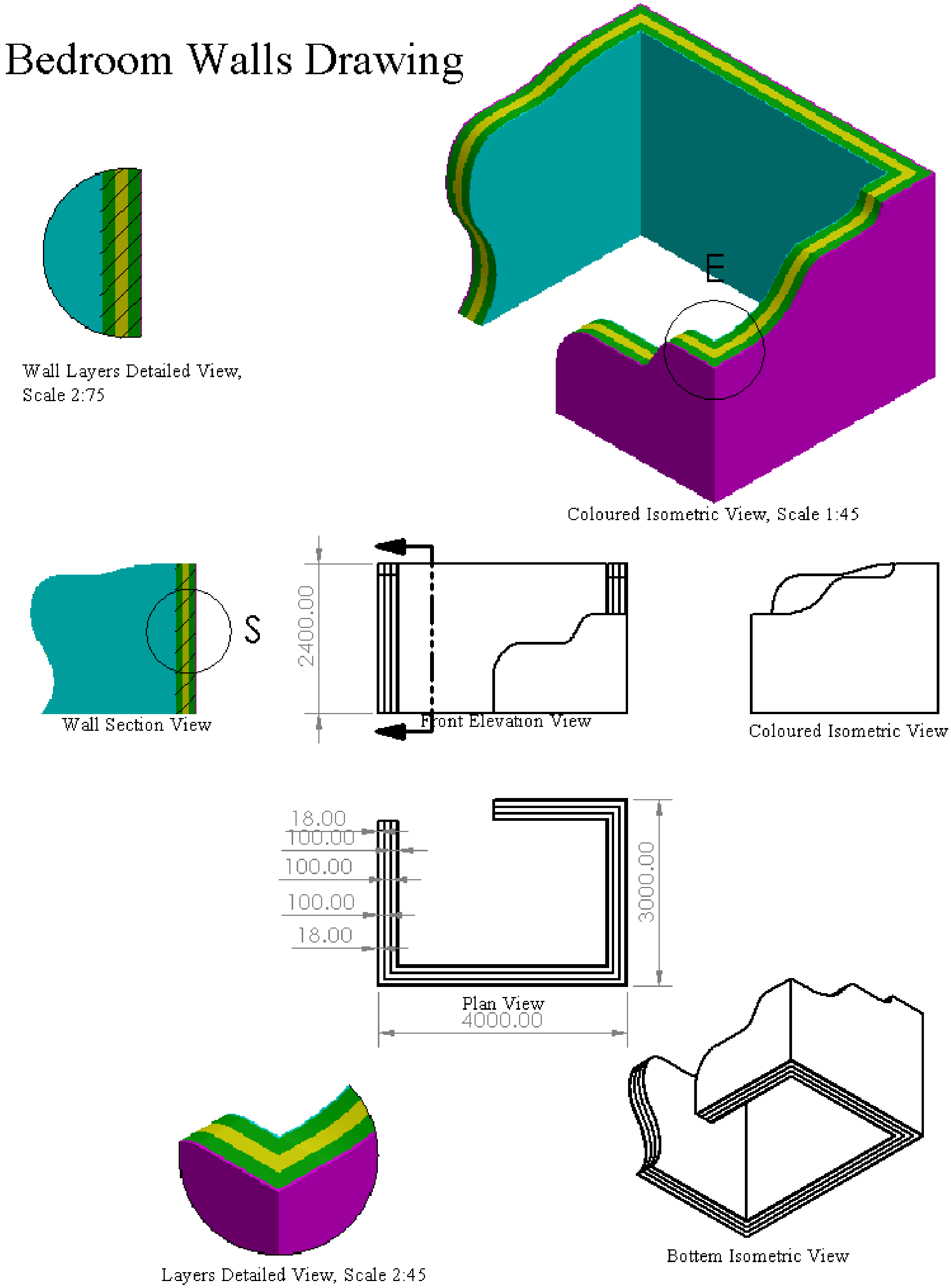
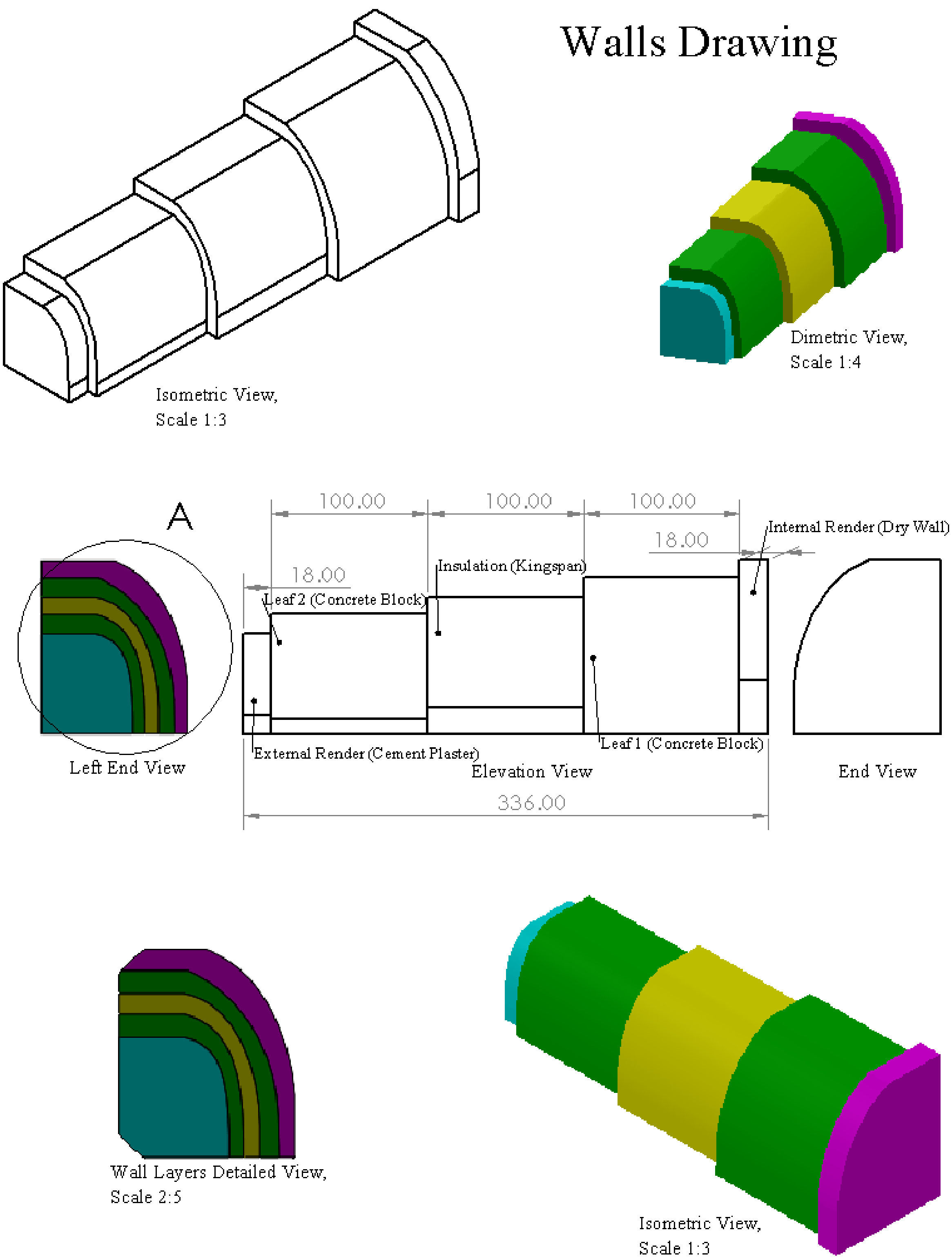
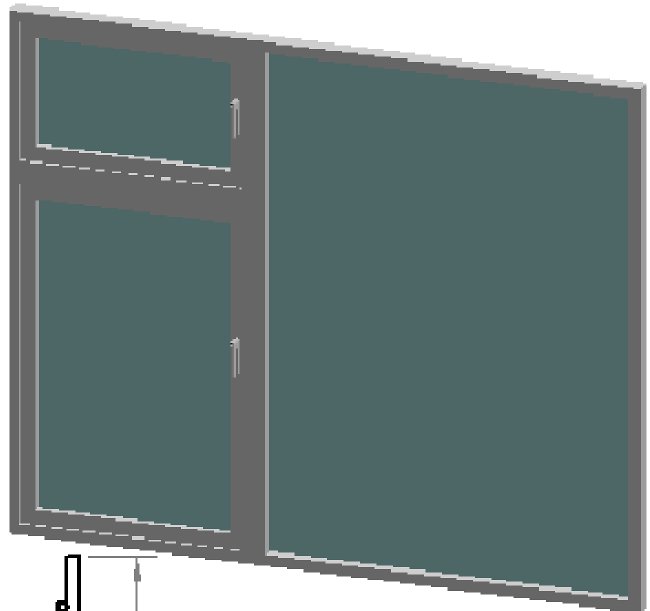


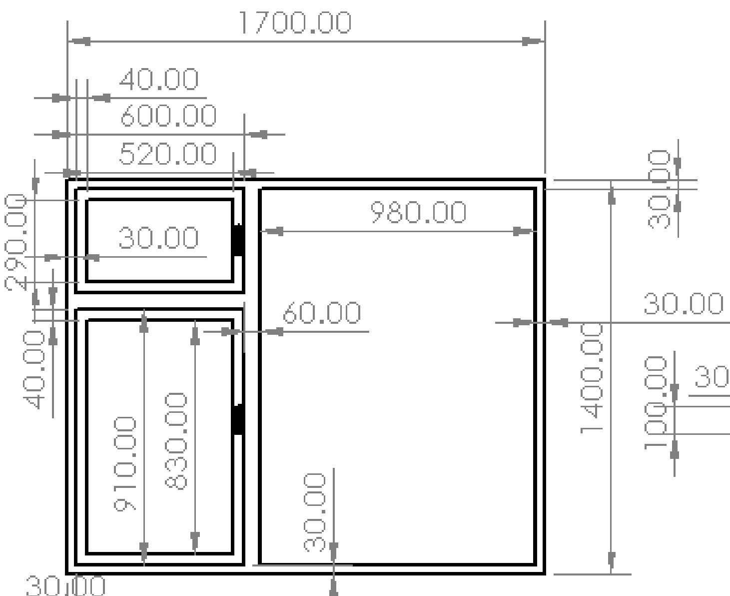
Figure 2.6: External Wall Layers



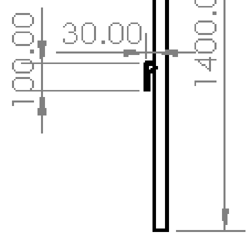
Window Drawing



Coloured Dimetric View, Scale 1:17

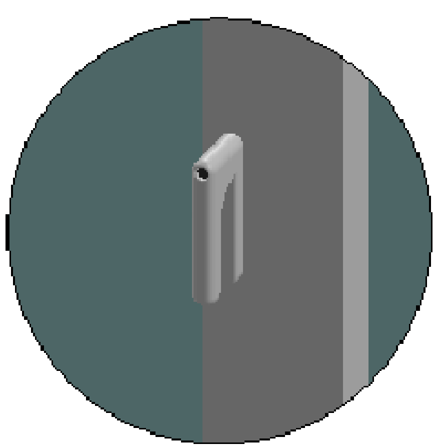


Front Elevation View, Scale 1:24

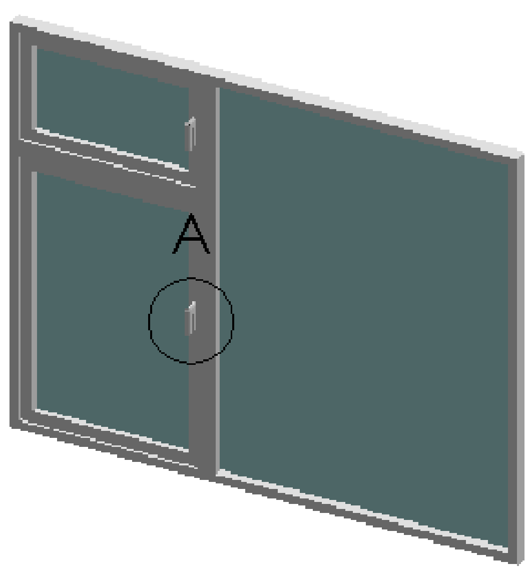


End View, Scale 1:24

Plan View, Scale 1:24



Window Door Handle Detail,
Scale 1:4



Trimetric View, Scale 1:20

Floor Plan Drawing

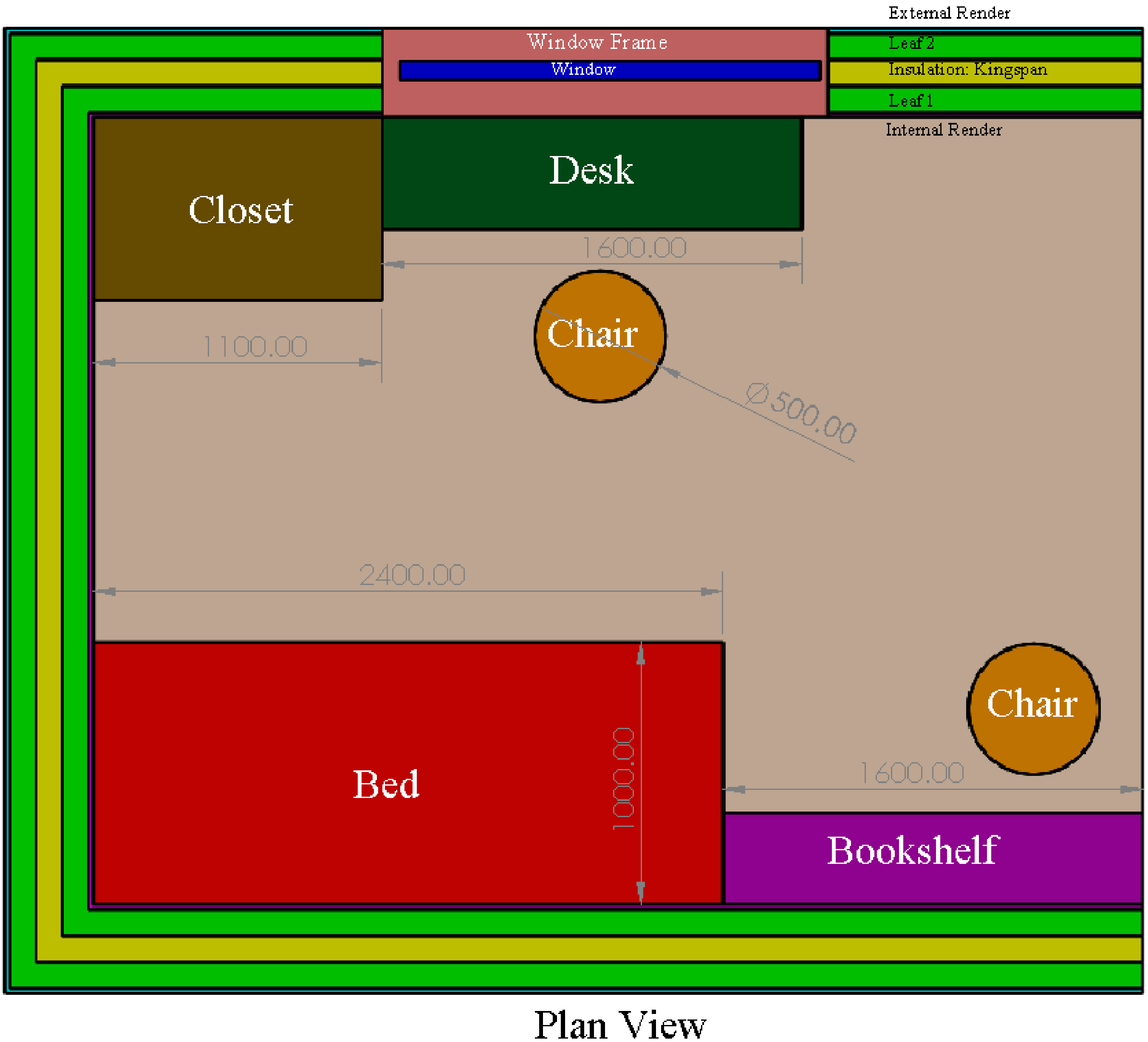
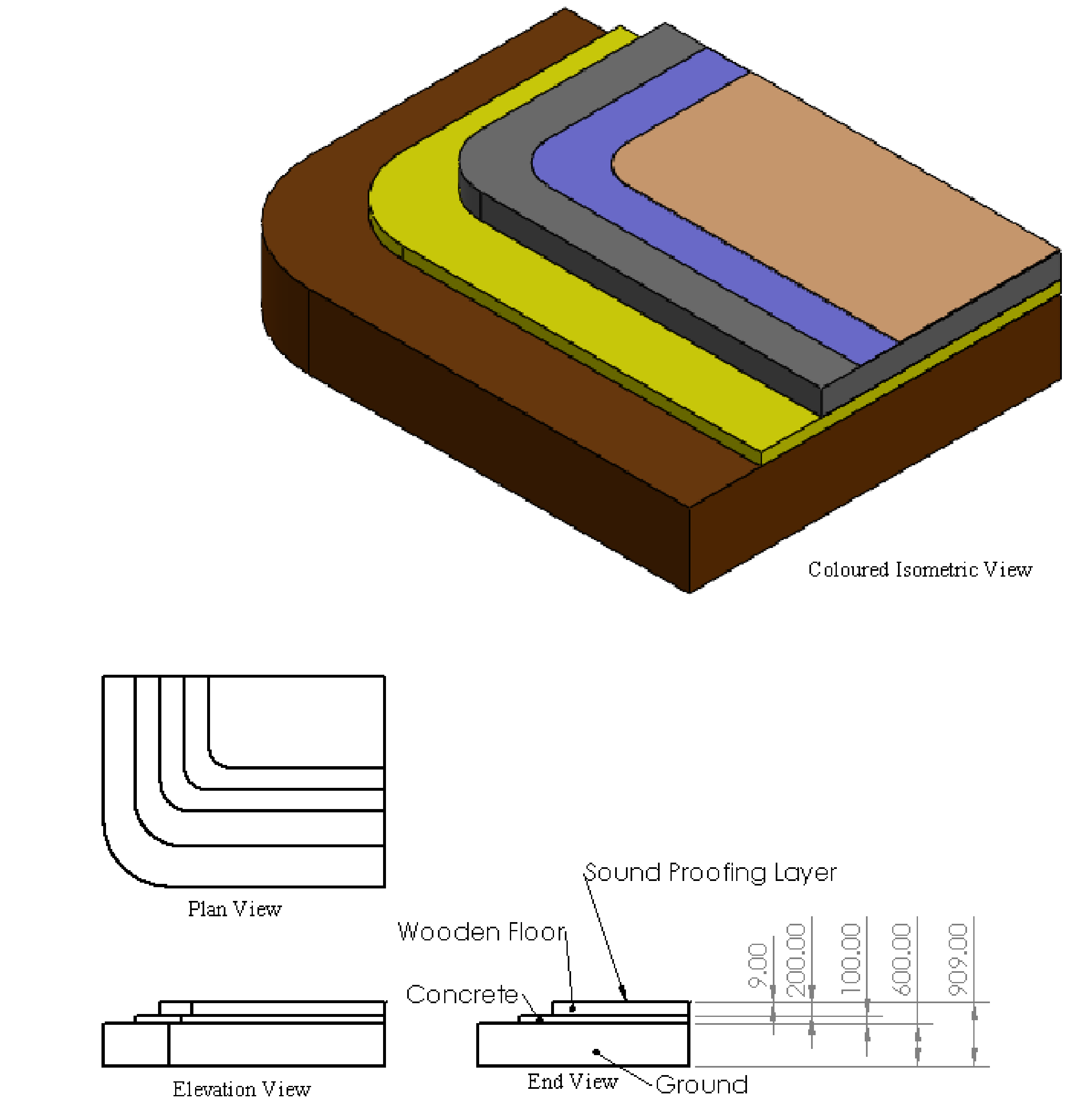


Figure 2.8: Floor plan

Floor Drawing



2.2 External Surface Description

2.2.1 External Wall

The external wall is made up of 5 layers as seen in Figure 2.1

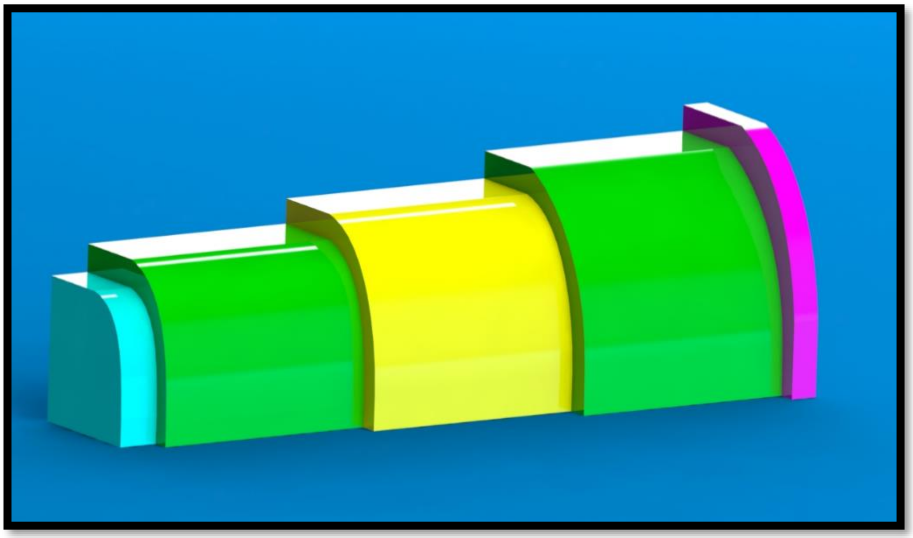


Figure 2.9: Model of the layers of the wall

Internal Plaster (0.018m) - Drywall

Leaf 1 (0.100m) - Standard Block Wall

Insulation (0.100m) - King Span Insulation

Leaf 2 (0.100m) - Standard Block Wall

External Plaster (0.100m) - External Render

The total conductivity resistance (Total Wall Res) is calculated by the sum of the resistances in Table 2.1. The resistance calculated regarding the convection (R_i for the inside and R_e for the exterior) are calculated with the formula:

$$\frac{1}{A*h} = R$$ **Formula 2.4:** Resistance

Where:

A = The area of the wall

h = the convection coefficient as stated in Assumption 11 (h_o and h_i). R_i refers to h_i = 8.29 W/m^{2}K, while R_e refers to h_o = 34 W/m^{2}K.

The R_{wall} (Total Res) is simply the sum of the resistances discussed in Table 2.1 added to the two resistances calculated in table 2.4 representing the resistance due to convection.

The U-value is calculated with the formula

$$\frac{1}{R_{wall}*A} = U$$ **Formula 2.5:** U value

Where:

U = The U – value of the wall
R_{wall} = The total resistance of the wall
A = The area of the wall

2.2.2 External Window

The external window is constructed of three layers, and the window frame has multiple layers, although for this report it will be viewed as one layer of U value 1.503. See Figure 2.10

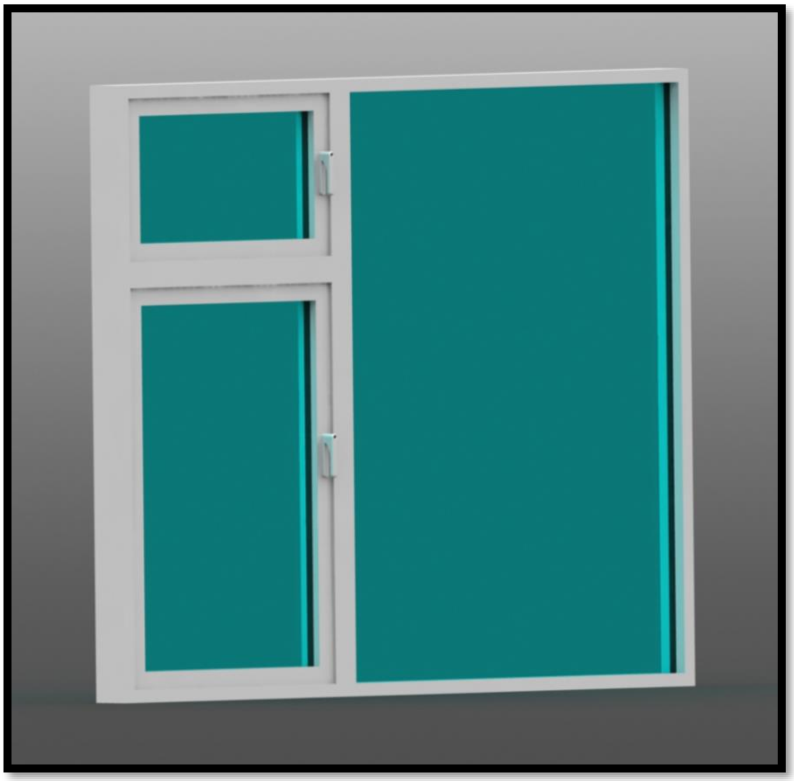


Figure 2.10: Model of the layers of the window (frame included)

Internal (0.004m) - Low Emissivity Pane

Air cavity (0.016m) - Air Insulation

External (0.004m) - Single Pane

Window Frame (0.072m) - Window Frame

Given the U value of the window is 1.3 from, Table 2.4 relays the summation of all the resistances in the window from Table 2.2 on this table to express the Total Resistance of the Window.

Given that the U value was sourced from for this project, there was no calculation to determine its value. Merely the Total Resistance of the Window Frame was calculated

Similarly the U value for the Frame was found on (Hayna H, 2021) and therefore not calculated, this table shows the sum of the resistances to calculate the total resistance.

2.3 Ambient Air Temperature

The formula used to determine the Temperature of the exterior* at any given hour of the 168 hours across the 7 days.

$$T_{outside} = 7 - \left[A * sin\left(2\pi \frac{h}{24}\right)\right] - sin\left(2\pi \frac{d}{7}\right) \qquad \text{(in °C)}$$

Formula 2.6: Exterior Temperature

Where:

$T_{outside}$ = The temperature of the outside ambient air temperature for a given hour of the week

h = The hour of the week being examined

d = The numerical day of the week being examined

A = (6 + 6 + 3)/3 = 5

'A' was retrieved from the average of the last digit of each of the team members' student numbers

The temperature of the exterior is this value of sin wave at any given time in a place that is infinitely far away from the wall, as the temperature of the exterior surface of the wall is calculated but it loses energy to the air around it causing the air temperature closest to the wall to be close to, but not exactly equal to the surface temperature, and the air further away becomes logarithmically/ exponentially colder until it tends towards a specific temperature infinitely far away from the wall. This temperature it tends towards is calculated using the above formula.

Similarly, at a point infinitely far away from the interior wall, the temperature tends towards 21°C.

2.4 Heat losses and heat gains

The net heat loss and the net heat gains for this system should be equal to maintain thermal comfort for the occupants; keep a constant temperature of 21°C.

heat gained due to internal appliance + heat gain due to heating system - Sum of heat loss through all components - Heat loss due to ventilation = 0

$$\dot{Q}_{int} + \dot{Q}_{heating} - \dot{Q}_{total} - \dot{Q}_{vent} = 0$$

Formula 2.7: Net Heat Loss

By convention heat gained by the system is positive and heat lost by the system is negative

We are trying to find the heating requirements for the room therefore if we solve for every variable besides $\dot{Q}_{heating}$ we can isolate the heat gain needed to keep a constant temperature of 21°C at every hour of the week. $\dot{Q}_{vent}$ and $\dot{Q}_{int}$ will be calculated later in this section but below the overall heat transfer through the wall ($\dot{Q}_{total}$) will be calculated now

$$\frac{\Delta T}{R_{total}} = \dot{Q}_{total}$$

Formula 2.8: Total Heat Loss

Where:

ΔT = The difference in temperature between the inside ambient air temperature and the outside ambient air temperature for each hour of the week

R_{total} = The total resistance of all components of the wall

To calculate the total resistance of the wall (R_{total}) we used the formula:

$$R_i + R_{parallel} + R_e = R_{total}$$

Formula 2.9: Total Heat Resistance of the Wall

Where:

R_i = Resistance due to convection from the inside air to the interior surfaces

R_e = Resistance due to convection from the exterior surfaces to the exterior air

$R_{parallel}$ = The parallel resistance of several components

The formula used to calculate the parallel resistance of the wall was as follows

$$\frac{1}{\frac{1}{R_{wall,ex}}+\frac{1}{R_{window,ex}}+\frac{1}{R_{frame,ex}}} = R_{parallel}$$

Formula 2.10: Parallel Resistance

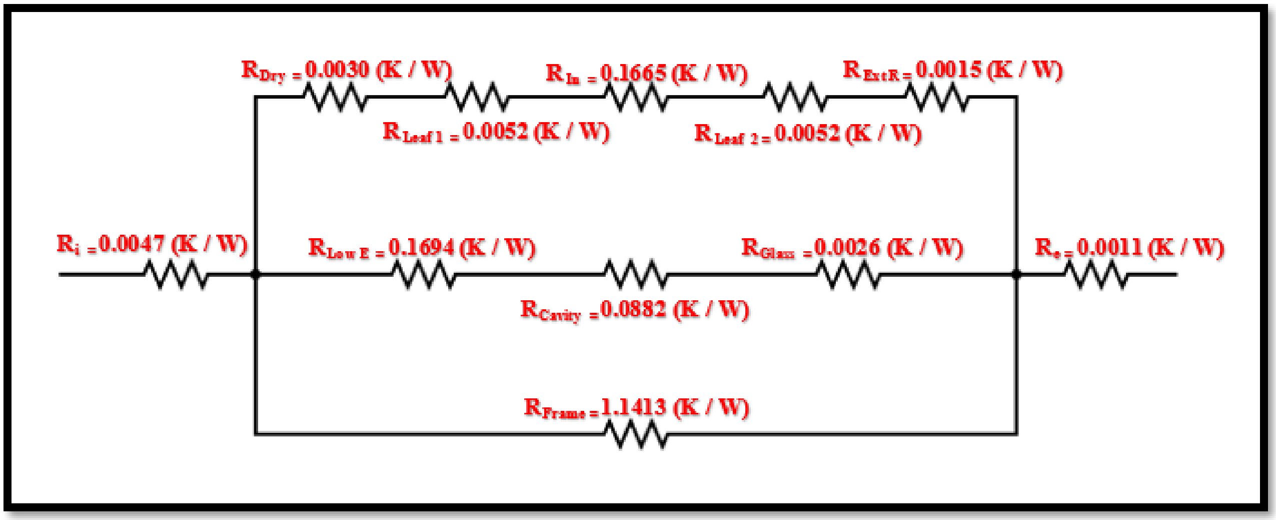
Where:

$R_{wall,\,ex}$ = The sum of the resistances of the wall excluding R_i and R_e

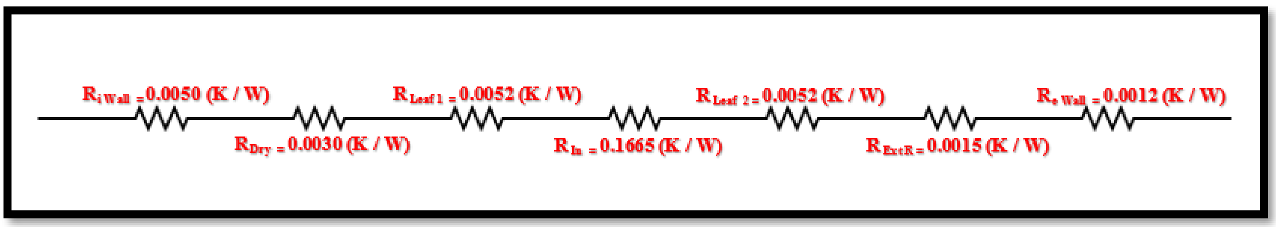
$R_{window,\,ex}$ = The sum of the resistances of the window excluding R_i and R_e

$R_{frame,\,ex}$ = The sum of the resistances of the frame excluding R_i and R_e

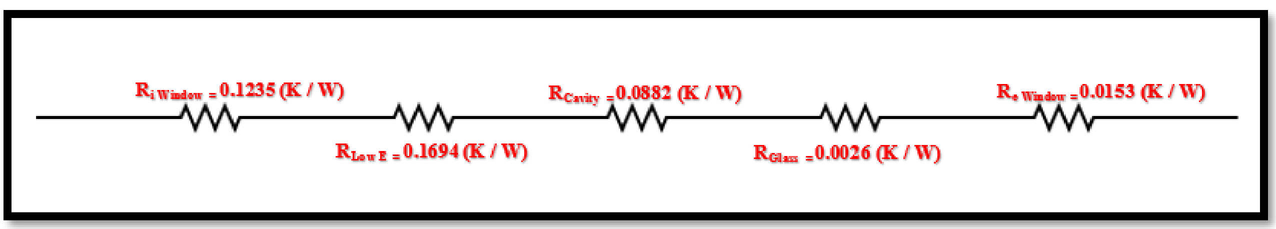
R_{total} is a constant for every hour however ΔT varies so the calculation for $\dot{Q}_{total}$ must be repeated for each hour of the week.



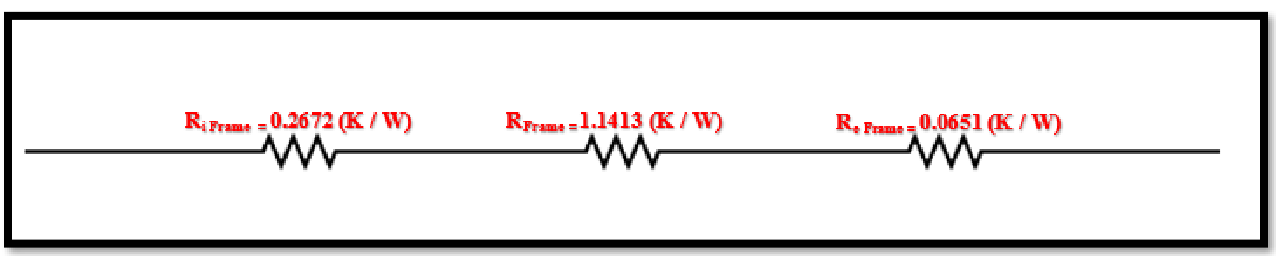
Resistance Diagram 1: Total Resistance



Resistance Diagram 2: Wall



Resistance Diagram 3: Window



Resistance Diagram 4: Window Frame

2.4.1 Ventilation heat losses

$$\dot{V} * \rho_{air} * c_{air} * (T_i - T_o) = \dot{Q}_{vent}$$

Formula 2.11: Heat loss by Ventillation

Where:

$\dot{Q}_{vent}$ = heat loss due to ventilation in joules(J)

$\dot{V}_{air}$ = rate of air change in metres cubed per second (m^3/s)

ρ_{air} = the density of air in kilograms per metre cubed (kg/m^3)

c_{air} = specific heat capacity of air in joules per kilogram per degrees Celsius (J /(kg °C))

T_i = Inside ambient temperature in degrees Celsius (°C)

T_o = Outside ambient temperature degrees Celsius (°C)

Then air enters a building through ventilation and equivalent amount of air must be removed from the building. This is a heat loss and is calculated as above. The inside ambient air is changed at a certain rate with the ambient outside air. The rate was defined by assumption. The rate was given in air changes per hour (ACH) so it needed to be converted to SI units of m^3/s. The volume of air replaced per hour is 1.5*(volume of the room). It then needs to be divided by 3600 to give the volume of air change per second. The ventilation heat loss depends on the difference in temperature between the inside and outside. This means the calculation must be repeated for all 168 hours in the study. For the values of a doubled(3ACH) and halved (0.75ACH) the final value was doubled or halved, and the calculation was repeated for each value of temperature difference over the 168 hours

2.4.2 Internal heat gains

$$L * B * 12$$

Formula 2.12: Heat gain by occupants and appliances

Where:

L= length of the room in metres(m)

B = breadth of the room in metres(m)

As per assumption 2(see 1.2) the heating due to appliances and residents is assumed to be 12 watts per metre squared of floor area. This is the heat gained by the room by sources other than heaters.

2.4.3 Heat losses from the window

$\Delta T/R_{window} = \dot{Q}_{window}$

$$\frac{\Delta T}{R_{window}} = \dot{Q}_{window}$$

Formula 2.13: Heat transfer through the window

Where:

ΔT = change in ambient air temperature

R_{window} = Total Resistance of all the components of the double-glazed low e windows

$\dot{Q}_{window}$ = Heat transfer through the window

This formula is stating that heat transfer is impeded by the thermal resistance of a window and helped by the temperature difference in the window

R_{window} was calculated as above in 2.2.2

2.4.4 Heat losses from the wall

$$\frac{\Delta T}{R_{wall}} = \dot{Q}_{wall}$$

Formula 2.14: Heat transfer through the wall

Where:

ΔT = change in ambient air temperature

R_{wall} = Total Resistance of all the components of the twin leaf wall

$\dot{Q}_{wall}$ = Heat transfer through the window

This formula is stating that heat transfer is impeded by the thermal resistance of a wall and helped by the temperature difference in the wall

R_{wall} was calculated as above in 2.2.1

2.4.5 Electric Heating Requirement

$$\dot{Q}_{total} + \dot{Q}_{vent} - \dot{Q}_{int} = \dot{Q}_{heating}$$

Formula 2.15: Heat transfer through

Where:

$\dot{Q}_{total}$ = The total heat transfer through the wall

$\dot{Q}_{vent}$ = The heat loss due to ventilation

$\dot{Q}_{int}$ = The heat gain due to internal appliances and humans

$\dot{Q}_{heating}$ = The heat gain through a heating system

Isolating for $\dot{Q}_{heating}$ we find the formula above. It is stating that the heat losses – heat gains by the internal appliance aren't enough to keep a constant temperature of 21 therefore we find the heating need to maintain the temperature. This calculation was repeated for each hour of the week and also for each of the different modifications to the initial situation (extra insulation and different air changes per hour). For 0.75 ACH the value of $\dot{Q}_{heating}$ for some hours was negative. This implies that the heating due to the internal compliance overcompensates for the heat losses therefore during this hours manual ventilation (windows) would need to be used.

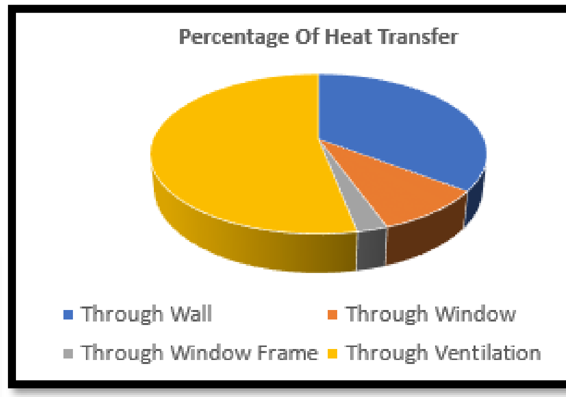
Results and Analysis

3.1 Heat Losses

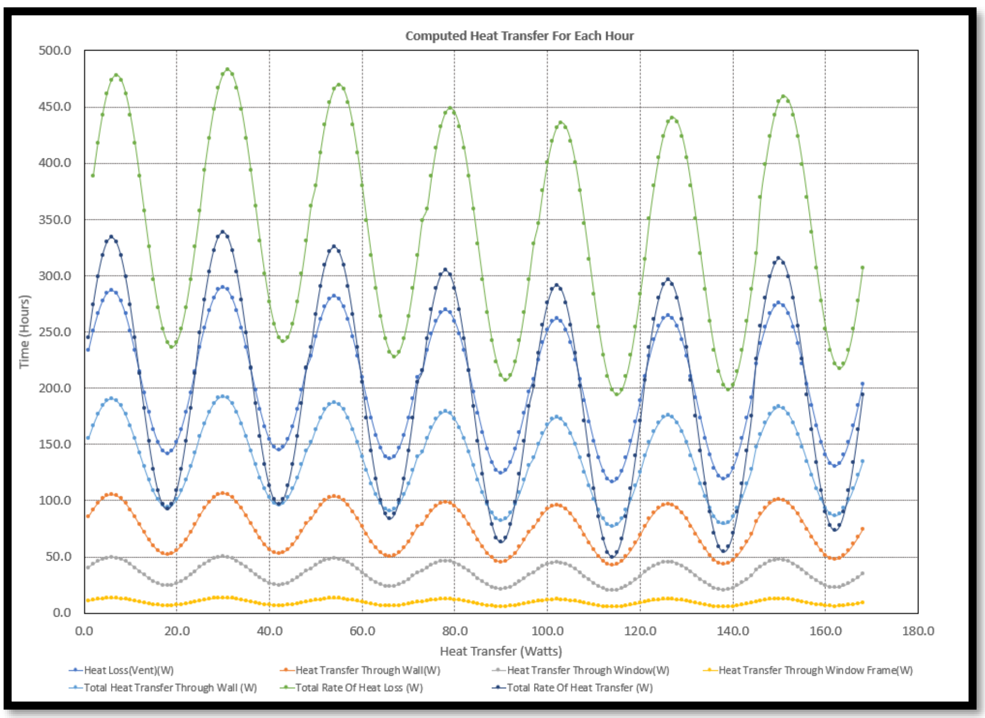
The maximum difference in the surface temperatures also occurred during the 30th hour of the project. The greatest difference calculated in the wall surfaces temperatures was 19.2901°C (internal surface was 20.4455°C while external surface was 1.1554°C). The window surfaces were

Figure 3.1: Pi chart of heat loss
Figure 3.2: Computed Heat Transfer

When analyzing the information gained from the excel



calculations, we can see that the majority of the heat transfer is through the ventilation system, working out to be just over 60 percent, its max rate of heat transfer is 290.0407 Watts, while the min value was 116.5260 Watts.



When looking at the rest of the values we can see that our max rate of heat loss works out at 482.8673, the min value works out at 193.9954, and the average value works out at 338.4314 watts. We can see looking at the tables the max values for heat transfer all occur at the same hour 30, day 2, whilst the lowest rate of heat transfer occurs on hour 114, day 5, this is then the opposite when looking at the max and min values of temperature.

3.2 Interior and exterior temperatures of external building elements

When looking at the values of temperature, we see that the highest temperature is located at the internal wall (max value of 20.7772), then internal window (max value of 19.6945), then internal frame (max value of 19.4906), then exterior frame (max value of 13.3297), then exterior window (max value of 13.2818), then exterior wall (max value of 13.0273) and finally the exterior temperature value (max value of 12.9749).

We can see that the max temperature difference between interior and exterior temperature is 19.9749 degrees, the min difference is 8.0251 degrees, and the average is 14 degrees.

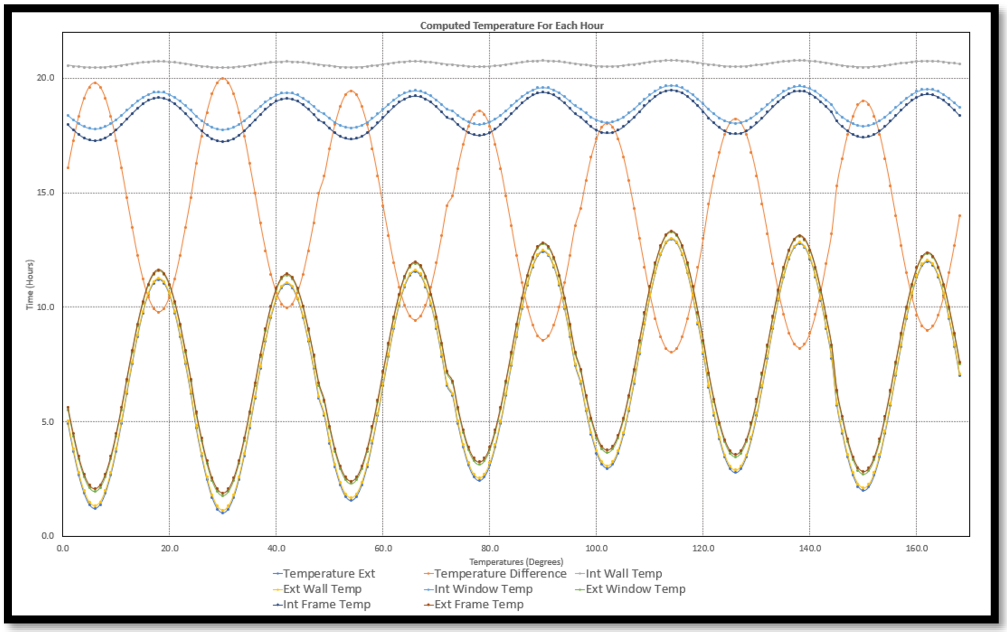


Figure 3.3: Computed Temperature

3.3 Maximum heating load and radiator capacity

The maximum heating load of the system was 338.8673W with no modifications therefore it would only be necessary to use one 500W radiator to maintain 21°C.

The maximum heating load of the system decreases when the ACH is modified to 0.75ACH. The max value is 107.4520W which is as expect seen as though Ventilation accounts for most of the heat loss. Similarly, when the ACH is changed to 3ACH the maximum heating load is increased to a max of 542.5131W.

The U-value of the wall meets building regulation therefore the extra insulation was expected to do very little to the max heating requirements. This was true as the maximum heating load only decreased to 308.7776W

3.4 Additional insulation

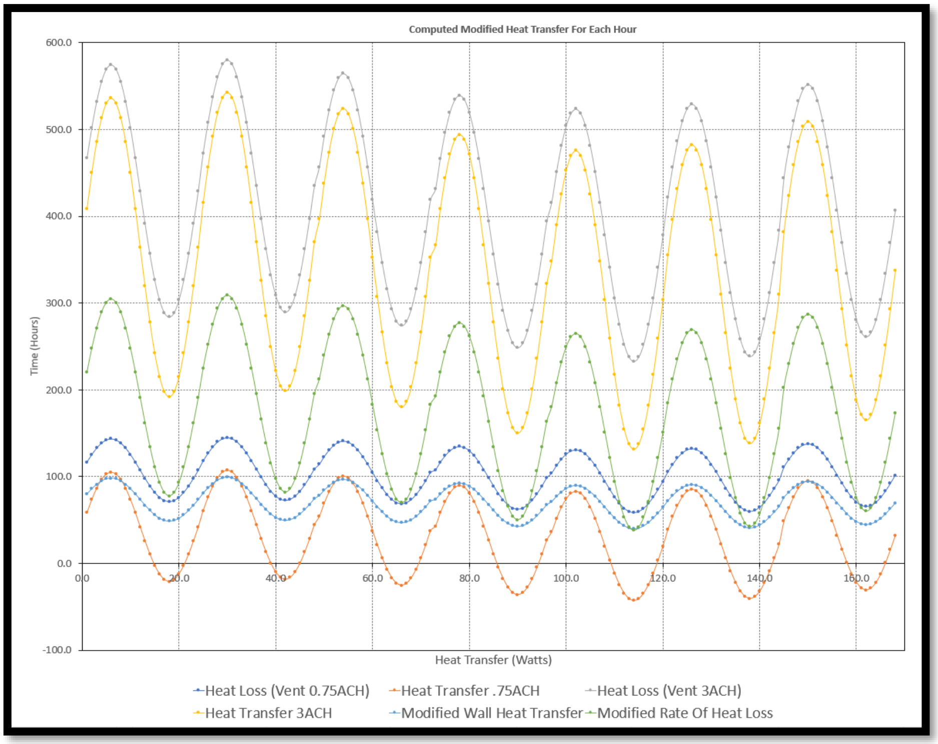


Figure 3.4: Computed Modified Heat Transfer

Next when looking at the modifications made to our values. We can see that Difference In Heat Loss (Vent 0.75ACH), Difference In Heat Transfer .75ACH, Difference In Modified Wall Heat Transfer & Difference In Modified Heat Transfer all decrease in value due to the better insulation and ventilation changes. Difference In Heat Loss (Vent 3ACH) & Difference In Heat Transfer 3ACH both increased in value. Meaning its value became worse.

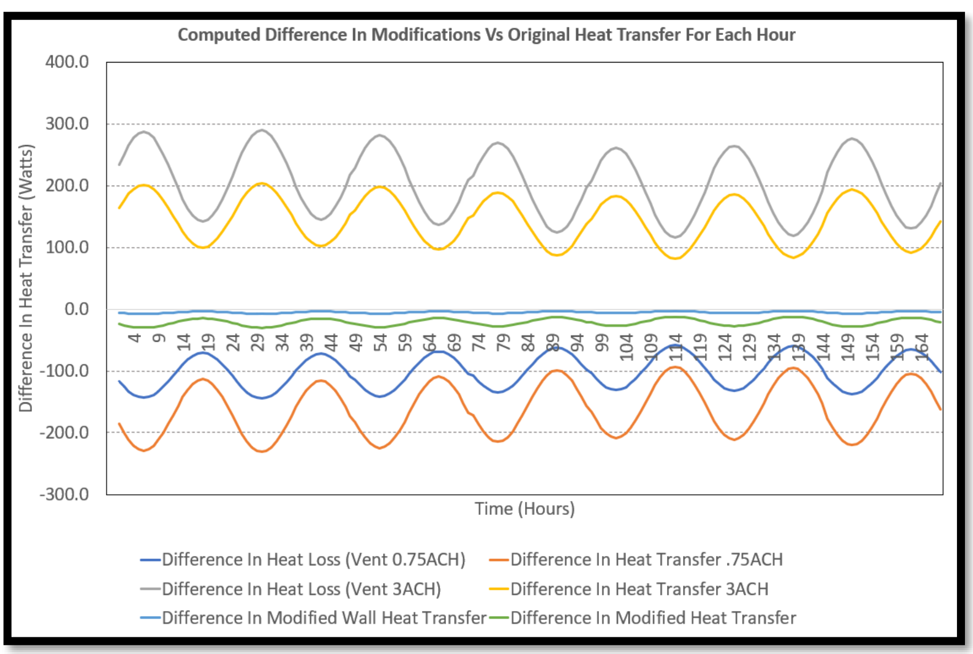


Figure 3.5: Computed Difference between modified and original heat transfer

3.5 Errors & Uncertainties.

There was a major uncertainty in the method of how we were supposed to calculate the resistances, as if we are taking them in parallel or not.

The formulae used were incredibly simplified due to the fact we're dealing with one dimensional steady state heat transfer. This treats the wall as one large continues plane that we look at a single section. This disregard corners. The method we used using parallel resistance of each component before treating the heat transfer by convection is a more accurate method, but we didn't consider how the heat transfer may change at the meeting points of the different components. We also didn't consider smaller factors like the resistance of the window cill (small effect as it has a small area) and heat losses or gains through internal walls.

Conclusions

Ventilation was the main form of heat loss through the wall and thus when the ventilation was modified it had a much larger impact on the total heating required then the 100mm extra of insulation. However even with the increase of Ventilation from 1.5ACH to 3ACH the maximum heating requirement never rose above 500W therefore we never needed more then one 500W radiator the maintain the temperature.

The calculated causes of the heat loss are the heat transfer through the window, the heat transfer through the window frame, the heat loss due to ventilation, the heat transfer through the wall. The greatest cause of heat loss is the ventilation as shown in Figure 3.1. The calculated causes of heat gain within the room were the occupants and appliances, and radiators. The maximum heat loss was during the second day, on the 30^{th} hour of the week, the total heat loss at this hour was 482.8673W.

As expected, the component of the wall with the lowest U value (the wall) had a surface temperature closest to that of the actual external and internal ambient air temperature. The surface temperatures were calculated by use of ideal models of convection and conduction.

These building materials meet current buildings standards as stated in the Irish Department of Housing Local Government and Heritage (2021). Therefor the additional insulation had very little effect on the total heating required to maintain 21℃.

Appendix A

The group gathered for discussions and group work particularly in the early stages, lots of work took place together over calls as the group members do not all live near each other. The work was a combination of individual work and group work.

Alan – Graphs, Formatting of Excel, 3.1, CAD models and Resistance Diagrams
Eoin – Research, Calculations, 2.4 in its Entirety, Citation, Equations, Conclusions
Cathal – Research, Introduction, Abstract, 2.1 – 2.3, Formatting of Report

Appendix B

This report could theoretically forward several of the UN sustainability development goals.

Affordable and clean energy- this report shows the importance of both airtightness and insulation to limit the amount of energy needed to heat a room. Ventilation was the largest contributor to heat loss due to the fact the wall already met modern housing standards. The simplicity of the calculations may also make it easier for the general public to grasp how insulation and airtightness are important to saving energy.

Sustainable cities and communities- this report again emphasis the more simplistic ways of increasing the sustainability of our communities by saving on consumption of fossil fuels for heating in both a domestic and commercial setting.

This report also is teaching us first year engineers about important topics which may become relevant in later studies where the knowledge we gained through this report could be used to forward a solution to any of the UN’s goals.

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