Weight determination of glazing properties for Trombe wall application in Johannesburg: An entropy method implementation

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Abstract-
Glazing materials have been found to greatly influence the performance of trombe wall systems. this is due to its role in determining the quantity of thermal energy that reaches the massive wall. in this article, a multi-criteria decision-making analysis for proper glazing selection for trombe wall system was considered, the location of interest is Johannesburg metropolis. four different glazing types and four criteria were considered using the entropy method for weight determination. the four criteria considered were the solar heat gain coefficient (shgc), the u-value, visible transmittance and cost respectively. the result showed that the u-value is of utmost importance vis-a-vis other performance criteria for the glazing material. decreasing order of weights assigned was as follows; 71.2% weight factor for the u-value, 16% weight factor to cost, 10.2% weight factor to shgc and 2.6% weight factor to the visible transmittance respectively.

Key words: Trombe wall, SHGC, U-value, Visible transmittance, Entropy method.

1. Introduction
Glazing is a major component of a Trombe wall and the properties of the glazing used in a Trombe wall greatly influences the performance of the system [1], such properties as the solar heat gain coefficient, U-value, visible transmittance, number of glazing panes, the thickness of the glazing material e.t.c. play a very significant role in the thermal performance of the Trombe wall system [2]. the site of installation also contributes to the choice of glazing materials and combinations to be adopted for optimum performance [3]. The city of Johannesburg on geographical coordinates of 26.2041° S, 28.0473° E and UTC+2time zone has been chosen for the purpose of this study [4]. Trombe walls are passive solar devices used for storing thermal energy for either heating or cooling applications [5]. This concept was popularised by a French engineer by name Felix Trombe, hence the name Trombe wall [6]. Trombe walls are used to maintain thermal comfort in buildings without the use of electricity, the temperature of the application lies within the human comfort zone, usually from 20°C to 30°C or a little bit higher as the case may be. Material selection in engineering applications is very key to the performance of the system, the erroneous material selection often leads to reduced performance and sometimes complete failure of the system [7]. there are various decision methodologies existing in literature such as the analytic hierarchy process (AHP), fuzzy analytic hierarchy process (FAHP), multi-criteria optimization and compromise solution (MCOCs) and Bayesian algorithm. Mohana et al applied the AHP technique for selecting appropriate materials for the solar flat plate collector [8], while adhikary et al applied the fuzzy logic method in selecting
optimum materials for turbine blade [9]. The use of decision models in material selection has greatly improved the performance of the systems modelled and thus have a significant role in practical applications.

Fig 1: solar resource map of South Africa [10]

For an optimal performance of a trombe wall, there are some desirable glazing properties such as high U-value, high SHGC, High T-vis, low emittance. The objective of this work is to examine the thermal properties of available glazing material and using the entropy method to assign weights to these properties in order to select an optimum glazing material for improved performance of a trombe wall.

2. Methodology

Three stages of decision analysis have been employed for this purpose and presented in figure 2 below. The first stage is the goal we want to achieve, which is the selection of suitable glazing materials, the second stage presents the factors that determine the performance of glazing materials namely, solar heat gain coefficient (SHGC), a measure of heat transmission through the glazing (U-value), the visible transmittance (T-vis), and cost. The various types of glazing materials under consideration were presented at the third stage namely; single glazing type, double glazing with low emissivity coating, double glazing with high emissivity coating and triple glazing respectively.

**SHGC**: The solar heat gain coefficient is a measure of the incident solar radiation transmitted through a glazing, the absorbed fraction and the quantity released into the building. It is usually expressed as numbers between 0 and 1. A higher SHGC value indicates a higher solar heat transmission while a lower SHGC value means a lower solar heat transmission [11].
U-value: This is a measure of the quantity of either the heat gains or loss through glazing due to the thermal conductance of the glazing material and the temperature difference across the glazing [11].

Visible transmittance: The visible transmittance of glazing reflects the fraction of visible light transmitted through the glazing [11].

![Decision criteria for weight determination](image)

**Figure 2: Decision criteria for weight determination**

### 2.1 The entropy method

Suppose we have m alternative of glazing materials and n criteria to consider while selecting the most suitable glazing for trombe wall application. The entropy method requires that we set up the decision matrix first represented in the equation below

\[
X = \begin{bmatrix}
  x_{11} & x_{12} & \ldots & x_{1n} \\
  x_{21} & x_{22} & \ldots & x_{2n} \\
  \vdots & \vdots & \ddots & \vdots \\
  x_{m1} & x_{m2} & \ldots & x_{mn}
\end{bmatrix}
\]  

(1)

The second step will be to normalize the decision matrix using the equation below

\[
r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}
\]  

(2)

Where  
- \( i \) = number of alternatives
- \( j \) = number of criteria
- \( X_{ij} \) = normalized value of the ith experimental run related with jth output response outcome.
The next step stipulates that the entropy value be calculated using equation 3 below.

\[ e_j = -h \sum_{i=1}^{m} r_{ij} \ln r_{ij}, \quad j = 1, 2, \ldots, n \]  

Where \( h = \frac{1}{\ln(m)} \), \( m = \text{number of alternatives} \).

The next stage is to compute the weight vector, and it can be computed with the expression given below

\[ w_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)}, \quad j = 1, 2, \ldots, n. \]  

The quantity \( d_j = 1 - e_j \) is known as the degree of diversification

### Table 2: Glazing properties as obtained from PFG glazing, Johannesburg [12]

| Types of glazing | SHGC  | Properties | U-Value | T-vis | Cost (R/Sqm) |
|------------------|-------|------------|---------|-------|--------------|
| Single           | 0.855 |            | 5.68    | 0.901 | 300          |
| Double L         | 0.775 |            | 2.83    | 0.817 | 500          |
| Double H         | 0.589 |            | 1.4     | 0.708 | 500          |
| Triple           | 0.407 |            | 0.68    | 0.625 | 800          |

### 3. Result and discussions

The entropy procedure for weight determination was carefully implemented using Microsoft Excel. The normalization of the decision matrix was carried out using equation 2, and presented below is the normalized matrix table.

### Table 3.1: Normalized matrix table of glazing properties

| Types of glazing | SHGC  | Properties | U-Value | T-vis | Cost (R/Sqm) |
|------------------|-------|------------|---------|-------|--------------|
| Single           | 0.32559 |            | 0.53636 | 0.29531 | 0.14286 |
| Double L         | 0.29513 |            | 0.26723 | 0.26778 | 0.23810 |
| Double H         | 0.22430 |            | 0.13220 | 0.23206 | 0.23810 |
| Triple           | 0.15500 |            | 0.06421 | 0.20485 | 0.38095 |

Furthermore, the entropy associated with each glazing properties considered is determined using equation 3. This seeks to determine how important a property is in relation to the achieving an improved thermal performance of our system. The table below presents the entropy value associated with each property, the degree of diversification of each of the properties and the associated weight vector.
Table 3.2: Weight distribution table of glazing properties.

| Types of glazing | SHGC       | Properties | U-Value | T-vis | Cost (R/Sqm) |
|------------------|------------|------------|---------|-------|--------------|
| Single           | 0.32559    | 0.53636    | 0.29531 | 0.14286|
| Double L         | 0.29513    | 0.26723    | 0.26778 | 0.23810|
| Double H         | 0.22430    | 0.13220    | 0.23206 | 0.23810|
| Triple           | 0.15500    | 0.06421    | 0.20485 | 0.38095|
| \( e_j \)        | 0.97363    | 0.81554    | 0.99314 | 0.95868|
| \( d_j = 1 - e_j \) | 0.02637    | 0.18446    | 0.00686 | 0.04132|
| \( w_j \)        | 0.10180    | 0.71220    | 0.02647 | 0.15954|

The entropy method assigns weight by analyzing the degree of discreteness of the criteria. This was achieved by implementing equation 4. More weight was to the U-value of the glass, cost of glazing, the solar heat gain coefficient and the visible transmittance in decreasing order respectively, in essence, this implies that in considering thermal properties of glazing to be used in a Trombe wall, including cost, the U value accounts for the amount of thermal energy transfer through the glazing owing to the materials ability to conduct heat, also considered is the temperature difference through the glazing. The assigned a weight percent of the glazing properties considered in increasing order are as follows; Visible transmissivity = 2.6%, solar heat gain coefficient = 10.2%, cost = 16%, and the U-value = 71.2% totaling up to 100%.

4. Conclusion
There are several applications of glazing in solar thermal technologies, this could be high, medium or low-temperature applications, for whatever application we so desire to employ glazing the performance indicators such as the U-value, SHGC, Tvis, cost is always considered. In this article, we have considered glazing application in Trombe walls. In the selection of the type of glazing to be used, the aforementioned factors were considered, and the entropy method for weight determination was employed. From the thermal performance of the glazing types considered for the city of Johannesburg, the U-value has been considered the most important, followed by the cost, the solar heat gain coefficient, and the visible transmittance respectively

5. Recommendation
Having determined the various weight factors, further research work can be done in selecting the appropriate glazing material using established methods in literature such as the TOPSIS method, the grey’s rational analysis method, the Bayesian algorithm e.t.c. The goal of selecting an optimum material with minimal cost in engineering applications will be achieved by employing these novel procedures.

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