Envelope wall/roof thermal performance parameters for non air-conditioned buildings

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Abstract

Many parameters have been used to evaluate the thermal performance of envelope wall/roofs, most of them for air-conditioned buildings. In this paper, the interest is focused on parameters to assess the thermal performance of envelope wall/roofs for non air-conditioned buildings. Five groups of parameters, some previously used and some newly-proposed, have been analyzed. To test the evaluation parameters, numerical simulations of the periodic heat transfer through five different roof configurations have been carried out. This research shows the suitability of the energy transferred through the wall/roof during a day, the decrement factor, the discomfort degree hours, and the hot (or cold) thermal performance index to be used for thermal evaluation of wall/roofs in non air-conditioned buildings. The sensitivity of these parameters with climatic conditions and with the outdoor surface solar absorptance is analyzed. Additionally, it has been shown that the steady-state thermal transmittance, the thermal admittance modulus, the periodic thermal transmittance modulus, and the surface decrement factor, calculated with surface temperatures, are not suitable parameters to evaluate wall/roofs in non air-conditioned buildings.

Keywords: wall/roof thermal performance, parameter, index, periodic outdoor conditions, non air-conditioned.

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1. Introduction

Walls and roofs of the building envelope play an important role in the heat transfer between the exterior and the interior spaces of the building. From a thermal point of view, a good wall/roof is one that contributes to thermal comfort conditions inside the building without using heating or cooling air-conditioning systems or using them with minimum energy consumption.

Many parameters have been used to evaluate the thermal performance of an envelope wall/roof in terms of its thermal performance, *i.e.*, to assess the contribution that these components make to thermal behavior of the building. In this paper, interest is focused on parameters used to evaluate the performance of envelope wall/roofs in non air-conditioned (nA/C) buildings, i.e. buildings that do not use heating or cooling air-conditioned systems. This type of building is also known as free running [1] or naturally ventilated [2].

Studies and publications from developed countries show concern about reducing energy consumption for heating or cooling air-conditioning, because their climates require the use of these systems and the majority of people can afford their costs. There are countries, like Mexico, where a considerable part of the territory has climates where it is possible to achieve thermal comfort with an adequate building design without using air-conditioning systems. Air-conditioning systems are not affordable by the majority of the population. For these countries, it is important to have adequate parameters to assess the thermal performance of envelope wall/roofs for nA/C buildings.

The most widely-used parameters for wall/roof thermal evaluations are the thermal transmittance, U, and its reciprocal the thermal resistance, R. It is considered that the smaller U (the bigger R), the better the thermal performance [3, 4]. These parameters have been used in regulations for air-conditioning energy efficiency, such as ASHRAE [5] and Mexican regulations [6, 7]. These parameters are based on steady-state heat transfer that can be an acceptable approximation for air-conditioned (A/C) buildings in climates with small solar gains and small outdoor temperature oscillation amplitude compared with the indoor-to-outdoor average temperature difference. But these parameters do not properly evaluate the thermal performance of envelope wall/roofs of nA/C buildings in climates with large outdoor temperature oscillation amplitude [3, 8, 9, 10]. Other parameters based on steady-state heat transfer are the solar factor for wall/roof [11, 12], the mass overall thermal efficiency and the equivalent thermal conductivity of hollow blocks [13].

Many parameters have been proposed to assess wall/roofs thermal performance in periodic outdoor conditions in A/C buildings. The most frequently-used are the surface decrement factor, DF_s, and the surface lag time, LT_s, based on indoor and outdoor surface temperatures. Some authors [14] have also included, as an evaluation parameter, the daily average of the indoor surface temperature, $\overline{T_{is}}$. Zhou et al. [2] have used DF_s and LT_s values as known data in a method for estimating the role of internal thermal mass in nA/C buildings.

The International Standard ISO 13786 [15] describes dynamic thermal parameters of multi-homogeneous-layered wall/roofs based on sinusoidal variations of temperature or heat flow rate at one side and constant air temperature at the other side. The parameters relate cyclic heat flow rate to cyclic temperature variations. These parameters are expressed as complex numbers. Thermal admittances relate heat flow rate to temperature variations on the same side of the component, considering a constant temperature on the other side. To evaluate envelope wall/roofs, the thermal admittance that considers the inside temperature constant, Y_{22}, is used. Dynamic thermal transfer parameters relate physical variables on one side of the component with those on the other side. These parameters are periodic thermal transmittance, Y_{12}, areal heat capacities, and decrement factor. The decrement factor defined by the ISO 13786 standard is the ratio of the dynamic thermal transmittance modulus to U. The smaller the thermal admittance modulus, $|Y_{22}|$, and the periodic thermal transmittance modulus, $|Y_{12}|$, and the higher their corresponding time shifts, the better the thermal performance.

The ISO periodic parameters have been used by some authors to assess building components. Aste et al. [16] studied the correlation of Y_{22} and Y_{12} with the heating and cooling demands in simulations of an air-conditioned room. They showed the importance of controlling both dynamic parameters of the wall to reduce the heating and cooling energy demand. Gasparella et al. [17] analyzed the deviations arising by the use of the Y_{12} compared with results from Finite Difference Methods and Transfer Function Methods in A/C buildings using real climate conditions. They proposed corrections on the ISO Y_{12}.

Other definitions of the decrement factor and the time lag have been proposed by Zhou et al. [18] in terms of the indoor surface heat flux respective to the outdoor surface heat flux. For phase change materials, they defined an additional evaluation parameter: the phase transition keeping time, or flat time, given by the time that the wall inner surface heat flux remains constant at or near the zero point.

Fewer parameters have been used to assess the thermal performance of wall/roofs of non-air conditioned buildings. These include the decrement factor, DF, and the lag time, LT, based on the indoor air temperature and the sol-air temperature [10]. The smaller the decrement factor, the better the thermal performance. In general, the larger the lag time, the better the thermal performance, although for hot humid climates small time lags are recommended [19, 20]. Gregory et al. [21] defined a decrement factor as the difference between the daily average indoor air temperature and the desired room temperature over the difference of the daily average outdoor temperature and the same desired temperature.

Other parameters used to evaluate the thermal effect of a wall/roof configuration in nA/C buildings are the number of hours of discomfort [22, 23], the maximum (or minimum) indoor temperature [22], and the discomfort degree hours, DDH [24, 25]. The Predicted Mean Vote method, PMV [26, 23] and adaptive comfort methods [27] have been used to determined comfort conditions for the evaluation of the thermal effect of a wall/roof in nA/C buildings.

Special indexes have been proposed to evaluate envelope wall/roofs in terms of their radiant heat effect for A/C and nA/C buildings [9, 28]. Kabre [9] proposed one that, in percentage terms, evaluates the thermal performance of a roof in a particular climate, on a scale with a range from the acceptable increase of the roof indoor surface temperature above the average air temperature to the worst temperature increase. The worst temperature increase is obtained with a thin galvanized iron roof. The greater the index, the better the thermal performance.

The aim of the present work is to examine parameters to evaluate the thermal performance of envelope wall/roofs in non air-conditioned (nA/C) buildings. Five groups of parameters are presented and discussed. Numerical simulations of the periodic one-dimensional heat transfer through five roof configurations are used to test the evaluation parameters.

2. Parameter definitions

Five groups of parameters for the thermal evaluation of envelope wall/roofs in nA/C buildings are analyzed in this work. The first three have been previously used and the last two are newly-proposed, their definitions are presented in this section.

2.1. Surface decrement factor, surface lag time, and daily average indoor surface temperature

The surface decrement factor, DF_s, and surface lag time, LT_s, of the indoor surface temperature with respect to the outdoor surface, together with the daily average of the indoor surface temperature, $\overline{T_{is}}$, are considered in the analysis.

The surface decrement factor is calculated by

$$DF_s = \frac{T_{is_{max}} - T_{is_{min}}}{T_{os_{max}} - T_{os_{min}}}, \tag{1}$$

where $T_{is_{max}}$ and $T_{is_{min}}$ are the maximum and minimum of the indoor surface temperature during a day, respectively, and $T_{os_{max}}$ and $T_{os_{min}}$ are the maximum and minimum of the outdoor surface temperature, respectively. The surface lag time is defined as

$$LT_s = t(T_{is_{max}}) - t(T_{os_{max}}), \tag{2}$$

where $t(T_{is_{max}})$ and $t(T_{os_{max}})$ are the time of day when the indoor surface and outdoor surface temperatures reach their maximums, respectively.

The smaller DF_s, the better the thermal performance. In general, the larger the LT_s, the better the thermal performance. For hot climates, the smaller $\overline{T_{is}}$, the better the thermal performance; for cold climates, the larger $\overline{T_{is}}$, the better the thermal performance.

2.2. Decrement factor, lag time, and daily average indoor air temperature

The decrement factor, DF, and lag time, LT, of the indoor air temperature with respect to the sol-air temperature used in [10], together with the daily average of the indoor air temperature, $\overline{T_{in}}$, are considered.

The smaller DF, the better the thermal performance. In general, the larger the LT, the better the thermal performance. For hot climates, the smaller $\overline{T_{in}}$, the better the thermal performance; for cold climates, the larger $\overline{T_{in}}$, the better the thermal performance.

2.3. Discomfort degree hours

The discomfort degree hours, DDH, is the sum of the cold discomfort degree hours, DDH_c, and the hot discomfort degree hours, DDH_h. DDH_c and DDH_h, respectively, are calculated by

$$DDH_c = \sum (T_n - T_{in})\Delta t \qquad \text{if} \qquad T_{in} < T_n, \tag{3}$$

and

$$DDH_h = \sum (T_{in} - T_n)\Delta t \qquad \text{if} \qquad T_{in} > T_n. \tag{4}$$

The summatories are taken during a day, Δt is the simulation time step and T_n is the neutral temperature, given by $T_n = 13.5^oC + 0.54\overline{T_a}$, $\overline{T_a}$ being the daily average temperature of the outdoor air, in ^oC [27].

The DDH_c measures how far the T_{in} is below T_n and DDH_h measures how far T_{in} is above T_n. The smaller the DDH, the better the thermal performance.

2.4. Cold and hot thermal performance indexes

Two thermal performance indexes are proposed as parameters in this work: one to be used in cold climates and the other to be used in hot climates. For these indexes, the greater the index value, the better the thermal performance.

The cold thermal performance index, TPI_c, indicates in percentage terms the quality of the thermal performance. The range is from zero (when the indoor temperature is equal to the sol air temperature with the external surface solar absorptance $a = 0$) to 100 (for non values of the indoor air temperature below the neutral temperature). The cold thermal performance index is calculated by

$$TPI_c = \left(1 - \frac{\sum (T_n - T_{in})}{\sum (T_n - T_{sa0})}\right) \times 100 \qquad \text{if} \qquad T_{in} < T_n \text{ and } T_{sa0} < T_n, \tag{5}$$

where T_{sa0} is the sol-air temperature [3] considering $a = 0$. The summatories are taken during a day.

The hot thermal performance index range is from zero (when the indoor temperature is equal to the sol air temperature with $a = 1$) to 100 (for non values of the indoor air temperature above the neutral temperature). The hot thermal performance index, TIP_h, is calculated by

$$TPI_h = \left(1 - \frac{\sum (T_{in} - T_n)}{\sum (T_{sa1} - T_n)}\right) \times 100 \qquad \text{if} \qquad T_{in} > T_n \text{ and } T_{sa1} > T_n, \tag{6}$$

where T_{sa1} is the sol-air temperature considering $a = 1$. The summatories are taken during a day.

2.5. Energy transferred through the wall/roof

It is clear that a wall/roof configuration is better as the heat transferred through it is lower. Thus, the physical parameter that measures the thermal energy transferred through the wall/roof in periodic conditions during a day, Q, is a reliable thermal parameter to select the best configuration.

The energy is calculated during a day, so it is expressed in $Wh/(m^2 day)$ and radiative heat transfer for the wall to the interior has been neglected. The numerical simulations are carried out with periodic conditions, so the energy that enters the room is equal to the energy that exits it.

3. Numerical simulations

To analyze the usefulness of the parameters presented in Section 2, numerical simulations of the periodic one-dimensional heat transfer through five roof configurations used in Mexico are carried out. The model for non-air conditioned (nA/C) buildings , presented in Ref. [10], was used. In all numerical simulations, the values of outside and inside film heat transfer coefficients are $h_{out} = 13 W/m^2\,^\circ C$ and $h_{in} = 6.6 W/m^2\,^\circ C$, respectively [6, 7]. The climatic conditions used in the simulations correspond to Torreón, Coahuila, Mexico, which has a hot dry climate. The typical day for January and the one for May, which are the coldest and the hottest months of the year in Torreón, were taken from Meteonorm data [29] for a typical year. The typical day for each month is constructed by averaging the daily corresponding values of the maximum solar radiation, the maximum and minimum outdoor temperatures and the time when these ocurr, which are the required data for the outdoor conditions model [10].

The five roof configurations are presented, from exterior to interior layers, in Table 1. The thermal properties of the materials are given in Table 2.

4. Analysis of the parameters

The parameters are calculated for four cases: January with $a = 0.2$; January with $a = 0.8$; May with $a = 0.2$; and for May with $a = 0.8$, for the five roof configurations. The relationship between the parameters and Q is analyzed. The thermal parameter Q is considered the most reliable parameter to select the best configurations since it measures the thermal energy transferred through the wall/roof in periodic conditions. Figure 1 presents the energy transferred trough the wall for the five configurations for

Table 1: Roof configurations. Description is given from exterior to interior layers and the layer thickness in parentheses. Materials: expanded polystyrene foam (EPS), high density concrete (HDC), lightweight plaster (LP), flexible elastomeric foam (FEF) , and galvanized zinc sheet (GZS)

Number	Description
1	HDC (5cm) + EPS (10cm) + LP (1cm)
2	GZS (0.09cm) + EPS (5cm) + GZS (0.09cm)
3	FEF (0.2cm) + EPS (3.8cm) + HDC (10cm) + LP (2.5cm)
4	FEF (0.2cm) + HDC (10cm) + LP (2.5cm)
5	GZS (0.09cm)

Table 2: Thermal properties of the different materials used in the configurations [30]. Materials: expanded polystyrene foam (EPS), high density concrete (HDC), lightweight plaster (LP), flexible elastomeric foam (FEF) , and galvanized zinc sheet (GZS).

Material	k	ρ	c
	$W/(mK)$	kg/m^3	$J/(kgK)$
EPS	0.04	15	1400
HDC	2.00	2400	1000
LP	0.16	1000	600
FEF	0.05	70	1500
GZS	110.00	7130	390

the four cases described. Each set of results was scaled with its maximum energy trasferred, corresponding to configuration 5, and the results were averaged, $\overline{Q/Q_5}$. The maximum standard deviation for each configuration is 2.5%, so the quantitative relationship between configurations in the four cases is conserved. The order of roof configurations, from best to worst, is: 3, 4, 1, 2, and 5. The thermal parameter Q increases with outdoor temperature, solar radiation, and a. The parameters, that give the same order of configurations than Q, for the four cases, are considered adequate parameters for the assessment of roofs in nA/C buildings.

As an example, the results for May and $a = 0.2$ are shown in Figure 2. In Figure 2 (a) DF_s, DF, TPI_h, and DDH are presented as a function of Q. As Torreón has a hot dry climate, the hot thermal performance index, TPI_h, is used. The order of configurations in increasing order of Q, corresponds to configurations numbers 3, 4, 1, 2, and 5. Under all these parameters, the roof configuration 3 has the best thermal performance, due

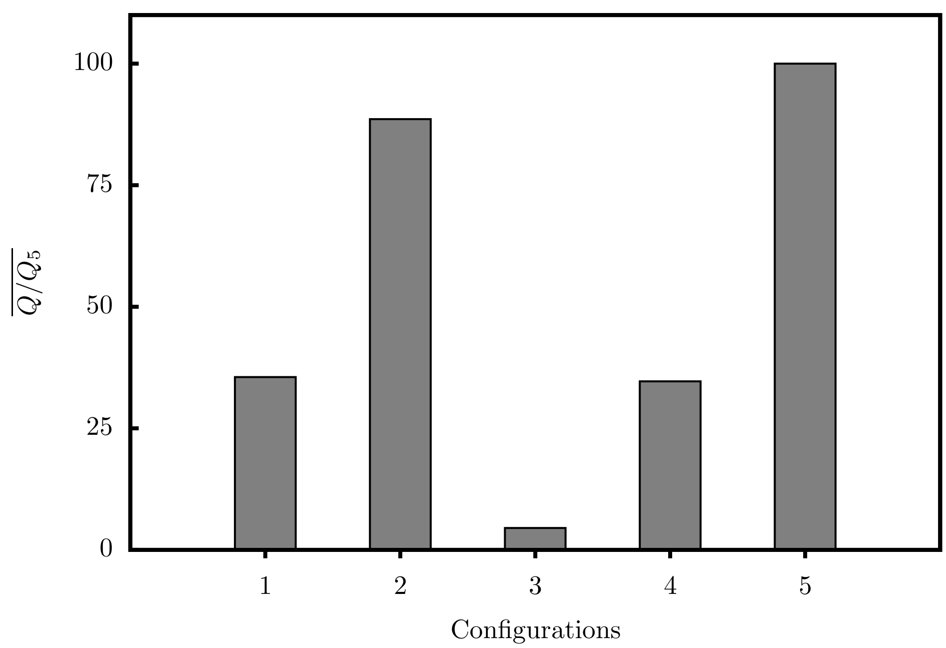

Figure 1: Energy transfered through the roof Q scaled with the maximum energy trasferred Q_5 with the following conditions: (a) January, $a = 0.2$, with $Q_5 = 1.67 \times 10^{-2} kWh/(m^2 day)$, (b) January, $a = 0.8$, with $Q_5 = 3.86 \times 10^{-2} kWh/(m^2 day)$, (c) May, $a = 0.2$, with $Q_5 = 1.95 \times 10^{-2} kWh/(m^2 day)$, and (d) May, $a = 0.8$, with $Q_5 = 4.98 \times 10^{-2} kWh/(m^2 day)$. The maximum standard deviation is 2.5%.

to the combination of an external layer of thermal insulating material (EPS) and an internal layer of a high thermal capacity material (HDC). The roof configuration 5 has the worst thermal performance, due mainly to its small thickness and besides has the largest thermal conductivity. As can be observed in Figure 2 (a), DF_s does not always increase as Q increases: configuration 1 ($Q = 7.55Wh/(m^2day)$) has a greater value of Q than configuration 4 ($Q = 6.78Wh/(m^2day)$), but has a smaller value of DF_s. This is because configuration 1 has an intermediate layer of insulating material (EPS) that causes the outdoor surface temperature to have a greater oscillation amplitude than that corresponding to configuration 4, while their indoor surface temperatures have similar values. Thus, DF_s is not a suitable parameter for the thermal evaluation of wall/roofs.

The parameters DF, DDH, and TPI_h determine the same order of configurations as Q, showing their ability as parameters to evaluate roofs in nA/C buildings. As expected, DF and DDH increase as Q increases, and TPI_h decreases as Q increases. The parameter DF has a linear correlation with Q (99% of confidence [31]).

The average temperatures $\overline{T_{is}}$ and $\overline{T_{in}}$ are equal due to periodic condition assumed. They are represented by $\overline{T}$ in Figure 2 (b), where LT_s, LT, and $\overline{T}$, are presented as a function of Q. Both lag times, LT_s and LT, do not give the same order of configurations as Q. Thus, these parameters alone are not useful as evaluation parameters. The temperatures averages $\overline{T_{is}}$ and $\overline{T_{in}}$ have a constant value independent of Q, for a given climatic condition and a value. That means that $\overline{T_{is}}$ and $\overline{T_{in}}$ do not depend on the roof configuration, this is because of the periodic outdoor condition assumed. Thus $\overline{T_{is}}$ and $\overline{T_{in}}$ are not useful as evaluation parameter of the configuration. These parameters depend on the climatic conditions and a. For January and $a = 0.2$, $\overline{T} = 13.7^oC$; for January and $a = 0.8$, $\overline{T} = 21.4^oC$; for May with $a = 0.2$, $\overline{T} = 28.4^oC$; and for May with $a = 0.8$, $\overline{T} = 41.7^oC$. As expected, $\overline{T_{is}}$ and $\overline{T_{in}}$ increase as $\overline{T_a}$, solar radiation or a increase. Thus, these parameters can be used to evaluate the influence of a.

Additionally, the relationships of the ISO-6946 [4] steady-state thermal transmittance, U, and ISO 13786 [15] periodic thermal admittance modulus $|Y_{22}|$, periodic thermal transmittance modulus $|Y_{12}|$, and their product $|Y_{12}||Y_{22}|$ [16] with Q are analyzed. As can be seen in Figure 2 (c), none of these parameters gives the same order of configurations than Q. Thus, they are not suitable parameters for assessing thermal performance of envelope roofs for nA/C buildings under periodic outdoor conditions. This result is

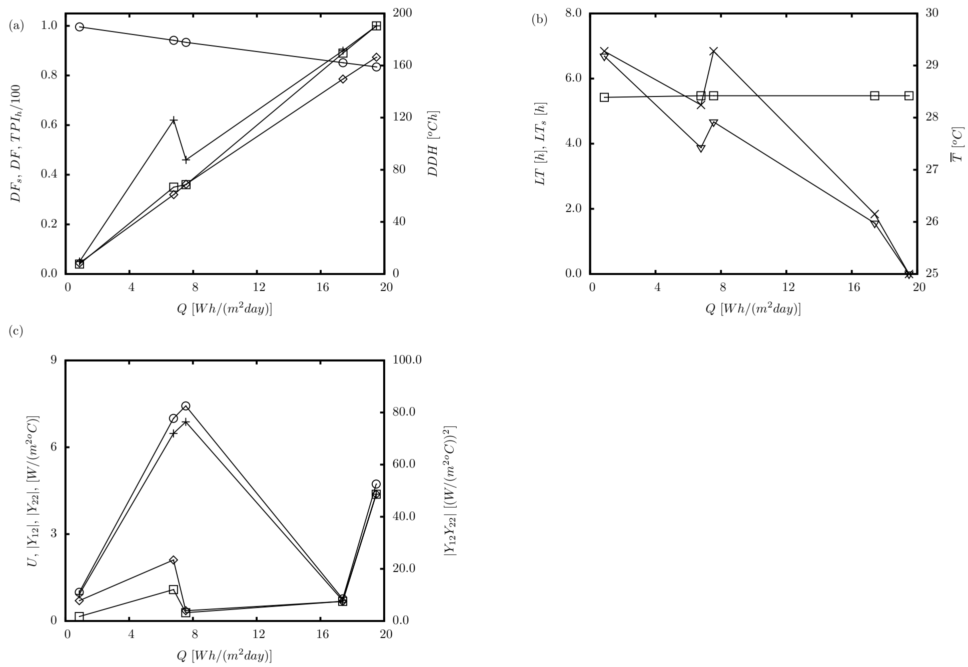

Figure 2: Thermal evaluation parameters as function of Q for a roof in May with $a = 0.2$. The order of configurations in increasing order of Q correspond to configurations 3, 4, 1, 2 and 5. (a) Surface decrement factor, DF_s (+), decrement factor, DF (□), hot thermal performance index, $TPI_h/100$ (◯), and discomfort degree hour, DDH (◇), as a function of the energy transferred through each roof configuration, Q, and (b) lag time, LT (×), surface lag time, LT_s (▽) and daily average temperatures, $\overline{T_{is}}$ and $\overline{T_{in}}$, as they are equal, are represented by $\overline{T}$(□), as a function of Q, (c) steady-state thermal transmittance, U (◇), periodic thermal admittance modulus, $|Y_{22}|$ (□), periodic thermal transmittance modulus, $|Y_{12}|$ (+), and their product $|Y_{12}||Y_{22}|$ (◯), as a function of Q. For May with $a = 0.2$.

consistent with the fact that ISO periodic thermal parameters are suitable for assessing building components in air-conditioned spaces [16], and that thermal performance of wall/roofs configurations are different in A/C buildings than in nA/C buildings [10].

The parameters DF, DDH, and TPI_h give the same order of roof configurations than Q. In the following, the sensitivity of those parameters to variations of climatic conditions and solar absorptance is analyzed. As the parameters LT can be use as a complementary parameter, its sensitivity is also studied. The results are presented in Figures 3-5. Figure 3 shows the decrement factor, DF, and lag time, LT. As can be observed, for a given

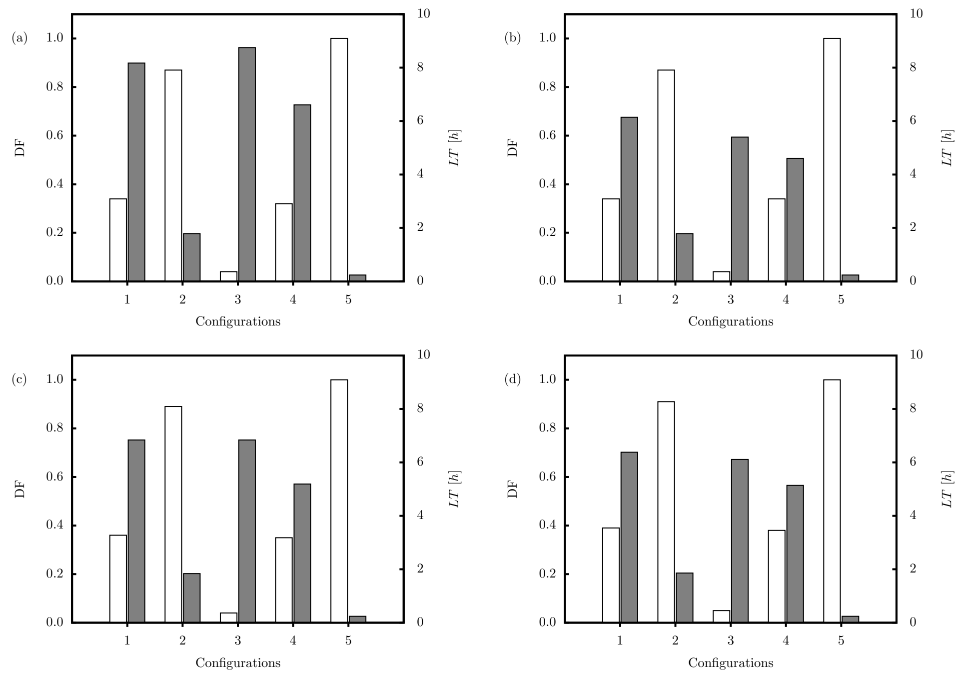

Figure 3: Decrement factor, DF (white) and lag time, LT (gray). (a) January with $a = 0.2$, (b) January with $a = 0.8$, (c) May with $a = 0.2$, and (d) May with $a = 0.8$.

configuration, DF is almost constant for the four cases: its variation with climatic conditions and a values is smaller than 0.06. Thus, this parameter is a good evaluation parameter for configurations, disregarding the outdoor conditions and absorptance value. The LT decreases as a increases and as outdoor temperature and solar radiation increase.

The parameters DDH, DDH_c, and DDH_h are presented in Figure 4. As expected, DDH_c is greater for $a = 0.2$ than for $a = 0.8$, and is greater for January than for May. The reverse happens for DDH_h. DDH shows higher differences among configurations for January with $a = 0.8$ and May with $a = 0.2$. The DDH are greater for May with $a = 0.8$ than for January with $a = 0.2$, this reflects the advantage of using a roof with a low value of a in a hot climate.

Figure 5, shows the hot thermal performance TPI_h for the five roof configurations. The thermal evaluation of the configurations using this parameter is recommended to be performed during the hottest month. When evaluating configurations in a cold climate, the cold thermal performance index TPI_c

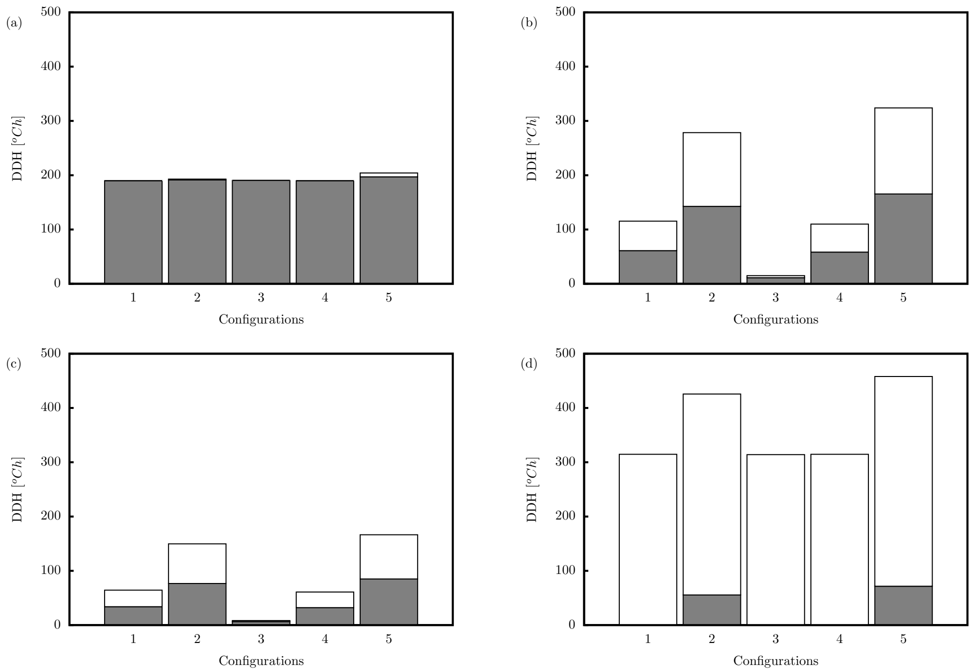

Figure 4: Discomfort degree hours, DDH, is the sum of the cold discomfort degree hours, DDH_c (grey), and the hot discomfort degree hours, DDH_h (white). (a) January with $a = 0.2$, (b) January with $a = 0.8$, (c) May with $a = 0.2$, and (d) May with $a = 0.8$.

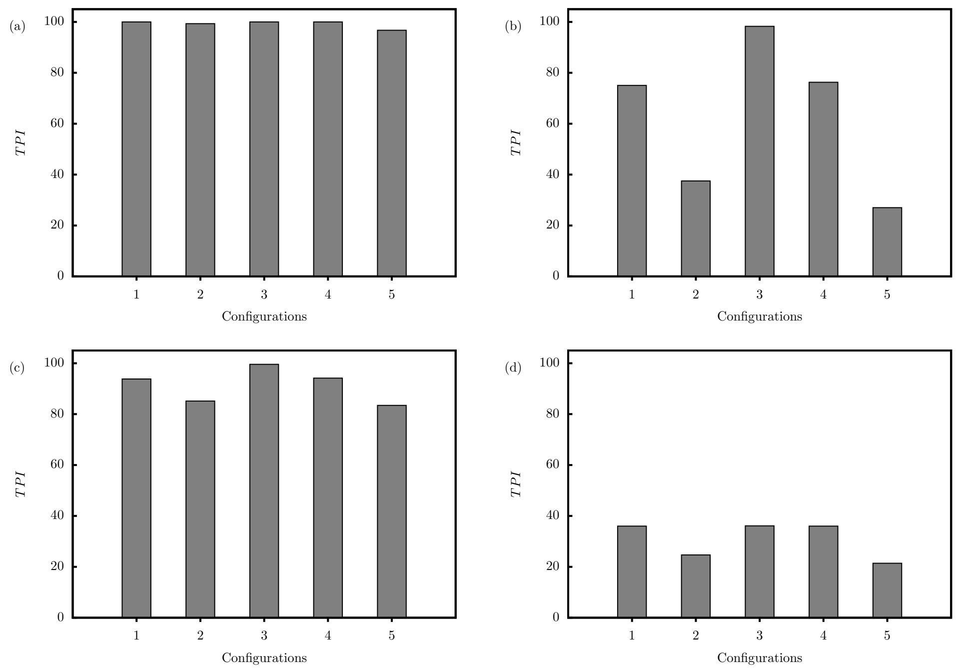

Figure 5: Hot thermal performance index, TPI_c, for (a) January with $a = 0.2$, (b) January with $a = 0.8$, (c) May with $a = 0.2$, and (d) May with $a = 0.8$.

must be used during the coldest month. As can be seen, for January, all the configurations with $a = 0.2$ have similar good qualifications measured by TPI_h, using this parameter in a cold month can lead to an erroneous configuration selection. It can be observed, that this parameter depends on outdoor conditions and a.

5. Conclusions

Five groups of parameters for the evaluation of the thermal performance of envelope roofs in non air-conditioned (nA/C) buildings have been analyzed, using numerical simulations of the periodic heat transfer through five different roof configurations. To extend this analysis to wall configurations, the only change that has to be done is the incident solar radiation. Thus, the conclusions obtained from the analysis performed in this research for roofs are also valid for wall configurations.

The energy transferred through the wall/roof during a day, Q, is a reliable thermal parameter to select the best configurations, in particular for periodic conditions. The thermal parameter Q depends both on climatic conditions and on a. The quantitative relationship between configurations is conserved while varying the climatic condition and a. This parameter is recommended for assessing the full effect of the wall/roof configuration and the external surface solar absorptance in the thermal performance of envelope wall/roofs in non air-conditioned buildings.

The decrement factor, DF, the discomfort degree hours, DDH, and the hot thermal performance index, TPI_h (or the cold thermal performance index, TPI_c) give the same order than Q, from best to worst thermal performance of the five configurations. Therefore, all these parameters are suitable for use in the evaluation of the thermal performance of envelope wall/roofs in non air-conditioned buildings. The surface decrement factor, DF_s, does not have this property, thus, it is not recommended for evaluations in non air-conditioned buildings. Although, the lag time, LT, does not have the aforementioned property, it can be used as a complementary parameter to choose a suitable configuration.

It has also been shown, for the presented roof configurations and climatic conditions, that the steady-state thermal transmittance, U, the periodic thermal admittance modulus, $|Y22|$, the periodic thermal transmittance modulus, $|Y12|$, and the product $|Y_{12}||Y_{22}|$ are not suitable parameters to evaluate wall/roofs in non air-conditioned buildings.

The decrement factor, DF, evaluates the wall/roof configuration alone and does not depend on climatic conditions or on the wall/roof external surface solar absorptance, a. The daily average indoor air temperature, $\overline{T_{in}}$, does not depend on the configuration, it only assesses the effect of outdoor temperature, solar radiation, and a. The discomfort degree hours, DDH, the cold discomfort degree hours, DDH_c, the hot discomfort degree hours, DDH_h, the cold thermal performance index, TPI_c, and the hot thermal performance index, TPI_h, by definition, depend on the indoor air temperature and the neutral temperature. Although the actual indoor air temperature in a real building is a complicated function of many variables, not only of the heat transferred through the wall/roof, as has been simplified in the present work approach, the aforementioned parameters give a comparative assessment of the effect of the wall/roof configuration and the a value, for a given climatic condition. The use of a cold or a hot thermal performance index is recommended according to the climatic problem of the place where the wall/roof is going to be situated. Thus TPI_h is used for hot climates and the configuration evaluation must be done in the hottest month and the TPI_c is used for cold climates performing the evaluation in the coldest month.

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