BUILDING ENVELOPE AND CONDITIONING UNIT INTERACTION: A CASE STUDY

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ABSTRACT The building may be seen as a "container" of a conditioned environment where man comfortably carries out a number of activities. The achievement of acceptable indoor environmental conditions depends on the way such a container is realized. In other words, the whole building, which is designed to create a space in which man can suitably carry out certain activities, contributes with all its parts to controlling the desired environmental conditions. Nevertheless, some of its parts, more than others, affect the environmental quality and control, namely: the envelope and the air-conditioning unit (HVAC). The paper presents the results of the experimentation carried out on different types of boiler systems combined with different types of heating terminals in order to determine the best combination, also considering the influence of the systems on the indoor environment. The experiments were carried out considering two types of envelope. The methods for the evaluation of the behaviour of the systems is also presented. The analysis has been carried out by using a three-floor experimental building conceived and realized by ICITE with the aim of characterizing and comparing the various systems under real working conditions.

1 Introduction

The building is the main instrument that can meet man's comfort needs: it modifies the natural environment so as to get as close as possible to the optimum liveability conditions. Nevertheless, some of its parts also affect the indoor comfort conditions more than others. Among these, the envelope and the conditioning unit (HVAC) play a particularly important role since their interaction is the main factor responsible for keeping the desired indoor environmental conditions.

Unsatisfactory thermal conditions inside the dwelling space may be caused by incorrect assessments made during the design phase concerning the envelope (wrong choices for the envelope element construction layers, thermal bridges, etc.) or the conditioning unit, which may for instance be due to:

- wrong dimensioning;
- incorrect installation of the conditioning unit, in terms of on-site balancing;
- bad regulation of the conditioning unit's parameters: flow temperature, speed of the pump for the circulation of the heat transport fluid;
- bad fixing of the parameters of the control system.

While the flow rate has some influence, the flow temperature determines a particular operating ΔT of the radiator, on which the radiator's efficiency depends.

$$\Delta T = \left(\frac{T_i + T_o}{2}\right) - T_a \qquad 1)$$

Where: T_i = input radiator temperature;
T_o = output radiator temperature;
T_a = ambient temperature.

The adaptation of the unit to indoor and outdoor thermal and hygrometric loads (mediated by the building envelope) depends on the on system.
A flexible boiler, able to autonomously modify the way it has been set (flow rate, flow temperature, delivered power, etc.) to respond to the load variations, when matched with a suitable controller, can produce:
- an improved efficiency and a reduced consumption (energy problems);
- an improved comfort (functional problems);
- reduction of noxious emissions (environmental problems).

2 The case study

The presented case study concerns the performance assessment of different types of boilers coupled with different types of radiators. The obvious difficulty met in the performance assessment of the two main sub-systems of the building, i.e. envelope and conditioning unit, only under laboratory conditions, made it necessary to create on a suitable experimental set-up able to provide data about the performance of these sub-systems under real working conditions. It was therefore decided to use a full-scale structure that was built in Lecco under an agreement between ICITE, the Constructors' Association of Lecco and ESPE (Professional Building School).

The structure used for the experimentation consists of a full-scale experimental building with three above-ground floors characterised by interchangeable envelope and installations making it possible to test and compare innovative materials, components and building systems under real working conditions. The internal volume of the experimental building has been subdivided so as to obtain three dwelling configurations (one for each conditioning unit) of about 100 m^2. Out of the two most meaningful envelope types, six unit combinations among those tested, were chosen.
The heating unit proposed in this paper are floor heating panels with T_f = 40°C and cast iron radiators with T_f = 70°C.

2.1 Envelope types

- High insulation ($U \approx 0.30$ W/m^2K) and low thermal inertia (prefabricated panels);
- poor insulation ($U \approx 2.65$ W/m^2K) and reasonable inertia (brick masonry t = 12 cm).

2.2 Heating unit combinations

a) Condensing boiler combined with heating floor panels.
b) Condensing boiler combined with cast iron radiators.
c) Air/gas boiler combined with heating floor panels.
d) Air/gas boiler combined with cast iron radiators.
e) Traditional boiler combined with heating floor panels.
f) Traditional boiler combined with cast iron radiators.

3 The experimentation

Systems performance, working according to the set combinations, has been assessed under standard service conditions. All the unit and environment parameters needed for the analysis have been monitored. In particular, the experimentation allowed to collect and process the data concerning the following:
- outdoor meteorological conditions (air temperature, incident solar radiation, etc.)
- indoor air mean temperatures with reference to each floor of the building
- temperature of the boiler's flow and return water
- exhaust smoke temperature
- fuel consumption of each boiler type
- boiler's on/off periods
- power consumption on each floor.

The independent variables of the experimentation are represented by outdoor conditions (temperature and radiation) and by the type of configuration (envelope + unit combination). The parameters used to assess the performance of the building/heating plant system are efficiency (h) and hourly consumption (C_h) defined as:

$$\eta = \frac{Q_H}{Q_G + Q_E} \qquad 2)$$

Where: Q_H = energy absorbed for heating purposes;
Q_E = primary electric energy;
Q_G = primary energy supplied by gas.

$$C_h = \frac{V_G}{T_{on}} \qquad 3)$$

Where: V_G = daily gas consumption;
T_{on} = daily operating period of the burner (h).

4 Results

4.1 Analysis of different unit and envelope combinations

Starting from similar indoor environmental conditions, the six unit combinations have been compared with two envelope types.

Table 1 Performance of the building/heating plant system

	Prefabricated panels		Traditional masonry	
Combination	Efficiency (2)	Hourly consumption (3)	Efficiency (2)	Hourly consumption (3)
a	0.996	1214	1.035	1187
b	0.953	1453	0.998	1444
c	0.897	1270	0.904	1794
d	0.979	1209	0.869	2504
e	0.751	1578	0.864	2052
f	0.700	1556	0.844	2218

An increase in the hourly consumption may be easily noticed in those cases in which the used envelope is a poorly insulated one, except for combinations where the unit contained the condensing boiler, in which case such a value is nearly constant, since in the former case the boilers did not work correctly (see section 4.3) and therefore did not allow to obtain the thermostat temperature.

The condensing boiler, which recovers the heat contained in the exhaust steam (latent heat), has been conceived to operate at low flow temperatures, just as radiant panels; their coupling is therefore optimal and the obtained satisfactory results. In considering the way efficiency is calculated, the condensing boiler shows efficiency values that are higher than of other boilers.

The use of a high-technology boilers (such as the condensing boiler) allows to obtain, especially with low temperatures, higher efficiency levels, having positive effects from the energy, environmental and functional point of view. Another analysis concerned the assessment of efficiency as a function of outdoor temperature. Generally speaking, no strong correlation was noticed in the unit combinations whose efficiency values remained on average unaltered as to the variation of outdoor climatic conditions.

4.2 Influence of the unit on thermal comfort

As far as comfort is concerned, the reported diagrams show the pattern of ambient temperature measured, floor's surface temperature and that of operative temperature. As it may be noticed by examining the diagrams, the best comfort conditions are reached with the condensation boiler/heating floor panels combination.

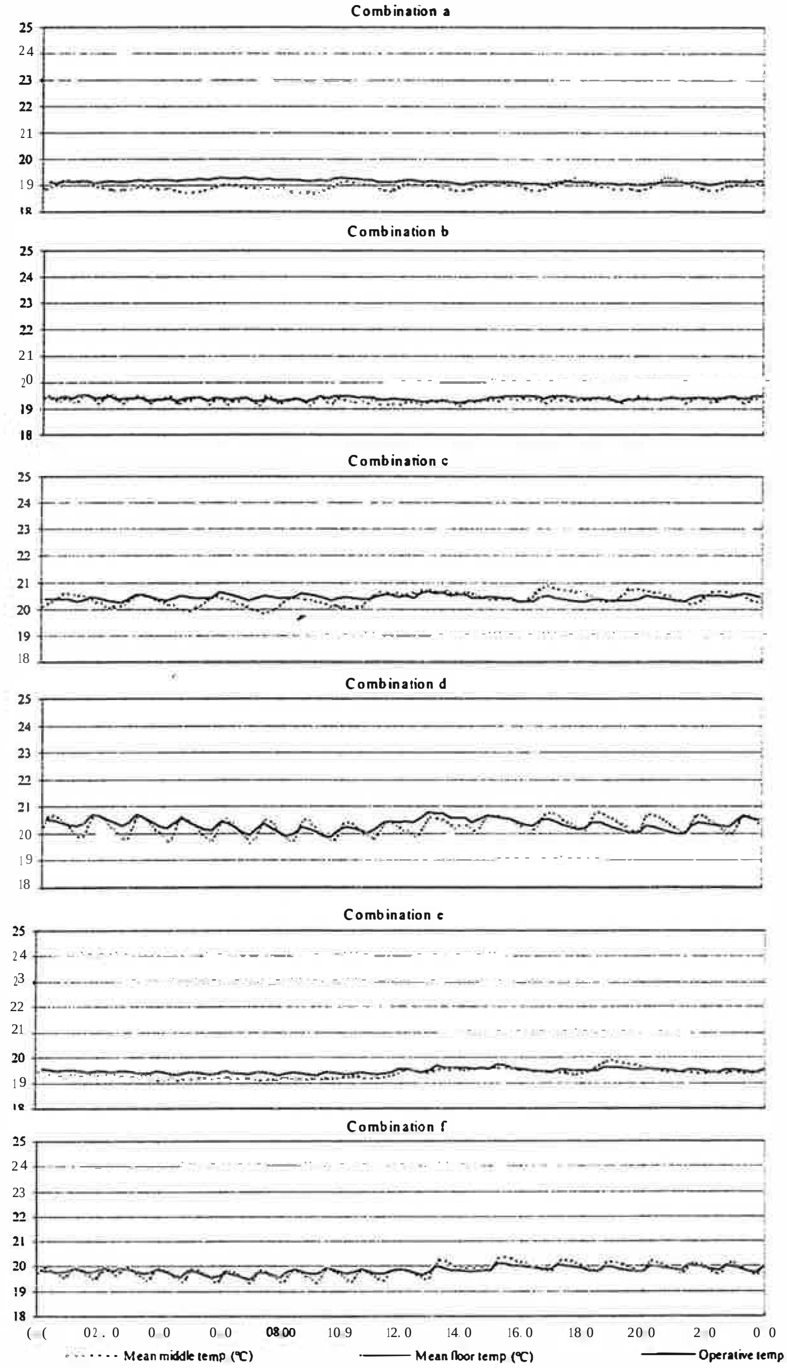

Fig.1 Pattern of thermal comfort parameters according to the different combinations

The diagram in Fig.2 shows the pattern of indoor humidity, concerning configurations *a* and *b* as an example. Bearing in mind that none of the two unit combinations actively contributed in modifying the value of indoor relative humidity, it may be noticed that this value is practically identical for the two types of radiators. During the operation of these types the heat transport fluid has very different temperatures, but this preliminary experimental campaign seems to outline that the only inconvenience is represented by the generation of localised convective motions in the area of the radiators.

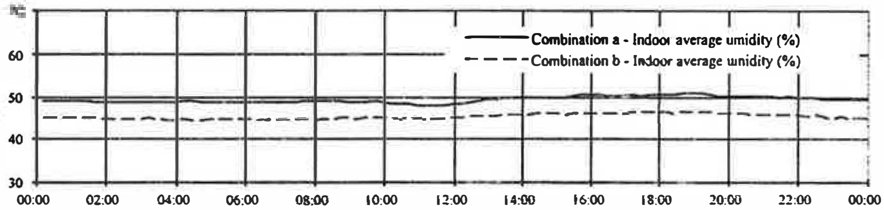

Fig.2 Pattern of indoor relative humidity value

4.3 Analysis of boiler operation

It is first of all necessary to underline the importance of the dimensioning of the elements making up the heating unit. Users and mainly installers are obviously interested in verifying whether the components chosen by the boiler's producers comply with the actual needs. It is also important to quantify, in terms of efficiency, the effect of a wrong coupling, badly performed testing or the consequences produced when no action is taken to correct the whole unit following a modification of one of its parts.

In particular, when the boilers used are those with flame modulation (therefore with power modulation), we have a sort of adaptation of the burner to the thermal load needed by the building. When the load becomes very low, for instance during an in-between season, and outdoor temperature gets close to the thermostat setting, the progressive reduction of the thermal load may cause the boiler to go off, even though the ambient thermostat reads an ambient temperature which is lower than the thermostat setting, due to boiler going below its minimum power level.

In some particular situations this working configuration happens to repeat several times thus making it impossible to reach the thermostat temperature and, as a consequence, the comfort conditions. This type of pattern has been pushed further by applying particular regulations of the delivery temperature, when the thermal load determined by the season was low (see Fig.3). During the experiments the burner continuously and repeatedly went on and off (hunting) due to the reduced thermal exchange with the environment and to the ambient temperature which is lower than the thermostat setting. Fig.4 shows the same type of unit combination with a correct modulation, in which case the burner did not go off.

5 Final remarks

The analyses carried out so far cannot be considered exhaustive nor can they encompass all the problems connected with the operation of heating systems. Nevertheless, on the basis of the experiments that have been carried out, it is possible to draw some particularly meaningful conclusions.

1. Correct dimensioning of the unit components is particularly important, according to the actual thermal needs of the building. The analyses carried out on boilers and on the optimisation of the boiler/heating units system proved to be meaningful: in particular, satisfactory results have been obtained from the efficiency and consumption point of view by coupling high-technology boilers (high thermo-hydraulic level and high-level operational features) with the two heat emitter types considered.

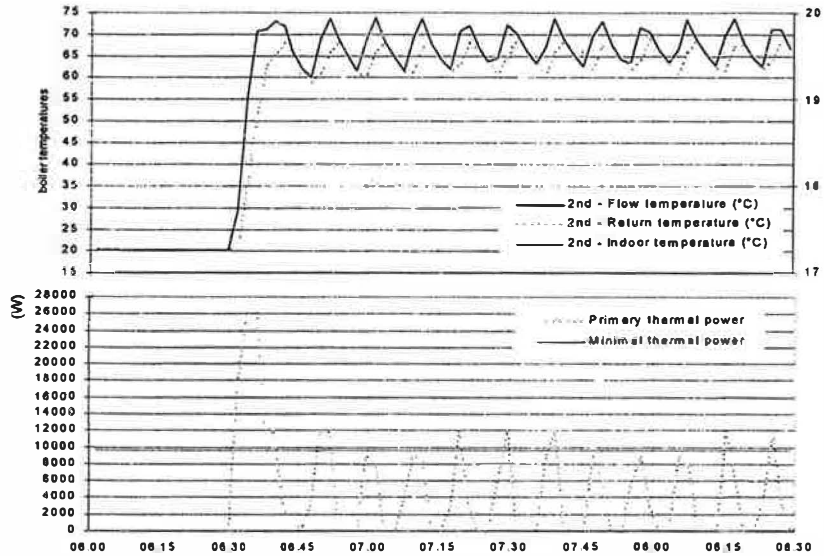

Fig.3 Operation of a boiler badly dimensioned in relation to the envelope

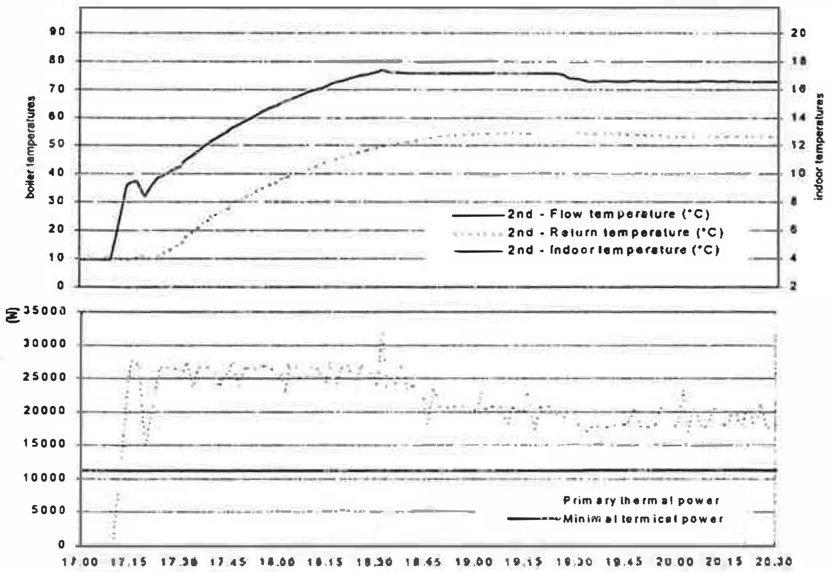

Fig.4 Operation of a boiler correctly dimensioned as to the envelope

2. Under normal working conditions the heat distribution in space and time produced by the use of heating floor panels was better than that produced by cast iron radiators.
3. The last remark concerns the minimum power of boilers. Over the last years, the will to save energy has led people to increasingly insulate their homes; therefore, the thermal need of buildings has increasingly reduced. A too high value of minimum power of the boiler may lead to malfunctions (hunting), just like in the presented case, due to the shortening of the modulation range of the burner power related to the decrease of the thermal requirements of the building.

Continuing of the experimentation will allow to better clear up the dynamics of the different systems involved in the thermal comfort, energy saving and decrease of polluting emissions.