ORFEO
A NEW MULTIFUNCTIONAL SYSTEM PROVIDING HEATING, COOLING AND WATER HEATING FOR LOW ENERGY HOUSES

B. Peyronnet, President, Prime-Technology
Bourgoin-Jallieu, France
J-P. Galloin, Consultant
Saint-Gratien, France

Abstract. The ORFEO project started from an analysis of the roadblocks to a fast growth of the Heat Pump market, and other renewable energy markets. The conclusion of this preliminary study led to consider two axes. One axis for improvement is to optimize the use of the collected energy to make full use of the 'low cost' heat together with a reduced use of the 'high cost' supplemental heat. This led to the notion of global system control need. The global system analysis includes the indirect measurement of the building reaction trends on top of the other variables The second axis of action was related to the need to market a totally packaged control system that will render engineering, contracting, commissioning and maintenance of heat pump or solar systems and their auxiliaries at least as simple as for a modern classical boiler with its controls.

Key words: ***heat pumps, solar systems, energy use, central control system, optimization, simplification of installation, auto-adaptation, user-oriented, simplicity***

1 INTRODUCTION

Heat pumps and other 'new energy systems' such as solar systems require specific control systems to provide both an optimized comfort for the users and full usage of the 'low cost' energy which is collected, as well as a perfect monitoring of the supplemental energy required by the system.
Quite often the design of this very important part of the system is not offered as part of the equipment sold, and left to be designed on a job by job to the installers.
The ORFEO project now comes to a full development and mature stage, after 7 years of research, mostly based on direct field experimentation. The ORFEO project sets trends for:

- New energy controls energy optimization
- Simplified installation and start-up procedures
- Industrialization of a field-proven auto-adaptative system

The project is aiming also at providing professionals with trouble free design and installation system including features such as auto-adaptation. It will minimize installation and commissioning time.
Both of these characteristics should help in the promotion of Heat Pumps and Solar systems as 'simple' packaged units, as easy to handle as traditional boilers well known from the promoters and partners of the heating, air-conditioning industry.

2 KEY OBSERVATIONS WHICH LED TO THE PROJECT

A number of observations based on existing systems and a strong knowledge of the European heating and cooling needs and of the business and market structure led to the idea that improvements to develop energy conservation using renewable energies, including heat pumps should be designed to compensate the following problems:

- The largest portion of the collected energy is lost due to overshooting of the control systems while trending to the temperature levels required by the users.
- More energy is further lost due to the lack of anticipation of the system reaction due to the ignorance of its inertia.
- Supplemental energy is generally injected in the energy storage system, leading to a loss when future system requirements are on the downtrend.
- Numbers of systems have an inefficient regulation due to both the controls and the hydraulic piping design, since installers have little experience in the “new energy” field requirements and technologies.
- Most systems will require the presence of a control expert at start-up time, as well as the presence of a technician when further adjustments are needed after start-up.

When all these observations are accounted simultaneously they can be turned into a major project that will be the design of a packaged control center that leads to a trouble-free contracting, start-up and maintenance. The control package will use the resources provided by existing and reliable market technologies.

The goals of the ORFEO project are to simplify all the phases starting at the decision making process. Simple to manage for the owner, simple to specify, since pre-engineered, for the consulting engineer, simple to install, since fully packaged, for the contractor.
ORFEO is to provide the utmost energy usage for the user and his community.
Let’s now review the main features developed as part of the project.

3 PROJECT FEATURES – TECHNICAL

3.1 The hydraulic circuitry

The hydraulic circuitry is part of the efficiency factors for the system, and it should always receive the greatest care when designed.
In the schematics shown below, there are two key points to be noted.

- The supplemental heat should be ‘injected’ after the storage tank and not in the storage tank.
- The piping sizes and pump should be respectively designed and selected to minimize piping losses and energy consumption, as the auxiliaries such as the pumps are a major consumption factor in any heating and/or cooling system.

The hydraulic circuit is so important that the ORFEO project also includes recommendations for hydraulic circuits to match different building configurations and heating system requirements.

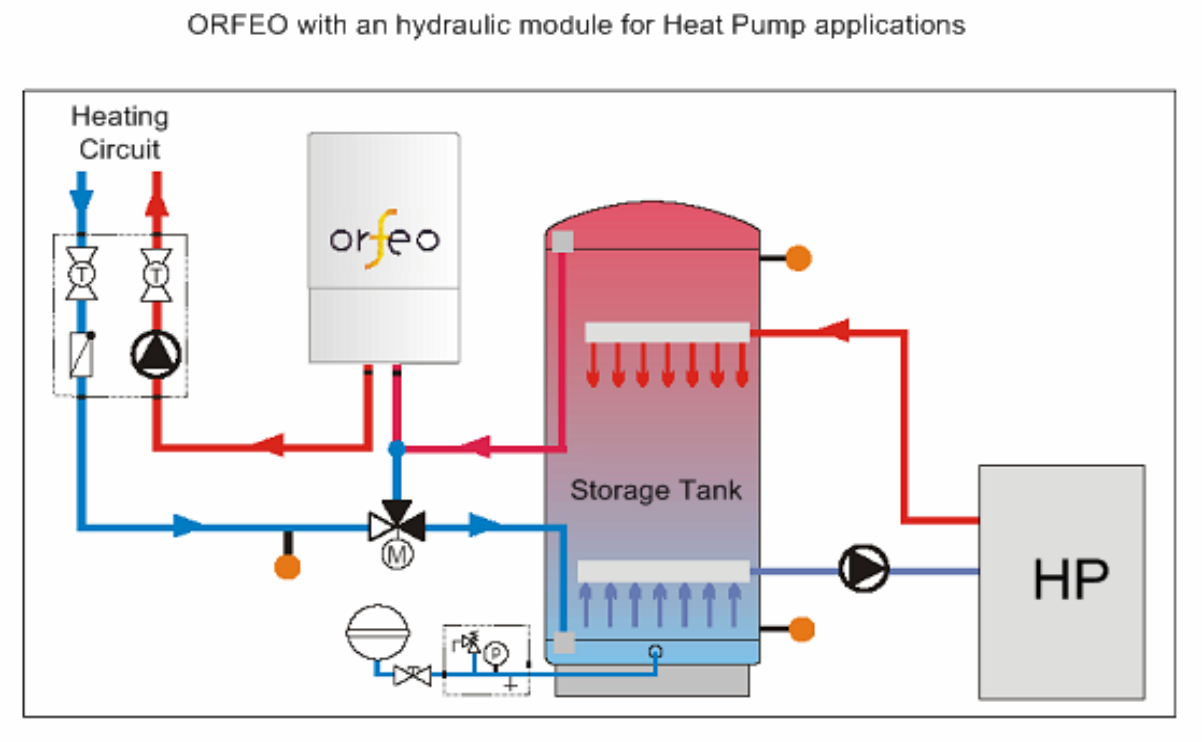


Figure 1: Typical hydraulic arrangement

3.4 The energy storage technique

The energy collected from the heat pump system or the solar panel system should be stored into the storage tank to provide a maximum usage year-round. The ORFEO control project will provide storage management according to the season and the instantaneous needs.
It is only when the temperature of the storage system will be lower than the requirement of the heating circuit that the ORFEO control will start 'injecting supplemental heat into the heating system.
The case of an application including the production of the domestic hot water is not shown in this paper, to simplify the presentation, but is possible within the application cases of the ORFEO project.

3.4 The supplemental heat production

Within the scope of the ORFEO project a specific low inertia heat exchanger has been developed to enable the system to provide immediate reactions whether the demand is increasing or decreasing, thus avoiding overshooting of the set demand values.
The heat exchanger, as seen on the schematic below, is composed of four (4) cylinders containing the water (or fluid) to be heated. Each cylinder is equipped with a heater up to 3.7 kW capacity allowing the supplemental heater to reach a total production of 15 kW when all four heaters are turned on at 100% capacity demand.
To allow for instantaneous reaction each cylinder is designed to contain a very minimum quantity of water (or fluid). The total water (or fluid) capacity of the four cylinders is about 1.3 liter.
This means that when the heat is on demand the reaction is immediate, when heat is no longer required there is almost no loss of energy compared to the total water (or fluid) capacity of the heating circuit.

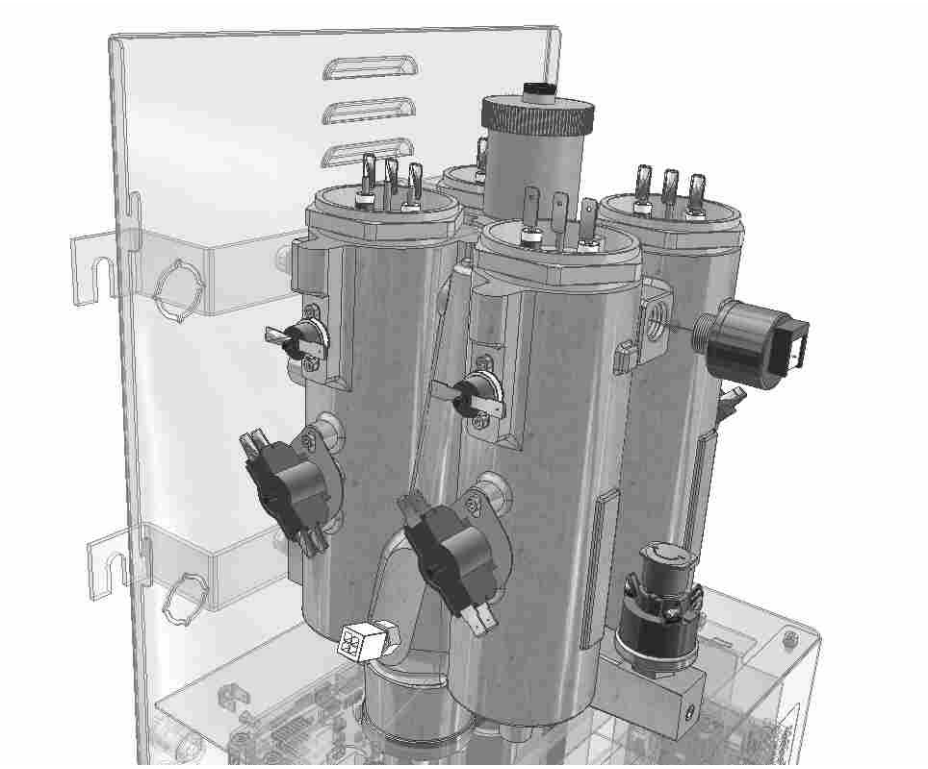


Figure 2: Heat exchanger with heaters

3.3 The control system objectives

The objectives of the control systems are quite simple to define…
… the control system needs to be extremely reactive to provide:

- Stability of comfort level as required by the user, all year-round (heating and cooling).
- Avoid excess energy usage by reacting immediately and adequately to any change in the building energy requirements, whether these changes are provided by the outside conditions (variation of the outside temperature, fluctuation of the solar gains, cloudy conditions, wind pressure, …), or if the evolution of the energy requirements is provoked by a variation of indoor conditions (activities, number of people, etc. …).

The ORFEO control project uses components available on the market place. These components are of the latest, reliable technologies to obtain a maximal reliability of the system, and at the same time a competitive industrial cost.
This prompt reaction should also account for the inertia of the building. This means that a permanent analysis of the building situation and of the evolution trends should be part of the control system capabilities, and fed to the calculator which will then be able to anticipate the requirements and avoid a use or production of excess energy.

3.3.1 The goals of the control system

The goals of the control system are:

- To monitor the use of the collected so-called “free energy” and to optimize its usage.
- To monitor the consumption of the costly supplemental heat and minimize its usage.
- To monitor the building reaction – accounting for its inertia – to avoid any overshooting of the required comfort and temperature levels which would lead to immediate excess energy consumption. Both the stored energy, and also the costly energy used for the supplemental heat are monitored.

- To monitor the auxiliaries, those are participating largely into the overall system consumption. The consumption of the auxiliaries is widely influencing the result of the seasonal COP of heat pump systems, but it has even more influence when the heating system is a solar application.

3.3.2 The features of the control system

The control system should be designed to give priority to the utilization of the “free heat” whether it is collected by a heat pump or a solar system.
Then, it should ‘inject’ additional heat as required by the setting of the comfort level into the circuit feeding the terminals and not into the storage. This particular disposition which has been shown previously in the section of this paper discussing the configuration of the hydraulic circuitry is the key to the optimization of the energy use.
The additional heat control should be **continuously** monitored from zero to the maximum level needed by the application on the coldest day with an utmost reactivity.
To obtain this result the project has also included the design the specific heat exchanger described earlier in the presentation.

4 DESCRIPTION OF THE CONTROL SYSTEM

The control system has six main functions, and other secondary functions:

4.1 Analysis of the system energy requirements and evolutions

The system is defined as the total entity including the heat pump, or the solar system, the supplemental heat system and also the complete building. This notion is important, and should be fully understood, as one of the main features of the control defined in the ORFEO project is to take into account the reaction of the building to anticipate the needs for the exact requirements and control accordingly the machinery.
The analysis and the decision making process for the control system is mainly based on the measurement of the speed at which the different parameters are changing.

4.2 Sequencing the use of the stored heat and the supplemental heat

The ORFEO control sequences the usage of the stored heat and supplemental heat.
The priority is given in any case to the stored heat, as long as the temperature levels are suitable for a direct use into the emitters.
The supplemental heat is only produced when the stored heat usage has been fully optimized, and according to the exact requirements. It is controlled on the base of a continuous full modulation from zero to the maximum requirement.
This modulation capability is a major advantage over other control systems, and the use of other energies than the electricity. It is exploited thoroughly by the ORFEO controls to the point that the electric energy is competitive against oil and gas not only in terms of energy measurements, but also in terms of currency values.
However, the great advantage introduced by the ORFEO control concept is the prediction calculation to avoid overshooting due to the floor and/or building inertia.
The ORFEO control system measures all accessible temperatures, such as: outdoor, actual indoor, water to and from the emitters (radiators, fan coils, floor). It also observes the speed of variation of these parameters to feed the calculator with the best available information.
Using these observations will allow the algorithms contained in the calculator to predict the future demand, for example of the floor heating system. The calculation will account for the floor inertia to slow down the water temperature ahead of time to maintain the required comfort level in the ambiance without any overshooting when the demand indicates a downtrend and vice-versa when there is an uptrend of the demand.

This process is permanent due to the self-learning capabilities of the calculator which will re-calculate permanently the new requirements starting from the last calculation and the newly collected information to set the mixing valve(s) and the production of the supplemental heat avoiding any excess.
This avoids overshooting and is a major factor of reduction of the consumption of energy while optimizing the comfort level required by the end-user.
It is one of the key features of the ORFEO concept.

4.2.1 Controlled modulation of the supplemental energy

Based on the original design of the supplemental heat exchanger, a number of advantages are exploited to optimize the use of the costly supplemental direct energy.
The water temperature is raised only to the required level, and the heat exchange is optimal at any time. A cyclonic design (patented) allows for the water to circulate around the heaters.
Each of the four heaters is activated in turn, somewhat like in a car the four cylinders of the engine are ignited successively. To obtain a continuous modulation each cylinder is not only activated successively, but also on a proportional time basis. (see the schematic below).
In combining both non significant inertia based on the small quantity of water in the heat exchanger, and the low temperature setting of the fluid required by the system together with a true modulation of the control down to zero, any excessive loss of energy is avoided, and the reaction for an upward or a downward demand is immediate.
The minimal adjustment of the energy level is linked to a minimum time base equivalent to half of an alternance of the alternative electric current.
The heat generator life span is also maximal due to the soft and continuous control of the variable demand.

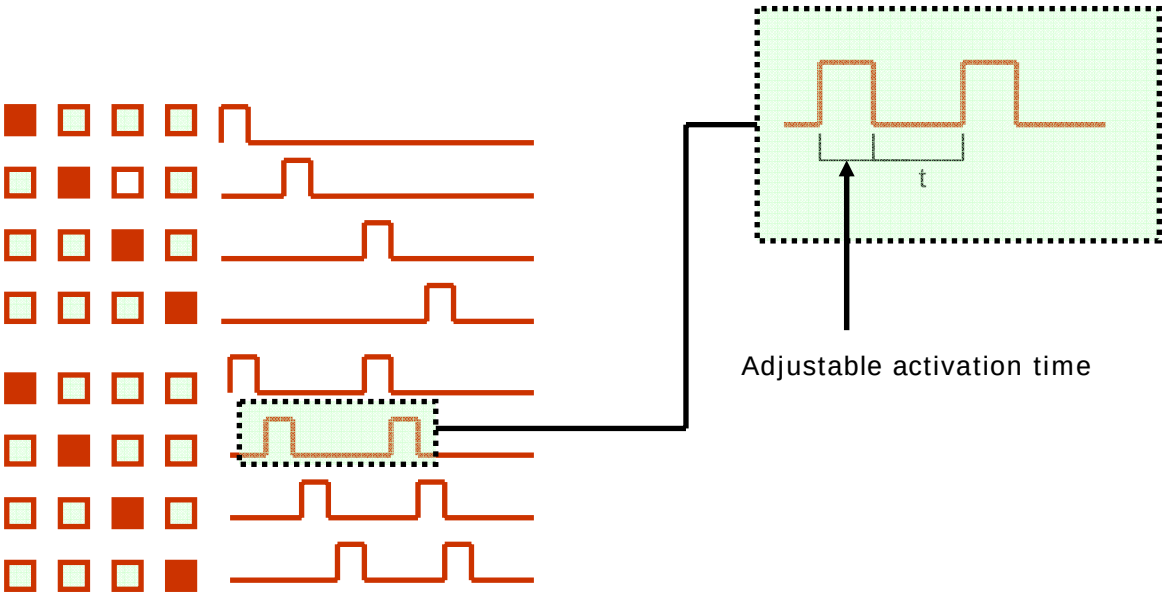
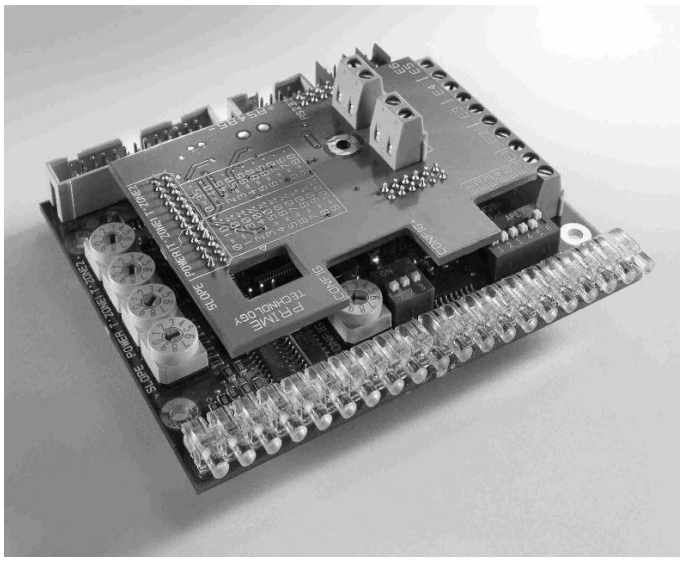


Figure 3: Heater capacity variation principle

This control design provides for a real competitiveness of the direct electric energy versus other fossil energies which by nature cannot be modulated easily, continuously and progressively or cannot be modulated all the way down to zero.
The economy in energy value compensates largely for the difference in financial rates of the fossil energies versus the electric energy at the present energy rates.

4.2.2 The control system and the OpenTherm standard

The control system operation is based on a micro-processor and the use of the OpenTherm standard thermostat to exchange information concerning the status of the required comfort level with the ORFEO control system. The OpenTherm standard also avoids the on-off command to enable a two-way continuous exchange of information for a progressive adjustment.



Picture 1: Electronic control board

4.3 The other main functions

The ORFEO project contains numbers of other functions than those directly related to energy saving, such as some of the following:

4.3.1 Controlling the auxiliaries

ORFEO has the capability of controlling the auxiliaries, mainly the circulation pumps and the mixing valves.
The speed of the circulating pumps, when their control box is compatible, can also be controlled by the ORFEO control system to reduce the quantity of energy used to circulate the fluids. It should not be forgotten that the pumps are generally running while the heating or cooling systems are on.

4.3.2 Distance control and settings

ORFEO has also the capability to be controlled remotely to allow for an adjustment of the parameters, but also for the end user to start, stop or adjust the comfort level he requires when away from the premises.

4.3.3 Energy meter

The possibility of recording the history of the consumption throughout a complete winter season is included in the ORFEO concept. This feature allows for a better analysis and usage of the energy as comparisons can be made from one heating season to the next for a better adjustment of the parameters.

4.3.4 Energy consumption limiter

An energy limiter feature is part of the system to ensure that the electric subscription will not be exceeded. It allows for a control of the supplemental heat consumption while the dishwasher and other domestic ancillaries are running. At that moment the inertia of the building will act as flywheel and minimize the change in the comfort level.

5 PROJECT FEATURES - MARKETING

5.1 General

The ORFEO project has been developed with more than the aspects of the technical features aimed at controlling a heating and cooling system associated with heat pumps or solar systems, including the preparation of the domestic hot water.
The other main target of the project is to serve all of the actors of the heating and cooling trade channels, and, finally, the end-user, making their life simple. To do so, the ORFEO control and supplemental heat system has been packaged into a very tight volume that can fit most locations. (Size – Height: 495 mm – Width: 310 mm – Depth: 260 mm)

Picture 2:
3D Drawing

Picture 3:
ORFEO casing

Picture 4:
ORFEO wo casing

5.2 The end-user and his architect

The end-user will find a system easy to use; the only decision he has to make is the setting at the thermostat level. A simple thermostat, using the 'OpenTherm' industry standard is sufficient. All other parameters are adjusted via the auto-adaptative feature.

OpenTherm®

Figure 4: OpenTherm Logo

Picture 5: OpenTherm Thermostat

The end-user will also feel secure since he will be aware that in case of a break-down of its heat pump or solar system the ORFEO control and supplemental heat system will automatically take over.

5.3 The consulting engineer

The consulting engineer will find a concept that is dealing both with the optimization of the energy use, that can be implemented in number of pre-designed applications, but is still easily adapted to other application mostly through an addition or an adjustment of the algorithms in the control system.

5.4 The contractors and installers

The acceptance of the package concept for the control of the global system will attract number of installers and contractors who may have been reluctant to put together all the various elements of a sophisticated control system.
Furthermore the fact that the ORFEO control system has an auto-adaptative feature will greatly simplify the commissioning of their installation. Only a few settings describing the characteristics of the installation are needed, such as: one or two heating circuits, floor heating or other, etc. ….
Also, one can imagine that the ORFEO concept can be carried one step further by packaging the concept with other elements of the system such as the storage tanks, and/or the pumps and mixing valves together with the circuitry safety controls. See tentative prototype configuration below.

Picture 6:
Prototype package - HP application

Picture 7:
Prototype package - Solar application

The benefits for these professionals will be mainly the reduced installation and commissioning time plus a single responsibility point at the supplier level for the system.

5.5 The maintenance team

Last point in this paper, but not least, one of the major advantages resides in the fact that most of the service troubleshooting can be made at distance, since the system includes both a series of tricolor LEDs which can be seen by the end-user and reported during a telephone call, and a telephone connection to be used via a computer by a serviceman.

6 CONCLUSIONS

The ORFEO control concept has been developed by a small team of people using the support of German and French universities and schools, but the computer algorithms were mostly developed based on field experiments.
This method of development makes the concept very pragmatic.
The ORFEO concept will bring an ideal support for the promotion of the Heat Pump market in many countries, since it covers the control of heating, cooling and domestic hot water production and usage while keeping it simple for the installers and end-users.
The concept can be implemented at different levels of integration of the systems either by the manufacturers of Heat Pumps, as an integrated part of their product control and supplemental heat system, or by manufacturers of integrated solar systems.
The concept will fit both 50 and 60 Hz market with only minor adaptations mainly related to local safety codes.
The first hundred units assembled were sold to key installers and contractors to test the concept, the ease of installation and the economy.
The acceptance was highly positive, since almost any installer or contractor that tried the ORFEO concept became a recurrent user for the control and the packaged supplemental heat system. This has led to an industrialization of the base product that will become available in substantial quantities in April 2008.
Furthermore, the first users (installers or contractors) have insisted on an industrial development of both the Heat Pump package and the Solar package. Both packages, which will includes the appropriate storage tanks, as well as the pumps, the mixing valves, the probes, the piping, the electrical wiring (power and control), will become available during the Fall of 2008.
The case of the ORFEO concept shows that pragmatism and packaging are necessary to accelerate the installation of heat pumps and other renewable energy systems.
The professional actors in the renewable energy market segment want to be comforted with pre-engineered systems qualified by field test and natural evolution as new applications are discovered.