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Impact of Form on the Energy Performance of Buildings: A Contribution to Sustainable Buildings in Hot and Dry Climates

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Abstract

The question of the influence of human activities on climate has preoccupied scientists for over a century; the scarcity of fossil energy; climate change, and the greenhouse effect are normal consequences of an imbalanced environment. The construction sector is one of the principal actors involved in the increased anticipated impacts. Because it represents approximately 30% to 40% of global energy consumption, it is imperative to participate in the development of innovative actions in the field of energy efficiency and reducing environmental impact. From this perspective, we think about the production of sustainable buildings (high energy), while ensuring maximum comfort to the user. The objective of this work is the minimization of energy consumption sickles by the study of the relationship between the morphological characteristics of the form of buildings and the climatic parameters, to improve energy performance. Without resorting to technological solutions, very advanced and very costly and contribute to the sustainable development of buildings in the regions hot and dry.

The high outside air temperature and intense solar radiation are the two main sources of discomfort, the numerical simulation is based on the study of the form factor influence (Cf = surface of the envelope /habitable volume) on the coefficient of heat gain G (heat gain coefficient of the habitable volume), we have tested the interaction between the volume, geometry, the proportions of a hand and the two parameters above on the others. Software -called- OPTI-01 developed with mat lab gave satisfactory results for all the simulations.

The results of this research have identified a significant improvement in the optimization of energy performance by varying parameters, such as volume -50% to -90%, geometry-20%to -40%, and the optimal proportions of the building as parallelepiped: L = 8 H &L = 4 l Tower: L = l & H = 5 L. Finally, this study focuses on work the promotion of research in the field of energy efficiency.

Key words: hot and dry climate, form factor, energy efficiencyof building.Sustainable development

Nomenclature

G Heat gain coefficient of the habitable volume

Q Quantity of heat gains in entering the building (w)

Qc Quantity of heat gain transmitted by conduction (w)

Qs Quantity of heat gain transmitted by radiation (w)

I Intensity of solar radiation (w/m2)

O Radiation factor

Sv Surface of the glass envelope (m2)

Sn Opaque surfaces of the walls of the envelope (m2)

KE Coefficient of heat transmission through the envelope (w/m2. °C)

a Absorption factor of the external surfaces of the envelope

fe Exchange coefficient of external surfaces (w/m2. °C)

V Habitable volume (m3)

Cf Form factor

Δt The difference between external and internal temperature (°C)

TSA The temperature in the sun (°C)

L Length (ml)

l Width (ml)

H High (ml)

INTRODUCTION

Several forums that have been held on the environment and the future of our planet show that our climate is in crisis and it will be more acute if we do not take the necessary preventive measures. The impacts of rising temperatures, less rainfall, and the intensity of extreme events may increase the pressures associated with human activities on the existing natural environment, particularly in urban areas(Özvan and Aslantaş 2022, Imd 2022). That could have serious consequences - in the 21st century on the climate and environment in general(Morales 2022). Many options should be identified and implemented to minimize these effects as much as possible. Energy is at the heart of these actions; on the first hand, it's the main sector issuer of greenhouse gases,on the other hand, consumption of energy (electricity in particular) with very strong growth in hot regions could be exacerbated by the additional demand needed to mitigate the effects of climate change (cooling of buildings)(Mahfuza and Eshkoraev 2022, Yun et al. 2018). However, the current situation and the expected in the coming years are characterized by rapid rates of change. This factor makes the magnitude the most important of the anticipated impacts of relatively rapid changes, which do not allow acclimatization and gradual adaptation of ecosystems and societies. In addition, we notice new weather events which have never been recorded(Yun et al. 2018).

Since 1970, the world has experienced a warming of about 2°C(UNEP 2009). This warming is also evident in regions with warm dry climates, even if it is more difficult to quantify because of the lack of a complete observation network. Thus, these regions are called "hot spots of climate change". Climate change affect these areas more than other regions of the world in the 21st century(IPCC 2007). So, the development and improvement of energy efficiency to curb rising consumption and the growth of CFC emissions is now a requirement rather than a choice.

The region, case of study, has potential in renewable energy among the world's most important through sunshine, wind to multiple sites, or significant geothermal resources. In addition, we believe the potential for progress in energy efficiency. To exploit this potential, we must adopt a Sustainable Development Strategy that proposes guidelines, actions, and targets for the rational use of energy to improve energy efficiency. Despite its options, the control of energy is underutilized.

The construction and residential/tertiary sectors are key to the action as they consume about 40% of the final energy. It is imperative to participate in the development of innovative actions in the field of economic energy and reduce environmental impacts. This initiative is an awareness related to the fact that fossil fuels are exhaustible and polluting(de Chalendar 2016). In this perspective, we think about producing a framework of good quality buildings while providing maximum comfort to users of the buildings in regions with a hot arid climate.

Measures to Reduce Climate Change (Responsibility of the Building)

Today, the issue is over whether to reduce our emissions of greenhouse gases, but how can we reduce the energy consumption of buildings? Starting with a simple observation: the building is the largest consumer of energy, with 42.5% of the final consumption, air conditioning accounts for 2/3 of consumption generated by this sector "for regions with hot dry climate"(IEA. 2021). The building constitutes the main source of reduction of greenhouse gases, and this requirement becomes the most effective measure to conserve the climate, we are at the dawn of a revolution that has to be materialized (UNEP 2009), but no significant change in this sector is possible. So, we must strengthen the regulatory standards and the necessary measures. On this point, the priority is a regulation that would consider the principal source of energy saving “the building”. For us, the challenge is to strengthen standards and propose measures for improvement. Among them, priority should be given to the overall shape of the buildings.

The energy consumed in buildings is less perceived as a possible source of economy, as the consumption of buildings now represents about half of the energy consumed(Santamouris and Vasilakopoulou 2021). It seems logical to bring in the building energy notable efforts.

Our objective look at the role of building in climate change. Starting from the following questioning: What are the forms of buildings appropriate to the climatic and environmental conditions in hot dry climates? In addition to what extent the design of the building envelope allows it to limit the waste of resources and pollutant emissions.

The Building Sector as a Key Player

The building sector is now positioned as a key player in solving the environmental problems we face. This evolution is linked to a recent realization that this sector may be the only one that offers sufficiently strong possibilities for progress to meet our ambitions to reduce greenhouse gas emissions. Indeed, we can see that the paths to progress in the building sector can be much better identified now than in the past. This is because the improvement of the energy performance of the buildings can be programmed over several years and this evolution reinforces each time the value of the well-being of the occupants of the buildings.

High-Energy Performance Building

Before addressing the technical aspect of low-energy buildings, it should be noted that a building is not built to save energy, but to accommodate users, or to fulfill a particular function. What is important above all is that the principal mission is well performed by the building under interesting ecological conditions. If it fulfills all the energy-saving requirements but does not function properly, it would be a failure. A high-energy performance building is a good quality building and, in addition, it has controlled its environmental cost as possible(Alwetaishi 2022). It is the two together that we must see, and not one or the other. That’s why we might need an evaluation system that recognizes and quantifies energy performance so that we can answer the question: how do you make an environmentally beneficial building, how do you design it, and how do you organize yourself to achieve it?

Actions to Improving the Energy Performance of Buildings

When a new building is designed, and if the Land-Use Plan allows it, the first element to look for is the shape of the building. Similarly, for questions of summer comfort, it is necessary to protect oneself from the heat input of the sun. One of the revolutions of the building will certainly be in the building envelope or the concept of the “thermal envelope”.

The Impact of the Form on the Climate

The forms have a major impact on the environment because they change the ground, the biosphere, and the weather (the microclimate). The scale of impact is dependent on the degree of change in geometric characteristics of the land surface or morphological characteristics of the buildings (Agirbas 2020, Rahmani and Al-Sallal 2019). These parameters can be used in evaluating the energy and environmental quality of the built environment, in addition to assessing the impacts of building on the climate.

Evaluation of the Impact of Shape-Form- on the Climate

Designers should be aware of their forms’ impact on the building’s energy consumption. This objective can be achieved through a simulation (numerical modeling) that allows estimating the variation of energy consumption depending on the variation of the envelope of the buildings. Then, for the construction of this system, we must inquire about the qualitative morphological parameters of the form to reformulate and analyze their influence on the energy and environmental quality.

The proposed hypothesis is based on the principle of minimizing energy consumption by reducing the rate of thermal needs. For this purpose, we propose an indicator that translates in numerical terms the variations of the energetic performance according to the quality of the envelope, at the same time it will allow us to evaluate the influence of the choice of the envelope on the climatic environment.

Our choice is carried on the form factor, it allows us to translate into figures the interaction between the form of the buildings and the climatic variations as it can apply to the particular and general cases.

Indicators have for the main vocation to simplify the complex situations with the stakeholders of the built environment by an evaluation at different scales, we will try to experiment with the influence of the building envelope on the interior space (comfort and energy saving) (Košir, Gostiša, and Kristl 2018)and on the exterior space (preservation of the environment and minimization of the emissions of Greenhouse gases)(Kumar and Raheja 2016)

METHOD AND MATERIALS

Analysis of the Energy Performance

Our objective, through this part, is the study of the influence of form on the energy performance of buildings in hot and arid areas, by seeking an interaction between the energy performance of the form and the need for air heating in our study. So, it is necessary to simulate the effects of shape on the amount of energy gains by modeling the value of the coefficient of form in the three variables (the size, volume and geometry), which will be compared and combined to lead to ways that better meet the thermal needs of the regions.

Literature Review

The question of the energy performance of the form has been the subject of several studies which we have tried to review, mainly (Lim and Kim 2018, Manz et al. 2018, Lee et al. 2016, Ling, Ahmad, and Ossen 2007, Ratti, Raydan, and Steemers 2003, Bahrami 2008). Whether the methods used in graphics and digital simulation share the same characteristics, they simplify the modeling of the form using factors or coefficients, which interpret the form and the morphological characteristics in numerical representative expressions. So, these methods simplify the actual conditions on certain assumptions, using parameters to fixed values and other assumptions that improve the simulation model.

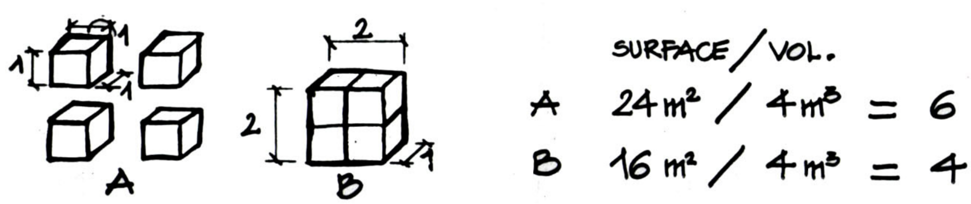


Figure. Densification of volume compactness and minimization of exposed surfaces. David Wright, 1979

The research should not be limited to finding the solution to our question by examining the energy performance by scientific solutions (mathematical or physical), based on needs assessment based on mathematical equations and physical help modeling form factor.

Specifically, the numerical models are based on the laws of physics, thermodynamics, and mechanics. The combined resolution of these equations allows us to follow the evolution of the main characteristic variables of the shape. The numerical resolution speed depends on the method of solving the multiple mathematical equations, but also on the calculation performance of the computers. Each of these variables is thus quantified and monitored by Software - OPTI-01developed with mat lab to extinguish the objectives of the study.

Description of Simulation Models

The accuracy of solutions depends on the choice of the physical model (form factor), their physical description, the choice of performances, as well as initial conditions (climatic and thermal) without forgetting the choice of representative forms that will make the simulation (fig1).

Table 1. Physical data for the simulation models.

Type	Envelope Area	Volume	Proportions	Form Factor
Cube	S_{E0}=5 a^2	$V_0 = a^3$	/	Cf_0'= 5/a

Parallelepiped	S_{E1}=2LH+ 2*lH+LH	V_1 = L l H	L=3/2* l H=3/4* l	Cf_1'=14/3l
Tower	S_{E2}=2*LH+ 20*lH+LH	V_2 = L l H	L=3/2* l H=9/4* l	Cf_2'= 34/9l
Dom	S_{E3}=2*ΠR^2	V_3 =2/3* ΠR^3	/	Cf_3'=3/R

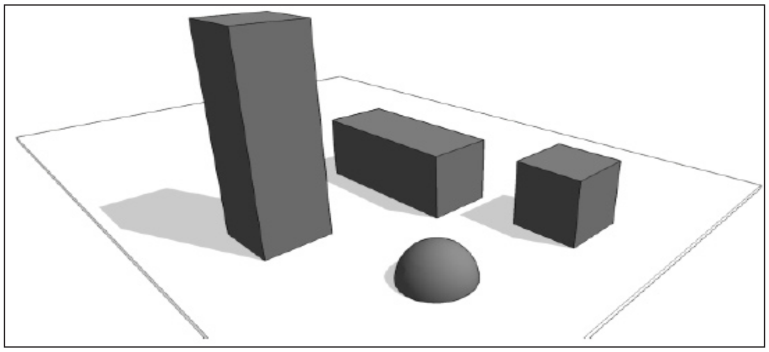


Figure 1. Representative forms that will make the simulation

Simulation Conditions, Climatic and Thermos-Physical

The simulation is theoretically for an altitude 30° during July 21, the calculation of gains is done in a steady state. The thermos- characteristics and climate data are fixed in advance for basic conditions as:

KE = External wall conductance(1.3 w/m2.°C).

a = Envelope absorption coefficient(0.7).

fe = Exchange coefficient of external surfaces(3 w/m2.°C).

ti = Indoor temperature(25 °C).

te = Base outdoor temperature (40 °C).

I1 = Intensity of radiation incident on S1 (East) = 516 w /m2.

I2 = Intensity of radiation incident on S2 (roof) = 776 w/m2.

I3 = Intensity of radiation incident on S3 (West) = 516 w/m2.

I4 = Intensity of radiation incident on S4 (South) = 94 w/m2.

I5 = Intensity of radiation incident onS5 (North) = 50 w/m2.

Outline of the Simulation Model

Q = Qc + Qs = Σ Kn Sn Δ t + Σ Sv I O……………… (1)

To obtain the number of inputs provided by the habitable volume "gain coefficient G" dividing the two sides of the equation with "V" the volume under consideration

This expression G = $\frac{\sum S}{V}$ KE Δ t shows that to minimize heat gain, it should be:designed forms such as the report $\frac{Se}{V}$ refers to the form factor is especially low as possible.

The Variables of the Simulation

The Geometry and Volume

In determining the value of volume "V" should look for the geometric shape that has minimal form factor Cf = $\frac{Se}{V}$ for minimal gains in the volume set on the geometry to study the influence of the value of volume "V" on the thermal performance of the form

G = Cf KE Δ t.

The Dimensions

In determining the geometry, we will try to define each form of the dimensions of the wall surfaces of East, West, and the roof according to the three levels of simulation by studying changes in the form factor part-Cf1, CF2, CF3 ... ... cfn, is that we should provide a good grasp of the orientation of the form.

$$G = C_f K_E \Delta t + C_{fn} \frac{aI}{fe} \quad \text{.................... ....(2)}$$

RESULTS AND DISCUSSION

Study of Volume Influence on the Form Factor Using Four Geometries

The study showed that regardless of the geometry. The relation between the volume and the form factor is inversely proportional to a minimum form factor it is necessary to enlarge the habitable volume.

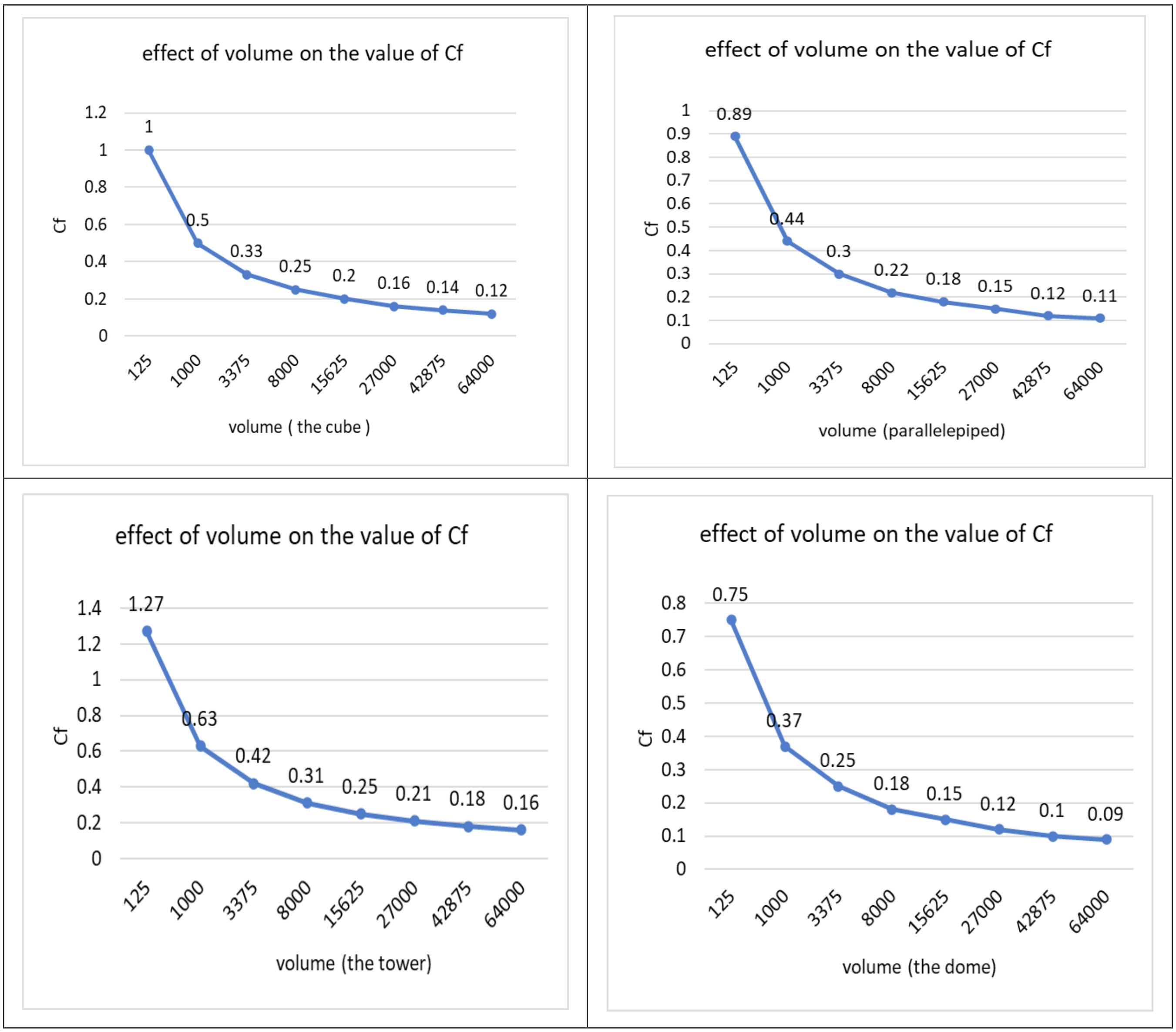


Figure 2. Study of the volume influence on the form factor using four geometries

Study of Geometry Influence on the Form Factor Using Various Volumes

The study showed that regardless of volume. The relationship between geometry and the form factor is proportional. For a minimum form factor, it is necessary to have less exposed surfaces such that 1 -dome 2-parallelepiped 3-cube 4-tower.

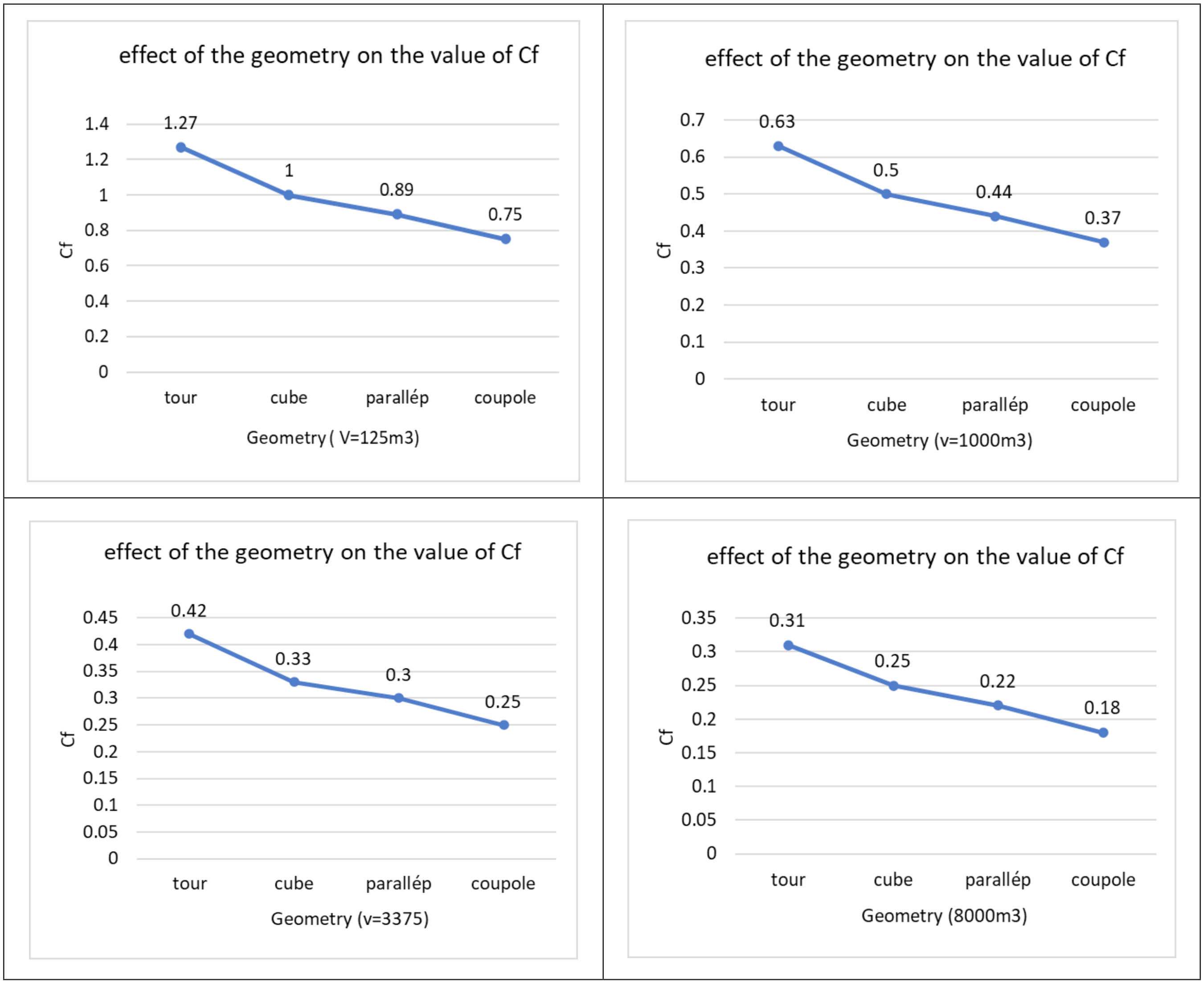
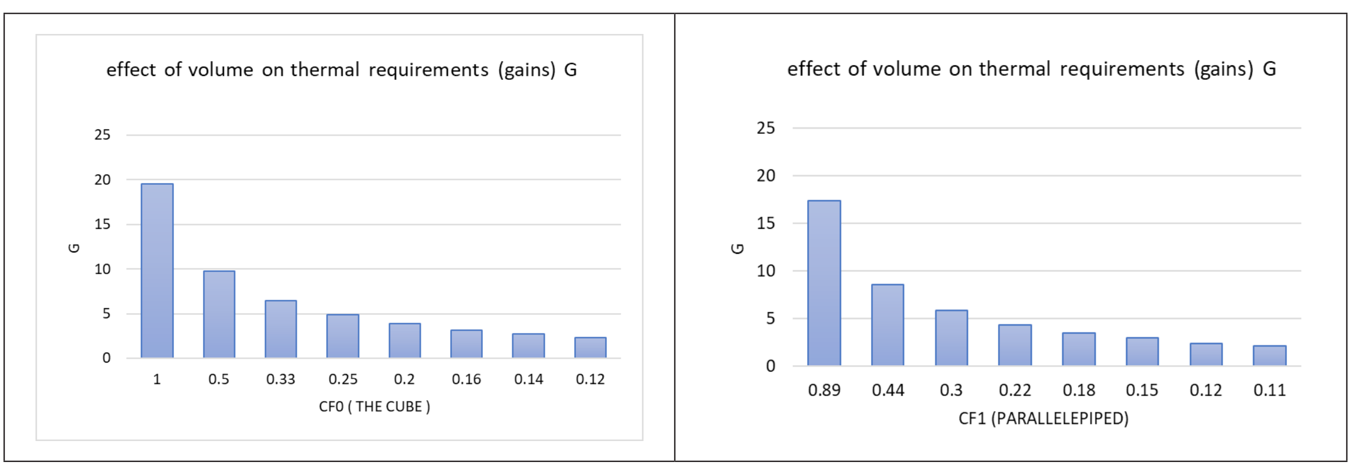


Figure 3. Study of geometry influence on the form factor using various volumes

Study of Form Factor –Volume- Influence on the Gain Factor G Using Various Volumes for the Four Geometries

The graphs illustrate the proportionality of the variation of the heat gains factor G in relation to the changes of the form factor Cf. for the four geometries. As he shows that the optimization of energy efficiency according to the choice of volumes varies from -50% to -90%



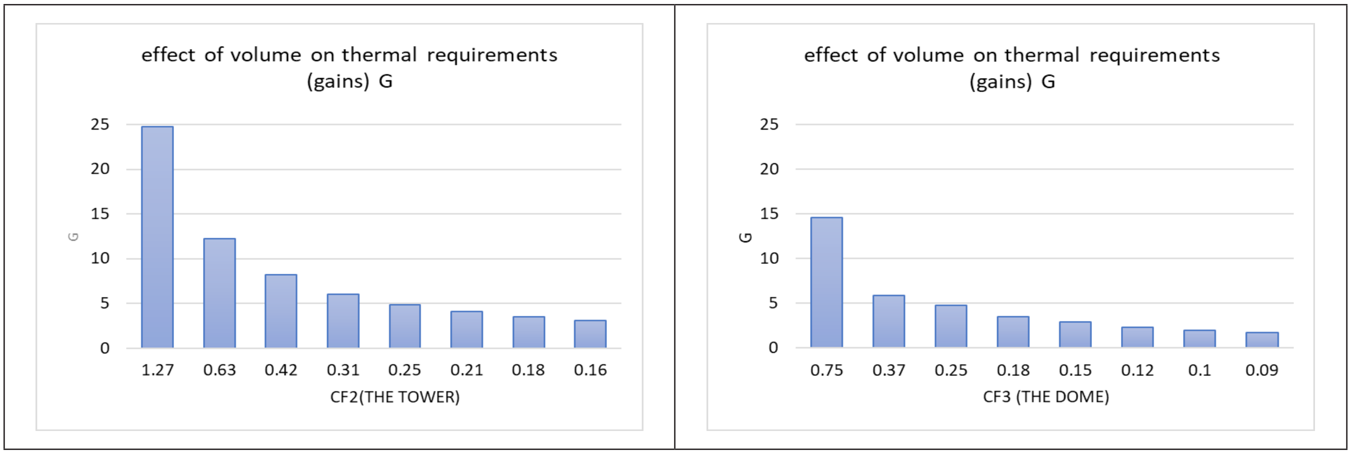


Figure 4. Study of form factor –volume- influence on the gain factor G using the four geometries

Study of Form Factor–Geometry- Influence on the Gain Factor "G" Usingfour Geometries- Tower-Cub-Parallelepiped-Domesfor the Constant Volumes

The graphs illustrate the proportionality of the variation of the heat gains factor G in relation to the changes of the form factor Cf. for various volumes.As he shows that the optimization of energy efficiency according to the choice of geometry varies from -20% to -40%

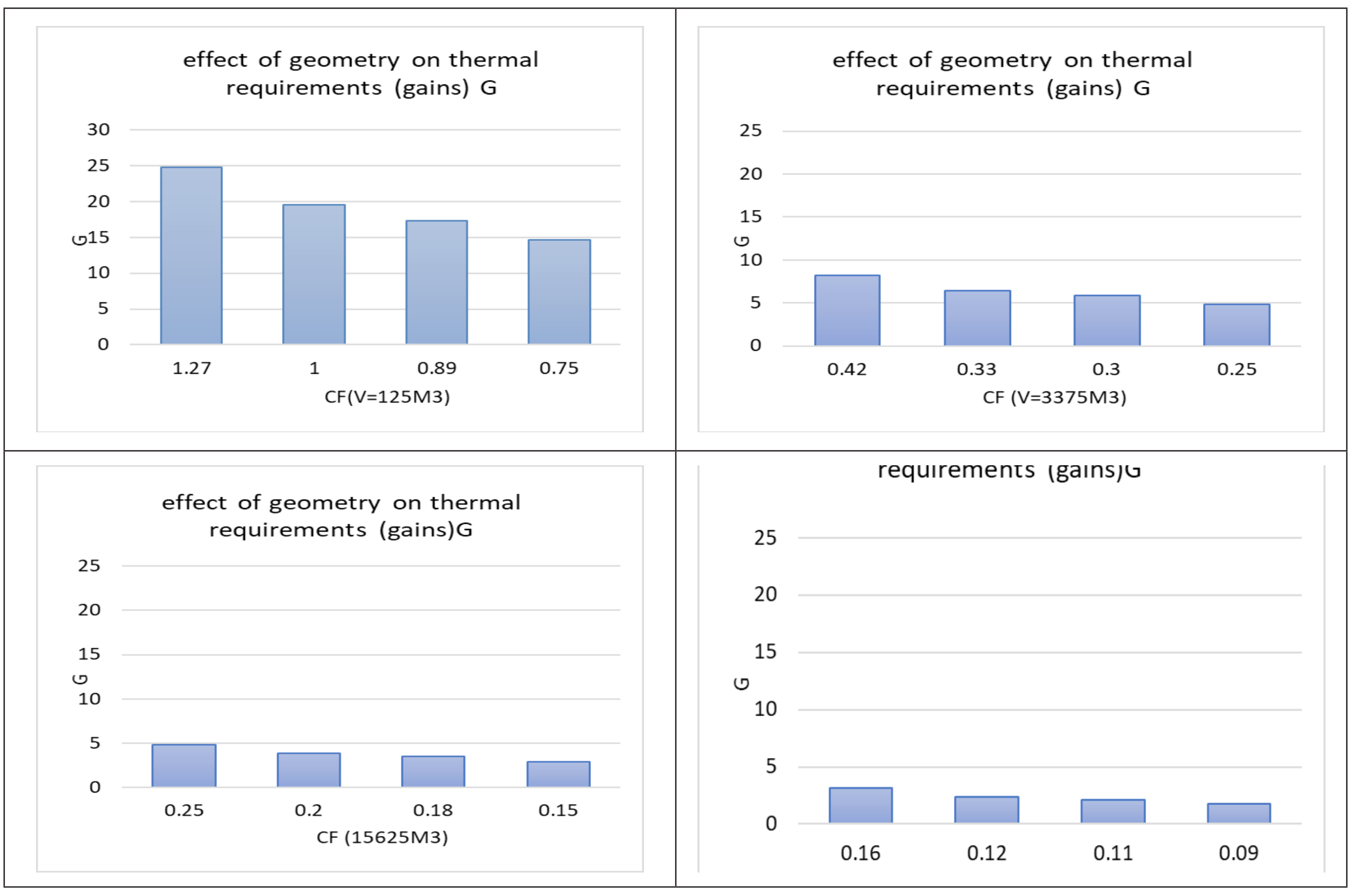


Figure 5. Study of form factor –geometry- influence on the gain factor "G" using various volumes

Interpretation of Results

The amount of heat gain "G" is relatively proportional to variations in the shape factor "Cf. This relationship can be expressed in two situations:

1 / - If you set the volume V, the factor "G" is proportional to the geometry as classified by successive calculating "Cfmin

(dome, parallelepiped, cube, tower). With -20% to -40% optimization of energy efficiency.

2 / - If we fix the geometry, the factor "G" is inversely proportional to variations in the volume "V", which means that for a "Gmin" must have "Cfmin by increasing the volume" V ".With -50% to -90% optimization of energy efficiency.

Study of the Influence of the Extra Temperature (TSA)

It is expected, through thispart, to study the influence of the extra temperature on the quantity of heat gains. In addition, the influence of solar radiation on the definition of the proportions between the sizes of the form allow for a constant volume geometry with minimal heat gains.

Then the factor of heat gains "G" should be written as:

$$G = C_f \Delta\, t\, K_E + \frac{aI_n}{fe} C_{fn} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Minimizing gains that heat in the building by determining the proportions of forms performance is by a definition of the optimal value of the function **G** according to the values of **L (l), l (w),** and **H** (height). It was **G =** $\frac{a}{L} + \frac{b}{l} + \frac{d}{H}$

The identification of variables (w, l, h) for the minimum value of G towards the minimum is a purely mathematical problem which is the optimization of a non-linear three variables under the following constraints:

The identification of variables **(w, l, h)** for the minimum value of G tend

- **V = l. L.H**, Volume constant.
- **H ≤ L or H ≥ L** Constraint of geometry (parallelepiped or tower).
- **O ≤ l ≤ L** Constraint of good guidance. Or of **O** is a constant greater than one following.

KE = External wall conductance (0.9 - 1.3 - 2 w/m2°C).

a = Envelope absorption coefficient (0.4 - 0.7 - 0.9).

fe = Exchange coefficient of external surfaces (1.5 - 3 – 5 w/m2°C).

This part of the study made by an algorithm interpreted with a computer program under Matlab.

OPTI 01 has reached satisfactory results, such as.

Final Results

According to the study and the actual audit results, it was concluded that the parallelepiped form is always better than the tower, with a constant volume.

To ensure optimal thermal performance of the form, the proportions are:

- The parallelepiped: L = 8H et L = 4 l

- The tower: L = l et H = 5L

The latter, widespread expectations of research and can be adapted by developers as reasons for land use, and functional organization of the formal aspect to adapt the level of 01 (parallelepiped) or Level 02 (the tower), provided that these proportions are used with measures of protection.

This case also has the advantage of having a horizontal surface (roof) very small, but areas east and west must be protected from heat gains due to horizontal sunlight in the morning or evening.

CONCLUSION

During thermal analysis, we can draw some conclusions that can be summarized in three points. What can be said is that the thermal performance of a building depends largely on the choice of form climatic conditions and place needs for heating. The study, comparison, and correlation between the geometric aspect, the volume, and proportions of the shape with the amount of heat gains on the latter should do this one.

First, and according to the variations of the coefficient of heat gains compared to the geometry, it was found that the dome is the most powerful geometry because it offers the most space with the below surface.

Parallelepiped shape is better than the tower and the cube because it has a surface footprint very important. This allows protection of a large area from its heat transfer and for the same reason that the cube is better than the tower. The choice of geometry can minimize **35%** of consumption of energy.

Secondly, the analysis of the influence of volume on the need of minimizing heat gain shows that the increased volume may minimize the gains of up to **90%**, so that collective housing is thermally more advantageous than individual housing, and the tour has been more successful than other examples studied through morphological analysis.

Thirdly, the study of the influence of the extra gains due to the exposure of the surfaces of the envelope the solar radiation has helped us to determine the better proportions of the parallelepiped and the tower.

According to an east-west as follows:

1/ the parallelepiped: L = 8 H & L = 4 l

2/Tower: L = l & H = 5 L.

For normal use of these results (proportion, volume, geometry), which presents the morphology of the building. Some recommendations and measures will be essential to ensure the smooth operation of our future heat buildings, once made. Ultimately, this work allows the optimization of the energy performance of buildings about the form indicator - thermal envelope - by the development of a digital simulation tool based on an algorithm programmed under Matlab.

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