Thermodynamics of Dormitories

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Abstract

The project presents a computational model to measure the change in the average temperature of a dorm-room in Ashoka University over a period of 24 hours using Fourier's law of conduction. The model was then compared with experimental data that measured the temperature change in the dorm room using various temperature probes. This data along with the computational model were then utilised to determine the energy required to cool the dorm room to an ambient temperature to work via a reverse Carnot engine.

Keywords: Carnot Cycle, Sustainability, Thermodynamics of radiation, Heat conductivity

1 Introduction

Buildings still use 20 to 40% of the world's total energy consumption and Heating, Ventilation and Air Conditioning (HVAC) account almost half of this energy. At the same time, the heating energy is predominantly based on fossil fuels. Considering this, it is important to understand the thermodynamics of buildings in order to optimise their temperature, creating an ambient environment conducive to living. Modeling heat transfer in buildings is important for sizing heating, ventilating, and air conditioning equipment; determining the effect of design changes; and developing control strategies. These objectives often require accurate calculation of transient heat transfer processes, which involve significant computational effort. In a university, much of its dormitory room share identical building properties and are connected usually by a central cooling system. In such a situation, gauging how temperature changes in a room with time can help decide when it is most optimal to cool a room. The aim of this paper is to create a computational model that is simple in the sense that it only utilises the properties of materials used to build and the geometry of the room itself. The existence of such a model may help in making the right decisions when it comes to selecting building materials for the upcoming college campus. A dorm room in Ashoka can be visualised by the following plan:

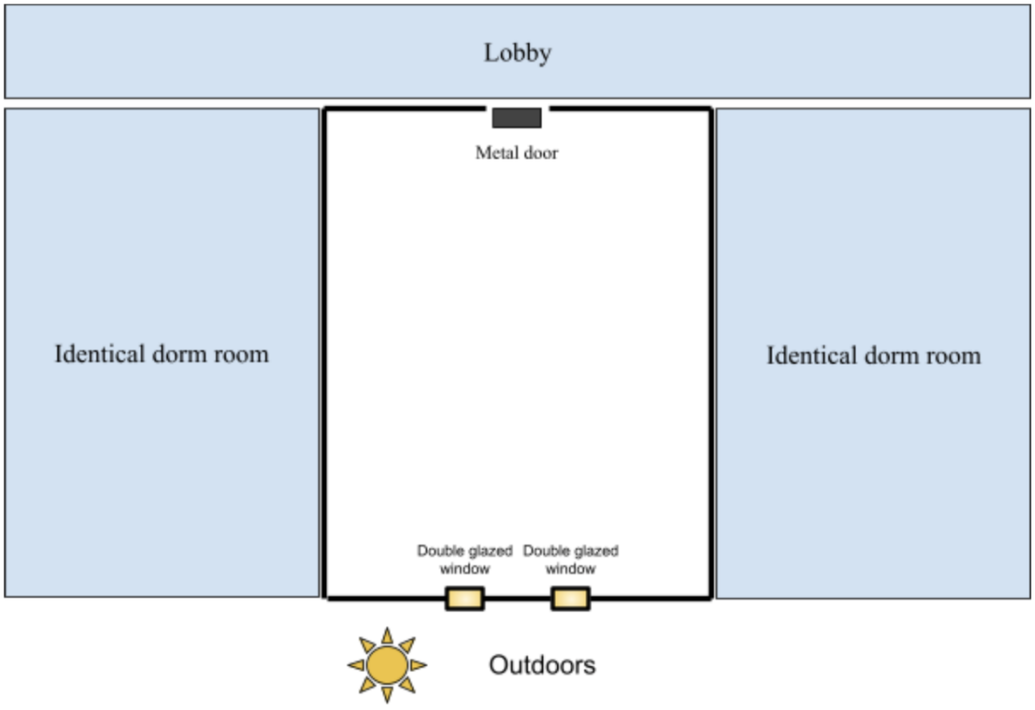

Figure 1: The design of the dorm-room

From the point of view of materials, the room consists of vitrified tiling on its floor that is identical to each room. Similarly, each room has two walls that touch other rooms. These walls are made from cement and brick. Each room consists of two glass windows that have double glass with an air pocket in the middle. The room has a metal door on the end opposite to the side with windows. Each room is also equipped with a ventilation duct that also acts as an air conditioner when it is switched on.

Figure 2: Brick wall with double window that is glazed and a metal door

2 Methodology and sources of data:

2.1 Computational model

A computational model depicting the temperature fluctuation of the dormitory room over the course of a day was created using python. It is based on the model presented in the paper titled A Thermal Model of the building for the Design of Temperature Control Algorithms, by Pawel Skrush. The dimensions of the room and that of its various components, such as windows, doors and air vents, were measured. This was used to calculate the surface area through which heat could potentially flow in or out of the room. Next, the materials used in the construction of the room were identified. Some of these materials include glass, wood, metal, cement and brick. This data was further used to calculate the resultant heat transfer coefficient of each component corresponding to different materials, depending on their respective surface areas. Further, the amount of heat radiated from the room is dependent on the temperature difference of the room and the outdoor temperature. This data was obtained from Solcast, which is a toolkit that provides actual and forecast solar irradiance and power data, globally, using satellites and surface measurements. The function representing the temperature variation inside the room with respect to time was obtained through the means of Euler integration, while the plot was created through the means of the matplotlib library in Python.

2.2 Experimental verification

Once the computational model was obtained, the relation was verified experimentally. An east-facing dormitory room was chosen on the fifth floor of the residence hall. Next, a Pt-100 sensor and two other temperature probes were setup across various points in the room. One probe was attached near the window that allowed sunlight to flow into the room. The other two were placed at strategic locations towards the interior of the room, however at the same height from the floor as the first. All the temperature probes, were attached to multimeters that returned readings in the units of either resistance (in the case of Pt-100 sensor), or directly in the units of temperature (Celsius; in the case of other temperature probes). The calibration of the Pt-100 sensor, and the conversion to give temperature readings have been discussed in the next section.

Once the probes were setup across the room, the temperature readings were recorded every hour for a period of twenty four hours. The outdoor temperature at these particular time instants was also noted down. This data was then used to calculate the temperature difference at each of these instants, which was further used to plot the temperature vs. time graph for the room over a period of twenty four hours. This plot has been compared to the plot obtained from the computational model in following sections.It is important to note that over the course of this experiment, the windows and doors of the room were kept shut, while the air conditioner remained switched off. Hence, it is assumed that the ventilation in the dorm room occurs only through the means of the air ducts.

2.2.1 Calibrating Pt100 Sensor

Platinum is a noble metal that has the most stable temperature vs. resistance range over the largest temperature range. These temperatures are particularly suitable when the measurements are to be made over a relatively narrow range of temperature. It is observed that the electrical resistance of platinum increases linearly with temperature, and its coefficient of thermal expansion is large. Further, platinum has a very high boiling point, making it a suitable material to be used in thermometry. The resistance probe is named as such because its resistance at 0^0C is 100 Ω (ohms). Since the variation of resistance with temperature has been established to be nearly linear, the following relationship is obtained:

$$R_T = m \times T + R_{0^0C}$$

Here, R_T is the the resistance offered by the pt-100 sensor at temperature T, m is the coefficient of change of resistance with variation in temperature, and R_{0^0C} is the value of resistance at 0^0C, which is theoretically expected to be 100 Ω. It is important to note that m is assumed to be constant over the range of temperature that is being studied.

For the calibration of the pt-100 sensor, the resistance it offers at known temperatures (in this case the freezing and boiling point of water) was measured. The variation in measured resistance of the platinum-100 as the temperature changes is plotted as follows:

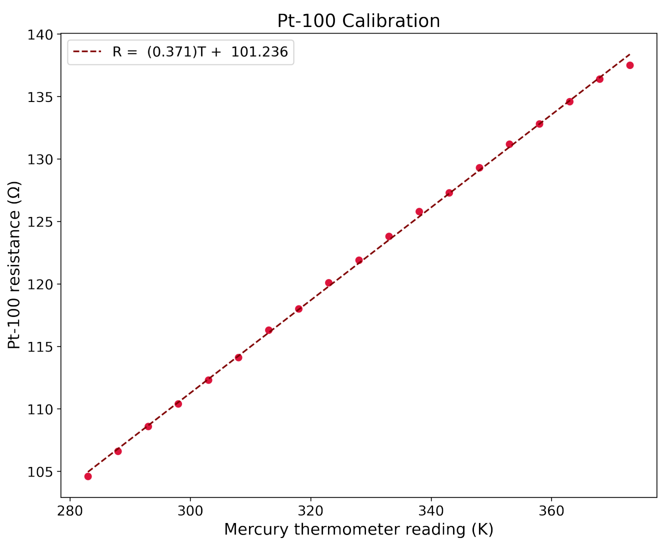

Figure 3: Calibration plot for pt-100 resistance thermometer. It is a linear plot with positive slope and intercept.

The best fit trend line for the plot is obtained as follows:

$$R(T) = 0.371 \times T + 101.236$$

From the trend line, it can be observed that at when $T = 273K$, the resistance is 101.236 Ω, whereas when the temperature is $T = 373K$, the expected reading would be 138.336 Ω

2.3 Carnot's Engine in Reverse

Initially,COP (Coefficient of Performance) was found for the computational model, seeing the temperature required for the experiment. The Co-efficient of performance (COP) is an expression of the efficiency of a heat pump. After calculating the COP, a coolant was recommended for the relevant COP to cool the room. Using this efficiency, the input power was calculated to see how much energy it will take. Using this relation, the maximum heat dissipation in the room was also found.

3 Parameters and Symbols:

These parameters were used in order to create the Computational model. The details of these would be explained in the later sections:

Parameter	Symbol	Value	Unit
Specific heat capacity of air	c	1005	J /(kg K)
Density of air	ρ	1.205	kg / m^3
Air recovery factor	β	0.5	-
Length of room	l_1	3.98	m
Width of room	b_1	3.05	m
Height of room	h_1	2.09	m
Length of window height Width of window	l_2 b_2	1.59 0.72	m m
Length of door	l_3	2.20	m
Width of door	b_3	0.92	m
Emissivity of glass	ϵ	0.95	-
Overall heat transfer coefficient of doors	U_1	1.89	W/ (m^2 K)
Overall heat transfer coefficient of double glazed windows	U_2	2.7	W/ (m^2 K)
Overall heat transfer coefficient of a brick-wall	U_3	0.6	W/ (m^2 K)
Overall heat transfer coefficient of tiles	U_4	1.1	W/ (m^2 K)
Airflow rate of air	q_{air}	1.65	m^3/ (s)

Table 1: Parameters and their values used in the model

4 Computational Model without ventilation:

The change in a room's temperature over a given time period depends on the heat exchanges that take place in the room during that time. For this model, the system taken into consideration is the room's air while the environment consists of the rooms adjacent to the modelled room and the outdoors. Let us consider a single dorm room that is composed of four walls, one floor, and one ceiling. The room has two double glazed windows and has one door. Considering the size of the room, the temperature of the air inside the room with the volume V_{room} is assumed to be uniform and is denoted as T_{in}. This temperature is a result of the thermal interaction that the room's air undergoes over time. There are inflows of heat in the room denoted by Q^{in} and at the same time there are certain outflows of energy in the system Q^{out}. Therefore from the first law of thermodynamics, at any given time t the energy possessed by the room is given by:

$$\dot{Q}_{room}(t) = \dot{Q}^{\text{in}}(t) - \dot{Q}^{\text{out}}(t)$$

Now since the major chunk of the room is made from air, this equation can be approximated at a small interval in time dt to give:

$$m_{air}c_{air}\frac{dT_{in}}{dt} = \dot{Q}^{\text{in}}(t) - \dot{Q}^{\text{out}}(t)$$

The mass of air can be approximated by its density and the volume of the room. Similarly for the temperature range we are working with, the specific heat capacity of air can be assumed to be constant. This gives the equation:

$$\frac{\mathrm{d}T}{\mathrm{d}t} = \frac{1}{c\rho V_i}\left(\dot{Q}_i^{\text{in}} - \dot{Q}^{\text{out}}\right),$$

This first order ODE can be solved numerically using the Euler method of integration as follows:

$$\frac{\mathrm{d}T}{\mathrm{d}t} = \frac{T(t+h) - T(t)}{h}$$

Here h is the step size for which we are integrating. This model uses $h = 0.01$ since it is sufficient enough for integration. Therefore,

$$T(t) = T(t+h) + \frac{\mathrm{d}T_i}{\mathrm{d}t}(T,t)h$$

In this ODE, the inflow of heat is a function of time. For a dorm room, the inflow of heat depends on two major factors: Energy from the sun coming in through the window, and energy from human metabolic activity and appliances. Therefore for the window with an area A_{window} the energy that arrives every second can be given by:

$$\dot{Q}^{\text{solar}}(t) = \sum_{i}^{n} A_i \epsilon_i I_{sun}(t)$$

In the equation above the index i represents the number of windows and A_i are their respective areas. ϵ_i indicates the emmisivity of the material of the window, or in other words, how much radiation is allowed to flow in. $I(t)$ indicates the intensity of the sun falling on the window at a time t. This function $I(t)$ was found empirically using data from Solcast. Solcast gave hourly data for the solar intensity in Rai, Sonipat (The locality in which the dorm is in). The hourly data was then interpolated linearly using Numpy's Interpolation package in order to make the data continuous. The function $I(t)$ can be shown below:

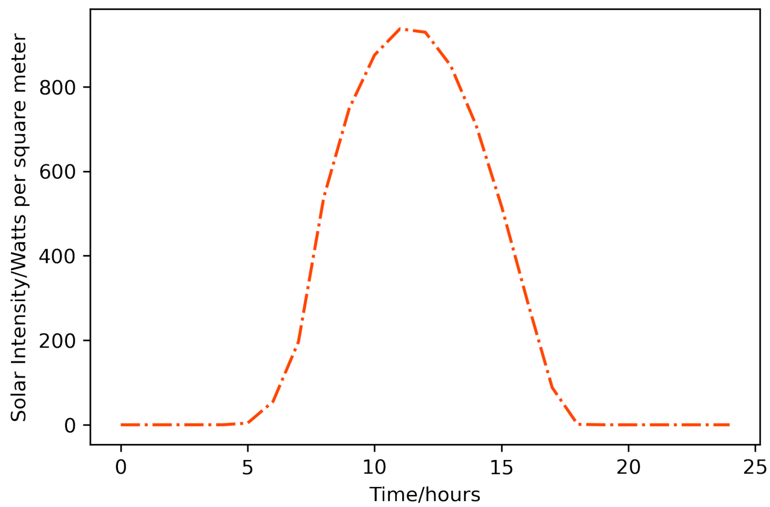

Figure 4: Solar intensity as a function of time

The zero values occur after sun-set since there is barely any solar radiation coming through the windows. The y-axis represents the intensity falling on the window, or the s̈olar load:. The x-axis represents hourly time beginning from 12:00 a.m. or 0 hours.

Another form of inflow of heat comes from metabolic activity or using appliances in the room. This is the effect of the room being used. This model only approximates this calculation. Most individuals in a dormitory use the room at night, ranging from 20:00 to 8:00 where the metabolism was expected to contribute $40W$ whereas for the other times in which the room is barely in use, it was approximated to be $20W$. This is an approximation and is just the half of the human base metabolic rate. Now, this can be written as a piecewise function to be:

$$Q^{\text{metabolism}}(t) = \begin{cases} 40 & \text{if } 20:00 \leq t \leq 8:00 \\ 20 & \text{if } t = \textbf{otherwise} \end{cases} \tag{1}$$

These two factors were assumed to be the inflows for heat in the room. For outflows, one of the major consideration was the dissipative losses through the walls of the room, the ceiling and the floor. Essentially there were 9 elements in the room: 4 brick-walls, 1 ceiling, 1 tiled floor, 1 door, and 2 windows. Each has a different thermal transfer coefficient and each has a different area. From Newton's law of cooling, the rate at which the energy is lost from these elements, is directly proportional to their thermal transfer coefficient, their surface area, and the temperature difference between the inside and the outside. Therefore, we can express these losses as a summation again to give:

$$Q^{\text{dissipative}}(T,t) = \sum_{i}^{n} A_i U_i (T(t) - T_{sun}(t))$$

The index in the above equation represents the wall under consideration. U_i is the relevant thermal coefficient corresponding to the wall under consideration and A_i represents the area of the wall. Similarly T indicates the temperature of the room at time T whereas $T_{sun}(t)$ represents the temperature outside at a given time. The outside temperature was obtained from the data from Solcast and again made continuous using the Interpolate function on Numpy. The change in the temperature outside as a function of time can be visualised as follows:

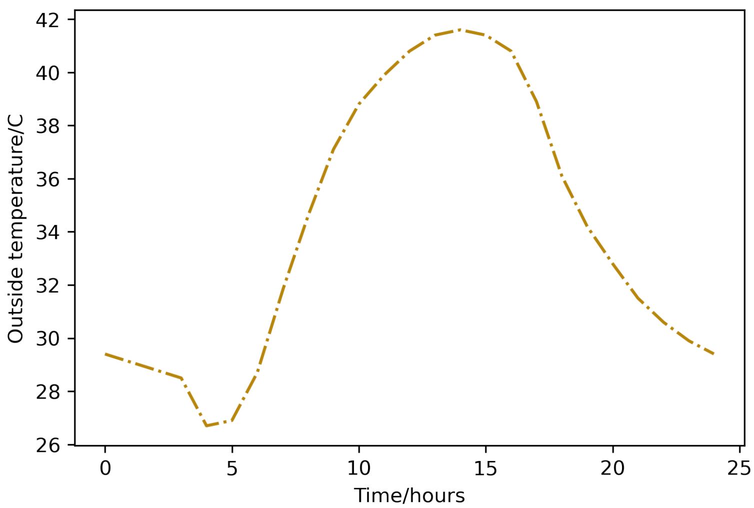

Figure 5: Outside temperature as a function of time obtained from *Solcast*

Assumptions in the Model

1. The experiment assumes that all points within the room are in thermal equilibrium with one another or that there is no temperature gradient inside the room.

2. The room has no furniture or losses due to that

3. Density of air is constant throughout all rooms and does not depend on temperature. The specific heat capacity is also assumed to be temperature independent.

4. Human metabollic activity and its heating effects are approximated to a crude degree of accuracy.

5. The mass of air remains constant and there is currently no ventilation factor in the model.

NOTE: The geometry of the room and transfer coefficients were assumed to be known from empirical data, these will be enumerated later.

The following graph was obtained for the case with the simple model consisting of losses through the walls and gains through activity and solar radiation:

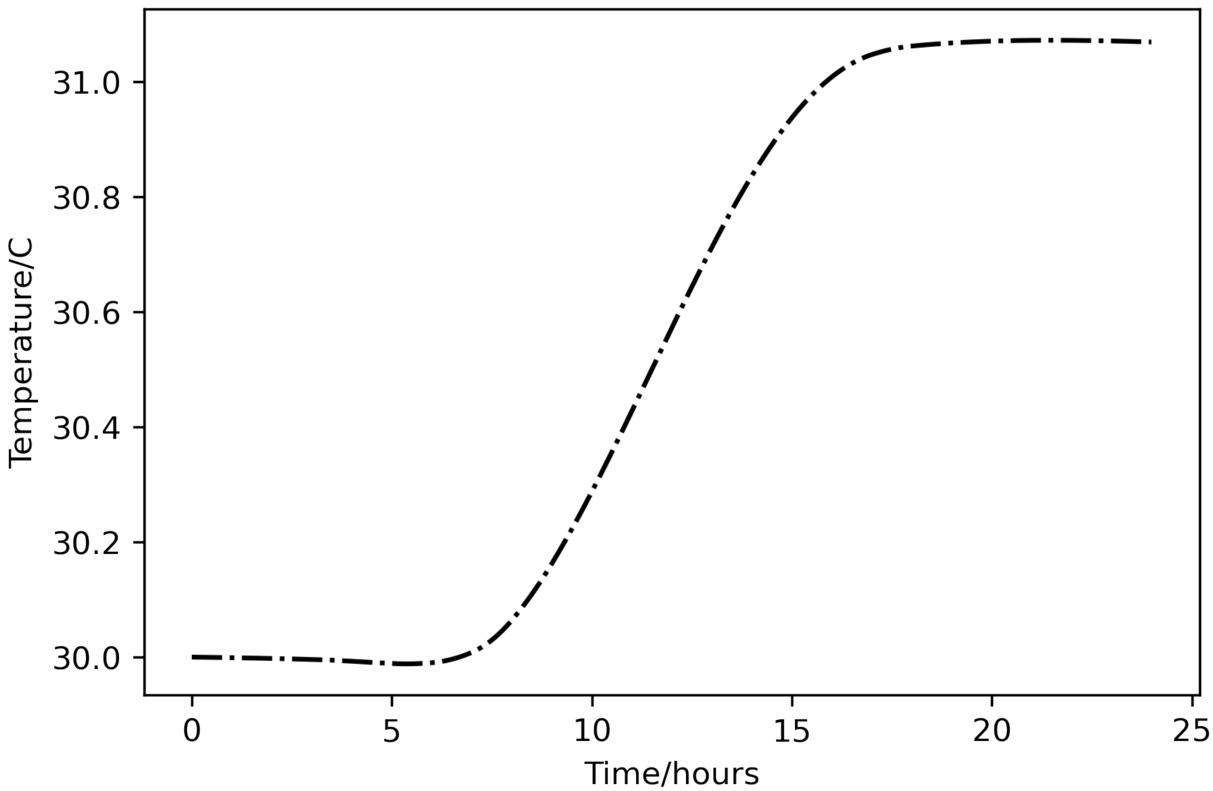

Figure 6: The primary model that shows the change in room temperature

The graph indicates that the temperature remains steady in the early hours of the day where solar radiation is minimal. As the day progresses the temperature increases and peaks at 3:00 in the afternoon where the temperature of the room becomes 31 degrees. From a comfort point of view, the temperature is still quite high. The problem in the model arises after 3:00 pm (15:00 hours). Rather than reducing the temperature, the temperature plateaus at the maxima.The temperature range here is about one degree change during the day, this also needs to be modified. If the temperature keeps plateauing,it would mean that as soon as the sun goes up again, the temperature would increase more. This indicates that radiation does not leave the room as it should. If we continue the same pattern for other days we see that the temperature continuously increases. This implies that after a period of 5 days, the temperature would be much higher than before. If this were continued, we would end up with a condition where the room would change into an oven. This is demonstrated by:

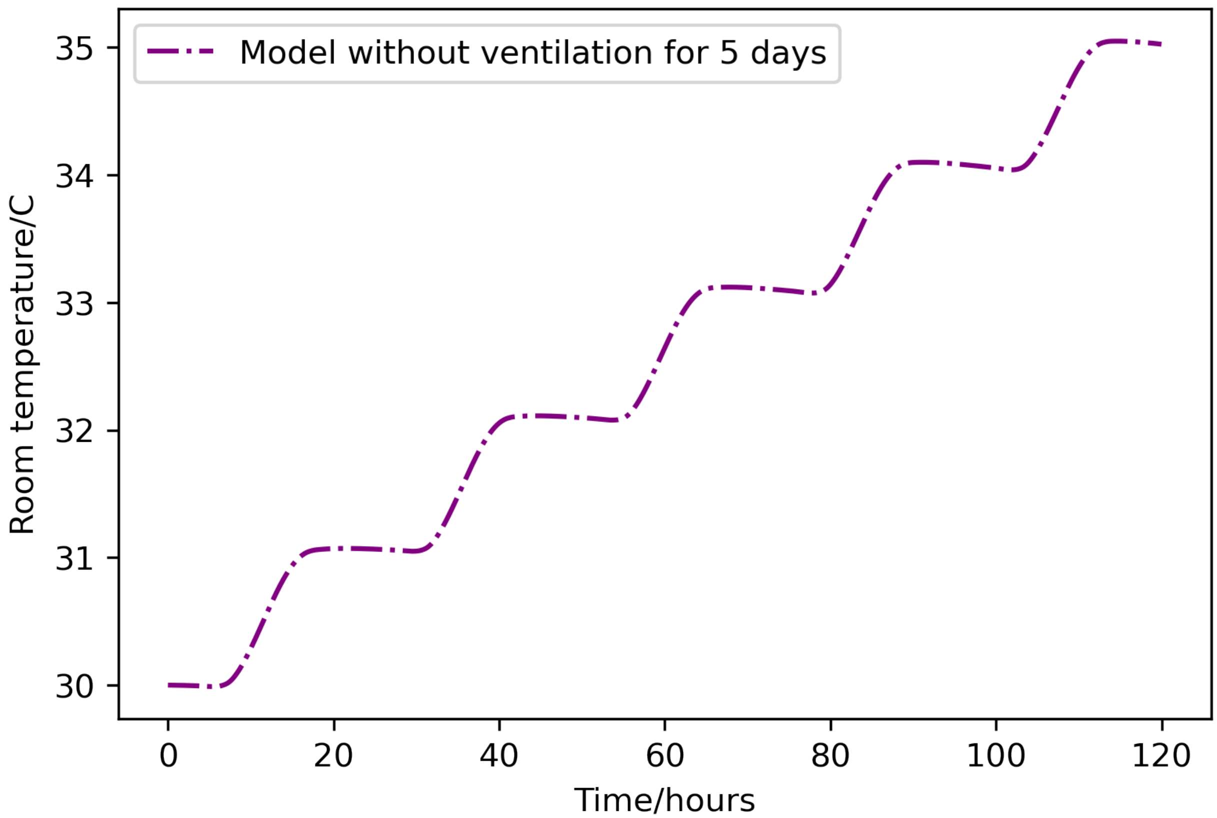

Figure 7: Increasing temperature over multiple days

The model therefore must include a ventilation factor that takes the heat out of the system and cools it. The ventilation factor can be explained in the next section.

5 Ventilation as a correction factor:

With the assumption that no mass exchange takes place between the system and the environment, we can model the flow of air using fluid dynamics. The air flow rate $\dot{q}_{air}$ is given by the following definition:

$$\dot{q}_{air} = v_{air} \times A_{duct}$$

for the Ashokan dorm, the duct of the AC has a length of 3 meters and a height of about 0.25 meters. If we assume there to be a cooling comparable to a fan, an average speed for the wind would be about 2.2 meters per second. Hence the q_{air} was found to be around 1.65 $m^3 s^{-1}$. For the heat transfered by the air now we can use the following equation:

$$\dot{Q}^{air}(t) = m_{air} c_{air} (T - T_0)$$
$$\dot{Q}^{air}(t) = \rho_{air} V_{air} (T - T_0)$$

Now since:

$$\dot{q} = \frac{\text{Volume of air}}{\text{time}}$$

$$\dot{Q}^{air}(t) = c\rho_{air}\dot{q}(T - T_0)$$

here, T_0 refers to the initial temperature of the day. Consequently, the following changes occur in the model:

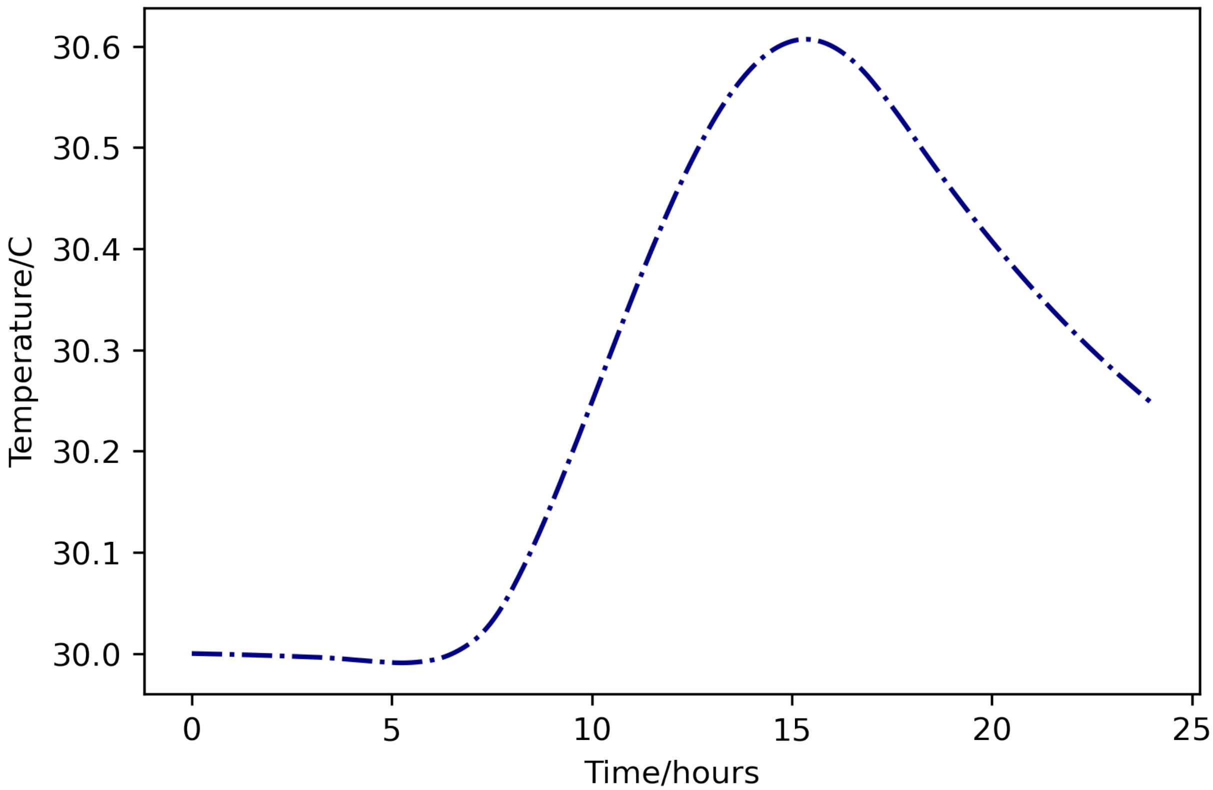

Figure 8: After implementation of cooling through ventilation

From this it can be concluded that the temperature range comes down to about 0.6 degrees change during a day. This means the room does not heat as much as before. The important change that occurs in this model is the fact that by introducing a very simple term, instead of a plateau, we see a decline in the temperature. The decline in the temperature indicates natural cooling by introducing some sort of ventilation in the system. This indicates that ventilation is an essential aspect to cool the dormitory.

6 Experimental verification

6.1 Raw data

The data for temperature variation inside the room over a period of twenty-four hours was collected with the help of two temperature probes and a pt-100 sensor. The temperature of the room at any particular instant in time was considered to be the average of the three readings. It is important to note that it has been assumed that all points within the room are at the same temperature, i.e., there is no temperature gradient within the room, as discussed earlier.

The least count of the multi-meter readings in the case of the pt-100 sensor is 0.1 Ω, while in the case of the temperature probes, it is 0.1^0C. The temperature of the room vs. time plot using experimentally obtained data for a period of twenty-four hours was graphed as follows:

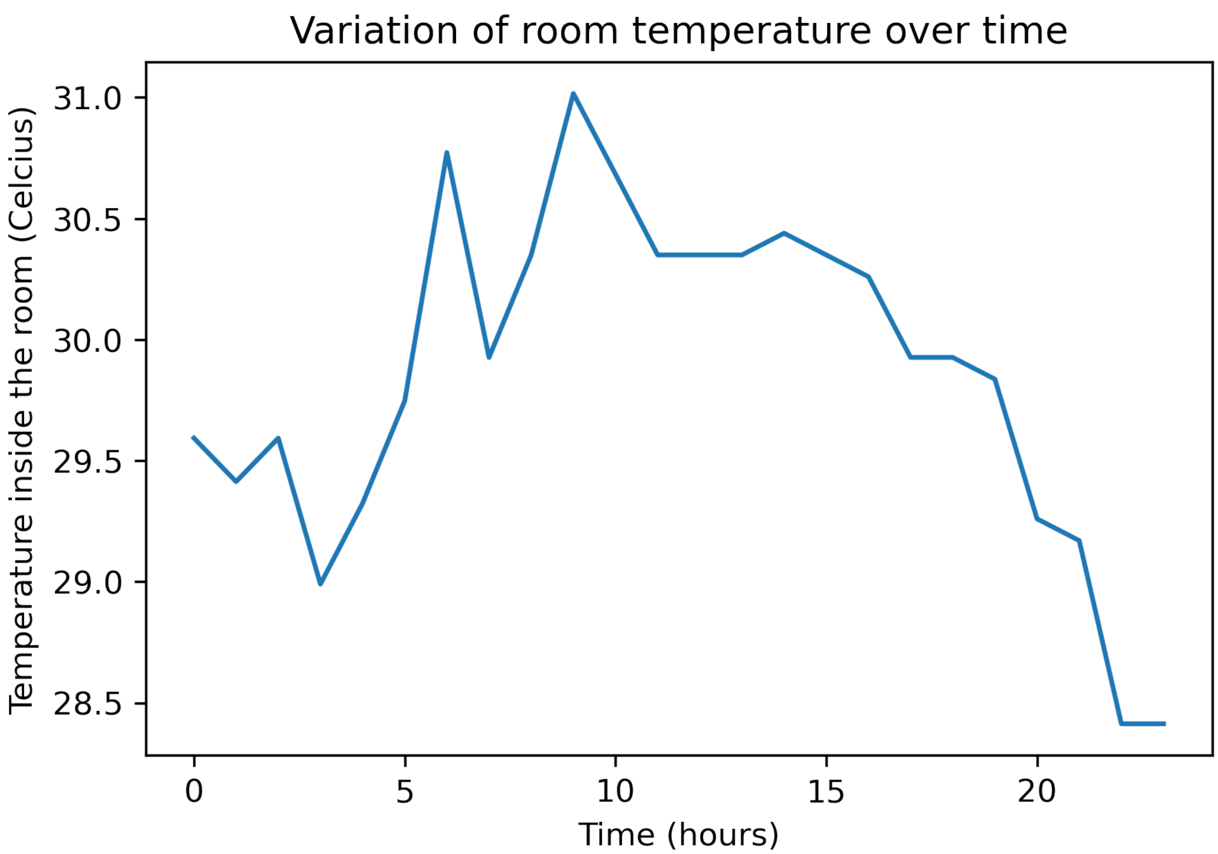

Figure 9: Temperature of room. vs time plot

6.2 Comparison

There are several differences that one can observe between the theoretically expected and experimentally obtained plots (Figures 8 and 9). The computational model was built for a generalised case, not taking into account the positioning of the room. The dormitory room chosen for the collection of data during experimental verification was east-facing. This implies that there was direct sunlight incident on the windows from sunrise till noon, which is the time around which the sun is at its maximum position in the sky. This can be seen from the experimental plot as there is an initial dip in the temperature of the room as the outside temperature falls to its minimum at around 4 am. However, the temperature of the room start rising as soon as the sun rises. Similarly, during the afternoon, the room is located at a relatively cooler position, due to the shade of the buildings. This implies that after 12:00 pm, there is no direct sunlight falling upon the windows, and hence, the room does not heat up as much. This factor plays an important role in the cooling of the dorm room.

Further, in the computational model, the temperature of the room at any instant of time is dependent on the difference of thermal radiation flowing in and out of the room. It also depends on the effectiveness of the ventilation system that is set up inside the room. Hence, in the case of the theoretical model, the peak of the plot represents the instant of time when the the inflow of thermal radiation, predominantly through the windows, is equal to the outflow of the same, which is through the means of effective ventilators.

Lastly, one can observe that temperature range over time in the case of the experimental obtained data is higher than that of the computational model. Again, this is mainly due to the fact that the location of the room (east-facing) has not been taken into account in the theoretical model. The computational model also does not account for direct solar radiation incident on the windows till noon. Further, it indicates that the heat outflow or the transfer parameters, such as the ventilation of the actual dorm room, is better than what was estimated theoretically. This resulted in the room heating up and cooling down more than expected.

7 Energy consumption and Carnot's engine

A Carnot engine is a theoretical thermodynamic system that works on the principle of Carnot's cycle. This system approximates the maximum possible efficiency that a heat engine of a heat engine during the process of converting the heat output into work.

7.1 Reverse Carnot Engine: Heat Pump

We know that Carnot cycle is a reversible process with consisting of two isothermal and two isentropic processes. This fact of reversibility can be used to create a theoretical system that works completely opposite to that of Carnot's cycle, thus acting like a refrigeration system. The processes involved in this reversed cycle are,

- Isothermal heat transfer from cold medium to refrigerant (**Evaporator**)
- Isentropic (Reversible adiabatic) compression.
- Isothermal heat rejection (**condenser**)
- Isentropic Expansion.

The following schematic diagram shows the components of a carnot's refrigerator,

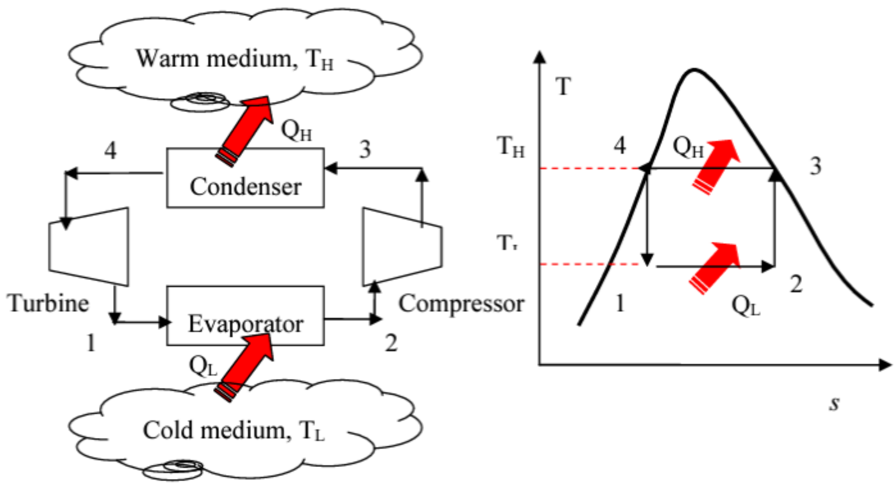

Figure 10: **Schematic diagram of the major components of a Carnot's refrigerator. (Bahrami, 2001)**

Now, using the above figure and our understanding about Carnot's cycle, the coefficient of performance, i.e., the efficiency for our refrigeration system can be written as,

$$\mathrm{COP}_{\mathrm{reverse}} = \frac{T_L}{T_H - T_L} \tag{2}$$

In the above formula, T_H: is the temperature of hot reservoir, and T_L: temperature of cold reservoir. Now, for our case, the above formula can be converted in terms of outside temperature, inside temperature, and dimensions of the room. The practical engine is very hard to make, and the closest model that can be formulated is the *ideal vapor-compression refrigeration cycle*. From eq(2), we can find the average $\mathrm{COP}_{\mathrm{reverse}}$ value for our defined model, where T_H will be the net-room temperature, and T_L will be the average lower temperature we would want our room to attain. Now, we'll be comparing our obtained value of COP, and then compare to the data given below,
From last part of the paper, we found out that the average temperature of our room is $T_H = 30.52°C$. Now, for human beings average comfortable temperature is, $T_L = 22.00°C$. Now, using these values in eq(2), we can find $\mathrm{COP}_{\mathrm{reverse}}$ for our system,

$$\mathrm{COP}_{\mathrm{reverse}} = \frac{22}{30.52 - 22} \implies \mathrm{COP} = 2.58. \tag{3}$$

Refrigerant	Ref (Btu/lb)	Isen. Comp Work (Btu/lb)	COP
R12	61.73	22.70	2.719
R134a	80.42	29.40	2.735
R152a	126.46	46.69	2.709
R22	83.29	32.72	2.545
R115	43.42	15.79	2.749
R124	59.40	22.63	2.624
R134	85.25	30.51	2.794
R142b	88.75	31.54	2.812
R143a	78.35	29.57	2.649
R218	36.17	12.96	2.790
R290	152.16	56.77	2.704
RC270	179.36	66.79	2.685
RC318	44.65	15.33	2.912
R600a	143.68	49.59	2.897

Figure 11: **Different type of refrigerant according to the COP required. (D. R. Riffe, 1994)**

From above calculations, we found out that for our particular system, the required COP = 2.58 Since, the value is close to 2.5, thus, the best refrigerant for us will be R22. Now, for a R22 refrigerant, average power input is,

$$P = 83.29 Btu/lb \implies P = 193.73 KJ/Kg$$

The following equation defines a relationship between maximum rate at which heat can be eliminated using our system,

$$\frac{dQ_{\text{ref}}}{dt} = P \times \left(\text{COP}_{\text{reverse}}\right) \tag{4}$$

Putting values in the above equation, we can find the rate described above,

$$\frac{dQ_{\text{ref}}}{dt} = 193.73 \times 2.58 \text{KJ/Kg} \implies \frac{dQ_{\text{ref}}}{dt} = 499.82 \text{KJ/Kg} \tag{5}$$

From the above calculated values, we can conclude that for our system best refrigerant will be $R22$, and the corresponding maximum rate of heat elimination, $\dot{Q}$, was found to be

$$\dot{Q} = 499.82 \text{KJ/Kg} \approx= 500 \text{KJ/Kg}$$

8 Conclusion

This paper attempts to present a pragmatic approach to model the transfer of heat and its dynamics within a building. This model is more general and can be utilised for any space as long as the materials used to construct the space are known, and its geometry is known. The advantage of using such a model is that each parameter can be uniquely set, and multiple heat sources or sinks such as ventilation or radiators or other kinds of inflows can be easily incorporated into the differential equation used. The computational model uses a single order differential equation to model the room temperature with a range of 2 degrees. However the experimental data suggests a range of at least 3-4 degrees. The peak of the experimental data and theoretical data is different since the theoretical does not account for an east facing window, which has a different solar load compared to a more general system for which we have solved. The Carnot engine used to cool the room to bring it to a comfortable temperature suggests that an R22 refrigerant is ideal for the system.

9 Discussion

There are several errors that arise over the course of this experiment.In both, the computer model and experimental verification, it has been assumed that the temperature of the room is the same at all locations in the room. However, it is known that practically this is not the case as the room temperature need not be uniform. This is a source of error in the model. Further, during experimental verification, it was again assumed that the room temperature is the average of the three readings given by different probes, located in different parts of the room. This implies that temperature satisfies a linear relationship, which is often incorrect. Though the dorm room is considered to be isolated, the door was opened and closed several times throughout the course of this experiment. This was because people had to enter and exit the room in order to note down readings every hour. This may cause some amount of unwarranted heat exchange, as energy and matter could flow in and out of the system at these instances. The computational model ignored such human interventions and the errors generated due to the same. Further, the room was not fully sealed. There existed gaps in the door frames and window panes that allowed for the exchange of energy and air pockets with the surroundings. Next, there were several lights, equipment, outlets, and machinery in the room. Though they were not continuously switched on throughout the day, they might still have radiated some amount of heat energy due to usage or various malfunctions, causing heat gain within the system (the dorm room). Further, it is not necessary that the ventilation system is as effective as estimated in the computational model. This could be due to architectural or mechanical malfunctions that have not been accounted for. Next, the computational model heavily relies on the materials, and their thermal properties, used in the construction of the room. This is because different materials have different thermal conductivities. Though, the model accounts for a certain number of materials (glass, brick, cement, metal, tiles), it does not take into consideration all the elements used in the process. This may lead to a different effective thermal conductivity than what was calculated in this case. Next, the least count of the multimeters used in the experiment were too less to precisely measure the temperature variation throughout the course of the day. From experimental verification, it can be observed that the range of temperature is approximately 3^0C, which is a relatively small range. Hence, a temperature probe and multi-meter with higher sensitivity would have given more accurate readings. Further, the systematic errors in the multi-meter led to small inaccuracies in the obtained readings.

9.1 Future scope of the study

- Creating a general model that is not restricted to a room with identical walls, but any space
- Account for seasonal variations and weather conditions
- Creating a simulation for modelling the temperature gradient inside a room rather than assuming its constant temperature
- Use actual air-conditioning data to predict its efficiency more accurately

10 Recommendations to the university

- Keep fans that can generate speeds faster than 2 meters per second in order to ensure sufficient cooling solely by the fan
- Considering how crucial ventilation is, ensure that all windows are openable (classroom windows are often sealed in the university)
- Can integrate a parapet wall on the head of the window so that no direct sun reaches it. This will create a shade, stopping the room from increasing its temperature.
- Use an R22 refrigerant in order to cool most efficiently.
- Consider increasing the size of the vents on the top of the room to increase air flow rate rather than increasing airconditioning
- Attempt to increase COP to 2.7 by implementing energy consumption measures on campus so that the cooling can shift to R134a or R152a which are greener alternatives to CFCs.

11 References:

1. Skruch, P. (2014). A thermal model of the building for the design of temperature control algorithms. Automatyka/Automatics, 18(1).

2. Björsell, N., Bring, A., Eriksson, L., Grozman, P., Lindgren, M., Sahlin, P., ... & Vuolle, M. (1999, September). IDA indoor climate and energy. In Proc. of the 6-th IBPSA Conference (pp. 1035-1042).

3. International Refrigeration and Air Conditioning Conference: School of Mechanical Engineering: Purdue University. Site. (1994). Retrieved April 28, 2022, from http://docs.lib.purdue.edu/iracc

4. Bahrami, M. (n.d.). Refrigeration cycle - simon fraser university. Refrigeration Cycle. Retrieved April 27, 2022, from https://www.sfu.ca/~mbahrami/ENSC%20461/Notes/Refrigeration%20Cycle.pdf

5. Yang, S., Wan, M. P., Ng, B. F., Zhang, T., Babu, S., Zhang, Z., ... Dubey, S. (2018). A state-space thermal model incorporating humidity and thermal comfort for model predictive control in buildings. Energy and Buildings, 170, 25-39.

6. Hietaharju, P., Ruusunen, M., & Leiviskä, K. (2018). A dynamic model for indoor temperature prediction in buildings. Energies, 11(6), 1477.

7. Cheng, J., Zhang, Z., & Peng, C. (2020). Parametric Modelling and Simulation of an Indoor Temperature Responsive Rotational Shading System Design.