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A Methodology for the estimation of the Thermal and Cooling Loads of urban areas

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Abstract: - A methodology to evaluate thermal and cooling loads of urban areas is presented in the present work.Characteristic quantities of interest in such a study are the geometrical characteristics, length - width - height, the quality of construction through which the natural and thermodynamic characteristics, such as the average heat transfer coefficient. The energy consumption of buildings is estimated assuming that the buildings during the periods of winter and summer function according to the ASHRAE standards. The area chosen as an application of the above methodology is the broader area of Athens, since its thermal and cooling needs come up to the forty percent (40%) of the total Greek energy consumption, providing original and vital information for energy saving research.

Key-words:- building thermal loads, building cooling loads, urban area, energy-saving

1 Introduction

It has been reported in [1] that building energy consumption within the European Union (E.U.) reaches the 40% of the total energy used. In 1998 it reached 252 Mtoe of which the 25% was electrical and the rest was thermal. The production of renewable energy sources (RES) reached a percentage of 2,75%. According to the same source of reference, the use of energy in public and commercial buildings reached 108 Mtoe with a percentage of 68% of electrical over thermal. In the U.S.A. the buildings consume about 36,6% of the total energy. Residences use about 500 Mtoe whereas commercial ones 415 Mtoe. The environmental impact of buildings in the greenhouse air emission is about 30%.

All countries are interested in knowing their degree of energy self-sufficiency that is defined as the percentage of the energy consumption that is covered by domestic production. In Greece, Athens is the city with the highest energy demands. These demands although high, they still can be measured and therefore it would be worthless in the near future to have discussions for alternative or new sources of energy without knowing the real energy demands of Athens which represents the 40% of the Greek population.

A methodology to determine the thermal and cooling loads of urban areas is described in the first part of this work. In the second part the wider urban area of Athens is chosen as an application of the methodology. The building characteristics of interest are the geometrical quantities such as length, width, height, as well as the quality of the construction through which the natural and thermodynamic characteristics (building density, weight, average specific heat, and average heat transfer coefficient).

2 Methodology

The first step is the determination of the area of research, i.e. the wider region of interest to be audited. The total surface is subdivided in a finite number of square districts, NSD, that have the same area A_m expressed in km^2

Consequently the total area of the region under consideration results from the

multiplication of the number of districts times the area
$A_{Ath} = NSD \, x A_m$ expressed in km^2 (1)

The second step consists of the selection of a number of the NSD square districts, namely NSSD, that is defined as the regions of sampling. Hence the total area of the sampling is

$A_{tS} = NSSD \times A_m$, expressed in km^2

that fixes the percentage of the sampling to the total region of interest

A_{tS} / A_{Ath}

In each NSSD, building squares are selected by the urban maps, and the following steps are taken:
- Building registration and characterization according to the criteria of use, type of construction, age and height.
- Collection of electricity consumption bills (2 summer and 2 winter months).

As far as it concerns the building age, a building is characterized as “old” when it is constructed before 1960 and otherwise it is characterised as “new”.
The values of medium material density (ρ_{mean}) and heat capacity are related to the structural manufacture of building and their values are given in [1,2,3].
The quoted density is the average density of the building (ρ_B) and is calculated by the relation: $\rho_B = M_B \cdot V_B$.
The values for the average heat transfer coefficient U are given in the reference [4], where it is stated that the values of average heat transfer coefficient of stonework depending on the building age for both domestic and commercial use is U = 1,3 Watts/m ^{2} K for old buildings and U = 0,6 Watts/m^2 K for new buildings obeying to the national regulations of heat insulation of buildings that are in force in Greece.

3 Calculations

After collecting the data from the audits, the following calculations are performed:
A) Per building
- Perimetric building surface (A_{Bp}):

$$A_{Bp} = 2\,LB + 2\,LH + 2BH \quad (m^2)$$

- Surface of building base (A_{Bb}):

$$A_{Bb} = LB \quad (m^2)$$

- Building volume (B_B):

$$B_B = L \cdot B \cdot H \quad (m^3)$$

-Building mass: $M_B = \dfrac{\rho_B \cdot V_B}{1000}$ (ton)

Building thermal losses:

$$TLS_B = \left(\left(A_{Bp} + A_{Br}\right) \cdot U \cdot \Delta T\right) + \left(A_{Bb} \cdot U \cdot \Delta T^*\right)$$
where

TLS_B are the thermal building losses
A_{Bp} is the perimetric building area
A_{Br} is the roof building area
A_{Bb}, is the base building area
U is the mean building heat transfer coefficient
ΔT is the temperature difference between an average building interior and exterior temperature
ΔT^* is the temperature difference based on the building material absorption and its thermal hysteresis.

Building cooling losses:

$$CLS_B = \left(\left(A_{Bp} + A_{Br}\right) \cdot U \cdot \Delta T\right) + \left(A_{Bb} \cdot U \cdot \Delta T^*\right)$$
where

CLS_B are the building cooling losses

Thermal energy needs:

$$ET_B = TLS_B \cdot DD_T \quad \text{(MJ/year)}$$

where
ET_B are the building thermal energy demands
DD_t are the heating kelvin days

Cooling energy needs:
i) $EC_B = CLS_B \cdot DD_C$ (MJ/year)
where
EC_B are the cooling building energy demands
DD_C are the cooling Kelvin days

$$\text{ii)} \quad EC_B = \sum_{1}^{CM} \sum_{1}^{30} \sum_{1}^{24} CLD \quad \text{(MJ/year)}$$

where
EC_B are the cooling building energy demands
CLD are the cooling loads resulting from the CLTD (Cooling Load Temperature Deference) method.

where
CM is the number of cooling months

B) Totals per region (with N is the number of audited buildings per region):
- Total base surface of audited buildings (ΣA Bb):

$$\Sigma A_{Bb} = \sum_{i=1}^{N} \left(A_{Bb}\right)_i \qquad (m^2)$$

- Total volume of audited buildings (ΣB B):

$$\Sigma V_B = \sum_{i=1}^{N} \left(V_B\right)_i \qquad (m^3)$$

- Total mass of audited buildings (ΣM B):

$$\Sigma M_B = \sum_{i=1}^{N} \left(M_B\right)_i \qquad (ton)$$

- Total thermal losses of audited buildings (ΣTLS$_B$):

$$\Sigma TLS_B = \sum_{i=1}^{N} \left(TLS_B\right)_i / 1000 \qquad (kW)$$ - -

Total cooling losses of audited buildings (ΣCLS$_B$):

$$\Sigma CLS_B = \sum_{i=1}^{N} \left(CLS_B\right)_i / 1000 \qquad (kW)$$ -

Total thermal needs of audited buildings (ΣET$_B$):

$$\Sigma ET_B = \sum_{i=1}^{N} \left(ET_B\right)_i \qquad (MJ / year)$$

-Total cooling needs of audited buildings (ΣEC$_B$):

$$\Sigma EC_B = \sum_{i=1}^{N} \left(EC_B\right)_i \qquad (MJ / year)$$

4 Reduction of results in each sampling district surface

The following relations are used for the results reduction of each sampling district surface:

- Surface factor Λ_{1j} (Square district area / Sampling area) for the each j - square district, that is

$$\Lambda_{1j} = \frac{A_m}{A_j}$$

where A_m is the area of square districts and A_j is the sampling area of the j-region.
- Sum of building base surface in each square district:

$$\left[A_{Bb}\right]_j = \frac{\Lambda_{1j} \cdot \Sigma A_{Bb}}{10^6} \qquad (km^2)$$

- Sum of building mass in each square district:

$$\left[M_B\right]_j = \frac{\Lambda_{1j} \cdot \Sigma M_B}{10^6} \qquad (Mton)$$

- Sum of building thermal losses in each square district:

$$\left[TLS_B\right]_j = \frac{\Lambda_{1j} \cdot \Sigma TLS_B}{10^3} \qquad (MW)$$

- Sum of building cooling losses in each square district:

$$\left[CLS_B\right]_j = \frac{\Lambda_{1j} \cdot \Sigma CLS_B}{10^3} \qquad (MW)$$

- Sum of building thermal needs in each square district:

$$\left[ET_B\right]_j = \frac{\Lambda_{1j} \cdot \Sigma ET_B}{10^3} \qquad (GJ / year)$$

- Sum of building cooling needs in each square district: (2)

$$\left[EC_B\right]_j = \frac{\Lambda_{1j} \cdot \Sigma EC_B}{10^3} \qquad (GJ / year)$$

5 Application of the above methodology to the urban area of Athens

Athens was chosen to evaluate the methodology described since it is the largest urban area of Attica that extents up 3.808 square kilometres (percentage of 2,9% of total surface of Greece). Its population comes up to the 35% of total population of country (3.522.769 individuals according to the National Statistics Bureau in 1991).

Athens' climate is mild Mediterranean type. This climate results from the latitude (37° 58′) of the city, the presence of the Mediterranean Sea and the winds that prevail in the south end of the Balkan Peninsula, that are reported in the weather forecast data [5,6]. According to these data, the average monthly temperatures in the city of Athens are between 10°C and 29°C with an average annual temperature of 19°C. The highest temperatures during summertime are usually about 38~39°C whereas the minimum ones during winter are about 0°C. The average annual number of cloudy days is 68, whereas the cloudless ones are 113.

For the reduction of results in the urban area of Athens, the following relations are used:

As it can be seen from Fig. 1, the wider region of Athens was divided in 157 square districts and 43 of them were chosen to be the sampling districts.

- Surface factor Λ (Area of 43 square districts of / Area of wider region Athens = Area of 157 square districts)

$$\Lambda = \frac{A_{Ath}}{A_{tS}} = \frac{157}{43} = 3{,}651$$

- Sum of building base surface in each square district:

$$[A_{Bb}]_t = \Lambda \cdot \sum_{1}^{43} [A_{Bb}]_j \qquad (km^2)$$

- Sum of building mass in each square district:

$$[M_B]_t = \Lambda \cdot \sum_{1}^{43} [M_B]_j \qquad (Mton)$$

- Sum of building thermal losses in each square district:

$$[TLS_B]_t = \frac{\Lambda \cdot \sum_{1}^{43} [TLS_B]_j}{10^3} \qquad (GW) -$$

Sum of building cooling losses in each square bronchus:

$$[CLS_B]_t = \frac{\Lambda \cdot \sum_{1}^{43} [CLS_B]_j}{10^3} \qquad (GW) -$$

Sum of building thermal needs in each square district:

$$[ET_B]_t = \Lambda \cdot \sum_{1}^{43} [ET_B]_j \qquad (GJ / year) -$$

Sum of building cooling needs in each square district:

$$[EC_B]_t = \Lambda \cdot \sum_{1}^{43} [EC_B]_j \qquad (GJ / year)$$

Figures 2,3,4,5,6 illustrate the results audit measurements.

6 Conclusions

In the present work, an original methodology was presented that allows the estimation of thermal and cooling loads of urban areas. The method is based on a sampling of square districts that represent the main characteristics the whole urban area.

The urban area of Athens was chosen to be examined because it combines all the necessary characteristics needed in the methodology with great variety. These variations were verified in the cooling and thermal loads of the various areas of the Greek capital due to the differences in the average age of buildings, year of construction, population density and construction material used.

This application of the methodology could be easily extended in the other urban areas of Greece providing useful information to researchers for energy saving studies.

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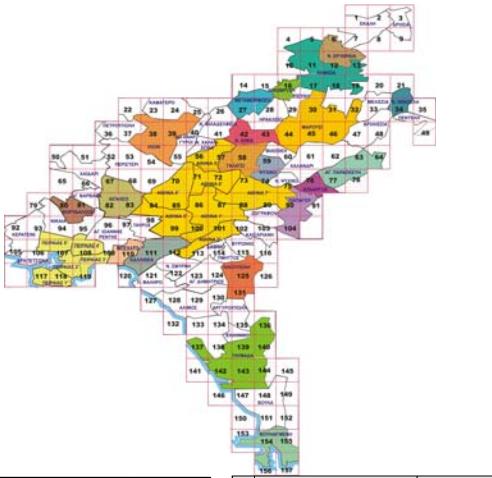

No.	Municipality, Region	Square No
1	Agia Paraskevi	77, 78
2	Athens (Sec. 1), Plaka	100
3	Athens (Sec. 2), Pagrati	101
4	Athens (Sec. 4), Kolonos	70
5	Athens (Sec. 5), Patissia	56, 57
6	Athens (Sec. 7), Ampelokipoi	88, 89
7	Cholargos	76
8	Egaleo	82, 83
9	Galatsi	58
10	Glyfada	143, 144
11	Glyfada, Terpsithea	140
12	Helioupolis	125
13	Ilion	38
14	Kallithea	111

No.	Municipality, Region	Square No
15	Kifissia	12, 18
16	Korydallos	80, 81
17	Lykovrisi	16
18	Marousi (KAT)	17, 30
19	Metamorfosi	27, 28
20	Moschato	110
21	Nea Erythraia	12, 13
22	Nea Ionia	42
23	Nea Penteli	34
24	Papagou	90, 91
25	Pireaus (Sec. 1), Kallipoli	117, 118
26	Pireaus (Sec. 3, 4 & 5)	107, 108, 119
27	Psychico	74
28	Vouliagmeni	154, 155

Fig. 1: Map of Athens and areas of sampling

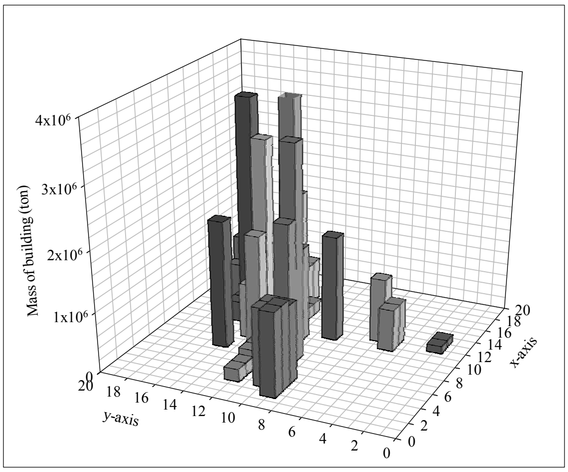

Fig. 2: Audited mass of buildings in the 43 square districts of Athens.

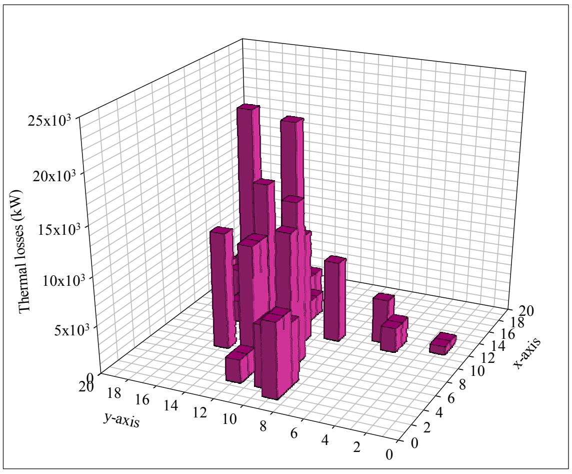

Fig. 3: Thermal loss distribution in the audited buildings.

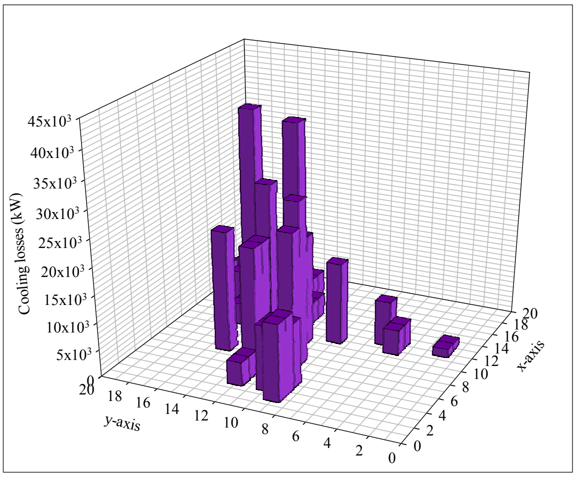

Fig. 4: Cooling loss distribution in the audited buildings.

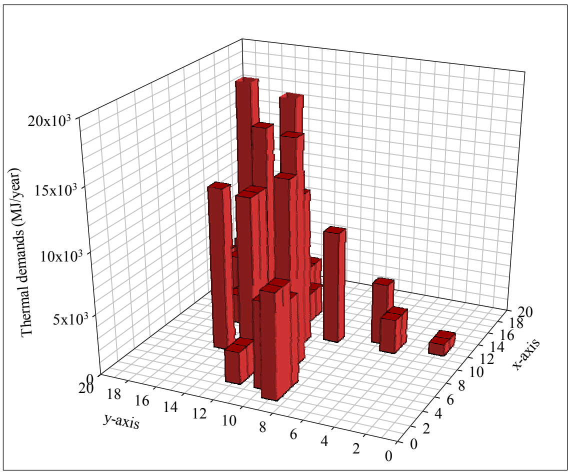

Fig. 5: Thermal demands of the audited buildings.

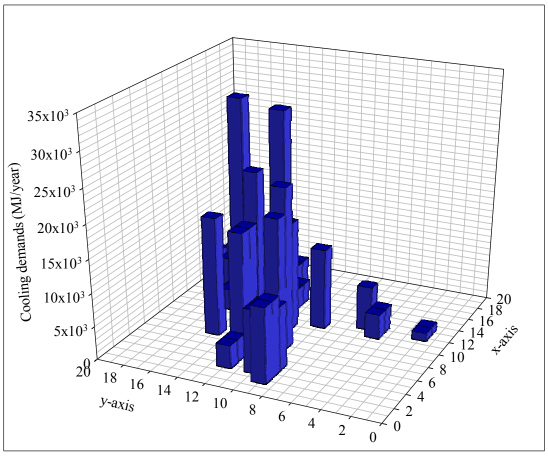

Fig. 6: Cooling demands of the audited buildings.