Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 12 (1984)

Artikel: Advanced control heating system for residential buildings

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DOI: https://doi.org/10.5169/seals-12171

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Advanced Control Heating System for Residential Buildings

Système moderne de contrôle de chauffage pour des bâtiments d'habitation

Fortschrittliches Heizregelsystem für Wohnbauten

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Jürg Gass, born 1943, got his Ph.D in experimental nuclear physics at the University of Zürich. Since 1977 he has been working in the field of building physics where he is involved in different research projects, especially those pertaining to building monitoring and computer simulations.

SUMMARY

The energy conservation potential of a microcomputer-based heating control system was evaluated in a total building monitoring project. This led to the conclusion that, due to a strong positive coupling effect between the control system and the inhabitants, a conservation potential of at least 25% can be expected.

RESUME

Le potentiel de conservation d'énergie pour un système de contrôle de chauffage, basé sur un micro-ordinateur a été évalué dans un projet de mesure d'un bâtiment entier. Grâce à l'effet de couplage fortement positif entre ce système et les habitants, un potentiel de conservation d'au moins 25% peut être anticipé.

ZUSAMMENFASSUNG

Innerhalb eines grösseren Messprojektes an einem gesamten Gebäude wurde das Energiesparpotential eines neuen Heizregelsystems ermittelt, das auf einem Mikroprozessor basiert. Dank einer starken positiven Wechselwirkung zwischen diesem Regelsystem und den Bewohnern ist ein Sparpotential von ca. 25% zu erwarten.

1. THE LIMMATSTRASSE PROJECT

The town of Zurich is owner of a complex of 25 old townhouses at the "Limmatstrasse" with a total of 225 apartments. During the early 70's it was discussed whether these buildings built in 1907/8 should be destroyed or renovated. An economical study showed that the buildings were worth renovating.

One part of the renovation was, that the apartements were brought to an up-to-date standard with new kitchens and new bathrooms. The heating by single heaters in the rooms was replaced by a new central heating system. A central hot water supply was also introduced. The new renovated houses offer quite good living conditions now (see Fig. 1) for a reasonable price.

Fig. 1: View into one of the inner courts of the Limmatstr.-estate

The other part of the renovation was a thermal retrofit with the aim, that the comfort conditions should be raised without increasing the energy consumption. In this thermal retrofit an experiment was included to compare the efficiency of retrofits with different investment levels.

The cases to be compared were:

- Zero level investmentcase (Type 0 building): One of the houses was kept without special thermal retrofits as a reference case for the evaluation of the retrofit efficiency of the other cases.
- Low level investment case (Typ 1 building): The standard thermal retrofit, apllied to most of the houses, consisted mainly of triple glazed windows, additional insulation on part of the outside walls and thermostatic valves. The investment for these thermal retrofits was about SFr. 4'000.- per apartment.
- High level investment case (Type 2 building): One of the houses was used as an experimental house. The whole building envelope was especially well insulated. As a pilot study for high level retrofits on old buildings, different advanced systems were introduced as follows: a gas engine driven heat pump with sewage heat recovery and roof absorbers, a solar collector system for domestic hot water and a microcomputer based temperature control system for the heating.

For the comparison of the three cases, an intensive instrumentation system with more than 140 measuring channels was installed. The sensors were distributed in three different houses, each representing a case. The quantities measured were:

- Outside climate (air temperature, solar radiation, wind)

- Inside climate: In each of the houses all the room temperatures in two apartments have been measured as well as certain return temperatures in the heating system, in order to monitor whether the heating is on or off.
- Heating energy consumption: In each of the houses the heating energy consumption of five apartments, including the two with the monitored temperatures was measured.
- Advanced technical systems: In the heat pump and solar collector-system all the heat fluxes were measured to determine the performance of these systems. Special measurements have been made in the "temperature control system" to investigate its use by the inhabitant.

2. THE CONTROL SYSTEM

2.1. Technical aspects

The experimental house is equipped with an advanced, microcomputer-based temperature control system, which allows individual, time dependent temperature set points for each room. The system also delivers the information for individual charging of the heating costs.

A schematic view of the heating and the temperature control system is given in Fig. 2. In the actual case, the system was relaized for ten apartments with 5 controlled rooms per apartment.

The function of this control system can be described on three different levels:

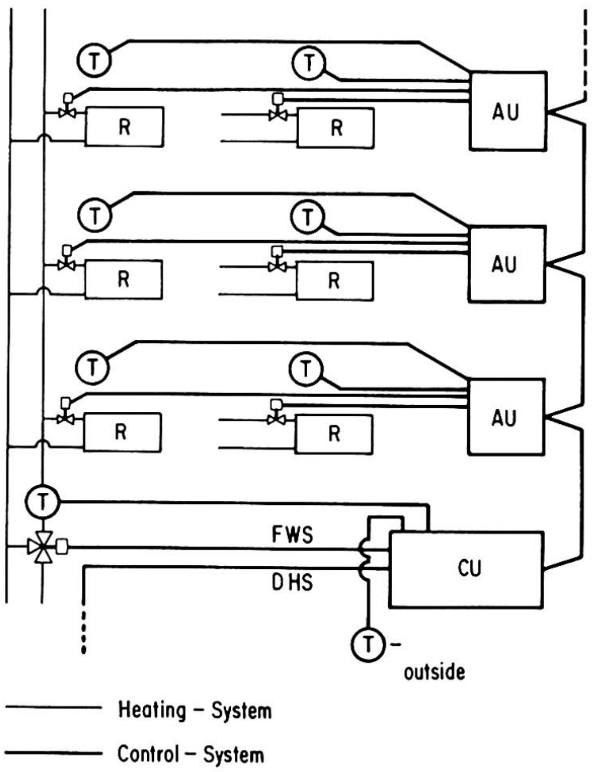

Fig. 2: Schematic view of the control system
AU = Apartment unit
R = Radiator
DHS = Deficiency heat supply
CU = Central unit
FWS = Feedwater supply

- Each controlled room is equipped with a temperature sensor, which delivers the actual temperature value and a control valve, which regulates the heat supply to the room. All the valves and temperature sensors are connected to a substation, called the apartment unit.
- Each apartment is equipped with such an apartment unit (see Fig. 3). It transmits the temperature values from the sensor to the central unit and the adjusting values for the control valve from the central unit to the valve. It also enables the inhabitant to communicate with the central unit. There he can choose for each room a different program of temperatures (a maximum of 4 steps). The information is stored in the central unit. The allowed temperatures to be chosen are limited to the range of 15°C to 22°C.

The whole system is run by the central unit. It stores the information of the inhabitants programs and calculates the adjusting values for the room control valves. The supply water temperature and the deficiency heat supply (when the heat pump does not deliver enough heat) are also controlled by the central unit.

Fig. 3: The apartment unit with the programming possibilities

The central unit and the apartment substations are connected to a loop by a simple telephone wire for serial data transmission, which allows easy installation. The supply water temperature is controlled in such a way that the mean position of the room control valves is one third open. In this way, the total heat distribution system is controlled by the actual needs of the house. This allows an optimal use of the free heat. The maximum supply water temperature is limited to 55°C, in order to give preference to the heat supplied by the heat pump.

The system produces also a distribution index for the individual charging of the heating costs. This distribution index is based on the time integral over the difference between the measured outside temperature and the demanded room temperature. It also takes into account the size of the room. So the individual inhabitant is charged for the demanded temperature comfort and not for the consumed heat. The advantage of this method is that there is no "punishment" for an unfavourable position of the apartment but there is also the disadvantage, that there is no "punishment" for an excessive opening of windows.

2.2. The use of the control system by the inhabitants

To investigate the use of this programmable control system by the inhabitant, the programming activity was itself especially monitored.

A typical program is given as follows:

0 - 5 h: 17°C   5 - 16 h: 20°C   16 - 21h: 22°C   21 - 24 h: 17°C

However programs with 15°C or 24°C constant during the day were also found.

An interesting question poses itself: To what extent was this programming facility used by the inhabitants. The complexity of the chosen programs is represented by the number of set point changes during the day. This number shows how far the inhabitant was willing to adapt the programs to his real needs.

The statistics of the set point changes in all the programs is as follows:

No changes	42 % of the programs
Two changes	41 % of the programs
Three changes	7 % of the programs
Four changes	10 % of the programs

Another figures, which shows how intensively the programming facility was used is the frequency of midification of the programs has been changed during the heating season (200 days) according to the changing needs of the inhabitants. These figures are:

less than 6 changes:	5 apartments
between 6 and 12 changes:	3 apartments
more than 12 changes:	2 apartements

The different use of this control system leed to a variation of the temperature comfort (integrated difference between inside and outside) of 1 to 1.5 which means that the least economizing inhabitant uses 50 % more heat than the most economizing one.

These above results for this prototype installation show that in the case of series production, certain simpilifications are necessary for an efficient use of programs. There are in the new version a defaultprogram with dual set back (day and night) as well as a switch for a constant set back which operates during times, where the inhabitant will be absent is affored.

3. COMPARISON OF THE ENERGY CONSUMPTION OF THREE BUILDINGS

In the experiment, the energy consumption of three different houses (each one of the types 0, 1 and 2) was measured during two heating seasons. These three buildings had several differences (see table 1) which have to be taken into account when evaluating the results.

For a better understanding of the results, the heat consumptions for the same periods have been calculated with a simple steady state model, assuming the same boundary conditions and the same influence of the control system for all of the three buildings. The results for a full heating season are given in table 2.

The calculated results show the differences due to the variations in the building envelope, taking also into account the larger contribution of the free heat with encreased insulation. The deviations of the measured from the calculated figures show the differences of the inhabitants influence combined with the different control systems.

	Type 0	Type 1	Type 2
Heating System	Radiators under the windows, design temperature for the supply water 90°/ 70°C	as Type 0	Radiators at interior walls, design tempe- perature for the supply water 55°/ 40°C
Control System	Supply water tempe- rature controlled by outside thermo- stat + manual values	as type 0 + thermostatic val- ues	micorcomputer con- trol system (see chap. 2)
Building envelope	no insulation sin- gle glaze windows + storm windows	partical insulat- ion, triple glazed windows	full insulation triple glazed

Table 1: Main differences of the test buildings influencing the heat consumption

	Measured	Calculated	Deviation of measured from calculated
Building type 0	219,4 GJ	190,4 GJ	+ 15 %
Building type 1	219,1 GJ	162,4 GJ	+ 35 %
Building type 2	101,1 GJ	133,5 GJ	- 24 %

Table 2: Comparison of calculated and measured energy consumption for the three test buildings.

That there is an important inhabitant influence, differing from one building to the other, can be seen by looking at the energy signatures (see fig. 4). These energy signatures show the monthly energy consumptions as a function of the monthly mean outside temperature.

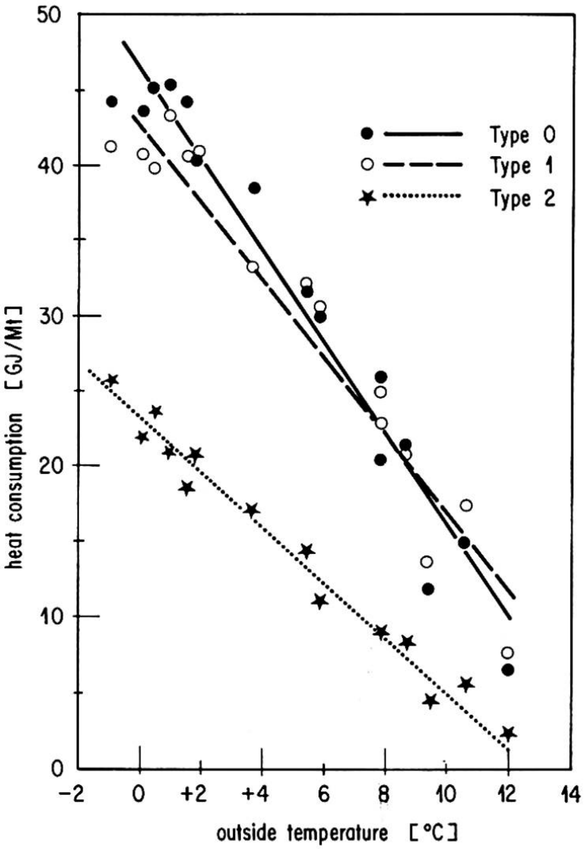

Fig. 4: Energy signatures of the three test buildings

The lines for the buildings type 0 and type 1 are crossing at an outside temperature of 8°C. Without inhabitants, one would expect for the type 1 building a line, always below the type 0 building line because of the somewhat better insulation. This difference should be bigger for higher outside temperatures due to the greater amount of free heat, which should be more efficiently used in the type 1 building with thermostatic valves. The fact that the energy consumption of the type 1 building, especially in the spring period, is even higher than the consumption of the type 0 building must be due to excessive window opening increasing with higher outside temperatures.

4. INFLUENCE OF THE ADVANCED CONTROL SYSTEM

As the experiment was rather complex, which means, that the buildung with the microcomputer-control system encludes also a lot of other differences influencing the heat consumption, the isolation of the influence of the control system alone is difficult and not completely possible.

The importance of the role of a control system can be seen by looking at the specific heat consumption in KJ/DH (DH = degree hour) (see fig. 5). If there were no free heat and no user influence, the values would be the same for one type of building for all the outside temperatures. Now in the case of the type 0 and 1 buildings, with only outside thermostatic control and thermostatic valves respectively, the values are generally increasing with lower outside temperatures, which is coupled to a lower amount of free heat available from the sun. For temperatures below 2°C, the values are decreasing again. This must be due to a reduction in the opening of windows out of comfort reasons. That there is an important amount of temperature control by the windows can also be seen from the large scatter of data points caused by the statistical scattering of the inhabitants behaviour.

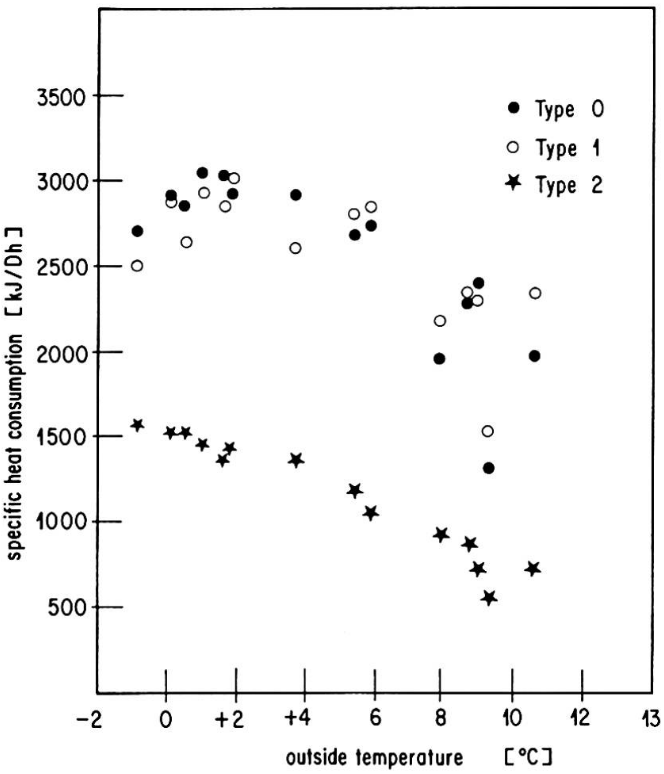

Fig. 5: Specific heat consumption of the three test buildings for two heating seasons (DH = degree hour)

In the type 2 building with the microprocessor control system, the values are increasing monotonously with lower outside temperatures and with a much smaller scatter, showing that the temperature control is really done by the control system in an energy efficient way.

For the quantification of the energy conservation potential of the control system, one has to consider the relation between the actual energy consumption including the inhabitants behaviour and the calculated one with the given boundary conditions without inhabitants.

The buildings type 0 and 1 are using 15 % and 35 % respectively more heat than the calculated case where as the building type 2 is 24 % below the calculated case.

There are two effects independent of the control system, which may be contributing to a lower energy consumption of the building type 2:

- The radiatiors are mounted along an inside wall causing lower surface temperatures at the inner side of the outside walls and smaller convective air currents along the windows.
- The average age of the inhabitants is somewhat smaller in comparison with the other buildings. The general attitude towards energy conservation may be different.

If one takes into account, that the building type 1 may not be representative concerning the inhabitants behaviour, that the accuracy of the calculation (especially the utilization of free heat) is limited and that there are other effects reducing the energy consumption in the building type 2 (as mentionned above), one can still postulate an energy conservation potential of at least 25 % for the control system an its coupling to the inhabitants behaviour. This coupling to the inhabitants behaviour is important and means that the comparison in buildings without inhabitants will never give a similar result.

The energy conservation effect of the control system itself is based on the following facts:

- The temperature comfort can be limited to the times, when it is really needed.
- The algorithm in the microprocessor allows one to follow the setpoints in each room precisely.
- The supply water temperature is controlled according to the needs for heat of the building. In this way, the heat emission of the total distribution system is controlled.

The coupling effect between control system and inhabitant may be mainly due to:

- The definition of the temperature setpoint in a digital way (input at the apartment unit) creates a better understanding of a thermostat function than a thermostatic valve.
- The possibility for the individual billing of heating costs, which is connected to the control system enhances the will for energy conservation (this possibility was not used at its full extent, but an award was paid to the most economizing inhabitant).
- The better quality of the temperature control prevents an overheating, also in situations of high solar radiations, so that no additional temperature control by opening the windows is necessary.

It is clear, that the guessed energy conservation potential of this control system is valid for this individual case only and the result has been evaluated in connection with other changes in the buildings, which cannot be separated properly. At the moment, another project is on the way, where the influence of this control system can be looked at separately.