Heating Load Project

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EG-410 Heat Transfer

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Abstract

The goal of this project is to calculate the total heating load of a four-story multi-use building. This includes calculating the heating load due to heat transfer through external walls windows and roof's, the heating load due to ventilation, and the heating load due to infiltration. Once the total heating load in the building is calculated, the components due to heat transfer through walls/windows/roofs, ventilation, and infiltration will be compared. It was concluded from this project that ventilation is the largest contributor to the heating load, while infiltration is the smallest contributor. Also, heat transfer through the windows is significantly higher than heat transfer through the walls.

Introduction

The design of a heating system for a building includes many steps. These include, determining the heat load and air distribution, duct design, and equipment selection. However, this project will be centered only on the process of determining the necessary heating load for the heating system. The heating load will be calculated for a $1140m^2$ multi-use building with 4 different floors. To do this, architectural drawings of the building will be used. These drawings show the dimensioned layout of the building's rooms as well as the function of said rooms. For this project the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards will be used to assist in the calculation of the total heating load. All used documents and standards can be found in the references section of this report. Also as, the wall/roof/window construction is not giving in the drawings, they will have to be designed as well. As well a factor of safety of 10% will be used to ensure the heating load will be sufficient to heat the building.

The heating load of a building is comprised of three different components: Heat Transfer through external walls/windows/roofs, ventilation, and infiltration. Heat transfer through external walls/windows/roofs is the heat transfer due to conduction and convection between the inside and outside of the building. Ventilation is comprised of the need to replace air in the building. This includes replacing air that occupant’s breath in, as well as the need to provide makeup air in rooms such as kitchens and bathrooms where air must be exhausted. This air comes from the outside and must be heated to the inside temperature. Infiltration is caused by cold air leaking through the walls of the building due to pressure changes and wind. This air also must be heated to the inside temperature. Once the heat transfer due to these components is calculated, they will be compared to determine which causes the biggest effect on heat load.

Assumptions

1. Indoor Air Temperature is 20°C
2. A rate 0.25 air changes per hour of is sufficient for heating load due to infiltration
3. 85% of the exhaust air flow rate will be used for the makeup air flow rate
4. Rooms not listed in the ASHRAE 62.1 assumed to have 0 occupancy

Theory

Climate Conditions/Properties of Air

The temperature of the outside air was found from ASHRAE chapter 14 for Manchester to be -17.2°C. This temperature is colder than 99.6% of days in Manchester, so the heating system should be able to handle almost any winter condition here. Air properties are evaluated at the mean temperature of $\frac{20+(-17.2)}{2} = 1.4°C, so\ \rho\ at\ 1.4°C = 1.287\frac{kg}{m^3}, and\ c_p\ at\ 1.4°C = 1005\frac{J}{kg*C}$.

Heat Transfer Through External Walls/Windows/Roofs

Heat is transferred from the hotel to the outside via convection and conduction through external walls/windows/roofs. The inside of the building will be assumed to have uniform temperature which means no heat transfer through internal walls. The governing equation for the heating load through the external walls/windows/roofs is the following: $Q = A * U * \Delta T$. The A represents the area of the wall. This area of the wall will be calculated using the dimensioned drawings. The U represents the overall heat coefficient of the wall and is the reciprocal of the total thermal resistance. As the wall is composite, there are multiple different resistances that will be added together, including the convection resistances on both sides of the wall. ΔT represents the temperature change between the inside and outside of the building. The inside temperature will be assumed to be 20°C and the outside temperature are -17.2°C as mentioned earlier. The heating load will be calculated on a room-to-room basis, and then added together to get a final answer.

Thermal Transmittance

The thermal transmittance, which will be referred to as the U-factor from now on, is what expresses the heat transfer through a composite material. In this project U-factor will be calculated for the walls and ceilings which will be referred to as Uwall and Uceiling respectively. To calculate these U-factor a composite wall and ceiling need to be created using materials from the ASHRAE chapter 26 then using the resistances or the conductivity of the materials chosen as well as the properties of the air. If given conductivity, resistance must be calculated which is given as: $R = \frac{L}{k}$. After determining the resistance add up the total resistance then calculate for the U-factor which is given as: $U = \frac{1}{R_{total}}$.

Ventilation

The occupants residing in the building will consume a certain amount of the air in the different rooms. Additionally, rooms like bathrooms, kitchens, etc. will need to have air exhausted from the room to prevent smell and will need makeup air to be supplied. A large amount of this consumed air will need to be replaced with outside air. This air will of course need to be heated up to 20°C to maintain the building temperature. The governing equation for the heating load due to ventilation is as follows: $Q = \rho * V_{dot} * c_p * \Delta T$. ρ is the density of air. V_{dot} is the volumetric flowrate of the air and will be calculated differently depending on if it is makeup air or breathing air. The ventilation for breathing volumetric flow rate is a function of the number of people occupying a room, as well as the size of that room. Values for the flow rate per person and per area will be acquired in ASHRAE standard 62.1. Multiplying these values by the number of people and area per room respectively and then adding these two values will be the total breathing flow rate for said room. The makeup air supplied should be 80% of the exhaust air. The exhausted volumetric air flow rate is calculated by determining the number of air changes per hour required for specific rooms which is found in ASHRAE chapter 16 table 1. Using that value and the volume of the room, the exhaust volumetric flow rate can easily be found. Multiplying that rate by 0.8 will yield the required volumetric flow rate for the makeup air. Adding breathing volumetric flow rate with the make up volumetric flow rate will give the total ventilation volumetric flowrate. c_p is the specific heat of the air, and ΔT is once again the temperature difference between the inside and the outside of the building.

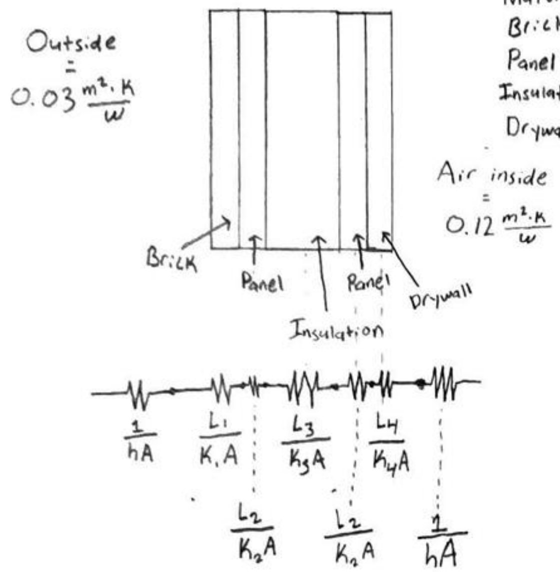
Infiltration

Infiltration is cold air that leaks into the building due to wind pressure. This air needs to be heated up as well. The governing equation for the heating load due to infiltration is also $Q = \rho * V_{dot} * c_p * \Delta T$. To calculate the volumetric flow rate, it is assumed that the infiltration rate is 0.25 air changes per hour as mentioned in the assumptions section of this report. Using the volume of each room from the drawings, the volumetric flow rate needed for each room can easily be found. The equation can then be applied to each room to find the heating load due to infiltration.

External Wall Design

Material:
Brick
Panel = Plywood
Insulation = Polyethylene
Drywall = Gypsum

Wall



$$K_{poly(150mm)} = 0.025\ \frac{W}{m \cdot K}$$

$$K_{Brick(1760)(102.5mm)} = 0.75\ \frac{W}{m \cdot K}$$

$$R_{ply(12.7mm)} = 0.14\ \frac{m^2 \cdot K}{W}$$

$$K_{gyp(13mm)} = 0.16\ \frac{W}{m \cdot K}$$

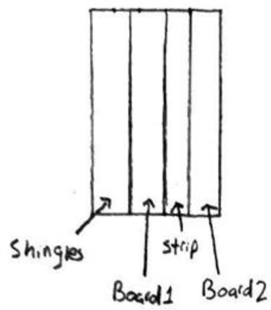
$$R_{poly(150mm)} = \frac{L}{KA} = \frac{.150m}{(0.025\frac{W}{m \cdot K})(1m^2)} = 6\ \frac{m^2 \cdot K}{W}$$

$$R_{Brick(1760)(102.5mm)} = \frac{.1025m}{(0.75\frac{W}{m \cdot K})(1m^2)} = 0.13\overline{6}\ \frac{m^2 \cdot K}{W}$$

$$R_{gyp(13mm)} = \frac{.013m}{(0.16\frac{W}{m \cdot K})(1m^2)} = 0.08125\ \frac{m^2 \cdot K}{W}$$

For the wall it consisted of a brick layer, then a panel of plywood, some insulation made from polyethylene, with an additional panel of plywood, and finally a layer of drywall made from gypsum. The U-factor for the wall was calculated to be 0.1504 using the equation mentioned previously.

External Roof Design



Material:

Shingles = Built up roof membrane

Board 1 = Cellular polyisocyanurate

Strip = Mineral fiber board

Board 2 = Concrete

Roof

$\underline{R_{concrete\,(Limestone)(200mm)}} = 0.37 \frac{m^2 \cdot K}{W}$

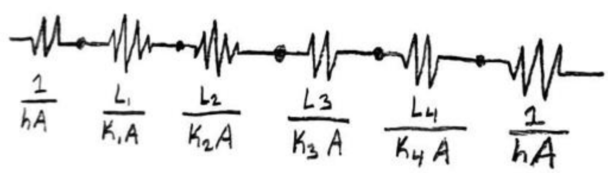
$K_{cell(75mm)} = 0.025 \frac{W}{m \cdot K}$

$K_{min(25mm)} = 0.036 \frac{W}{m \cdot K}$

$\underline{R_{men(10mm)}} = 0.059 \frac{m^2 \cdot K}{W}$

$\underline{R_{cell(75mm)}} = \frac{.075m}{(0.025 \frac{W}{m \cdot K})(1m^2)} = 3 \frac{m^2 K}{W}$

$\underline{R_{min(25mm)}} = \frac{.025m}{(0.036 \frac{W}{m \cdot K})(1m^2)} = 0.69\bar{4} \frac{m^2 \cdot K}{W}$



The ceiling design consisted of layers of shingles made with built up roof membrane, the first board which is made with cellular polyisocyanurate, then a strip of mineral fiberboard, and finally the second board made with concrete. For the outside and inside resistances it was assumed to be equal to the values listed in the wall design. This U-factor for the ceiling was calculated to be 0.2379 using the equation mentioned previous.

Window Design

The window design that was chosen was a double-glazed window with a 12.7mm air gap. The height of all the windows in the building is the same and we are determined to be 1.2m tall. The U-factor was found to be 3.36 $\frac{W}{m^2*K}$ from table 4 in ASHRAE chapter 15.

Results

Ground Floor Summery

The ground floor of the building serves as a multifunctional space. Upon entering the building, visitors encounter three shops. Adjacent to the shops, is a large restaurant with an accompanying kitchen, equipped with a dedicated food preparation room, sorting room, and five freezers. Located at the rear of the kitchen is the service entry, small lockers, and an employee bathroom. Nearby is a spa providing a massage room, foot massage room, sauna, a commercial gym, and a barbershop. Adjacent to the spa is the locker rooms connecting the spa area to the pool. Since this is the ground floor, ceilings do not need to be incorporated into the calculations for the heating load, as only the external walls and windows are exposed to the external temperature.

1st Floor Summary

The floor located above the ground floor is the 1st floor which is a residential floor with 11 different apartments. These apartments include a bathroom and bedroom, and some include an additional bedroom plus bathroom, and kitchens, living rooms, as well as a dress room. Since this floor is beneath the second floor which includes a roof section in its floor plan, several rooms will be considered to have a ceiling. This means these ceilings need to be incorporated into the calculations for the heating load since the room is coming into contact with the external temperature through the roof.

Mezzanine Floor:

This floor is located between the ground and the first floor. The term “mezzanine” comes from Italian word Mezzano, which means "middle". And it is a partial floor or intermediate level between the main floors of a building. This floor mainly consisted of multipurpose rooms meant to hold larger groups of people. It also had a reception area with walls mainly lined with glass. The heat transfer through glass is much higher than through the walls which caused the energy to heat the room much higher.

2nd Floor Summary

The 2nd Floor is a residential floor with 6 different apartments. Each apartment contains 2 people with 1 extra per extra bedroom. In each apartment there is a kitchen and a bathroom which are the only rooms that require exhaust. There are also a few service storage areas as well as a large common walkway in the center. Because this is the top floor in the building, all the rooms have ceilings that are external to the outside and thus the heat transfer through the roof must also be calculated for every room.

Floor	Walls (KW)	Windows (KW)	Roof (KW)	Infiltration (KW)	Ventilation (KW)	Total (KW)
Ground Floor	1.29	11.13	N/A	12.68	99.59	124.69
Mezzanine	1.85	10.08	N/A	8.71	113.98	134.63
1st Floor	2.2	7.86	3.42	10.73	50.18	74.4
2nd Floor	1.64	4.32	4.87	5.98	26.9	43.7
Total	6.98	33.39	8.29	38.1	290.65	370.43

Total Heating Load (With FOS)	**407.5 (kW)**

Discussion:

Tables 1 and 2 show the results of this project, including the components of heating load due heat transfer through the wall/windows/roof, ventilation, and infiltration. There are some key takeaways that can be made from this project. First of all, the heat transfer through the walls and roof is very little compared to the other components. This makes sense, as they contain insulating materials that make the thermal resistance high. Comparably the heat transfer through the windows is much higher due to glass having a low thermal resistance. This is especially interesting because the total area of the windows is much lower than the area of the wall. However, this also makes sense because windows are much thinner than the walls and contain much less insulating material. The heat transfer through the roof is only applicable on a couple floors, but is still higher than the heat transfer through the walls. The far and away biggest contributor to the heating load is the ventilation. The ventilation is responsible for 78% of the total heating load. So, no matter how insulating the walls are, the large majority of the heating load will still be there. The final answer for the heating load through the building, incorporating the 10% factor of safety was 407.1kW.

Conclusion:

This project determined the total heating load for a four-story, multi-use building, considering heat transfer through walls, windows, roofs, ventilation, and infiltration. Ventilation was found to be the largest contributor to the heating load, while heat loss through the walls had the smallest impact. Heat transfer through windows was significantly higher than through walls, highlighting the importance of efficient window design. These findings emphasize the need for careful material selection and adherence to ASHRAE standards to design effective and sustainable heating systems.

References:

ASHRAE Handbook. Fundamentals (si ed.). (2009b). . American Society of Heating, Refrigerating and Air Conditioning Engineers.

Ventilation for acceptable indoor air quality. (2015). . American Society of Heating, Refrigerating and Air-Conditioning Engineers.