GAS - FIRED HEATING PLANT MANAGEMENT

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ABSTRACT.

In order to define a global control strategy leading to a more rational use of energy, the CSTB, in collaboration with Gaz de France (GAR), has carried out a large study on gasflred heating plants, taking into account three types of heating and ventilation systems.

The first investigated system is a hot water radiator coupled with a single-flux ventilation.

The second system of interest combines a double-flux ventilation with standard hot water radiators.

Finally, the last one uses an upgraded double-flux ventilation ductwork to provide a central aeraulic heating, a terminal heat exchanger ensuring a perfect local temperature adjustment.

The required models were developed (or adapted), validated and finally implemented on the ASTEC 3 numerical simulator. Furthermore, all of the models were documented in a standardized way (PROFORMA form).

This paper intends to focus on the studies which were undertaken enabling, by simulation, to test the sensitivity in both energy and economic terms of:

Terminal heating equipment sizing
Boiler sizing
boiler-plant arrangement
boiler-plant management.

INTRODUCTION.

In France, one third of non-residential buildings (schools, office buildings,...) are using natural gas as primary energy. Among these buildings, a large part (as well new constructions as rehabilitated ones) is equipped with a heating system matching conventional and condensing gas-fired boilers. To be really efficient, this system requires to be associated with a relevant heating plant control strategy. Such a control strategy is all the more important as the intermittent heating practice is become compulsory in the new French thermal regulation for buildings with discontinuous occupation.

A previous study undertaken by the CSTB for the AFME (French public agency for energy savings) outlined the main parameters which have an influence on energy savings resulting from intermittent heating practice (VISIER and BICARD, 1988).

As a follow-up, the collaboration between the CSTB and Gaz de France is oriented towards buildings equipped with collective gas-fired boiler plants. Its general goal is the optimization of the installation based on technical and economical considerations. The selected methodology is presented in chapter 1. Three types of heating and ventilation systems are considered which combine hot water radiators or local heat exchangers, with single or double flux ventilation (chapter 2). Modelling and simulations results (for hot water radiators) are developed in chapter 3 and 4, while double flux ventilation systems are analysed in chapter 5.

1 – METHODOLOGY.

The methodology selected for this project entails different complementary aspects :

- a typological study was conducted to pinpoint tendencies in systems design (type of buildings, sizing methods, selection of controllers), and to define reference cases to be modelled ;

- a detailed modelling of the building and heating systems was conducted in order to perform a sensitivity study on the performance of system design and energy management strategies. The aim of the task was not to develop a new strategy, but to classify the performance of conventional controllers ;

- an exploratory work on simplified models was performed to test optimization techniques (optimal control, linear programming) that could ultimately be applied to this case of energy management (HALGAND, 1990). It was also analytically demonstrated that minimum gas consumption in a building with intermittent heating is achieved with a strategy where full power is released at the latest possible time ;

- tests were conducted in GAZ DE FRANCE experimental building and standard boiler room to enable standard controllers implementation and tuning. Part of the data base was used to validate models of components specifically developed for this project ;

- the influence of HVAC system design on the costs of an installation with intermittent heating were assessed.

2 – GAS-FIRED SYSTEMS.

The first part of the study is dedicated to systems combining hot water radiators and single-flux ventilation. Heat generation is provided by matching conventional and condensing gas-fired boilers. The main goal of the study was to outline tendencies linked to component sizing and controllers selection. It is intended for a designer who has to optimize a new system or to define the specifications of a BEMS. However the quantitative results related to energy management measures also apply to retrofit projects.

The second part of the study aims at providing a new light on the design of systems based on a new concept promoted by the GdF. It consists in coupling condensing boilers with a double-flux ventilation. Its main interest lies in the observation that even after energy recovery from the exhaust air through a heat exchanger, the incoming air temperature is still lower than the return water temperature of a standard hot water installation. Heat recovery from the condensing process is then enhanced.

Two systems are being considered that combine double-flux ventilation with :

- hot water radiators ;
- terminal coils (water-air heat exchangers).

Full-scale operations have demonstrated that these systems achieve high energy-efficiency in office buildings and in hospitals (CROQUELOIS, 1989). This study will provide guidelines for system sizing and operation.

3 – MODELLING.

Various component models have been developped or adapted according to the needs, and then validated in various ways as it will now be explained.

3.1 – Components.

- **Gas-fired boiler** :

The dynamic performance of a collective gas-fired steel boiler is modelled using a simplified analysis of the combustion process and the heat exchange inside the boiler (lumped capacitance).

A simpler model was derived afterwards from the initial model (equivalent current source) to lower computation time.

- **Condensing heat exchanger** :

The steady-state performance of a condensing heat exchanger is modelled using the Lewis'analogy between heat transfer and mass transfer [6]. Set next to a conventional gas-fired boiler, the system allows the recovery of the latent heat of vaporization in the flue products.

- **Hydronic components** :

Pump, pipe, tee-piece, valve, hot water radiator.

- **Controllers** :

Thermostatic valve, three-way valve, intermittent schedulers, regulator (with non-linear heating curve).

- **Ventilation** :

When single-flux ventilation is considered, the outside air is not treated (0.8 ACH).

When double-flux ventilation is considered, the air handling unit entails a plate heat exchanger (low efficiency) or a rotary heat exchanger (high efficiency), and one or two coils (for the heat recovery on the condensing heat exchanger).

- **Building** :

A simple lumped parameter model is used, representing the building as an electrical network with nodes connected by capacitances and resistances. Parameters of the 2nd order model are identified using a comprehensive model. It is then assumed that the building has a homogeneous thermal response. Solar gains are not taken into account but there are scheduled internal gains. There is only one hydronic network of radiators.

- **Schedulers** :

Three intermittence schedulers are modelled. The first controller (label N1) simply enables commutation between two heating regimes, (daytime and reduced nighttime regimes) ; it does not enable either to switch off the heating system completely at night or to use its full power to reheat the building ; the second and third controllers enable both to switch off the heating system and to reheat the building by using the full power of the heating system. The second one (label N2) starts reheating at the same time all over the year ; the third one (label N4) includes an optimal starting algorithm which modifies this time according to inside and outside temperatures.

- **Boiler-plant controller** : two strategies were modelled :

. The first strategy, still encountered in standard applications consists in maintaining the primary loop at a high temperature to meet the demand at any time. Therefore, the conventional gas-fired boiler is continuously irrigated. Aquastat setpoints take constant values (associated with a differential) ; they are just shifted from each other in order to ensure a higher priority to the condensing gas-fired boiler, while the conventional boiler will get on-line only when the primary loop temperature drops.

. The second strategy tries to match the power supply with the demand. Aquastat set-up are varied with the boiler scheduler state between a high level during the preheat period and a low level during the shut down. During the occupation period, aquastat setpoints (for the two boilers) are linear functions of the outside air temperature, so that the output water temperature varies in proportion to the load. Furthermore, in ordre to save energy, the conventional gas-fired boiler is by-passed except during the pre-heat boost and on cold days.

3.2 – Validation procedure.

Most of the models of components have been validated from full-scale tests in the GdF's facilities. Tests of boilers were conducted with various loads on the standard boiler room. The detailed model of the installation leads to similar results when connected to the comprehensive and simplified models of the building. The latest was selected to enhance the computation speed.

It was not possible to validate the global model against experimental data. However it was shown that yearly simulated performance of a representative building compared favorably to average ratios of a large GdF data base of existing buildings. Furthermore, emphasis is given to the fact that results should be interpreted as tendencies rather than absolute values.

Simulation results were also challenged in two other ways :

- the models were documented by the CSTB in a standardized way (PROFORMA form) and later implemented by GdF on the ALLAN/NEPTUNIX package (JEANDEL and PALERO, 1990). Therefore assumptions and parameter settings were checked by two different teams using two different tools. Discrepancies (lower than 2%) between the original ASTEC 3 results and the later results, could be traced to the difference between the two equations solvers.

- a recent paper written by the IKE team (University of Stuttgart) on IEA Annex 17 work (MADJIDI and STEPHAN, 1990), indicated similar trends in the sensitivity of performance to system sizing, although the reference cases were slightly different.

4 – SIMULATION RESULTS FOR RADIATORS.

Simulation results are presented for the installation with hot-water radiators and single-flux ventilation.

4.1 – Basecase.

The layout of the global model is shown in figure 1. The main characteristics of the setup are as follows :

- Building of 5560 m^3 with medium inertia (250 kg/m^2 of floor) and high insulation level (0,57 $W/m^3.K$).

- The central heating plant is made up of a conventional and a condensing gas-fired boilers of high efficiencies. Initially, it is assumed that they have the same power capacity (total of about 175 kW).

- The terminal heating equipment installed in the heated space is hot water radiators equipped with thermostatic valves.

- The occupancy period ranges from 8 a.m. to 6 p.m., 5 days a week.

- The average internal gains due to people and lights are of 169 kWh per day.

- Three intermittence schedulers, each of them corresponding to a different control strategy, are successively tested during a simulation (see chapter 3.1).

- Two boilers-plant management systems are considered. Both assume that priority is given to the condensing gas-fired boiler in order to benefit from its higher efficiency.

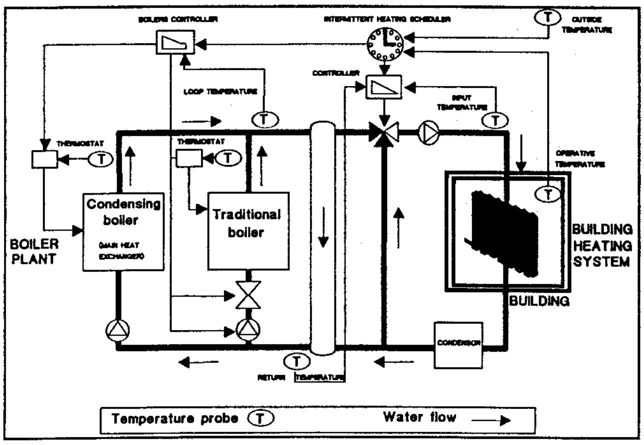

Figure 1 : Layout of the global hot water heating plant model.

Performance comparisons are based on the same average level of comfort during occupation, that is an operative temperature of 19,5°C.

4.2 – Parameter sensitivity studies.

Parameter sensitivity studies undertaken for a collective gas-fired plant system were as follows :

- Radiator sizing
- Boiler sizing
- Boiler-plant arrangement
- Boiler-plant management.

- **Radiator sizing**.

Sizing an emitter consists in exactly matching the power delivered by the emitter to the building (or room) heat losses calculated in the most unfavorable conditions.

Oversizing an emitter, in percent, consists in taking a safety factor respect to the initial sizing. The amount of oversizing must integrate the following criteria :

. Necessity to obtain an acceptable thermal comfort even if heat losses or ventilation rates have been under-estimated.

. Oversizing an emitter leads to lower return water temperature so it is better for the condensing process.

Two values of oversizing (10% and 25 %) have been selected because representative of common practice in the HVAC field.

Simulations over a heating season were performed for the two values. Results are summarized in figure 2.

It clearly appears that whatever the intermittence scheduler adopted (N1, N2 or N4), a 25 % oversized radiator produces higher energy savings than a 10 % one. This value will be kept in the simulations to come.

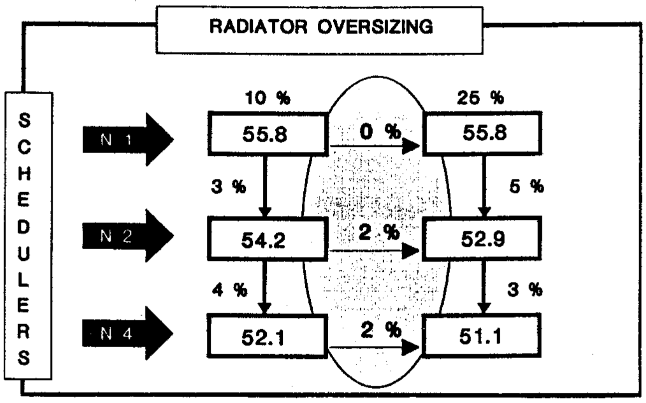

Figure 2 : Influence of radiator oversizing on energy savings (gas consumptions are given in kWh/m^3).

- **Boiler sizing**.

Standard boiler sizing (the principle applies to any number of units) may be defined as the ratio between the installed global capacity (minus heat losses in the distribution network) and the building heat losses calculated in the most unfavorable conditions.

We have tested three different configurations corresponding to a ratio of 1, 1.5 and 1.9. Simulations over a heating season were performed for each of the three configurations.

Simulation results show that oversizing a boiler has no relevant influence on the total energy consumption.

This study could lead to suggest that a ratio of 1 is an optimum since it deals with the lowest initial cost. However it is advisable to prevent from any risks of heating failure during the coldest days of the year. A specific study has been carried out in order to draw conclusions from such a scenario. The conclusion was that the minimum boiler sizing should lead to a high degree of discomfort in the building, spreading over many days. Consequently, in regard to safety, a 1.5 boiler sizing is recommended for an installation with conventional controllers and a low frequency maintenance procedure.

However for a building project including a BEMS system and on-site supervisatory control and maintenance, the designer has a way to lower the investment cost.

- **Boiler-plant arrangement.**

Up to now, we have considered that the maximum available power output was equally provided by the two units. In order to assess the influence, on the total energy consumption, of a different partition of the capacity between conventional and condensing gas-fired boilers, three different configurations were investigated.

The part of the condensing boiler was consecutively set to 30 %, 50 % and 70 % of the maximum installed capacity.

As it was foreseeable, the energetical optimum is reached when the condensing part is of 70 % although other configuration results are not far from this optimum.

The economical optimum is also rather flat because of the upfront higher price of condensing furnaces compared to conventional ones.

In regard to safety, the original boiler-plant arrangement (a 50 % - 50 % dividing up) was judged to be the best compromise between the two gas-fired boilers in this case (hot water radiators). This would of course not hold for buildings with continuous occupancy or domestic hot water consumption.

- **Boiler-plant management.**

Control and management of large buildings are a complex process which needs different systems on different levels. The association of the two boilers in a boiler-plant is a part of the process and consequently requires to be well managed.

The main trends of the impact of a boiler-plant management on potential energy savings were found as follows (see figure 3) :

- Energy savings due to the management of the boilers are not affected by intermittence schedulers that is to say that whatever the intermittent heating strategy adopted, energy savings remain stable enough (in relative value).

- Going from a standard boiler management to a more sophisticated one, leads to a 6 % decrease of energy consumption.

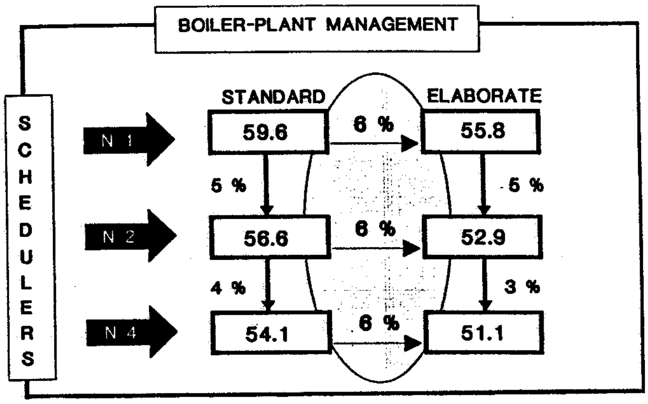

Figure 3 : Influence of the management of the boilers on energy savings (gas consumptions are given in kWh/m^3).

4.3 - System optimization.

Figure 4 summarizes the annual energy consumptions numerically obtained from the base case with different energy management strategies.

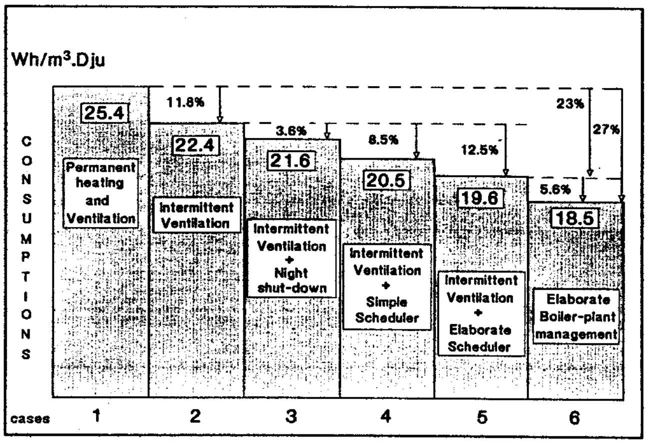

Figure 4 : Comparison of annual energy consumptions for various energy management strategies.

In the first strategy, heating and ventilation are permanently maintained on. In the second strategy, a ventilation intermittency is practiced during inoccupied periods. This simple action leads to energy savings close to 12 %. The third strategy is characterized by the setting of a night shut-down. The two following strategies are completed by the introduction of two heating intermittence schedulers respectively a simple (N2) and an elaborate one (N4).

As it can be observed, just by acting on heating and ventilation intermittence, a 23 % energy gain is obtained while the level of comfort still remains the same during the occupation periods.

This result can be enhanced with an elaborate boiler management strategy (last case) which enables a 6 % energy gain.

In conclusion, intermittent ventilation and heating practice associated with an elaborate boiler management lead to energy savings of up to 27 % compared with a continuous heating and ventilation strategy (for the considered reference).

Controllers are readily available to implement these strategies. An economical analysis shows that the first cost of the required equipment is less than 6 % of the heating system (boiler room and hydronic network). On the other hand, energy costs take about half of the total cost (first cost and running costs) projected over 10 years. Therefore the controllers selection can influence up to 13 % of the total cost.

These results have been summarized in a guide intended for design engineers and decidors, which include practical and economical considerations (HUTTER and al., 1991).

5 - ANALYSIS OF DOUBLE-FLUX VENTILATION SYSTEMS.

Double-flux ventilation systems (DVF) are classically design to preheat the fresh air entering the building. They enable :

- a reduction of heat losses due to air change (so, radiators can be undersized),

- an enhancement of thermal comfort because fresh air is blown at a mild temperature,

- an increase of air quality since fresh air is filtered while humidity control becomes possible.

On the other hand, double-flux ventilation systems are more expensive and more cumbersome than single-flux systems.

In the following sections, the accent is on the interest of coupling DFV with condensing boilers. Two systems are proposed. The first one combines DFV with hot water radiators, the second one DFV with terminal coils (water-air heat exchangers).

5.1 - DFV and radiators.

Enthalpy recovery in the exhaust flues of a boiler is classically undertaken with the water returning from a radiators network. One improvement (energy-wise) is to feed the condensor with water from the mains to preheat domestic hot water in residential applications, but this option is rather expensive.

An ingenuous solution, which has been successfully tested since the mid-eighties, consists in superseding the water medium by the preheated air coming from the double-flux ventilation system. This solution is all the more interesting as the outside temperature drops because heat recovery from the condensor is further enhanced just when heating load is high.

The air handling unit is made up of (figure 5) :

- intake and exhaust fans,

- an air-to-air heat exchanger which recovers part of the energy of the exhaust air to preheat the fresh air (from 10 to 20°C),

- a hot water coil for enthalpy recovery. This coil must be fitted with the condensing heat exchanger,

- a hot water coil to adjust the air temperature to a level comparable to the indoor air temperature (about 20°C).

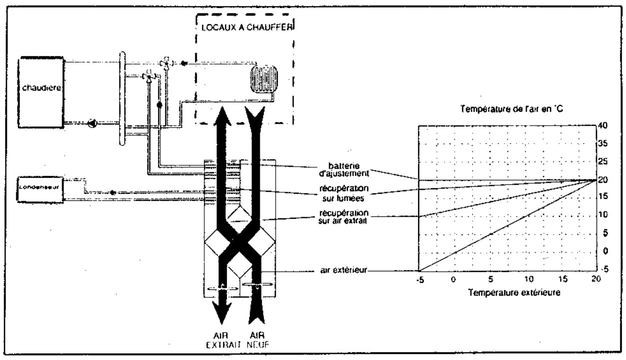

Figure 5 : Double-flux ventilation with condensing boilers and radiators.

Several installations (office buildings) are now in operation for several years. Monitoring showed that parasitic losses are very low during inoccupation périods. Heating start-up is faster when using the air system in a complete recirculation mode.

Aim of the ongoing tasks is to quantify the performance of this system on the same reference case that was previously studied.

5.2 - DFV and terminal coils.

Under stricter thermal regulations, buildings are getting tighter and more insulated. It is then conceivable to design an aeraulic heating system working at low temperature. For example, a building with wall losses of 0.37 W/m^3-K, can be heated at 2 ACH with a maximum air temperature of 36°C (for an outside temperature of - 3°C). Hence thermal comfort is acceptable while radiators are suppressed. Temperature adjustment is made locally by a terminal coil controlled by a room thermostat (figure 6). One unit was specifically studied to fit cylindrical air ducts.

A first reference building (offices) proved to be very energy-efficient with a combustion efficient continuously above 95 %, and a stunning energy consumption ratio of 47 kWh/m^3/an. Similar performance levels were achieved in an hospital.

The ongoing task should confirm these experimental observations and provide insight on the best strategy for intermittent heating.

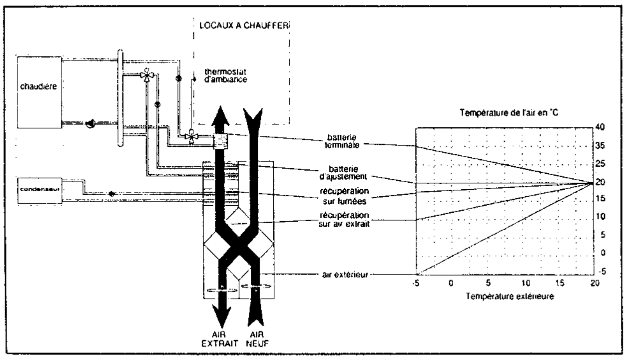

Figure 6 : Double-flux ventilation with condensing boilers and terminal coils.

6 - CONCLUSIONS AND PROSPECTS.

It was shown that computer modelling and numerical simulation provided a very powerfull method for analysing energy management strategies. System optimization was addressed for a gas-fired boiler plant and radiators. Current work on double-flux ventilation will shortly be completed.

A feasability study is now under way to develop an emulator based on the aforementioned models, to test BEMS systems. Research is finalized on the optimal control of the same boiler plant. If the potential energy savings are justified, a BEMS implementation will be considered.

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