Optimization of energy and exergy ratio by mineral insulator in a room

Morteza Adibkia[1*], Abbas Salemi Tajjarod[1], Mohammad Adibkia[2]

1- Department of Chemical Engineering, College of Chemical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran.
2- Department of Management, Abadan Branch, Islamic Azad University, Abadan, Iran
* P.O.B. 6315977439 Mahshahr, Iran, Morteza.Adibkia@gmail.com

Abstract
Limited energy resources and the need for saving them necessitate the use of the suitable paint to prevent energy waste in various buildings and industries. Ceramic insulations are of particular importance due to the use of ceramic microparticles of high thermal resistance, low absorption coefficient, and easy operation and implementation. To assess the precise number, we consider a three-dimensional chamber with real dimensions and different boundary conditions. The air inside the chamber is considered as incompressible. Using Boussinesq approximation and given the low Reynolds number, modeling and simulation were done using k-ε turbulence model (LRN), Do radiation model, and Piso algorithm. In this research, new methods such as TPA technique, Exergoeconomic calculations, and exergy rate were used for economic calculations and exergoenvironmntal factor is used for environmental impacts. The results indicate that exergoeconomic factor varied in the range of 45% to 85% On average, exergy ratio was about 1.5 kw and the efficiency had an average value of 90%. Finally, it was shown that the use of ceramic microparticles in the external wall of buildings saves energy up to 18%.

Keywords
Optimization, exergoeconomic, exergoenvironmntal, ecological assessment, ceramic microparticles, energy saving

1- Introduction

Energy is one of the most important economic indexes and its supply is regarded as a basic government tool. Due to the reduction in energy reservoirs and increase in energy consumption, optimizing the energy use and reducing its losses are of great importance. One of the things that has recently been considered is using the technology of mineral insulations combined with paint for optimization of energy consumption. Due to the high heat losses from the walls and ceilings of buildings, attention must be paid to the optimization of the transmission of energy in buildings and industrial sites. Using mineral coatings, the amount of received heat and heat loss in buildings can be decreased by reducing the heat absorbed by the walls, ceilings, and roofs of buildings [1]. By creating a radiant barrier in paint and converting it to a heat reflector, paints and mineral additives are regarded as the third-generation of building insulations [2]. In building paints, hollow spherical ceramic particles can be used as thermal barriers with very low heat transfer coefficient. These particles are extremely light as a result of which the obtained paint is very light and has much lower weight and volume compared to other insulations [3]. Insulation paint directly sticks to the material and protects it. This coating is hydrophobic which prevents moisture as a corrosion factor from reaching the surface of metals. This coating completely covers the metal surface. Thus, there will be no microscopic space for the penetration of oxygen [4]. Papendik studied mineral coatings and showed that adding insulations and ceramic thermal barriers to common paints reduces the heat flux of these paints by more than 37% [5]. Li examined energy savings using ceramic particles in interior walls. He showed that when the outside temperature and the temperature of rooms are respectively kept at 0℃, the use of inorganic particles leads to reduction of more than 12% in energy consumption [6]. Donald et al. showed energy savings with the use of ceramic particles by thermograpghy experiments [7]. Hui et al. demonstrated that the walls with ceramic particles have a temperature difference of 7.4 °C compared to the walls without this cover [8]. Synnefa et al. demonstrated that additive ceramic particles of paint reduce the emission factor and thermal dissipation [9]. In another study that was conducted at Nevada University, it was shown that the use of ceramic particles reduces the building energy consumption by 50% compared to ordinary paints [10]. Using numerical modeling of insulation parameters and cost for improving energy efficiency in residential buildings, Aksoy et al. found that the use of thermal insulation leads to energy consumption of up to 78% [11]. Arvind et al. showed that by combining chemical additives based on ceramic microparticles, they can improve the strength and durability of building paints with densities lower than 1350 kg/m3 [12]. In recent years, there has been considerable effort to harnesses the power of computer for designing air conditioners and studying the phenomena governing it. By studying and thermal modeling of a room with the use of inverse analysis, Li et al. could provide an accurate estimation of the temperature gradient in the boundary layer [13]. Marino et al. analyzed energy consumption based on paint characteristics of buildings. They found that on this basis, the amount of annual savings will be equal to 21. [14]. Temperature of buildings, whose outer surfaces are white or whitish and have building materials with medium thermal resistance and capacity as well as relatively small windows equipped with awnings, is lower than the outside temperature. However, buildings with dark colored outer walls or large windows without awnings have a warmer indoor temperature during day. Hence, the importance of ventilation in changing the inside air of a building depends on the quality of its exterior walls as well as the window size and quality of awnings. when a room is not ventilated, the air inside the room is heated to the temperature of its surrounding inner surfaces. And the indoor air temperature will fluctuate around the mean temperature of the external surfaces of room walls. The external air temperature fluctuation depends on the capacity and thermal resistance of the materials used in walls as well as temperature fluctuations of outer wall surfaces [15]. Actual states of the air and heat transfer in a residential room coated with ceramic microparticles have a three-dimensional nature. Accordingly, the aim of this research was the review and detailed comparison of the heat flux and economical energy consumption in three-dimensional coordinates with computational fluid dynamics. For study of this system, after a brief description of it, a room was considered as a three-dimensional chamber and its exergy and economic parameters were obtained using numerical simulation and modeling. In this study, performance of ceramic microspheres insulations was evaluated by analyzing and comparing the energy, exergy ratio, efficiency, exrgoeconomic and exergoenviromental indexes, and total cost as well as calculating the percentage of reduction in energy consumption. As well, using TPA technique, ecological assessment was done on insulations of the room external walls.

Table 1 .Physical and chemical properties of the spheres[16]

Microspheres	Average diameter (μm)	Solid properties				Aqueous extract		
		composition (% w/w)		Density (g/ml)	Oil absorption (ml/g)	Soluble material (mg/g of sphere)	Conductivity (μS/cm)	PH
		SiO_2	Al_2O_3					
LCM-121	100	53.6	38.6	3.2	0.293	1.6	128	6.68

2- Methodology

2-1 Problem description and numerical method

In this study, air flow and heat transfer inside a room which is heated by floor heating system and wall heating system are investigated numerically. The floor construction for floor heating system and the inner wall construction for wall heating system are illustrated in Fig.1. As seen in the figure, pipes of diameter 16 mm are installed into the floor for floor heating system and into the inner wall for wall heating system. The finishing layer is assumed to be wood for floor heating system while it is assumed to be gypsum plaster for wall heating system which of both are the most common materials. Thus, conductive resistance of the wall heating system is lower than that of floor heating system. Since a comparison study is carried out in this study the carpet on the floor is not considered in the computations which increase the conductive resistance further and reduce the thermal performance of the floor heating system. The exterior wall is in contact with environment of 3 ℃ temperature which is design temperature for Tehran, Iran. The heat transfer coefficient between the exterior wall surface and the environment for winter conditions is 34 W/m^2K.Conductive resistance of the exterior wall is taken as a standard wall with insulation material of thickness 200μm whose thermal resistance is calculated as 1.36 m^2K/W. In Table 1. The physical and chemical properties of micro-particles has been studied. Heat loss from the heated wall to outward is assumed to be zero.

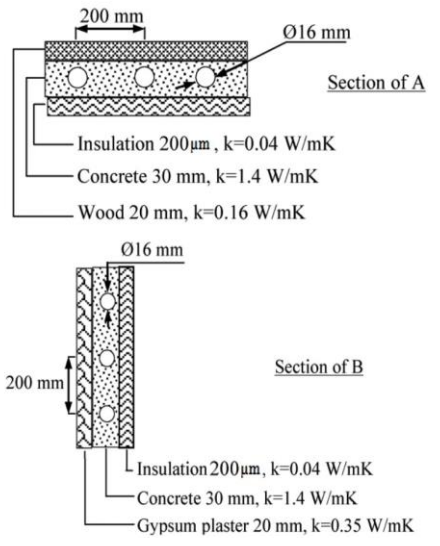

Figure . 1 The schematic representation of the geometries (Fifteen pipes in the wall or floor is intended)

2-2 Room modeling

In this study Anysy Fluent software routines, which are based on finite volume method, are used to analyze the heating systems. The effective boundary conditions on the performance of the system will be investigated. The overall dimension of the system is $3 \times 3 \times 3$ meter. The advantage of the present configuration is that, supply and return pipes are in reverse flow direction, so that the floor surface temperature is uniform and the pipes do not intersect with each other. The average temperature of the supply and return water is used as the calculated water temperature in this work.

2-3 Theoretical assumptions

The following theoretical assumptions were made: The investigated systems were real systems, The systems complied with a continuous open flow system model, The materials were homogenous, and standard parameters were sourced from the literature, Immeasurable parameters were based on database values, The energy efficiency of the system components are calculated from data collected, At the end of the lifespan, the necessary improvements in the system and the part exchanging were made; as such, disposal calculations were ignored for reused or recycled parts.

2-4 Configuration of the heating systems

In the present work a three dimensional model are proposed to investigate the optimum working of floor and wall heating systems. The model is generated in the Ansys Workbench software.

2-5 Mesh

In order to ensure the independence of the model rational outputs from the number of grid cells and number of nodes required, various grids for modeling is tested and compared with the total heat flux. Observed that, the number of grid nodes with the 212,400 cell numbers is almost identical to the results and the error is less than 5%. In addition, to optimize the time equations, reducing excessive grid cells is dispensable. Considering that the geometry is symmetrical and intuitive, a unstructured mesh is used. Given the importance of the heat transfer mechanism in the solid boundaries (including walls and ceilings), much finer grid cells along the near walls used the adaptive mesh. For the upper surface which is the room area, the structured Quadratic elements. For the heating surfaces in which the tubes are placed in every 20 cm alog the x direction, the unstructured triangles elements, the Pave type is used with the same interval count. The room area is the fluid part and the floor area is the solid part. The relevant boundary conditions are walls and tubes which will be investigated next. In the present work, the PISO algorithm, an implicit formulation is used for solving pressure velocity coupling. The PISO algorithm uses a relationship between velocity and pressure corrections to enforce mass conservation and to obtain the pressure field. By setting the time step size equal 1 and 5 seconds, the results do not change. So it is concluded that the problem should have a steady state solution. To cheek that the solution is in laminar region or turbulent region, the Rayleigh number equal to 3.6×10^7 which is in the transient region is calculated. The discretization method for pressure is set to PRESTO which is suitable for free convection problems. For momentum and energy, first order upwind is considered.

Table 2 .Results during heating process (Wall heating systems)

Microspheres	Energy ratio [kW]	Exergy ratio [kW]	Efficiency[%]	Exergoeconomic factor	Exergoenvironmental factor	Total cost [$/h]
LCM-121	72.094	1.825	87.56	75.33	33.16	1.793

Table 3 .Results during heating process (Floor heating systems)

Microspheres	Energy ratio [kW]	Exergy ratio [kW]	Efficiency[%]	Exergoeconomic factor	Exergoenvironmental factor	Total cost [$/h]
LCM-121	84.094	1.543	91.34	85.23	43.06	1.793

3- Results and discussion

3-1 Exergoeconomical assessment

Exergoeconomic analyses include exergy analyses, economic analyses and the identification of exergy costs. These analyses are generally conducted at the level of system elements. The costs related to all materials and exergy flows in the system are calculated, and thermodynamic inefficiencies in all fields are identified (e.g., exergy destruction and loss). Comparisons of exergy destruction costs of each element in the system and the corresponding investment costs provide beneficial information in enhancing the expenditure efficiency of the element. These analyses also highlight points in the system where structural and parametric values should be changed. An exergoenvironmental analysis assesses environmental impacts based on exergy analyses. In further detail, an exergoenvironmental analysis reveals the environmental impact associated with each system component and the real sources of the impact by combining an exergy analysis with a comprehensive environmental assessment. The results of ceramic micro-particles for both types of heating systems are given in Tables 2 and 3. As can be seen, this type of insulating microparticles have a very high efficiency (an average of 80 percent). The energy rate in each heating system is suitable and below 100 kW. From the standpoint of exergy, in accordance with Ashrea's definition, it has very good values with an average of 1.5 kW. Other factors, including exergoenvironmental and exergoeconomic ones, were also investigated in both systems. Exergoenvironmental and exergoeconomic factors ranged between 45% - 85%. However, exergoenvironmental factors for all system and each system element determined. This value for all system calculated as 33.16%.

3-2 The ecological assessment of the investment

The role of the Typical Periodic Assessment (TPA) in identifying and measuring the impact of material-energetic flows on the environment of the analyzed technological process is becoming more and more popular and essential from point of view of the iteration of the obtained results. In particular, in case of searching for the alternative management policy within: designing, used raw materials and semi-finished products (chain of supplies), production process and product disposal after its life period. The analysis of life cycle can substantially contribute to the quantitative expression of environmental loads of these alternatives in order to compare and make decisions. The methodology of the environmental life cycle assessment has been frequently mentioned in the subject literature. According to which a properly conducted TPA analysis includes four consecutive stages:

- Goal and scope definition. In this article the aim of the research is the assessment of the impact of particular component elements of the external building wall on the environment. The permutation of different building walls was

also suggested in terms of choosing an optimally ecological wall (the lowest value of environmental loads). The analysis does not include the process of neutralizing after the period of products' life for regard of the lack of clear knowledge concerning the way of utilizing this waste in the future. In the phase of the energetic utilization of the building a total annual demand for the heat of the building was taken as a functional unit.

- The data-in was taken from the database of SimaPro 7.1 program and also the data gathered in the factories producing these products in Poland.
- For the realization of this stage the mentioned computer program SimaPro 7.1 was used altogether with Ecoindicators 99 procedure. This procedure enables to allocate eleven impact categories to three damage categories and therefore allows to conduct the assessment of impact on: human health, quality of environment and utilization of natural resources.

The ecological indicators are often constructed as an integrated set for representing key information and features of ecosystem, which are closely connected with the objectives of environmental management. Ecological indicators play a more and more important role in monitoring ecosystems, assessing damages occurring in them as well as managing them. An adequate selection of the indicator becomes an indispensible condition for the effective operation of environmental management system . For many investments the examination of the impact on the environment seems to be well-grounded. For the ecological evaluation of investments the technique of typical periodic assessment presented in the article was used. Similarly to financial measures, the ecological ones were defined, although the expenditure is connected with the additional increase of the load of the environment, and incomes are associated with the decrease of the load of the environment as a result of the implementation of investments. Additionally it is assumed that the values of environmental loads do not change while being discounted in time. The results of TPA analysis of one year thermal phase of the building usage are strongly differentiated in particular in terms of the type of heat source used. The kind of the thermo insulating material used does not provide essential differences in the results due to similar overall heat transfer coefficient for the same heat sources. Results of TPA for microparticles as well as comparison of the two types of heating systems are given in Table 4. Of course, this value offered highest rate of the assumed computational periods for some of the microparticle which can be justified due to their high heat resistance .According to the definition of TPA analysis presented in the previous section, these values were measured by calculations in a specified time period which emphasize the correctness of this analysis method.

Table 5 . Energy saving Comparison

Microspheres	Floor heating system (W)		Efficiency %	Wall heating system(W)		Efficiency %
	Without microsphere	With microsphere		Without microsphere	With microsphere	
LCM-121	320.4	262.06	18.21	307.6	240.61	20.91

Table 4 .The results of TPA analysis of one year insulation of external walls

	LCM-121
Floor heating system	715
Wall heating system	655

The effect of using these ceramic microparticles in paint as a cover comparing with wall without cover is 4-5℃ in creating comfort and welfare of residents. Table 5, shows least heating loss is for using cover at external wall .external wall cover is better considering cost-effectiveness. Amount of reducing heating losses from external walls painted with ceramic microparticles relative to external wall without any coat is 18% and 20%, respectively which indicated specific characteristic of using these coats in energy saving. It was observed that energy consumption will decrease to 18.21 % by floor heating system and 20.91% by wall heating system. Finally, The best posture of mineral insulations is on the external walls of buildings.

4- Conclusions

The paper proposes additionally indicators for the ecological assessment of the investment impact on the environment. TPA technique was applied to it. For regard of all proposed indicators: ecological net present value, ecological profitability indicator and ecological payback period, in all analyzed variants investments occurred to be favorable for the environment causing the decrease of its load. Ecological payback periods were obtained within 0–5 years. The most widely used on the outer walls of a room and their impact on energy consumption, exergoenvironmental and exergoeconomic indexes, efficiency, exergy ratio, energy ratio, ecological assessment, and total coast were studied and compared. Finally, the following results were obtained:

- Exergoenvironmental assessment showed that the optimum amount ranges from 45 to 85%.
- Exergoeconomic study showed that its value is between 26 to 75%.
- Total cost calculations yielded an average of about 0.9 $ / h, which presents the best cost rate.
- Efficiency of this type of microparticles was an on average of 18 percent savings in energy consumption.
- Alternative technologies along with renewable energy sources should be developed, and some work has to be done accordingly to allow these systems to be used. Especially, floor heating and wall heating systems are noteworthy as a renewable energy convert technology.
- It is found that in order to determine economic and environmental impacts of irreversibilities occurring in the system and its components, economic and environmental analyses of thermal system as well as wall heating systems, should be done based on exergy concept.
- The energy and exergy efficiencies of the entire system were 67.36% and 27.40%, respectively.

Using mineral insulators in room walls in 3D coordinates was studied by energy consumption and exergy ratio in floor and wall heating systems and it was obtained that:

- The best condition for placing insulators in external wall of buildings.
- It was observed that ceramic microparticles coat acted as a heat insulator and using this coat with ceramic microparticles have 18% saving in energy consumption in winter comparing with typical coating.

5- References

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