

The benefits of upgrading a conventional batch heating system using multiple temperature measuring points analysis

[Costel-Ioan CIOBAN]

Abstract— The supply of heat to buildings in Romania and beyond is at a turning point and the main reason is the ever-increasing price of fuel and electricity. In the current context, climate change, energy dependence, depletion of fossil fuel reserves and the current geopolitical context generated by the war between Ukraine and Russia are forcing national and European institutions, local and national authorities to be concerned with increasing the quality of life of citizens (or at least preserving it at its current level) and meeting the conditions for ensuring their comfort. Another important issue is the safe operation of heating systems and the provision of minimum indoor thermal comfort parameters. The long-term security of energy resources and the fight against climate change require measures for the introduction, modernisation and expansion of efficient heat supply systems. In order to achieve these objectives, conditions for the efficient use of energy resources must be developed and ensured by optimising the conversion of fuels of all kinds into heat energy and managing it in an intelligent way to ensure thermal comfort with the lowest possible energy consumption. In order to achieve this, new technologies for temperature measurement and energy management will be used to make efficient use of existing energy resources.

Keywords—energy, heating installations, ASHRAE, thermal comfort, climate change, quality of life.

I. The importance of heating installations Introduction

Heating techniques and methods have developed gradually over time in parallel with other areas of human life as civilisation and the economy have developed. Air-conditioning systems have developed over the centuries from open fires to complex air-conditioning systems. The most empirical heating method used almost everywhere since the beginning of human civilisation has been the open burning of coal and wood in living spaces after their discovery and usefulness. This method of heating, although harmful to health because of the combustion gases that were inhaled by people, was used for a long time and in some cases is still used today.

As technology has developed in many areas of human activity, so has plant technology. Heating systems, together with other systems in buildings, were designed to provide

Romania

optimum comfort where people work or live.

At first glance, almost 40% of the energy produced is used in the form of heat to heat residential buildings, administrative and social buildings, production premises, etc. It is quite clear that these energy consumptions are quite high and this makes the usefulness of heating installations very important as well as the way these installations are designed and operated. These issues bring into focus their energy consumption and economic efficiency.

II. Research aims and objectives

The aim of the research is to highlight the ability of certain installations to produce and distribute heat inside buildings using the lowest possible energy consumption and to achieve maximum comfort for most people. This is possible when the heat source is equipped with the latest and most efficient technology, the heat is produced with a reduced amount of fuel and the whole process can be controlled and automated.

Achieving this goal therefore requires the following objectives:

- ✓ Identify thermally, economically and energy efficient (alternative) solutions;
- ✓ Using installations to modify indoor air quality without harming the environment;
- ✓ Identification of solutions to achieve optimal thermal comfort with lower energy consumption and for a longer duration with faster compensation of thermal inertia of the installation and the building.

A. Research methodology

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B. *Quality requirements*

As energy-intensive heat production plants, it is incumbent on them to make efficient and rational use of this resource. From this point of view, a number of measures are required, starting with the consumers and ending with the heat source. People need to be provided with the heat they need in line with their needs and the current potential offered by modern technical solutions.

The heat source must be equipped with the latest and most efficient technology, heat production must be fuel-efficient and the whole process must be controlled and automated. The role of thermal energy plants is not only to design and implement new, modern and efficient heat production solutions, but also to manage the energy used. For this reason, in addition to the solutions adopted, it is preferable that they are constantly monitored in terms of the thermal conditions they achieve and with what energy consumption. Doing so will ensure that the heating system used in a building fulfils its role correctly and efficiently, i.e. achieving the desired comfort conditions with the lowest possible energy consumption [5].

In view of the above we can say that the usefulness of a heating installation is mainly enhanced by [7]:

- ✓ maintaining a thermally constant environment in the building at a good temperature for people;
- ✓ in the building it is necessary that the surface temperature of the building elements is at a level that does not give the feeling of cold and that the situation where water in the air condenses on the surface of walls and ceilings is avoided;
- ✓ temperature regulation in rooms in accordance with daily needs but also taking into account the thermal inertia of the building;
- ✓ heating without altering indoor air quality and without damaging the environment;
- ✓ heating without disturbing draughts in the rooms;
- ✓ efficient technical solutions in terms of both heating installation and operating costs.

The heating installation therefore requires the introduction of modernisation elements that reduce the discomfort caused to the beneficiaries and maximise the thermal comfort obtained.

III. Thermal comfort [2]

The ultimate goal for any new or upgraded building is to provide a comfortable environment for all the people who will benefit from that space.

"That state of mind which expresses satisfaction with the thermal environment" [6] is the ASHRAE standards definition of a person's perceived thermal comfort.

There are six [1] main factors to consider when defining thermal comfort conditions and these are listed below:

1. Metabolic rate;
2. Level of insulation of clothing;
3. Air temperature;
4. Radiant temperature;
5. Air velocity;
6. Humidity.

All six factors are likely to vary over time. Therefore, people entering a space that meets the requirements of this standard may not immediately find a comfortable environment if they were exposed to different environmental conditions before entering the new environment. The effect of contact with a different environment or a previously performed activity may alter the perception of comfort for up to an hour.

It is verified that if a group of people is exposed to thermal conditions in the same room, achieving comfort for all of them at the same time is not possible due to individual physical conditions [10]. For this reason we can say that achieving thermal comfort for the largest percentage of that group should be targeted if optimal thermal comfort is to be created for all [4]. We can conclude that the main objective of heating and air conditioning equipment is to create thermal comfort for the majority of people.

Considering independently any of these six factors affecting thermal comfort is not possible. Achieving thermal comfort can be done by mixing these variables and using several different thermal systems.

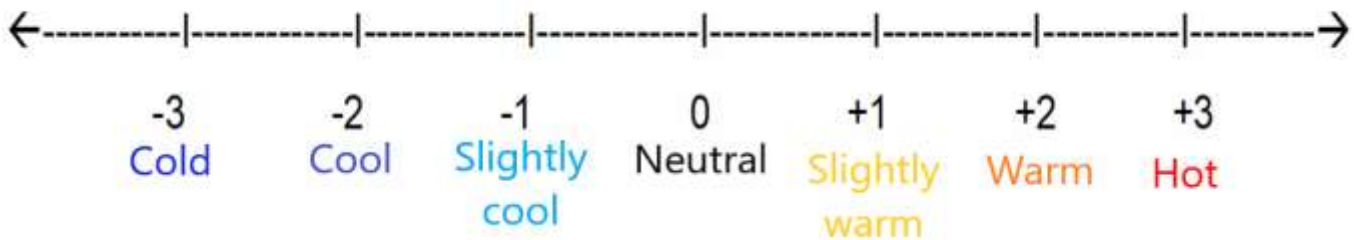
Thermal comfort [8,9] in a built space can be evaluated as the total sensation of heat or cold felt by people. In addition, if the indoor space is not excessively hot or cold, then it is considered thermally comfortable. Thus, the comfort zone can be defined as a thermal condition in which minimal or no effort is required from people to adapt their bodies to the ambient conditions of the environment.

The human body has a certain thermal balance and to maintain this balance it should be protected from the effects of external conditions, sometimes severe. In other words, a building is an envelope that separates its people from the outside environmental conditions and provides them with adequate thermal comfort. Generally speaking, buildings achieve this by means of heating or air-conditioning systems.

Factors that alter thermal comfort in buildings can be divided into two categories [9,11]. Those in the first category of factors include environmental conditions, conditions outside the building, outdoor environmental temperature, relative air humidity, solar radiation, geographical area and the effect of neighbouring buildings, etc. The second category of factors includes the materials used in the construction of the building, the type and size of doors and windows, the orientation of the building, the thermal mass of the building, the surrounding environmental factors, the surrounding vegetation, the insulation of the building, the ratio of transparent to opaque structures, shading, shading vegetation, the shape of the building, etc. We can see that there is a possibility to control the second group of factors in order to have superior thermal comfort in new buildings. Thermal comfort depends to a large extent on making optimal decisions about these factors during the preliminary stages of design.

The comfort equation [3], which takes into account all the above factors, is a requirement for optimal thermal comfort. Even if these factors are taken into account the equation does not provide information on how to combine the variables to provide maximum thermal comfort. It cannot be used to understand the thermal characteristics, the thermal sensation of people in an arbitrary climate, because the variables cannot be expected to satisfy the equation. Given the comfort equation, a useful index has been generated to develop predictions of comfort sensation for any combination of environmental conditions, physical activity level, thermal value of clothing. The seven-level ASHRAE Psychophysical Scale [2] was used as a measure of thermal sensation:

Chart no.1 ASHRAE psychophysical scale



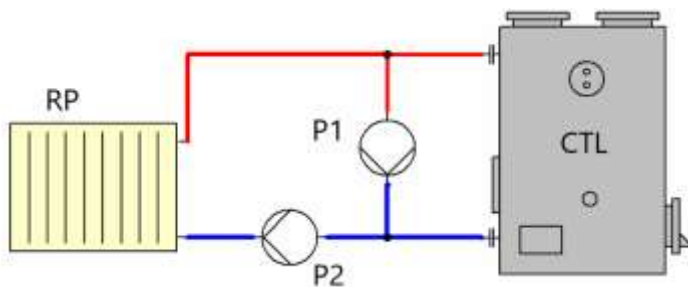
A. **Presentation and description of the proposed solution**

All water heating systems must control the temperature of the water supplied to the heat exchangers. Here we can talk about radiators, fan coils, instantaneous hot water exchanger etc. A simple system can be set to provide one water temperature for all the loads it serves (figure 1). A more sophisticated system containing several types of heat exchanger may need to supply two or more water temperatures simultaneously. In this paper I propose several water

temperature control points and the solution required to achieve this.

The easiest way to control the water temperature is called "set point control". As can be deduced from the name, a single (regulated) water temperature is sent to the heating system, regardless of what the needs are, or how high the heat demand is (if there is a demand).

In our approach, we started the retrofit from a conventional wood-fired heating system providing heat for a single-family home.



- CTL - wood-fired central heating
- P1 - recirculation pump for central heating system
- P2 - heating circuit recirculation pump
- RP - panel radiator

Fig. 1 Classic wood-fired heating circuit

The initial complete circuit of the heating installation

corresponds to the one in figure 2.

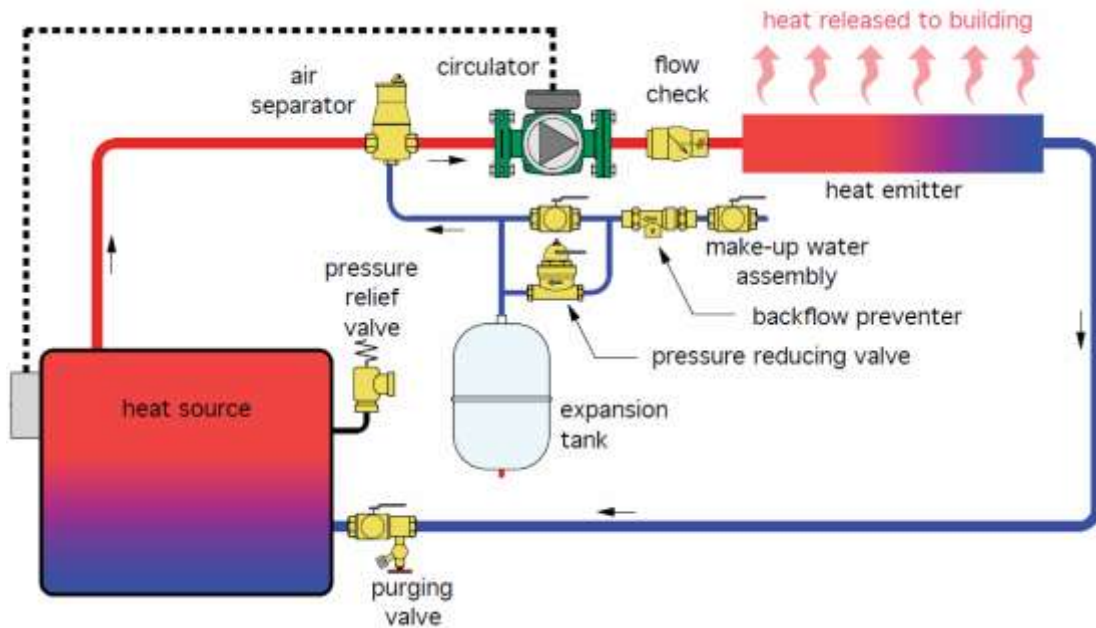


Fig.2 Single-circuit heating system

Source: Manual for ClimateMaster Training Course: Essentials of Hydronics for GSHP Professionals, 2011, USA, p.10

This heating circuit provides heat in the home at least 2 hours after the fire has been lit and a maximum of 1 hour after the fire has been extinguished. The heat sent to the heating circuit is not uniform in intensity, the indoor temperature in the house fluctuates and does not provide the expected level of comfort.

The modernisation of the heating installation aims to solve all these problems and achieve optimal thermal comfort with lower energy consumption and for a longer period of time with faster compensation of the thermal inertia of the installation and the building. The heat source

has remained the same but in addition solar thermal panels and a 2,000 litre heat storage tank have been installed.

While in the classic installation the operation involved lighting the fire, feeding the fuel, obtaining heat after a fairly long time and after extinguishing the fire reducing the indoor temperature and the comfort level at the moment things are gradually proceeding as follows (see fig.3):

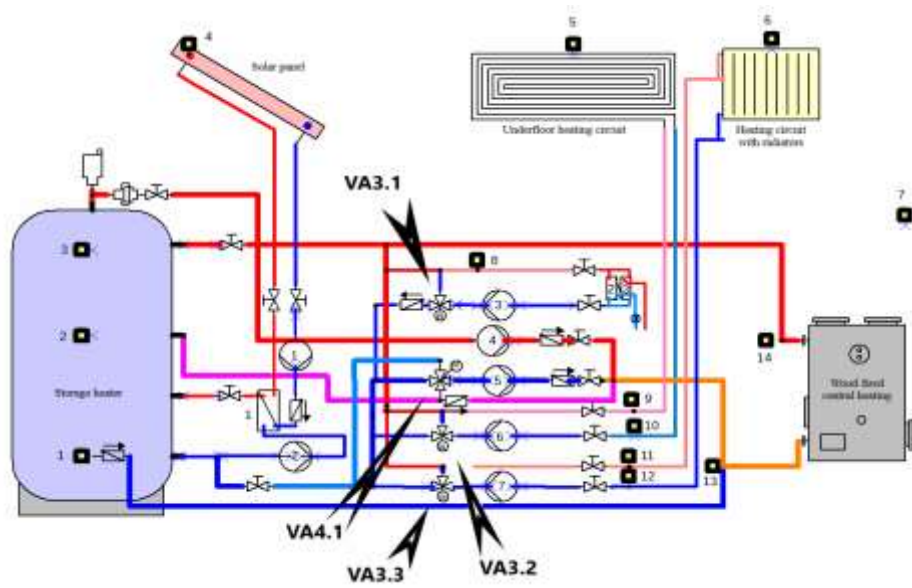
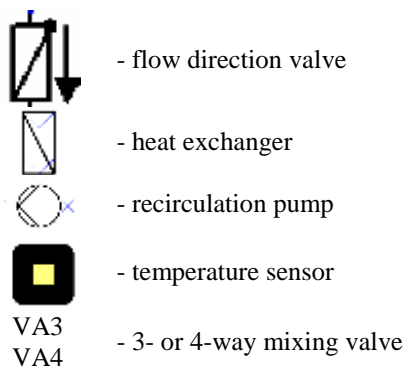


Fig.3 Heating installation with mixing valves, heat exchanger, temperature sensors and recirculation pumps



B. How the upgraded heating system works

- ✓ Level 1: the fire is lit which leads to a rapid rise in the lap temperature of the plant which receives heat from the heat accumulator lap in its return and sends it into the house circuit. The return heat is directed into the storage tank by means of the 4-way valve (VA4.1);
- ✓ Level 2: after a certain time the return temperature of the radiators exceeds the temperature of the storage tank lap and the supply of heat medium from the storage tank is shut off by repositioning the flap of the 4-way valve (VA4.1);
- ✓ Level 3: the lap temperature of the radiators reaches the working temperature set as required for the heat supply to the dwelling; the working temperature of the three-way valve (VA3.3) is maintained until the required room temperature is

reached at the same time as the surplus heat is sent to the storage tank (VA4.1);

- ✓ Level 4: the plant four exceeds the temperature of 800 C and the heat medium is directed to the storage tank (VA3.2 and VA3.3);
- ✓ Level 5: the ambient temperature has been reached and from this moment the recirculation pumps serving the house (pumps 6 and 7) are turned off, the heat supply circuit for the house from the mixing valves (VA3.2 and VA3.3) is closed and all the heat is directed to the storage tank; the power plant will supply heat to the storage tank only when the temperature difference between the power plant tower and the storage tank return is $\Delta t > 10^{\circ} \text{C}$ and the energy transfer is stopped when it reaches $\Delta t < 5^{\circ} \text{C}$.
- ✓ Level 6: the storage heater is heated up to 800 C or until the fuel in the plant runs out and if it is estimated that the energy input from the panels cannot bring the storage heater to 800 C and the outside temperatures are lower than estimated, fuel is added to the boiler.

By using 3-way valves, the lap temperature required by the installation for various applications (heat or hot water) is regulated. For underfloor heating the lap temperature will fluctuate between 27 - 370 C and for radiator heating the lap temperature will fluctuate between 55-750 C. These temperatures are regulated according to 3 factors: outdoor temperature, existing ambient temperature and required ambient temperature.

In order to make the most efficient use of the available heat energy we need temperature measuring devices or temperature sensors.

The sensors serving the installation, fig.3, are mounted in different places and provide information on the following points of interest in optimising the operation of the installation:

- ✓ Sensors 1, 2 and 3 provide information about the bottom, middle and top temperature in the heat store and have a role in managing the energy in the heat store when there is a demand for heat for heating or hot water;
- ✓ sensor 4 measures the temperature at which the solar panels are working and manages the operation of pumps 1 and 2 involved in transferring heat from the sun;
- ✓ sensor 5 is an ambient sensor for the room that has underfloor heating;
- ✓ sensor no. 6 is an ambient sensor for the room with radiator heating;
- ✓ sensor No 7 measures the outside temperature;
- ✓ sensor No 8 measures the temperature of the heating medium used for domestic hot water preparation;
- ✓ sensor No 9 measures the lap temperature of the thermal medium supplied for underfloor heating;
- ✓ sensor No 10 measures the return temperature of the thermal medium leaving the underfloor heating;
- ✓ sensor No 11 measures the lap temperature of the thermal medium supplied to the radiator heating;
- ✓ sensor No 12 measures the return temperature of the thermal medium leaving the radiator heating circuit;
- ✓ sensor No 13 measures the return temperature of the thermal medium entering the heating system;
- ✓ sensor No 14 measures the lap temperature of the thermal medium leaving the heating plant.

The way of optimizing the thermal agent recirculation also involved the use of mixing valves for a result as close as possible to expectations but also thermal agent recirculation pumps with the following functionalities:

- ✓ recirculation pump no.1 serves the solar panel circuit through heat exchanger no.1;
- ✓ recirculation pump no.2 transfers the heat from the solar panels to the heat accumulator via heat exchanger no.1;
- ✓ recirculation pump no.3 transfers heat for domestic hot water preparation via heat exchangers no.2 and 3;

- ✓ recirculation pumps 4 and 5 transfer the heat transfer medium between the heat accumulator, the central heating plant and the solar panels in order to achieve the highest possible efficiency in the operation of the whole installation (I will come back with functional details);
- ✓ recirculation pump no.6 provides the return circulation for the floor heating circuit;
- ✓ recirculation pump no.7 provides the return circulation for the radiator heating circuit.

IV. Conclusion

Heating installations are a necessity in our lives, whether we are talking about heating the home, preparing hot water or various production processes involving heat input. Rising fuel prices are an immediate reality and a major problem for everyone, individuals and businesses alike, which is why efficient resource management is of particular interest.

Efficient fuel management leads to financial and fuel savings, but also to a reduction in environmental pollution, which is another topical issue.

The main aim of this mixed heating installation was to obtain and maintain thermal comfort over a longer period of time, bearing in mind that we are talking about a wood-fired heating plant, and of course also to monitor fuel consumption.

The implementation of the ideas and the construction - modernisation of the original installation was done with the preservation of the heating elements and the heating plant. In the study of the operation of the installation (experimental research) the same amount of fuel (30 kg of wood) was used at an outside temperature of -150 , the same surface of the house was heated.

The starting point was the temperature in the dwelling, TA=17 degree Celsius, central temperature TCT= 17 degree Celsius and storage tank/puffer temperature TP = 40 degree Celsius. The boiler is fired and after 15 minutes the temperature in the central plant is TCT= 18 degree Celsius and the data collection is done which generated the graph in Fig. 4.

From the analysis of the graph we can observe, the most important aspect, that 90 minutes after lighting the fire in the plant the comfort temperature, 22 degree Celsius, is reached in the house, taking into account that we started from an initial temperature of 17 degree Celsius and we know that the thermal inertia of a house is quite high. It can also be seen that by efficient management of the heat resources the thermal boiler enters the optimum operating mode after only 30 minutes, reaching a temperature of 65 degree Celsius, which allows heat to be sent into the home, shortening the heating time.

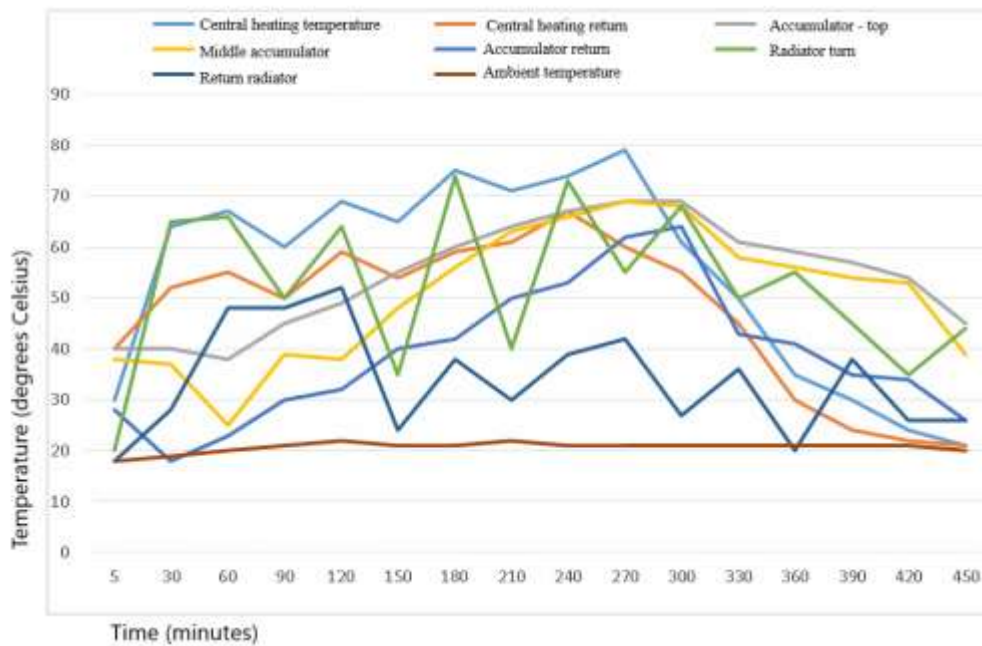


Fig. 4 Measuring the temperature evolution in the installation over time at various points

From the evolution of the other temperatures it can be concluded that the management of the combustion of fuel and thermal agent is done using all the equipment installed in the plant, sensors, mixing valves, pumps, heat exchangers, all with the main purpose of managing the heat resource as efficiently as possible.

When TCT= 35 degree Celsius is reached, the heat transfer medium from the storage tank return is transferred through the boiler by starting pump 4, and after 10 minutes the temperature TCT= 65 degree Celsius is reached and the heat transfer medium is sent into the dwelling by starting pumps 6 and 7 and releases heat into the living space and then returns to the storage tank return.

When the temperature TRR >TPM , the 4-way mixing valve changes the direction TRR - TPR to TRR -TPM .

If the TRR temperature is equal to TPR >TPS , pump control 5 will direct the TRR TCR path.

When the TCR temperature >65 degree Celsius is reached, pump command 4 is cancelled which helps the boiler to increase its temperature faster.

When the TRR temperature >75 degree Celsius is reached, the radiator circuit reduces its absorbed lap flow and the return-radiator mixing with the lap-radiator mixing is done by controlling the three-way valves VA3.2 and VA3.3 in the floor and radiator circuits. If the TCT > 76 degree Celsius is reached, the TPM - TCR circuit is changed to TPR - TCR. When the temperature in the dwelling,

measured by the room thermostat is TA >21 degree Celsius, the control of pumps 6 and 7 is cancelled and the mixing valves VA3.2 and VA3.3 are closed. When the temperature reaches TCT<TPS+5 degree Celsius the control of pump 4 is cancelled and when the temperature situation becomes TCT>TPS +10 degree Celsius the control of pump 5 is started. The heating system is far from perfect, but considering that it started from a simple heating circuit that required frequent fuel supply and had fluctuations in the heat supply, the initial objectives, thermal comfort over a longer period of time and lower fuel consumption, have been achieved.

Although small on an individual basis, the market for residential heating systems is much larger than all commercial and industrial heating systems combined. The residential market is sensitive to homeowner preferences and initial costs. This market requires simple systems because of the homeowner's sensitivity to maintenance costs and the possibility of maintenance visits being as infrequent and, if nothing else, as short as possible.

Every year, new housing starts are being built. Others undergo renovation. New or in need of refurbishment most buildings will need to have their heating system fitted or reconfigured. These aspects taken together with many other details that require people's attention make it difficult to choose a heating system.

Unfortunately, and in very many cases because of the multitude of details, the choice of a heating system is made

taking into account aspects that in the end do not lead to the satisfaction of the comfort need expected from the heating system.

In many situations, the heat supply system, which is an important and necessary part of a building, is chosen solely on the basis of the final purchase and installation price. There are situations, many in fact, where the purchase is based solely on what the seller or builder recommends or what "sells best".

This kind of choice leads in most situations to long years of frustration and discomfort and sometimes coupled with technical and thermal problems in the home.

In such a situation people who made the wrong first choice and experienced the consequences of their choice would quickly re-orientate themselves if given the opportunity. Many would be willing to have their heating system reconfigured, even if it meant spending a considerable amount of money, but in the end it would also give them the satisfaction and comfort they were looking for.

TPS	Accumulator temperature – top
TPM	Accumulator temperature - middle
TPR	Accumulator return temperature
TCT	Central heating temperature
TCR	Central heating return temperature
TRR	Radiator return temperature
TA	Ambient temperature

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