

A Fast Evaluation Method for Energy Building Consumption Based on the Design of Experiments

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Abstract. Building sector is one of the effective consumer energy by 42% in Algeria. The need for energy has continued to grow, in inordinate way, due to lack of legislation on energy performance in this large consumer sector. Another reason is the simultaneous change of users' requirements to maintain their comfort, especially summer in dry lands and parts of southern Algeria, where the town of Ouargla presents a typical example which leads to a large amount of electricity consumption through the use of air conditioning. In order to achieve a high performance envelope of the building, an optimization of major parameters building envelope is required, using design of experiments (DOE), can determine the most effective parameters and eliminate the less importance. The study building is often complex and time consuming due to the large number of parameters to consider. This study focuses on reducing the computing time and determines the major parameters of building energy consumption, such as area of building, factor shape, orientation, ration walls to windows ...etc to make some proposal models in order to minimize the seasonal energy consumption due to air conditioning needs.

1. Introduction

Nowadays, Building is one of the most consuming energy sectors, it is responsible for approximately 40% of annual total energy consumption in worldwide [1], [2]. Both residential and commercial, has steadily increased between 20% and 40% in developed countries [3]. In Algeria this sector ranks first by 42% of total energy consumption [4] and it is growing by exaggerated way because the Algerian state has launched a huge plan of housing construction without taking into account the legislation of energy performance, in the absence of awareness and lack of culture on the energy control the energy consumption achieved remarkable level especially for HVAC system, the most reasons that led this increase are: low prices of conventional energy and increase number of air conditioners in each house to maintain the comfort of occupant, knowing that in Algeria there is big variety climate it is one of the largest solar potential in the world. It is valued at more than 3000 hours of sunshine per year and 5 kWh of daily energy received on a horizontal surface on most part of the country and more than 35000 hours in the Sahar region. Buildings face problems of discomfort, mainly due to the overheating phenomenon and the facades exposure to solar radiation. These lead to a large amount of electricity consumption by using air conditioning. Bioclimatic design can minimize the seasonal energy consumption; it refers to the reduction of energy consumption without causing a decrease in the level



of comfort [5]. Some published simulation results show that protection against solar radiation and glare has a great influence on the arid climate [6]-[9]. The objective is to optimize the HAVC system, and to reduce the need of the seasonal energy consumption through air conditioning and analysis of the total energy consumption. Many studies have been proposed Design Of Experiment for optimization energy envelop building consumption Romani and al [10] developed and validated metamodels of heating and cooling energy needs for single family houses in six Moroccan climate zones. Xuejun and al [11] enveloped including wall, window, roof and door were selected as the interesting factors regarding to the different layers, materials and insulations. Response factors were: (1) annual building energy consumption, (2) cooling energy consumption, and (3) heating energy consumption in the small-sized commercial building respectively. Jaffal and al [12] evaluate the heating demand used model with a small number of dynamic simulations using the design of experiments.

2. Methodology

This study attempts to develop a new methodology for residential building, by using the co-simulation and investigate the influence geometric envelope building (surface walls, surface roof, ration wall windows, ceiling height, ration shape... etc.) And thermal properties on the energy performance of buildings. We divided our parametric into two types; (1) thermo physical properties and geometric parameters building envelope, also we can reduce envelope building parameters from 10 to 7 parameters, by using the relationship between geometric envelope, the total number of parameter in this study will be 13, Walls and roofs of the building envelope play an important role in the heat transfer between the exterior and the interior spaces, also the windows to wall ration interact between thermal properties and geometric, DoE can lead to modelling this complex problem.. The application field considered in this work is represented by residential buildings, Energy consumption could be divided into two types; the first one is the continuous energy consumption of equipment which is working during the year as lighting, fridge, TV and other equipment to reduce this consumption we should use the height efficiency equipment. The second one represents the seasonal equipment which is used for air conditioning (HVAC system). For many years improving the thermal performance of the building envelope meant predominantly keeping the thermal transmittance values of the opaque and transparent elements as low as possible those building based on high insulation levels of envelope, this simple approach till the easiest way to reduce the energy consumption but doesn't give the optimum solution. During the last years the evolution of computing and software gives the opportunity to study complex systems as building envelope, which the number of parameters are very important such as climatic, architectural, social constriction and material... etc [13].

2.1 Design of experiments method

Design of Experimental is a tool for engineer and scientists to use for product design and development, this tool can reduce development lead time and cost, leading to processes or simulations, and have high reliability than other approaches. The main objective of the experiment is to determine which variables are most influential on the response, even you can set the influential factors that response is near than the desired value with its variety, and reduced the effects of less influence factors [14]. The obtained mathematical model has quadratic/second-order polynomial, the equation resulting (1) from statistical regression analysis or response surface regression,

$$y(x) = a_0 + \sum_{i=1}^k a_i x_i + \sum_{i=1}^k a_{i,i} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^k a_{i,j} x_i x_j + \epsilon \quad (1)$$

Here, $y(x)$ is the predicted response variable a_0 , a_i and $a_{i,i}$ are the regression coefficients of the intercept, linear, quadratic and interaction effects, respectively, while x_i and x_j are independent input variables, and ϵ is a random error. Moreover, Eq. (2) can be analyzed graphically by using three-dimensional response surface plots or contour plots in order to evaluate the optimal values [14], [15]. An analysis of these plots is providing a method to reveal the interactions between two significant factors, all their combinations in one studied response variable in order to determine the most efficient conditions for an optimal target response variable[8]

3. Data collection and case study

Ouargla city is located 800 km southern from Algiers the capital Fig.1. It is one of the most important cities of Algeria and the main source of wealth. It is known as the oil and the oasis capital. It is difficult for people to deal with a lot of natural obstacles, particularly the hard climate that is characterized by high temperatures, low rainfall and low humidity, especially in summer. The values of the average temperature are shown in Fig. 2.

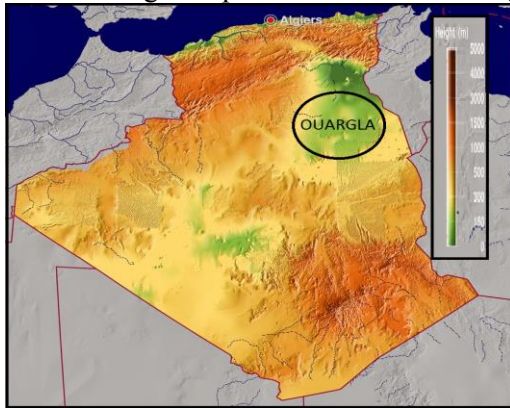


Fig. 1. Geographical situation of Ouargla city

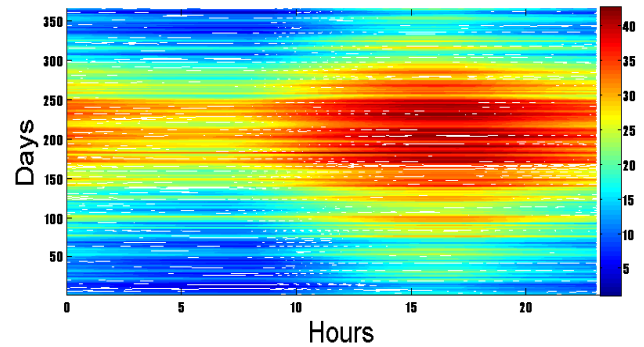


Fig. 2. Yearly temperature degree C ° in Ouargla

3.1 House design characteristics and optimization

Generally the cover surface of house (used HVAC system) is between 60 to 90 m². To estimate yearly energy consumption, 100 houses are taken from 5 different zones to be more representative in the real sample, in order to improve the yearly average energy consumption; we depend the selection on a reference type house which has all the characteristics of the buildings in this region. , we noticed that the maximum load penetrates the building envelope through its roof and walls. Air conditioning system consumes a large proportion of the generated electrical energy and it increases the fuel consumption which causes more environmental pollution. We depend in our study on two types of electrical energy consumption; the first is seasonal consumption which is the value of the seasonal consumed energy (air conditioning in summer and heating in winter), while the continuous consumption is the value of the yearly consumed energy. The historical energetic data analysis of one year shows that the cooling system of the building counts more than an average of 63% of the total energy consumption. The following figure shows the continuous and seasonal consumption of electric energy in the 5 zones of Ouargla. The function of building envelope is to separate physically the building interior from the external environments. Therefore, it serves as an external protection to the indoor environment while facilitating as climate control at the same time. The continuous and seasonal electric consumption per subscriber. The proportion of the continuous electrical energy consumption stays almost constant at five zones with a value of 30% and seasonal consumption of electrical power of 70%.

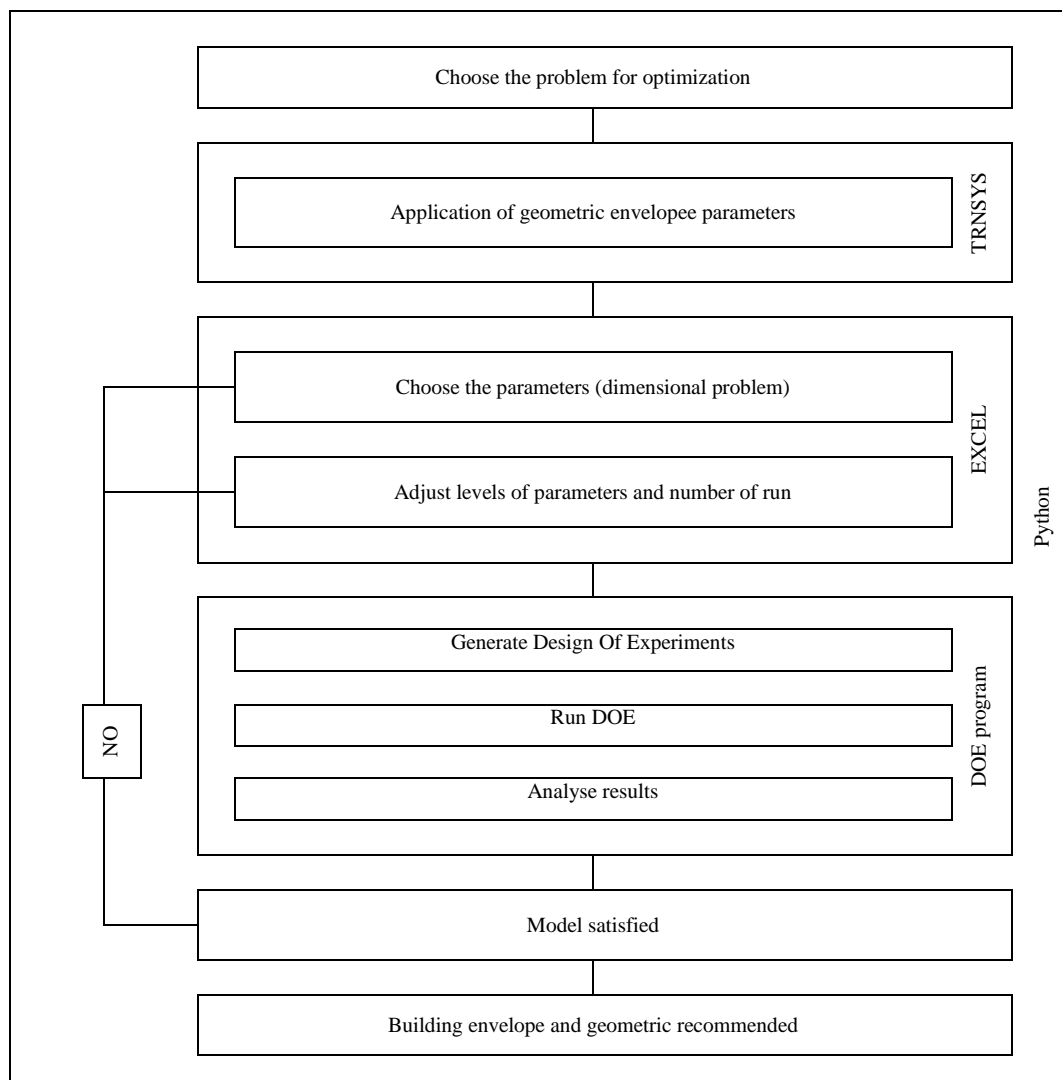
4. Co-simulation and optimization

The parameter selection is difficult operation and expensive to perform all experiments or simulations. The DOE method can be employed as an efficient technique to accomplish the suitable and necessary simulations with high accuracy. To investigate main and multiple interactions between parameters in this study, a fractional design was employed with two levels for each parameter +1 for high level and -1 for low level, we choose 13 parameters are: Thermal transmission through the vertical walls (U_{wall}), Thermal transmission through the roof (U_{roof}), Thermal transmission through the ground (U_{ground}), Thermal transmission through the windows (U_{wind}), Windows to Wall Ratio North wall (WWR_N), Windows to Wall Ratio South wall (WWR_S), Windows to Wall Ratio East wall (WWR_E), Windows to Wall Ratio West wall (WWR_W), Absorption coefficient of the solar radiation of the wall (A_{wall}), Absorption coefficient of the solar radiation of the roof (α_{roof}) Ceiling Height (CH), Area floor A Factor Form (FF) Table(1).

Table 1: Lower and upper levels for each physical parameter

Parameter	Uwall W/m ² K	Uroof W/m ² K	Ufloor W/m ² K	Uwind W/m ² K	WWR _N %	WWR _S %	WWR _E %	WWR _W %	Awall	αroof	CH m	A m ²	F F
N	1	2	3	4	5	6	7	8	9	10	11	12	13
Lower level	0.338	0.339	0.354	2.95	5	5	5	5	0.1	0.1	2.5	60	1
Upper level	2.325	2.346	3.351	5.74	10	10	10	10	0.9	0.9	3.2	90	2

We used TRNSYS 17 [16] to simulate building envelope and Minitab for DoE, in this dynamic simulation we use Python as processor Fig. (3), we need Excel to converter dimensional matrix to less dimensional matrix that's can reduce the number of parametric in our study, this process reduced geometric factors from 10 to 7, the complex co-simulation can reduce dramatically the time and avoid the error when the user introduce the data by hand from software to another.

Fig.3 Co-simulation and optimization of cooling and heating energy demands

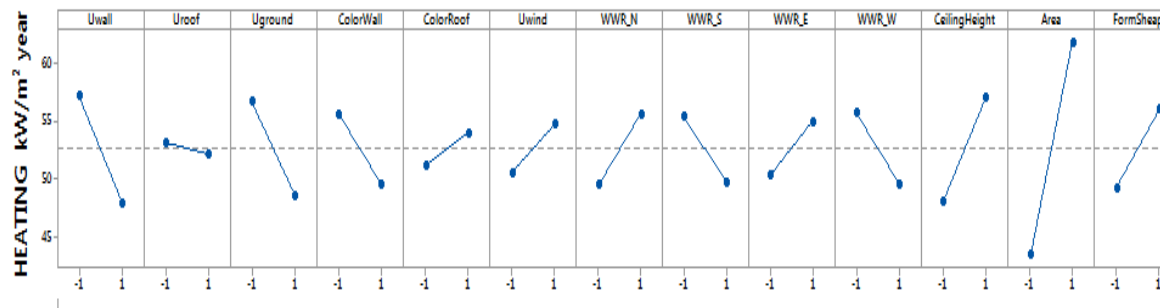


Fig.(4) The graphs of main parameter effect Heating case

The predictor model of Heating energy consumption

(2)

$$\begin{aligned} \text{HEAT} = & 52.64 - 4.70 \text{ Uwall} - 0.46 \text{ Uroof} - 4.08 \text{ Uground} - 3.02 \text{ CWall} + 1.36 \text{ CRoof} \\ & + 2.14 \text{ Uwind} + 3.06 \text{ WWR_N} + 2.90 \text{ WWR_S} + 2.31 \text{ WWR_E} - 3.15 \text{ WWR_W} + 4.51 \text{ CH} \\ & + 9.19 \text{ Area} + 3.40 \text{ FS} \end{aligned}$$

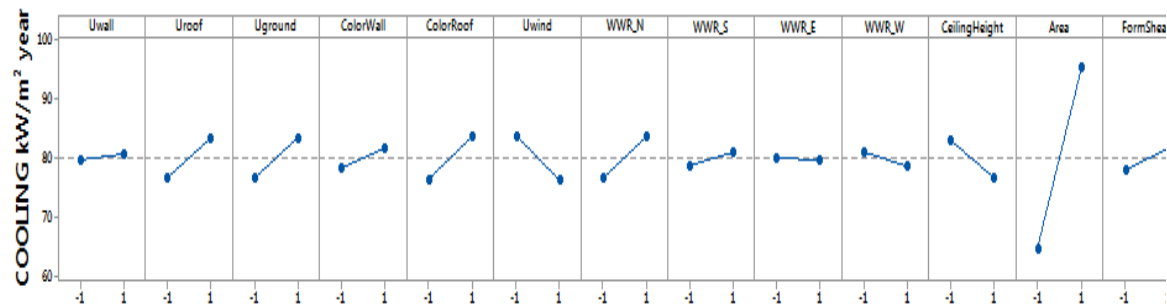


Fig.(5) The graphs of main parameter effect Cooling case

The predictor model of Heating energy consumption

(3)

$$\begin{aligned} \text{COOL} = & 80.12 + 0.53 \text{ Uwall} + 3.32 \text{ Uroof} + 3.45 \text{ Uground} + 1.59 \text{ CWall} + 3.69 \text{ CRoof} - \\ & 3.57 \text{ Uwind} + 3.52 \text{ WWR_N} + 1.18 \text{ WWR_S} - 0.15 \text{ WWR_E} - 1.10 \text{ WWR_W} - \\ & 3.08 \text{ CH} + 15.49 \text{ Area} + 1.81 \text{ FS} \end{aligned}$$

5. Results

The simulation results obtained shows the factor which most influence is the surface in both cases cooling and heating, the selection of this parameter is very important. The simulation shows the cooling energy consumption is height than the heating energy consumption, that's returned to the hot climate of Ouargla city, this result gives the cooling consumption the priority for optimization in the case of inverse influence factors, The surface influenced in heating case more than the cooling, the second factor is the factor form, it has big influence in heating case and less important in cooling case, so the square ship is the best for both cases. The influence of thermal transmission through the vertical walls can reduce energy consumption for heating 10 Kw/m² year, but in the case for cooling their influence is so limited, the influence of thermal transmission through the ground has inverse influence in the case of cooling, but its influence is important in the heating case it can reduce this consumption about 8 Kw/m² year, absorption coefficient of the solar radiation of the roof has the same influence for both cases.

6. Conclusion

The DoE methodology has gained importance for a wide range of industrial applications, pharmaceutical, biotechnology...etc. the advantages of DoE are various its allowing a rapid evaluation of the effects of different parameters or important factors on the selected response variables and their possible interactions, thus factors can be simultaneously changed and optimized, DoE approach provide the possibility of studying a large number of parametric as the case of the envelope building and the feasibility to operate as a promising and efficient optimization technique. In this study a new methodology of building performance evaluation and tool could be developed based on co-simulation and parametric design, to reduce the need of the seasonal energy consumption through air conditioning and analysis of the total energy consumption. plots of this curves give the choose between many factors as thermal property, insulation wall, windows wall ration for each face ceiling high, type of window ...ect quickly and accurately according to the performance requirements of designers. The developed polynomial model have simple form and can calculate rapidly the energy needed, which allows to study different factors for all energy envelope building design. Moreover, the design of the experiments reduces significantly the number of dynamic simulations required to determine the coefficients of the parametric models. In fact, a multidisciplinary design tool can integrate all aspects of a building's performance. This type of co-simulation combined with four software can reduce the time of simulation and contribute to the design of low building energy consumption.

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