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Thermal Load Calculations of Multilayered Walls

Bashir M. Suleiman

***Abstract*—**Thermal load calculations have been performed for multi-layered walls that are composed of three different parts; a common (sand and cement) plaster, and two types of locally produced soft and hard bricks. The masonry construction of these layered walls was based on concrete-backed stone masonry made of limestone bricks joined by mortar. These multilayered walls are forming the outer walls of the building envelope of a typical Libyan house. Based on the periodic seasonal weather conditions, within the Libyan cost region during summer and winter, measured thermal conductivity values were used to implement such seasonal variation of heat flow and the temperature variations through the walls. The experimental measured thermal conductivity values were obtained using the Hot Disk technique. The estimation of the thermal resistance of the wall layers (R-values) is based on measurements and calculations. The numerical calculations were done using a simplified analytical model that considers two different wall constructions which are characteristics of such houses. According to the obtained results, the R-values were quite low and therefore, several suggestions have been proposed to improve the thermal loading performance that will lead to a reasonable human comfort and reduce energy consumption.

***Keywords*—**Thermal loading, multilayered walls, Libyan bricks, thermal resistance

I. Introduction

THERMAL load calculations of already constructed walls where much of the fine details may not be readily available, are possible only through the use of the very suitable and simplified methods. Using such methods, the calculation procedures are much easier to perform.

It is worth to mention that, there are two ways to calculate the R-value, namely the numerical and the simplified methods; however, the numerical methods are based on a detailed computer calculation that needs detailed input data and may include a non-uniform multi-dimensional heat flow [1-6]. In general, they involve detailed variations in heat flow in all three dimensions, however, it is almost always the case that the construction is uniform in one direction, in other words, the 3-dimensional effects do not significantly affect the overall R-value. In this work, a simple R-value calculations formula is used to estimate the R-values for outer multi-layered walls of a typical Libyan house that are based on concrete-backed stone masonry made of limestone bricks joined by mortar. These bricks are excavated from two major places (mines) in the north eastern province of Libya. These bricks were the building blocks of houses built during the seventies (1970's) with the lack of any technical data on the construction materials such as the thermal properties of the individual components of the wall structure. Thus they were built without performing thermal load calculations or considering any insulation measures. This made the house very unpleasant to occupants during both hot and cold seasons.

Bashir M. Suleiman, Applied Physics Department, College of Sciences, University of Sharjah, P. O. Box. 27272, Sharjah, UAE. (phone: 971-6-5050374; fax: : 971-6-5050352; e-mail: bashir@sharjah.ac.ae).

Therefore, technical data such as R-values within the structure of such buildings are essential for the calculations of thermal loads and/or estimating energy consumptions for the purpose of energy savings. Furthermore, such calculations could provide basis for insulation materials manufactures to produce suitable insulation materials that can be used to improve the thermal performance of such houses.

II. The Walls Description

The multi-layered walls are composed of three different parts; a common (sand and cement) plaster, and two types of locally produced soft and hard bricks, see the picture depicted in Fig. 1. The bricks are excavated from two major rock mines used as a supply of solid building bricks. The plaster sample was peeled off the walls then cut into the desired dimensions for thermal conductivity measurements. The values of thermal conductivities of the three parts (samples) were measured using the Hot-disk technique [7-8]. Each sample consists of two different disc-shaped pieces with diameter in the range of 7-10 cm and a thickness in the range of 2-2.5 cm. The samples have an average apparent densities ranging from 1444-1970 kg/m^3. These values were calculated using the dimensions (volume) and masses of the individual samples. A characterizing parameter such as porosity can also be estimated, using the following formula: $r = 1- (\rho_{ave}/ \rho_{cal})$.

Where, ρ_{ave} is the average apparent density of the sample pieces, and ρ_{cal} is the calculated density based on the atomic weights of the constituting atoms and the dimensions of the unit cell. However, these samples contain micro-voids and composed from large diversity of its individual constitutes (compounds and elements) and it was not possible to estimate the porosities of the samples. To illustrate this large diversity a preliminarily x-ray scan at room temperature of the non-homogeneous plaster sample is depicted by the optical image in Fig. 2. The X-ray was preformed as first run of the recently installed energy dispersion X-ray fluorescence (EDXRF) analyser at the National X-ray Fluorescence Lab in our Department at the University of Sharjah. The analyzers is of The HORIBA XGT-7200 type includes a 1.2 mm x-ray beam , high pure Si detector and a Nai(Tl) scintillator as transmitted X-ray detector. K_α lines of Rh target were used for characterization of elements. The X-ray beam was controlled according to the optimal condition of the spectral lines. The automatic computer control of the X- ray generator allows the 50 kV and 1 mA settings to be adjusted automatically. The indexation of the peaks and the mass % of the individual elements were determined using the provided data base through the software Emax, see table I.

TABLE I
THE BASIC ELEMENTS COMPOSITION OF THE PLASTER SAMPLE

Element	Mass %	Element	Mass %
Mg	3.96	Ti	0.33
Al	3.99	Cr	0.07

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Si	13.84	Mn	0.05
S	1.78	Fe	2.94
K	1.94	Zn	0.02
Ca	71.01	Zr	0.06

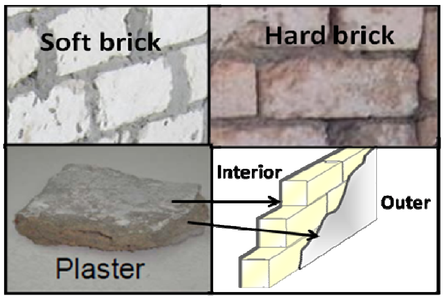

Fig. 1 Actual pictures of brick types and the plaster

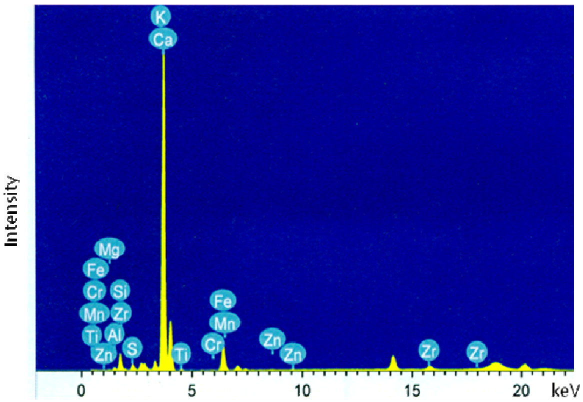

Fig. 2 The X-ray fluorescence (EDXRF) spectrum of the plaster sample

In general, the estimated porosity values should be proportional to the apparent densities. Table II, gives the detailed parameters characterizing the samples including the apparent densities.

TABLE II
CHARACTERISTIC PROPERTIES OF THE BUILDING MATERIALS OF THE MULTI-LAYERED WALL

Material	Thickness (m)	Thermal conductivity (W/m-K)	Density (kg/m^3)
Plaster	0.020	0.658	1708
Limestone Hard	0.200	1.533	1900
Limestone Soft	0.200	0.751	1444

III. The Theoretical Model

The simplified model, according to standards, it involves one-dimension calculations of the upper and the lower limits of thermal resistance R_T of the wall layers. The thermal load calculations of the layers (the arithmetic mean of these two limits) can be used to estimate the expected thermal load of the wall. The results should lie within these limits, provided the difference between the limits is not too large. If we consider multilayered walls with simplified index, to represent the total heat-transfer processes, the *R*-value or total thermal resistance of the wall is given by

$$R_T = \sum_{i=1}^{N} \frac{x_i}{\lambda_i} \qquad (1)$$

Where, N is the total number of layers, with x_i referring to the thickness and λ_i the thermal conductivity of each layer.

As first approximation, the overall heat-transfer Q_T through an area A and within a temperature difference ΔT, then can be estimated by:

$$Q_T = \frac{A\Delta T}{R_T} \qquad (2)$$

This equation has been considered as a useful tool and is often used to estimate the heat transfer. It assumes steady state heat conduction and ignores the dynamic aspects of material behavior and spatial differences. In order to include the dynamic aspects of material behavior with spatial differences, the variations of thermal conductivity with temperature should be included [9-11]. In this work, the thermal conductivity values of the investigated sample materials were measured in the laboratory at fixed temperature value of 25 ^oC, therefore, our analysis was limited to using Eq.(1) to estimate R_T values of the layers. Since such layered walls are forming the house outer envelope, it should be mentioned that a more detailed calculation should involve the effect of energy savings through the heating, cooling and ventilation system (HCVS). These buildings have no HCVS and the full detailed information (fine details) was not available, in fact only recently they have been equipped with the split-unit air condition type. Due to the present legislative technical difficulties, the thermal conductivity measured values were the only readily source of data that can be used. Therefore, it was not possible to do such detailed calculations. In relation to the handbook of air conditioning [12], the cooling load (QC) of the building should be possible to estimate using such split-unit conditioners. According to ref. Hatamipour et al. [13], to estimate the total cooling load the effect of several parameters should be considered according to the following equation:

$$QC = QT + QS + QI + QA$$

where, QT is the transmission cooling load due to heat transfer from exterior walls and envelopes, QS is the solar cooling load due to sun radiation transmitted from windows, QI is the internal cooling load due to heat generated by appliances, persons, etc. and QA is the cooling load due to airflow into the building (sensible and latent heat). For each of above terms some well-known equations are developed and can be used with care [13].

We are planning for possible future work to incorporate some of the fine details in the thermal load calculations including the effect of intensity of the solar radiation through the windows. This can be done by incorporating a network of temperature and humidity sensors within and around the walls to collect data and build a data-base of information throughout the year.

IV. Discussion and Results

The Hot Disk technique was used to measure the thermal conductivity of these materials at an average room temperature of 25 ^oC. Depending on the time of the day and the seasonal variations, in the eastern costal province, the average outer walls surface temperature can vary from 40 to 10 ^oC. The thermal conductivity of these samples was measured at around 25 C^o, this value is a good approximation to the average temperature of the local climate average temperature. Looking at the temperature variations in the northern part of the country, in the hot summer days the temperature will not exceed 40 degrees and in cold winter nights it will not go below 10 degrees. Thus measuring the thermal properties of the materials at room temperature gives a good approximated average value of the thermal conductivity, and hence all measurements were performed at an average temperature of 25 ^oC. These measurements were done on isotropic basis with respect to micro-voids distributions in the sample matrix.

These materials are the building blocks of the multi-layered wall, which is the major component of the house envelope, namely the outer walls. The outer walls are of traditional masonry type based on concrete-backed stone masonry made of limestone bricks joined by mortar and covered from both sides by common (sand and cement) plaster layers of 20 mm each, see the schematic drawing in Fig.3. The actual pictures of soft and hard bricks external walls network with and without the plaster layer are shown in Fig.4.

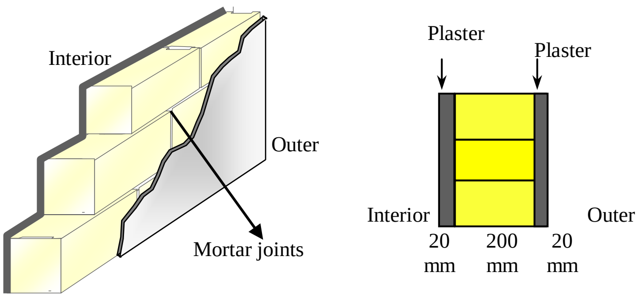

Fig. 3 A schematic drawing of the bricks type with the mortar joints network

Fig. 4 A group of buildings with exposed and non-exposed lime-stone external walls showing the mortar joints network and the plaster layers arrangement

The choice of these three samples was based on the fact that construction of the outer walls are the major components of the house envelope that effect the thermal load calculations. The construction materials of the roofs were not included due to the following two reasons:

First, most of these buildings are multi-stored and the effect is limited to the highest floor, which has different outer wall bricks (manufactured common cement type).

Second, the large variations of roof design in terms of their thickness, methods of constructions mortar types, iron (steel) networking and types of concrete used.

Table III shows the R_T of two types of external walls that were made of soft and hard limestone bricks covered on both sides by 2 cm thick plaster layers.

TABLE III
THE R_T OF THE LAYERED CONSTRUCTION WALLS AND THE CORRESPONDING ESTIMATED ANNUAL ENERGY CONSUMPTION E

Construction Element	Effective thickness(m)	R_T (m^2 k/ W)	E (kWh/m^2)
External wall(Soft bricks)	0.240	0.33	40.26
External wall(Hard bricks)	0.240	0.19	69.93

Based on R_T values an estimation of the annual energy consumption for a split unit air conditioning system is shown in the last column of table III, to be discussed.

We can see that the calculated R-values are quite low, especially for the hard brick type. These values are without including irregular thermal bridges such as concrete beams and/or regular (frequent) thermal bridges due to the mortar joints between the bricks. We may include the mortar joints in the calculation for both inner and outer sides of walls simply by treating the bricks layer as a bridged layer. The joints, to some extent, may increase the R-value if the difference in thermal resistance between bridging material and the bridged material is exceeding 0.1 m^2k/W. In our case, the differences are in the range of 0.1-0.25 m^2k/W. The mortar fraction between the bricks can be estimated using the ratio of the surface area of the brick with and without the mortar joints as follows:

$$\text{Mortar fraction} = 1 - \left[\frac{BL \times BH}{(\text{BL} + \text{JT}) \times (\text{BH} + \text{JT})} \right]$$

Where, BL is the brick length , BH is the brick height, JT is the joint thickness.

Using the dimensions (in meters) of the limestone bricks, as 0.40, 0.20 and 0.02 for length, height and joint thickness, respectively, the calculations lead to a mortar fraction of around 13% of the total surface area.

Furthermore, the possibility of including the surface resistances of naturally presented thin insulating layers of air at the inner and outer surfaces of the external walls, which are in the range of 0.03-.013 m^2K/W, may further increase the estimated R-values. Unfortunately, including these effects, namely mortar bridging and air insulations will not help very much and the R-values are still low and far from comfortable.

The annual energy consumption *(E)* given by the last column in table III was calculated using the following equation from ref. [10]:

$$E = \left[\frac{0.024\times D}{R\times C}\right] \text{kWh/m}^2$$

Where, D is the degree-days of the location (D = 1476); R is the thermal resistance of the construction element, and ($C = 2.65$) is the coefficient of thermal performance (COP) of a commonly used LG wall split unit air-conditioning system. The value of C was taken from the technical specification catalog for LG wall split unit 2.5 ton capacity / heating & cooling mode (model # S306GH). It is worth mentioning that the efficiency of hot and cold air conditioning systems is measured by a coefficient of performance (COP) - the amount of heat they generate compared to the amount of electricity needed to run them. A good quality air conditioning system can have a COP of around 3 to 1.(which means you can transfer 3 kilowatts of heat for 1 kilowatt of electricity).

The D value was estimated over a period of five years using the mean value of the heating and cooling degree-days of the location HLLB (Benina airport) in Benghazi-Libya (20.27E,32.10N)[14]. According to ref.[10],the E values can be used to calculate the total discount cost or the net present value per square meter of the construction elements.

Unfortunately, this requires parameters such as the present worth factor and energy discount/inflation rates that are not available for this type of walls.

It should be noted that R_T calculations were made at dry conditions, not including the moisture effect on the thermal conductivities of the individual materials and/or the overall thermal conduction of the walls. The source of this moisture may be caused by wind-driven rains, foggy weather conditions, or relatively high outside temperature leading to high humidity. Moisture effect on thermal conductivity had been estimated in a previous work [8].

The moisture has considerable effect on the conductivity of the materials, owing to the fact that liquid water has thermal conductivity which 25 times greater than that of air. In addition to that, it is the complexity related to moisture content that is associated with several factors such as mode of heat transfer (sensible and/or latent), the moisture location, arrangement of moisture in the building blocks, etc. Such factors result in considerable effect on the measured heat conduction. Because of the complexity, there are no tables which can state that for a given percentage of moisture in the material there will be a certain percentage increase in its conductivity. The only certain statement which can be made is that moisture in the liquid phase will increase the conductivity.

It is well known that the insulating value of most materials is greatly reduced by the presence of free water. Furthermore, it is generally agreed that the durability of masonry depends primarily on its resistance to the penetration of moisture into the body of masonry [15].

Therefore, we conclude that reliable insulation and/or vapor barriers are required for such buildings.

In this work, it is not possible to do quantitative analysis regarding the benefits of insulation/vapor barriers, however, there are two factors that could illustrate such benefits:

(a) The estimated values of the annual energy consumption depicted in table III are clear indication of the effective role of insulation barriers in reducing energy consumption.

(b) During hot season, vapor molecules in the form of moisture will flow into the building from the outside. Vapor barriers provide protection from external wind-driven moisture or bulk water penetration through capillary water breaks and /or micro-cracks in the wall structure. If buildings are not well ventilated during summer the indoor air quality could cause health hazard – mold conditions known as SBS, (Sick Building Syndrome). Thus, beside reduction in energy use, the benefits of improving indoor air quality are invaluable.

In general, adding insulation and vapor barriers to the walls will damp temperature fluctuations and prevent vapor penetration inside the house envelope and provide better comfort [16].

As it was stated in section 3, more detailed work of thermal load calculation that include other parameters and/or factors such as the thickness of insulation as well as the surface to volume ratio [17], the location and extreme weather conditions will be presented in the near future. However, according to the calculated R-values, the external walls of these houses are in need for proper assessment and building codes to select a suitable insulation scheme to improve their performance in terms of energy conservation and human comfort. As far as my knowledge, for the time being, there are no specific energy conservation building codes to promote energy efficient buildings in Libya; however, there are some universal rules to implement energy conservation and environmental issues. This work is a very small contribution to the basis of such codes that require extensive building simulations followed by detailed measurements in model building.

V. Conclusions

Two types of limestone bricks, and plaster used in the construction of typical multi-layered walls were used to estimate the R-values for the external walls in a Libyan house.

The external walls are of traditional masonry type based on concrete-backed stone masonry made of limestone bricks joined by mortar and covered from both sides by common (sand and cement) plaster layers of 20 mm each.

Including the surface resistances of naturally presented thin insulating layers of air at the inner and outer surfaces of the external walls will not increase the R-values more than few percentage. Furthermore, including the mortar bridging through the bricks have a little effect due to the fact that the mortar fraction surface area is less than 13% of the total surface area of the individual brick. It is anticipated that the situation is more severe if moisture reaches the walls and the insulating value is greatly reduced by the presence of free water.

The calculated R-values indicate that the external walls of these houses which are built using two types of bricks are in need for proper assessment to select a suitable insulation scheme to improve their performance and to make the houses pleasant and comfortable. Thus, this work might provide the basis for insulation materials manufactures to produce suitable and reliable insulation materials that can be used to improve the thermal performance of such houses. It should be noted that measurements made by laboratory test may not be truly indicative of the properties of the materials in service and aging effects on dimensional stability (ability to retain size and shape) should be anticipated. Finally, a more detailed work of thermal load calculation which includes other factors such as the location and moisture effect and extreme weather conditions should be investigated. In order to develop reliable building codes in Libya, it is recommended to do more detailed measurements in model building and extensive building simulations.

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