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Investigación de la resistencia térmica de ladrillos de arcilla perforados mediante modelos numéricos
A thermal resistance investigation of red colored perforated clay bricks by numerical modeling

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***Resumen*— Uno de los factores más importantes que afectan el comportamiento térmico de las paredes exteriores de la construcción es la conductividad térmica de ladrillos de arcilla huecos perforados horizontalmente que son ampliamente utilizados en muchos edificios en nuestro país. Los ladrillos que se encuentran comúnmente en las paredes exteriores tienen dimensiones de 13.5x19x19 cm. En este estudio, se eligieron para ser analizados dos tipos diferentes de ladrillos. Un tipo es un horizontal ladrillo hueco perforado estándar de esas dimensiones y el otro tipo es un ladrillo horizontal perforado hueco con las mismas dimensiones pero con sytropor instalado en algunos de los huecos. El efecto conjunto de la conducción y la transferencia de calor por convección natural en este tipo de ladrillo se estudió numéricamente para calcular la conductividad térmica general de los ladrillos y los demás aspectos tales como la producción y el diseño del ladrillo. La energía, el impulso, y las ecuaciones de transferencia de masa asociadas con los modelos de ladrillo se han resuelto numéricamente mediante el empleo del software comercial llamado ANSYS. La distribución de la velocidad del aire en los huecos y de la distribución típica de temperatura se muestran en las figuras, y se han determinado la conductividad térmica y la función de la diferencia de temperatura, y los resultados de conductividad térmica se compararon con los indicados en las normas. Los resultados muestran que las conductividades térmicas de los ladrillos con y sin sytropor son casi la mitad de los que figuran en las normas. Por lo tanto, se puede decir que los valores dados en la norma se consideran extremadamente conservadores. Los resultados también muestran que la convección natural que ocurre en las cavidades de aire afecta a la conductividad térmica por 0,046% y 0,068% en los casos de con y sin sytropor, respectivamente.**

Palabras clave — Ladrillos de arcilla; Transferencia de calor; Número de Grashof

***Abstract*—One of the most important factors affecting the thermal behavior of building exterior walls is the thermal conductivity of red fired horizontally perforated hollow clay bricks which are widely used in many buildings in our country. The bricks commonly encountered in the exterior walls have dimensions of13.5x19x19cm. In this study, two different types of the bricks were chosen to be analyzed. One type is a 13.5x19x19cm horizontally perforated standard hollow brick and the other type is a 13.5x19x19cm horizontally perforated hollow brick with sytropor board installed in some of the hollows. The conjugate conduction and natural convection heat transfer in these brick types was studied numerically to compute the overall thermal conductivity of the bricks and the further aspects such as the brick production and design were also investigated. The energy, the momentum, and the mass transfer equations associated with the brick models were solved numerically by employing the commercial software called ANSYS. The air velocity distribution in hollows and the typical temperature distribution were shown in figures, and the thermal conductivity as a function of temperature difference were determined and the thermal conductivity results were compared with those given in the standards. The results show that the thermal conductivities of the bricks with and without sytropor board are almost half of those given in the standards. Therefore, it can be said that the values given in the standard are considered to be extremely conservative. The results also show that the natural convection occurring in air cavities affects the thermal conductivity by 0.046% and 0.068% in cases of with and without sytropor board, respectively.**

Index Terms—Clay Bricks;Conjugate Heat Transfer; Grasshoff Number

I. INTRODUCTION

Perforated bricks are widely utilized as construction elements in buildings in our country. Thermal resistances of bricks to constitute the exterior surfaces of walls especially have a significant role to play on cumulative heat losses of buildings, since the heat transfer, either loss or gain is occurred through those elements. Therefore in optimizations, thermal resistances of bricks must be as high as possible in order to keep the heat losses–or gains below the determined regional values.

Thermal resistances of perforated bricks are calculated and published to use in engineering calculations by manufacturers considering the heat transfer is confined to occur in one direction, using a constant convection coefficient or assuming the air is within the cavity a steady solid. This calculation method commonly fails to represent the reality since it is a rough method of approach. Although some universities build representative walls using particular bricks of $1m^2$ total surface area to determine the thermal resistance of bricks experimentally, this method also lacks a sufficient compromise since mortar layers between bricks involve into the calculation, therefore hindering the analyst from obtaining a single bricks thermal resistance. Thermal resistances of perforated bricks are submitted in TS-825 regarding thickness of mortar layer on them but again leaving a single bricks thermal resistance undetermined. Besides, there are neither domestic nor international experimental or theoretical studies upon thermal resistances of perforated bricks commonly used in our country.

Coz Diaz et al. performed two studies, similar to this study in which they researched the heat transfer nature of various perforated concrete blocks (which are widely known as “briquette” in our country) used in walls as building elements through finite elements method. One of those studies (Coz Diaz, Garcia-Nieto, Rodriguez, Martinez-Luengas&Biempica 2006) emphasizes a wall of unit area ($1m^2$) constructed using perforated concrete blocks through which a non-linear heat transfer analysis via finite elements method took place and compares those results with experimentally obtained data. Analyses include effects of radiation as well as conduction and convection which occupy the majority of total heat transfer realized. Expanding heat transfer equations with the effects of radiation gives the equation set its non-linear nature. Analyses performed on two different brick models andmortar with three different heat conduction coefficient assuming heat convection coefficient for vertical and horizontal surfaces and surface temperatures are constant. Results of the study indicate a rather small difference of 2.6% between finite elements method and experimental data obtained therefore finite elements method can apply this sort of studies securely. Next study (Coz Diaz, Garcia-Nieto, Biempica, & Prendes-Gero 2007) using finite elements method focuses on analysis and optimization of a wall of unit area consisted of five different types of perforated concrete blocks. Values and conditions are adopted from the previously described paper. Study defines certain thermal performance parameters and lines up several perforated concrete blocks. Parameters crucial for designers like thermal conductivity and some configurations based on density for a variety of configurations are calculated. Al Hazmy(Al-Hazmy, 2006) on the other hand, instead of dealing with entire body of a perforated brick, analyzed only the perforated regions of brick, polystyrene sticks located around holes and polystyrene layer of certain thickness that covers holes using finite elements method. Study offers 36% heat economy when polystyrene sticks around the holes are utilized and 6% when polystyrene profiles located within the hole.

BaigandAntar(Baig&Antar, 2008) performed analyses governing finite elements method to compare thermal conductivity coefficients for 5 different perforation geometry in a brick with fixed section. Surface temperatures are assumed to be constant during analyses. Lorente(Lorente, 2002) in his study compiled a collection of studies in which the analysis of heat losses through building walls were performed and compared the effects of hole geometry and temperature gradient on thermal conductivity coefficient. As seen on the summarized papers, no analysis studies have been made so far to focus on thermal resistances under varying temperature differences for horizontally perforated red bricks conventionally used to constitute building walls in our country. Coz Diaz (Coz Diaz, Garcia-Nieto, Suarez-Sierra &Biempica, 2008) investigated nonlinear thermal optimization of external light concrete multi-holed brick walls by the finite element method. They found that an overall heat transfer coefficient increases if the mortar and material conductivities increase.

Coz Diaz (Coz Diaz, Garcia-Nieto, Suarez-Sierra, & Sanchez, 2008) carried out the optimization and numerical study by the finite element method of internal hollow bricks walls in order to determine the best candidate brick from the thermal point of view. Based on the previous thermal analysis and the optimization procedure described in this paper, the best candidate was chosen and then a full 122x23x105cm wall made of these bricks was simulated for fifteen different compositions. Antar(Antar&Baig, 2009) studied conjugate conduction-natural convection heat transfer in a hollow building block. The results of this study indicated that when a number of six cavities are used, the heat flux value approaches the case where all the cavities are filled with a low conductivity insulating material due to the insignificant effect of natural convection. Antar(Antar, 2010)investigated the effect of thermal radiation on the heat transfer (or R-value) across hollow building blocks of different internal layouts. He reported that Thermal radiation plays a considerable role in the heat transfer across a multiple-cavity building block.

Coupled heat transfers in hollow structures uniformly heated from below or from above were numerically investigated by Ait-taleb (Ait-taleb, Abdelbaki&Zrikem, 2008).

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The conservation equations were solved by a finite difference method and the pressure–velocity coupling was solved by the SIMPLE algorithm. Li (Li, Wu, He, Lauriat & Tao, 2008) investigated for finding the optimum configuration of the number of holes and their arrangement for the 29x14x9cm hollow clay bricks with 3D numerical simulation by a home-made code with finite volume method.

Sala(Sala, Urresti, Martin, Flores &Apaolaza, 2008) investigated static and dynamic thermal characterization of a hollow brick wall. The results of a test for a heterogeneous wall were also presented in a dynamic temperature rating. These results were compared with those obtained from a simulation carried out on the performance of the same wall through the application of a finite volume software. Investigations on the effect of insulation and energy storing on the cooling load, were showed that dispersion of the insulation within the building material was less effective than using a continuous equivalent insulation layer placed on the outdoor frontage by Al-Turki(Al-Turki&Zaki, 1991). Ciampi(Ciampi, Leccese&Tuoni, 2003) investigated ventilated facades energy performance in summer cooling of buildings. The wall material and the roughness of the cavity were influenced the reduction in heat transfer rate. Sutcu(Sutcu, Coz Diaz, Alvarez-Rabanal, Gencel&Akkurt, 2014) studied the thermal behavior of hollow clay bricks made up of paper waste and optimized their thermal performance. Coz Diaz (Coz Diaz, Garcia-Nieto, Hernandez & Alvarez-Rabanal, 2010)carried out a FEM comparative analysis of the thermal efficiency among floors made up of clay, concrete and lightweight concrete hollow blocks. Zukowski(Zukowski&Haese, 2010) carried out an experimental and numerical study to investigate the thermal performance of the new material composition in a hollow brick filled with perlite insulation.

Bricks to be modelled mathematically by generating solid models, 3D meshing to be applied and brick thermal resistances to be calculated and compared with standard values for each case where the calculations are performed in which real-life boundary conditions with varying temperature differences hence for different Grasshoff numbers, very important for heat convection phenomena, are applied into a steady state heat convection throughout the holes and two dimensional conduction near the brick walls and numerical analyses are performed through finite elements method. It is anticipated from this study to largely contribute to the literature and will be genuine for both national and international field.

II. Methods

Heat transfer through perforated bricks commonly used in building walls as construction elements occurs in two different fashions: most effectively by conduction through solid partitions and by natural convection through air within the perforations on brick body. However rate of heat transfer by natural convection is quite small when compared to heat transferred by conduction. These heat transfer mechanisms take place simultaneously. Brick transfers the heat by conduction through its solid sections while convection occurs through air within its perforations. Although the effects of which is neglected in this study since temperature differences between those surfaces are small, confronting surfaces on perforations also allow heat transfer via radiation as a third way of heat transfer mechanism, Therefore by neglecting the effect of thermal radiation, the heat transferred is confined to conduction and natural convection in this study. Thermal conduction coefficient for heat transfer via conduction is considered to be constant since temperature differences are relatively low. For natural convection, instead of defining a heat convection coefficient into equations, natural convection scenarios will be defined through equations which relate natural convection hence determining certain heat transfer coefficients for each case involving different perforation locations and boundary conditions. Conduction, mass-momentum and energy equations are given below by assuming the heat transfer through conduction and natural convection is continuous and two-dimensional:

Heatconductionequation:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}=0 \tag{1}$$

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{2}$$

Mass-momentum equation for x-direction:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{3}$$

Mass-momentum equation for y-direction:

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\rho g\beta(T-T_\infty) \tag{4}$$

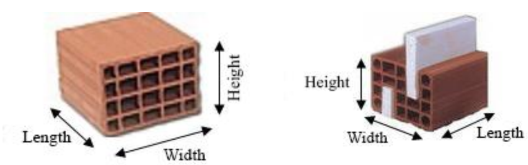
Conservation of energy equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho C}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{5}$$

where T is temperature, $T\infty$ is environmental temperature measured at an adequate distance from brick surface, P is pressure, k is thermal conductivity, C is specific heat coefficient, ρ is density, β is thermal expansion coefficient, μ is dynamic viscosity, g is gravitational acceleration and u, v, z are x, y, z direction constituents of velocity vector. Equations (1) to (5) define general conduction and convection problem of heat transfer controlled by thermal conductivity inside solid section of brick and buoyancy inside of perforations, respectively. Different temperatures will be applied to interior and exterior surfaces of brick and separate solutions for each temperature difference combination will be driven. An average air velocity is proportional to temperature difference between perforation surfaces at every turn. Increasing temperature difference will also raise air flow rate, delivering an enhanced convection rate as a result. Therefore thermal resistance calculations will be performed under varying temperature differences, hence for different Grasshoff numbers which is very important in natural convection approach. Velocities on surfaces are "zero" since no-slip on surface condition is adopted. Equations will be solved in ANSYS, benefiting finite elements method.

III. RESULTS

Red colored perforated clay bricks are widely used in both interior and exterior walls of buildings in our country. When examined, bricks come in a large variety, in terms of dimensions and shape. The essential classification, however, offers three groups of bricks; horizontally perforated, vertically perforated and sytropor layer inserted. It is apparent that the majority of bricks utilized in the exterior walls of buildings today are the 13.5cm standard horizontally perforated brick and 13.5cm sytropor inserted standard horizontally perforated brick. Perforated bricks are commonly named by manufacturers depending upon their dimensions of height. Fig. 1a shows the placement and laying of a brick inside a wall. The brick with 13.5cm height, 19cm width and 19cm depth is generally called "13.5cm standard horizontally perforated brick", named depending upon its dimension of height.



(a) **(b)**

Fig. 1: Brick geometries **a)** 13.5 cm standard horizontally perforated brick **b)** 13.5 cm sytropor inserted horizontally perforated brick

Fig. 1b shows 13.5cm sytropor inserted horizontally perforated brick. Providing the same dimensions as 13.5 cm standard (without sytropor layer) brick, this block is inserted with a sytropor layer of 2.5cm thickness and 0.04 W/m°C of thermal conductivity. Sytropor layer increases the thermal resistance without any additional volume to the brick body, hence reducing the thermal conductivity, yielding a better isolation. In this study, these two types of perforated bricks are modeled and analyzed.

Thermal conductivities of brick and mortar were determined through researching TS1745 Masonry and Masonry Units-Design, Thermal Properties Assessment Methods and TS825 Regulation of Thermal Isolation in Buildings standards. It is shown that thermal conductivity values of both products display dependence to density. As a large variety is available in mortar thermal conductivity and density parameters, 4 different combinations were utilized thus the calculations were performed staying on that basis. These values are given in Table I. As seen on the table, 2nd scenario reflects the real-world situation and values of that section is also the values suggested and used by Brick and Roof Tile Industries Organization (TUKDER). 4th situation represents the maximum possible thermal conductivity values of brick and mortar. The 1st and 3rd situations were also included into calculations to provide a basis for comparison.

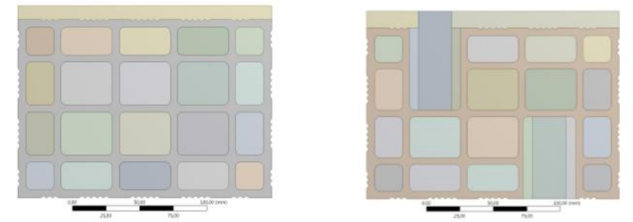
TABLE I
THERMAL CONDUCTIVITY AND DENSITY PARAMETERS OF BRICK MATERIAL

B: Brick M: Mortar	Case 1		Case 2 (Real Life)		Case 3		Case 4	
	B	M	B	M	B	M	B	M
Density (ρ, kg/m³)	1700	1000	1800	1800	2100	1000	2400	2000
Thermal Cond. (k, W/m°C)	0.51	0.3	0.55	0.93	0.69	0.3	0.84	1.28

TUKDER performs thermal conductivity tests for various brick designs via a program called TRISCO. Program carries out calculations by using the values given in Table.1, Case 2 and assuming that the convection coefficients for horizontal and vertical perforation surfaces are constant. In reality, however, different heat convection rates are achieved due to varying temperature difference that the wall is exposed, resulting different convection coefficients for each perforation. That causes the calculations based on constant heat convection values fail eventually. In this study, instead of utilizing a common heat convection coefficient for entire body, separate heat convection rates for each perforation is preferred as a concept and different temperatures are assigned for both surfaces as sole boundary conditions in numerical model. Dialog with this association also revealed that the calculations for determining heat conduction coefficients have been performed for a brick with 1cm mortar coated. To enable the analysis results in a later comparison, a mortar layer of 1cm thickness is added to brick structure.

A survey realized in the scope of this study shows companies that manufacture bricks do not perform calculations or analyses in their facilities, instead make the same association (TUKDER) located in ANKARA/TURKEY to carry out those operations to determine the heat conduction coefficients for their designs. Survey also indicates that facilities to manufacture bricks do not possess 3D data of their own designs, but TUKDER does. Therefore 3D design data to analyze in this study were obtained by courtesy of TUKDER.
Technical drawings of solid models are shown in Fig.2. Technical data were acquired from TUKDER, as mentioned before, then edited by adding mortar layers of 1cm thickness (vertically located rectangles represent mortar layers) and translated into ANSYS Design Modeler environment. Layers seen on the brick blocks on Fig. 2 are 1cm thick mortar layers. Since both brick geometries offer symmetries both in form and

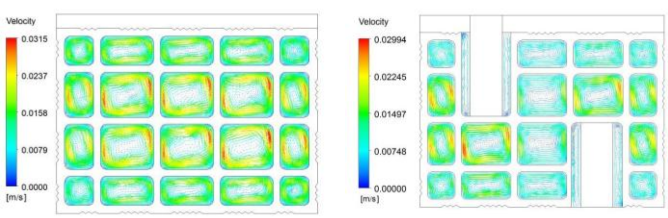
thermal properties, only a slice of 1cm thickness is subjected to numerical analysis. Meshing procedure is applied first, generating approx. 3.5 million elements then case is solved taking advantage of 18GB of RAM of workstation utilized for the study.



(a) **(b)**

Fig. 2: Brick models with mortar **a)** Section of 13.5cm standard horizontally perforated brick with mortar layer of 1cm **b)** Section of 13.5cm sytropor layered horizontally perforated brick with mortar layer of 1cm.

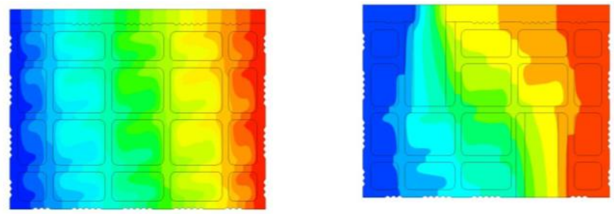
Including the entire geometry of brick as test model is a matter of RAM capacity of Workstation/cluster utilized in the analysis since increasing RAM capacity allows a larger proportion of body to be included into analysis. Model to be analyzed however, reduced in size to avoid excessive time consumption and costs. Temperature distributions and conduction coefficients for both bricks are determined for different temperatures by altering temperature differences on exterior vertical surfaces between 10°C and 50°C. This approach allows understanding the effects of natural convection takes place inside the perforations to thermal conductivity. Fig. 3 shows air velocity distributions due to air circulation occurred inside each perforation of 13.5cm block. Air velocity is relatively high in central lanes in both cases as seen on figure. One reason to this phenomenon is perforation shapes getting closer to squares in central portion of bricks. Also increasing sectional areas of central perforations cause more and more air drawn to these geometries, hence generating the peak air velocities through them.



(a) **(b)**

Fig. 3: Typical velocity variations through perforations **a)** Air velocity distribution through perforations of a 13.5cm horizontally perforated standard brick **b)** Air velocity distribution through perforations of a 13.5cm thick horizontally perforated brick with sytropor layers.

Fig. 4 shows a typical temperature distribution through a cross-sectional area of brick. As seen on figure, temperature gradients are available through air containing perforations as well as solid ceramic portions of brick body. One possible reason for this phenomenon is near-stabile behavior of air contained within the perforations.



(a) **(b)**

Fig. 4 Typical temperature distributions **a)** Through 13.5cm horizontally perforated brick **b)** Through 13.5cm horizontally perforated brick with sytropor layers.

Various thermal conductivity values of bricks at different temperatures are defined using functions in ANSYS environment and results of calculations adopted directly. Heat transferred from a thickness of 1cm is determined (where 1cm of thickness represents a direction orthogonal to the cross sectional area of body).

Thermal reluctance of brick R(ºC/W) is calculated via expression below,

$$\frac{1}{R} = \frac{19.Q}{\Delta T} \tag{6}$$

where Q(W) stands for the rate of heat transfer occurred through a body of 1cm thickness and ΔT is the temperature difference of both surfaces of brick, noting that 19 thermal reluctances are assumed since the total length of brick is 19cm. Thermal conductivity of brick, k (W/m°C) is calculated using the expression,

$$k = \frac{L}{R.A} \tag{7}$$

where L (m) is width, R (ºC/W) is thermal reluctance calculated via (6), and A (m²) is cross-sectional area of brick vertical to heat conduction direction (including mortar layer).

TABLE II
VARIOUS THERMAL CONDUCTIVITY VALUES FOR ALTERNATIVE TEMPERATURE DIFFERENCES

Brick Type	ΔT (°C)	Case 1 (W/m°C)	Case 2 (W/m°C)	Case 3 (W/m°C)	Case 4 (W/m°C)
13.5cm Standard Horz. Perforated	10	0.162146	0.199219	0.212507	0.296482
	20	0.172127	0.209234	0.222234	0.306109
	30	0.179341	0.216317	0.229605	0.313262
	40	0.185052	0.222153	0.235446	0.318993
	50	0.189801	0.226895	0.239976	0.323717
13.5cm Sytropor Layered Horz. Perforated	10	0.11516	0.13291	0.14809	0.16900
	20	0.12244	0.13967	0.15412	0.17444
	30	0.12882	0.14564	0.15940	0.17915
	40	0.13442	0.15098	0.16433	0.18358
	50	0.13943	0.15585	0.16883	0.18774

Utilizing (6) and (7), the heat conductivity values calculated for four different temperature difference variations, being 10, 20, 30, 40 and 50°C are given in Table II and diagrams representing those values in Fig. 5. As seen on table, the second case reflects the real applications which are adopted by TUKDER to be utilized in thermal conductivity calculations.

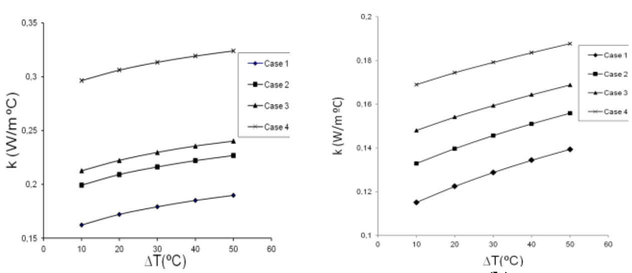
Fourth case on the other hand, represents the situation where conductivity values reach their peaks. Calculations are expanded by using 1st and 4th cases in order to satisfy a healthy comparison.

As seen on Table II, thermal conductivity values indicates an increase while temperature difference is going up from 10°C to 50°C, being 0,068% for standard perforated brick and 0,046% for standard perforated brick with sytropor layers, at every case.

Natural convection occurred within each perforation provides this increment in thermal conductivity while greater temperature differences enhance the air circulation within the perforations, enabling the thermal conductivity values to increase even further. These values also represent the data that manufacturers provide to customers.

Brick manufacturers use only those values given in TS825 and not the values they obtained from their own estimations or clay properties which they use for mass production. In other words, those are standard values given for 13.5cm bricks and provided by manufacturers to end user, which is 0.32 W/m°C and 0.24 W/m°C for standard horizontally perforated bricks and horizontally perforated bricks with sytropor layers, respectively. Those values represent the data given in Table II, Case 4, calculated for the peak temperature difference, where the thermal conductivities also reach their highest values.

Conductivity for brick with sytropor layers is approached with 0.18W/m°C. In reality, however, bricks are generally exposed to temperature differences not above 10°C, hence conductivity values reduce to 0.20W/m°C for standard brick and 0.13W/m°C for brick with sytropor layers. So it is obvious that the values given in relevant standard are well above the results obtained through analysis, which indicates the safety factor is too high due to standards hence utilizing isolation materials of excessive thickness to satisfy possible requirements are inevitable.



(a) (b)

Fig. 5: Change in thermal conductivities depending on temperature difference **a)** 13.5cm standard horizontally perforated brick **b)** 13.5cm horizontally perforated with sytropor layers.

As seen on Fig. 5, on both types of perforated bricks, increase in thermal conductivities are approximately in the same proportion due to temperature difference, since the curves are almost parallel to each other. Conductivity value of standard brick due to temperature difference increases 0.068% while conductivity of brick with sytropor layers displays an increment of 0.046%. There the effect of sytropor layer is obvious and thermal conductivity dramatically drops as applied isolation is getting more efficient. The basis under the ascent of thermal conductivities of bricks is no doubt the heat transferred from one surface to another via natural convection, the larger amounts due to increasing temperature difference, since the air circulation increased by the temperature difference accelerates the procedure. Increasing temperature manages the air to be circulated quicker, and the thermal energy is transferred faster.

IV. Discussion

In this study, calculated thermal conductivity values participated in TS825 Standard of Thermal Isolation Regulation in Buildings and numerically determined values for 13.5cm standard horizontally perforated brick and 13.5cm sytropor layered horizontally perforated brick are compared. Thermal conductivities of 13.5 cm standard horizontally perforated brick and 13.5cm standard sytropor layered horizontally brick are 0.32 W/m°C and 0.24 W/m°C, respectively, based on the standards. However, conclusions of numerical analysis study performed for temperature differences less than 10°C (which is a probable measure in real-life circumstances), yield 0.20 W/m°C of thermal conductivity coefficient for 13.5cm standard horizontally perforated brick and 0.13 W/m°C for sytropor layered horizontally perforated brick. A comparison shows that the standard values given in regulation are far greater than those determined via numerical analysis. Additional assessments upon the results obtained along the analysis are given as follows;

a) It is shown that the thermal conductivity values given in standards are excessively high than the real values. A heat loss study performed using these values would give a great isolation thickness, thus the isolation performance of any building will be satisfied with an unnecessary expense of material, possibly diverging from the optimum cost/performance ratio. Considering the numbers given in standards reveals that they are extremely safe, yielding rather high factor of safety (FOS) values.

b) Brick manufacturers generally adopting the values given in standards instead of surveying thermal conductivity values of their products or researching the properties of clay material they utilize. Hence the values given in product datasheets are basically the ones given in standards. When the company manufactured a brand-new type of clay brick, several specimen products are sent to TUKDER and thermal conductivity values are determined via performing some analyses on a program named TRISCO. The program utilized tends to ignore the effects of natural convection through the perforations that the brick-body maintains and take constant convection coefficients on brick exterior surfaces.

c) Thermal conductivity values suggested by manufacturers on datasheets usually includes the effect of an additional mortar layer of 1cm thickness, adjacent to brick body. This involves the effect of thermal conductivity of additional mortar layer into the calculations involuntarily.

d) Increasing temperature differences also increase the thermal conductivity of brick blocks. The increments observed are 0.068% for 13.5cm standard horizontally perforated brick and 0.046% for sytropor layered type of the same size. The main reason to this phenomenon is basically the increment in heat convection rate via accelerating circulation of air filling the perforations due to increasing temperature difference. The reason that the increment in sytropor layered version being greater than that of standard brick is basically a result of relatively low thermal conductivity of sytropor layered version.

e) As clearly seen on Fig. 3, circulation velocities through the perforations to the middle section of bricks are higher than that at circumferential perforations. The peak velocity through those structures reaches up to 0.03m/s. It is highly recommended to improve the design features applied to middle section perforations of brick bodies. Through velocity reducing perforations, thermal conductivity values definitely can be minimalized.

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