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Application of Phase Change Material (PCM) in building envelope for Cooling

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Abstract: ***India is a hot climate country. A new study on climate change in India has confirmed a rapid rise in surface temperatures in the past 70 years. To get comfort and increase productivity use of Air Conditioning is also increasing in residential, commercial, institutional, public buildings etc. The electricity consumption is highest for Air Conditioner compare to other appliances. In India, about 71% of electricity consumed in India are generated by thermal power plants. Thus emissions of greenhouse gases and other pollutants due to burning of coal are increasing in India with the increasing demand for electricity. While buildings and development provide countless benefits to society, they also have significant environmental and health impacts. The construction and renovation of buildings uses precious natural resources. When in use, buildings are responsible for a significant proportion of all our carbon emissions due the energy consumption of its users. The growing concerns over the environmental impacts of buildings have led to increasing demands for more environmental friendly buildings and building materials. Thus it is now necessary to develop building in such a way that it has minimum negative impact on environment. To achieve this, building should be made by innovative materials and methods that are ecofriendly to the environment. In this study, number of case studies and literatures would be reviewed to rectify the several types of Phase Change Material (PCM) that can be used inside the building in such way that indoor air temperature might be reduced. First of all The desirable comfort conditions inside building and its factors such as body's heat loss & production, humidity, air movement, radiation etc. are evaluated. Than a 3D model of a typical building is created. Then model based study using simulation process in Revit software is carried out to evaluate the effect of Phase Change Material (PCM) on indoor temperature of the building and subsequently reduction in energy used by building can be determine. Based on the reports generated by the Energy Analysis using simulation, the cost comparison and reduction of emissions of Green House Gases (GHG) be also analyzed. This study will help to make energy efficient building by using innovative building materials such as Phase Change Materials (PCMs) with sustainable building approach.***

Keywords**: *Phase Change Material, Building envelope, passive cooling, Simulation, thermal property, carbon emission, Revit.***

I. Introduction:-

Phase change materials (PCMs) offer great potential as a latent heat energy storage technique to provide energy efficient systems in new and existing residential buildings. Due to their unique characteristic of high storage densities and latent heat properties, PCMs provide opportunities for greater energy storage in many applications for residential buildings. These applications include, but are not limited to, solar water heating, space heating/cooling, and waste heat recovery. Phase change material (PCM) in commercial buildings save energy by actively absorbing and releasing heat. PCMs help maintain comfortable building temperatures with the potential to reduce peak sensible cooling loads and annual energy consumption in California and western climate zones with enough variation in day and night time temperatures. PCMs maintain a near-constant temperature within the conditioned space while undergoing a phase change. Melting temperatures typically range from 70 to 80°F in building cooling applications. This temperature range is varied, based on application, to minimize the heating and cooling loads for the building while maintaining the comfort of its occupants. PCMs can be installed as follows: Packaged in microencapsulated or microencapsulated cells for application in interior wall construction (adjacent to insulation and wallboard), between attic joists, above ceiling panels in a drop ceiling, inside the wallboard, ceiling panels, and floor tiles.

Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system. A simulation is an approximate imitation of the operation of a process or system. The act of simulating first requires a model is developed. This model is a well-defined description of the simulated subject, and represents its key characteristics, such as its behavior, functions and abstract or physical properties. The model represents the system itself, whereas the simulation represents its operation over time.

Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video games. Often, computer experiments are used to study simulation models. Simulation is also used with scientific modelling of natural systems or human systems to gain insight into their functioning as in

economics. Simulation can be used to show the eventual real effects of alternative conditions and courses of action. Simulation is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist.

Key issues in simulation include the acquisition of valid source information about the relevant selection of key characteristics and behaviors, the use of simplifying approximations and assumptions within the simulation, and fidelity and validity of the simulation outcomes. Procedures and protocols for model verification and validation are an ongoing field of academic study, refinement, research and development in simulations technology or practice, particularly in the field of computer simulation.

Energy simulation can help to analyze the movement of energy in, out, and through the rooms and volumes in a building model. This information can help designers make better informed, cost-effective decisions that improve the performance and reduce the environmental impact of buildings. Whole building energy simulation measures expected energy use (fuel and electricity) based on the building's geometry, climate, building type, envelope properties, and active systems (HVAC & Lighting). It takes into account the interdependencies of the building as a whole system. To perform whole building energy simulation for Revit models, Energy Analysis for Autodesk® Revit® is useful. It is Autodesk's core whole building energy simulation engine. This flexible cloud-based service uses the DOE2 simulation engine. It allows to run building performance simulations to optimize energy efficiency and to work toward carbon neutrality earlier in the design process. It helps extend the ability to design high performance buildings at a fraction of the time and cost of conventional methods.

Use Energy Analysis for Autodesk® Revit® to perform energy simulation for conceptual forms and detailed architectural models created in Revit. The simulation results can be used to understand building energy use. Then iterate the designs to improve their sustainability ratings. The energy model created from the Revit building model can be displayed in Revit, so anyone can view and validate the energy model used for analysis. The energy model can also be exported to third-party applications for further analysis in a variety of common formats: gbXML, DOE2, and EnergyPlus.

II. Research Methodology:-

In this study, following research had been adopted as shown in figure – 1

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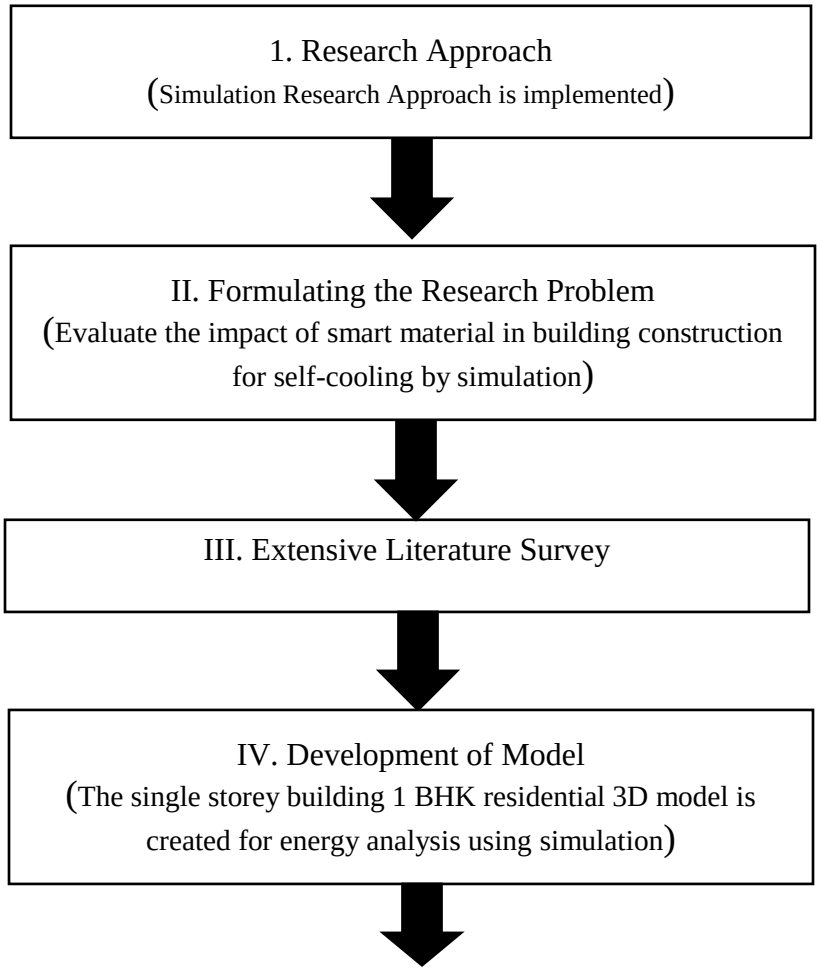

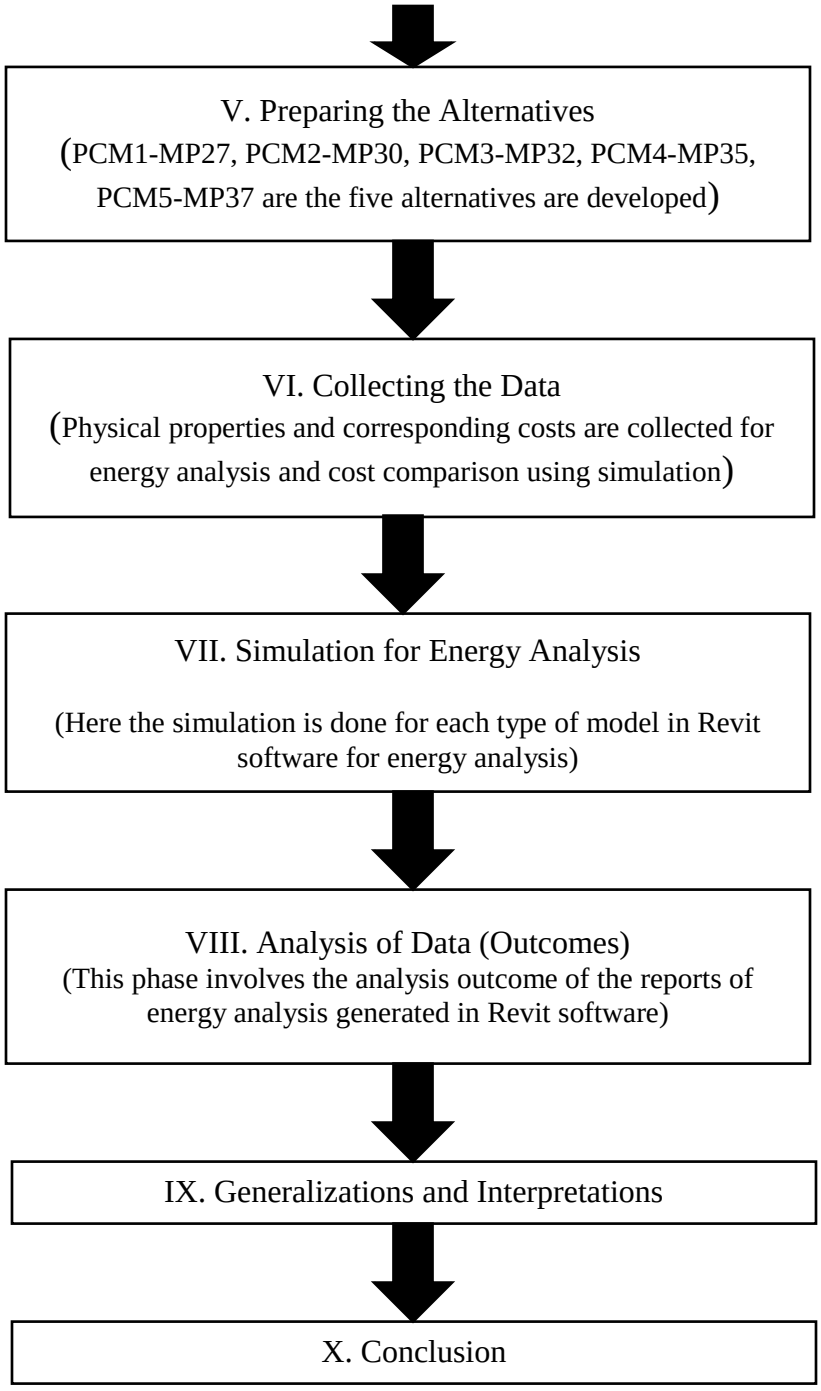

Figure 1 – Flowchart of Research Methodology

III. Analysis and Discussion:-

In this section the outcomes derived from the energy analysis report that generated in Revit software for all types of model using simulation is analyzed in context of utilization and corresponding reduction of energy in the alternative models. Than the subsequently reduction in coal and oxygen utilization and reduction in air pollutants caused by burning the coal are analyzed in different phases.

The annual energy consumption in the form of electricity in kWh (units) for each model is summarized in table 1 and figure 2 below.

Table 1 - Energy utilization and its Reduction in different Models

Types of Model	Energy utilization (Units) (Annual)	Reduction In Energy utilization (Units) (Annual)
Basic	**18626**	**-**
PCM1-MP27	**18152**	**474**
PCM2-MP30	**18206**	**420**
PCM3-MP32	**18163**	**463**
PCM4-MP35	**18089**	**537**
PCM5-MP37	**18057**	**569**

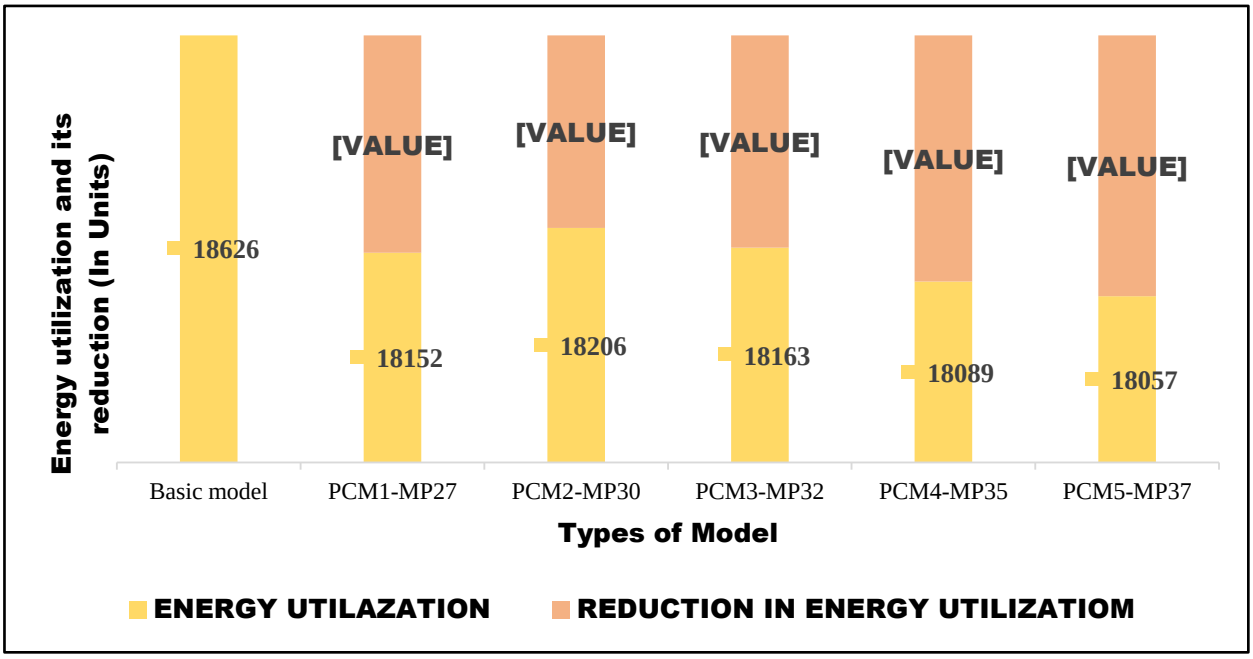

Figure 2 - Energy utilization and its Reduction in different Models

❖ **Analysis Phase – 1 (Annual Energy Consumption and Cost)**

This phase is deal with the utilization and corresponding reduction in energy cost annually in alternative model with compare conventional model. The annual energy consumption is carried out by the 3 hour occupancy for conventional model and 8 hour occupancy for alternative model. The following Table – 2 shows the summary of Energy Utilization and its reduction along with Utilization of Energy cost and corresponding Savings in Energy costs in different models.

Table - 2:- Summary of Analysis Phase - I

Types of Model	Energy utilization (Electrical Units) (Units)	Reduction In Energy utilization (Units) (Annual)	Utilization of Energy Cost (INR) (Annual)	Saving In Energy Cost (INR) (Annual)
Conventional	6192.0	-	30128.55	-
PCM1-MP27	2268.0	3924.0	11034.96	19093.59
PCM2-MP30	2278.8	3913.2	11087.72	19040.83
PCM3-MP32	2268.0	3924.0	11034.96	19093.59
PCM4-MP35	2257.2	3934.8	10982.49	19146.06
PCM5-MP37	2246.4	3945.6	10929.88	19198.67

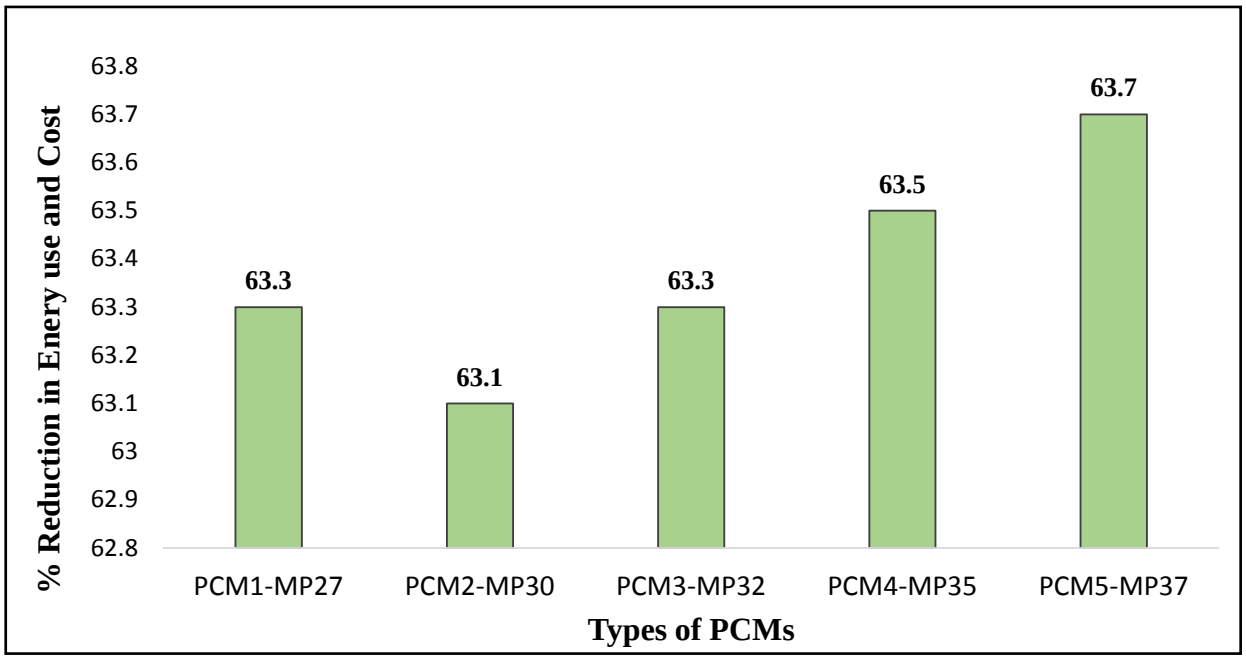

Figure 3 - Percentage Reduction in Energy Consumption in Different Models

❖ **Analysis Phase – II - Cost Comparison (Using Life Cycle Cost)**

The cost comparison between the conventional model and PCM5-MP37 which has the lowest annual energy cost among all the alternatives is carried out using Life Cycle Cost (LCC) method. Life cycle costing is an economic estimation method that evaluates the entire cost of a building over its operating life, including initial capital costs, maintenance costs, operating costs and the ultimate disposal of the asset at the end of its life.

However, for the models to be compared, having same initial cost and maintenance costs and disposal cost of the asset at the end of its life. Thus, in this analysis, the operating cost will only be considered. Here, the Life Cycle for both the model is 30 years be considered.

(A) The Life cycle cost of conventional model

The Life cycle cost of conventional model is the operating cost during the its life cycle of 30 years. Therefore the operating cost of the conventional model is 30128.55*30 = 903856.5 INR (A)

(B) The Life cycle cost of PCM5-MP37

The Life cycle cost of conventional model is sum of the operating cost during the its life cycle of 30 years and the cost associate with PCM.

(a) The cost associate with 0500- Q37 Bio-PCM

The cost associate with 0500- Q37 Bio-PCM is the sum of cost of same and the installing cost of the same.

(i) The Market price of 0500- Q37 Bio-PCM is 2500 INR per square meter. The crated model in this study have 92.92 square meter that can be considered as 93 square meter.

Thus, the cost of 0500- Q37 Bio-PCM to be used in the model is 2500*93 = 232500 INR.

(ii) The installation cost to install this curtain type of material on the interior surface of the building envelope is around 5000 to 8000 rupees. Let take approximately 7500 rupees.

Thus the total cost associated with PCM is 232500 + 7500 = 240000 INR (a)

(b) The energy cost associate with PCM5-MP37 model

The energy cost of PCM5-MP37 model is the operating cost during the its life cycle of 30 years. Therefore the operating cost of the conventional model is 19198.67*30 = 575960.10 INR (b)

Thus the total life cycle cost of PCM5-MP37 model is (a) + (b) = 815960.1 (B)

Thus it can be concluded that the saving in cost using PCM5-MP37 in building envelope is about 87896.4 INR for of life cycle period of 30 years.

❖ **Analysis Phase – III Reduction (Coal and Oxygen Utilization)**

The following table – 3 and Figure - 4 shows the summary of Phase – II as it contains the annual reduction in Energy utilization, Coal Utilization and Oxygen Burnt respectively.

Table 3 - Summary of Analysis Phase - II

Types of Model	Reduction In Energy utilization (In Units) (Annual)	Reduction In Coal Burnt (In kg) (Annual)	Reduction In Oxygen Burnt (In kg) (Annual)
Basic	-	-	-
PCM1-MP27	3924.0	15256512	25020679.68
PCM2-MP30	3913.2	15214521	24951814.44
PCM3-MP32	3924.0	15256512	25020679.68
PCM4-MP35	3934.8	15298502	25089543.28
PCM5-MP37	3945.6	15340492	25158406.88

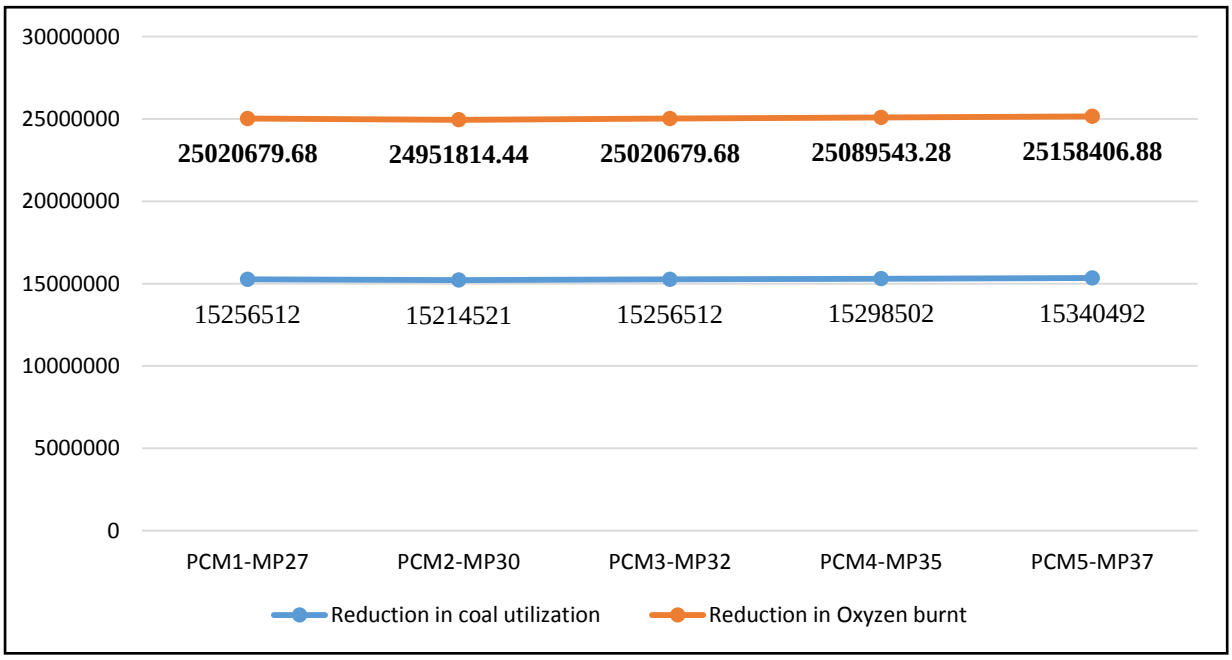

Figure 4 - Reduction in Coal Utilization and Oxygen Burnt

❖ **Analysis Phase – IV (Reduction in different Air Pollutants)**

In this phase, the quantity of different Air Pollutants such as CO2, SO2, NO and CO emission that caused by burning of coal is carried out.

As we know, the burning of 1 kg of coal cause 1.62kg, 15.19g, 3.71g, 0.76g of CO_2, SO_2, NO, CO emission respectively. Therefore the reduction of these air pollutants in each alternative modes can be summarized annually, monthly and daily basis.

The following table – 4 shows the reduction in CO_2, SO_2, NO and CO Emission on Annual, Monthly and Daily basis in different Models

Table 4 - Summary of Analysis Phase - IV

Types of Model	Reduction In CO_2 emission (In kg) (Annual)	Reduction In SO_2 emission (In kg) (Annual)	Reduction In NO emission (In kg) (Annual)	Reduction In CO emission (In kg) (Annual)
Conventional	-	-	-	-
PCM1-MP27	24715549.44	231746.41	56601.65	11594.94
PCM2-MP30	24647524.02	231108.57	56445.87	11563.03
PCM3-MP32	24715549.44	231746.41	56601.65	11594.94
PCM4-MP35	24783573.24	232384.24	56757.44	11626.86
PCM5-MP37	24851597.04	233022.07	56913.22	11658.77

IV. Conclusion:-

A simulation is an approximate imitation of the operation of a process or system. The act of simulating first requires a model is developed. This model is well defined description of the simulated subject and represents its behavior, functions and abstract or physical properties. The model represents the system itself whereas the simulation represents its operation over time.

Simulation have several advantages such as it can forecast the result under uncertainty, it may able to answer many questions at once. It requires low data to model, it serves easy what if scenario analysis. Thus, the simulation approach can be considered as innovative approach.

In this study, simulation is used to rectify the effect of various types of Phase Change Materials (PCMs) in building envelope in context of energy savings and thermal comfort criteria's. A model of 1BHK residential building is created that simulated one time with conventional building material without Phase Change Material (PCM) and simulated again five times with five different types of Phase Change Materials (PCMs) as interior building material. The reports generated by the simulation are analyzed and valuable findings are rectified. On careful analysis, we observed followings.

1. There is direct relation between thermal comfort in building envelope, building energy consumption and emissions of Green House Gases (GHG) in hot and dry climate region.
2. The human thermal comfort greatly depends on air temperature, humidity, radiation, air movement and interior material in building envelope.
3. The Autodesk Revit can be used to carry out whole building energy simulation for energy analysis as it uses the DOE2 simulation engine.
4. The best alternative among the five models is PCM5-MP37 as it saves 569 Units of electrical energy as per the Energy Analysis reports generated by simulation.
5. The reduction in energy utilization and its corresponding cost is 63.3 %, 63.1 %, 63.3 %, 63.5 % and 63.7 % in PCM1-MP27, PCM2-MP30, PCM3-MP32, PCM4-MP35 and PCM5-MP37 respectively.
6. The saving in building energy cost using PCM5-MP37 (the best alternative) in building envelope is about 87896 INR for 30 years of life cycle period.
7. There is huge amount of reduction in coal utilization using all types of PCMs considered in this study. Reduction in coal utilization ultimately reduce the emissions in different air pollutants that causing from coal burning.

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