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Influence of passive solar gains on the energy consumption of a typical house in Algiers

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Abstract - *The purpose of a bioclimatic house is to make every effort to reduce the need for heating and cooling. For this a well studied architecture of the house is essential: - the positioning of windows to capture the maximum solar radiation, - Good thermal insulation of the house to reduce heat loss. This study focuses on the effect of solar and internal heat gain on the energy consumption of a typical well insulated house. The degree day's method is used to determine the heat losses by transmission and ventilation according to international standards on thermal insulation of building (NBN B62-301), the results are very interesting and promising. By including the solar and internal gains, which vary from 900 to 1400 kWh, the energy consumption decreases significantly. The thermal load for heat reaches 60 kWh, but by including the free thermal gains, 10 kWh of energy can be saved daily.*

Résumé - *L'objectif d'une maison bioclimatique est de tout mettre en œuvre pour réduire les besoins en chauffage et en refroidissement. Pour cela une architecture bien étudiée de la maison est indispensable: - le positionnement des vitrages pour capter le maximum de rayonnement solaire, - une bonne isolation thermique de la maison pour diminuer les pertes de chaleur. Cette étude se concentre sur l'effet des gains de chaleur solaire et interne sur la consommation énergétique d'une maison typique bien isolée. La méthode des degrés-jour est utilisée pour déterminer les pertes de chaleur par transmission et ventilation conforme aux normes internationales sur l'isolation thermique du bâtiment (NBN B62-301), les résultats sont très intéressants et prometteurs. En incluant les gains solaires et internes, qui varient de 900 à 1400 kWh, la consommation d'énergie diminue de manière significative. La charge thermique atteint 60 kWh, mais en incluant les gains thermiques gratuitement, 10 kWh d'énergie peuvent être économisés quotidiennement.*

Keywords: Heat transfer - Degree day's method - Heating of building - Thermal insulation, - Energy saving.

1. INTRODUCTION

The use of solar energy in buildings is one of most important contribution for reduction of fossil fuel consumption and harmful emissions into environment. More than 25 % of total energy consumption is due to buildings heating and cooling.

In 2003, the final energy consumption for heating and cooling buildings (EU-32) represented about 3600 TWh, with 93 % for heating and only 7 % for cooling [1]. Solar energy can also contribute to meet heating demands, both for indoor spaces and hot water.

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The use of degree-day methods in the energy analysis of buildings is presented in several studies [2-4].

The heating degree-day method was used to determine the natural gas consumption in residential heating in Turkey [2]. The heating degree day and cooling degree day numbers are calculated for various base temperatures by using daily maximum and minimum temperature data for the long-term (21 years), measured at meteorological stations in 79 city centers of Turkey [3].

The heating and cooling degree-hours for two main cities in Greece were studied [4], the heating degree-hours were calculated for base temperatures from 10 to 20 °C and the cooling degree-hours for base temperatures from 20 to 27.5 °C, using a temperature step of 0.5 °C.

The results are presented in tabular form and serve to the energy requirements estimation, heating fuel consumption and air conditioning systems for either monthly or seasonally operation.

Liu Yang *et al.* [7] used the overall thermal transfer value (OTTV) method and the heating degrees-days technique for heating and cooling analysis of needs in 5 sites in China.

An evaluation was conducted on monthly consumption data registered by the property holders for over 100 multifamily buildings/real estates in Sweden [8]. The approach used, based on the energy signature method, was developed for evaluating the energy performance of multifamily buildings in terms of the overall heat loss coefficient K_{tot}. To compensate for the missing data, different assumed consumption profiles have been used. More precisely, the under floor heating has been studied by several authors.

The unsteady thermal performance of a test room heated by circulating hot airflow under the floor was analyzed using a developed mathematical model based on heat transfer equilibrium among the air flow, the floor and the indoor air [11].

A method for calculating the floor surface temperature in radiant floor heating/cooling system has been studied [12]. A new formula is derived to estimate the floor surface temperature.

The method assumes the floor is divided into two layers. Based on the numerical model of the radiant floor system built in this paper, the correlation of the thermal conductivity of the lower layer is developed. With this method, the floor surface temperature can be obtained easily without solving the partial differential equations.

The results show that the floor surface temperature values derived from the proposed method are in agreement with the experimental and numerical values. The method is helpful to design the radiant floor system and estimate the system heating/cooling capacity.

An interesting article [13] addresses a different topic and specific: the thermal comfort and ventilation efficiency can be achieved by combining under floor heating / cooling with displacement ventilation.

Radiant floors provide uniform thermal conditions inside the rooms, the reduction of vertical differences of air temperature and radiant temperature asymmetries, because they exchange heat with the environment (walls, furniture, occupants and air) by radiation and convection in similar quantities[13].

In this work, the energy consumption was evaluated for heating a standard house having volume of 313 m^3 located in Algiers, it's built with local materials according to required insulation standards.

By using NBN B62-301 worksheet, based on the calculation of thermal resistances, the level of total thermal insulation was determined, $k_S = 0.43$ was found, and the house satisfies the first requirement imposed by the thermal regulation. The degree day method is most adapted for monthly and annual energy analysis of building, by considering effectiveness and conditions of use of building which vary according to outside temperature.

The solar contributions by glazed surfaces and opaque walls affect the house energy consumption; their influence on energy consumption was studied.

2. METHODOLOGY

By using good house insulation and double glazing installation, the level of total thermal insulation agrees with European standards on thermal habitat insulation.

The method used for calculations is the degree day's method which appears to be most suitable. Degree-day methods are the simplest methods for energy analysis and are appropriate if the building use and the efficiency of the HVAC equipment are constant.

Where efficiency or conditions of use vary with outdoor temperature, the consumption can be calculated for different values of the outdoor temperature and multiplied by the corresponding number of hours; this approach is used in various bin methods.

When the indoor temperature is allowed to fluctuate or when interior gains vary, models other than simple steady state models must be used. The concepts of degree-days and balance point temperature remain valuable tools. The severity of a climate can be characterized concisely in terms of degree-days.

Also, the degree-day method and its generalizations can provide a simple estimate of annual loads, which can be accurate if the indoor temperature and internal gains are relatively constant and if heating or cooling systems operate for a complete season. For these reasons, basic steady-state methods continue to be important [5].

2.1 Heating degree days

The equivalent degree days can be written as follows: [5]

$$\mathrm{HDD} = \int_{\Delta t} \left(T_{NH} - T_{WH} \right) \times dt \tag{1}$$

Where:

Δt is the chosen period;

The non heating temperature (T_{NH}) is the temperature from which we can stop heating the buildings, taking into account the free internal contributions.

The temperature without heating (T_{WH}) is the temperature which would be obtained in a building not heated and not occupied. This temperature is equal to average outside temperature.

After simulations based on 15 °C and 18 °C, it was opted for T_{NH} = 18 °C which gives results closer to actual values of energy demand.

2.2 Calculation of the thermal losses by degree day's method

The need of useful heat of a building depends on thermal qualities of its envelope (thermal resistances), and its losses by ventilation.

$$Q_{L,heat} = \left[H_T + H_V\right] \times HDD \tag{2}$$

With:

$$H_T = k_s \times A \qquad \text{and} \qquad H_v = C_p \times \beta \times V$$

2.3 Ratio utilization factor of heat gain

The using rate of solar and internal gains is function of thermal losses, solar and internal thermal contributions and building inertia [9].

$$\gamma_{heat} = \frac{Q_{g\,heat}}{Q_{L\,heat}} \tag{3}$$

- if $\gamma_{heat} \geq 2.5 \quad \Rightarrow \quad \eta = 1/\gamma$
- if $\gamma_{heat} < 2.5$

$$\begin{cases} \eta = \dfrac{a}{a+1} & \text{for } \gamma_{heat} = 1 \\[2ex] \eta = \dfrac{1-(\gamma_{heat})^{a}}{1-(\gamma_{heat})^{a+1}} & \text{for other cases} \end{cases} \qquad \text{(3.1) and (3.2)}$$

With:

$$a = 1 + \frac{\tau_{heat}}{54000} \tag{3.3}$$

$$\tau_{heat} = \frac{C_{building}}{H_T + H_V} \tag{3.4}$$

With:

$C_{buildng}$: Building effective thermal capacity, (Light construction type $C_{buildng} = 8451\ kJ/K$.

2.4 Monthly Net energy needs for house heating

By making the energy balance, the solar contributions intervene in energy needs for either house heating or cooling, from where the ratio utilization factor of heat gain is function of thermal losses and solar contributions by glazing and opaque walls.

$$Q_T + Q_V = \eta \times (Q_I + Q_S) + Q_{heat\,réel} \tag{4}$$

The net monthly energy needs for heating are determined as follows [6]:

$$Q_{heat\,réel} = Q_{Lheat} - \eta \times Q_{g\,heat} \tag{5}$$

The net heating depends on the heat loss by transmission and ventilation and the ratio utilisation factor of free gains.

3. ANALYSIS OF RESULTS

3.1 Free heat gains

A percentage of heat gains by roof, glazing and internal gains relative to total heat input were plotted.

In winter, heat gains by glazing are very important due to low position of the sun. (Fig. 2).

In summer, heat gain through the roof are higher. This corresponds to changing solar irradiance as shown in Fig. 5.

Internal inputs are considered constant throughout the year (In the regulatory calculations [10] CSTB evaluates fixed internal contributions to 100 Wh per day per m² of living space).

In winter (December and January) the heat exchange through the roof is negative, there is heat loss from the house to the outside (-40 kWh in January and -23 kWh in December).

Free heat gains vary from 900 kWh in January to 1400 kWh in August (Fig. 3).

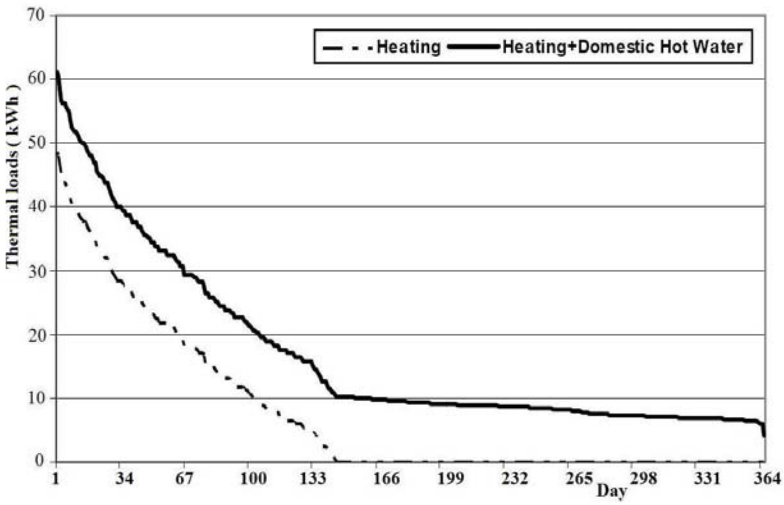

Fig. 1: The monotonic of thermal loads without free heat gains

The heat gains occur by the glazing or by the roof; their importance is according to the season. Gains are more important by glazing in winters, while they are more important by the roof in summer.

Their sums are almost constant and are in the interval from 1000 to 1400 kWh.

Therefore they are quite important and influential on energy consumption in building.

3.2 The monotonic of thermal loads

The monotonic of thermal loads is the curve of daily energy demand for house space and water heating (Fig. 1 and Fig. 4), this curve allows determining the boiler power to be installed.

The monotonic of thermal load for the year 2008 was plotted by considering the heating based on set temperature of 18 °C and hot water of 35 litters per person per day.

The thermal load reaches 60 kWh if free gains are ignored (Fig. 1), but including thermal contributions by opaque walls and glazing, energy demand goes down to 50 kWh, which allows us to save 10 kWh of energy for heating and hot water (Fig. 4).

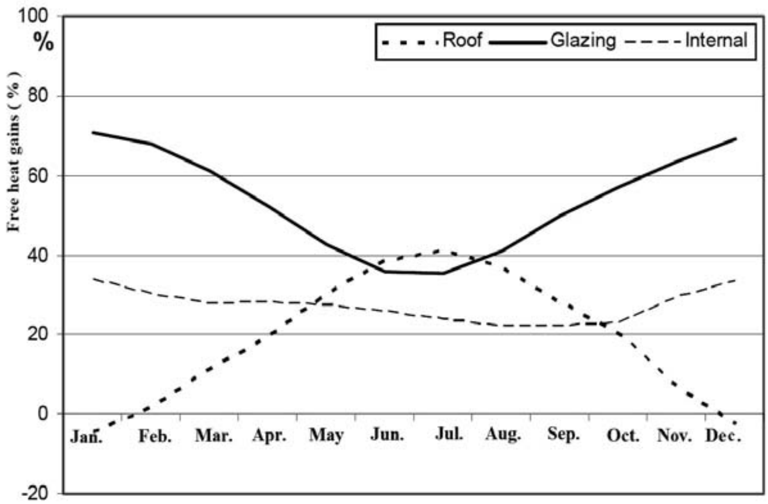

Fig. 2: Free heat gains by roof, glazing and internal

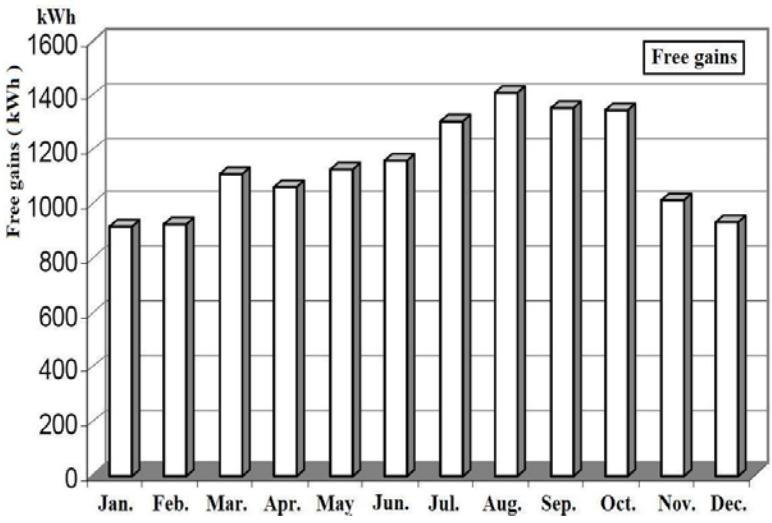

Fig. 3: Free heat gains (Solar and internal)

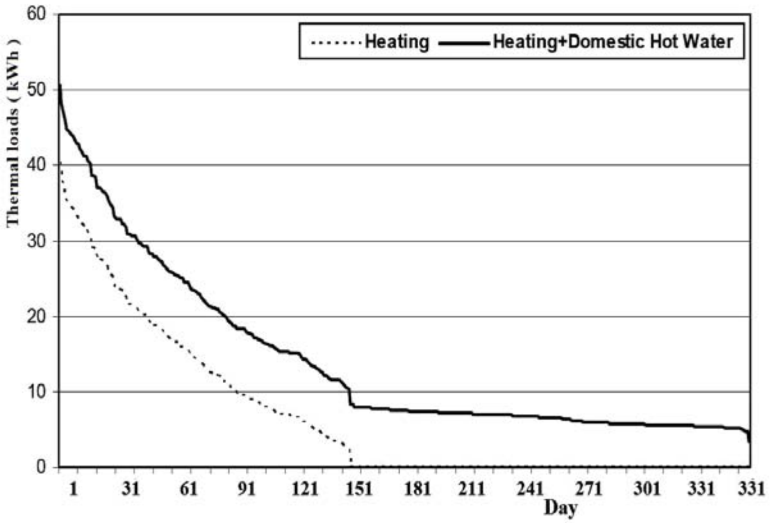

Fig. 4: The monotonic of thermal load with free heat gains

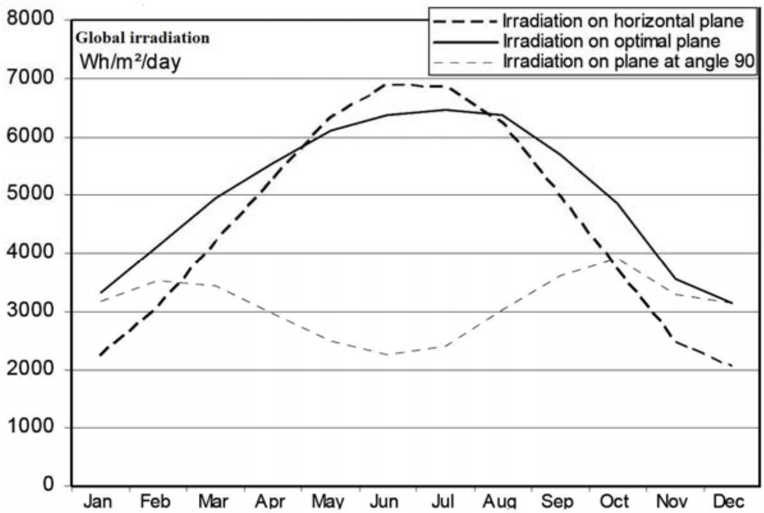

Fig. 5: The Global solar irradiance in Algiers

4. CONCLUSION

Solar energy potential is very high in Algeria (5 billions GWh per year), thus solar techniques have to be developed in order to take most advantage of this energy.

The building parameters must be optimised for use of solar gains. It would be necessary to well insulate the opaque walls and use the double glazing.

A good insulation decreases the heat losses of housing thus the energetic demand is would be less. The monotonic of thermal loads allows determining the boiler size to be installed for heating, domestic hot water and sizing of solar installation.

In this work, emphasis was made on good house insulation by using local materials for construction. An insulation level K43 was obtained which is in compliance with required standards on building insulation.

This allows to install a boiler of power 2.10 kW instead of 4 kW without solar contributions.

NOMENCLATURE

H_T : Coefficient of monthly losses by transmission, (W/K)

A : Building surface of losses, (m^2)

k_S :Coefficient of total thermal transmission of the considered building, (W/m^2K)

β : Ventilation rate of the room, (h^{-1})

a : Numerical parameter

Q_T : Losses by transmission, (MJ)

Q_I : Heat internal contributions, (MJ)

$Q_{heat, net}$: Net monthly energy needs for heating, MJ

$Q_{g, heat}$: Monthly heat gain by radiation and heat internal production, (MJ)

H_V : Coefficient of monthly losses by ventilation, (W/K)

C_p : Air specific heat, (Wh/m^3K)

γ_{heat} : Ratio of monthly thermal gain and monthly thermal losses

V : Air volume included in the room, (m^3)

τ_{heat} :Times-constant of energetic sector(s)

Q_V : Losses by ventilation, (MJ)

Q_S : Solar contributions, (MJ)

$Q_{L, heat}$: Monthly heat losses by transmission and ventilation, (MJ)

η : Ratio of monthly utilization of heat gain

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