Energy and environmental audit of buildings: an indirect evaluation

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Abstract

A simple indirect way of performing energy and environmental auditing of buildings is here presented. It is based on the proper application of a recently released Italian standard aimed at the energy saving in climatisation of buildings. Its structure, that can be easily turned into a computerised frame, enables such standard to be employed as a complete analysis tool for predicting the thermal behaviour of buildings. By means of the application of this model, the effectiveness of the adopted technical solutions can be usefully ranked in terms of saved energy for climatisation purposes. Another relevant feature of the method is the possibility of getting environment related information, in terms of amount of released CO_2, resulting from the use of the selected equipment. An application to a simple building module, located in a southern Italian town, is also presented.

1. Introduction

Building energy auditing represents one of the best known procedures which allow to achieve information about the energy performance of a dwelling. Above all it is very useful in verifying the energy savings resulting from retrofit measures and in detecting occasional or systematic occurrences of high energy consumption.

Many auditing tools are currently available to technicians. They can belong to the highly sophisticated simulation models like, for example, DOE (1) or ESP (2), that provide estimates of energy consumption on the basis of the knowledge of thermal and physical characteristics of buildings and equipment, along with information concerning local climatic data. Other tools can also refer to the so-called energy signature procedures, like PRISM (3), that predict the building energy consumption by means of a proper regression curve (generally linear) of the heating energy demand versus the outside temperature. Alternatively, some manual methods can also be employed, mainly referring to energy inspection procedures (4).

However, at present, building auditing represents a very time and work spending operation, due to the complexity of the above mentioned available tools, at any level of detail. On the contrary, technicians do require easier methods, in order of getting fast information about the consequences of the adopted design choices, even at a rough stage of precision.

In the recent years, several domestic technical rules have been released by most of the industrialised countries, with the aim of promote energy saving in the climatisation of buildings.

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Many of these rules need a computerised frame and allow the thermal analysis of buildings to be performed with an enough detailed level. As that, this kind of models can be directly adopted like auditing tools, since they are capable of providing almost the same range of results. A newly released Italian rule can be assumed as a typical example of such kind of methods. It can be easier operated in comparison with the classic auditing methods. In addition, as it will be emphasised in the following, the method can be also utilised for drawing environmental information concerning the consequences resulting from the working of the HVAC system.

As a matter of fact, the new awareness concerning the environmental implications of the use of energy at urban scale, strongly affects the structure of the standards that are nowadays to be compiled. Most of these standards are now so comprehensive and well defined that they can be used, not only for checking the law-related compatibility of the design choices, but directly as working tools for selecting layout and plans.

2. Using an Italian standard as a computation tool

The recent Italian law n° 10/1991 (5), for example, released in the aim of accomplishing the national energy plan (PEN), candidates itself like a prominent one in the European context, with respect to the energy use for climatisation of buildings. It, in fact, could be directly employed for design procedures, referring to the envelope and to the HVAC system of a given building. This law in fact, rejecting the older approaches that only estimated the heating loss through the building envelope, makes use of a limitation to the energy demand of the system, defined by the building and the heating and air-conditioning equipment. The method relies on a global energy balance, taking into account different contributions (primary energy used in the HVAC plant, solar radiation, internal loads) and various types of heat losses (transmission and ventilation through the building, losses of the HVAC system due to the separate steps of production, regulation, distribution and emission of the required heat).

The rule assumes as reference parameters the "normalised energy demand" of the building, FEN (kJ/m^3 DD), and the "global mean seasonal efficiency", η_g, to both of which limit values are imposed. An accurate analysis of several complex energy issues is also involved in the procedure, like the estimation of the solar gains and the detailed treatment of the components of the climatisation system, among other things.

These features obviously ask for the use of a computerised procedure. A comprehensive nomenclature of the several parameters involved in the procedure is given in the following Table (1). Figs. (1) and (2) illustrate the logical sequence and the calculating operations to be accomplished in order of getting the final energy parameters that characterise the selected building, that is the normalised energy demand, FEN, and the global mean seasonal efficiency, η_g. Obviously these parameters can be directly adopted as energy auditing indexes.

Table 1. Nomenclature of the symbols used through the procedure

Pn: useful power of the heater; **C'd**: heat loss volume coefficient; **V**: building volume; **DD**: degree days; **n**: number of hourly air changes; **I**: average solar irradiance on an horizontal surface; **a**: thermal internal gains; Q_i: demand of primary energy required by the HVAC system; Q_c: primary energy required for the thermal conversion in the furnace; Q_e: primary energy corresponding to the electric consumption of the auxiliary systems; Q_p: thermal energy generated by the HVAC system; Q_{aux}: thermal energy transmitted from auxiliary systems; Q_{bu}: electric energy required by the burner; Q_{pu}: electric energy required by the circulating pump; η_{tu}: useful thermal efficiency; η_{sen}: Italian electric board efficiency; Q_{hs}: useful energy demand; Q_{hvs}: useful energy demand in the actual working duty cycle (non continuous); Q_L: overall heat losses by transmission and ventilation; Q_{Se}: thermal energy due to the solar radiation absorbed by the opaque surfaces; Q_{Si}: thermal energy due to the solar radiation falling on the glazed surfaces; Q_I: thermal energy due to the internal gains; Q_T: thermal energy exchanged by transmission with the outdoor environment; Q_G: thermal energy exchanged by transmission with the ground; Q_V: thermal energy exchanged by ventilation and infiltration; Q_U: thermal energy exchanged by transmission and ventilation with adjacent non-heated confined environments; Q_A: thermal energy exchanged by transmission and ventilation with zones characterised by a constant (and known) value of the air temperature; N: number of days in a month; H_k: heat loss coefficient; $\Delta\theta_k$: difference of temperature between the interested elements or thermal zones; H_K: overall thermal losses coefficient; η_g: efficiency of the HVAC system; η_d: efficiency of the distribution system; η_c: efficiency of the regulation system; η_e: efficiency of the heating elements; η_u: utilisation factor of heat gains; F_{tl}: reduction factor of the transmission heat losses (depending on the intermittent working regime); F_{ig}: reduction factor of the thermal energy due to the solar radiation and the internal heat gains (depending on the intermittent working regime); k: coefficient taking into account the working profiles; $q_{s,j}$: overall daily irradiance on the surfaces with j exposition; $A_{e,j}$: equivalent area of the surfaces with j exposition.

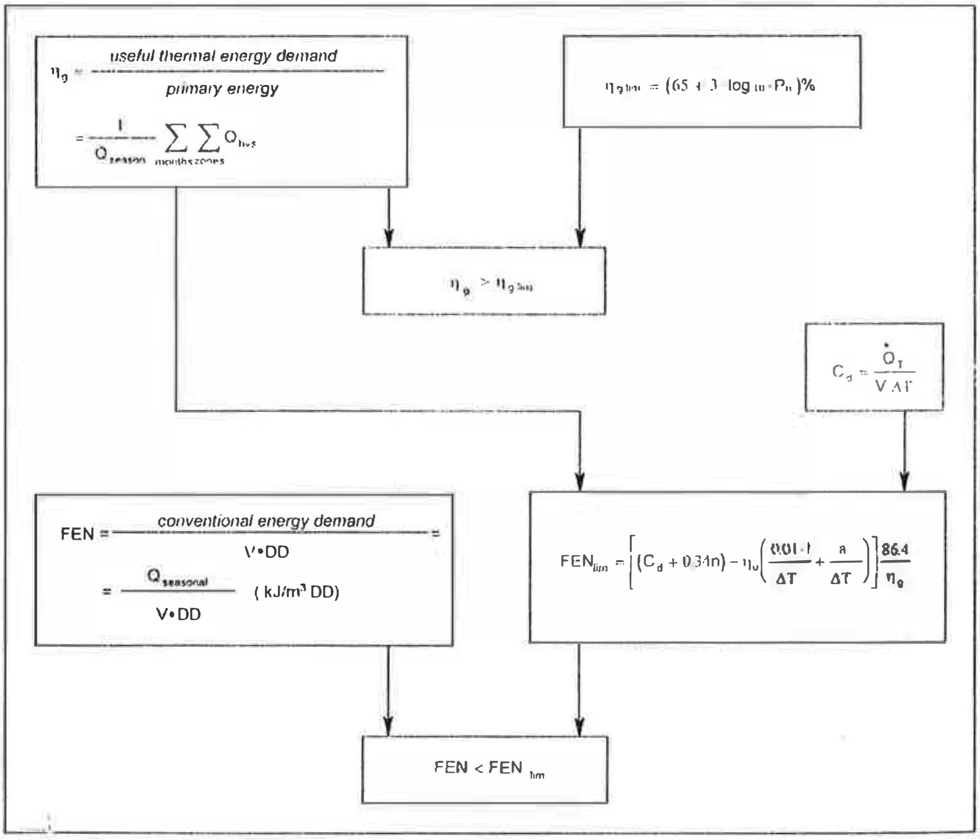

Fig. 3 Procedure for the computation of the energy parameters for the auditing process.

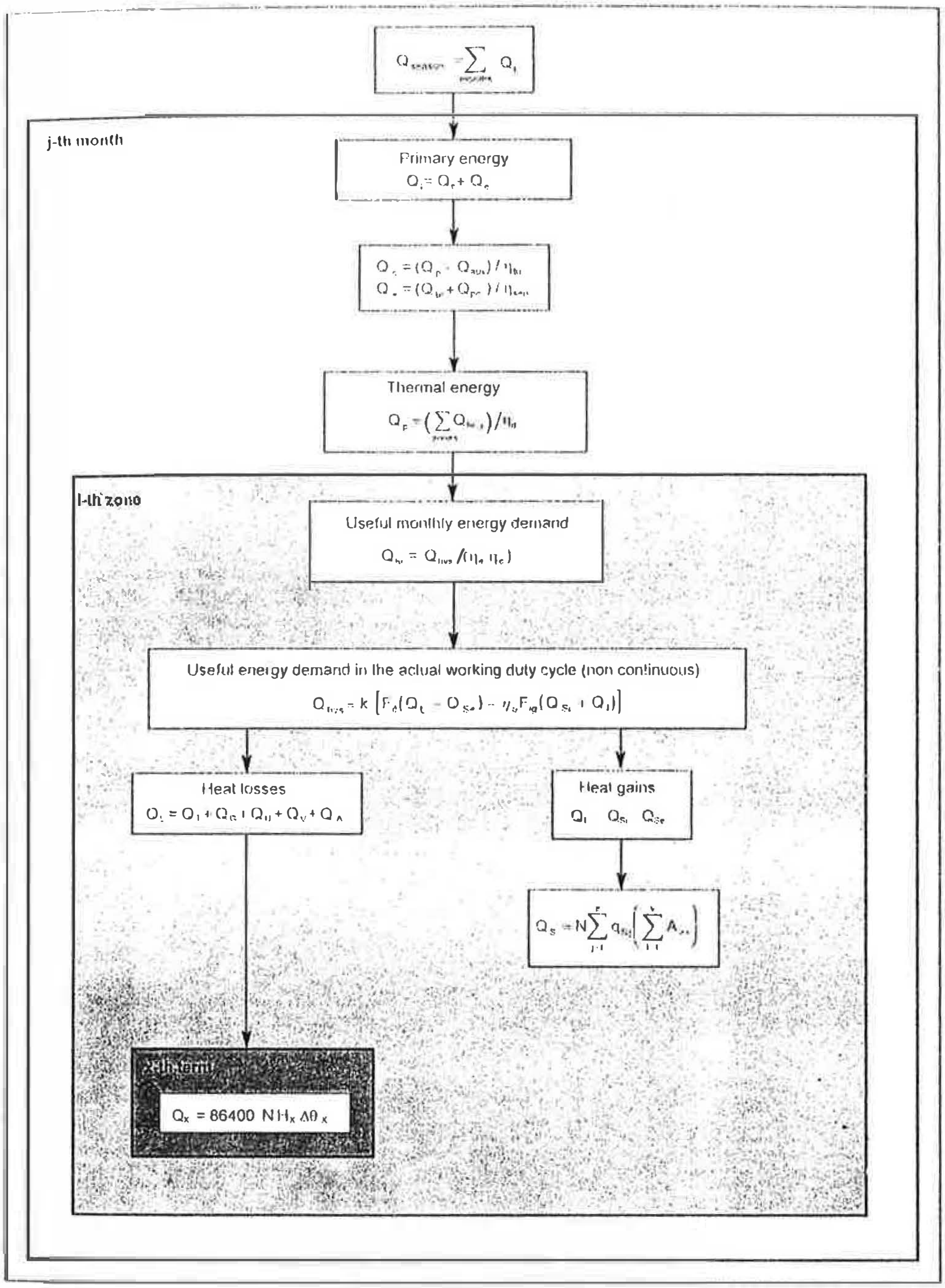

Fig. 2 Detailed sequence of the algorithms involved in the audit method.

3. An application

Using a commercially available electronic sheet, the Italian standard is here managed as a fully comprehensive design tool for a whole system represented by the envelope and the heating, ventilating and air conditioning equipment. As selecting parameters, we assume here both the seasonal energy demand, $Q_{seasonal}$, and the environmental suitability of the design choices. With this aim and in order of showing the feasibility of the method, a very simple building is here adopted, for which the energy demand required for the climatisation and the released amount of CO_2 from the heating plant are computed.

The simulated building is a simple parallelepiped module (4x5x3 m^3) supposed to be located in the climatic condition of Palermo, Italy (38°3 north latitude, 751 DD): both mean monthly temperatures and mean monthly solar irradiance can be assumed as typical of the whole Mediterranean area, as it is reported in Table (2) for the heating period. All external surfaces of the envelope are supposed to face the outdoor condition, while the indoor temperature is set at 20°C; the ventilation rates are set at 0.5 changes per hour, according to the Italian rule. Some main thermal features of the envelope are also reported in Table (3).

Table 2. Main climatic parameters for the heating season of Palermo

	Outdoor temperature (°C)	Solar irradiance on south surface (MJ/m^2)	Solar irradiance on horizontal surface (MJ m^2)
January	11.1	11.9	7.7
February	11.6	13.3	11.1
March	13.1	13.4	15.7
December	12.6	11.0	6.9

Table 3. Thermal characteristics of the building module.

	Vertical surfaces	Floor	Ceiling	West window	East door
Overall transmittance (W/m^{2}K)	0.85	1.00	0.90	4.50	3.00
Linear transmittance of the related thermal bridges (W/mK)	0.135	0.010	0.010	0.150	0.150

After all the calculation described in Figs. (1) and (2) has taken place, the most relevant results for the given building, to be assumed as auditing information, can be split into two different categories, that are respectively related to energy and environment issues.

As representative parameters of the energy performance of the building we adopt here the whole seasonal average efficiency of the heating plant, η_g, and the normalised energy demand, FEN. As representative parameters of the environmental performance of the building we select the primary seasonal energy demand, Q (directly linked to the amount of fossil fuel and electricity required by the heating plant) and the quantity of carbon dioxide released through the heating period of time. These parameters are labels that feature the building and are considered as the most relevant indexes in order of auditing the building. By means of the indirect way here introduced, Table (4) reports the profile of the simulated building, both in terms of energy and environmental issues.

Table 4. Energy and environmental labels of the selected building.

Energy profile	
Average efficiency of the heating plant, η_g	0.71
Normalised energy demand, FEN (kJ/m^3/DD)	117.73
Environmental profile	
Primary seasonal energy demand, Q (MJ)	5305
primary energy required for thermal conversion, Q_c (MJ)	5125
primary energy corresponding to the electric consumption of the auxiliary systems, Q_e (MJ)	180
CO_2 released (kgC)	114.2

The total amount of released carbon dioxide is evaluated by means of the emission factor computed through the whole cycle of the pertinent fuel (7). In the hypothesis of oil (or any oil derivative) employed as fuel for the furnace heating plant, the corresponding emission factor to be adopted is 21.52 gC/MJ.

4. Conclusions

An indirect method, based on the application of an energy saving standard, has been proposed for a quickly auditing of buildings. The method, implemented on a commercially available electronic sheet, can be usefully employed in the early stages of the thermal analyses, when general information about the performances of buildings are required. It only needs data referring to the thermal characteristics of the envelope, to the features of the HVAC system and to the climatic site.

Another relevant characteristic of the procedure is the possibility of obtaining information about the environmental impact of the building (at least in terms of greenhouse gas released), once that the heating plant and the used fuel are defined.

The final result of the method is a table where the energy and the environmental profiles of the building are reported by means of four relevant parameters.

5. References

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