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DEVELOPMENT OF A COMPUTATIONAL CODE TO CALCULATE HEAT TRANSFER IN MULTILAYER WALLS

GONÇALVES FILHO. PEDRO BATALHA
AMARAL. HENRIQUE MARIANO COSTA DO
pedro.goncalves@ifma.edu.br
hmca13@gmail.com
State University of Maranhão
Av. Lourenço Vieira da Silva, nº 1000 - Bairro: Jardim São Cristovão, 65055-310 ,Maranhão, Brazil
SOUSA FILHO. LOURIVAL MATOS DE
somebody3@elsewhere.com
State University of Maranhão
Av. Lourenço Vieira da Silva, nº 1000 - Bairro: Jardim São Cristovão, 65055-310 ,Maranhão, Brazil

Abstract. The main objective of this research is to analyze the thermal behavior of walls submitted to different situations, through a program developed by the author. In the program, it is possible to vary the amount of layers in the wall with different materials, to change the color of the surface submitted to the solar radiation, as well as the orientation of the wall in relation to the Sun. The transient and one-dimensional model of the heat equation for solve the problem. Four examples with different properties (number of layers, azimuth, surface absorptivity) were analyzed. The influence of these variations was verified in each case. In one example, the outer wall temperature without insulation was 28.1667 ° C, internal 27.0295 ° C, while the insulated wall temperatures were 28.1127 ° C and 25.5351 ° C. An internal wall reduction of 1.4944 ° C, with a decrease of 5.5287% of the temperature with the inclusion of 2cm (1 cm on each surface) of polystyrene, pearls.

Keywords: Finite Volume Method, Multilayer, Thermal Insulation.

1 Introduction

From the earliest days, man seeks shelters to protect himself from environmental aggression and, through a process of millennial evolution, has developed mechanisms to obtain adaptation to the environment in order to improve his well-being [1].

The aim of this work is related to the need to reduce energy waste and increase the thermal comfort of the human being, through better thermal insulation in buildings. Energy-efficient building projects require knowledge about the external and internal conditions of the environments, in order to create solutions that associate different materials and thicknesses of the layers [2]. The study of heat transfer is justified by the possibility of mitigating the waste of energy, optimizing the thermal comfort of unheated environments such as public houses and public spaces, for example [3].

In this, computational simulation is used to demonstrate the problem of heat transfer, since it presents numerous advantages over analytical and experimental methods.

2 Physical and Mathematical Modeling

2.1.1 Physical model

It is noted in the diagram that one of the walls is subjected to solar radiation, which depends on the time, represented by a function $G(t)$, as well as convection, represented by the convection coefficient and the outside temperature is $T_\infty(t)$. Note that the wall on the right side is subjected to convection only, and its temperature is $T_{int}(t)$.

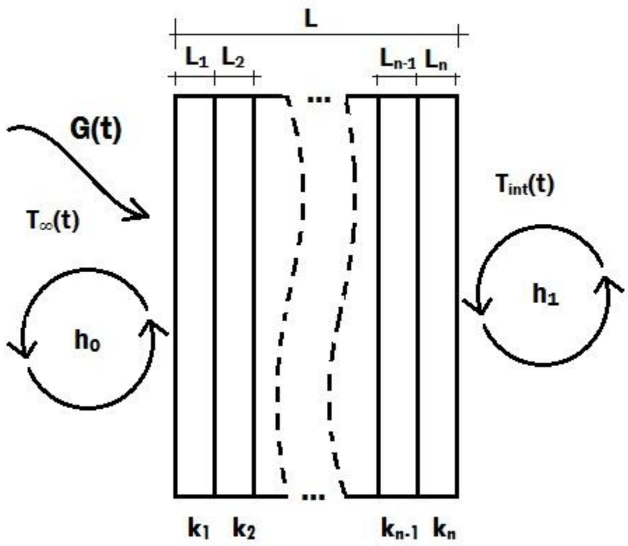

Figure 1. Physical model of a wall with n layers

2.2.2 Optical equations

Equations (1) and (2) represent the factors that are responsible for the variation of radiation throughout the day, year and surface orientation.

Hourly angle:

$$\omega = \left(\left(\frac{t}{3600} \right) - 12 \right) 15 \tag{1}$$

Solar Decline:

$$\delta = 23,45.sen\left(360 \frac{284+n}{365} \right) \tag{2}$$

As the present work deals with the estimation of heat transfer in buildings of São Luís - MA, which also has great influence on the intensity of the radiation in the place, considered was φ =-2,53073°.

Inclined surface incidence angle cosine:

$$\begin{aligned} cos(\theta) &= sen(\delta)cos(\varphi)cos(\gamma) + cos(\delta)sen(\varphi)cos(\gamma)cos(\omega) \\ &+ cos(\delta)sen(\gamma)sen(\omega) \end{aligned} \tag{3}$$

Horizontal incident angle cosine:

$$cos(\theta_z) = sen(\delta)cos(\varphi)cos(\omega) + sen(\varphi)sen(\delta) \tag{4}$$

Radiation Conversion Factor:

For positive values of $\frac{cos(\theta)}{cos(\theta_z)}$, it is represented by equation (5).

$$RB = \frac{cos(\theta)}{cos(\theta_z)} \tag{5}$$

For negative values $\frac{cos(\theta)}{cos(\theta_z)}$, we consider equation (6).

$$RB = 0 \tag{6}$$

2.2.3 Thermal equations

Energy equation:

$$\frac{\partial T}{\partial t} = \alpha \left[\frac{\partial}{\partial x} \left(\frac{\partial T}{\partial x} \right) \right] \tag{7}$$

External wall:

$$-k(1)\frac{\partial T(1)}{\partial x(1)} = h_0(T_{ext} - Ta) + \alpha_{abs} G(t) RB \tag{8}$$

Interface:

$$-k(i)\frac{\partial T(i)}{\partial x(i)} = -k(i+1)\frac{\partial T(i+1)}{\partial x(i+1)} \quad (9)$$

Internal wall:

$$-k(n)\frac{\partial T(n)}{\partial (n)} = h_1(Tb - T_{int}) \quad (10)$$

4 Numerical Analysis

This chapter presents the procedure used to discretize the governing equations and the boundary conditions of the problem. There was spatial discretization through the Finite Volume Methods and for the transient terms, the temporal discretization using the implicit formulation.

5 Results

The collected data (ambient temperature, radiation and latitude) are about São Luís - MA and were collected from INMET National Meteorological Institute [4].

For each simulation, 10 volumes were used in each layer; process time: from 8:00 a.m. to 4:00 p.m. internal temperature: 25°C; external convection coefficient $28W/m^2K$: and internal: $6W/m^2K$; with time step of 0.1s.

In all, four (4) different examples were performed, in which the input parameters were varied for the evaluation of the relation cause effect of the properties, as shown in Table (1).

Table 1. Examples used in the simulation

	Azimuth	Surface	1st layer	2nd layer	3rd layer
Ex.1	270°	white paint	0,09m brick	–	–
Ex.2	270°	white paint	0,01m polystyrene, pearls	0,09m brick	0,01m polystyrene, pearls
Ex.3	90°	white paint	0,01m polystyrene, pearls	0,09m brick	0,01m polystyrene, pearls
Ex.4	90°	black paint	0,01m polystyrene, pearls	0,09m brick	0,01m polystyrene, pearls

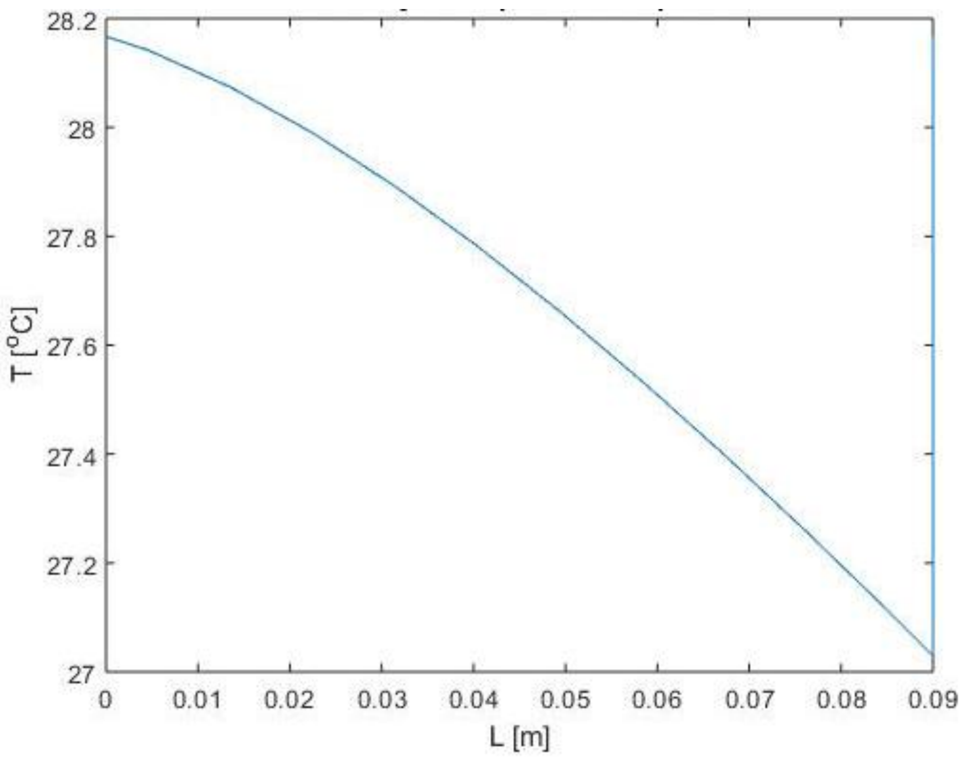

Figure 2. Temperature distribution on the wall. Ex.1

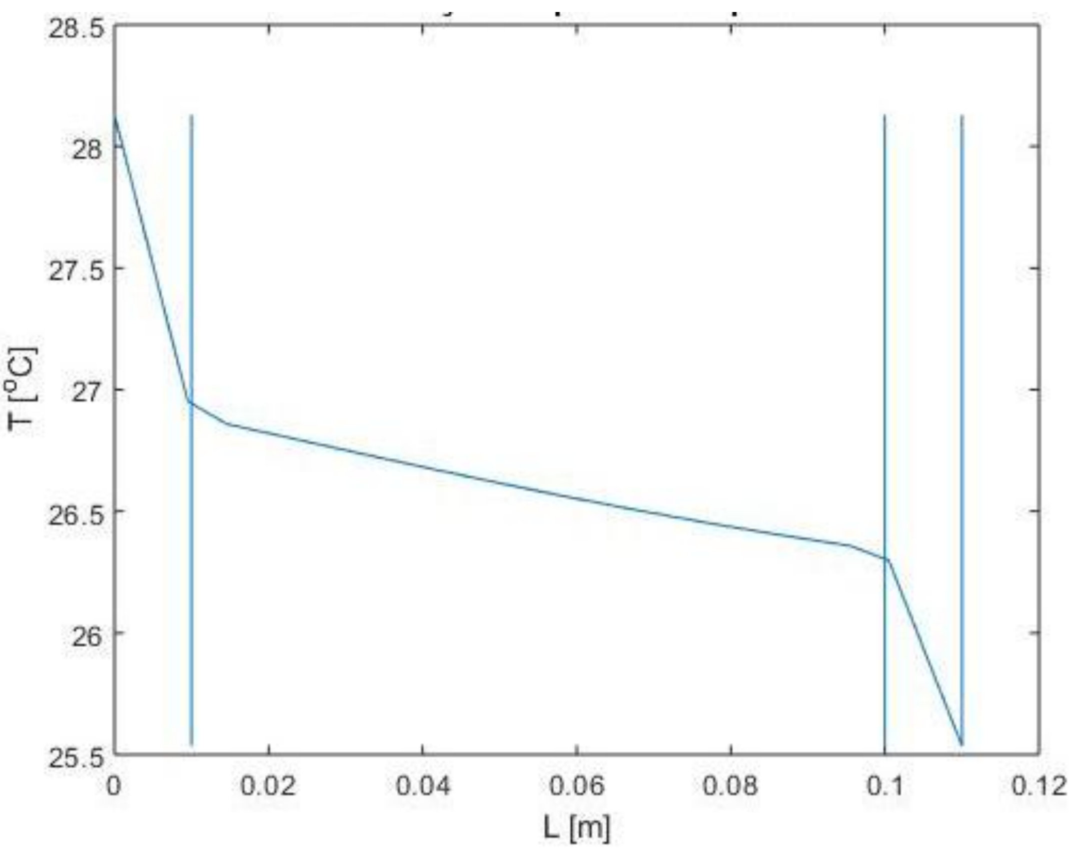

Figure 3. Temperature distribution on the wall. Ex.2

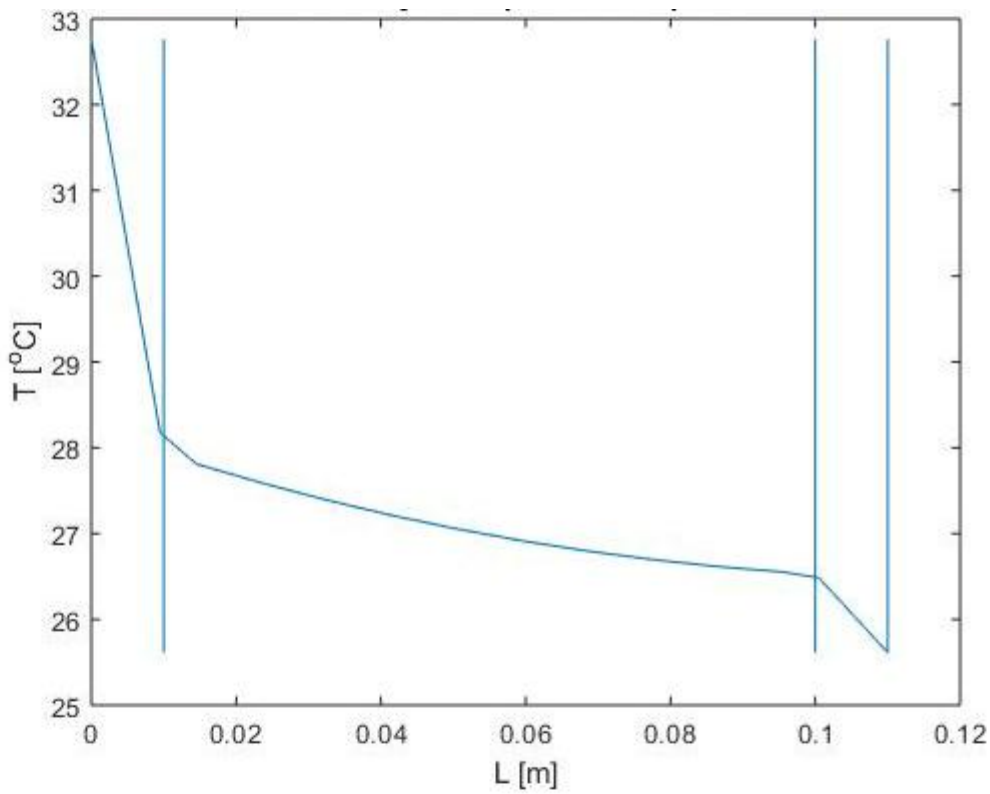

Figure 4. Temperature distribution on the wall. Ex.3

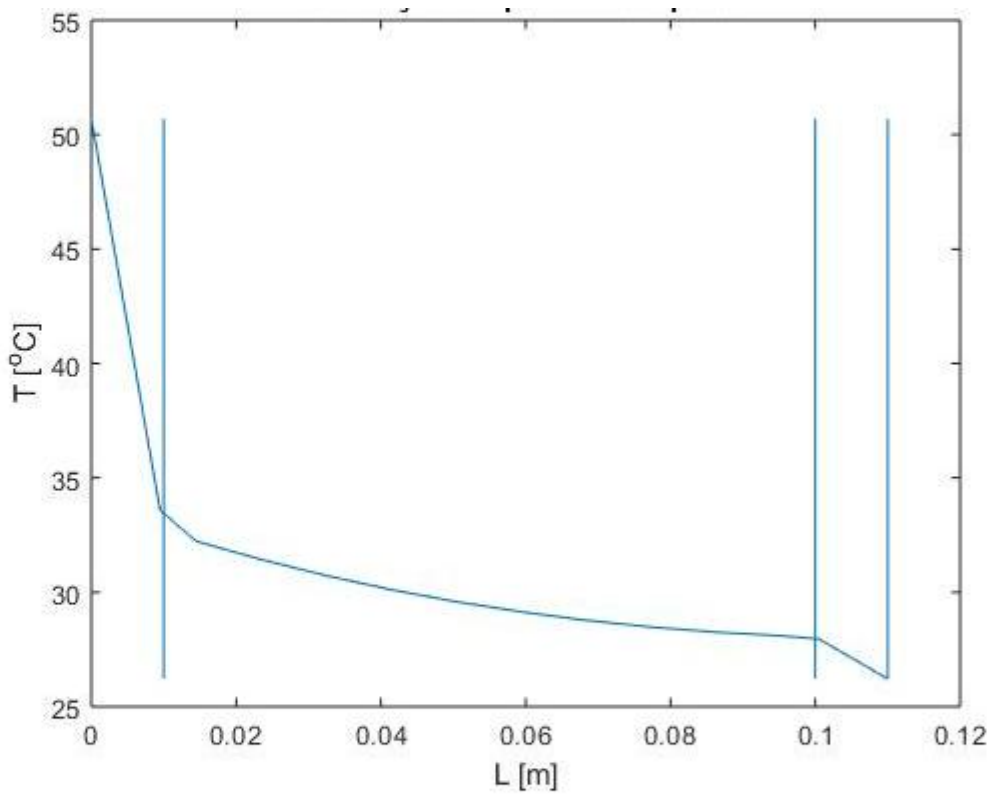

Figure 5. Temperature distribution on the wall. Ex.4

In Ex. 1, the external wall temperature was 28.1667°C, internal 27.0295°C, while the temperatures in Example 2 were 28.1277°C and 25.5351°C. An internal wall reduction of 1.4944 ° C, with a decrease of 5.5287% of the temperature with the inclusion of 2cm (1 cm on each surface) of polystyrene, pearls. Figure (3) illustrates the temperature distribution in Example 2.

When comparing the temperature distribution between examples 2 and 3, Figures (3) and (4), a significant difference is noted between the two external temperatures, 28.1277 ° C in example 2 and 32.7606 ° C, in Example 3.

It is noteworthy that, although there is a considerable temperature difference in the external surfaces, the internal surfaces of Ex 2 and Ex 3 were respectively: 25.5351°C and 25.6111°C, error of 0.2967%, evidencing the effectiveness of the insulation with polystyrene, pearls.

The external wall of Ex. 3 has an external temperature of 32.7606°C, against Ex. 4, 50.6815°C, a difference of 35.3598%. Already the percentage difference of the internal surfaces was of 2,3114%.

6 Conclusions

In this work a numerical-computational study on the temperature behavior of multilayer walls was developed, analyzing 4 (four) examples with different properties (number of layers, azimuth, surface absorptivity).

The results indicated that:

• Without the presence of the insulating material (polystyrene), the internal temperature of the wall is considerably more sensitive to the temperature of the external surface of the wall.

• The presence of two layers (one on each side of the wall) of polystyrene pearls contributed in a relevant way in the thermal insulation of the wall, generating remarkable temperature difference between the external and internal surfaces under the most diverse situations.

• Due to optical issues of solar radiation, it has been noted that different orientations lead to different temperatures on the inner and outer surfaces. When solar declination is zero, there is a higher solar incidence in the morning on the eastward-facing wall and greater solar radiation in the afternoon on west-facing walls and zero radiation on north- or south-facing walls.

• When solar radiation on a horizontal surface is maximum at noon, the vertical surface (wall) will always have zero radiation.

• Because the wall declination is 90 °, regardless of the azimuth, each wall will remain a few hours during the day suffering direct solar radiation.

• The exterior painting of a building is very relevant for the temperature in the wall, the lower absorbance surfaces being the best for the reduction of the internal temperature in a tropical environment.

• The effect of the convection tends to oppose the effect of the radiation when it has higher intensity, because it causes the wall to give up the heat that it gained from the radiation to the medium when the temperature of the medium is smaller than the wall.

Acknowledgements

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References

[1] RUAS, Álvaro César. **Conforto Térmico no Ambiente de Trabalho.** Fundacentro, 1999. São Paulo: McGrawHill do Brasil, 1985.

[2] SENGER, SANDRA CRISTINA TELLES. **Determinação das Propriedades Térmicas de Materiais de Construção Através do Método do Regime Regular e Sua Aplicação na Transferência de Calor em Paredes.** Dissertação de Mestrado, UNIJUÍ. Ijuí, 2012.

[3] DAGA, OJANES MARIA BAGIO DA. **Modelagem Matemática da Transferência de Calor em Paredes Multicamadas de Edificações de Três Dimensões**. Dissertação de Mestrado, UNIJUÍ. Ijuí, 2011.

[4] INMET- **Instituto Nacional de Meteorologia**. Disponível em: <http://www.inmet.gov.br/portal/index.php?r=home2/page&page=estacoesDoAno>. Acesso em: 02 Jan. 2018.
[5] DUFFIE, John A.; BECKMAN, William A. **Solar Engineering of Thermal Process**. New Jersey: John Wiley & Sons, Inc., 2013.
[6] VEERSTEG H. K., MALALASEKERA W. **An Introduction to Computational Fluid Dynamics, The Finite Volume Method.** 2ª ed. England, Pearson Education, 2007.
[7] AMARAL, HENRIQUE MARIANO C. **Introdução aos Fenômenos de Transportes,** 2017.
[8] E. WANG, W. LIU, **Unsteady Heat Transfers through a Multi-layer Wall**, Applied Energy, vol. 31, pp. 83-99, 1988.
[9] FORTUNA, ARMANDO DE OLIVEIRA. **Técnicas Computacionais para Dinâmica dos Fluidos**: Conceitos Básicos e Aplicações. São Paulo: Editora da Universidade de São Paulo, 2000.
[10] G. ARMANDO, B. ARMANDO, V. CHRISTIAN, R. HERNÁNDEZ, J. FLORES. **Analysis of the Conjugate Heat Transfer in a Multi-layer Wall Including an Air Layer**, Applied Thermal Engineering, vol. 30, pp. 599-604, 2010.
[11] OUTHWAITE, AARON. **Numerical Solutions for 1D Conduction using the Finite Volume Method.** Department of Process Engineering and Applied Sciences, Dalhousie University.
[12] P. F. L. DIAS, L. M. SOUSA FILHO, W. D. P. FONSECA, **Numerical Investigation of Heat Transfer in a Multi-Layer Wall Used in Brazilian Buildings**, Heat and Mass Transfer, pp. 115, 2018.
[13] TELES, MAVD DE PAULA RIBEIRO. **Análise Óptica e Térmica de um Coletor Solar de Tubo Evacuado**. Dissertação de Mestrado, UNICAMP, Campinas, 2018.
[14] VARNIER, ROSANE. **Determinação de Propriedades Térmicas de Materiais em Paredes Compostas Utilizando o Método do Problema Inverso.** Dissertação de Mestrado, Ijuí, 2010.
[15] LAMBERTS, R. et al. **Eficiência Energética na Arquitetura**. 03 ed. Rio de Janeiro: Ministério de Minas e Energia, 2004.