International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 21 No. 1 Mar. 2016, pp. 140-149

http://www.ijisr.issr-journals.org/

Simulation Study of Thermal Zoning and its Impact on energy balance sheet of Building

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ABSTRACT: This paper presents simulations of the energy consumption for heating and cooling of residential building, by using different methods concerning thermal zoning. In this study we compared the simulation results of the single and the detailed zoning strategies. The Zoning is done during model creation to define its complexity. The Simulated models have been performed using the Program Ecotect. According to The results of this study, it was determined that the simulated energy load and indoor temperature were particularly sensitive to the thermal zoning, outdoor temperature and the rate of air exchange.

KEYWORDS: Thermal modeling, zoning strategies, rate of air exchange, energy demand, admittance method.

1 INTRODUCTION

Residential buildings are characterized by conceptual and operational specifications. In Morocco the building represents about 36% of total energy consumption, this energy consumption increases by 4.3% every year [1]. An urgent intervention to save energy is necessary to deal with this problem. Modern concepts like simulations and modelling are needed to meet the demands of the environment and to raise awareness of future legislation on energy efficiency. Building energy simulation is valuable during the early stages of design, when decisions can have the greatest impact on energy performance [2]. Despite the growing sophistication of building modelling tools, errors can arise from approximations that are made by a practitioner during model creation [3].

When using thermal modeling, the first step to be achieved is the definition of building components and its distributional geometry. Because of the high geometric complexity of certain buildings, thermal modelling can only be achieved by a suitable subdivision of the building in thermal zones. Several criteria and strategies with applicable assumptions are to be considered for modelling of thermal zoning of buildings. For modelling, a building should be subdivided into thermal zone [4]. In addition, there are no standard methods or restrictions that limit the number of thermal zones in a building.

In the literature there are few publications, who are studying in depth the problem of the impact of the thermal zoning on the energy balance of buildings. Concerning the effect of the thermal zoning on the energy loads, Chengchu Yan et al. [5] developed a simple analytical model for evaluating the impact of radiant heat on the building cooling load. The authors concluded that the most important factors determining the inner radiation effect are the radiative heat gains and the building zoning configurations. The single zone approach was a significant milestone in the field of thermal modelling. In this model all spaces are arranged in one zone and internal thermal parameters are perfectly uniform. According to the authors: Maas [6] and Foura [7] this modelling approach, despite its simplicity, has shown its limitations in terms of accuracy, especially when the building has conditioning system.

In their paper Kim et al [8] compared the energy consumption of a building by three zoning strategies: the room zoning, zoning, the floor zoning and the sunny area zoning. The results obtained by their models show that compared to room zoning, the floor zoning and zoning sunny surface have successively standard deviations of 3.57% and 3.17%, in cooling loads in a typical summer day. Regarding the heating loads in a typical winter day, the results comparing to the room zoning showed a standard deviation of 11.6% for sunny zoning and 6.13% zoning floor.

Clarice Bleil et al [9] proposed to investigate tow methods of zoning for a non-residential building, namely; zoning based on perimeter and zoning according to orientation, combined with the following strategies: a “single zoning” model, a” 5 zone” model and a “ room zone” model . The authors concluded that settings for internal gains and ventilation rates combined with the use of different zoning strategies leads to significant variations regarding the expected energy demands.

Italo Guimaraes et al [10] propose to integrate in the process of thermal zoning the following passive phenomena: the thermal radiation of the roof, solar radiation through windows and cross ventilation. For this, three strategies were tested on a large building, specifically the single-zone model, the 3-zones and finally the 9-zones model. Taking into account the results obtained, the authors recommended finally the single zone model to reduce modelling time and treatment.

Andrzej Baranowski et al [11] tested many zoning strategies, from the simplest to complicated, for three types of building. They concluded that the use of the simplest models with single zoning provides more realistic results.

2 STUDY METHODOLOGY

2.1 METHODS OF ANALYSIS

In this study a dynamic simulation tool is used to examine the impact of thermal zoning on energy modeling and highlights thermal optimal performance of building. The calculation of thermal loads is an important step in building energy simulation. According to V. Szokolay [12], a building can be considered as a thermal system with a series of inputs and outputs of heat. The system can be described by the following equation:

$$Q_i + Q_c + Q_s + Q_v + Q_e = \Delta S$$

Where:

ΔS: is the change of the heat stored in the building
$\mathbf{Q_i}$: is the internal heat gain
$\mathbf{Q_c}$: is the conduction heat gain or loss
$\mathbf{Q_v}$: is the ventilation heat gain or loss
$\mathbf{Q_s}$: is the solar heat gain.
$\mathbf{Q_e}$: is the evaporative heat loss

ECOTECT [13] is the program used in this study. The thermal calculation used by the program is based on the so-called "Admittance Method" [14]. It is used to describe the thermal inertia of a building in the dynamic mode [15].

The admittance Y is expressed as a function of thermal properties of building components [16].

$$Y = \sqrt{\frac{2\pi\rho\lambda C}{P}}$$

Where:

ρ : density
λ : thermal conductivity
c : specific heat
P: period of 24 hour

2.2 BUILDING DESCRIPTION

Our study focuses on a typical Moroccan house Figure 1 , located in the city of Kenitra (latitude 34.30°), in the climate zone 1 of the thermal building regulations in Morocco [17].

The size of the apartment is 124 m². The facades are oriented successively the south and west. The Rate of windows referring to the south is 17% and to the west is 28%. The building does not have conditioning system, therefore it is naturally ventilated. The low and high temperatures inside of the building are respectively 18 ° C = Tmin and Tmax = 26 ° C. Four people live in the building, with a 50% occupancy rate from Monday to Friday and 100% for Saturday and Sunday. The simulations are considering the hottest and the coldest day of the year.

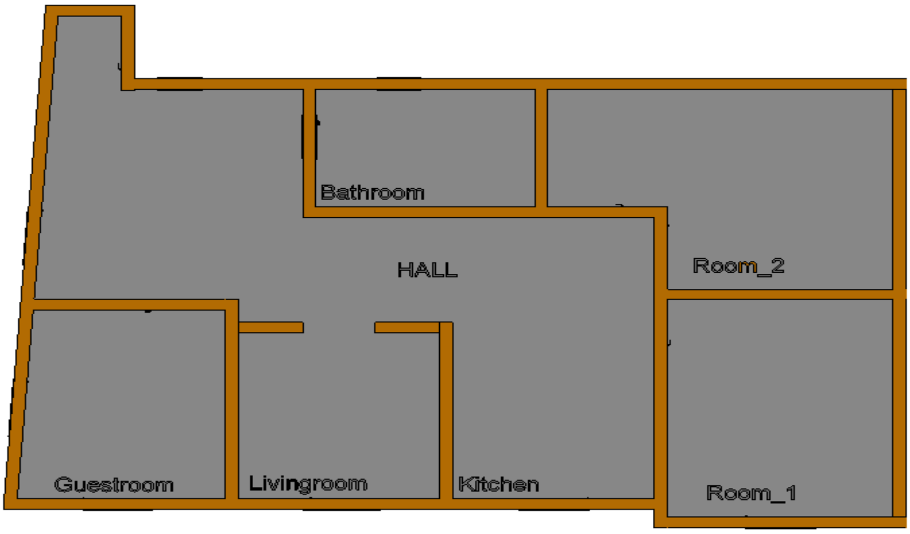


Fig. 1. Schematic description of the studied apartment

The envelope parameters are fixed for all simulations. Key parameters in this study are: the number of zones and the rate of air exchange. A description of the materials used in the construction of the building is summarized in Table 1.

Table 1. Buildings envelop settings

Item	U [W/m².K]
Ceiling	3.22
Floor	4.05
Wall	1.54
Window	5.33
Door	2.16

2.3 ZONING CONFIGURATION

In this study two zoning approaches were discussed, namely the single-zoning and multi-zoning configurations. For each configuration, simulations were made in two typical days of the year representative of extreme weather conditions by imposing different rate of air exchange. They are shown in ACH and can be expressed as a function of the incoming air flow and volume:

$$ACH = \frac{q}{V}$$

Where: q : Incoming air flow, and V: Volume of space

The air exchange rate includes both outside air coming in through the openings and through the air leaks of the building envelope. Air exchange rates examined in the simulations of this study are: 0.5.ACH, 1.ACH, 2.ACH and 5.ACH.

3 RESULTS AND DISCUSSION

To have a view on the influence of the simplification and detailing in the thermal zoning of the building, the required energy for both configurations, and the indoor temperature were determined.The assigned rate of air exchange to the reference situation for the both alternative zoning was an average of 1.ACH. For both strategies zoning, the same technical and Constructional constraints were used.

Fig.2 and Fig.3 below show the distribution of the annual heating and cooling consumption by the single zoning and Multi-zoning. According to result, the amount of energy required varied throughout the year. The annual heating demand varies on average between 565kw for multi zoning and 290kW for single zoning. The relative difference between the both configurations is around 49%. More the heating energy consumed in winter for the multi-zoning configuration is about 78% of the total annual energy. Whereas in case of single zoning only 67% of the total annual energy is consumed in the same season Fig.4. It can show also that the heating demand is underestimated or overestimated depending on application of the zoning method used. This can be justified by the nonuniform distribution of the building surfaces and the corresponding heat gains.

Comparing the cooling energy demand for the both configurations, the values change on average between 230KW for Multi zoning and 260kW for single zoning. The relative difference between the both configurations is around 6%. The difference here is much smaller than that of the heating demand .The single zoning characterizes the zoning strategy with the highest cooling demand. This is significantly influenced by the large surface area of the zone.

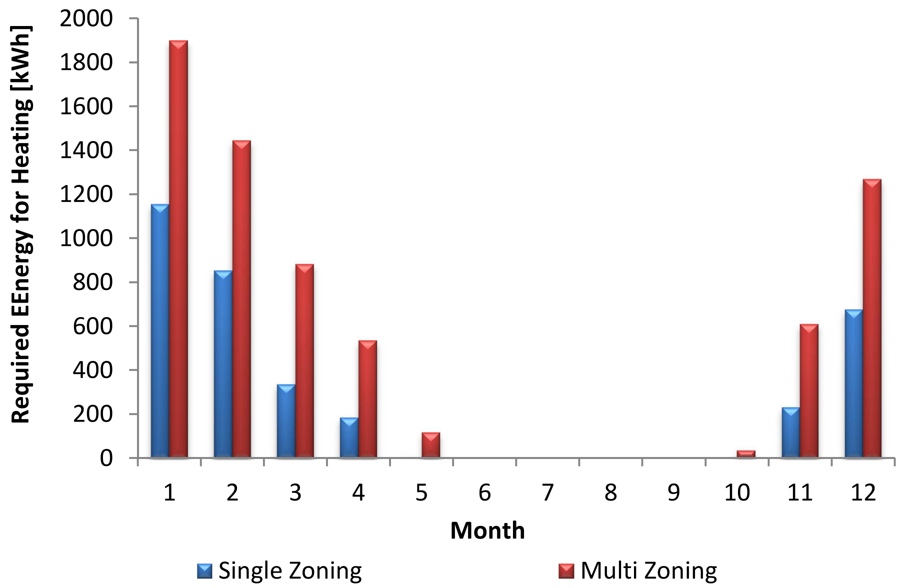


Fig. 2. Monthly Heating Energy Demand [kWh]

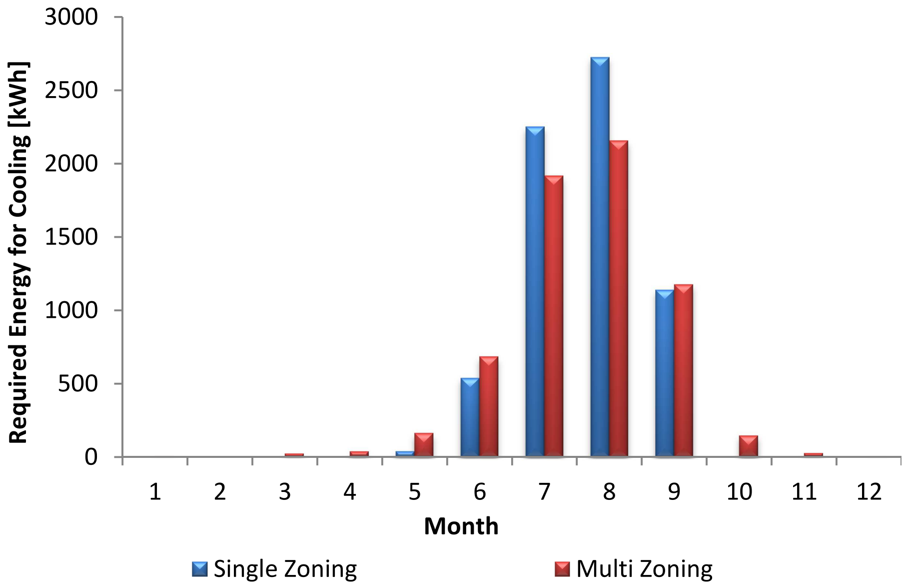


Fig. 3. Monthly Cooling Energy Demand [kWh]

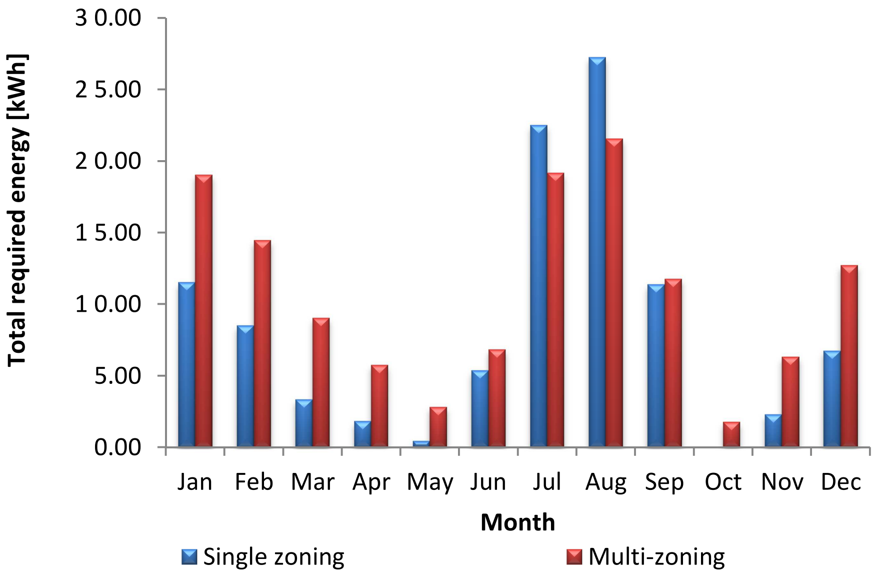


Fig. 4. Monthly Total Energy required for heating [Wh]

Figure 5 shows the effect of air change rate and the zoning configuration on annual energy consumption. These histograms show that the increasing rate of air exchange involves an increasing energy demand for both zoning strategies. Furthermore the detailed zoning configuration presents the dominant energy demand compared to single zoning method. More, in the interval from 0ACH to 1ACH, the reduction in energy consumption relative to Mutli-zoning compared to single zoning remained relatively constant. But from 2ACH energy reduction becomes weak.

The relative reduction of total energy consumption of the Multi-zoning compared to single zoning increases progressively, while the air change rate increases from 0ACH to 1ACH Fig. 6. As the air change rate continues increases to 2ACH, the relative reduction total energy consumption keeps almost constant value. After that, the relative change decreased significantly when the air change rate becomes 5 ACH.

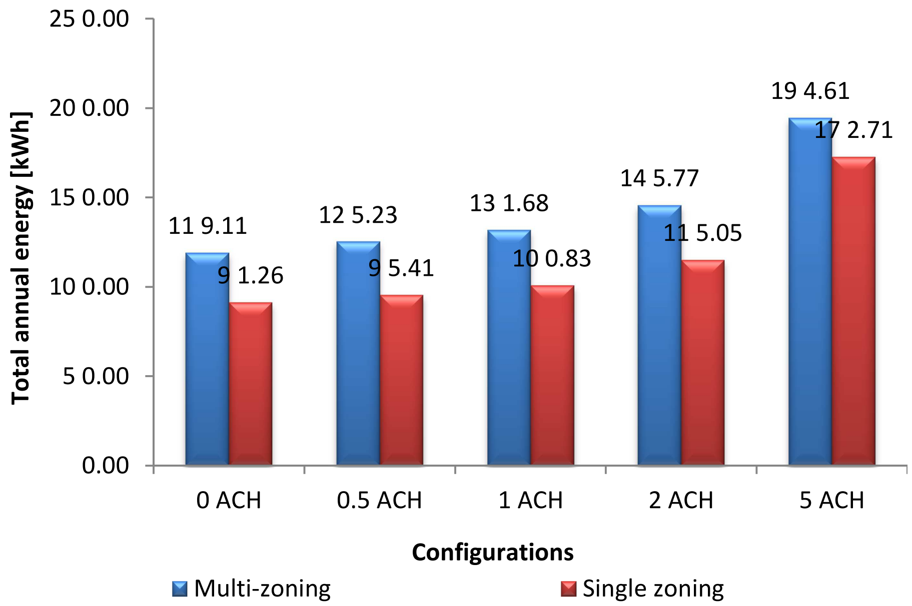


Fig. 5. Total annual energy requirement depending on the rate of air exchange

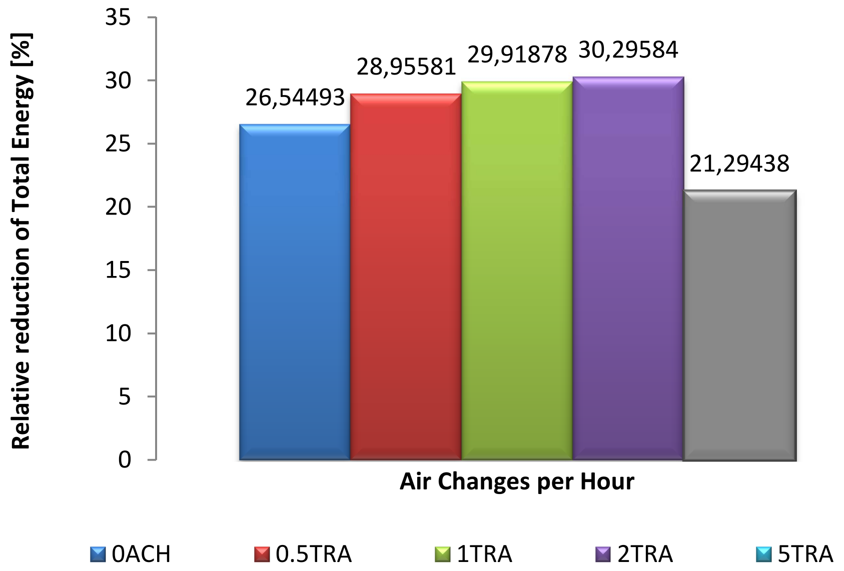


Fig. 6. Reduction in total annual energy of the Multi-zoning compared to single zoning based on the rate of air exchange

According to the Fig. 7, fig. 8 and fig.9, the thermal behavior of both configurations is similar. Significant increase in the average indoor air temperature occurred with applying the multi zoning strategy when the rate of air exchange was changed from 0ACH to 5 ACH in the winter and summer. Lower temperatures tend to appear in the single zoning model especially in the case of low air exchange. This is probably due to the surface representative of the area of the zone.

As seen in the figures, during periods of high solar gain, at noon until 16h, when all zones begin to overheat, the curves, for both configurations, tend to merge, when the rate of air exchange increases.

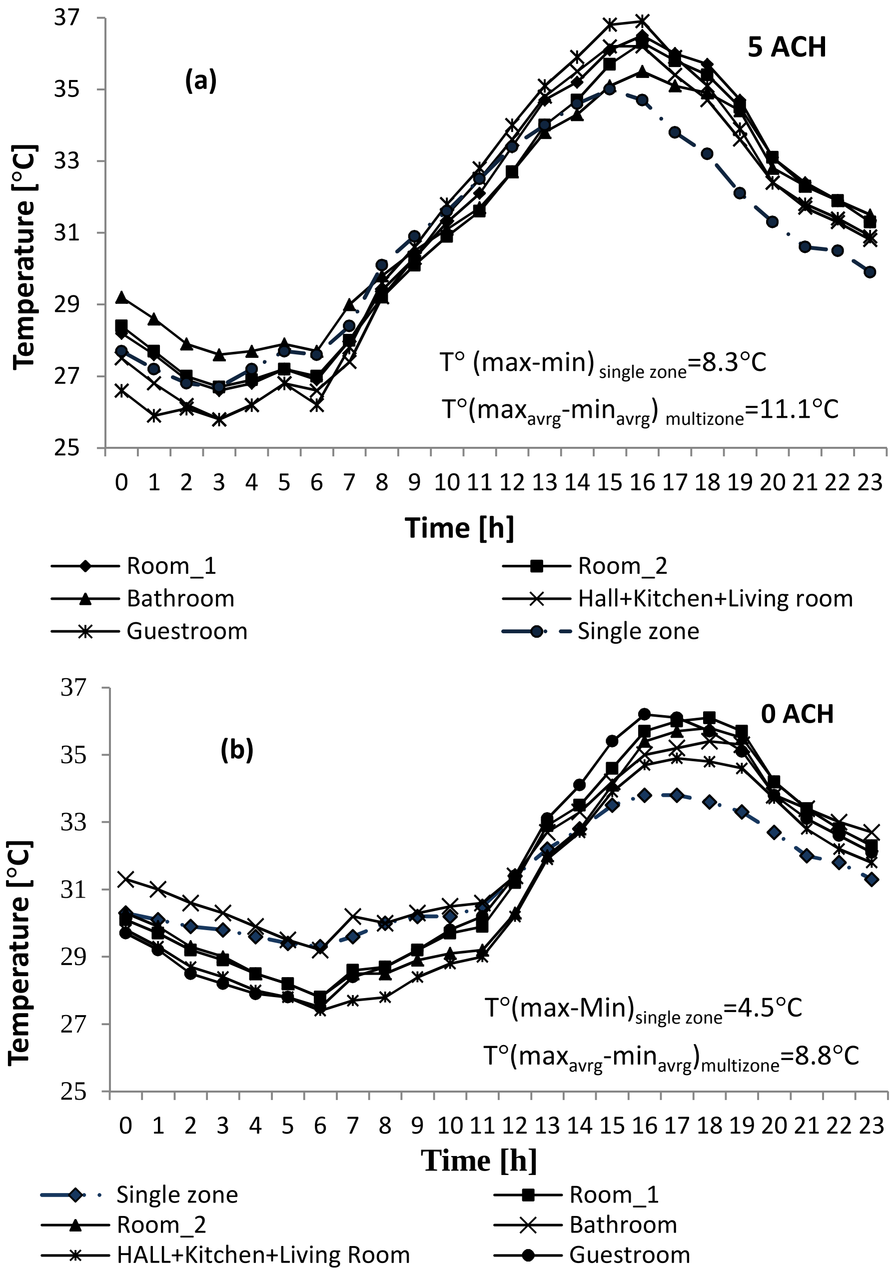
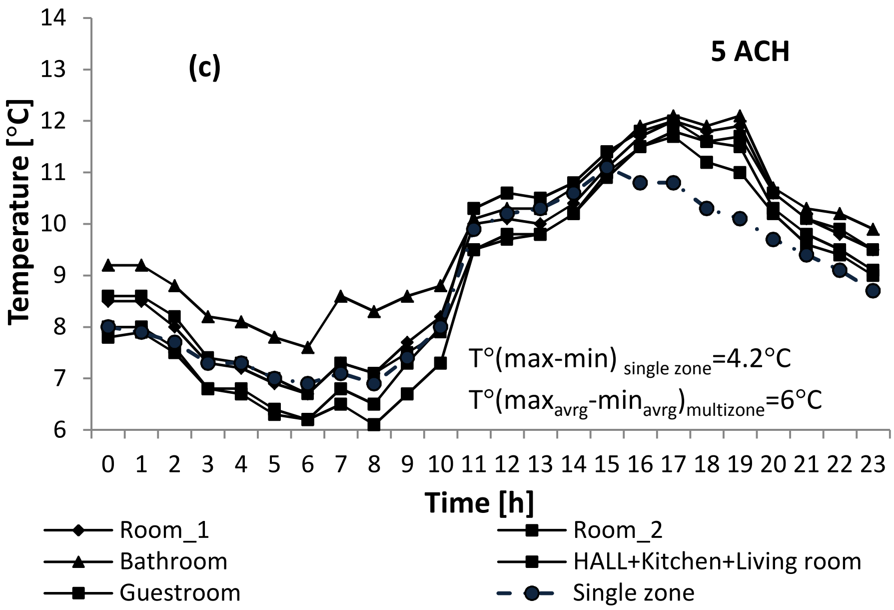


Fig. 7. a, b: Variation of internal temperatures for both configurations during a typical day in summer



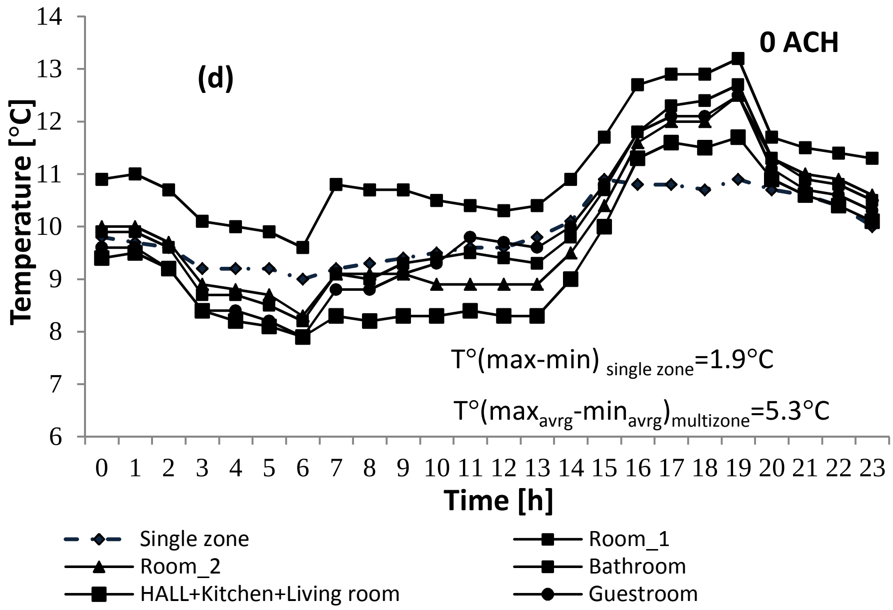


Fig. 8. c, d: Variation of internal temperatures for both configurations during a typical day in winter

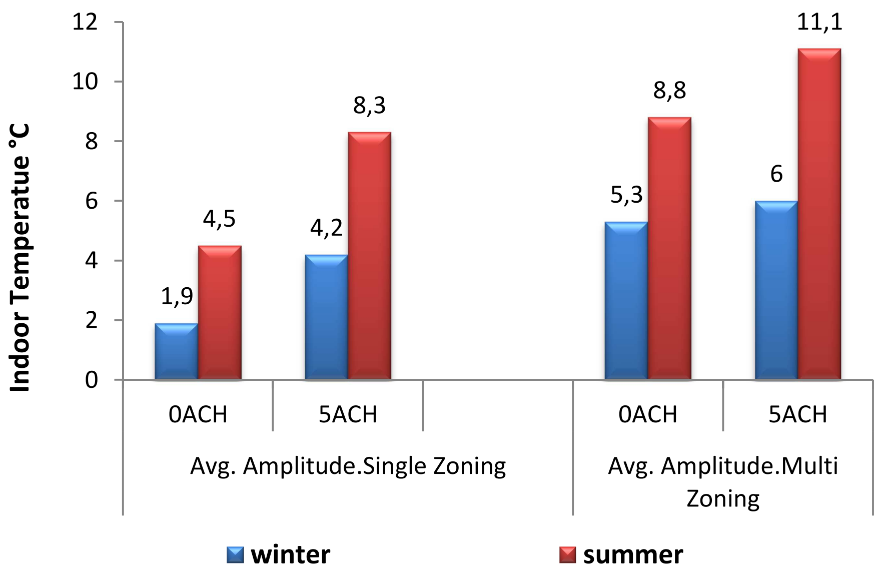


Fig. 9. Variation of internal temperatures for both configurations in winter and summer

4 CONCLUSION

The thermal zoning configuration of a building is the important factor by which the predicted energy consumption is determined. In this study, this subject has been analyzed by Ecotect software for a residential building in Kenitra, Morocco. Based on the results of simulation we can concluded that the assumptions made on the thermal zoning can significantly affect the prediction of energy demand as well as the indoor temperature, and furthermore the optimal building design. The use of a large number of zones predicts an increase in energy consumption, because the solar heat gain is not uniformly distributed in the building, which leads to overheating of certain areas. In case of single zone configuration the air heated by sunlight or by the heater is fully mixed throughout the building, thus using its heat capacity to compensate the losing heat in zone with less thermal gain. It can be shown also that the heating demand is underestimated or overestimated depending on the used zoning method. According to the results, there is a remarkable variation of the amplitude of the indoor temperatures, when the rate air exchange increases for the multi-zoning strategy.

In this work, only the rates of air exchange and the outdoor temperature, combined with the zoning methods, have been taken into account. Future research can take advantage of the examination of additional parameters like building orientation, the windowing rate, to make a complete assessment of the different zoning strategies, which is more representative for the real energy demands in the residential building. Furthermore, it is believed that in order to have a more representative idea concerning the energy loads of building, in-situ measurements should be conducted.

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