Impact of building morphology, thermal inertia and glazed area on the energy consumption of residential houses

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ABSTRACT

This paper presents the energy savings that could be obtained by the appropriate design of the building in terms of morphology, thermal inertia and glazed area. Based on an extended database of values obtained by simulations, this parametric study gives a new approach for the architects or design engineers as support guidelines in the very first stage of their projects in finding efficiently energetic solutions.

One of the analyzed parameters is the building shape coefficient which is defined as the ratio between the volume of a built form and its external heating losses area. It is shown that there is strong relationship between the shape coefficient and the heating demand, major energy reductions being possible with the right building form, values that could reach up to 40%. Another aspect of this study is to illustrate the interaction between different design parameters and what it is their impact on the energy demand of residential houses during the winter season. It was also investigated the building time constant that characterizes the thermal inertia and which is defined as the ratio of the effective thermal capacitance to the steady-state heat-loss coefficient of the building. The most noticeable effect of inertia on the building was seen especially in mid-season period when the heating energy demand is highly reduced when using a heavyweight building by comparison to a light one. A 10-12% energy reduction on the heating demand could be achieved with the correct glazing surface and building time constant. These two parameters were found to be connected and must be analyzed in the same time.

Keywords: *heating demand, building shape, thermal inertia, glazing area*

1. INTRODUCTION

In France, the building industry contributes to 25% of greenhouse emission gases and 43% of total energy consumption, making it the biggest consumer of energy across all of the economy sectors. The energy spent to heat the occupied spaces in the residential sector represents more than 40% from the total energy demand that includes electricity, hot-water and air-conditioning. In this area a major energy reduction can be achieved if a building is correctly designed by engineers and architects.

Heating, ventilating and air conditioning (HVAC) systems, which consume large quantities of energy, have become a necessity for almost all the buildings (ASHRAE, 1992) to provide a comfortable indoor environment. Knowing the influence of certain design parameters on the energy consumption, it's mandatory to find out what is their correlated impact on the building.

With the energy policy and as well its active role putting energy issues on the agenda of the EU, France is making big efforts to reduce the energy consumption and the CO_2 emissions.

2. APPROACH

2.1 Building morphology overview

Building morphology is an important factor that could influence an increase/decrease of energy demand to heat or cool the occupied space. The shape of a building has also an important impact on the construction costs but most important on the energy consumption and implicitly on the costs. (Depecker et al., 2001) have investigated the relation between the form of the building and the energy consumption and (Ourghi et al., 2007) have developed a simplified analysis method to predict the impact of morphology for an office building on its annual cooling demand. They concluded that optimizing the shape of a building is an essential part if we want to minimize construction costs or to find the minimum seasonal demand of heating energy.

Optimizing the shape and functional structure of energy-savings buildings has been the research work of (Jedrzejuk & Marks, 2007). A good solution to analyze the effect of building geometry on the energy consumption is to use an indicator, called building shape coefficient (C_s) which is defined as the ratio between the heated volume of the building and the sum of all heat loss surfaces that are in contact with the exterior, ground or adjacent non-heated spaces.

A building is more compact as the shape coefficient takes higher values and it's deficient in form when it has lower values. A compact shape is desirable to minimize the costs and energy consumption of the building; however a hyper-compact building is not desirable from architectural and daylight-use point of view so a compromise must be found when sketching the project.

The greater the heat loss surface area, the more the heat losses through it, so small ratios imply high energy demands. This indicator could be criticized in several ways, mainly by the fact that does not capture the amount and distribution of the glazing area and secondly by not taking into account the orientation of the building (south versus west). The problem connected to the building orientation it's not so strongly related by the walls orientation. The most important is the glazing area and its distribution on the building's envelope.

Given these critical considerations, the present study examines different glazing scenarios through variance in glazing area and orientation. In Figure 1 are presented different building shape coefficients used for this research study, which are corresponding to the residential sector where the C_s is usually between 0.7 and 1.2.

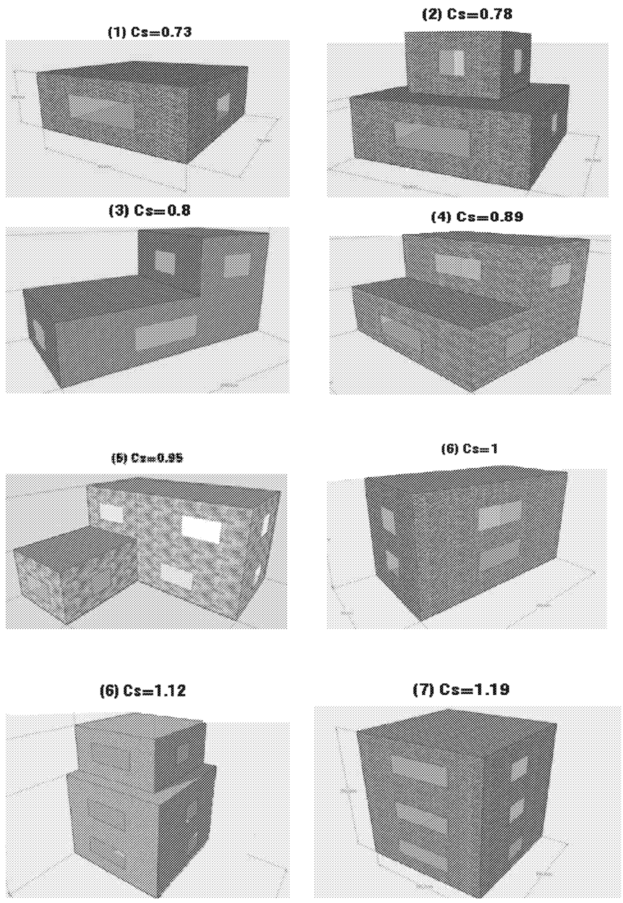

Figure 1. Building shape coefficients

2.2 Glazing area and distribution

The glazing area is an important building element for architects and engineers due to its effects on natural lighting and its potential on reducing the heating demand in winter. (Persson et al., 2006) showed that by using energy efficient windows it would be even better than having a highly insulated wall without windows.

This is because the window can collect and use the solar energy to heat the houses during periods when the sun is shining and the outdoor temperature is lower than the indoor temperature. The most appropriate size of a window for energy smart design depends on building orientation and the amount of thermal mass in the internal building materials. The French Standards (2005) are proposing an optimum of 16.5% of window to floor area ratio (WFR) but this value could go up to 22%, higher values increasing the risks of overheating during the summer period. Houses that implement passive solar strategies using thermal mass and south orientation must be evaluated on an individual basis. For this study several cases were analyzed (see Table 1) and for different WFR from 12% to 22%.

Table 1: Analyzed glazing surface cases

Cases	Percentage of glazing facing (%)			
	North	South	East	West
Uniform	25	25	25	25
South (1)	20	40	20	20
South (2)	20	60	10	10

2.3 Building thermal inertia

Incorporating thermal inertia when making the design of a building is a delicate issue, designers being obliged in most of cases to use dynamic simulations to better see the impact of inertia on building energy consumption. The most noticeable effect of inertia on the building is seen especially in mid-season and in summer periods when the cooling demand is highly reduced when using a heavyweight building by comparison to a light one. The benefits of a high building thermal mass are not only related to energy reduction but also with the indoor thermal comfort of inhabitants. In this study to express the thermal inertia of the analyzed buildings it was used the building time constant (τ), which is defined as the ratio of the effective thermal capacitance to the steady-state heat-loss coefficient of the building (including the transmission heat loss coefficient of the building envelope and the ventilation heat loss coefficient) (EN 832,1998) (Antonopoulos, 2000).

The higher the time constant of the building is, the larger fraction of solar gains can be used in winter and the slower it responds to sudden changes (Szalay Z., 2004). Higher time constants can be reached either by increasing the thermal mass of the volume or by decreasing the heat losses of the analyzed building. (Norén en al., 1999) simulated with three different simulation programs the thermal inertia of a reference building. Their results showed that a reduction of 16-18% of energy heating demand could be obtained when using heavyweight inertia (τ=325h) compared to a lightweight one (τ=31h). For the present research article, simulations for different building time constants were performed, starting from τ=10h to τ=200h.

2.4 Transient simulation and weather data used

The simulations data used for this study were based on the dynamic simulations with an hourly time-step realized using the TRNSYS (Klein et al., 2000) building simulation software. TRNSYS is a transient system simulation program with a modular structure that was designed to solve complex energy system problems by breaking the problem down into a series of smaller components. For our problem we have modeled the studied cases using the standard library of components that exists in the software database.

One climate from France was investigated: Lyon which has a temperate climate. Table 2 presents the monthly outdoor temperature and the global horizontal solar radiation of the analyzed climate.

Table 2: Lyon monthly weather data

Month	Outdoor temp. [°C]	Global solar radiation [kWh/m²]
January	8.67	31.6
February	9.35	49.79
March	10.9	95.52
April	13.1	127.44
October	17.1	66.75
November	12.3	37.05
December	9.64	25.98

3. RESULTS

The results were obtained for different parametric cases, an important number of simulations being realized. The first simulation data investigate the impact of building morphology on the annual heating demand (kWh) for a building insulated based on the recommendations of French standards (CSTB, 2005) (building envelope U-value of 0.75 W/m^2K and a ventilation rate of 0.7 ach).

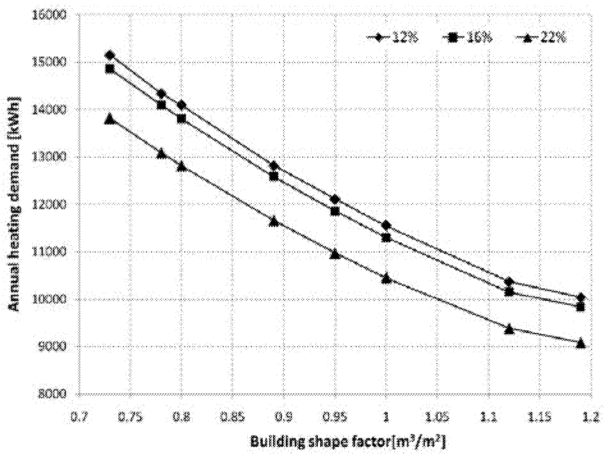

Figure 2. Building morphology and WFR impact on the annual heating demand

The hypotheses considered for Figure 2 were that the occupied space was of $100m^2$ and the building time constant was 17h which corresponds to a lightweight building. It can be observed that a maximum of 40% reduction on the heating demand could be obtained for more compact buildings. Moreover, increasing the glazing area has a benefic role in reducing the energy consumption due to the higher solar energy received during the winter season. The results confirm the fact that the building morphology is an important design parameter for architects, major energy reductions being possible with appropriate solution.

Figure 3 shows that the building time constant has a certain impact on the reduction of heating demand. The obtained results are corresponding to a glazing area of 12%, 16% and 22% with South(1) distribution on the orientation and for a building shape coefficient of 1. Increasing the building thermal inertia could be an interesting solution to reduce the energy consumption, for example between a heavyweight building (τ=200h) and a lightweight one (τ=5h) (see Figure 3 and 4).

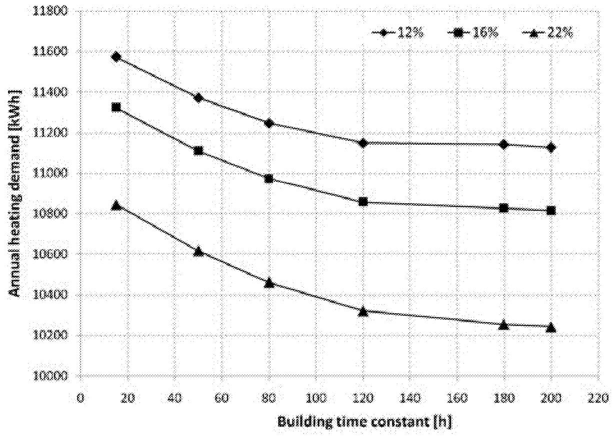

Figure 3. Building time constant and WFR impact on the annual heating demand

The lightweight building (low τ) reacts faster on weather changes and variation in internal heat gains than the more heavy buildings (higher τ). It is possible also that for short periods of time, if for a lightweight building is necessary to supply a certain heat energy, for a heavyweight this quantity could be reduced or even non necessary.

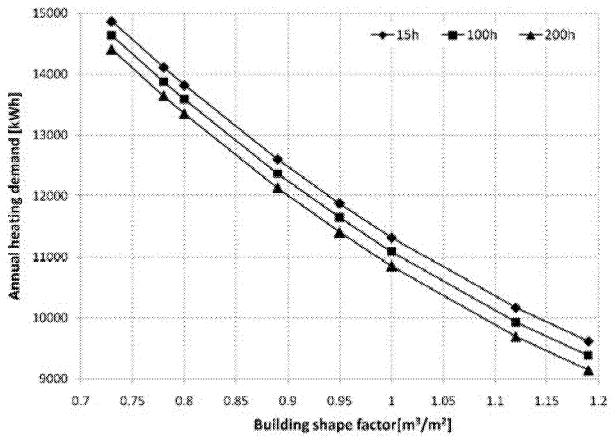

Figure 4. Building time constant and shape coefficient impact on the annual heating demand

The fenestration area of a building is an important factor in reducing or increasing the energy consumption during winter or summer periods. Figure 5 indicates that for different WFR and orientation distribution an energy reduction is achieved, especially for mid-season periods like October or April when the solar radiation takes higher values.

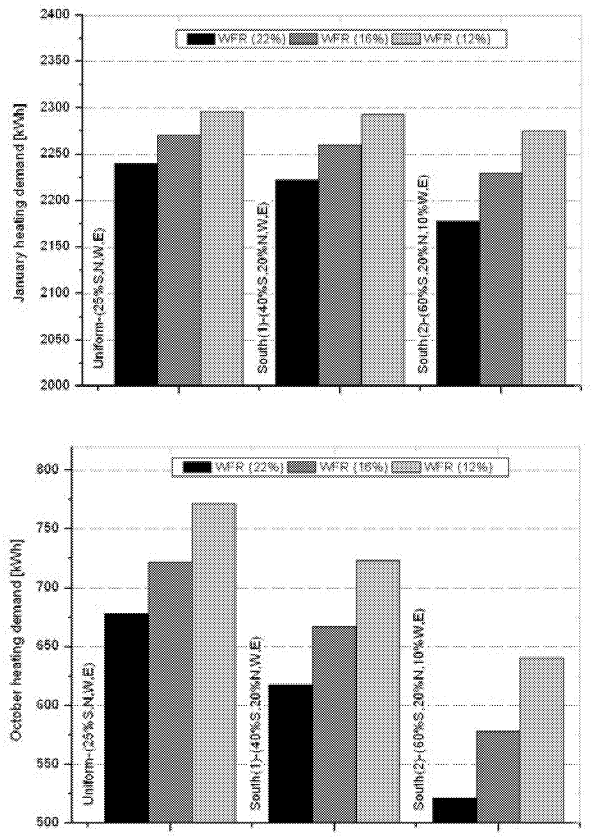

Figure 5. WFR impact on heating demand for Lyon

The data results presented in Figure 5 respect the same hypothesis from previous results, double-pane windows and a building shape coefficient of 1, but a better inertia with a τ= 100h.

4. CONCLUSIONS

The research study presented shows that the building morphology is an important design parameter in the process of finding an energy efficiently project. Lyon climate was analyzed and simulations were made for different building forms, glazing areas, orientation or thermal inertias. A first conclusion is related to the building morphology: a 40% reduction in the heating demand could be obtained if a building is more compact in shape.

The glazing area and its distribution are also essential parameters when sketching the future project. In this article different cases of surface area and orientation were analyzed. It is demonstrated that the heating energy requirement can be reduced with appropriate window surface and orientation. The building thermal inertia was analyzed by the mean of the building time constant. It was observed that thermal inertia allows an energy reduction up to 12%. The lowest specific energy requirement is obtained with a heavy concrete construction (a building time constant of 200h and a WFR of 22%). It is concluded that the above design parameters, presented in this study are very important for building energy analysis and major energy reductions are possible with proper directions.

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