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WARM AIR HEATING MODEL BUILDING, DESIGN AND DEVELOPMENT

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ABSTRACT

Launched in 1985. The general study of warm air heating in dwellings which associates, among others, the Research and Development Division of Gaz de France, the Research Division of the Fédération Nationale du Bâtiment and the Centre Scientifique et Technique du Bâtiment, is starting to produce results.

In this paper, the progress of work undertaken is described, notably in the following fields :

- Models and simulation of the behaviour of warm air heating systems. A comparative study of energy consumptions has been conducted for various control and intermittence strategies.

  Using simulations, the influence of air recycling in a dwelling on the recovery of free heat input has been evaluated.

- Models and simulation of air movements in dwellings equipped with warm air heating with a view to studying the risks of condensation, recycling of odours, effects of wind, etc ...

- Development of simple and practical design, construction, installation and energy performance calculation methods for warm air heating systems.

  Based on these results, a guide for professionals has been drawn up.

- Application and validation of this work in the R & D Division test houses and in 25 inhabited houses. These 2 to 5 bedroom houses, built near LYON by Maisons PHENIX, are equipped with POUJOULAT air heaters.

  Detailed thermal monitoring of these houses over two heating seasons has confirmed the validity of the techniques chosen, as regards both comfort and energy performance.

RESUME

Lancée en 1985 et associant notamment la Direction des Etudes et Techniques Nouvelles du Gaz de France, la Direction de la Recherche de la Fédération Nationale du Bâtiment et le Centre Scientifique et Technique du Bâtiment, l'étude générale sur le chauffage aéraulique dans l'habitat commence à porter ses fruits.

La présente communication se propose de faire le point sur ces travaux, particulièrement dans les domaines suivants :

- Modélisation et simulations du comportement des systèmes de chauffage aéraulique. Une étude comparative des consommations énergétiques a ainsi pu être menée pour diverses stratégies de régulation et d'intermittence.

  Les simulations ont notamment permis d'évaluer l'influence du recyclage de l'air d'un logement sur le rendement de récupération des apports gratuits.

- Modélisation et simulations des mouvements d'air dans les logements équipés de chauffage aéraulique. Les risques de condensation, de recyclage d'odeurs, les effets du vent, ... ont ainsi pu être étudiés.

- Elaboration de méthodes simples et pratiques de conception, de réalisation, d'installation et de calcul des performances énergétiques des systèmes de chauffage aéraulique.

  Un guide destiné aux professionnels a ainsi été rédigé.

- Application et validation de ces travaux dans les pavillons expérimentaux de la DETN puis dans 25 pavillons habités d'autre part. Ces logements, de 3 à 6 pièces, construits près de LYON par la Société des Maisons PHENIX sont équipés du générateur d'air chaud POUJOULAT.

  Un suivi thermique détaillé de ces logements durant deux saisons de chauffe a confirmé la validité des choix techniques, tant du point de vue du confort que du point de vue des performances énergétiques.

INTRODUCTION

To increase the share of gas heating in new homes is a major strategic challenge for Gaz de France, demanding considerable research and development investment. The Research and Development Division is currently exploring several different avenues with a view to developing a whole range of attractive solutions for the future : "hygro-wire" heating (water circuit comprised of microbore plastic pipes)), low temperature underfloor heating, "individualized" collective heating, semi-collective heating ... Individual warm air heating is yet another of these promising avenues.

Warm air heating is the most common type of heating in certain countries, notably in the United States, where it is often associated with an air-conditioning system. In France, professionals in the building industry generally hold a poor opinion of this technique as in the 1960s many badly designed systems were installed, marring its reputation.

At that time, new housing in France was not subject to any heating regulation. To combat high thermal losses, the adjustment of flow rates and temperatures was set too high for satisfactory heating comfort.

High levels of insulation, on the other hand, would appear to favor the development of high performance and comfortable warm air heating systems. However, this hypothesis must be carefully validated in order to avoid bringing the technique into further disrepute.

Warm air heating also offers very interesting potential for air management and treatment. New services, derived from warm air heating, may be able to satisfy customers with demanding requirements for "indoor air quality".

Aware of these possibilities, the Gaz de France Research and Development Division, the Research Division of the Fédération Nationale du Bâtiment and the Centre Scientifique et Technique du Bâtiment launched in 1985 a general study of warm air heating in dwellings.

A rigorous approach was adopted, involving modelling, laboratory testing and pilot operations. These studies have already been presented in several papers [1] - [3]. This article describes the progress made in this work by the end of 1988.

1 - FIELD OF APPLICATION AND INITIAL TECHNICAL CHOICES

The field of application being that of new, highly insulated dwellings (for example : basic losses of around 6 kW for a house with 100 m^2 living area), a certain number of technical choices regarding the design of different components of the warm air heating system were made :

- <u>the generator</u> must at least satisfy all heating and hot water requirements.However, the heating output may be less than 7 kW, and this has made it possible to design (through collaboration between Poujoulat and Gaz de France) a generator working on a new principle where the heating function is derived from domestic hot water production [1].

- <u>the distribution circuit</u> may be a short circuit installed centrally in the dwelling in a false ceiling (fig.1). This more economical configuration is made possible by high levels of insulation which significantly reduce cold wall effects.

- the warm air inlets are therefore mounted at the top of the inner wall of each room.

- the air return does not make use of an air circuit but occurs through the doors of the dwelling. The surface area of space around the door, through which the air is able to circulate, must therefore be calculated with care.

- control of warm air heating is generally ensured by a single centralized system (warm air heating benefits from a ministerial derogation which frees it from the obligation of room by room control) which may be associated with additional systems.

- programming is facilitated by the low inertia of warm air heating.

- association with air change. The initial choice involved separating warm air heating from controlled mechanical ventilation. As for all types of heating system, the air inlet is through the outer wall of the main rooms (fig.1). Air is extracted in the utility rooms via the same system as for the combustion products (VMC-Gas).

Figure 1 shows the characteristics of the configuration adopted :

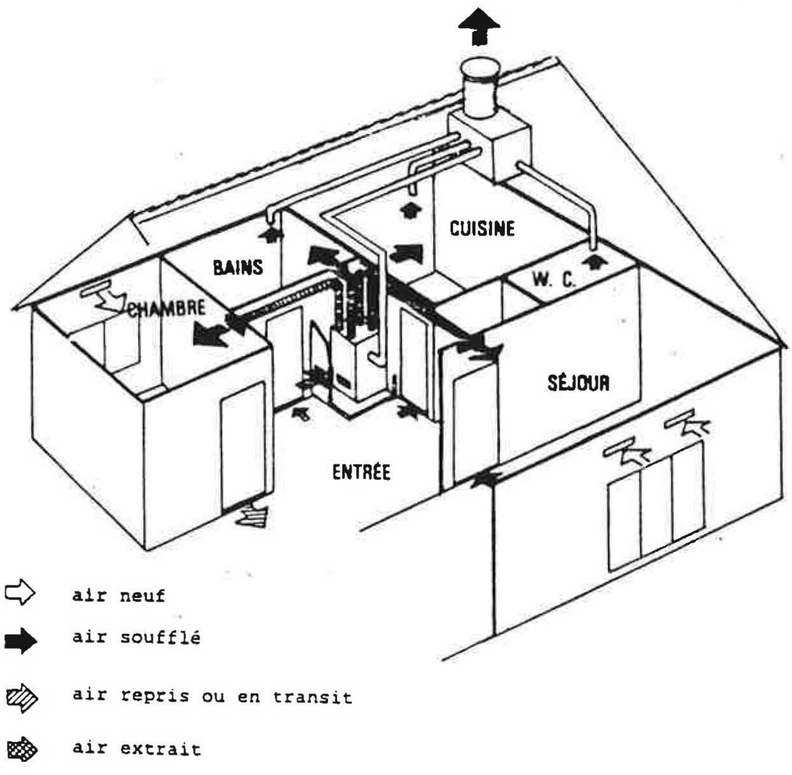

Figure 1 - Gas fired warm air heating : standard configuration.

The objectives of the studies conducted by the Centre Scientifique et Technique du Bâtiment, the Fédération Nationale du Bâtiment and Gaz de France's Research and Development Division are :

- to validate certain choices (short distribution circuits, air inlets in the inner wall of the room...)

- to provide accurate answers to the questions raised (how should a warm air heating system be sized ? How can compatibility with controlled mechanical ventilation be ensured ? What are the alternatives as regards control ? ...).

2 - MODELLING

In order to augment and refine the theoretical and experimental work carried out, digital simulations were conducted involving the behaviour of heating and warm air in buidings equipped for warm air heating.

2.1 - Thermal modelling

The use of detailed thermal models has made it possible :

- to calculate precisely the amount of energy transferred between zones thanks to air recycling, and to deduce the recovery efficiency of free heat input (solar and internal)

- to assess the value of different control processes by determining energy gains obtained using systems offering a compromise between room by room control and single thermostat central control.

All simulations are based on four-room dwellings at two sites with contrasting meteorological conditions.

A detailed parametric study shows that continuous air recycling in the dewlling only slightly increases (by less than 5 %) the recovery of free heat input, and that the energy gain is offset in part by ventilator operation.

The following heating control units were tested :

- a thermostat in each main room,

- a single thermostat in one room, either the living room or the corridor

- two thermostats set to different cut-in temperatures (in addition to the main thermostat located in the living room, a second thermostat set 1°C apart was placed in another room).

Intermittent nighttime operation was also studied.

The following main conclusions were drawn from the simulations :

- a single thermostat, located in a central area of the dwelling, controlling the warm air temperature and shutting off the ventilator when there was no need, is an efficient solution for reasons of both comfort and consumption. Yet the ideal solution in terms of recovery of free heat input involves room by room control. Simulations have demonstrated that the difference in consumption between the two systems is proportional to the following quantity :

$$= 1 - \frac{NR}{1 + NR}^{4}$$

where NR = the recycling rate (vol x h^{-1})

- use of a lower nighttime rate is a very interesting solution, as the flexibility of warm air heating allows for quick resumption of temperature, and ventilator consumption is greatly reduced.

These simulations laid the foundation for the preparation of a simplified method for calculating annual warm air heating consumption.

2.2 - Air exchange modelling

There is a pressing need to study the compatibility of controlled mechanical ventilating systems and warm air heating, first by detecting any possible occurence of air being recycled from utility rooms to main rooms and the concurrent appearance of condensation in main rooms.

We built air exchange models between rooms equipped for controlled mechanical ventilation and warm air heating. The model building hypotheses are stated below.

The pressure in each room is a function of its height and temperature. The air is assumed to be homogeneous and isothermic, and mixtures are assumed to be instantaneous and perfect. The effects of wind are taken into account on the basis of extrapolated coefficients of additional pressure measured under test conditions. Manufacturers' output pressure specifications were used for air grilles and ventilators [6].

Algorithms used were validated by experiments carried out on test houses of the Research and Development Division using search gas whose movements were modeled [7].

In building a warm air heating model, we introduced a classic scenario of controlled mechanical ventilation operation involving low throughput in the kitchen ($45m^3/h$) when there is not cooking and high throughput ($120m^3/h$) when steam is produced.

As illustrated in figure 2, showing air exchanges between rooms, non circulation of air from utility rooms to main rooms was observed during so-called "critical" periods of kitchen use and provided that needs for maximum throughput were respected.

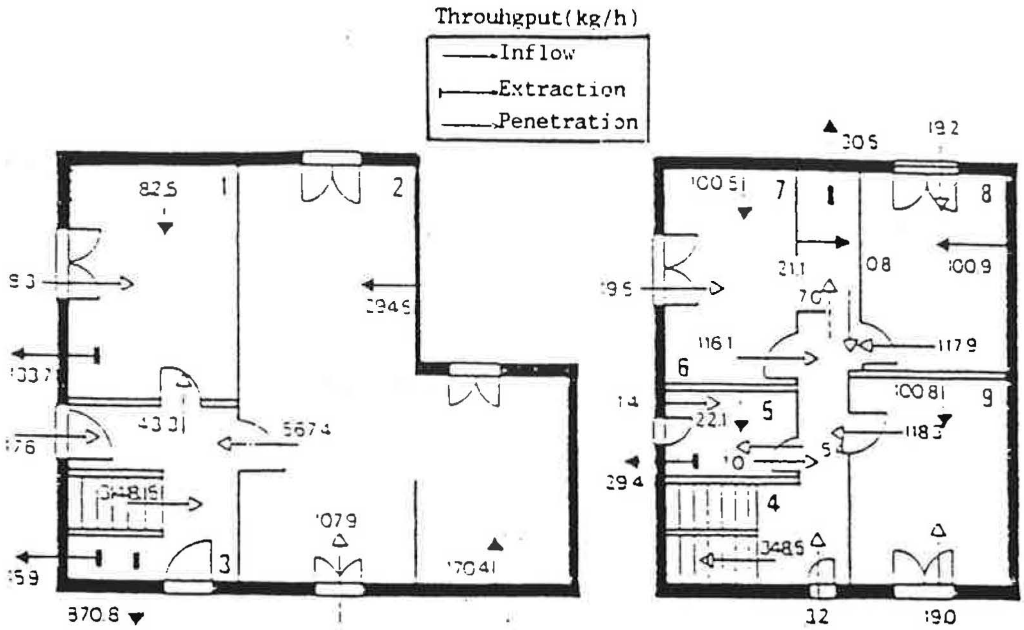

Figure 2 : Air exchange models

A number of air flow disturbances were simulated, including the effect of wind and the opening of doors.

First, we compared the air change rates obtained with mechanical ventilation operating either alone or in combination with warm air heating. The correlation between wind and air change rate is virtually identical in both configurations.

Furthermore, although the maps showing air flow from room to room are logically modified (taking into account the influence of outer wall permeability) as the direction and velocity of wind change, in most cases, air does not consequently circulate from utility rooms to main rooms.

The sensitivity of control systems to wind was also studied. In single control systems, the thermostat should not be installed in a room subject to serious drafts in order to limit the risks of overheating the other rooms. In the case studied, the best locations in terms of comfort are the entrance and the living room. The two options offer greater homogeneity of temperature for the entire dwelling, each for a different reason.

When all the internal doors are open, increased air flow from zone to zone does not impede the operation of the installation, leading to homogeneous temperature levels in all rooms and reduced temperature variation from room to room.

3 - SIZING GUIDELINES

A practical guideline for designing and installing home warm air heating established during the study offers designers and installers the information they need to install a system properly, and it contains rules for sizing air grilles and air flow between rooms [5].

3.1 - Sizing air grilles

The sizing suggested is based on a theoretical study [4] validated by tests, which will be discussed in another document (behaviour of a hot-air jet in a room), and basically concerns horizontal air inlets installed at one end of a room.

The following rules must be adhered to in order to determine flow rate, temperature, and air inlet sizing :

- the diffuse thermal power per air inlet should be limited to the value given by the equation :

$$P_{max} = 78 \frac{(H + L)^3}{HL}$$

  where L and H express the length in meters, in the direction of the air jet and height of the room,

- air temperature (TA) should fall within two extremes :

  * the minimum value, (TAmin) is intended to limit the input rate into the kitchen in order to avoid any recycling of bad air. In any case, the input rate is limited to 3/4 of the maximum extraction rate. TAmin is given by the equation :

$$TAmin = 18 + 4 \frac{Pkitchen}{q\ max}$$

  where Pkitchen is the power to be supplied to the kitchen [W] and q max is the maximum extraction rate from the kitchen [m^3/h] as shown in the table below :

Number for main rooms in the dwelling	1	2	3	4	5 and up
q max (m3/h)	75	90	105	120	135
(TAmin - 18) pour 100 W [°C]	5.3	4.4	3.8	3.3	3.0

* the maximum value, TAmax, is intended to avoid a concentration of hot air at the ceiling and is given by the formula :

$$TAmax = 18 + 8 \left(\frac{P}{L^2}\right)^{1/3}$$

where P [W] designates the power per air inlet in the room with the lowest losses (excluding washrooms) and L[M] the length of the room in the direction of the air jet.

Initially, therefore, air temperature TA can be chosen at the midpoint of a range defined below :

$$TAmax = 18 + 4 \left(\frac{P}{L^2}\right)^{1/3} + 2 \frac{Pkitchen}{q\ max}$$

- the section of each air inlet should be chosen within a range defined by the following equation :

$$\frac{p^2}{(L + H)^2 (TA - 18)^2} \leq A \leq \frac{18}{(HL)^{2/3}} \frac{p^{4/3}}{(TA - 18)^2}$$

3.2 - Air flow between rooms

Air openings between rooms should be sized in order to allow for the flow of recycled air and changed air with limited and balanced pressure losses.

Air flow velocity should fall between 0.9 m/s and 1.4 m/s, which would give an area value, in cm^2, equal to two to three times the value of the air flow rate expressed in m^3/h.

In order to avoid any backflow of bad air towards the circulating equipment, doors directly connecting main and utility rooms should be as airtight as possible.

4 - FULL SCALE TESTS

4.1 - Test houses

The design and sizing methods defined in the guide mentioned above were first tested in the Research and Development Division's test houses.

The tests showed that warm air heating systems thus sized, and connected to Poujoulat generators, provide heating comfort and output that are generally comparable to those obtained from central warm air heating systems associated with a condensation boiler.

4.2 - Pilot operation

Half of a 50-house development built at La Valbonne (Ain, France) was fitted for warm air heating ; the other half contained conventional heating systems using radiators equipped with thermostatic valves and powered by a condensation boiler [8].

In both types of houses, a thermostat located at the entrance controlled the generators ; in the houses equipped for warm air heating, a timer installed in the garage allowed for intermittent operation (although as the timer was poorly situated and difficult to use, it limited the use of programmed intermittent operation).

All the houses were built by Phénix, with two stories and average inertia (cf. fig.3) (nighttime heated area upstairs) ; their coefficient of volume losses as calculated varies between 0.6 and 0.7 $W/m^3 \times °C$.

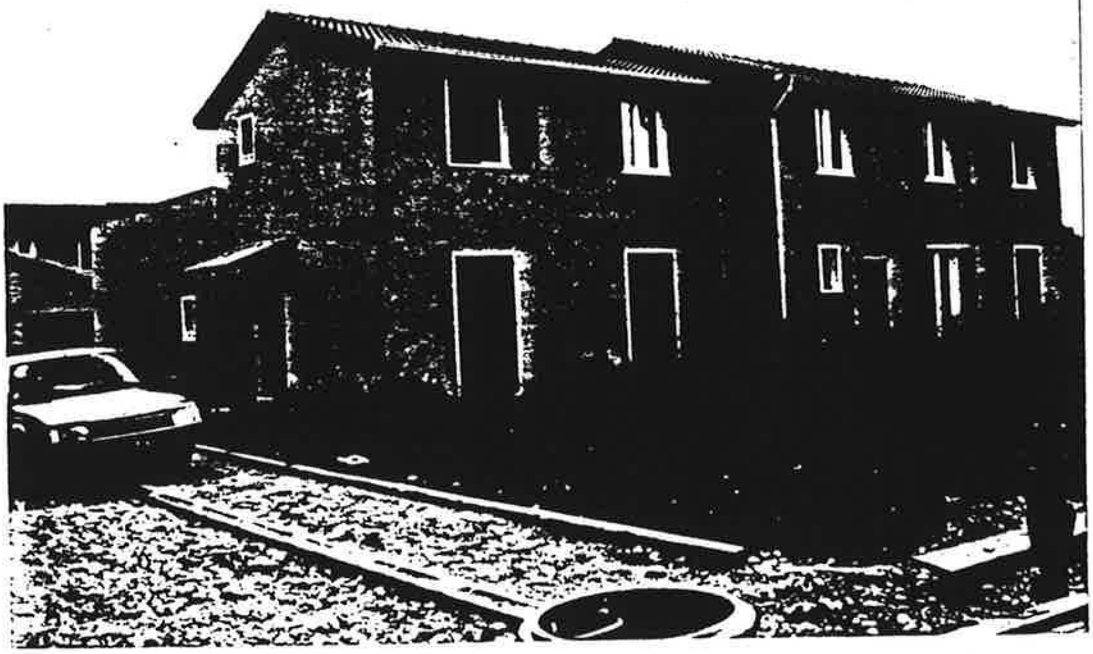

Figure 3

The pilot operation at La Valbonne

Surveys conducted between March 1987 (when the houses were first occupied) and September 1988 were intended :

- to compare consumption statistics of the 25 houses with warm air heating compared to that of the dwellings equipped with radiators

- to study in greater detail six warm air heated houses representative of the group for reasons of their size and exposure (two 3-room, one 4-room, two 5

- room, and one 6-room dwelling) and in which the instrumentation installed made it possible to monitor the changes in inside temperature and consumption by the hour.

A counter measuring the thermal energy supplied by the generator was installed in each of the two 5-room dwellings ;

Figure 4 allows for a house-by-house comparison of overall energy consumption.

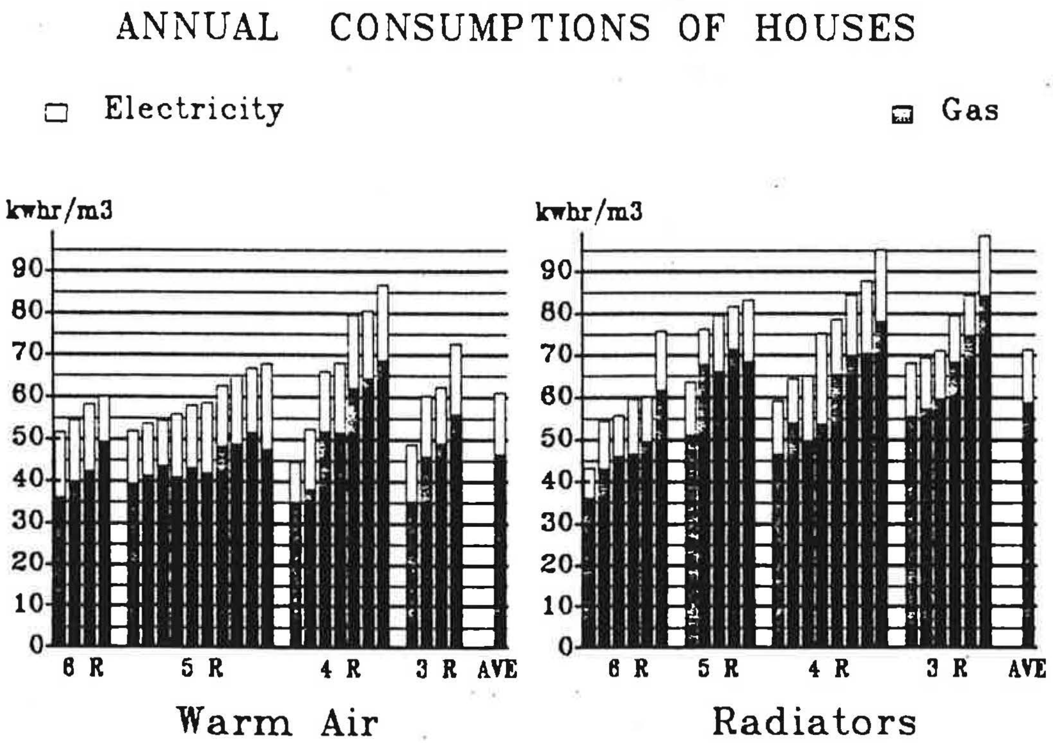

Figure 4

Total energy consumption of the 50 houses

Total average consumption (gas + electricity) of the warm air heated houses was 15 % lower than those equipped with radiators, although energy transfers from the less expensive energy source (gas) toward the more expensive one (electricity) led to operating costs only 5 % lower.

The fact that warm air heated houses consumed less energy can be explained by the following reasons :

- intermittence (often manual) facilitated by the flexibility and low inertia of the heating system

- better recovery of free heat input from internal and solar heat due to recirculation of air between rooms

- good generating efficiency when the heating system is in operation.

Tests carried out in the six houses equipped with measuring instruments showed that :

- system operation was satisfactory, especially in terms of air control and distribution

- occupants understood and used their intermittent heating capability to varying degrees

- the balancing method proposed made it easy to obtain the desired result, yet most occupants criticized the lack of room by room control

- generator efficiency (heating + domestic hot water) while heating was 90 % g.c.v., yet losses from the water heater throughout the warm air heated system produced efficiency of between 60 and 70 % in domestic hot water production alone (summer operation).

5 - INITIAL CONCLUSIONS AND OUTLOOK

A number of points are now certain :

- heat monitoring of the pilot operation at La Valbonne demonstrated that warm air heating can be a <u>very high energy producing</u> technique (equivalent to hot water central heating associated with a condensing boiler)

- <u>design and construction guidelines</u> should enable engineers and manufacturers to size and install this type of heating system correctly

- a high-performance tool for studying warm air heating systems has been developed ("Aerogaz" program)

- a simplified method for calculating consumption has been developed.

Other points, however, require additional study. Sociological surveys of the La Valbonne operation, commissioned by the French Housing Ministry, should help identifying problems that need to be solved [9]. It is now likely that particular attention will continue to be devoted to heating comfort, noice comfort, dust, and room by room balancing and control.

It will also be necessary to consider developing new services related to air management (forced air filtration, humidification, cooling, and clothes drying ...).

There are many reasons to believe that France has more of a potential market for air treatment and management than a market for warm air heating. Perfecting warm air heating techniques and learning to offer new services are thus two necessary conditions affecting future development.

BIBLIOGRAPHY

[1] M.Gouez and G.Grochowski (Gaz de France, Research and Development Division) ; Les actions menées par la Direction des Etudes et Techniques Nouvelles du Gaz de France dans le domaine du chauffage aéraulique (Work carried out by Gaz de France's Research and Development Division in the field of warm air heating) ; ATG Congress, 1986

[2] Ph.Guillemard (Fédération Nationale du Bâtiment, Research Division), E.Hutter (Centre Scientifique et Technique du Bâtiment), G.Gréco and E.Perray (Gaz de France, Research and Development Division) ; Gaz et chauffage aéraulique : modélisation, conception et première réalisation (Gas and warm air heating : model building, design, and first installation) ; ATG Congress, 1987)

[3] Ph.Cassagne and N.Castaing (Gaz de France, Research and Development Division) ; Le chauffage aéraulique : état des études en France (Warm air heating : status of research in France) ; VIIG Congress, 1988

[4] Centre Scientifique et Technique du Bâtiment ; Comportement d'un jet d'air chaud dans un local (Behaviour of a warm air jet in a room)) ; to be published

[5] Centre Scientifique et Technique du Bâtiment-Gaz de France ; Guide de conception et de réalisation d'un chauffage aéraulique dans l'habitat (Guide for designing and installing warm air heating in the home) ; to be published.

[6] R.Fauconnier and Ph.Guillemard (Fédération Nationale du Bâtiment, Research Division), A.Grelat (CEBTP) ; Algorithmes des simulateurs du comportement thermique des bâtiments BILGA et BILBO (Algorithms for BILGA and BILBO heating behaviour simulators in buildings) ; Annals of ITBTP no.457, September 1987

[7] R.Proix and P.Valton (COSTIC), R.Fauconnier and Ph.Guillemard (Fédération Nationale du Bâtiment, Research Division), C.Tahon and E.Perray (Gaz de France, Research and Development Division) ; multizone (Experimental validation of a multizone air exchange model) ; Promoclim E, vol.19 no 1, January/ February 1988

[8] Centre Scientifique et Technique du Bâtiment ; suivi thermique de l'opération pilote de La Valbonne (Thermal monitoring of the pilot operation at La Valbonne) ; to be published

[9] CETE Lyon ; suivi sociologique de l'opération pilote de La Valbonne (Sociological monitoring of the pilot operation at La Valbonne) ; to be published.