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Energy Saving of the Paint with Mineral Insulators: Simulation and Study on Different Climates

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Abstract**—**By using an adequate thermal barrier coating in buildings the energy saving will be happened. In this study, a range of wall paints with different absorption coefficient in different climates has been investigated. In order to study these effects, heating and cooling loads of a common building with different ordinary paints and paint with mineral coating have been calculated. The effect of building paint in different climatic condition was studied and comparison was done between ordinary paints and paint with mineral insulators in temperate climate to obtain optimized energy consumption. The results have been shown that coatings with inorganic micro particles as insulation reduce the energy consumption of buildings around 14%.

Keywords**—**Insulator, coating, climate, energy consumption.

I. Introduction

USING ceramic micro particle technology with paints could have an effect on energy consumption rate of a building. Since radiation heat transfer has major role in this regard, investigating the usage of inorganic coating in absorption and emission to and from building surfaces, could reveal the effect of painting on energy consumption.

Due to high heat loss from walls and roof in building, it is necessary to reduce these heat transfers to have lower energy costs. Usage of inorganic micro particle coatings could reduce heat loss of buildings by reducing heat absorption of walls and ceiling [1]. In fact, use of building paint as a heat barrier could reduce heat absorption and therefore, keep the indoor spaces more independent from outdoor summer condition. This issue has a spectacular effect in tropical and warmer climates. In addition, it is possible to reduce heat loss from building during cold seasons. One way for saving energy consumption and decreasing a cooling load in buildings is a suitable material same as curtains, paints and inorganic material coatings [2].

Thermal radiation is emission of electromagnetic waves from a body due to its temperature. When the emitted radiation reaches a surface, some part of it is absorbed, some is transferred, and the remaining is reflected, which all these three mechanisms, are shown by factors in radiation heat transfer equations. Light is visible part of electromagnetic waves of solar radiation which its wave length is located between 375 to 715 nm [3], [4]. The shortest visible wave length is for purple and the longest wave length is for red color.

Building with white or light exterior colors, medium thermal capacity, and resistant building components, and relatively small windows with overhead, has lower temperature relative to outdoor conditions. In contrast, buildings with dark exterior colors, and large windows without overhead, have higher indoor temperature than outdoor condition. It could be concluded that building ventilation and air conditioning is depending on its exterior color coats, window size, and overhead quality. Therefore, if a room is not conditioned, its air temperature rises up to the adjacent wall temperature and the air temperature will be around the average of walls temperature. In this case, the difference between the inner and outer temperature of the room depends on the external color coats of the walls. With the external color coats of walls getting darker, the room temperature gets warmer. However, temperature fluctuations in the room depend on the thermal capacity and resistance of the materials used for construction. Due to importance of paint coating specification in energy consumption in a building, effect of absorption coefficient for different colors and inorganic coatings in outer surface of buildings or the heating and cooling load of a building has been investigated. Also, the role of inorganic coatings in reduction of energy loss in heating and cooling mode of operation of HVAC systems has been investigated in industrials and residential buildings [5]-[8].

In the current study, the researchers have investigated the effect of different parameters including climatic condition, absorption coefficient, and thermal loads on paint coating about a range of wall paints with different observation in different climatic.

II. Climatic Regions

The climatic regions are usually defined based on latitude and elevation from sea level. Iran is located in warm region between 25 and 40 degrees of north latitude. The total amount of areas which have more than 475 m elevation from sea level has very low proportion [6].

In climate classification of Iran, the scientists focused on Coupon method and these climates include:

- Hot and humid (south coast's)
- Cold (west and north western)
- Mountainous
- Hot and dry (central plateau)
- Temperate and humid (south coasts of Caspian sea)

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- Mountain sides (marginal regions in mountain slopes, deserts and border regions)

III. Modeling of Typical Building

In order to investigate effect of building paint on heating and cooling loads, a residential six stories building were considered. This building modeled with identical geometry in different climatic regions. Heat transfer coefficient of building walls is shown in Table I. To model this typical building in different climatic regions, a city is selected from each climatic region as representative. The outdoor conditions of these cities are shown in Table II.

In order to specify minimum heating and cooling loads in climatic regions, Carrier software [9] were used and effect of absorptivity (Table III) of building paint were considered.

TABLE I
Amounts of Overall Heat Transfer Coefficients

Wall	Outdoor walls with inorganic	Outdoor walls	Ceiling with inorganic	Ceiling	Floor	Window
Heat transfer coefficient $(Btu/hr.ft^2.°F)$	0.05	0.077	0.041	0.047	0.1	0.65

TABLE II
Outdoor Design Conditions of Some Sample Cities

Elevation (ft)	Relative humidity %	Longitude (deg.)	Latitude (deg.)	Winter	Summer			Climates
				Td °F	Daily Range °F	Tw °F	Td °F	
7	85	48	30	39	32	82	116	Hot and humid
4300	78	48	38	-7.5	29	68	85	Cold
7300	80	51	31	7.5	37	61	92	Mountainous
3150	78	51	33	24	29	83	110	Hot and dry
-69	92	50	36	31	13	76	90	Temperate and humid
4000	78	51	35	22	27	74	100	Mountain sides

TABLE III
Absorption Values

Surface	Color	Material	Absorption
Face	White	Brick	0.25
Face	Yellow	Brick	0.4
Face	Red	Brick	0.75
Face	White	Brick	0.46
Face	Red	Brick	0.65
Face	Dark	Brick	0.9
Face	Black	Brick	0.96
Face	Yellow	Mineral Coatings	0.19

The suitable paint color and effect of inorganic coatings in the range of light colors, regarding the minimum heating and cooling load has been investigated.

IV. Heat Transfer Simulation

As we know, there are three kinds of heat transfer [10].

A. Conduction Heat Transfer

Heat conduction equation in the one direction (q_x) can be shown by:

$$q_x = -kA_x \frac{dT}{dx} \tag{1}$$

where; q = heat transfer per unit time (W), T = absolute temperature (K), Ax = area of the vertical of heat transfer direction (m^2), K= heat conduction coefficient, $\frac{dT}{dx}$ = temperature slop in the material in the heat transfer direction.

B. Convection Heat Transfer

Heat convection equation from a surface to fluid (q) can be shown by:

$$q = hA(T_w - T_\infty) \tag{2}$$

where, q = heat transfer per unit time (W), Tw = surface temperature (K), T∞ = fluid temperature (K), A = area of heat transfer (m2), h= heat convection coefficient.

C. Radiation Heat Transfer

Thermal radiation is the emission of electromagnetic waves from a surface due to its temperature. When the emitted radiation reaches a surface, it is absorbed or transferred and the rest is reflected. These three mechanisms can be shown by radiation heat transfer equation:

$$q = F_\epsilon F_G \sigma A(T_1^4 - T_2^4) \tag{3}$$

where; q = heat transfer per unit time (W), σ = 5.6703 10^{-8} (W/m^2K^4)-The Stefan-Boltzmann Constant, T = absolute temperature (K), A = area of the emitting body (m^2), F_e = View factor, F_G = Emissivity.

The heat gain at the interior surface of the wall or roof is computed using the following procedure from carrier software V4.5. Compute the sol-air temperature using the outdoor air dry-bulb temperature and the total solar flux on the wall or roof exposure. For energy simulations, simulation weather data is used and the sol-air temperature is computed using [11]:

$$Tsa = Toa + aIt/ho - eDR/ho \tag{4}$$

We used the sol-air temperature and the conduction transfer function coefficients together in the conduction transfer function equation to calculate the wall or roof heat gain. The heat gains calculated in upper are used together with the appropriate coefficients in the room transfer function equation to calculate wall or roof transmission loads.

Variable Definitions;

- Tsa= Sol-air temperature, F or C,
- Toa= Outdoor air dry-bulb temperature, F or C,
- a= Wall or roof exterior surface absorptivity for solar
- radiation, dimensionless,
- It= Total solar flux on wall or roof surface, BTU/hr/sqft or W/sqm,
- ho= Convective heat transfer coefficient on exterior wall or roof surface,
- A value of 3.0 BTU/h-sqft-F or 17.0 W/sqm-K is used,
- e= Hemispherical emittance of exterior surface. A value of is used,
- DR= Difference between long wave radiation incident on exterior surface and blackbody radiation at Toa, BTU/h-sqft or W/sqm. For vertical surfaces, DR = 0.0. For horizontal surfaces, DR = 20.0**,**

D. Solar Angles

In order to calculate solar flux quantities, a variety of angles describing Sun Earth geometry and the direction of the beam solar flux must be defined.

1.Declination (d)

The angular position of the Sun relative to the plane of the Earth's equator.

2.Hour Angle (H)

An angular expression of the apparent solar time, measured from solar noon:

$$H = 15\ (12\ AST) \qquad (5)$$

where, H= Hour angle, degrees. AST= Hour of day, apparent solar time. AST=0 for midnight, AST=12 for solar noon, AST=23 for 11pm.

3.Solar Altitude Angle (b)

The angle between the beam solar flux and a horizontal surface:

$$\sin(b) = \cos(L)\cos(d)\cos(H) + \sin(L)\sin(d) \qquad (6)$$

where; b= Solar altitude angle, degrees. L= Site latitude, degrees.

4.Solar Azimuth Angle (f)

The Sun's angular distance from due south. Positive angles are measured counter clockwise from south. Thus, when the Sun is east of due south, the solar azimuth angle is positive; when west of due south the azimuth is negative.

$$\cos(f) = [\ \sin(b)\sin(L)\ \sin(d)\ ] / \cos(b)\cos(L) \qquad (7)$$

5. Surface Azimuth Angle (y)

The angle between a line perpendicular to a vertical wall and due south. As with solar azimuths, positive angles are measured counter clockwise from south. Thus, angles for the principal exposures are as follows: north: y = 180, east: y = 90, south: y = 0, west: y = 90.

6.Surface Solar Azimuth Angle (g)

The Sun's angular distance from a line perpendicular to a vertical wall:

$$g = f\ y \qquad (8)$$

7.Angle of Incidence (q) for Beam Solar

The angle between the direction of the beam solar flux and a line perpendicular to a building surface. The general equation for the angle of incidence is:

$$\cos(q) = \cos(b)\cos(g)\sin(S) + \sin(b)\cos(S) \qquad (9)$$

where; S= Tilt angle for building surface, degrees (Measured from horizontal). For horizontal surfaces S = 0; for vertical surfaces S = 90.

E. Calculation of Clear Sky Solar Flux Profiles

The procedure used to compute hourly clear sky solar flux profiles is taken from the 1997 ASHRAE Handbook of Fundamentals [11]. The goal of the procedure is to determine hourly values of the beam, diffuse and reflected components of solar flux on each of the building exposures for clear sky conditions. Fluxes are computed for the twenty first day of each month according to ASHRAE procedures.

1.Beam Solar Flux

First, compute the beam solar flux on a surface perpendicular to the direction of the flux:

$$Ibn = ACN\ [\ A / \exp(B/\sin(b))\ ] \qquad (10)$$

where; Ibn= Beam solar flux on surface perpendicular to direction of flux, BTU/hr sqft or W/sqm. A= Apparent solar irradiation at air mass of zero, BTU/hr sqft or W/sqm. B= Atmospheric extinction coefficient, dimensionless. ACN= Atmospheric clearness number, dimensionless.

The procedure for computing Ibn was developed for a set of monthly reference atmospheric conditions. These reference conditions define the quantities of ozone, moisture and dust in the atmosphere for a site at sea level. For sites with unusually dry, wet, dusty, or clear atmospheres or sites at high elevations, the atmospheric clearness number (ACN) is used to increase or decrease Ibn values. For sites at which conditions are close to the reference conditions, a clearness number of 1.00 is used [11], [12].

The beam solar flux on a wall or roof exposure is computed using:

$$Ib = Ibn\ \cos(q) \qquad (11)$$

where, Ib= Beam solar flux on a surface, BTU/hr.sqft or W/sqm. q=Angle of incidence for direct solar flux, degrees.

2.Diffuse Solar Flux

Before computing the diffuse solar flux on an exposure, the factor "Y" must be calculated. "Y" is the ratio of diffuse solar flux on a vertical surface to the diffuse flux on a horizontal surface. This factor must be used because for clear sky conditions the intensity of the diffuse solar flux is not uniformly distributed over the dome of the sky. The diffuse flux from the area surrounding the Sun is most intense, while the flux originating from other portions of the sky is less intense. Hence, whether a surface is exposed to the Sun to some extent affects the amount of diffuse solar it receives. Y is computed using the following equations, For cos(q) greater than 0.2:

$$Y = 0.55 + 0.437\cos(q) + 0.313\cos2(q) \quad (12)$$

for cos(q) less than or equal to 0.2:

$$Y = 0.45 \quad (13)$$

where; Y= Ratio of diffuse flux on vertical surface to diffuse flux on horizontal surface, dimensionless. q= Angle of incidence for beam solar flux, degrees.

The diffuse solar flux is calculated. For a surface of any orientation the general equation is:

$$Id = C\ Y\ Ibn \quad (14)$$

For horizontal surfaces, the following equation is used:

$$Idh = C\ Ibn \quad (15)$$

where; Id = Diffuse solar flux on a tilted surface, BTU/hr sqft or W/sqm. Idh = Diffuse solar flux on a horizontal surface, BTU/hr sqft or W/sqm. C= Sky diffuse factor, dimensionless.

3.Reflected Solar Flux

Solar energy which strikes a tilted building exposure after being reflected by the surrounding ground is determined with:

$$Ir = rg\ Ibn(C + \sin(b))(1 - \cos(S)) / 2 \quad (16)$$

for vertical surfaces this reduces to:

$$Irv = rg\ Ibn(C + \sin(b)) / 2$$

for horizontal surfaces there is no reflected solar flux:

$$Irh = 0$$

where; Ir = Ground reflected solar flux on a surface of any orientation, BTU/hr sqft or W/sqm. Irv = Ground-reflected solar flux on a vertical surface, BTU/hr/sqft or W/sqm. Irh = Ground-reflected solar flux on a horizontal surface, BTU/hr/sqft or W/sqm. rg= Ground reflectance, dimensionless.

V. Results and Discussion

Using the selected model (Fig. 1) and assuming different climatic condition for the typical building, different situations were examined.

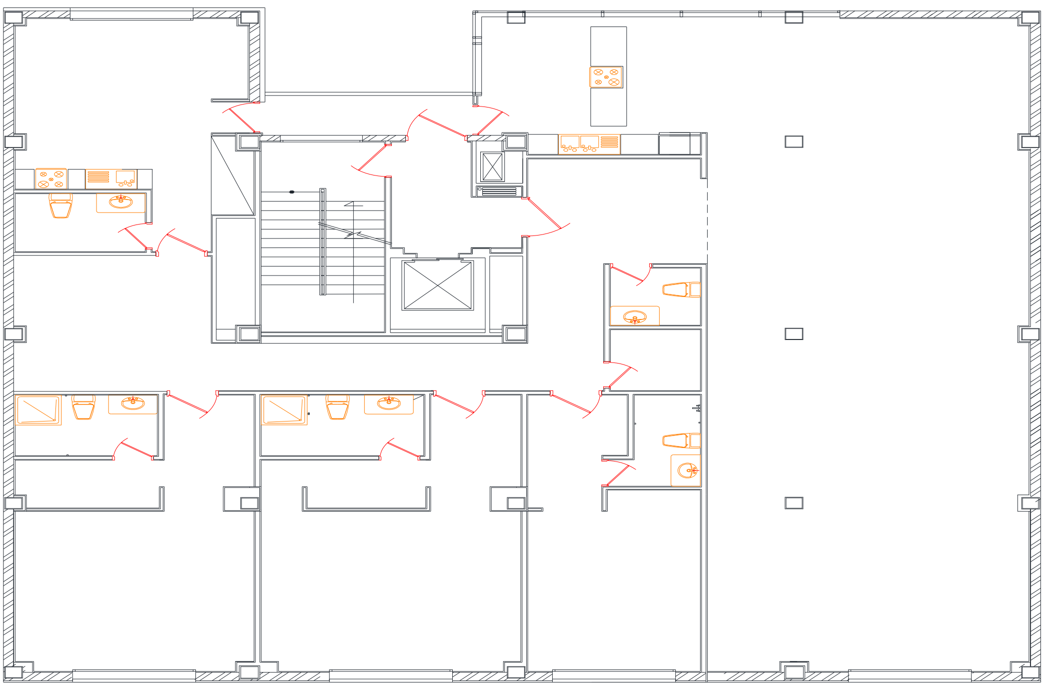
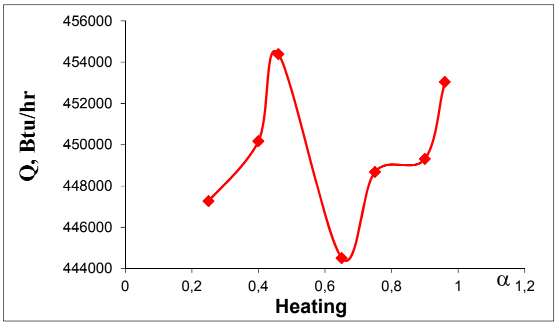


Fig. 1 The plan of the building

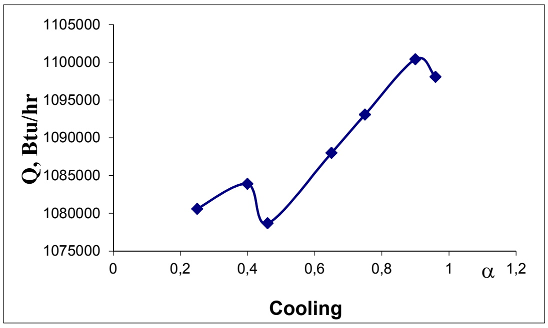
As could be seen in Figs. 2-7, with increasing the absorption coefficient, heating and cooling load of the building changes but its variations is not linear since the absorption coefficient depends on factors like temperature, wave length, surface color and angle of radiation.

A. Hot and Humid Climate

Fig. 2 (a) shows heating load and Fig. 2 (b) shows cooling load of typical building hot and humid climate.



(a)



(b)

Fig. 2 (a) Heating load of typical building in hot and humid climate, (b) Cooling load of typical building in hot and humid climate

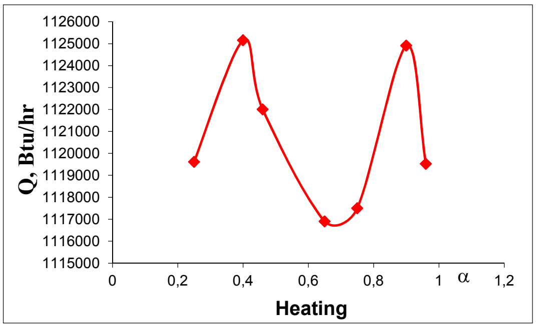
As could be observed in Fig. 2, minimum heating load is for absorption coefficient of 0.65 and minimum cooling load is for absorption coefficient of 0.45, which these absorption coefficient values are in the range of light colors in buildings.

B. Cold Climate

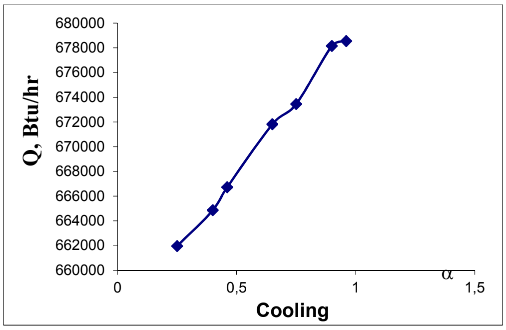
Fig. 3 (a) shows heating load of the typical building and Fig. 3 (b) shows cooling load in cold climate. As could be seen, minimum heating load is for absorption coefficient of 0.65 and minimum cooling load is for absorption coefficient of 0.25, which these absorption coefficient values are in the range of light colors in buildings.

C. Cold and Mountain Climate

Fig. 4 (a) shows heating load of the typical building and Fig. 4 (b) shows cooling load in cold and mountain climate. As could be seen, minimum heating load is for absorption coefficient of 0.9 and minimum cooling load is for absorption coefficient of 0.4.

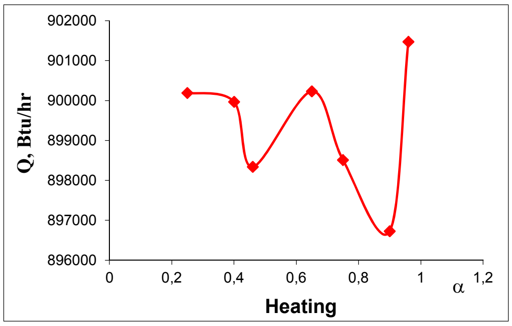


(a)

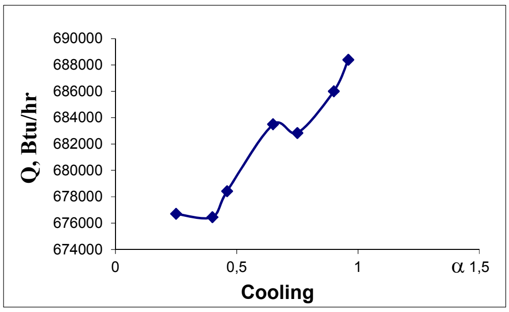


(b)

Fig. 3 (a) Heating load of typical building in cold climate, (b) Cooling load of typical building in cold climate



(a)

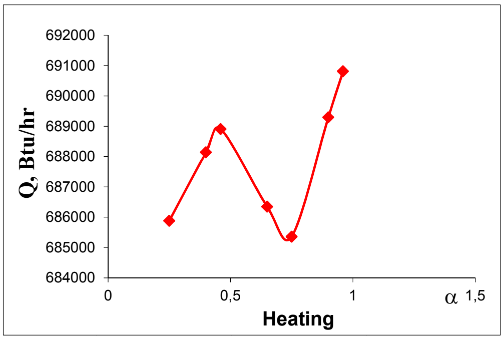


(b)

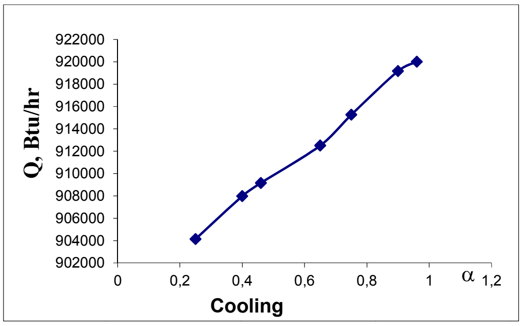
Fig. 4 (a) Heating load of typical building in cold and mountain climate, (b) Cooling load of typical building in cold and mountain climate

D. Hot and Dry Climate

Fig. 5 (a) shows heating load of the typical building and Fig. 5 (b) shows cooling load in hot and dry climate. As could be seen, minimum heating load is for absorption coefficient of 0.75 and minimum cooling load is for absorption coefficient of 0.25.



(a)

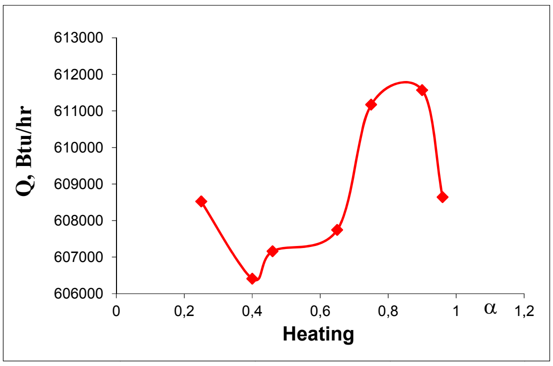


(b)

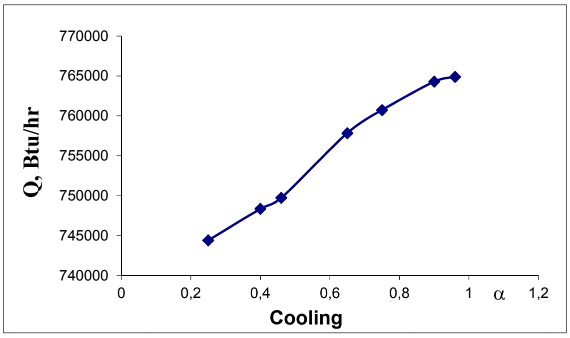
Fig. 5 (a) Heating load of typical building in hot and dry climate (b) Cooling load of typical building in Kashan

E. Temperate and Humid Climate

Fig. 6 (a) shows heating load of the typical building and Fig. 6 (b) shows cooling load in temperate and humid climate. As could be seen, minimum heating load is for absorption coefficient of 0.4 and minimum cooling load is for absorption coefficient of 0.25.



(a)

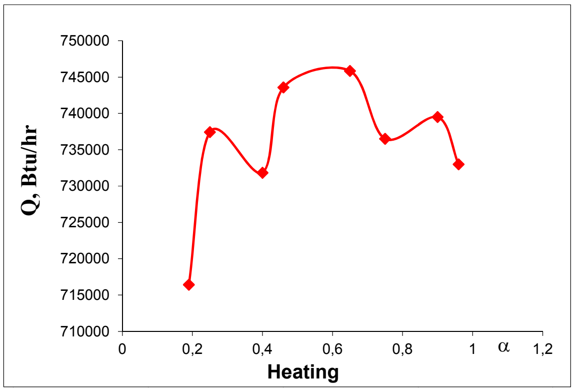


(b)

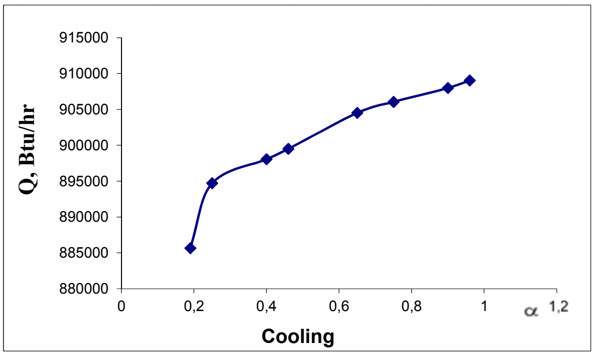
Fig. 6 (a) Heating load of typical building in temperate and humid climate, (b) Cooling load of typical building in temperate and humid climate

F. Mountain Sides' Climate

Fig. 7 (a) shows heating load of the typical building and Fig. 7 (b) shows cooling load in mountain sides' climate. As could be seen, minimum heating load is for absorption coefficient of 0.4 and minimum cooling load is for absorption coefficient of 0.19.



(a)



(b)

Fig. 7 (a) Heating load of typical building in mountain sides' climate, (b) Cooling load of typical building in mountain sides' climate

In the same condition by adding inorganic micro particles to light colors, absorption coefficient is reduced to 0.19 which means a decrease in heating load of building. It could be observed in Fig 7 (b), when micro particles are not used in colors, minimum cooling load is for absorption coefficient of 0.25 by adding micro particles to the paint, absorption coefficient is reduced from 0.25 to 0.19.

VI. Conclusion

According to the obtained results of the studied climates, that absorption coefficient in the range of 0.25 to 0.5 is desirable, so light colors (white, blue, yellow) are suitable colors from both energy consumption and physiological points of view. If any of the light colors could be used by some complementary colors, multiple effects may be observed. Also it was shown that by adding inorganic micro particles, absorption coefficient is reduced to 0.19 which leads to lower thermal loads. It could be stated that a coating with inorganic micro particles acts as insulation and reduces the energy consumption of building around 14%.

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