TECHNICAL AND ECONOMICAL INTEREST OF SUSTAINABLE REFURBISHMENT TECHNOLOGIES IN FRANCE, ITALY AND FINLAND

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ABSTRACT

The aim of the European SSHORT (Sustainable Social Housing Refurbishment Technologies) project is to increase and promote rational and efficient use of energy in the retrofitting of social housing buildings. In this scope, one step was to evaluate with simulation studies the technical and economical interest of selected sustainable technologies on standard collective social housings in participating countries. Selected technologies are dual flow ventilation with heat recovery, solar energy systems (solar domestic hot water (solar DHW), photovoltaic panels) and building energy management systems. Each partner was in charge to study the potential interest of one selected technology for each participating countries. According to studied technology, simulations have been conducted with f-Chart method, TRNSYS and CA-SIS tool (Electricité de France (EDF)'s tool based on TRNSYS models). The paper proposes to present the methodology to conduct studies, simulation results and main conclusions about the potential interest of selected technologies in the retrofitting social housing sector.

CONTEXT AND OBJECTIVES

Rational and efficient end-use of energy in the built environment will be a key-contribution to reduction of CO2 emissions. Regarding the built environment, the aim of the European Union is 30% energy savings by 2010 and 50% in the longer term.

The main part of total stock of social house buildings in Europe is now more than 25 years old. Many refurbishment works are performed nowadays throughout Europe in the social housing sector in order to:

- make buildings respectful of new standards and regulations (about electricity, water,...)
- reduce running costs (mainly by reducing energy and water consumption),
- increase inhabitants' comfort (essentially thermal, acoustic and visual comfort),
- increase building intrinsic value.

The SSHORT project, partly funded by the European Commission in the frame of the 5th RTD program, aims at validating the use of some sustainable energy technologies in the refurbishment of social housing.

The project is split into several workpackages (WP) and can be summed up so:

- social housing inhabitants, owners, and building professionals' expectancies (WP1)
- development of a decision making tool for refurbishment (WP2)
- adaptation of simulation tools to evaluate the technical and economical interest of different technologies in standard case of social housing in particpating countries (WP3)
- preliminary studies of selected technologies on demonstration operations in Finland, France and Italy (WP4)
- preparation of measurement procedures (WP5) which will be conducted on demonstration operations
- refurbishment and measurement campaigns on demonstration buildings (WP6)
- exploitation of demonstration results and spreading of project's lessons (WP7)

This paper proposes to present studies, simulation results and main conclusions linked with the workpackage 3 about the technical and economical interest of selected technologies in the retrofitting social housing sector.

In order to deal with energy related problems of different European parts, it has been decided to study selected and promising technologies in standard cases of European existing social housing in the participating countries (Northern, Middle and South Europe) : heating network optimization, solar hot water system and dual flow ventilation system with heat recovery.

CONTROL OF RADIATOR HEATING SYSTEM

Central heating systems are common in Finland and according to technical analysis greatest available savings and improvement of thermal comfort with hot water heating system lay in better inlet temperature and heat transfer controls.

Heating curve defines the inlet water temperature of heating system after the measurement of outside air temperature. Typically, heating curves are adjusted by method of trial and error. There is no actual feedback control from room air, but when inhabitants complain about uncomfortable thermal conditions, the heating curve is readjusted manually by maintenance staff.

Linked with the typical Finnish situation in social housing, VTT (Technical Research Center of Finland) has worked on the heating network optimization with the development of a method to adjust heating curves automatically. The method contains procedure to calculate a heating curve, which defines

a) inlet water temperature, or
b) water flow rate

as a function of outside air temperature. The method has been tested by computer simulations (TRNSYS program).

Principle of the method

To adjust heating curves automatically, room air temperature and outside air temperature are inputs. Fuzzy control system calculates the required change of inlet water temperature or the required change of water flow rate. Figure 1 illustrates the principle for the change of inlet water temperature.

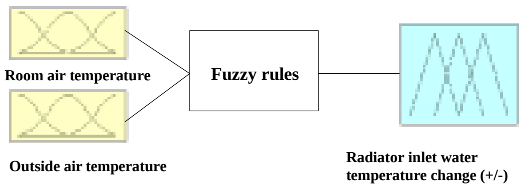

Figure 1 : Principle of the fuzzy control system

Linear function is used as a model for heating curve and fuzzy system calculates two points needed to define it. The heating curve is adjusted only at night when there is no solar radiation and other heat loads are constant. If the room air temperature is above the set point both in the evening and in the morning, the fuzzy controller calculates how much the inlet water temperature must be lowered. This value is used to define the new heating curve. Adjusting of the heating curve is not done if the room air temperature is above the set point in the evening and below the set point in the morning. Two measurements taken with several hours time step, and showing that the room air temperature is repeatedly either too high or too low, are required for the adjustment of heating curve to take place.

Simulations and main results

The fuzzy control system was developed with Matlab Fuzzy Toolbox and was connected to TRNSYS simulation software (Klein et al. 1996), which was then used to study and compare the performance of two different control strategies : with (new) and without (old) automatic adjustment of the heating curve.

Simulation period covered four months in winter (and spring). Weather data from Helsinki (Finland) was utilised. The structures of the simulated apartment are typical to Finland. There is a radiator heating system but no thermostatic valves in the building. If the method is able to control that system, it is able to control system with thermostatic valves.

In most of the simulated cases the heating curve defined the inlet water temperature for radiators, but it was also tested how the method is able to adjust heating curve, which defines water flow rate.

Room air temperature is displayed in Figure 2 for two simulated cases where the heating curve defined inlet water temperature. Heating curve was adjusted automatically only in the second case. Results from eight simulation cases are summarised in Table 1.

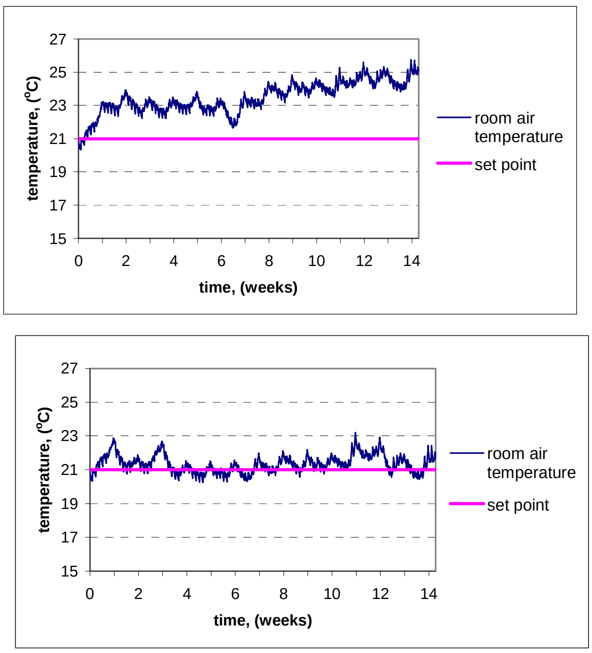

Figure 2 : Room air temperature. Above: heating curve was not adjusted (case1a in Table 1). Below: heating curve was adjusted automatically (case 1b in Table 1).

Simulations showed good results. Heating curve could be constructed quickly and room air temperatures could be kept close to the set points.

Since the developed method requires measured room air temperatures and these are not always available, another approach was also attempted. Instead of having measured room air temperatures, their estimates were derived from inlet and outlet (returning) water temperatures. In a next step, these estimated room temperatures were used to adjust the heating curve. Unfortunately the simulated results were not as good as in the cases with measured room air temperatures.

Table 1 : Average room temperature and average difference from set point (21°C) in eight simulated cases where the heating curve defined inlet water temperature

	Is heating curve adjusted automati--cally?	point 1 of heating curve in the beginning of simulation (°C)	point 2 of heating curve in the beginning of simulation (°C)	average room temperature in simulation period (°C)	average difference from set point in simulation period (°C)
1a	no	room air: -30 inlet water: 70	room air: 10 inlet water: 35	23.7	2.73
1b	yes	same as above	same as above	21.4	0.50
2a	no	room air: -30 inlet water: 60	room air: 10 inlet water: 40	23.4	2.71
2b	yes	same as above	same as above	21.2	0.74
3a	no	room air: -30 inlet water: 60	room air: 10 inlet water: 25	19.0	2.00
3b	yes	same as above	same as above	20.9	0.57
4a	no	room air: -30 inlet water: 70	room air: 10 inlet water: 25	20.8	0.54
4b	yes	same as above	same as above	21.2	0.54

Water flow rate has been constant in the previous simulations. Others simulations have been conducted with a variation of the pump speed. There is supposed to be a frequency converter attached to the pump. In this case, the heating curve is used to define the water flow rate (pump speed) from the outside temperature. In the simulated case (Table 2), the heating curve defining inlet water temperature does not change and the heating curve defining water flow rate is adjusted. The heating curve was found well: the average difference from set point is 0.57 °C.

Table 2 : Average room temperature and average difference from set point (21 °C) when the heating curve defining water flow rate is adjusted automatically.

point 1 of heating curve in the beginning of simulation	point 2 of heating curve in the beginning of simulation	average room temperature in simulation period	average difference from set point in simulation period
room air: -30 °C inlet water: 70 °C	room air: 10 °C inlet water: 35 °C	21.4 °C	0.57 °C

Average temperature of returning water decreased by more than 1.0 °C when compared to constant flow case. Approximately 70% saving in pumping energy can be achieved if automatically adjusted heating curve is used to control a variable speed pump. Heating savings of about 5% could be obtained because the method is able to keep room temperatures better at set points. Absolute annual savings are about 125 Euro in a residential building of 20 000 m^3.

SOLAR HOT WATER SYSTEM

The interest on solar hot water production in France, Italy and Greece has been studied by CRES (Center for Renewable Energy Sources). For Finland, the interest of such solar system was not considered enough sufficient for typical social housings.

Methodology

The f-Chart method (Klein et al., 1976) was used for the simulation of the solar water heating systems. It provides a means for estimating the fraction of a total heating load that will be supplied by solar energy for a giving solar heating system. The solar fraction is the percentage of seasonal energy needs of a building covered by a solar collector system. The method is a correlation of the results of many hundreds of thermal performance simulations of solar heating systems.

Using the relevant input data for each country, the fraction of the domestic hot water demand that can be covered by solar energy is calculated for each month. With the appropriate financial information (investment cost, fuel energy cost, etc), the cost efficiency of the system for the different cases is evaluated and compared to a conventional system. Alternative fuel types, oil, electricity and natural gas, are considered for the conventional systems. Information for a representative solar water heating system and its relevant technical and financial data were provided, for each country, by the project partners. Also, typical values of water consumption, weather data and local grid water temperature were used for each national case study.

Input data for simulations

The first step has consisted to define for each of the three countries representative solar water heating system and technical and economical characteristics of these systems.

Common solar systems are collective active solar systems in Italy and in France while in Greece typical domestic hot water collectors systems are the thermosiphonic ones.

Characteristic performance values of systems and the corresponding financial values for each countries are given in Table 3.

Table 3 : Characteristic data for typical solar systems

	ITALY	GREECE	FRANCE
Hot water daily consumption (lt/person)	50	70	40
Collector Data			
Test slope parameter (Fr Ul). W/m^2/^{o}C of the solar collector	6	6	6
Test intercept parameter (Fr (ta)n) of the solar collector	0.82	0.82	0.82
Optimal storage tank capacity	50 lt/m^2	70 lt/m^2	50 lt/m^2
Typical area of solar collectors (m^2/person)	1	1	1
Number of glass covers	1 (single-glazed)	1 (single-glazed)	1 (single-glazed)
Collector flow rate	0.015 kg/sec/m^2	0.015 kg/sec/m^2	0.025 kg/sec/m^2
Financial data			
Total cost of system (installed)	660 Euro/m^2	400 Euro/m^2	686 Euro/m^2
Cost of electricity	0.24 Euro/kWh	0.07 Euro/kWh	0.08/0.05 Euro/kWh

The slope parameter (coefficient of global thermal losses of the collector, K) and intercept parameter (optical factor, B) defines the intrinsec thermal quality of the solar collector. The effectiveness of the solar collector (η) is a function of the external temperature (T_{ext}), the average temperature in the collector (T_m), and the global solar radiation (E) according to the following expression :

$$\eta = B - K\left(\frac{Tm - Text}{E}\right)$$

Simulations have been conducted for the cases of Athens in Greece, Firenze in Italy, Trappes and Bordeaux in France.

Results

The monthly global solar radiation in Athens is about 13.5% higher than in Florence and in Bordeaux and about 24.5 % higher than in Trappes. The different design values of hot water daily consumption in the different countries - 70 lt/m^2/person in Greece instead of 50 lt/m^2/person in Italy and 40 lt/m^2/person in France, results to different demands of total water heating.

The combination of different solar radiation levels and daily hot water demands in the examined areas, leads to about the same value of the solar fraction f for the 3 cases, with the area of Trappes presenting slightly lower numbers (Figure 3). Globally, solar covering could represent about 40%-50% of the total domestic hot water demands.

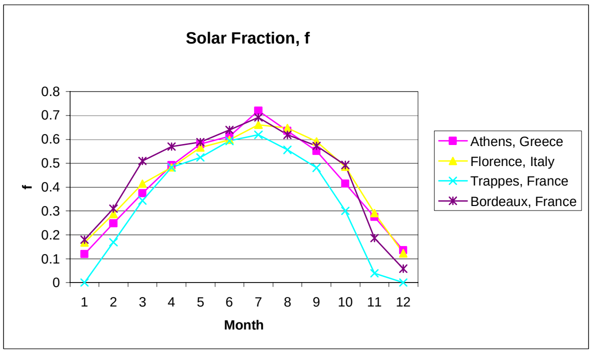

Figure 3 : Montly distribution of the solar fraction f

Due to the higher design value of hot water energy consumption in Greece, it appears that the total auxiliary energy required for hot water is higher in Athens and lower in Bordeaux, as it is shown in Figure 4.

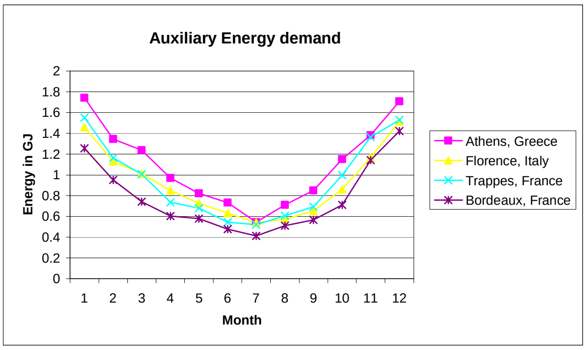

Figure 4 : Monthly distribution of the auxiliary energy demand for hot water.

If we assume the same daily energy consumption in all examined areas, 40 or 50 lt/m^2/person, we find that in Greece, the solar fraction f exceeds with great difference the other areas, reaching values in July of 0.948 (for 40 lt/m^2/person) and 0.877 (for 50 lt/m^2/person).

The difference in the 1st year fuel cost and savings for the different examined areas, is shown in Figure 5. The cost of electricity in Greece is cheaper that in Italy and this is the reason that the first year fuel cost and first year fuel savings for an electrical hot water system in Italy are about 45% higher. The cost for initial investment is lower in Greece because of the low price of flat plate collectors. The investment costs don't take into account any subventions.

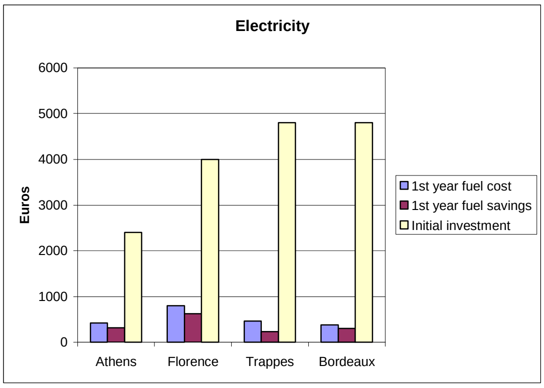

Figure 5 : 1st year cost, 1st year fuel saving and initial investment for the different site, for electricity as auxiliary energy source.

DUAL FLOW VENTILATION SYSTEMS

EDF has studied for France, Italy and Greece the interest of dual flow ventilation systems with heat recovery, system quite common in Finland and in northern Europe. In France, the general adopted system is either single flow or natural ventilation and in Italy and in Greece, it is natural ventilation. It seemed interesting to study the potential saving of using heat recovery in less rigorous climate than North, as a part of a renovation system. Preheated air through heat recovery can also increase thermal comfort and save energy in winter.

A dual flow ventilation system (Figure 6) is structured according to two distinct networks :

- the circuit of extracted air, similar to a single flow exhaust ventilation system
- the circuit of fresh pre-heated air which is constituted of a collective air inlet, of air supply fan and of the distribution collective network to supply pre-heated air in dwellings.

A plate heat exchanger is implemented at the crossroads of these two circuits.

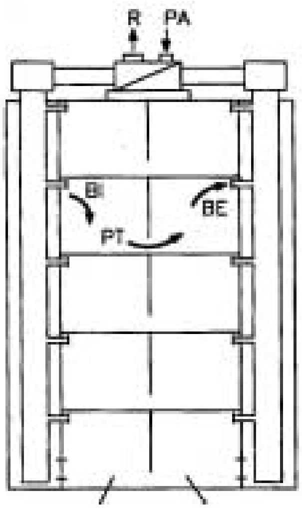

Figure 6 : Principle of dual flow ventilation system

Methodology

The study took place in three stages:

- definition of the configurations to be studied, and identification of the data necessary for modelling.
- gathering data thanks to the active participation of project partners, and data harmonisation,
- modelling by the CA-SIS tool and analysis of results.

The CA-SIS software developed by EDF R&D (Hartmann O. et al., 2000) is a dynamic thermal simulation tool for buildings based on hourly time steps. It determines the consumption and energy costs of all uses of a building (heating, air conditioning, ventilation, sanitary hot water, lighting…), according to tariff bands. It is especially designed for:

- forecasting costs and energetic consumptions of all energy uses,
- comparing systems and energies,
- determining an energy optimisation.

CA-SIS, which uses TRNSYS, is based on a combination of models, which makes it a flexible software package. The CA-SIS library currently contains more than sixty models and can be enriched according to need.

In each country studied (France, Italy and Greece), the heating solutions envisaged was an electrical solution (convectors). In each configuration, single and dual flow ventilations were compared, in terms of energy consumption, energy costs, investment costs and thermal comfort.

Three typical buildings have been defined : a French typical building, a Greek building and an Italian building, each one representative of the existing social buildings of each country. These typical buildings have been modelled with the CA-SIS tool, systems have been sized and modelled with CA-SIS tool.

Input data for simulations

Room air temperature was set at 21°C. Internal energy loads is taken to be 100 Wh/m^2.day, distributed throughout the day according to a standard occupancy profile. Ventilation was assumed to operate permanently at a constant rate in summer and in winter. Effectiveness of the heat exchanger is assumed to be 60%. The recovery system cannot be by-passed (in particular during summer period). Heat emitters were sized to satisfy heating requirements without internal and solar energy contribution. A set point of 19°C was taken into consideration.

The Table 4 shows the main assumptions adopted for each country.

Table 4 : Buildings assumptions

	Ventilation rate vol / h	Insulation performance $W/m^3.°C$	Infiltra-tion vol / h	Climate severity (DJUb18)	Energy costs € cts/kWh
France	0.9	0.82	0.46	2644	Elec 7.78/ 4.82
Italy	0.4	0.48	0.48	1754	Elec : 24.5
Greece	0.17	1.67	0.80	998	Elec : 7.2

The factor of ventilation flow rates presents a wide variation between studied countries. Ventilation flow rates are based on typical and average values considered in each country in case both of single flow ventilation and of potential dual flow ventilation systems. Technical recommendations and regulations according to this parameter can differs a lot according to the context of the locality and the practise.

Main results

Results are based on one year of simulation. The Table 5 and the Table ***6*** presents energy consumptions and costs for heating and ventilation uses of the building.

Table 5 : Heating and ventilation consumptions

	Single flow ventilation kWh/m^2	Dual flow ventilation kWh/m^2	Energy reduction kWh/m^2
France	266	229	37 (-14%)
Italy	101	96	5 (-6%)
Greece	164	161	3 (-1%)

The introduction of dual flow ventilation to replace single flow ventilation would result in energy savings and costs of 14% in France, 6% in Italy and 1% in Greece. In Greece, rate of air change is very low which, when combined with a clement climate, makes dual flow ventilation a non-viable option.

Table 6 : Heating and ventilation costs

	Single flow ventilation € INC. VAT/m^2	Dual flow ventilation € INC. VAT/m^2	Cost Savings € INC. VAT/m^2
France	23.50	20.23	3.27 (-14 %)
Italy	24.85	23.45	1.40 (-6%)
Greece	11.78	11.61	0.17 (-1%)

The additional investment costs of dual flow ventilation and associated return on investment are shown in the Table 7.

Table 7 : Extra investment costs and return on investment of dual flow ventilation

	Extra investment cost € INC. VAT/m^2	Energy cost gain € INC. VAT/m^2	Time to return on investment years
France	17.6	3.27	5
Italy	22.1	1.40	16
Greece	27.5	0.17	>100

The extra investment cost represents the difference between the installation of a dual flow ventilation system into an existing building and the installation of a single flow ventilation system. For the single flow ventilation, the cost installation takes into account the price of extraction grids, fans and extraction network. In the case of the dual flow ventilation systems, the cost considers in addition the plate exchanger, the supply distribution networks and air supply fan.

The over investment cost of dual flow ventilation differs by country. This is due to the threshold effect in terms of the equipment available (size of the heat recovery unit) in the target building. The differences are therefore not directly the result of national factors, but of the layout of the studied buildings in which the equipment is installed, and equipment size in relation to the building. The return on investment are acceptable in France. However, in quantitative terms, a degree of prudence is necessary, given the substantial contribution to the output figures of the initial assumptions. In Greece and Italy, on the other hand, it would appear that dual flow ventilation may be not be applicable.

In terms of comfort aspects, dual flow ventilation when modelled had very little impact on summer comfort. Slight overheating was observed on some very hot days, given that by-passing the heat recovery system was disallowed. The introduction of a heat recovery system on extracted air makes it possible by preheating the supply air to mitigate the thermal discomfort resulting from incoming outdoor air. The Figure 7 shows the temperature of supply air in dwellings for the French building, under single and dual flow ventilation systems.

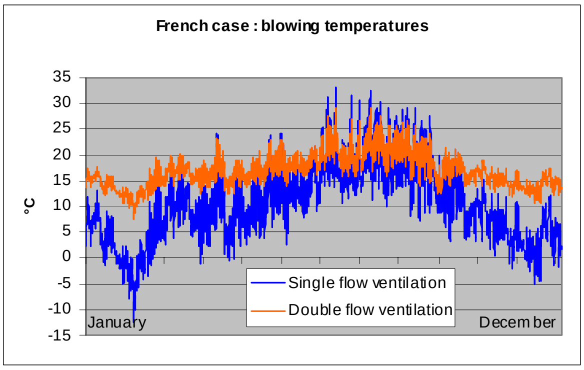

Figure 7 : Internal temperature of supply air in dwellings

Dual flow ventilation makes it possible to maintain the incoming air temperature above 15°C for the greater part of the year. The benefit is all the more appreciable as weather conditions are severe. Dual flow ventilation provides a considerable gain in terms of comfort in France, and to a lesser extent in Italy.

CONCLUSIONS

This study conducted by each partner involved in the SSHORT project aimed to precise the technical and economical interest of selected technologies for the retrofitting social housing sector.

Simulation results show that solar technologies such as solar hot water systems present an energetic interest in middle and South Europe social housing. Even if this type of technologies is more profitable in the South, results show that it can still be interesting even in the North of France, including interesting saving annual cost (between 40-50% of reduction on the energy cost for domestic hot water use). Because of over investment for building owners, the implementation of solar technologies in France and in Italy needs again some subventions.

The dual flow ventilation system, quite common in Finland, presents a great interest in the middle Europe social housing such as in France. About 14% in energy saving and costs on heating consumptions could be achieved in the case of electrical heated dwellings, in comparison to the installation of a single flow ventilation. The payback ratio has been estimated to about 5 years. Simulation results for Greece and Italy, closely dependent on the assumptions made for each country, show that dual flow ventilation seems non-viable solution. The dual flow ventilation presents also the interest to avoid injecting over-cold air into flats and keeps down the discomfort associated with the introduction of cold outdoor air (the temperature of supply air in winter was most cases above 15°C).

Solar technologies are difficult to introduce in Northern social housing. But in the context of Finland, interesting gains are already possible in improving standard technologies linked with the hot water heating system control. Saving in pumping energy can be achieved if automatically adjusted heating curve is used to control a variable speed pump. Approximately 70 % of the pumping energy were saved. About 5% of heating savings could be saved because the method is able to keep room temperatures better in set points. The algorithm needed to automatically adjusted heating curve must be implemented to a heating controller. The algorithm is simple and does not need much computing power or memory, so there is no additional cost, if it is implemented during renovation when whole district heating substation or its control system is replaced. The only additional cost is linked with the controlled speed pump, about 600 Euros more than a conventional pump.

Following step of the SSHORT project is the implementation of these selected technologies on demonstration operation in Finland and France. Measurement campaigns are conducted before and after refurbishment works in order to validate effectively the improving of inhabitants comforts and energy savings. Sociological inquiries will complement studies and experimental feedbacks about the inhabitants' acceptability towards these technologies. All these workpackages will allow to examine in the final step the interest of spreading such technologies at a large scale in Europe.

ACKNOWLEDGEMENTS

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