# Fluid Flow and Heat Transfer in Human Metabolic processes

Group-F

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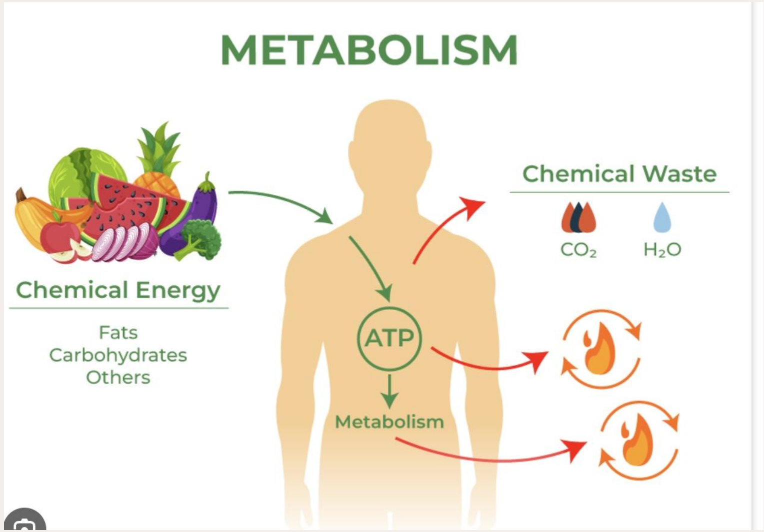
# Introduction

- Fluid flow and heat transfer are essential process for maintaining homeostasis in the human body.
- The human metabolic process is a complex and vital system responsible for converting nutrients into energy, maintaining temperature, and removing waste products.
- Metabolic processes generate heat, which needs to be efficiently dispersed by body to maintain it’s temperature.
- The human circulatory system with its network of blood vessels serves as a primary conduit of heat transfer.
- The primary mode of heat transfer from human body are conduction, convection, radiation and evaporation.

# Metabolism

- Metabolism is the set of chemical processes within an organism that maintain life. It involves anabolism (building complex molecules from simpler ones, requiring energy) and catabolism (breaking down complex molecules into simpler ones, releasing energy).
- Metabolism is crucial for energy production, growth, repair, and the overall functioning of living organisms.



# How Body Provides Energy for Work?

## Physical Work

- Muscle Contraction → Heat Generation
- Metabolism → Anaerobic & Aerobic Processes
- Fluid Flow → Adequate Blood Flow → Oxygen & Nutrients
- Heat Transfer → Dissipation of Excess Heat

## Cognitive Work

- Brain Metabolism → Increased Metabolic Rate → More Energy
- Neurovascular Coupling → Nutrients & Oxygen to the Brain
- Thermoregulation → Maintaining Optimal Brain Temperature
- Heat Transfer → Dissipation of Excess Heat

- **Physical Work**: When engaged in physical activities such as running, lifting, or any form of exercise, the body's energy production mechanisms come's into play. Here's a breakdown of these processes:
- **Muscle Contraction:** Physical work involves muscle contractions, which generate heat due to friction between muscle fibers.
- **Metabolism:** Energy for physical work primarily comes from two metabolic processes anaerobic and aerobic metabolism.
- **Fluid Flow:** Adequate blood flow is essential to deliver oxygen and nutrients to working muscles.
- **Heat Transfer:** Excess heat generated by muscle contractions and metabolism is dissipated through heat transfer mechanisms.These mechanisms help regulate body temperature during physical exertion.

- **Cognitive Work**: Energy provision for cognitive work, such as thinking, problem-solving,  is equally vital. Here's how the body ensures energy for mental activities:
- **Brain Metabolism:**  During cognitive work, the brain's metabolic rate increases, requiring more glucose/energy for optimal function.
- **Neurovascular Coupling**:  It ensures that the brain receives the necessary nutrients and oxygen to support cognitive processes.
- **Thermoregulation:** The brain's temperature must be maintained within a narrow range for efficient cognitive function. Heat transfer mechanisms help dissipate excess heat generated by increased brain activity.

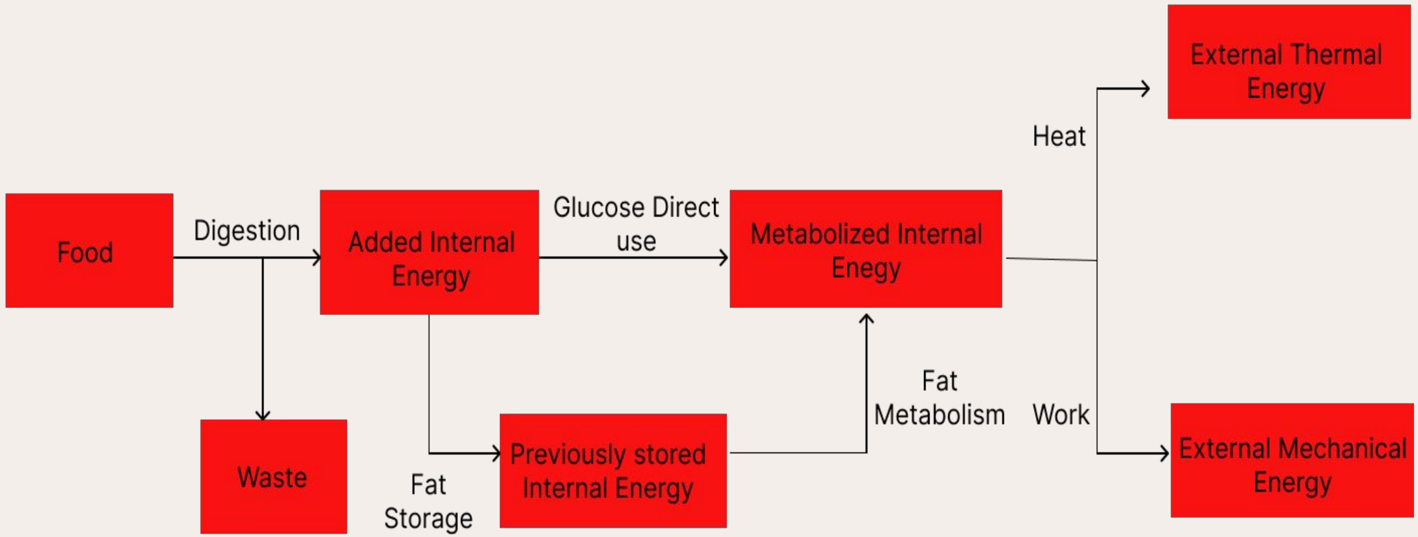
# Energy Conservation in Human Body

- Most of the chemical energy stored in food ends being stored as thermal energy in body. The difference between rate of evolution of this thermal energy and loss of energy through heat flow process determines if body's temperature remains constant.
- The human body can be analyzed as a heat engine whose performance is evaluated by principles of  conservation of energy.
- The engine operates on chemical energy from food which is oxidized and reorganized into specialized energy chemicals (glucose, amino acids. etc) for use in the body. Ultimately these chemicals are converted into energy to help body to (circulate blood, respire, walk etc) and some converted energy is lost due to temperature difference of body and environment.
- (Food energy into the body) = (Internal energy added) + (Chemical energy in waste)

# Energy Conservation in Human Body

- Internal energy added is stored largely in the form of glucose ,fats , amino acids etc., plus some thermal energy from the digestion process, is transformed in the metabolic processes of cell respiration. The internal energy stored is called metabolic energy.
- Metabolic energy = Thermal energy retained + Internal energy output
- Since the temperature of body fairly remains constant so thermal energy retained is equal to 0J.
- So by first law of thermodynamics : Internal energy outputted= Mechanical energy required + Heat Transfer.
- Metabolic rate= Mechanical power required by the body + Rate of heat transfer.
- Metabolic rate is the rate at which our bodies convert the chemical energy in glucose or fats into energy forms useful for body operation. The heat transfer rate is the rate at which excess thermal energy is transferred to the body’s environment. The mechanical power represents the rate at which mechanical work is being done by the body like walking , respiring, circulating blood etc.

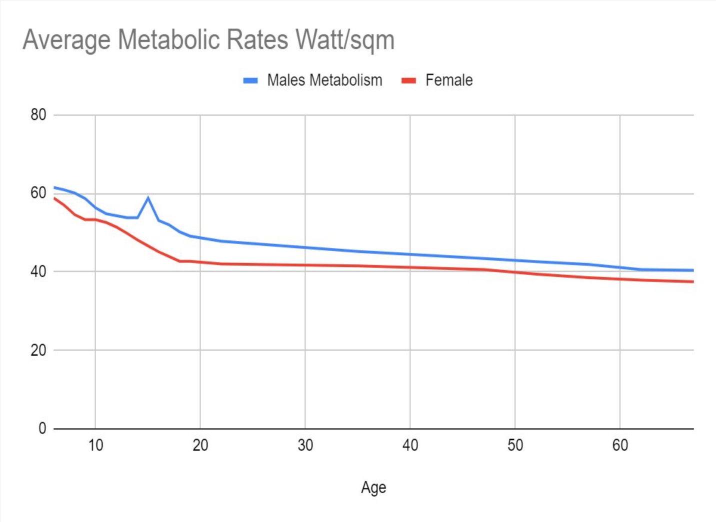
# How chemical energy from food is converted to usable Energy?



# Metabolic Rate

- Basal Metabolic Rate, or BMR, is the amount of energy our bodies need to maintain essential physiological functions at rest – think of it the minimum calorie requirement to keep your body functioning while you're not doing anything.

- There are two primary methods to measure this vital function:
  - **Direct Calorimetry**: This involves placing an individual in a specialized chamber to precisely measure the heat they emit, thereby gauging their energy expenditure.
  - **Indirect Calorimetry**: Here, we analyze the ratio of carbon dioxide produced to oxygen consumed to infer metabolic rate. This reflects respiratory gas exchange, which correlates with metabolic activity.




Metabolic rate = Rate of heat exchange + Mechanical power

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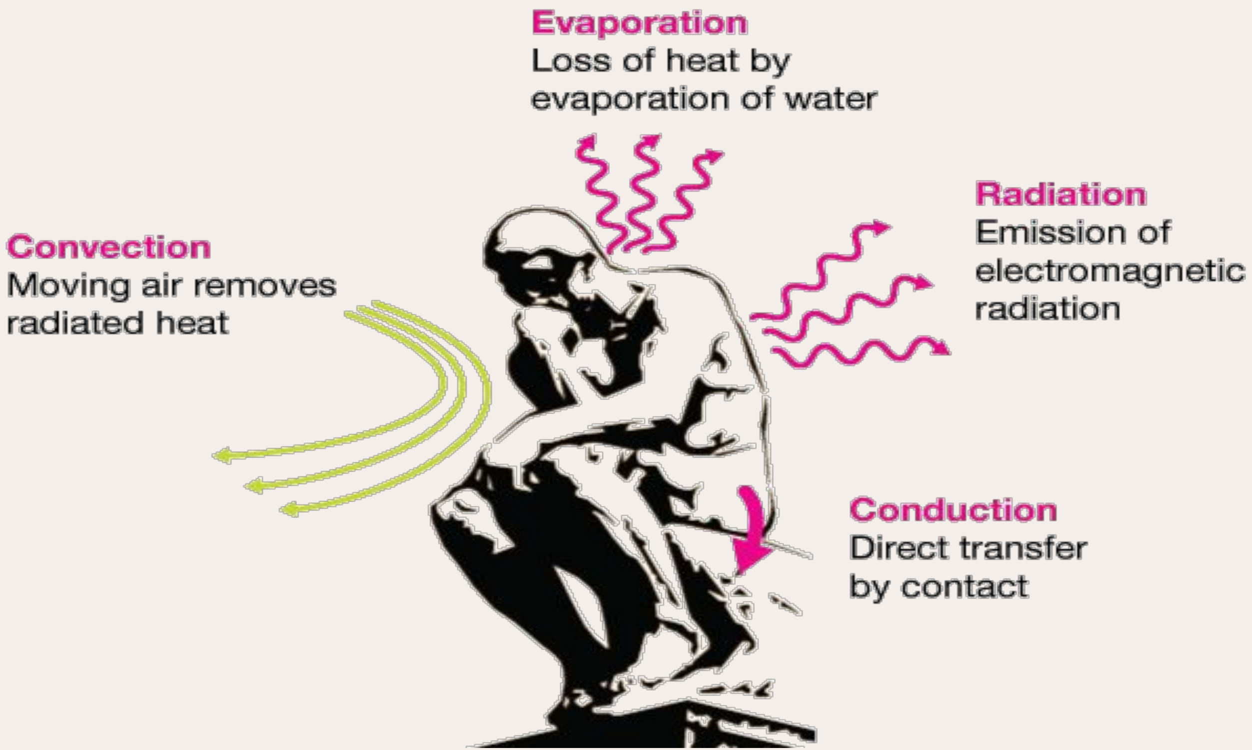
# Heat losses through body

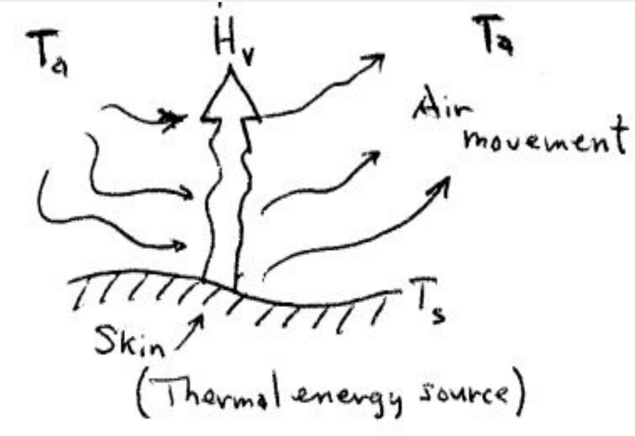
| | | |
|---|---|---|
| 01 | Convection | This involves the transfer of heat via air or fluid movement. As air or wind moves across the skin, it carries away heat from the body's surface, contributing to cooling |
| 02 | Conduction | Heat is transferred from the body to objects or surfaces it comes into direct contact with. Heat can also be gained through conduction from warm objects. |
| 03 | Radiation | The body emits infrared radiation, transferring heat from the body to the surrounding environment. This is a significant method of heat loss, especially in cold conditions. |
| 04 | Evaporation | Sweating is a crucial mechanism for heat loss. When sweat evaporates from the skin's surface, it absorbs heat, cooling the body. |
| 05 | Respiration | When you breathe, you exchange warm, moist air for cooler, drier air. This helps regulate body temperature by releasing some heat. |
| 06 | Vasodilation | Blood vessels near the surface skin can dilate,allowing more blood to flow closer to the skin,which enhances heat transfer to the environment. |

# Heat losses through body



# Convective Heat Loss From Human Body

- Convection is a vital mechanism of heat transfer. It occurs when air is actively circulated over the body surface or with natural air movement. This process enables the exchange of thermal energy between the body and the surrounding environment.
- Q = Kv * A * (Ts - Ta), where Q is heat flow, Kv is the convection coefficient, A is the body's surface area, Ts is skin temperature, and Ta is ambient air temperature.
- The convection coefficient, Kv, is determined experimentally and depends on factors like interface nature, air speed, density, and viscosity.
- About 30% of total heat flow from the body occurs through convection under normal indoor conditions.

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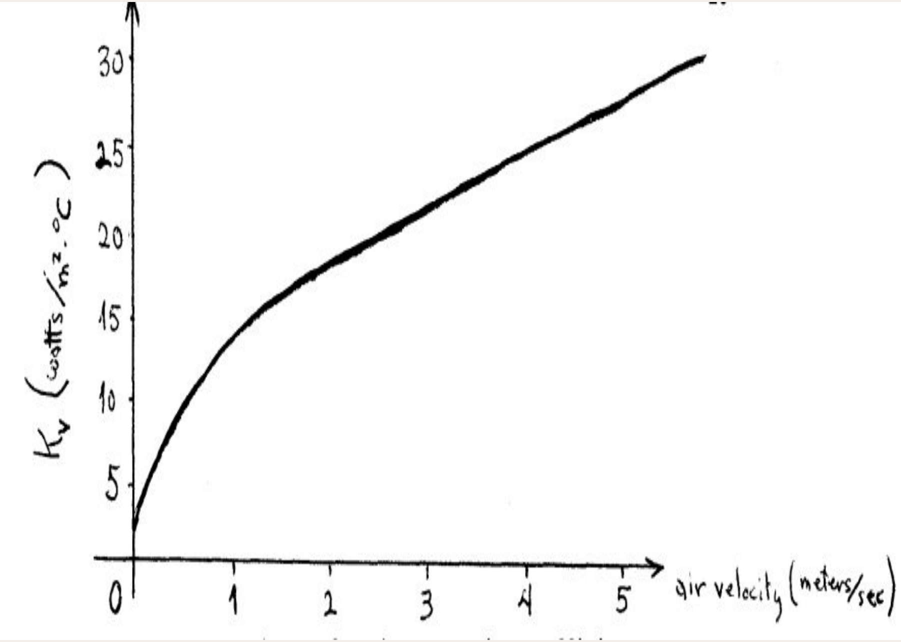
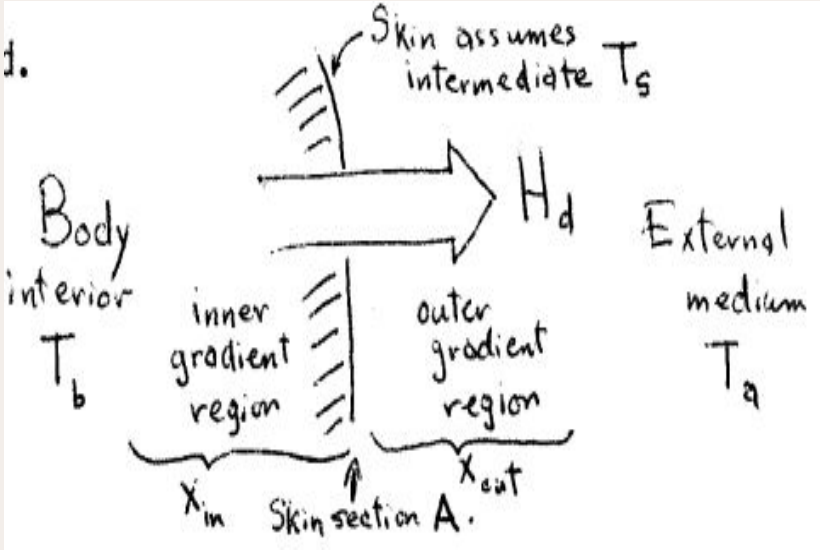
# Variation of Convective Heat loss coefficient with air velocity

- Graph of convection heat coefficient and velocity of air shows that increased air speed leads to higher convection coefficient.
- Increased air speed, as seen in activities like cycling, leads to a higher proportion of thermal energy being lost through convection.
- Body hair discourages body surface convection and serves as an evolutionary adaptation for regulating thermal energy exchange.



# Conduction Heat Loss From Human Body

- Conduction is a form of heat transfer which takes place when there exists a difference of temperature and a suitable medium between two objects. The rate of heat flow, Hd, for thermal conductivity can be written as Hd = Kd.A.(dT/dx) where, A is the cross sectional surface area Kd is Thermal Coefficient of Conductivity.
- Skin is acting like a layer between the interior body and surrounding environment.
- Thus, the heat flow must go through two different materials in succession, and two expressions of above equation is solved simultaneously.

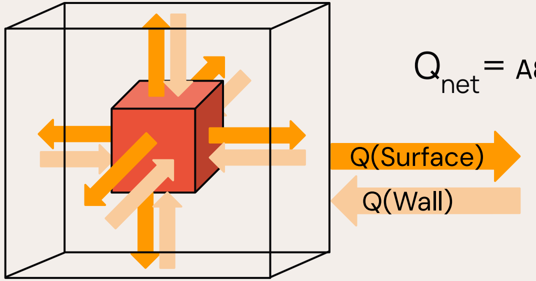


# Conduction Heat Loss From Human Body

- Let Ts be the skin temperature, Tb be the interior body temperature, and Ta be the temperature of the surrounding material. Further, let Xin be the (interior) skin thickness and Xout be the (exterior) thickness of the heated region which occurs in the vicinity of the skin surface.
- First for the body-skin conduction and then for the skin-environment conduction, we have that for the definite section of skin of area A, $Hs = (Ks.A.(T b - T s))/Xin$ ,where Ks is the coefficient of thermal conductivity of the skin and $Tb-Ts = \Delta Tin$.
- $Hm = (Km.A.(Ts - Ta))/Xout$ where Km is the coefficient of thermal conductivity for the surrounding material and $(Ts - Ta) = \Delta Tout$.
- If one considers only a definite section of skin, then the same heat flow must occur, successively, through both. Thus, $Hs = Hm = Hd$ and $Xin = Xout = \Delta X$.
- Eliminating the common Ts from these equations we obtain $Hd = ((Ks.Km.A)/(Ks+Km)).(\Delta T/\Delta X)$, where $\Delta T = Tb - Ta$.
- The rate of heat flow across the skin interface in proportional to the total temperature drop from the interior body temperature to the temperature of the surrounding material.
- The coefficient of thermal conductivity of still air is approximately $2.4 \times 10^{-4}$ watts/cm°C. This small conductivity restricts the rate of heat flow through the external layer Xout.

# Radiation Heat Loss From Human Body

Radiant energy emitted by a surface depends on its temperature(T) and nature.
Heat emitted by the surface is Q = $\varepsilon\sigma AT^4$.




$$Q_{net} = A\varepsilon(\sigma T_{body}^4 - \sigma T_{walls}^4)$$

The actual loss of energy by radiation depends upon the radiation absorbed by the skin as well as the radiation transmitted from the skin. If we consider a body in a room, the body radiates energy to the walls and the walls radiate energy to the body. So net heat $Q_{net} = A\varepsilon(\sigma T_{body}^4 - \sigma T_{walls}^4)$.

Human skin and ordinary clothing has a 98 percent absorptivity and emissivity properties for infrared heat radiation.

Most interior rooms also have high emissivity (above 95%). Thus $\varepsilon$ for both the body and room walls is approximately equal to one.

Radiation losses from the body contribute to about 44% of the total thermal energy lost.

# Evaporation Heat Loss From Human Body

- Evaporation is a process where liquid turns into gas. In the context of the human body, this usually refers to the evaporation of sweat from the skin or moisture from the lungs. This process requires heat, which is taken from your body, thus cooling you down.
- **Sweating:** When our body temperature rises, your sweat glands produce sweat, which is mostly water. As the sweat evaporates from your skin, it takes heat with it, cooling your body.We can sweat a maximum of 1 or 1.5 L/h. Given that 2.4 MJ is lost in the evaporation of 1L of water/sweat (for now we approximate them as the same), the power loss due to this:

$$\lambda \approx \left(\frac{2.4MJ}{L}\right)\left(\frac{1.5L}{h}\right)\left(\frac{1h}{3600s}\right) \approx 1000W$$

- **Respiration:** Moisture is also lost through the process of respiration. When you exhale, you release warm, humid air. As this moisture-laden air leaves your body, it carries heat with it.

# Evaporation Heat Loss From Human Body

The rate of evaporation, and thus the rate of cooling, depends on several factors:

- **Humidity:** The rate of evaporation increases with lower humidity. In high humidity, the air is already saturated with water vapor, so sweat doesn't evaporate as quickly.
- **Wind:** Wind or any kind of air movement over your skin can increase the rate of evaporation, enhancing the cooling effect.
- **Clothing:** Clothing can inhibit evaporation by trapping moisture. However, certain types of clothing, like those made from moisture-wicking fabrics, are designed to facilitate evaporation.
- **Body Surface Area:** The larger the surface area of the skin, the more space there is for evaporation to occur. About 600 - 900 ml of water evaporates from skin and lungs daily, resulting in water and heat loss.

# Conclusion

- Heat transfer from human body is necessary in order to maintain the temperature of human body and sustain life.
- Human body can be analyzed as a Heat Engine whose performance can be be evaluated by the principles of conservation of energy. The food we eat serves as a fuel to drive this engine. The food is converted into glucose, amino acids etc which can be breakdown to obtain energy.
- A part of this energy is used to carry out day to day activities of the boy and provide energy for carrying out physical activities.
- The extra energy remaining needs to be effectively transferred to the ambient temperature i.e. Environment in order to maintain the temperature of the body.
- Majority of heat transfer occurs through convection, conduction, radiation and evaporation.
- Equations for the heat transfer of the heat through this modes have been derived which helps in better understanding of these processes.
- The study of heat transfer in human body is important because it is further helpful in the field of medicine to understand diseases and how to cure those diseases. The effect of drugs/treatment of a particular disease on body's temperature is necessary to be studied to know how to dispose extra heat generated by the drug/treatment.

# References


- https://www.thermopedia.com/content/587/
- https://courses.lumenlearning.com/suny-ap2/chapter/energy-and-heat-balance/
- https://www.sciencedirect.com/topics/engineering/metabolic-heat
- https://en.wikipedia.org/wiki/Heat_transfer
- https://www.everand.com/book/282648556/Heat-Transfer-and-Fluid-Flow-in-Biological-Processes
- https://www.researchgate.net/publication/285431065_Heat_Transfer_and_Fluid_Flow_in_Biological_Processes
- https://www.scirp.org/journal/paperinformation.aspx?paperid=102327
- https://phys.libretexts.org/Bookshelves/College_Physics/College_Physics_1e_(OpenStax)/07%3A_Work_Energy_and_Energy_Resources/7.08%3A_Work_Energy_and_Power_in_Humans

# Contribution By Members

- **Priyanshu Singh(21ME30081):** Researched and wrote about Energy Conservation in Human Body and related mathematical equations , derived conclusion from the research of whole topic and made slides as well.

- **Abhinav Jain(21MF10001):** Researched and wrote about Metabolic Rate and plotted the comparison between male and female Basal Metabolic Rate.

- **Yash Foujdar(21ME30073):** Researched and wrote about the Conductive Heat Loss through Human Body and related mathematical equations.

- **Anik Dwivedi(21MF10007):** Researched and wrote about the Convective Heat Loss through Human Body covering its fundamental principles and HVAC systems.

- **Akshat Sharma(21ME30077):** Researched and wrote about the Radiation Heat Loss through Human Body covering its fundamental principles.

- **Akul Ahuja(21ME3EP02):** Researched and wrote about the modes of Heat Loss through Human Body and metabolism covering its fundamental principles.

- **Suman Das(21ME30065):** Researched and wrote about the Evaporation Heat Loss through Human Body covering its fundamental principles.

- **Ujjwal Gupta(21ME30069):** Researched and wrote about how body provides energy for different work and how this energy is transferred across the body.

# Thanks