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Building Physics and Energy Coursework 2

SECTION 1

INTRODUCTION
Buildings are constructed with a primary goal of providing a comfortable, protected and healthy environment for its occupants. The main factor that comes into play while talking about a building is a maintained comfortable temperature within it and to ensure that it is essential to know where and how the building gains and loses heat and the amount of energy that is required to maintain a level of thermal comfort within a building.

EDINBURGH
When design I a particular city it is important to design the building according to the climate of the case and hence for this purpose to consider extreme weather conditions, each region has a heating and cooling design day (lowest and highest mean temps. respectively)[A] as well as an acceptable internal temperature for buildings in that climate.

EXTERNAL TEMPERATURES [B]
HEATING DESIGN DAY
January
-5.4 ^{o}C (99.6%)

COOLING DESIGN DAY
July
22.4 ^{o}C (0.4%)

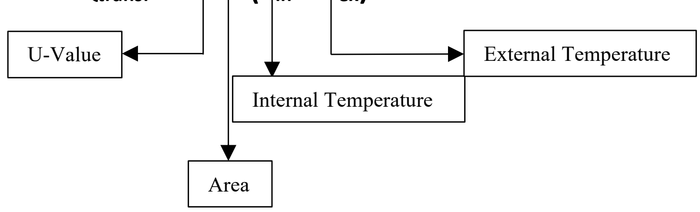
OFFICE SPACE
INTERNAL TEMPERATURES
HEATING DESIGN DAY
January
22 ^{o}C

COOLING DESIGN DAY
July
24.5 ^{o}C

GLAZING[C]
A clear, double-glazed, air-filled glazing was selected with a metal frame with 4 mm thermal break and 16 mm gap.
U-Value = 3.3 W/m^{2}K
Solar Transmittance [g] = 0.42
This is suitable for a city like Edinburgh as it reduces heat loss during the cold. [D]

Calculating Transmission Heat Losses Using the Formula

$\mathbf{Q_{transf} = - U\, A\, (T_{in} - T_{ex})}$



HEATING DESIGN DAY

Component	Quantity	Internal Temperature [T_{in}] (°C)	External Temperature [T_{ex}] (°C)	Temperature Difference [$\Delta T = T_{in} - T_{ex}$] (°C)	Area [A] (m^2)	U-Value (W/m^2K)	Q_{transf}: Heat Transfer (W)
Floor	1	22	12	-10	80	0.21	**-168**
Roof	1	22	-5.4	-27.4	80	0.22	**-482.24**
West Wall	1	22	-5.4	-27.4	35	0.21	**-201.39**
East Wall (the one with windows)	1	22	-5.4	-27.4	24.2	0.21	**-139.2468**
North and South Walls	2	22	-5.4	-27.4	56 (28(each))	0.21	**-322.224**
Windows (with glazing)	3	22	-5.4	-27.4	10.8 (3.6(each))	3.3	**-976.536**

Transmission Heat Loss on Heating Design Day = $\Sigma\, Q_{transf}$ = -**2289.6368 W**

COOLING DESIGN DAY

Component	Quantity	Internal Temperature [T_{in}] (°C)	External Temperature [T_{ex}] (°C)	Temperature Difference [$\Delta T = T_{in} - T_{ex}$] (°C)	Area [A] (m^2)	U-Value (W/m^2K)	Q_{transf}: Heat Transfer (W)
Floor	1	24.5	18	-6.5	80	0.21	**-109.2**
Roof	1	24.5	22.4	-2.1	80	0.22	**-36.96**
West Wall	1	24.5	22.4	-2.1	35	0.21	**-15.435**
East Wall (the one with windows)	1	24.5	22.4	-2.1	24.2	0.21	**-10.6722**
North and South Walls	2	24.5	22.4	-2.1	56 (28(each))	0.21	**-24.696**
Windows (with glazing)	3	24.5	22.4	-2.1	10.8 (3.6(each))	3.3	**-74.844**

Transmission Heat Loss on Cooling Design Day = $\Sigma\, Q_{transf}$ = -**271.8072 W**

In both the cases, the building loses heat as is indicated by the negative value of Q_{transf} as the outside temperature is lower that the inside.

SECTION 2

The warmest month in Edinburgh is July (CIBSE) and the day we consider is July 21, 2021 [B]

Using SunCalc we obtained the following data about Edinburgh using [E]
Latitude = N 55°57'15.76"
Longitude = W 3°12'5.18"

Time	Solar Azimuth (radian) [φ_s]	Zenith (radian) [θ_s]
9:00	1.72909769	1.03271132
13:00	3.00650417	0.62412974
17:00	4.39945145	0.94230326

Component	Surface Azimuth (radian) [φ_p]	Zenith (radian) [θ_p]
Roof	-	0
Floor	-	0
North Wall	0	1.57079633
South Wall	3.14159265	1.57079633
West Wall	4.71238898	1.57079633
East Wall	1.57079633	1.57079633

To calculate to value of $\cos(\theta_i)$ which is the cosine of the incidence angle of the sun on a plane, we use

$$\cos(\theta_i) = \sin(\theta_p)\sin(\theta_s)\cos(\varphi_s - \varphi_p) + \cos(\theta_s)\cos(\theta_p)$$

At 9:00

Component	$\cos(\theta_i)$
Roof	0.512492544
Floor	0.5124925436
North Wall	-0.8479549863
South Wall	0.1353650273
West Wall	-0.8479549863
East Wall	0.84795501

At 13:00

Component	$\cos(\theta_i)$
Roof	0.811471999
Floor	0.811471999
North Wall	-0.5790671
South Wall	0.57906716
West Wall	-0.0787046
East Wall	0.07870465

At 17:00

Component	$\cos(\theta_i)$
Roof	0.587926443
Floor	0.587926443
North Wall	-0.2490282
South Wall	0.2490282
West Wall	0.76962815
East Wall	-0.76962815

Since Edinburgh has a Midlatitude Summer Climate Type and we have been told to assume high visibility, the following constants are selected/calculated

r_0	0.97
r_1	0.99
r_k	1.02
a_0	0.129527752
a_1	0.745124736
k	0.389815139
Solar Constant (I_o)	1373 W/m^2
Altitude (A)	0.055km

$$a_0 = r_0\,[0.4237 - 0.00821 \times (6.0 - A)^2]$$

$$a_1 = r_1\,[0.5055 - 0.00595 \times (6.5 - A)^2]$$

$$k = r_k\,[0.2711 - 0.01858 \times (2.5 - A)^2]$$

We calculate the direct irradiance at normal incidence using the formula

$$I_{dir} = I_o\,[a_o + a_1 \exp(-k/\cos(\theta_s))]$$

Time	I_{dir} (W/m^2)
9:00	655.9912698
13:00	810.6511428
17:00	705.0078214

We calculate the diffuse irradiance (I_{dif}) on a horizontal plane for clear skies using the formula

$$I_{dif} = (0.271\ I_o - 0.2939\ I_{dir}) \cos(\theta_s)$$

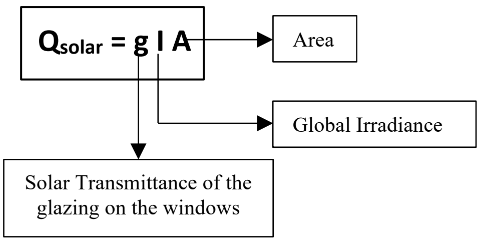
Time	I_{dif} (W/m^2)
9:00	91.88333589
13:00	108.6014311
17:00	96.93801826

We then calculate the Global Irradiance on a surface using the formula

$$I = I_{dir} \cos(\theta_i) + I_{dif}\ ((1+ \cos(\theta_p)/2)$$

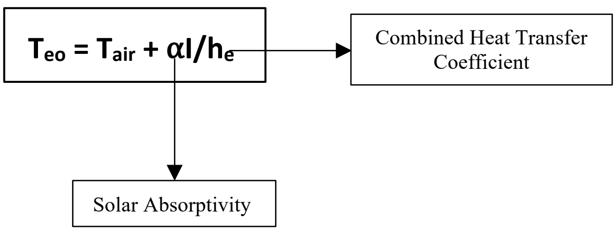
	Global Irradiance [I] (W/m^2)					
Time	**Roof**	**Floor**	**West Wall**	**North Wall**	**South Wall**	**East Wall**
9:00	428.0739703	428.07397	45.9416679	45.9416679	134.739944	602.19275
13:00	766.4221342	766.422134	54.3007155	54.3007155	523.722169	118.102727
17:00	511.4307593	511.430759	591.062871	48.4690091	224.03584	48.4690091

The radiative solar heat flux enters through the windows located on the East Wall and is given by the equation



Time	Q_{solar}
9:00	**8852.23343 W**
13:00	**1736.11008 W**
17:00	**712.494434 W**

The Sol-Air Temperature is given by the formula
$T_{eo} = T_{air} + \alpha I/h_e - \varepsilon I_1/h_e$
however since we make an assumption to ignore long wave radiation the term '$-\varepsilon I_1/h_e$' can be ignored and so we use the formula



h_e	25 W/m^{2}K
α_{walls} (white coloured) [G]	0.25
α_{roof} (black coloured) [G]	0.9
T_{air}	22.4 ^{o}C

Using the Sun Diagrams on Suncalc we can determine the surfaces that are affected by direct solar radiation at a given time [E}

At 9:00

Surfaces affected by direct solar radiation are the Roof, the South Wall and the East Wall

	Roof	South Wall	West Wall
Sol-Air Temperature[T_{eo}] (^oC)	40.81150734	24.6403584	28.3106287

At 13:00

Surfaces affected by direct solar radiation are the Roof, the South Wall and the East Wall

	Roof	South Wall	East Wall
Sol-Air Temperature[T_{eo}] (^oC)	37.81066293	23.7473994	28.4219275

At 17:00

Surfaces affected by direct solar radiation are the Roof, the South Wall and the West Wall

	Roof	South Wall	East Wall
Sol-Air Temperature[T_{eo}] (^oC)	49.99119683	27.6372217	23.5810273

Apart from these surfaces we also calculate the Sol-Air temperatures of surfaces that do not receive direct sunlight as they receive diffused sunlight

	Sol-Air Temperature[T_{eo}] (^oC)	
9:00	**North Wall**	**West Wall**
	22.8594167	22.8594167
13:00	**North Wall**	**West Wall**
	22.9430072	22.9430072
17:00	**North Wall**	**East Wall**
	22.8846901	22.8846901

Transmission Heat Gains for the building model can be calculated using the formula

$Q_{trans} = U\ A\ (T_{eo} - T_{in})$ (for the walls and the roof)

$Q_{trans} = U\ A\ (T_{ext} - T_{in})$ (for the floor)

Time	Transmission Heat Gains [Q_{trans}] (W)
9:00	-118.86869
13:00	-332.62269
17:00	-189.00893

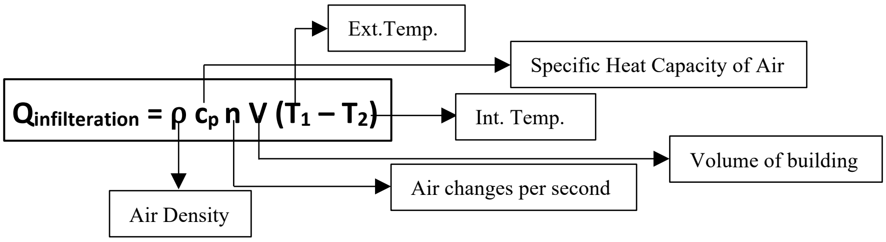
SECTION 3

The building is an office building and the chosen occupation density per square meter (as advised in the CIBSE Guide A) is 12 per m^2 per person. [F]

	sensible heat gain (W/m^2)			latent heat gain (people)
	people	lighting	equipment	
Heat Gain	6.7	12	15	5

$Q_{internal}$ = (Sensible Heat Gain + Latent Heat Gain)*Area of Floor

$Q_{internal}$ = **3096 W**

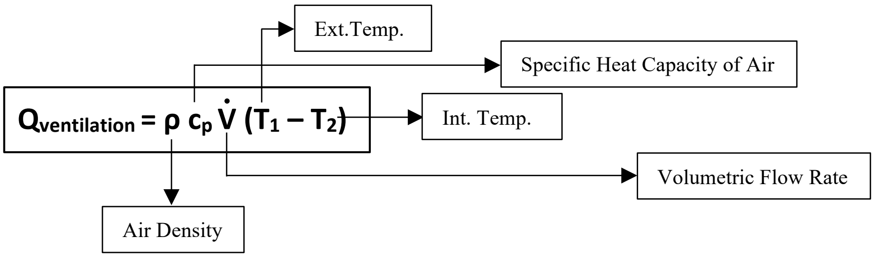


Summer	
ρ [H]	1.2 kg/m^3
c_p	1020 J/kg K
n	9.72222E-05 s^{-1}
V	280 m^3
T_1	22.4 °C
T_2	24.5 °C

$Q_{infilteration}$ = -69.972 W

Winter	
ρ [H]	1.3 kg/m^3
c_p	1020 J/kg K
n	9.72222E-05 s^{-1}
V	280 m^3
T_1	-5.4 °C
T_2	22 °C

$Q_{infilteration}$ = -989.048441 W



Summer	
ρ [H]	1.2 kg/m^3
c_p	1020 J/kg K
$\dot{V}$	0.07 m^3/s
T_1	22.4 ^oC
T_2	24.5 ^oC

$Q_{infilteration}$ = -179.928 W

Winter	
ρ [H]	1.3 kg/m^3
c_p	1020 J/kg K
$\dot{V}$	0.07 m^3/s
T_1	-5.4 ^oC
T_2	22 ^oC

$Q_{infilteration}$ = -2543.268 W

Cooling Loads is the amount of energy required to cool a building in warm weather season to maintain thermal comfort within a building. We use the energy balance equation to calculate the cooling load considering all sources of heating gains in summer.

$$Q_{HVAC} = - Q_{int} – Q_{sol} – Q_{trans} – Q_{inf} – Q_{vent}$$

Q_{HVAC}	at 9:00	-3426.526 W
	at 13:00	-4310.4029 W
	at 17:00	-3286.7872 W

Heating Loads is the amount of energy required to heat a building in cold weather season to maintain thermal comfort within a building. We use the energy balance equation considering that there is no solar or internal heat gain

$$Q_{HVAC} = -Q_{trans} – Q_{inf} - Q_{vent}$$

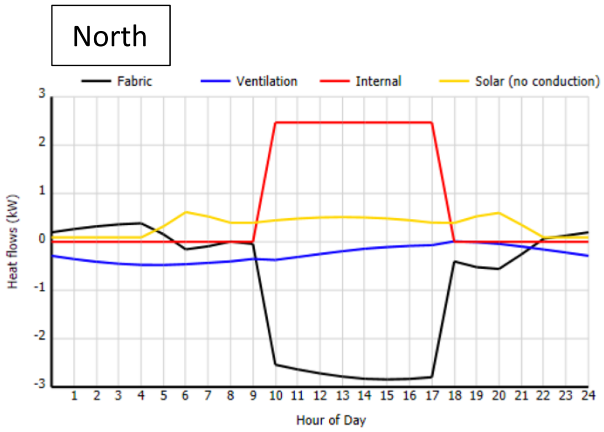
Q_{HVAC}	5821.953241 W

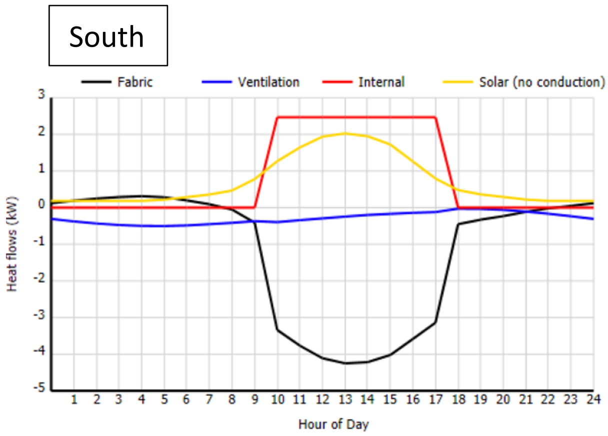
It can be observed from the above data above that the magnitude of energy required for heating during the winter is larger than the magnitude of energy required for cooling during the summer which is consistent with the climate pattern of Edinburgh.

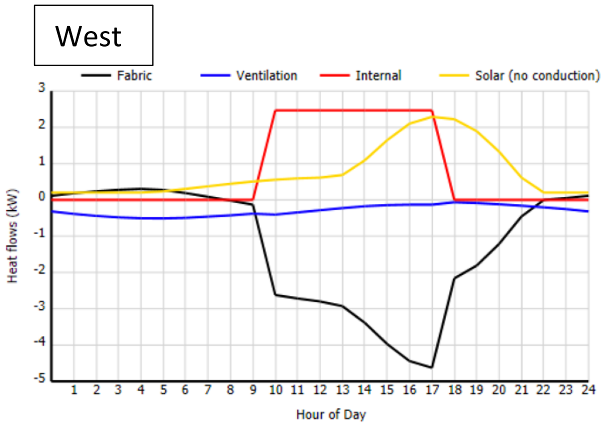
SECTION 4

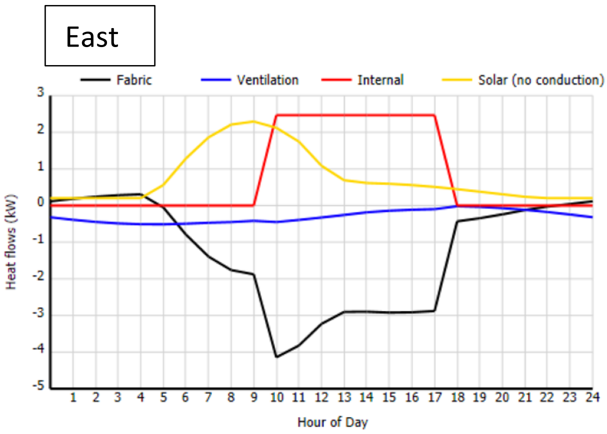
Three different parameters of building design were varied while the others were kept constant in order to observe their impact on Fabric, Internal, Ventilation and Solar Heat Gains and the observations and conclusions were drawn from the graphs. [Done using Passive Design Assistance]

Orientation





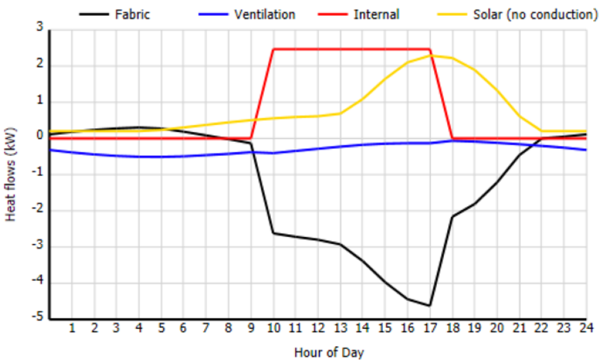




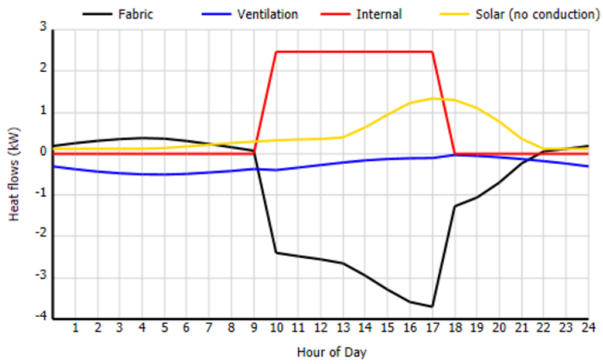
By changing the orientation of the given building, we observe that while the Internal Heat Gains and Ventilation Heat Gains do not vary with changing orientation.
However, the solar heat gains vary as the position of the windows with respect to the sun changes. It is the least when the orientation is North and maximum in orientations West and East in the evening and the morning respectively. In the South orientation, it peaks around 13:00 whereas for West its 17:00 and for East (face with windows) its 9:00.
The fabric is also affected by orientation as the different surfaces receive direct sunlight at different points giving rise to convective heat flow.

Glazing:

Double Glazing



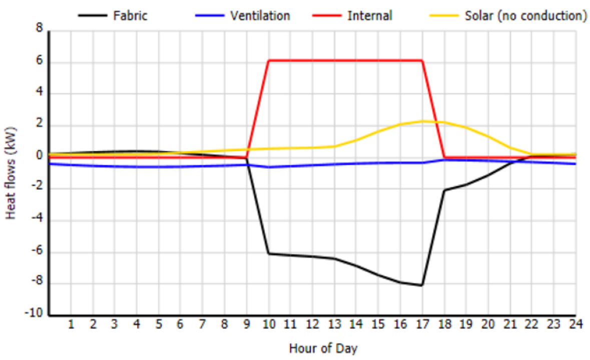
Triple Glazing



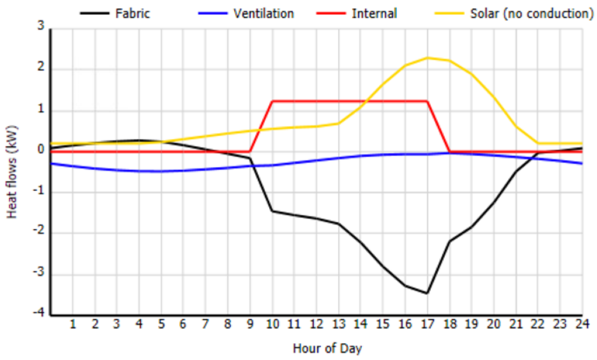
By changing the glazing of the given building, we observe that while the Internal Heat Gains and Ventilation Heat Gains do not vary with changing orientation.
However, the solar heat gains vary as the solar transmittance and the U-value of the windows changes with changing glazing. The extra air-cavity in triple glazing acts as an insulator resulting in lower solar heat gains than in the case of double glazing.
he Fabric values are more negative for double glazing than in the case of a triple glazing.

Internal Heat Gains:

High (occupancy, small power density , lighting power density)



Low (occupancy, small power density , lighting power)



As internal heat gains decrease, the solar heat gains increase whereas the Ventilation heat gains and the fabric become less negative values. Thus, higher internal heat gains imply the need for additional cooling loads (Q_{HVAC}) in comparison to lower values because of larger overall heat gain.

SECTION 5

Carbon Reduction Technology Chosen: **Offshore Wind Energy**

Due to its location with respect to the shore, as well as the high value of Mean Wind Power in the UK, Edinburgh has a great tapping potential of Offshore Wind Energy and would benefit greatly from this Carbon Reduction technology. In addition to this, Offshore Wind Energy is also extremely relevant to the office building that was studied previously as the electricity produced by this technology supplied energy for buildings. [I]

WORKING PRINCIPLE [J] [K]

Generation: Offshore wind energy is generated primarily from Offshore Wind farms that contain windmills. The principle behind their working is that the pressure of the wind causes the blades of the turbines to rotate (kinetic energy). The turbine is connected to a gearbox which greatly increases the speed and transfers it to a high speed shaft that transmits it to a generator.

Conversion: The generator then converts kinetic energy into electrical energy (electricity) which is coverted from Direct to Alternating Current by a convertor.

Transmission: For transportation, it is converted into a high voltage current so that it is able to reah buildings.

ADVANTAGES [K]

1. It is a renewable source of energy as it is obtained from a naturally replenishable source- wind.
2. It is non-polluting as well as unlimited source of energy generation as it is produced from winds which are naturally endless.
3. Offshore produced energy is more easily transportable than onshore produced energy.
4. It gives a much higher return on energy invested into the wind turbines.
5. There are no major conflicts in this field when it comes to use of land and care for the environment.
6. The wind at sea is less turbulent as it is planar and hence it aids in increasing the life-span of the wind turbines.
7. Offshore turbines are known to receive way more wind power than onshore.

LIMITATIONS [K]

1. Since the turbines are so close to the water, they often face mechanical wear and tear as well as corrosion of the blades.
2. The maintainence and repair of the farms is costly, inconvenient and difficult.
3. The initial cost of setting up the farm is quite high and this technology also requires large open spaces to set up hence are sometimes impractical.
4. There is no guaranteed output due to the uncertain and inconsistent nature of winds.

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