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SELECTION OF THERMAL INSULATION APPLIED IN INDUSTRIAL SHED ROOF USING GENETIC ALGORITHM

Michel N. Stamoulis
Gerson H. dos Santos
Ângelo M. Tusset
Douglas P. Vasconcellos
Carlos H. Diedrich
Federal Technological University of Paraná– UTFPR
Mechanical Engineering Graduate Program – 84016-260 – Ponta Grossa, Brazil
michelstamoulis@hotmail.com; gsantos@utfpr.edu.br; tusset@utfpr.edu.br; douglasvasconcellos@yahoo.com.br; chd145@hotmail.com

Abstract. *In order to obtain a better building energy performance through envelope building optimization, a decisive strategy to select appropriate thermal insulation material is required. This paper presents an Multi-Criteria Analysis Decision (MCDA) methodology to select most adequate insulation material on industrial shed roof, analyzing cost, thermal comfort, water vapor resistance factor and thermal diffusivity. To determine the appropriate insulation choice, thermal comfort indexes were obtained using a building performance simulation software (DOMUS®) in which four different insulation materials were used. This thermal comfort database has been utilized to the input of the Genetic Algorithm (GA), implemented in MATLAB® software, which provided the best choice of material and rank the several insulation layers. According to weightfactors applied on the selected criteria for which the alternatives are valued, ranked and selected, the insulation material rock wool appeared as first alternative for thermal energy safe from the range of insulation materials analyzed.*

Keywords: *Thermal Insulation, Genetic Algorithm, Building Simulation*

1. INTRODUCTION

The oil crisis in the 80´s and the necessity of building energy consumption reduction motivate other strategies of energy efficiency beside HVAC system optimization. Another approach to improving the energy efficiency of buildings is the application of optimized thermal insulation on roofs and envelope of buildings.

The concept of energy efficiency in buildings is based on promoting the thermal comfort to users with low energy consumption (Lamberts *et al.,* 2014*)*. Therefore, a building is more efficient than another, when in the same environmental condition, this presents a lower energy consumption. External environmental conditions such as geographic location and climate are important parameters that should take into account in an energy-efficient building design. In addition, internal factors also have great importance, such as the building features (commercial, public or residential), periods of occupation and users behavior and activities.

In this context, to control the indoor thermal comfort, an appropriate insulation material selection can be a good alternative. Thermal comfort defined by Fanger (1972), prescribes PMV (Predictive Mean Vote) and Predicted Percentage of Dissatisfied (PPD) thermal comfort indexes. This comfort indexes are the most used in the study of the reactions of the human body submitted to different climatic conditions.

Recently, Baniassadi et al.(2016) carried out studies of economic optimization using ENERGYPLUS software coupled to the genetic algorithm obtaining as result a significant variation of insulation thickness according to region´s climate. In this way, in this work, a genetic algorithm has been utilized as an optimization tool implemented in MATLAB, from thermal comfort data obtained in a building simulation software (DOMUS). In this case, four different insulation materials have been used on a industrial shed roof: EPS (Expand Polystyrene), PU (Polyurethane), Fiber Glass and Rock Wool. According to weight factors applied to cost, thermal comfort, water vapor resistance factor and thermal diffusivity, the insulation materials were classified to promove the best choice for designing and decision making processes.PROBLEM DESCRIPTION

2. COMPUTATIONAL MODELING

According to Civic and Vucijak (2014), the use of thermal insulation on the inside of wall is unfavorable to construction- physically point of view it is often more expensive due the need of additional problems solving of water vapor diffusion and safety aspects of fire resistance. The applications of insulations layers inside the wall can significantly change the heat flux and contribute to main bean wall reaches a cold temperatures and condensate formations. In addition, they suggest the use of insulation layers on external side of buildings and propose criteria to select best alternative and material considering that building in cold weather must retain the maximum of energy and summer time not accumulate energy from outside weather.

Based on their work, the objective of this research is providing the optimum insulation material selection method in range of Brazilian market in external application in roof of industrial shed. The selected criteria to choose the material insulation is analyses the follow alternatives that are valued, ranked and made final selection. The model has the following criteria:

A) Cost of insulation for U=2 $W/m^2.K$ in *R$,* criteria must be minimized
B) Thermal comfort PPD (*%*), criteria to be minimized
C) Water vapor diffusion resistance factor, to be maximized
D) Thermal Diffusivity (m^2/s), to be maximized

The cost of insulation was determined by actual pricing in Brazilian market and was obtained from thickness and density of each material which results a global heat transfer coefficient. The Brazilian Standard NBR 15220 has defined a global heat transfer applied for roofs that depends of geographic location. Curitiba city has been located in climatic zone 1 with an global heat transfer coefficient of U=2 $W/m^2.K$.

Thermal comfort of proposed model obtained from simulation in Domus for different insulations material and thickness defines the input parameters related to building environment satisfaction for human utilization. According Mendes *et al*. (2003), Domus was developed to simulate building models and has concentrated physical formulation for calculation of temperature, relative humidity and energy balance, programed in C $^{++}$ language and has an interface facilitated in CAD for editing geometries.

The water vapour diffusion resistance factor that describe the resistance of material to abandonment of water vapour into air, describe how water penetrate into material and smaller value means great permeability. This is an important parameter considered because can influences the insulation layer cost of life cycle.

In the end, the thermal diffusivity is an important variable on thermal control of buildings, because it can express how fast the building equalities the external temperature. Construction fabricated material with small thermal diffusivity slows down the heat transfer and variation of temperatures.

The computational model that was created on DOMUS® software CAD interface has been simulated based on climatic arquive data applying four material select properties in the roof model. The model was designed with the area 300 m² oriented to north face as presented on following Fig.1.

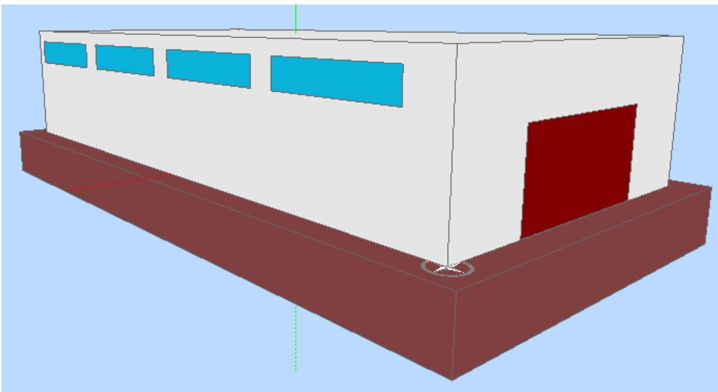

Figure 1. Industrial Shed Model

The model above has been created with solar geometry and orientation of the model has been designed so that the angle of shape that has incidence for the longest period throughout the year. The Tab. 1 shows the industrial shed model simulations parameters and geometry dimensions:

Table 1. Summary of building input data

Category	Subcategory	Indexes
Climatic Parameters	Curitiba	Bioclimatic Zone 1
Orientation	Front Side	North
Building function	Warehouse	Medium Volume
Building Dimensions	Total Volume	1500m^3
	Total Area	300m^2
	Heights	4,0*m*
	Side wall	2,7*m*
	Glazed total area	40m^2
	Doors area	36 m^2
Walls	Brick with 6 rolls (*mm*)	100
	Plaster: 2 layers (*mm*)	25
	Thermal transmittance (*W/ m2.K*)	2.68
	Thermal Capacitance (*KJ/ m2.K*)	270.30
	Solar Heat Factor	2.8
	Emissivity	0.94
	Absorvity	0.26
Simulation Parameter	Number of Zones	1
	Soil Albedo	0.2
	Infiltration	yes
	Ventilation	Natural
	Initial Humidity	50%
	Initial Temperature	20°*C*
	Simulation Time step	3600 *s*
	Reference Temperature	25°*C*

The simulation were performed considering an internal temperature of 20°*C* and external temperatures were provided by climatic arquives. The simulation time step of 01 h (3600 *s*) obtained 8760 values for four types of resistive insulation material. The following Tab. 2 shows the select material and respective thermal properties applied in roof layers industrial shed model:

Table 2. Thermal Property of Roof Insulations Layers

Materials	Density (Kg/m^3)	Specific heat ($J/ Kg - K$)	Diffusion Resistance Factor (μ)	Thermal Conductivity ($W/ m.K$)
EPS (Expand Polystyrene)	40	2.000	100	0.040
PU (Polyurethane)	32	1.045	185	0.017
Fiber Glass	50	700	1	0.050
Rock Wool	180	735	5	0.039

3. COMPUTATIONAL PROCEDURE

Accord to Tuhus-Dubrow and Krarti (2010), Genetic Algorithm (GA) based optimization approach uses the evolutionary concept of natural selection to converge on an optimal solution over several consecutive generations and differs from traditional optimization methods in a number of areas. First, rather than focusing on one potential solution at a time, the technique considers a set of solutions called a population. This ensures a global approach to the optimization and helps the GA avoid being stuck in local minima, which can be a problem with other methods. Second, the GA works with encodings of the parameters, not the parameters themselves. Parameters are traditionally encoded as binary strings, although other encoding options can be used. Finally, GAs use probabilistic methods for determining the parameter values in each successive iteration, rather than deterministic rules. In addition, they consider that GA´s that in simulating environment, the GA optimization procedure, implemented using MATLAB, utilizes three steps:

1. Selection Process: The populations are ranked in ascending order by fitness value (after the cost function is evaluated for each individual), and assign probabilities for selection based on each individual’s rank. A virtual roulette wheel is spun (by generating a random number between 0 and 1) to determine the members in the new population selected for reproduction.
2. Crossover Process: Once the population for reproduction is selected, the individuals are paired off and ‘‘mated’’ using a crossover procedure. A cross point is selected at random for each pairing, and two new individuals are created by joining the first part of the first string with the second part of the second string, and vice versa.
3. Mutation Process: this process is the last step in the formation of the population for the next generation, and involves flipping a bit at random in the population from a 0 to a 1 or vice versa. Mutation is intended to prevent the GA from converging prematurely and ensures a global search. The mutation rate is set at the beginning of the algorithm. Finally, this mutated population becomes the population of the next generation, and the process is repeated until convergence is reached.

After generating thermal comfort index values, the data obtained for the different insulation thickness has been implemented in the optimization of the selection of the best insulators and the genetic algorithm method will be used. Considering the thermal comfort index (PPD), the parameter (x), cost of insulation associate to thickness *(R$ / cm*), the parameter (y), and vapor diffusion resistance, the parameter (z). All individuals of any population should represent the variables x,y and z. A possible representation for the variables would be a vector of values (X , Y, Z).

Before use the GA to rank the best choice of insulation material, has been requeried to solve the selection criteria problem using the Multi-Criteria Decision Analysis (MCDA) method, in which is more flexible than strictly mathematical optimization techniques. In this case, before to define the GA computational resource it is necessary prepare the input data thought a normalization matrix values and assign weight factor for each alternative. Therefore, the steps for this analysis are as follows:

1. Determination of maximum value and weight matrix factors matrix (Tab. 4)
2. Determination of Genetic Algorithm input normalized matrix (Tab. 5)

To define the GA cost function the equation need to associate with cost minimization, diffusion maximization, thermal comfort index minimization and thermal diffusivity maximization. Once the weight matrix was defined, considered the important factors analyzing physical models and building cycle of life based on the weight matrix factor, the cost function with weight factor applied, as following:

$$Function(l) = 0.40 * InsulationCost(l) + 0.20 * ThermalComfort(l) + \frac{0.25}{Watervaporesistence(l)} + \frac{0.15}{thermalDifusivity} \quad (1)$$

As mentioned before, following the weight factor matrix that define cost function for each individual to use the optimization tool on GA methodology, an weight factor matrix should be applied to define the objective function. The function above has been implemented on the Genetic Algorithm code and controled all optimization criteria's.

4. RESULTS & DISCUSSION

The results for industrial shed model simulated Domus for PPD was performed in Fig.2 which shows the PPD variation accord to different insulation thickness for Curitiba climate zone archives.

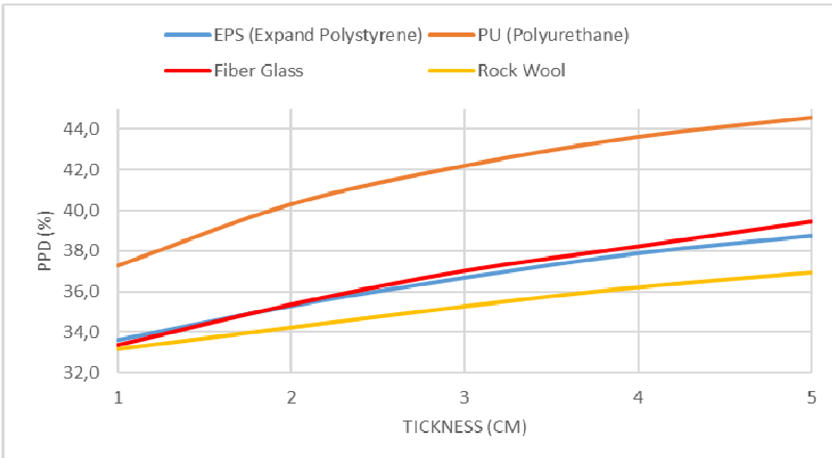

Figure 2 – Annual PPD variation for different insulation thickness.

As describe before, the cost of insulation term was calculated based on insulation thickness necessary to reach the global heat transfer coefficient of U=2 $W/m^2.K$ that is establish by an Brazilian standard NBR 15220. It is depend of the thermal conductivity and thickness. Using the thermal conductivity properties results on the following values for insulation thickness on Tab. 3:

Table 3. Insulation thickness

U=2 $W/m^2.K$	Thickness (*cm*)	Thermal Conductivity (*W/ m.K*)
EPS (Expand Polystyrene)	2.00	0.040
PU (Polyurethane)	1.75	0.017
Fiber Glass	2.50	0.050
Rock Wool	2.00	0.039

To define the the Multi-Criteria Decision Analysis (MCDA) method has been necessary to define input Genetic Algorithm matrix. The tables below show the matrix of MCDA preparation to input the results into GA code to rank insulation layers. First, has been important to normalize the factors value to obtain inputs at the same scale of mathematical greatness. The normalized factor numbers matrix was calculated dividing each element by maximum value for each factors. Once the normalized matrix is calculated, was possible to have the input values to GA code. As commented before, the weights factor has been included in objective function (1) that directed all optimization process. The Tabs 4 and 5 shows the factor values and Genetic Algorithm normalized input values, respectively:

Table 4. Factors value, maximum value and weight matrix

Factors	EPS (Extend Polystyrene)	Polyurethane (PU)	Fibre Glass	Rock Wool	Max.	Weight (%)
Cost of Insulation for (U=2 *W/m2.K*) in *R$*	7.12	13.50	3.85	2.40	13.5	40
Thermal comfort PPD (%),	35.30	40.30	37.00	34.20	40.30	20
Water Vapor Resistance Factor	100.00	185.00	1.00	5.00	185.00	25
Thermal Diffusivity (*k/ρ.cp*)	0.0034	0.0013	0.0050	0.0066	0.0066	15

Table 5. Genetic Algorithm normalized input values.

Factors	EPS (Extend Polystyrene)	Polyurethane (PU)	Fibre Glass	Rock Wool
Cost of Insulation for (U=2 *W/m2.K*) in *R$*	0,527	1,000	0,285	0,178
Thermal comfort PPD (*%*),	0,876	1,000	0,918	0,849
Water Vapor Resistance Factor	0,541	1,000	0,005	0,027
Thermal Diffusivity (*k/ρ.cp*)	0,515	0,197	0,758	1,000

To define the rank of insulation material was necessary to input the Tab. 6 values on GA code implemented in MATLAB® software. For the solution first ranked alternative is obtained as showed on table below. It is important to realize if the weight factor is modified, the ranking would also modify. As a result after run the implemented GA code it converge after 40 population interaction and 51 generation resulting in optimized insulation ranked as showed below:

Table 6. Insulation Ranking using Genetic Algorithm (GA) method.

Rank	EPS (Extend Polystyrene)	Polyurethane (PU)	Fibre Glass	Rock Wool
Genetic Algorithm Scores	0.6796	1.3628	0.7252	0.4367
Rank Position	2	4	3	1

5. CONCLUSION

Using specific problem of roof applied to industrial shed as practical case study, represented is a scientific method for selecting the alternative of insulation material for outside envelop cover using Genetic Algorithm (GA) method for multi - criteria optimization. Genetic Algorithm (GA) method provide that for select criteria and weights applied reach evaluation that the insulation material rock wool is first ranked alternative that should be used for thermal energy safe. The worst-case scenario is the application of Polyurethane (PU) for being most expensive material considering that price has a high score on GA objective function. It is important to realize that modifying the objective function on GA the results may vary and not converge to optimized results.

Even the GA need a computational code programing it can easily implemented using MATLAB® tool and it can be considered a successfully decision making code, especially when it is necessary to determine the optimized selection component. The approach of ranked priorities based on MCDA provide much better arguments to decisions makers. It is important to remark that based on model applied the weight matrix can different define and results can be changed.

In addition, besides choosing insulation building materials, other important contribution of this research is thermal comfort simulations from hydrothermal software DOMUS associate with water resistance and thermal diffusivity factors as components on the Multi-Criteria Decision Analysis (MCDA) method comprise the tooling reliability that can provide decisions maker algorithms and integrating physical modelling, environment and socio economic factor to selecting alternatives.

The aimed of this study was promoted the importance of energy efficiency associate to human thermal comfort building utilization and reducing cost of investment looking ahead to sustainable constructions and heating systems.

The research will continue into following two directions: first improve models and simulate in DOMUS® to reach an optimized building design and applied different insulation layers materials. Other direction is improve thermal comfort for building users associate different factor as orientation, building geometric factors, natural ventilation and other factors.

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7. RESPONSIBILITY NOTICE

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