Development Engineering Project-CP301

Natural and Forced Convection Strategies For Energy- Efficient Buildings

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2024

Abstract

Energy is one of the most important catalysts in wealth generation, economic growth, and social development in all countries. Buildings have a significant share in total energy consumed globally. Buildings are responsible for the annual consumption of 40 percent of the world's energy.With the cost of energy increasing and the energy crisis being an imminent reality, the need to provide energy-efficient building designs becomes more important.The potential of natural and forced convection techniques in buildings should be implemented to reduce energy consumption.We analyzed temperature gradient in tradition buildings and naturally inspired buildings.It is found that by integrating passive solar design strategies, energy-efficient equipment, and renewable energy sources, energy-efficient buildings can effectively optimize energy usage and reduce dependency on non-renewable energy sources.An energy-efficient building balances all aspects of energy use in a building by providing an optimized mix of passive solar–design strategies, energy-efficient equipment, and renewable sources of energy.

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Nomenclature

β	Coefficient of Thermal Expansion for Gas
μ_a	Dynamic Viscosity of Air
ρ_a	Density of Air
ρ_c	Density of Concrete
ρ_m	Density of Mound
C_{pa}	Specific Heat for Air
C_{pc}	Specific Heat for Concrete
C_{pm}	Specific Heat for Mound
g	Acceleration due to Gravity
Gr	Grashof Number
h	Heat transfer coefficient
k_a	Thermal Conductivity of Air
k_c	Thermal Conductivity of Concrete
k_m	Thermal Conductivity of Mound
Nu	Nusselt Number
P	Pressure
Pr	Prandtl Number
Ra	Rayleigh Number
S_ϕ	Heat Generating Source
T	Temperature
u	Velocity

1 Introduction

Energy demand continues to increase every year, and surely we are going to find more uses for it. Most of the energy we generate comes from burning coal and fossil fuels, which release harmful toxins like carbon dioxide and sulfur into the atmosphere. Burning coal and fossil fuels is temporary as resources will eventually run out, and this action causes negative impacts on our environment. It's high time to focus on energy-saving technologies or techniques. Taking inspiration from ancient architecture gives a better understanding of climate-responsive structures. Courtyard planning, lattice screens, cooling towers, jharokha, evaporative cooling, and landscaping with water bodies are a few techniques and elements that were used for passive cooling in traditional buildings.

By 2040, global primary energy consumption will increase by 32 percent more than that in 2017 [1]. Industry and buildings have been consuming most of the world's energy, especially buildings. Most people spend 90% of their time indoors daily[2]. Coupled with the rapid development of the economy and technology, people focus on living comfortably. Thus, people pay additional attention to heating-ventilation-air conditioning (HVAC) systems, hot water production systems, lighting systems, and other external equipment to improve their living conditions, thus making buildings the largest energy consumers in the world. Buildings accounted for 32% of the world's total final energy use in 2010, with the construction sector in some developed countries consuming as much as 40% of the total energy[3]. In addition to consuming large amounts of energy, the building sector also produces approximately one-third of the world's greenhouse gas emissions[4]. Therefore, effectively controlling and reducing building energy consumption (BEC) is a global focus.

Many efforts have been undertaken to reduce energy consumption in the building sector and improve the efficiency of building energy use. Scholars have introduced numerous techniques and approaches to deal with these cross-disciplinary complexities. For example, constructing a vegetated facade model[5], encapsulating phase change materials (PCM)[6] in the wall to improve the thermal performance of the wall facades, replacing windows and ventilation systems with heat recovery and external wall insulation[7], and improving the control system[8].

A study of the historical evolution of energy-efficient buildings is necessary for a better understanding of changes made through time to improve comfort and optimize energy consumption. Generally speaking, people are aware of the need to apply new concepts, standards, and laws when presented in contrast with old ones[9].

Naturally inspired techniques can be used to develop strategies to reduce energy consumption in buildings. Termite mounds, built by minuscule but remarkably skilled builders, are the ideal illustration of this. These mounds are more than just shelter; they're complex works of natural architecture that can keep their interior temperatures just right. This phenomenon makes us wonder: what if our building ideas could mimic the brilliance of termite mounds? Here lies the concept of biomimicry: the technique of improving man-made systems by taking hints from the designs seen in nature. The passive cooling techniques already found in historic buildings can also be incorporated to reduce energy consumption in buildings.

This report looks at how systems inspired by termite structures and other architectures can be used to improve energy consumption in buildings. We will use this analysis to propose design changes in existing buildings to optimize energy savings. We will perform this analysis for various climatic conditions in India.

2 Literature Review

We discuss the studies based on termite mounds in section 2.1 and other passive cooling techniques in section 2.2.

2.1 Flow Mechanism inside termite mounds:

The major motive of this project was to study how heat transfer occurs between the termite mound and the ambient. And how can we gain from it. The study investigates how temperature is regulated inside a mound. We are also looking at how to apply this technique to cool modern buildings. There are 2 different types of flow depending upon the nature of mounds i.e. closed capped or open chimney mounds 1, which are:

1. Thermosiphon Flow: This flow type is generally observed in the closed-capped mound. It works upon the principle that warm air is lighter than cold air. The heat absorbed from the mound makes the air warm hence it rises and comes down through the surface conduits of the porous mound.The gas exchange in this type of mound generally occurs due to the mound's porosity through diffusion.
2. Induced Flow: Induced flow generally occurs in an open mound. The wind velocity creates low pressure at the opening of the chimney; this pulls in the cold air from the air inlets, and hot air escapes through the chimney. It is a one-way flow, unlike the thermosiphon flow. 1

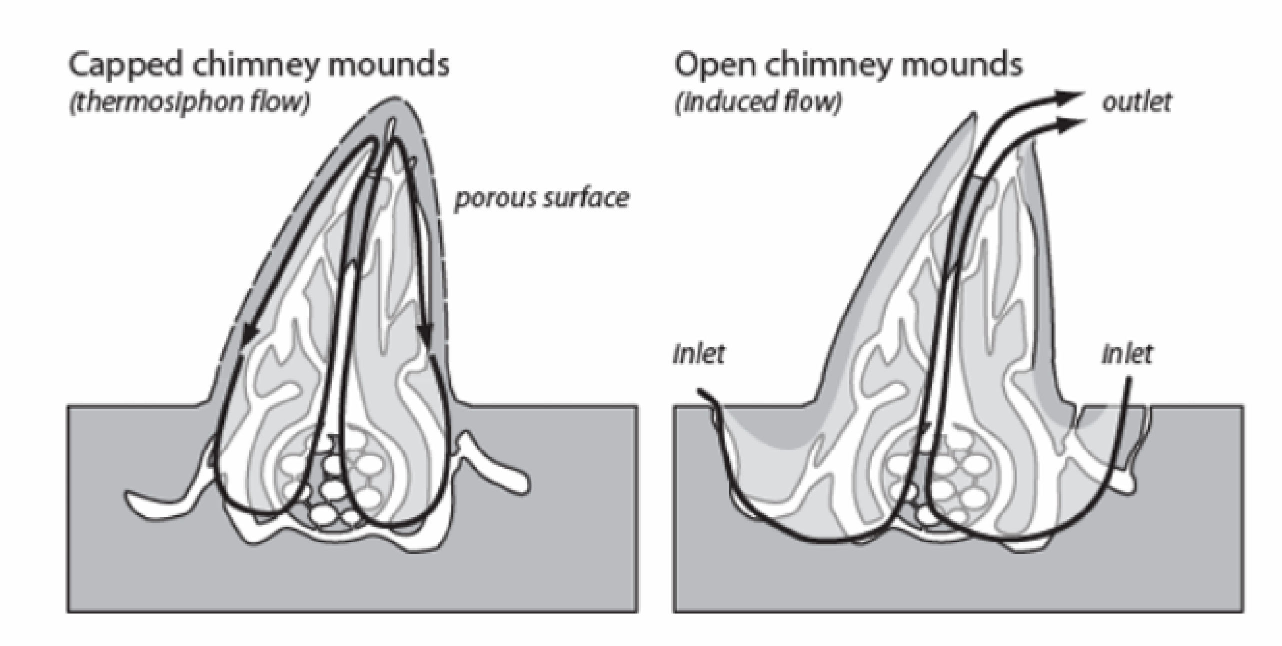

Figure 1: a) Thermosiphon flow b)Induced flow

It has been found that induced ventilation works in tall structures or buildings.Hence, termite mounds (which are around 2m tall) cannot be fully utilized properly. Hence, even in open chimney mounds, the reliability of induced flow is quite low, even though the structure seems ideal for induced flow. Mound ventilation and nest ventilation are completely different phenomena. Experiments have shown that air circulated in the mound is rarely driven into the nest. This implies that mechanisms apart from ventilation must be involved in monitoring the gas exchange. Turner Soar [4] compared the termite mound to human lungs.They stated that there are three regimes of gas exchange in termite mounds similar to that of human lungs. Here the mound, in comparison with the bronchi and nest,is analogous to alveoli. It is stated that the nest and mound are isolated from each other. The proposed model for thermosiphon flow and induced flow is shown in Figure 2.The different elements of the model are described below.

1.Egress tunnels and surface conduits: In this zone, forced convection is dominant. The air currents are driven by winds.

2.Nest, chimney, and subterranean tunnels: Due to high metabolism and non-existent velocity of air, natural convection becomes the dominant mode of convection in this zone.

3.Reticulum: Between these two regimes lies a transition zone where both natural and forced convection occur. 1

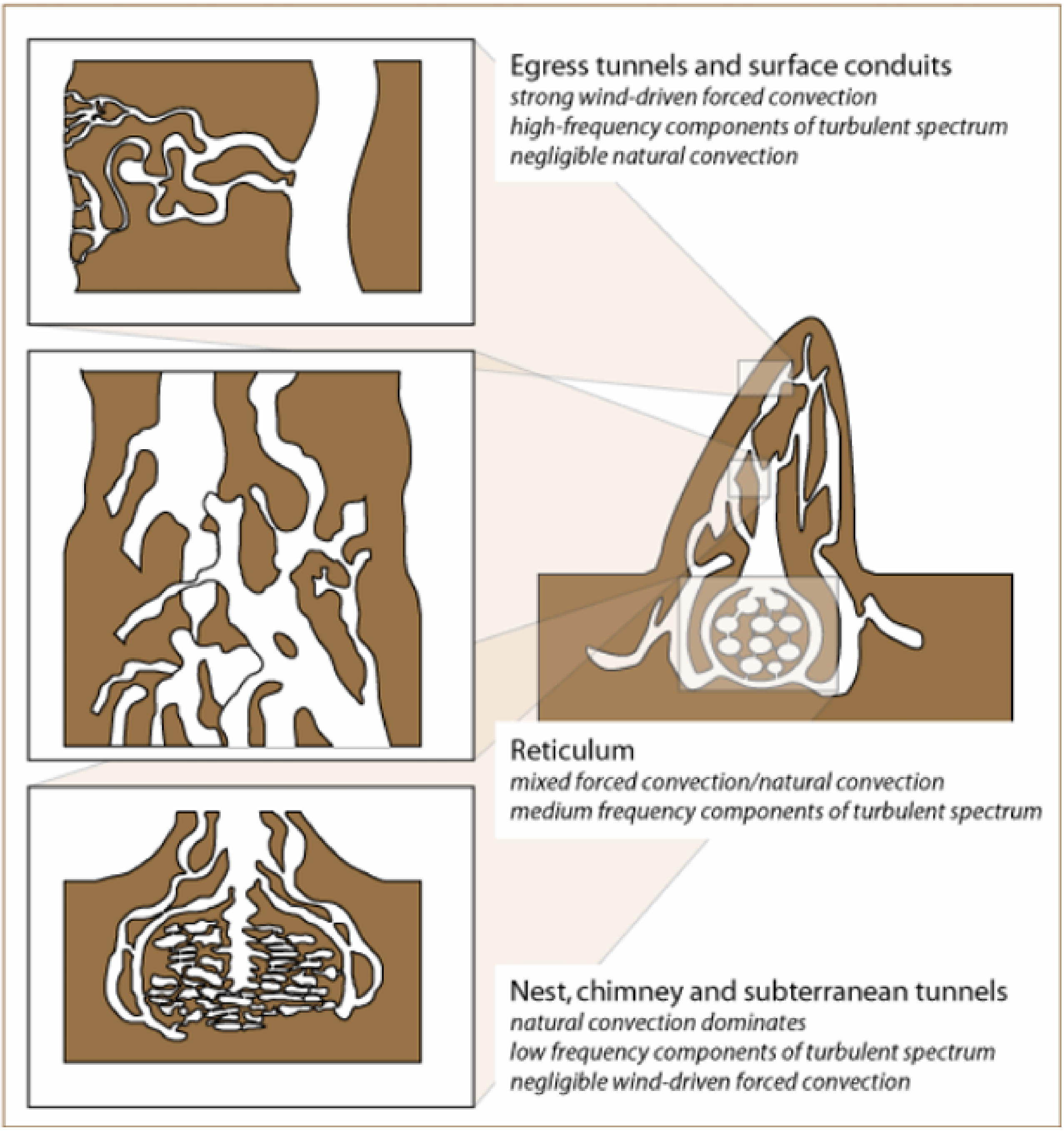

Figure 2: **Fig-2 The proposed models for thermosiphon flow and induced flow [Reproduced from Turner et. al., 2008]**

2.2 Historical Passive Cooling Techniques

Throughout history, passive cooling techniques have been utilized in buildings and palaces, particularly in locations experiencing high temperatures. Here are some historical instances of passive cooling methods in use:

1. Ventilation: Planning a building so that windows, doors, and vents are positioned thoughtfully to promote natural airflow. Wind catchers are towers intended to capture the prevailing winds and channel them into buildings for cooling, like those found in traditional Persian architecture.

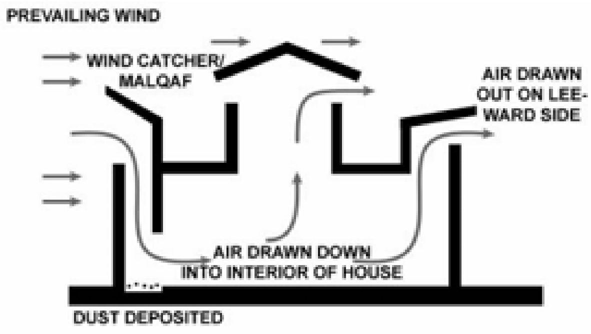

Figure 3: A windcatcher or Malqaf used in traditional persian / arabic architecture

2.Atriums and Courtyards: To encourage airflow and create shaded outdoor areas, many historic structures and palaces made use of atriums and courtyards. By allowing hot air to escape, these open spaces offer shade and cooling via evaporative processes.

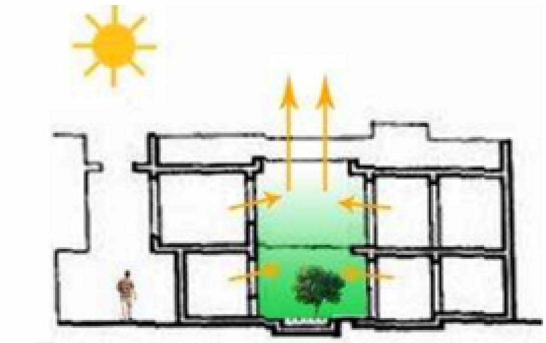

Figure 4: a)Effect of courtyard on ventilation during day

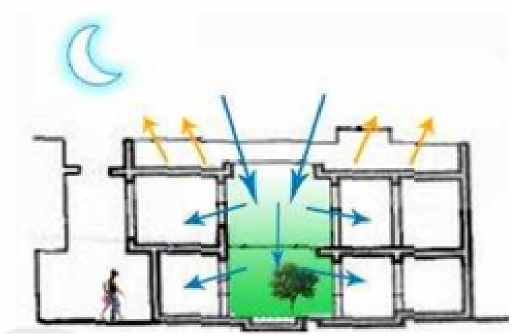

Figure 5: b) Effect of courtyard on ventilation during night

3.Lattice Screens "Jaalis": For millennia, people have cleverly used the lattice screen, also called "jaali" in ancient Indian construction, as a passive cooling method. While blocking off direct sunlight, the jaali's elaborate lattice structure lets diffused sunshine inside the building. This keeps the interiors of the building colder by reducing solar heat gain.Jaalis are frequently used as room barriers, in windows, and on balconies. By allowing air to pass through the perforations and preventing direct drafts, they promote natural ventilation. This improves comfort by generating a light breeze inside the structure. Jaalis enhance aesthetic appeal, adding visual interest to facades and interiors, and hold cultural significance, reflecting traditional craftsmanship and identity.

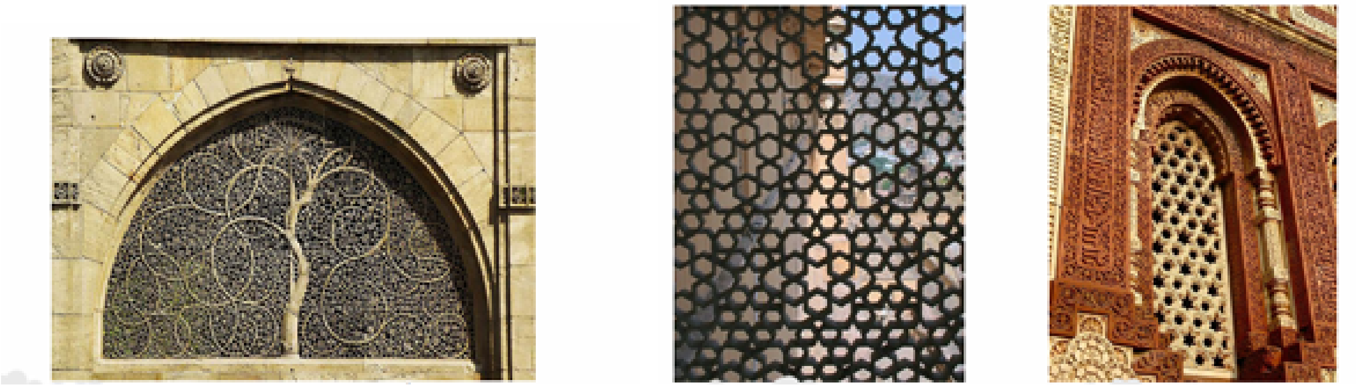

Figure 6: a) Common lattice screen of mughal Period, India. b) Lattice screen at Amber Fort. c) Lattice screen on Facade

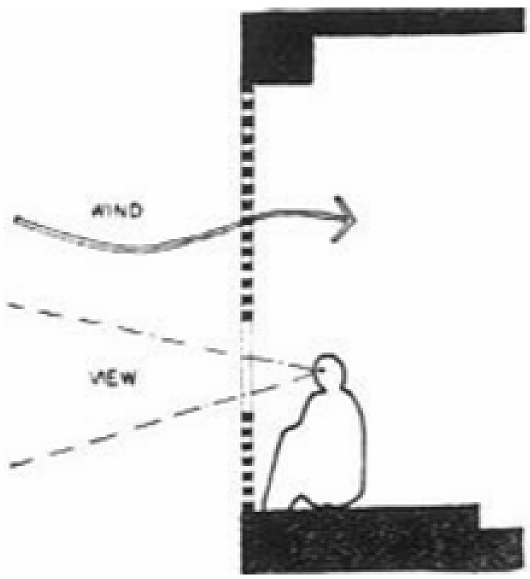

Figure 7: b)Window for view and ventilation used at Amber Fort

4. Thermal Mass: Buildings with high thermal mass materials, such stone or adobe, can collect heat during the day and release it gradually at night, thereby regulating internal temperatures.

5. Shading Devices: Using overhangs, awnings, and lattices as architectural features to block direct sunlight from reaching windows and walls in order to minimize solar heat gain. Jharokhas are commonly found in palaces, forts, havelis (traditional Indian homes), and other historical buildings all over India. They are usually erected on top floors. They are a great illustration of how passive cooling and shading strategies were incorporated into traditional architecture to improve comfort in hot regions.

Figure 8: a)Jharokhas In Hawa Mahal Jaipur, India b

Figure 9: b)Jharokha in haveli of Jaisalmer

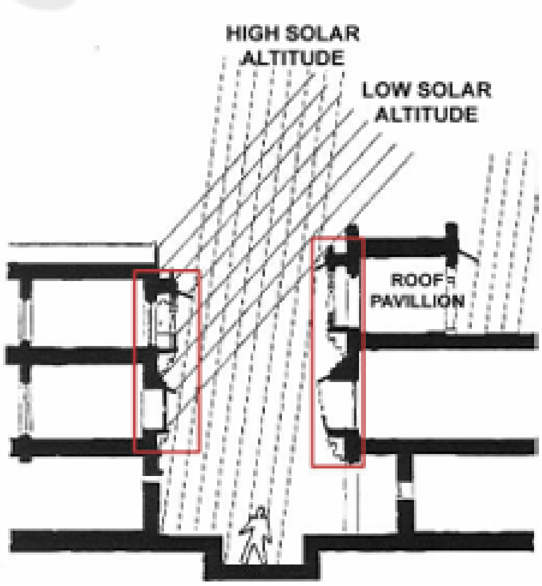

Figure 10: c)Jharokhas in Jaisalmer over narrow streets

6. Water features: Including water features in or near buildings, such as pools, fountains, and channels, to produce microclimates and cool the air through evaporation.

7. Earth Sheltering: Building partially or fully underground to benefit from the earth's insulating qualities and sustain colder temperatures in hotter climes is known as "earth sheltering."

8. Thermal Chimneys: Building vertical shafts or chimneys to extract hot air and expel it from the structure, allowing for natural cooling and convection.

9. Reflecting Surfaces: To keep buildings colder by reducing solar heat absorption, use light-colored or reflecting materials for exterior surfaces such as roofs.

10.Cross-Ventilation: The process of allowing cooler air to enter and warm air to escape a structure through the use of several apertures on opposite sides in a design known as cross-ventilation.

3 Analytical and Simulation Details

In this section, we discuss the details of the simulation. To begin with, we performed simulations of one-dimensional heat transfer problems with known analytical solutions to understand the implementation of boundary conditions such as insulated and constant temperature boundary conditions. We will then study temperature variations inside the termite mound using ANSYS Fluent and validate the results with [10], where the temperature regulation inside a termite mound is studied. We will eventually apply some of the techniques that can be used to reduce the energy consumption for the HVAC of a residential and commercial building inspired by the termite mounds.

3.1 Understanding the difference between insulated and constant temperature boundary conditions.

To understand the difference between the constant heat flux and constant temperature boundary conditions we will take an example of 1-D conduction in a rod. The governing equation for 1-D steady-state conduction is:

$$\frac{d^2T}{dx^2} = 0 \tag{1}$$

On solving the equation analytically, we get the solution as:

$$T = C_1 x + C_2 \tag{2}$$

The values of C_1 and C_2 will depend on the boundary conditions.

1. Constant temperatures specified at both ends: Let's assume that the right end of the rod is at 333K and the left end is at 303K. Upon solving equation 2 with the given boundary conditions, we get the solution:

$$T = 30x + 303K \tag{3}$$

We simulated the same example using ANSYS Fluent for a 1 m-long rod at a steady state using a mesh size of 0.001 m. The following results were obtained:

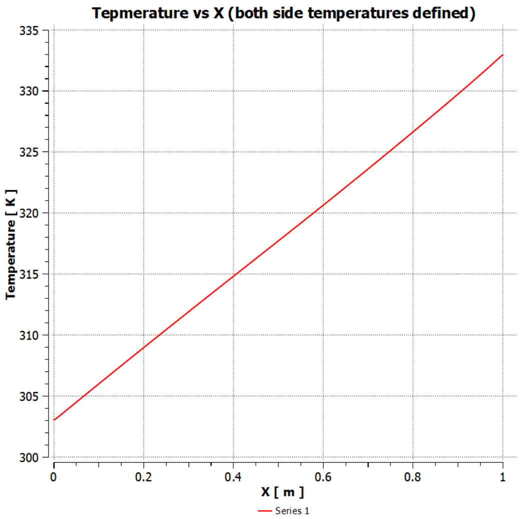

Figure 11: Temperature-profile when both side temperatures are defined

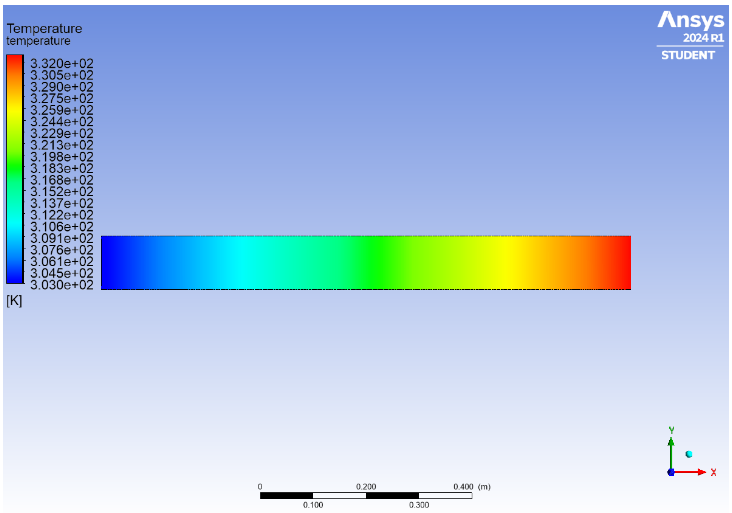

Figure 12: Temperature-contours when both side temperatures are defined

Since the temperature profile obtained from the analytical solution as well as the numerical solution is linear, we can now validate the numerical solution to the analytical solution. We can also observe that by specifying the temperatures on both sides of the rod, there is a constant heat flux leaving from the left end of the rod to maintain the specified temperature.

2. Insulated from one end: Let's assume that the right end of the rod is at 433K and the left end is insulated. Upon solving equation 2 with the given boundary conditions, we get the solution:

$$T = 433K \tag{4}$$

We simulated the same example using ANSYS Fluent for a 1 m-long rod at a steady state using a mesh size of 0.001 m. The following results were obtained:

Figure 13: Temperature-contour when one side is insulated and temperature is specified at the other end.

Since the temperature obtained from the analytical as well as the numerical solution matches, we can now validate the numerical solution to the analytical solution. We can also observe that by specifying the temperature on one side and insulation on the other side, we can say that the heat coming from the right side of the rod cannot exit through the left side, so eventually, the temperature of the whole rod increases to the temperature specified at the right end.

3.2 Simulation of Termite Mound

Now, with this understanding of the constant temperature and the insulated boundary conditions, we will study the temperature regulation inside a termite mound.

The following cases are considered for the simulation:

Case-1: Heat transfer study of a closed capped mound without any interior room.

Case-2: Heat transfer study of a closed capped mound with adding a room in the mound.

We compare our results in case-1 and case-2 with an earlier work[10].

3.2.1 Properties of materials:

For the entire simulations, the following properties of materials were used:

Properties of air at 310K:

β_a=0.00322 K^{-1}

$C_{p,a}$=1007 $J/kg.K$

μ_a=17.3×10^{-6} $N.s/m^2$

k_a=$27 \times 10^{-3} W/m.K$

ρ_a=1.2 kg/m^3

Properties of mound:

$C_{p,m}$=1381 $J/kg.K$

ρ_m=1746kg/m^3

k_m=0.6$W/m.K$

3.2.2 Mound Structure Without Interior Flow Regime:

First, we will consider the most basic case of a solid conical mound that is exposed to hot surrounding conditions of 318K. The optimum temperature for the living of termites is 303K[10]. Since the termites reside below the ground, and there is a very small variation in temperature below the ground level, we will keep the temperature of the base constant at 303K.

(a) Mathematical Model:

To understand the temperature profile and the heat transfer within a termite mound, we simulated the basic structure of the termite mounds using ANSYS Fluent. This method has been used in literature[10]. We will then make the structure more complex. For the sake of simplicity and less computational time, we are just looking at a 2-D model of the mound. Later we can extend this to 3-D models. First, we developed a mathematical model of the simplest structure of the termite mound, i.e. a conical solid mound made from clay, as shown in Figure 2, where the slant height of the cone is L_c=0.77308 m and inclined at an angle of θ =14.036° with the vertical. The base is of the width = 0.56012 m. This geometry has been used in the literature[10].

We first calculated the heat transfer coefficient for natural convection over an inclined plane analytically assuming there is no wind blowing.

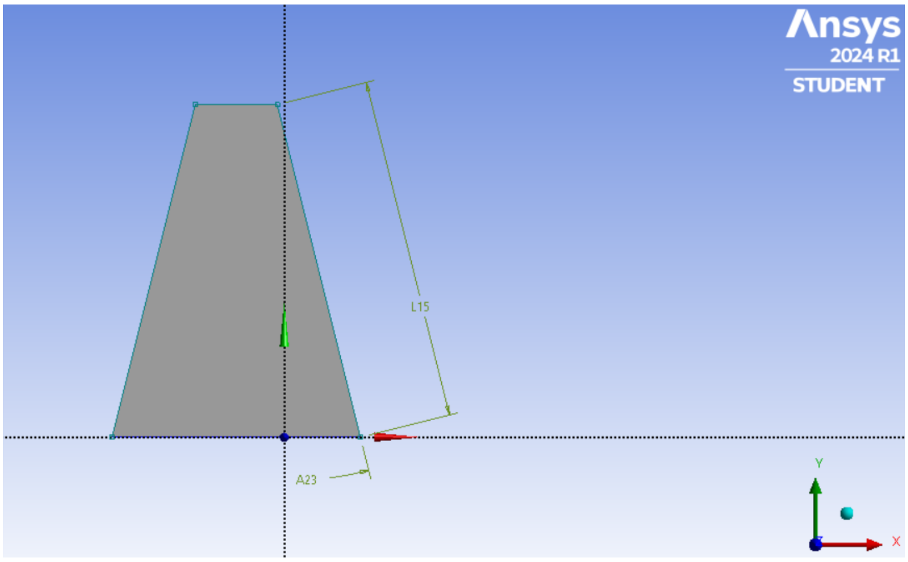

Figure 14: CAD model of basic mound structure

We will assume the average ambient temperature in summers to be 318K and the temperature inside the mound to be 303K, which is optimal for the termite to live i.e. $\Delta T = 15K$. The Prandtl Number for the air at 310K is given as,

$$Pr = \frac{\mu_a C_{p,a}}{k_a} = 0.645 \tag{5}$$

For the natural convection over the inclined plane, the Grashof Number is given by,

$$Gr = \frac{g cos\theta \beta \Delta T L_c^3}{\nu^2} = 1.0637 \times 10^8 \tag{6}$$

The Rayleigh Number is given as,

$$Ra = Gr \times Pr = 6.861 \times 10^7 \tag{7}$$

We chose the dimensions of the mound such that $Ra < 10^9$, so we can have a laminar flow over the walls of the plane.

From [11], the Nusselt number relation to find the heat transfer coefficient is given by,

$$Nu = \frac{hL_c}{k_a} = \left(0.825 + \frac{0.387 Ra^{1/6}}{(1 + (\frac{0.492}{Pr})^{\frac{9}{16}})^{\frac{8}{27}}}\right)^2 = 106.6426 \tag{8}$$

On solving for h, we get h = 3.848 $\frac{W}{m^2.K}$. We will validate the value of the heat transfer coefficient obtained from the simulations with this calculated value.

(b) Initial and Boundary Conditions:

For this case, we assumed that initially, the mound as well as the surrounding was at 303K. The mound is then kept open to the surrounding whose temperature is increased to 318K, and the base of the mound is kept at a constant temperature of 303K.

(c) Simulation Details:

We have applied the face meshing on the surface of the mound with an element size of 5×10^{-4} m. Since face meshing only involves meshing the surface of the object, it typically requires fewer computational resources (such as memory and processing power) compared to volumetric meshing. This can result in faster simulation and reduced computational costs. We solved the energy equation for the heat transfer analysis. The convergence criterion for the residuals of the energy equation is set to 10^{-6}. It means that if the residuals that are obtained from solving the equations numerically are below the desired criterion for all equations, we can say that the solution is converged. We solved the steady-state equations for 1000 iterations. The solution converged at 408^{th} iteration and the solution was obtained.

(d) Numerical Results:

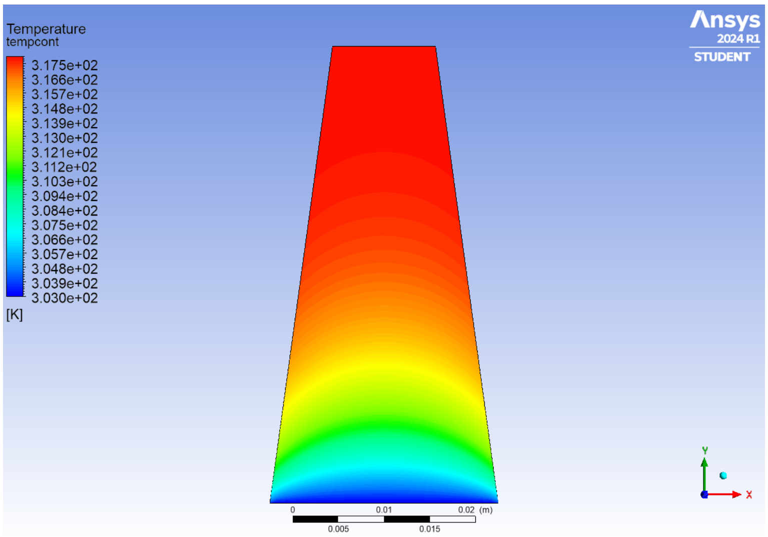

Figure 15: Temperature profile obtained for basic mound structure

Observing the conical mound, it becomes apparent that its base maintains a temperature of 303 Kelvin (K). Moving upward, the temperature gradually rises, reaching 317.5 K at its peak as one would expect.

Figure 16 shows the heat transfer coefficient along the outer wall. Remarkably, the value obtained, standing at 3.84 $\frac{W}{m^2 K}$, gives us the validation of the numerical result with the analytical value. We can also see some temperature gradients near the base of the mound, this is because the heat generated in the mound due to a relatively high ambient temperature, escapes from the base of the mound.

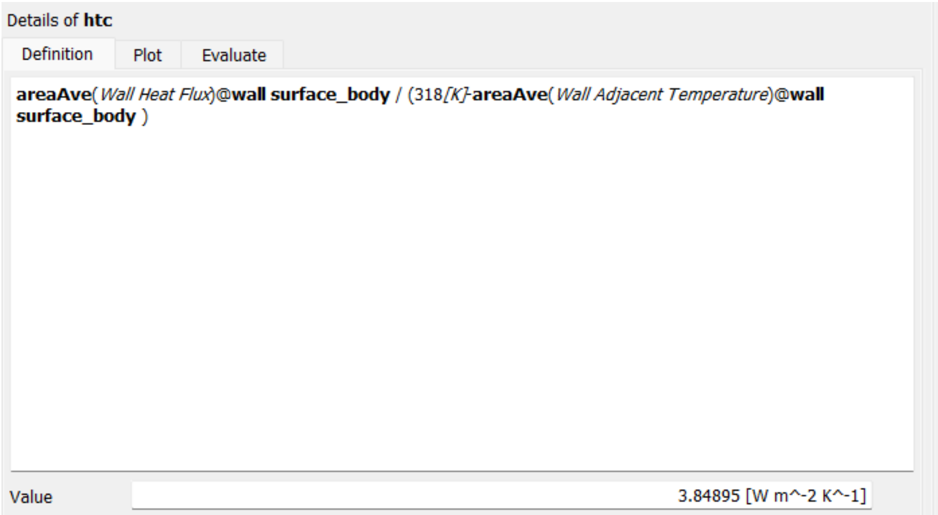

Figure 16: Heat transfer coefficient for basic mound structure

3.2.3 Mound Structure With A Room :

We will now add a room inside a mound which is to be maintained at 303K which is the optimum condition for living and we will observe what happens to the temperature profile in this condition and compare it to the earlier case 3.2.2.

(a) Mathematical Model:

We now added a room-like space inside the mound and we need to maintain its temperature at 303K as an optimal condition for the living of termites. All the other dimensions are the same as in the previous case 3.2.2, so there will be the same value of heat transfer coefficient for the outer walls. The height and the width of the room are 0.4m and 0.2m respectively. This geometry has been used in the literature [10].

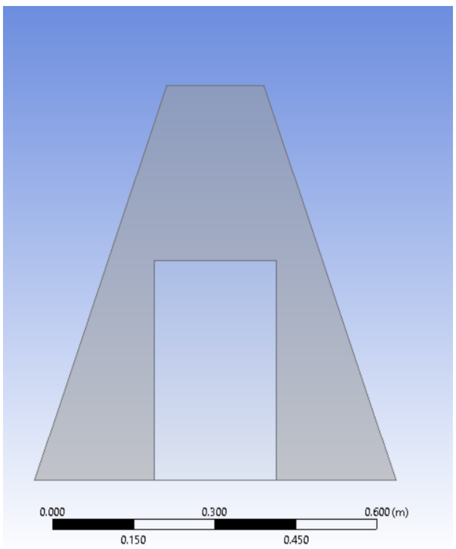

Figure 17: CAD Model for a mound with a room inside

(b) Initial and Boundary Conditions:

The initial and boundary conditions remain the same as in the case 3.2.2, the only thing changed here is that the room temperature is maintained at 303K. The ambient temperature is at 318K.

(c) Simulation Details:

We have meshed the model with a face meshing of element size 1×10^{-3} m. Again we solved the steady state energy equation assuming that the air inside the room is still i.e. the velocity of the air inside the room is 0. The convergence criterion for this simulation is set to 10^{-6}. We simulated for 1000 iterations and the following converged solution was obtained. **(d) Numerical Results:**

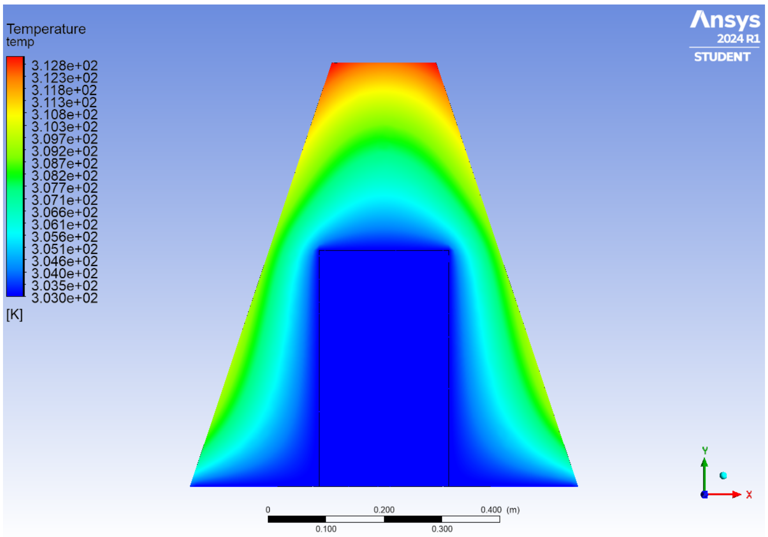

Figure 18: Temperature contours for a mound with room

After adding a room inside the mound and keeping the same parameters, we noticed significant changes in the temperature distribution:

1) The temperature profile became more refined, showing alterations in thermal distribution throughout the mound.

2) When we compared the updated temperature profile with 15, we noticed a considerable change i.e. the cooler area expanded considerably, while the region with higher temperatures contracted and became primarily concentrated at the top of the mound.

3.2.4 Mound Structure With A Heat Source Inside Room:

Till now, we didn't consider the metabolic heat generation inside the mound. In this section, we will now add a heat source inside the room which represents the metabolic heat generation rate inside a termite mound, and analyze the temperature profile inside the room.

(a) Mathematical Model:

As seen in the below figure 19, there is a circular heat source inside the room representing the metabolic heat generation. The other dimensions of the mound are the same as in case 3.2.3.

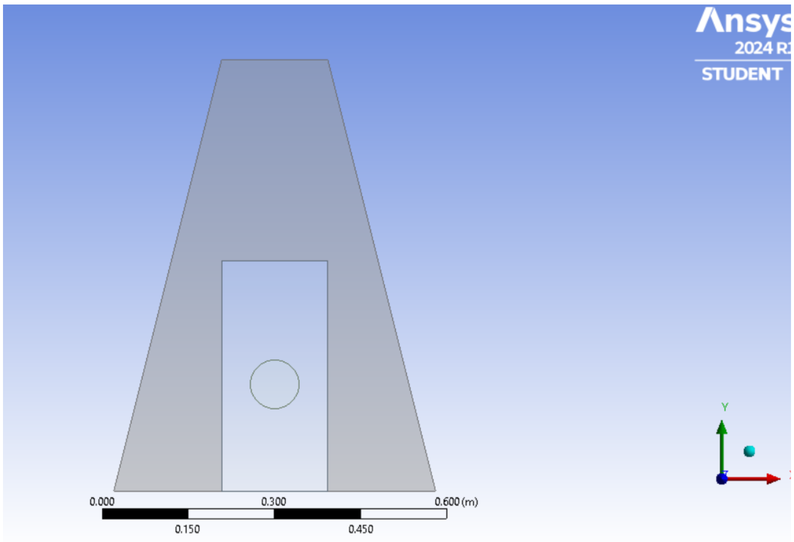

Figure 19: CAD model for the heat source inside room

(b) Initial and Boundary Conditions:

Initially, we considered the whole model to be at 303K. We then kept the surrounding temperature at 318K with a heat transfer coefficient of 3.84 $\frac{W}{m^2K}$ as calculated in the case 3.2.2. The metabolic heat generation rate inside the mound is typically 50 W [12]. Hence, the heat source emits heat at an average rate of 50 W.

(c) Simulation Details:

We meshed the model by using the face sizing of an element size of 3 mm. The following equations were solved simultaneously in ANSYS:

$$\frac{d^2T}{dx^2} + \frac{d^2T}{dy^2} = S_\phi \tag{9}$$

$$\nabla.(\rho \mathbf{u.u}) = -\nabla P + \mu \nabla^2 u \tag{10}$$

$$\nabla.(\rho\mathbf{u}) = 0 \tag{11}$$

To capture the density effects, Boussinesq's density model was used. Gravity was also turned ON. Again, the convergence criterion for the simulation was set to 10^{-6}. The numerical model was solved for 2000 iterations.

(d) Numerical Results:

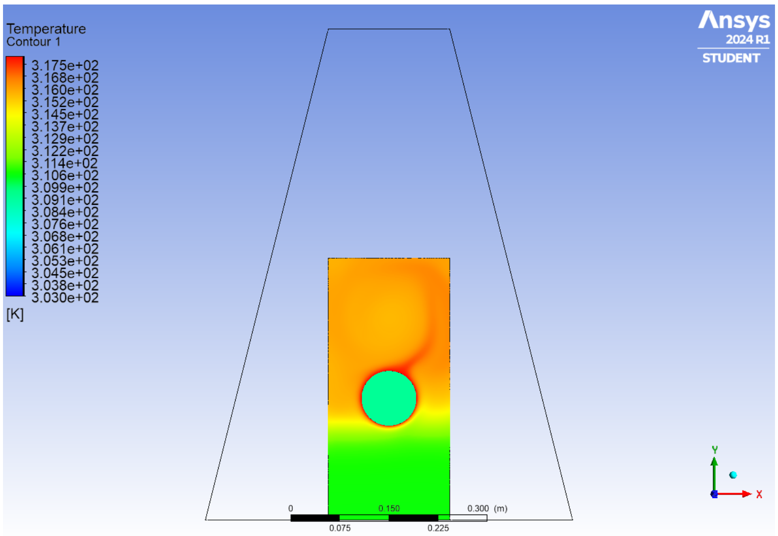

Figure 20: Temperature profile inside the room

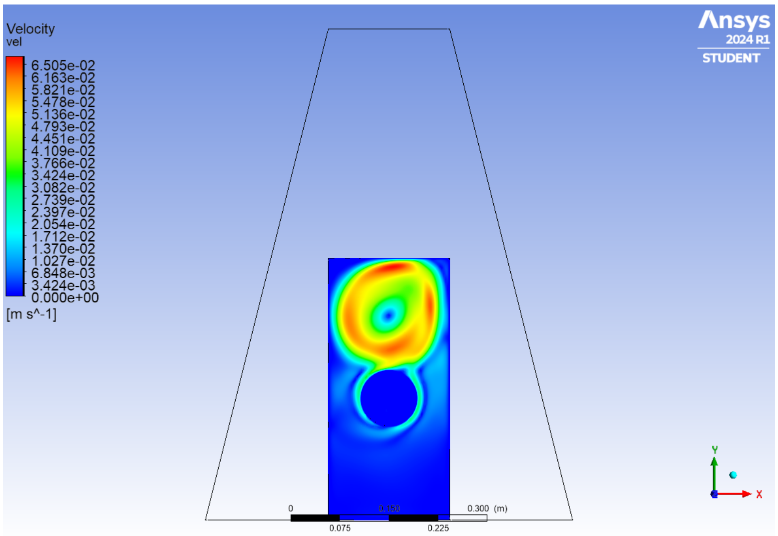

Figure 21: Velocity profile inside the room

As seen in Figure 20, the heat source heats the air inside the room and the hot air gets into the upper portion of the room which perfectly makes sense. By analyzing the velocity profile from Figure 22, we can see how the initially cold air when heated up by a circular heat source rises due to the density difference.

Now we want this hot air to escape the room. We will now implement the idea of forced convection inside a residential room where the hot air will escape through an outlet.

3.3 Implementing forced convection in a residential room:

Until this section, we have studied termite mounds and how they regulate the inside temperature. One major factor in the cooling of the termite mounds was forced convection through the chimney. Now we will implement the techniques in a residential room. We simplified the model of the room by taking it as a square room with a metabolic heat generation source inside it. We used the material as concrete for the walls of the room. Concrete possesses the following properties:

$C_{p,c}$=780 $J/kg.K$

k_c=0.72$W/m.K$

ρ_c=2300 kg/m^3

(a) Mathematical Model:

The dimensions of the room were taken to be 4m×3m. According to the dimensions, we calculated the heat transfer coefficient for the outer walls experiencing natural convection. The average air temperature was considered to be 310K.

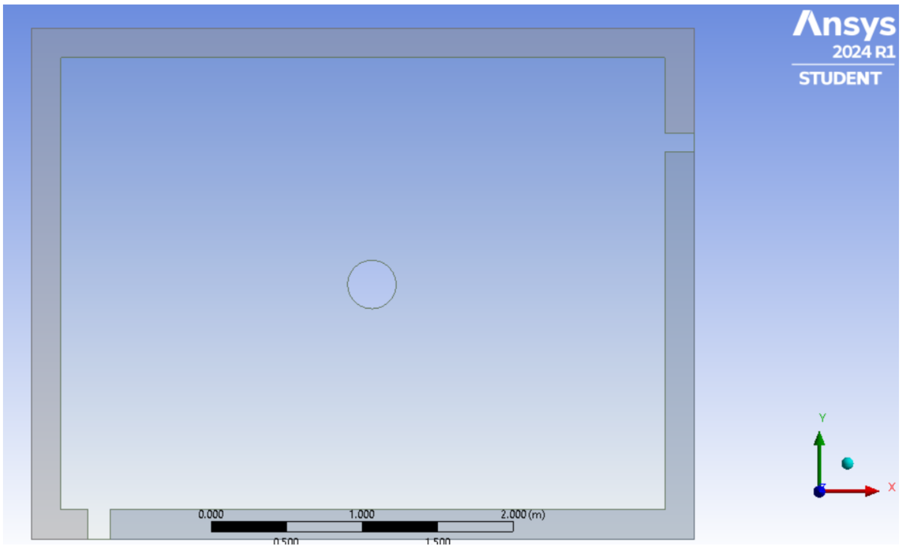

Figure 22: CAD model of the room with a heat source

The Prandtl number at 310K is given as:

$$Pr = \frac{\mu_a C_{p,a}}{k_a} = 0.645 \tag{12}$$

For natural convection on outer walls, the Grashof Number is given as:

$$Gr = \frac{g\beta\Delta T L_c^3}{\nu^2} = 6.15 \times 10^{10} \tag{13}$$

The Rayleigh Number is given as,

$$Ra = Gr \times Pr = 3.97 \times 10^{10} \tag{14}$$

Since $Ra > 10^9$, the flow is turbulent and accordingly, we need to consider the turbulent effects in the simulation.

From [11], the Nusselt number relation to find the heat transfer coefficient is given by,

$$Nu = \frac{hL_c}{k_a} = \left(0.825 + \frac{0.387Ra^{1/6}}{(1 + (\frac{0.492}{Pr})^{\frac{9}{16}})^{\frac{8}{27}}}\right)^2 = 385.53 \tag{15}$$

On solving for h, we get h = 4.14 $\frac{W}{m^2.K}$.

(b) Initial and Boundary Conditions:

Initially, we considered the room to be at the same temperature as the ambient equal to 318K. The air enters the inlet at $1m/s$ at an inlet temperature of 303K. The outlet is a pressure outlet with 0 gauge pressure and 318K outlet temperature. The solar radiation of 500 W/m^2 is incident on the outer walls and a heat transfer coefficient of 4.1 W/m^2K is applied to account for natural convection. The metabolic heat source emits a heat of 70 W/m^2 which is a standard value for a standing person [13]

(c) Simulation Details:

First, we meshed the model with an element size of 0.2 m. This time we solved unsteady energy, momentum, and continuity equations to have an estimate of the time it takes for the cold air to cool down the heated room. We analyzed the temperature profile inside the room every 60 seconds. The time step size of 0.5 s is used and iterated for 120 time steps with a maximum of 20 iterations per time step. The convergence criterion for the energy equation was taken to be 10^{-6} and 10^{-3} for the remaining equations. We monitored the residuals with the iterations. As seen in figure 23, the solver will iterate 20 times for one time step, and the residuals for the next time step will be higher than the end of the previous time step and then it will again iterate it 20 times. Hence the zig-zag pattern observed is considered good for any transient CFD simulation.

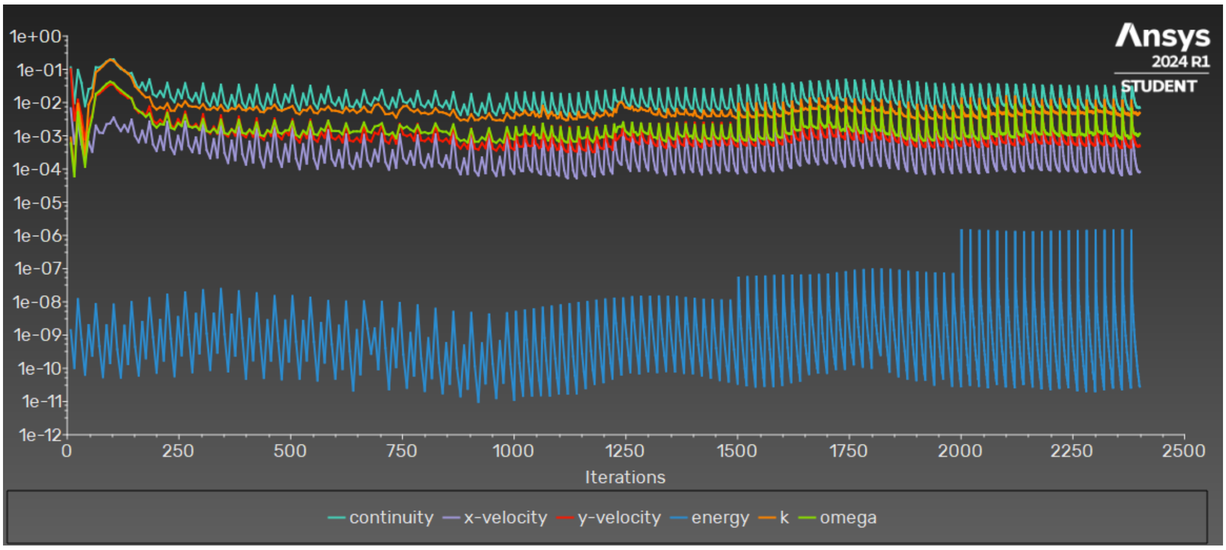

Figure 23: Residuals monitored with each iteration.

(d) Numerical Results:

We monitored the temperature profile inside the room every 60 seconds. After solving the model for the first 60 seconds, we got the following profile inside the room.

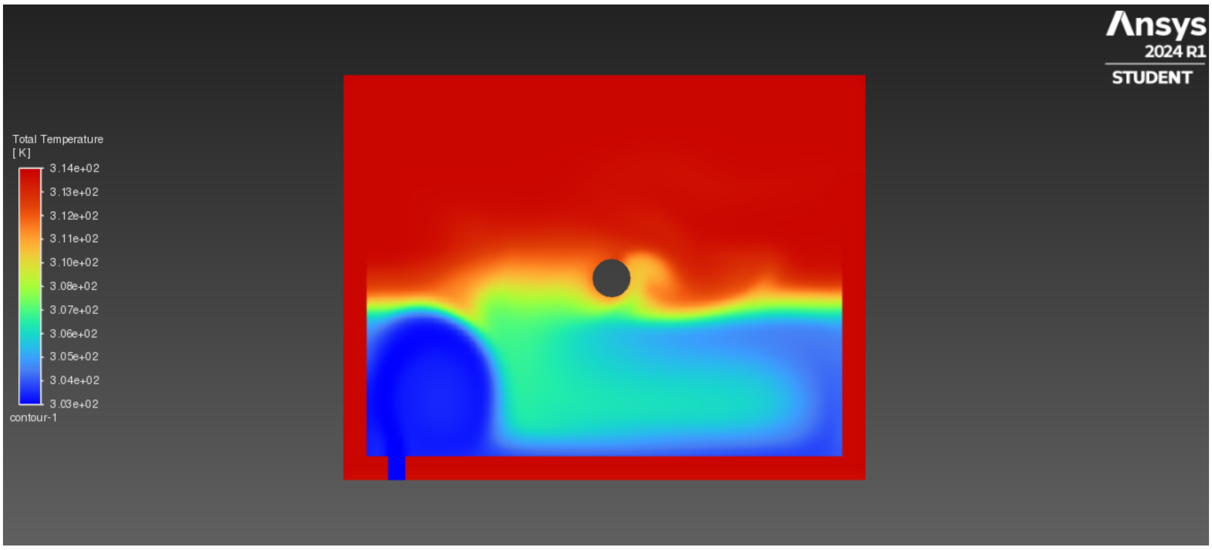

Figure 24: Temperature profile after first 60 seconds.

After the first 60 seconds, the major area of the room is hot since the cold air will first start to cool the area closer to it. We simulated for another 120 seconds and the room was cooler as seen in figure 25

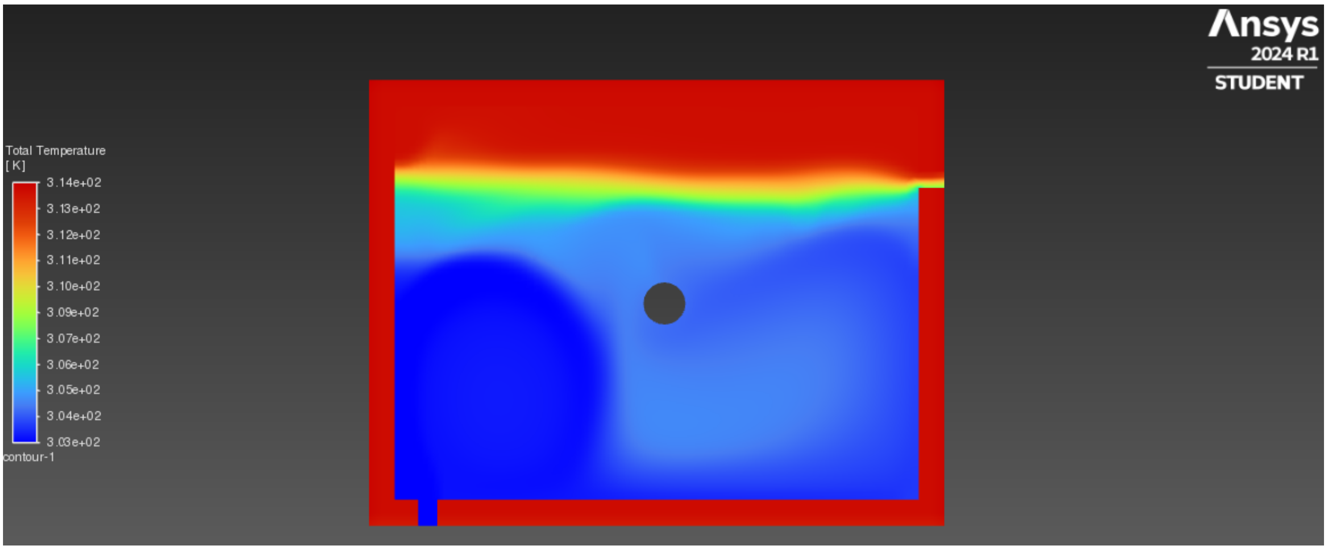

Figure 25: Temperature profile after first 180 seconds.

We simulated the model for 180 more seconds and the room was almost fully cooled as shown in figure 26

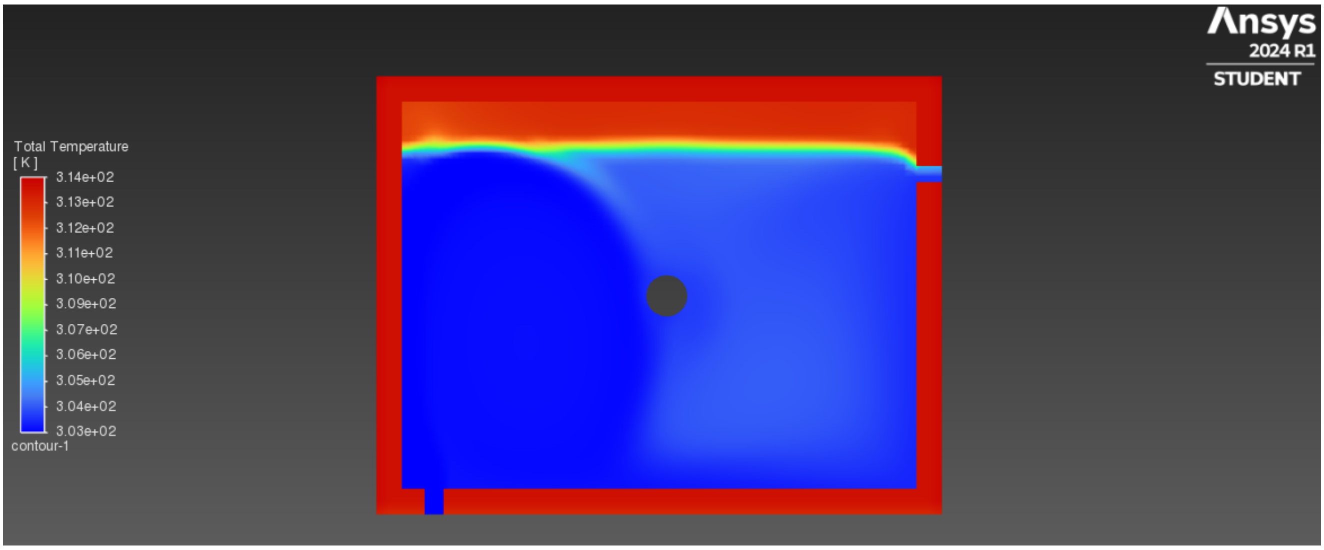

Figure 26: Temperature profile after first 360 seconds.

As seen in the above temperature contours, the room is cooled after flowing cool air into it for around 6 minutes. We also computed the inlet airflow rate to have an estimate of the energy required for the cooling.

```
Console

  Reading results.
Parallel variables...
Done.

                 Volume Flow Rate              [m^3/s]
-------------------------------- --------------------
                            inlet          0.073360401
```

Figure 27: Volume flow rate at inlet.

In order to carry away the majority of the heat from a residential room, we need a flow rate of 0.07 m^3/s for 6 minutes.

4 Results and discussions

In section 3, we first studied how termite mounds regulate the temperature inside through natural and forced convection. We then implemented the forced convection techniques in a residential room considering all the incoming heat sources. We found out that in order to cool a residential room, we would require a flow rate of 0.07 m^3/s of air at 303K. Earth Air Tunnel system is a passive cooling and heating technique can be used to regulate the temperature.

While analyzing of Eastgate builing,it is found that Passively cooled buildings uses only 10 percent of the energy needed by a similar conventionally cooled building.When actively cooled, the Centre consumes 35 percent less energy to maintain the same temperature as a conventionally cooled building.Earth Air Tunnel system is used to lower the temperature in day time and warmer in the night time.

The Earth Air Tunnel (EAT) system is a passive cooling and heating technique can be used in building design to reduce energy consumption. It involves the use of underground tunnels or pipes to pre-condition fresh air before it enters the building's ventilation system.

How it works:

1.Underground Tunnels or Pipes: Buried underground, these tunnels or pipes draw outdoor air into the building.

2.Temperature Exchange: As the outdoor air travels through the underground tunnels or pipes, it exchanges heat with the surrounding soil. In summer, the soil is cooler than the outdoor air, so it helps to cool the incoming air. Conversely, in winter, the soil is warmer, so it helps to warm the incoming air.

3.Pre-conditioned Air: The pre-conditioned air is then introduced into the building's ventilation system, reducing the need for mechanical cooling or heating.

The Earth Air Tunnel system takes advantage of the relatively stable temperature of the earth below the frost line, which remains cooler than the outdoor air in summer and warmer than the outdoor air in winter. This helps to regulate the temperature of the incoming air, resulting in energy savings and improved indoor comfort, making it a highly recommended solution for sustainable building design.

To store air underground,atrium's are used.An atrium ia an effectively store cool air by utilizing its design, ventilation, thermal mass, and strategic use of materials. The basic principle behind storing cool air in an atrium is to create a space that can capture, retain, and gradually release cooler air, thereby regulating the temperature within the building. To achieve this, high thermal mass materials such as concrete, stone, or brick are commonly used to construct the walls and floors of the atrium. These materials have the ability to absorb and store heat during the day and release it slowly at night, helping to maintain a more stable temperature. Ventilation is crucial, with windows, vents, or louvers positioned at the top and bottom of the atrium to allow for natural airflow. This allows cool air to enter the atrium while warm air escapes, aiding in temperature regulation. Additionally, shading devices like awnings or overhangs can prevent excessive sunlight from entering the atrium during the hottest parts of the day. The atrium's design and orientation, along with the incorporation of water features for evaporative cooling, further enhance its ability to store cool air effectively.

5 Conclusions

Based on 3, it can be concluded that the temperature inside the mound gradually increased from 303k at the bottom to 317.5k at the top before a room-like structure was created inside it. However, after the creation of the room,the temperature varied from 303k to 312.8k. This indicates that the cooler area expanded while the hotter region contracted. Therefore, having more room-like structures inside the mound can help maintain a balanced temperature.This adjustment not only improved the thermal behavior within the mound but also demonstrated the impact of adding a room on temperature distribution, highlighting cooler regions and concentrating heat towards the uppermost section.

When a heat is source is introduced into the mound,air inside the room and the hot air moves upwards,this is because of density difference(natural convection).In the final case of analytical analysis,implementing forced convection is done,resulted in lowering the room temperature.It can be concluded that using forced convection and chimney helps in maintaining lower temperature.

In section 3.3, We can observe how the temperature varied using ventilator at the top and cooler air from the ground,which is basically Earth Air Tunnel mechanism.Therefore,The Earth Air Tunnel (EAT) system is a highly effective passive cooling and heating technique for energy-efficient building design. By utilizing the stable temperature of the earth below the frost line, EAT systems pre-condition outdoor air, significantly reducing the energy demand for cooling and heating within buildings. Implementing the Earth Air Tunnel system not only enhances energy efficiency but also

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