International Journal of Scientific & Engineering Research, Volume 6, Issue 7, July-2015
ISSN 2229-5518

Editing the Solar Radiation values during all Stages of Building Projects in Sudan

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Abstract - This paper draws the attention of the structural designers and architects to the importance of employing the environmental data in all design and construction stages of buildings. The paper dispelled the fact that final design of buildings cannot be performed ignoring the environmental data and solar radiation, especially in Sudan asone of the hot-dry tropical regions. In that respect, the paper focused on the introduction of the solar radiation values that are received by the buildings during the day into the selection of most suitable construction material, as well as the design of thermal insulation thickness for walls and roofs of buildings at Khartoum State in Sudan.

The paper assumed the walls and roof are the media of heat exchange between the internal space and the climate, excluding the building floors. The traditional heat transfer equations were used for estimating the main values of thermal conductivity at the level of the building and not the region. The paper also minded the financial situation of the owners and assumed three thermal levels for a building in the study area at Khartoum State. Inside and outside temperature measurements on a study building, which is insulted using thermal level three, are presented.

The results showed that the thermal design of concrete sections qualifies it for operation with high efficiency by reducing the primary and secondary loads. Moreover, it raises the lifetime of the building and avoids the phenomenon of creep. On the other hand, the paper concluded that: reduction in the solar radiation by 20% to 40% will reduce the building thermal operational cost by same percentage. Also the paper puts preliminary steps towards establishing measures to assess the thermal performance of any building according to: thermal conductivity, solar radiation and latitude. Emphases for interaction and integration of the role of architect, civil, material, and air-conditioning engineers must starts in the early stages of building projects specially at the hot-dry regions.

Index Terms— solar radiation, hot-dry tropical regions, building projects, heat transfer coefficient, thermal energy, heat insulation.

1 Introduction

Thermal design of buildings is nowadays becoming one of most important sciences in modern building designs. It is high time to consider thermal design as part of the basic design process of buildings. Editing thermal data into all stages of building design and construction is essential since in most cases it is notices that the final outcome from thermally designed building projects are usually different from projects designed and constructed without editing thermal data during design stage, [1], [2].

Editing the thermal data prior to design is a common practice used by other designers, e.g. bridge designers. Thermal effects should be edited as basic input design data in design of bridges, especially for continuous bridges and jointless (integral) bridges where thermal expansion and contraction exerts tremendous forces which cannot be ignored. Figure 1 shows the effect of temperature change in the maximum bending moment on three integral bridges designed and constructed recently in Sudan, [3].

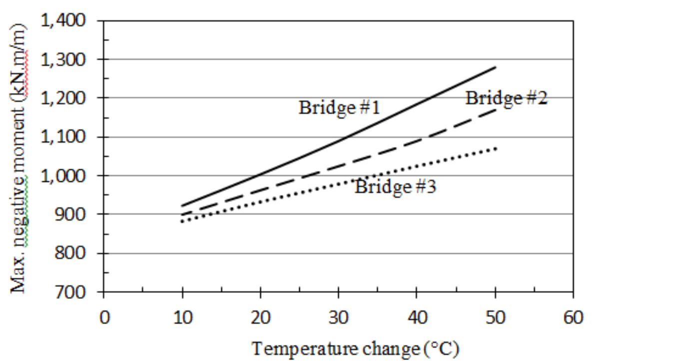

Figure 1. Effect of temperature change in the moments at 3 integral bridges in Sudan

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The three bridges are composed of 5, 4, and 3 equal spans, respectively. Note that although the spans between supports are equal for the three bridges (= 17m) the values of bending moments considerably varies because of thermal expansion and contraction due to daily and seasonal temperature change.

Design and construction stages of buildings comprise briefing and planning stage, design stage, implementation stage, and operation and maintenance stage.

In the briefing and planning stage initial ideas and feasibility of the building project are agreed to with the owners. Mistaken design, planning and/or design of building may result into high construction and running costs, longer construction time and insufficient performance. Editing the environmental data in this stage means establishing necessary climatic data which help in proper allocation of the buildings such that they are always subjected to minimal day-time heat radiation concerning countries in tropical regions, like Sudan. It is noticed that planning regulations in many tropical hot–dry countries do not interact with the effect of climate. Hence, it is not recommended to rely on such regulations during briefing and planning stage of building projects.

The design stage is usually concerned with all details of the project. This paper concentrates on the importance of considering the thermal effects on the structural analysis and design of building projects where working stress and ultimate limit theories are usually applied. Bear in mind that the factor of safety is increased when the structural performance is uncertainly assured and when the quality control of construction is insufficient. Such designs with high factor of safety result into excess materials that add to the dead weight of the building and adopt unused material for all building life-time. The thermal design of the thermal insulation help in achieving better performance of the building material, e.g. steel and concrete, by reducing the effect of the secondary loads which include, in many codes of practice, temperature loads, [4], [5].

The implementation of the project comes after completing the planning and design stages. Proper editing of thermal data will reduce the quantity of material used in the construction and hence reduces the construction time with no additional costs.

Thermal design of building projects usually reduces the maintenance cost by increasing the maintenance interval time during the operation and maintenance stage. Also proper thermal design can reduce the building operational cost by 20 to 40 %, [2].

This paper shows how environmental data is edited into all stages of building projects stages and the effect of editing the environmental data into the structural analysis of the buildings. Comparison of past researches with practical applications in Sudan, specialized studies usually tend to bind the owners' building projects with assumed thermal conductivity; this paper dispels the deficiency of such procedure. Table 1 shows values of Heat Transfer Coefficient (HTC) for residential buildings is some countries, [6].

TABLE 1
TOTAL COEFFICEINT OF HEAT TRANSFER FOR RESIDENTIAL BUILDINGS IN SOME COUNTRIES

No.	Country	Total Heat Transfer Coefficient ($W/m^2.°C$)		
		Walls	Roof	Floor
1	England	1.14 ~ 0.85	1.70 ~ 1.14	0.85
2	France	1.99 ~ 1.14	1.20 ~ 0.09	2.10 ~ 1.42
3	Nederland	0.97 ~ 0.68	0.97 ~ 0.68	0.97 ~ 0.68
4	Canada	0.85 ~ 0.57	0.68 ~ 0.47	0.85 ~ 0.57
5	Scandinavians	0.90 ~ 0.68	0.57 ~ 0.46	0.57 ~ 0.46
6	Cooperation Council for Arab States of the Gulf	0.744	0.570	-

Note that Table 1 does not include HTC for Sudan. It seems no local authority ever assumed such coefficients. This paper intends to propose HTC for walls and roof in three levels for Khartoum State (15° 33' 59" N, 32° 30' 59" E). In fact, this paper ascertains the methodology suggested in reference [2] where it was found that assuming values for thermal conductivity do not give successful heat insulation because of the following reasons:

i. Values of heat conductivity vary with the capacity of the concerned area, type and function of the building, and on the financial situation of the owner.
ii. Efficiency of the heat insolation available in the local market varies according to the supplier and brand.

2. RECEIVED THERMAL ENERGY

The received thermal energy by buildings in the hot-dry regions is the main source of unfavorable high temperature inside the building. To bring room temperature to the comfort temperature (20 to 25 °C), [7], all the surfaces of the building which transfer heat shall be thermally insulated. It this recommended in this paper to design the thermal insulation according to three levels as follows: for the first level use the received energy as calculated for the building and location; for the second and third levels use reduced energy by reduction factors namely: equals 0.8, 0.6 (respectively) depending on the financial situation of the owner, the type of building uses, and the thermal insulation cost compared with the cost of air conditioning. In other words, in the design of the building heat insulation use 100%, 80% or 60% of the received energy for the three levels, respectively.

The received thermal energy is usually calculated using the following known equation:

$$Q = A\,u\,(T_o - T_i) = A\,u\,\Delta T \quad (1)$$

Where:

Q = Received thermal energy by heat transfer (Watts)
A = Outer surface area of the building (m^2)
u = Total heat transfer coefficient ($W/m^2.\ °C$)
T_o = Air temperature outside the building (°C)
T_i = Air temperature inside the building (°C)
ΔT = Temperature difference between outside and inside the building (°C).

The thermal resistance for the study building is calculated by:

$$R_2 = \frac{1}{u} \quad (2)$$

Whereas the resistance required for thermal insulation design of the walls and roof is given by:

$$R = R_2 - R_1 \quad (3)$$

Where R_1 = Thermal resistance of the structure's members.

The thickness of heat isolator, d, can be calculated from the following equation:

$$d = R\,k \quad (4)$$

k = the thermal conductivity of the heat insulator ($W/m^2.\ °C$) obtained from Tables 2 and 4.

Study on correlation between thermal conductivity and the thickness of selected insulation materials for building wall, [8], found that a relationship between the thermal conductivity, k, and optimum thickness of insulation material, dopt, is non-linear which obeys a polynomial function of:

$$d_{opt} = a + bk + ck^2 \quad (5)$$

Where $a = 0.0818$, $b = -2.973$, and $c = 64.6$. Equation (5) will be very useful for practical use to estimate the optimum thickness of insulation material in reducing the rate of heat flow through building wall by knowing its thermal conductivity only.

3. APPLICATION TO STUDY BUILDING

An existing two floor building at Shambat (10 km to the north of Khartoum city center) is subjected to study the effect of using reduced heat insulation, within the exterior walls and the roof, on the reduction of inside room temperature. The building comprises roof area equals 330 m^2 and outer total surface area = 240 m^2 per floor.

In view of the high cost of polystyrene (1 cm thick costs about 3 Euros per m^2) the owner of the study building asked for reduction of the insulation thickness from design value (6 cm) to 4 cm. Figure 2 shows typical cross section at exterior walls of the study building. Table 2 shows the average readings of temperature difference between outside and inside three of the building rooms taken at 2:00 PM (local time) in many days during summer season of 2014. Double glazed windows are used in the exterior walls of rooms #1, #2 and #3 with section as follows: two leaves of 4 mm thick semitransparent glass sheets with 3 mm air gap between leaves. Note that room #4 is a reference room with wall thickness = 20cm, plastered at inside and outside faces and no thermal insulation is used.

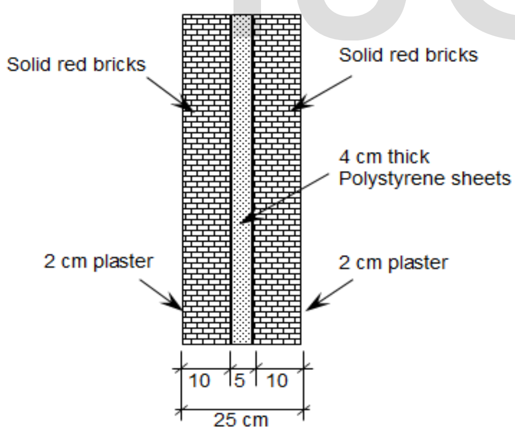

Fig. 2. Typical cross section at walls of the study building in Khartoum State

One can notice that: without using air conditioning the temperature dropped 5 to 6 °c when using 60% reduction in thermal insulation thickness; compare with 2.3 °c temperature drop recorded at reference room #4. This result supports the fact of heat insulation can be designed, in some circumstances, while bearing in mind the financial situation of the owners and the cost of insulation materials compared with cost of energy used in air-conditioning to bring inside temperature to comfort levels.

Table 3 shows the hourly solar radiation averaged from the last 10 years readings at Shambat Meteorological Station for May. May is the climatic design month for the region used for the experimental and theoretical investigation. The weather is sunny, hot, and dry in this month.

TABLE 2
TEMPERATURE MEASUREMENTS ON FOUR ROOMS IN THE STUDY BUILDING

Room No.	Plan area (m^2)	No. of sides exposed to outside hot air	Surface area exposed to outside hot air (m^2)	Area of windows (m^2)	Percentage ratio: area of windows/walls (%)	Temperature difference between inside and outside (°C)
1	16.6	1	12.8	2.4	18.7	5.0
2	18.9	2	28.8	3.9	13.5	6.0
3	37.6	3	60.8	8.5	13.9	5.7
4	16.6	2	32.0	4.5	14.0	2.3

TABLE 3
HOURLY SOLAR RADIATION IN MAY FOR KHARTOUM, (W/m^2)

Hours of the day												
AM					Noon	PM						
7	8	9	10	11	12	1	2	3	4	5	6	7
350	368	390	409	500	578	633	790	950	833	760	620	550

The cooling load is originated from the heat transfer through walls and the roof by convection conduction, and the solar radiation absorbed by the building walls and the roof.
It is worthwhile mentioning that the hourly solar radiation is, to some extent, not suitable for thermal design of buildings because of the wide temperature variations around the year in the hot-dry regions, [2]. Hence, adopting more realistic procedure for such design is sometimes inevitable. In the following sections more rational method for design of heat insulation will be presented.

The temperature difference may be moderated by:

i. Shading of adjacent buildings or walls and roof exterior.
ii. Use of different materials with different thermal expansion and heat transfer coefficients, or use of higher insulation thickness, especially for the roof.
iii. Use of different shapes of cross-section that directly exposed to the sun.

4. DESIGN OF THERMAL INSULATIONS FOR THE STUDY BUILDING

Table 4 shows the basic physical data regarding some building materials and thermal insulation materials usually used in the study area.

Tables 5 and 6 give the thermal conductivities, thermal resistance and possible thickness of insulations calculated using the above equations for the study building regarding the three suggested levels:

Notes: the roof is composed of: reinforced concrete hollow core slab of total thickness = 25cm (Ratio of hollow block to total roof area = 0.32), 2cm thick sand/cement plaster at inner face, and 2cm thick polystyrene sheets fixed at outer face. Polystyrene thickness included for Level 1 is obtained using Equation (5).

TABLE 4
PHYSICAL PROPERTIES OF SOME INSULATION MATERIALS USED IN SUDAN, [6]

No.	Type of building material and heat insulator	Specific heat (Joule/kg/°C)	Unit weight (kN/m³)	Thermal conductivity (*k*)
1	Khafgi*	1100	10.0	0.35
2	Concrete	653	23.0	0.93
3	Red solid bricks	829	17.9	0.60
4	Red hollow bricks	2000	8.5	0.55
5	Gypsum	1080	12.0	0.43
6	Wood	1900 ~ 2700	3.7 ~ 11.0	0.11~ 0.25
7	Polystyrene	3500	0.15 ~ 0.30	0.03 ~ 0.04
8	Cement/sand Plaster	900	13.0	0.50

* *Khafgi is a locally used damp proof course and heat insulator made from mixture of: sand, cement, crushed red bricks, and lime. [2]*

TABLE 5
THERMAL INSULATION FOR ROOF OF THE STUDY BUILDING

Type of thermal insulation	Thermal conductivity (*k*, W/m².°C)	Thickness of insulator, *d*, (cm)		
		Level 1	Level 2	Level 3
Concrete + hollow block	0.550	-	-	-
Polystyrene	0.037	4.0	3.0	2.5
Red solid bricks	0.600	-	-	-
Gypsum	0.430	-	-	-

TABLE 6
THERMAL ISULATION FOR WALLS OF THE STUDY BUILDING

Type of thermal insulation	Thermal conductivity (λ, W/m².°C)	Thickness of insulator, *d*, (cm)		
		Level 1	Level 2	Level 3
Red clay hollow block	0.93	-	-	-
Polystyrene	0.60	6.0	4.8	3.6
Red clay solid bricks	0.55	20	20	20
Plaster at two faces		4	4	4

5. CONCLUSIONS

The following conclusions are drawn from this paper:

i. Editing the environmental and thermal data into all stages of building projects reduces the secondary loads induced by creep, expansion and contraction effects on the building materials, hence adding better to the buildings durability and performance.

ii. Thermal design of buildings reduces some 25% of air pollution by reducing heat radiation and pollutions resulting from thermal production of electricity.

iii. It is recommended always to attach the thermal design of buildings together with the architectural and structural designs when applying for building permits from local authority in hot-dry regions on way to guarantee application of the this paper outcomes.

iv. Thermal design of heat insulation at buildings can be categorized, at will, according to the financial ability of the owners relative cost of thermal insulation compared with air-conditioning cost.

v. Editing the thermal data in the design stage of building projects can reduce up to 20% of the dead loads by reducing the concrete sections when using light weight finishing materials and hollow core slabs with high thermal performance.

vi The interaction and integration of the role of architect, civil, material, and air-conditioning engineers must starts in the early stages when designing energy-efficient residential buildings for hot climate.

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