Energy Heat Balance For Buildings, A Review Analysis

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Abstract: The analyses for energy heat balance for buildings are reported in this paper. The parameters influencing the interaction of heat balance was taken into account. Other aspect considered in this work is the building location and surroundings which plays a key role in regulating its temperature and illumination. The result of the estimation of the heat load and heat gains to the buildings were all reported in this paper.

Keywords; façade material, insulation values, heat load, energy cost, heat gain. building envelope

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1 INTRODUCTION

ENERGY is one of the most important factors in wealth generation, economic growth and social development in all countries. It is very important to think more efficiently about energy and new resources of renewable energy; because we don't have an ultimate energy resource we should start reducing energy consumption and to apply solar energy in our new energy design of buildings. When designing for low energy houses, construction detail should be taken into consideration which are: walls, roofs, ground floors and windows.

1.1 Benefits of Energy Management

The influence of energy to any organization cannot be over looked, so, all organization must manage energy to a large extent if only to ensure its availability. Energy management involves the strategic optimization of every &&&. System and procedures so as to reduce overall energy requirements without compromising quality or standards of performance (8) for profit oriented organizations, it entails the effective and judicious use of energy to maximize profits, minimize costs and enhance competitive positions (3). Improving energy efficiency is a keys strategy in making the world's energy system are economically and environmental sustainable. Energy management is the equally of vital importance to environmentalist who are ever concerned about the damage to the environment of harmful waste discharged from the use of non-renewable sources of energy. By reducing emissions, energy management is an important part of lessening climate change. Energy management facilitates the replacement of non-renewable energy.

Proper energy management is often the most economical solution to energy shortages, and is a more environmental design alternative to increased energy production. Facts in energy management that cannot be underestimated includes;

- Prices of energy are increasing – the continuation of growing energy consumption and limited energy supplies is causing energy prices to rise.
- Supplies of energy are reducing – there is limited coal, oil and gas in today world, quite scarce is most countries.
- The consumption of energy is increasing – growing population, improve living standards, advent of technology and rising wealth have driven energy consumption to record levels.

Electricity, is one of the most common forms of energy, is needed to power millions of computers and other electronic appliances worldwide. With improving technologies, new appliances appear on the market daily. As such the most rapid growth in energy demand in the next five years is projected to be for electricity. With the depletion of non-renewable energy reserves around the globe, our constant demand for energy as well as issues of global warming, the need for energy management cannot be overemphasized (12). Finally, the importance of energy management includes;

- Reduced energy cost
- Improved safety
- Enhanced productivity
- Helps the environment

Reduced need to increase the nation's power generation capacity (1

1.2 Levels in Energy Management Programme

Energy management programmes varies from one consisting of task to one spanning several phases, depending on priority an organization gives to the proper management of energy resources. The stages in a typical energy management programmes should include a single. Even though Survey, followed by monitoring of energy use in building services, and then model analysis using computer simulation of building operation (9). The degree of sophistication of the energy management programme is however strongly dependent on the complexity of energy use in the building a well as the organizations budget towards energy management (4). The first level is to reduce energy use in areas of gain of energy wastage within the

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facility. Adequate precaution must however be taken to ensure that the various reduction measures employed do not cause disruptions to the level of services performed in the facility. The energy consumption process begins with a detailed step by step analysis of the building energy use facto such as occupancy schedules, efficiencies of air conditioning system and lighting levels as well as energy cost which can be obtained from records of utility and fuel expenditures (15). The second level aim at improving the efficiency of energy conversion equipment and reducing energy use by proper operation and maintenance. For this reason, it is necessary to reduce the no of operating how according to load demands. This also helps in the full optimization of equipment operations. Areas where reduction can be achieved and this should be investigated include the following;

- Air condition
- Building equipment operation
- Lighting system
- Power systems
- Miscellaneous system

The first two levels can be implemented without remodeling buildings and existing facilities. The last level is to out large-scale energy reducing measures when existing facilities and equipment have passed their useful life, or require extensive repair or replacement because of obsolescence. In this case, higher energy savings may be achieved (11).

1.3 Building Design for Energy Heat Balance

A building's location and surroundings plays a key role in regulating it's temperature and illumination. For example, trees, landscaping, hills can provide shade and block wind. In cooler climates, designing building with a south facing window Increases the amount of sun (ultimately heat energy) entering the building, minimizing energy use, by passive solar heating. Tight building design, include energy-efficient windows, well sealed doors, and additional thermal insulation of walls, basement slabs and foundation can reduce heat loss by 25-50% (2) Proper placement of windows and skylights and use of architectural features that reflects light into a building can reduce the need for artificial lighting. Increased use of natural and task lighting have been shown by one study to increase productivity in schools and offices (12). Compact florescent lights use two-third less energy and may last 6-10 times longer than incandescent light bulbs. Newer florescent light produce a natural light, and in most cases, they are cost effective (8).

1.4 Heat Gain to Building

Sundry gains to building can sometimes comprise a high proportion of the input energy. In factories, and kitchen, internal heat losses from processes often overwhelm the heat loss from building fabrics, resulting in the need for excessive fresh air ventilation to maintain the internal environment in a comfortable condition. Solar Gains: Solar gains to office blocks can also be high, and unless insulation is reduced by employing blinds, shutter or solar control glazing, such building may have to be air conditional. The next heat gains or losses from or to the external environment though the building component can be calculated as follows;

For wall or roof

$$Q = UA\,(A_1 - T_{sa}) \quad \ldots\ldots \quad (1)$$

Where

Tsa(^{0}C) - mean external Sol – air temperature for glazing

$$Q = SAI - UA\,(T_1 - T_0) \quad \ldots\ldots\ldots(2)$$

S – Solar gain factor (0-1) for glazing

A – Area of glazing

I (Wm^{-2}) is the sum of diffuse solar energy normal to glazing
For the base

$$Q = UA\,(T_1 - (T_0 + 10^0C)) \quad \ldots\ldots\ldots\ldots(3)$$

1.5 ESTIMATION OF HEAT LOAD

Heat load within a building can be defined as the algebraic sum of heat from the following sources;

(A) Heat flow through the structure due to
  (1) Air – temperature differences
  (2) Solar radiation

(B) Sensible heat originating from
  (1) Air- movement through the building
  (2) Objects brought into the building at different temperature from building air temperature

(C) Heat generated within structures by persons, stored product, light, machines.

(D) Latent heat of fusion and evaporation

(E) Heat flows from the cracks on the walls and occasional opening of windows and doors.

It's difficult to predict the amount of heat exchanged at these media, and it's better to assure that exchanged through the media is between 10-20% of the amount obtained from A to D.

2 Interaction of Building Envelope With Environment

The building envelope separates the indoor space from the outdoor environment and acts as a modifier of the effects of climate variables such as the outdoor temperature, humidity, wind, solar radiation and rain.

2.1 Heat Transfer Paths between the Building and Its Environment

The primary heat transfer paths between the building and the external environment are conduction through walls, roofs, doors (opaque conduction), and windows (glazed conduction); solar radiation directly penetrating through windows; and sensible and latent heat gain from air exchange. The effective solar exposure of the glazed and opaque elements of the building's envelope (its wall and roof), the effective solar heat gain of the building, the rate of conductive and convective heat gain from, or loss to, the ambient air; and the potential for natural ventilation and passive cooling of the building are the four forms of interactions between the building and its environment through which heat exchange takes place.

2.2 Parameters Influencing the Interaction

There are two types of parameters, which affect the thermal performance of a building. The first type is the unsteady climatic conditions that the building is exposed to, which includes the solar radiation (direct, diffuse and reflected), net long wave radiation between the structure and its surroundings, air temperature, relative humidity and wind speed. The second type are the design features related to the building which include the building's layout and sitting, orientation and color of the walls and roofs, orientation and shading conditions of windows, the size and location of the windows from the ventilation aspect and the thermo physical properties of the building materials.

2.2.1 Building Layout

The building layout or shape affects the ratio of the envelope's surface area to its volume, which determines the relative exposure of the building to solar radiation and to the ambient air consequently affecting the rate of heat exchange of the building with the outdoor environment.

2.2.2 Orientation and Colour of Envelope

The external surface temperature of a wall depends on two factors, the ambient air temperature, which is independent of orientation and the amount of solar radiation, which is more dependent on orientation. The quantitative effect of the amount of striking solar energy is determined by the surface property of absorptivity, the elevation of surface temperature varying inversely with the lightness of the surface color and the wind speed next to the surface of interest. In the study conducted to examine the effects of orientation on external surface temperature for a wall painted gray a difference between the surface temperature and ambient air temperature of about 23oc was observed and for a wall painted white a difference between the surface temperature and ambient air temperature of less than 3oC was observed demonstrating that in the discussion of the thermal effect of orientation, careful consideration has to be given to the color of the external surface [14]. In the study conducted to assess the thermal comfort in classrooms in Singapore, it was concluded that the layout of the classroom block should be such that the long facades are facing the north and south and that this orientation will also increase the potential of using natural ventilation for cooling since the prevailing wind directions in Singapore are north and south [1].

2.2.3 Orientation and Shading of Window

The experimental studies have demonstrated that when buildings are effectively ventilated during the daytime, the orientation of the windows, and the differences in the solar gain associated with it, have minor effect on the indoor temperatures. With ventilated buildings there is, of course, no energy used for cooling so that the window's orientation has no effect at all on the energy use for cooling [5].

2.2.4 Window Size

In a wind tunnel study conducted by Givoni to determine the effect of different combinations of inlet and outlet openings on the indoor air speeds in a square model, it has been found that the indoor airspeeds are not proportional to the size of the windows: the effect of increasing the window's size is strong when the window is small but it decreases with increasing size suggesting that the effect of window's size is approximately proportional to the square root of the opening size [13].

3 Thermal-Control Characteristics of Materials

The most important thermal-control characteristic of building materials is their transmission behavior of heat and the two basic thermal properties of building elements, which control this transmission behavior and determine their impact on the thermal performance of buildings, are the thermal transmittance and heat capacity.

3.1 Insulation Value

The dampening effect is caused by the insulation value of the material, characterized by "U" factor (overall heat transfer coefficient expressed in W/Km2). The lower the U value, better the insulation effect.

3.2 Capacity Insulation

The "time lag" of the construction,which gives an opportunity to store peak heat, loads and releases them at low temperature periods and simultaneously reduces the amplitude of impact. This effect depends on the heat storage value of the material, characterized by the volumetric specific heat (p X c, density time's specific heat). The building's heat capacity has significant effect on the indoor temperature and the cooling needs in situations where the outdoor daily maximum is often above the comfort range while the minimum is below it. This time lag increases with the density of the material and its heat storage capacity. The larger the heat storage value, the slower the temperature changes that is propagated through the material.

4 Thermal Physical Properties of Building Materials

The properties of building materials which affect the rate of heat transfer in and out of a building and govern the relationship between the indoor average temperature and swing and the corresponding outdoor air temperature pattern are its thermal conductivity, resistance and transmittance, surface characteristics–absorptivity, reflectivity and emissivity, surface convective coefficient, thermal conductance of enclosed air space, heat capacity and transparency to radiation of different wavelengths.

4.1 Conductivity and Resistance

Thermal conductivity is the rate at which a unit area of material of unit thickness will transmit heat from one surface to the other when there is a unit difference in temperature between them [6]. It is expressed in the metric system by λ, in W/m ·°C. It is assumed that the temperatures on either side of the material, and the distribution of temperature throughout the material, are uniform and constant with time (steady state conditions). The reciprocal of the thermal conductivity is the thermal resistivity of the material. Both conductivity and resistivity are independent of the size and thickness of the building elements. The actual heat flow across a given building element (wall or roof) depends not only on the thermal conductivity of the material, but also on the thickness (d) of the element. The greater the thickness, the lower the rate of heat flow. Therefore the thermal resistance (r) of the element (i.e. its resistance to heat flow) is defined by:

$$r = \frac{d}{\lambda}$$

Similarly, the thermal conductance of the element (c) is given by:

$$c = \frac{\lambda}{d}$$

In calculating the rate of heat flow between the indoor and outdoor air, the thermal resistance of air layers adjacent to the surfaces must also be taken into account. A film of still air forms on any surface, its thickness decreasing as the velocity of the adjacent air increases. As the thermal conductivity of air is very low, and consequently its resistivity high, the air film attached to a surface gives an appreciable resistance to heat flow across that surface [7]. The U-value is the inverse of the total resistance to the flow of heat of all the surface, layers, and cavities in the thickness of a building element from the outdoor air to the indoor air. The U-value will determine the rate of gain (or loss) of heat through a unit area of wall or roof per unit difference in air temperature on the two sides. Since the U-value determines the rate of flow of heat for a constant difference in temperature, it is only valid for what is described as a 'steady state' condition. This is not likely to be found in practice as there are likely to be small but continuous variations in both internal and external air temperatures. However there are conditions which are close to the 'steady state' and the U-value can also be used to determine the rate of heat loss or gain for an average difference in temperature over a long time period. Hence, normally, U-value is used as an index to evaluate the thermal insulation of roofs and walls. In many countries in the world, there are clear requirements of the wall and roof U-value. According to China ministry of construction document [8], when outdoor mean air temperature during heating period is 1 to 2°C, the regulation of U-value for Roof is 0.8 W/Km2; for exterior wall is 1.1 W/Km2; for windows is 4.7 W/Km2. While, when outdoor mean air temperature is -12.1 to -14.5°C, the regulation of U-value for Roof is 0.4 W/Km2; for exterior wall is 0.52 W/Km2; for windows is 2 W/Km2.

S/No	Item	U value W/Km^2 Uk Canada	
1	Roofs	0.16-0.25	0.14-0.29
2	Walls	0.35	0.37
3	Windows	2.0-2.2	1.4-2.7

Since the U-value for dwelling building is related to the climate, people thermal sensation and country development and etc, the requirements of U-value are quite different among various regions and countries. To date, in Singapore, for air-conditioned buildings, the amount of heat gain through walls and roofs is controlled by Envelope Thermal Transfer Value (ETTV) requirement. The U-value of the roof and walls is one item in the equation to calculate ETTV [7].

ETTV = 12 (1-WWR) Uw + 3.4 (WWR) Uf + 211 (WWR) (SF) (CF)

Where WWR: window-to-wall ratio

Uw : thermal transmittance of opaque wall (W/Km2) – wall U-value

Uf : thermal transmittance of fenestration (W/Km2) --- fenestration

U-value

CF: correction factor for solar heat gain through fenestration

SC: shading coefficients of fenestration

However, for non air-conditioned buildings, there is no clear guideline governing the amount of heat gain through roof. For wall, there is only one that stipulates that the U value of external wall should not be more than 3.5 W/m2K [5].

4.2 Surface Characteristics of Façade Materials---Absorptivity, Reflectivity And Emissivity

The external surface of any opaque materials has three properties determining behavior with respect to radiant heat exchange, namely its absorptive, reflectivity and emissivity. For transparent and semi-transparent materials, the transmittance is also a property related with radiant heat exchange.

4.2.1 Reflectivity And Absorptive Of Façade Material

Radiation impinging on an opaque surface may be absorbed or reflected, being fully absorbed by a perfectly black surface and fully reflected by a perfect reflector. Most surfaces, however, absorb only part of the incident radiation, reflecting the remainder. If the absorptivity is denoted by r and the reflectivity by α, then

$$r + \alpha = 1$$

For the transparent and semi-transparent materials,

$$r + \alpha + \tau = 1$$

where τ is the transmissivity.

The albedo of a surface is defined as its reflectivity, integrated hemispherically and over wavelength. The albedo α is defined, with reference to a spherical coordinate system, as [10]:

$$\alpha = \frac{\int_{\lambda_1}^{\lambda_2}\int_0^{2\pi} I\uparrow \cos\theta d\omega d\lambda}{\int_{\lambda_1}^{\lambda_2}\int_0^{2\pi} I\downarrow \cos\theta d\omega d\lambda}$$

Where ***I*** is the radiant intensity (W/m2), θ is the zenith angle, defined as the angle between the normal to a surface and the incident beam, λ is the wavelength and ω is solid angle, defined as the ratio of a partial spherical area of interest to the square of the sphere radius. The up and down arrows indicate the reflected and incident radiation respectively. The albedo of one material varies with the solar radiation. The sun emits a very broad range of wavelengths of radiation. These wavelengths can be divided into 3 ranges --- Ultraviolet, Visible light and Near-infrared. The Ultraviolet (UV) range extends from 300 to 400nm, the visible light (VIS) range from 400 to 720nm, and the near-infrared (NIR) range from 720 to 2500nm. The distribution of the solar radiation energy against the wavelength is shown in the graph below (Figure 2.1).

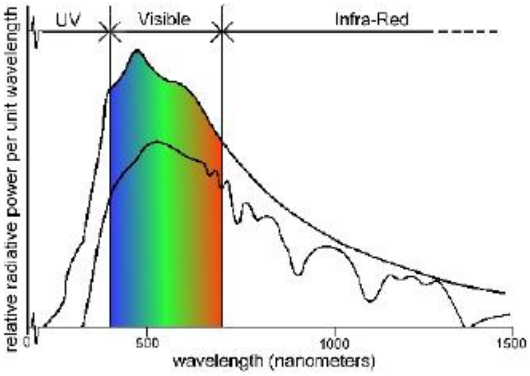

Figure 2.1. Distribution of solar radiation energy

In Figure 2.1, the upper line represents the distribution of the intensities of solar radiation wavelengths reaching the Earth's atmosphere. As this radiation penetrates the atmosphere, scattering processes and absorption by ozone, water vapour and oxygen molecules modify the intensities of the different wavelengths, resulting in a distribution given by the lower line below. This is known as 'attenuation'. The total solar power reaching the earth's surface (represented by the area under the lower line) is known as incoming solar radiation or 'global' radiation. Base on the standard spectrum the energy is distributed 5% UV, 46% visible, and 49% in the near-infrared. The albedo is one of the dominant parameters which can determine the material external surface temperature. Taha *et al.* measured the albedo and surface temperatures of a variety of materials used in urban structures. They found that white electrometric coatings with an albedo of 0.72 were 45K cooler than black coating with an albedo of 0.08 [10]. They also reported that a white surface with an albedo of 0.61 was only 5K warmer than ambient air, whereas conventional gravel with an albedo of 0.09 was 30K warmer than the air. Taha *et al*. also correlated the solar absorptivity of specific materials with their surface temperature when the materials were in horizontal position at noon on a clear, windless summer day in Austin, Texas (Figure 2.2). As shown in figure2.2 below, the temperature difference between white and black coatings is close to 45K and that between concrete and asphalt 20K.

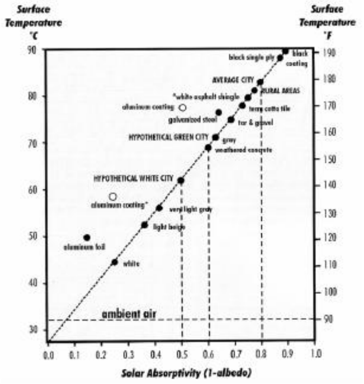

Figure 2.2. Solar absorptivity plotted against the surface temperature of horizontal surface for paints, roadways, roofing materials and cities; data refer to moon on a clear windless summer

Since roof temperature is a key parameter which essentially determines the heat leakage through the roof insulation into the space below, many studies on the impact of roof material abedo on roof temperature and the energy savings have been done. Taha *et al*. reported the surface temperatures of two-inch polyurethane roofs coated with various colours in Texas, USA, during August [13]. The result is showed in the Figure 2.3 below.

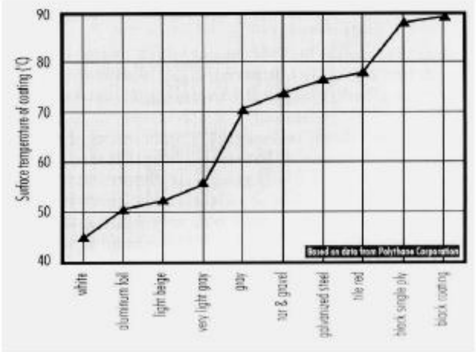

Figure 2.3 temperature for various coating (adapted from Taha *et al*

As shown in the graph, the surface temperature of the white coatings was close to 45°C, while the corresponding temperature of the black coatings was almost double this. To deal with the heat load on buildings caused by solar irradiation of the exterior envelope, radiation control coatings are fundamentally appealing. Defined as coatings with initial solar reflectances greater than 80%, they reflect a large fraction of the solar irradiation away before it is absorbed in the exterior surface of the envelope. They mitigate the need to retard the rate of heat transfer through the envelope by use of insulating materials or radiation barriers. Considerable energy can be saved through this way. The experimentation with model roofs and side-by-side testing of roofing structures has been performed at Oak Ridge National Laboratories (ORNL) [11]. This work found that reflective roofing systems can significantly reduce the heat flux through roofs and inferred that such surfaces may potentially reduce building cooling loads. A highlyinstrumented test building showed that reflective coatings reduced the peak heat flux on the underside of the roof decking by up to 82W/m2 relative to a blackcolored EPDM roof section [11]. This represented a reduction in overall roofrelated cooling load of 75%. In a 465m2 structure without roof insulation this would represent a reduction in the building thermal load of 10.8 tons (38KW) of air conditioning. The field research at the Florida Solar Energy Center has examined the effect of reflective roof coatings on submetered air conditioning consumption in a series of tests in nine homes in Florida. Coatings were applied to the residences at midsummer after an initial period of monitoring. Using weather periods with similar temperatures and insolation, air conditioning energy use was reduced by 2-43% at the various sites. The average drop in space cooling energy use was 7.4kWh/d or 19% of the pre-application air conditioning consumption. Utility coincident peak electrical demand reduction between 5 and 6pm varied from 201 to 988W (12-38%). Average peak reduction for the five homes with data averaged 427W or 22% [13]. Besides provide the energy benefit, the high albedo also lessens the degradation of envelope materials caused by high temperatures and thermal stresses as well as ultraviolet radiation. While these are necessary for the building façade system to keep its primary function which is to protect the underlying structure from the weather for a long period of time at a low cost.

4.2.2 Emissivity of Façade Material

All surfaces emit thermal radiation. However, at any given temperature and wavelength, there is a maximum amount of radiation that any surface can emit. If a surface emits this maximum amount of radiation, it is known as a blackbody. Most surfaces are not blackbody emitters, and emit some fraction of the amount of thermal radiation that a blackbody would. This fraction is known as emissivity. If a surface emits ½ or 0.5 as much radiation at a given wavelength and temperature as a blackbody, it is said to have an emissivity of 0.5. Obviously, a blackbody has an emissivity of 1.0 at all temperatures and wavelengths. For any specific wavelength, absorptivity and emissivity are numerically equal, *i.e*. α=ε, but both may vary for different wavelengths. Every surface emits radiation with a spectral distribution and intensity dependent on its temperature; radiation emitted by surfaces at ordinary temperatures is in the far infra-red range of the spectrum. There are well known equations, such as Plancks Law that can be used to calculate the amount of radiation emitted as a function of wavelength and temperature.

$$q_r = 4.9\varepsilon(\frac{T}{100})^4$$

Where qr is the total intensity of radiation emitted by a body, given in kcal/m2;

ε is material emissivity;

T is the absolute temperature in °K.

The emissivity of a perfectly black surface is 1.0; for other surfaces values range from 0.05 for some highly polished metals, to about 0.95 for ordinary building materials. Radiation is absorbed selectively, according to the wavelengths incident on the surface. Thus a fresh whitewash surface has an absorptivity of about 0.12 for solar radiation but the absorptivity for longwave radiation from other surfaces at ordinary temperatures (peak intensity 10μ) is about 0.95. Consequently this surface also has an emissivity of 0.95 for ong wavelengths, and is a good radiator, readily losing heat to colder surfaces; but at the same time it is a good reflector for solar radiation. On the other hand, a polished metal has a very low absorptivity and emissivity for both solar radiation and longwave radiation. Therefore, while being a good reflector of radiation, it is a poor radiator and can hardly lose its own heat by radiative cooling. The colour of a surface gives a good indication of its absorptivity for solar radiation. The absorptivity decreases and the reflectivity increases with lightness of colour. But colour does not indicate the behaviour of a surface with respect to longer wave radiation. Thus, black and white paints have very different absorptivities for solar radiation and a black surface becomes much more heated on exposure to the sun. But the long-wave emissivities of the two colour are equal and are therefore cooled equally at night by radiation to the sky [7]. Although emissivity in one important surface characteristic, some studies show that the impact of emissivity on the temperature is not obvious. Oke *et al.* simulated the effect of the optical and thermal characteristics of the materials used to the heat island intensity during the night and found that the role of emissivity is minor [8]. As the emissivity increased from 0.85 to 1.0, there was a slight increase of 0.4K in ΔT between the urban and rural environment for very tight canyons, while there was almost no change for higher view factors.

4.3 Surface Convective Coefficient

The convective heat transfer coefficient depends upon airflow velocity, the surface and air temperature, the roughness of the surface, position of the building component (horizontal or vertical).

4.4 Thickness of Building Element

The actual heat flow across a given building wall or roof depends not only on the thermal conductivity of the material, but also on the thickness of the element, decreasing with increasing thickness. The experimental studies conducted by Givoni on the effect of colors on external and internal surface temperatures of wall, made of concrete with different thickness, showed that the white wall of 22 cm thickness the indoor maximum was below outdoors' maximum and for the wall of 12 cm thickness the indoor maximum a little above the outdoors' maximum [5].

4.5 Surface Roughness

In the study carried out to estimate the importance of roughness for asphalt shingles coated with white aerosol coating shows that the rougher surface has only about 3/4 of the reflectance of the smooth surface [17].

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