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Optimization of combined solar heating through control decisions

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Abstract: - Solar combisystems are solar heating installations providing space heating as well as domestic hot water for the inhabitants of the building. This integrated system is more complex than a simple system used for domestic hot water production and this gives the opportunity for an advanced control strategy. In the present work for a system installed in Greece an advanced control philosophy is accessed and the obtained results are outlined.

Key-Words: - combined solar heating, control strategy, fractional solar consumption

1 Introduction

In recent years the growth rate of the use of solar energy for heating domestic hot water, has shown that solar heating systems are both mature and technically reliable. Every day, worldwide, thousands of systems demonstrate the benefits of this ecologically harmless energy source. Motivated by the success of these hot-water systems, more and more builders are also considering using solar energy for space heating.

Solar combisystems [1, 2] are solar heating installations providing space heating as well as domestic hot water for the inhabitants of the building. The primary energy sources are solar energy as well as an auxiliary source such as biomass, gas, oil and electricity, either direct or with a heat pump. The solar contribution, i.e. the part of the heating demand met by solar energy varies from 10 percent for some systems up to 100% for others, depending on the size of the solar collector surface, the storage volume, the heat load and the climate. As a general rule, collectors should be operated at the lowest possible temperature in order to have a good efficiency; at high temperature they have significant heat losses. Other individual requirements arise from the auxiliary heat source selected.

Much is already known about solar domestic hot water systems, but solar combisystems are more complex and have interactions with extra subsystems. These interactions profoundly affect the overall performance of the solar part of the system. The general complexity of solar combisystems has led to the development of a large number of widely differing system designs, many only very recently introduced onto the market. After the first period of combisystems (1975-1985), where design of non-standard and complex systems by engineers was the rule, a new period has been opened since 1990. Now essentially solar companies trying to sell simpler and cheaper systems do the design [3]. But current designs are based mainly on field experiences and they have not yet been carefully optimised. Experts believe that there is a great potential for cost reduction, performance improvement and increase in reliability, and that this needs to be scientifically addressed [4, 5].

We intended to study not only in theory but also in practice the thermal performance of a Greek solar combisystem. We installed a solar combisystem in the building of the Renewable Energies Laboratory of Technological Education Institute (TEI) of West Macedonia located in Kozani, North West Greece.

2 System Description

The collector loop circuit incorporates a controlled three way valve to feed either the storage tank or the space heating circuit via an external plate heat exchanger. As we can see in Figure 1, dashed line indicates hot fluid and continuous the cold fluid. Mode 1 is the route through the external heat exchanger (preheating of return fluid from radiators) and Mode 2 through the storage tank (domestic hot water). The selection of the route is decided according the collector strategy described at paragraph 3.

The conventional heat source of the system is an oil boiler with a nominal power of 34.9 kW. Its burner is controlled according the control strategy described also in paragraph 3. Under no circumstances it works for the period considered as "summer" which is from 15th of May until 15th of October. If external heat source is necessary for that period, the electric resistance of the storage tank is designed to cover the excess load.

The boiler loop circuit incorporates a controlled three way valve to feed either the storage tank or the space heating circuit (radiators and the external plate heat exchanger mentioned earlier). As we can see in Figure 2, dashed line indicates hot fluid and continuous the cold fluid. The selection of the route is decided according the collector strategy described also in paragraph 3 (either straight to radiators or to storage tank). The flow meters and temperature sensors installed provide all the necessary data for energy quantities calculations. The grey lines are the command lines from controller to the boiler pump and the three way valve.

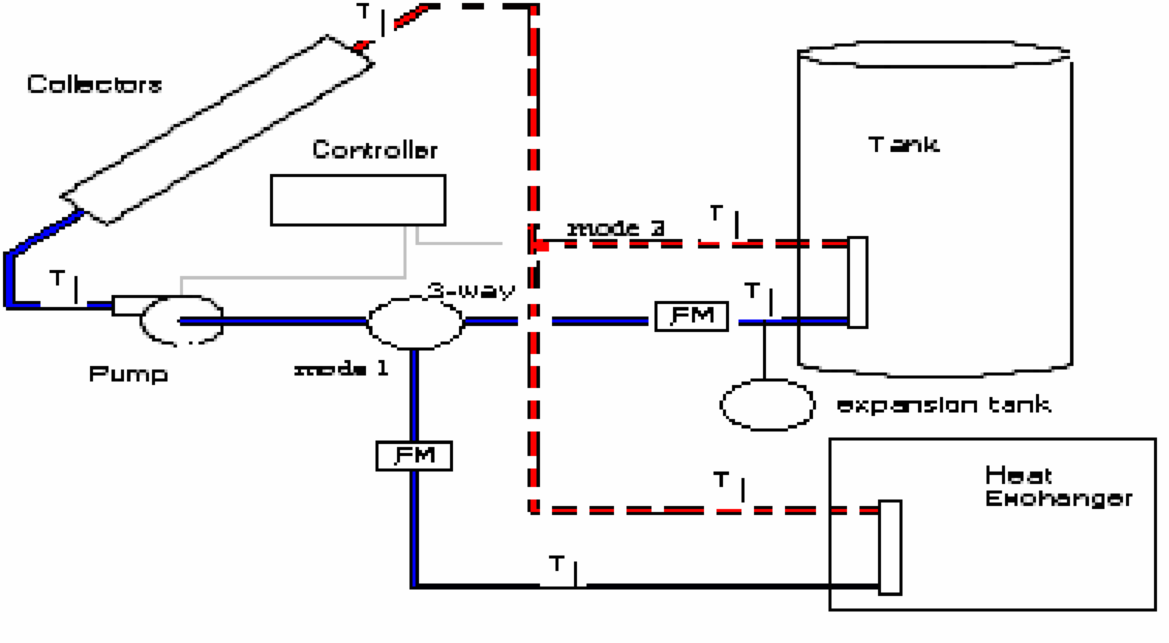

Fig.1 Collector loop of Renewable Energies Laboratory installation (FM are flow meters and T points of temperature measurement)

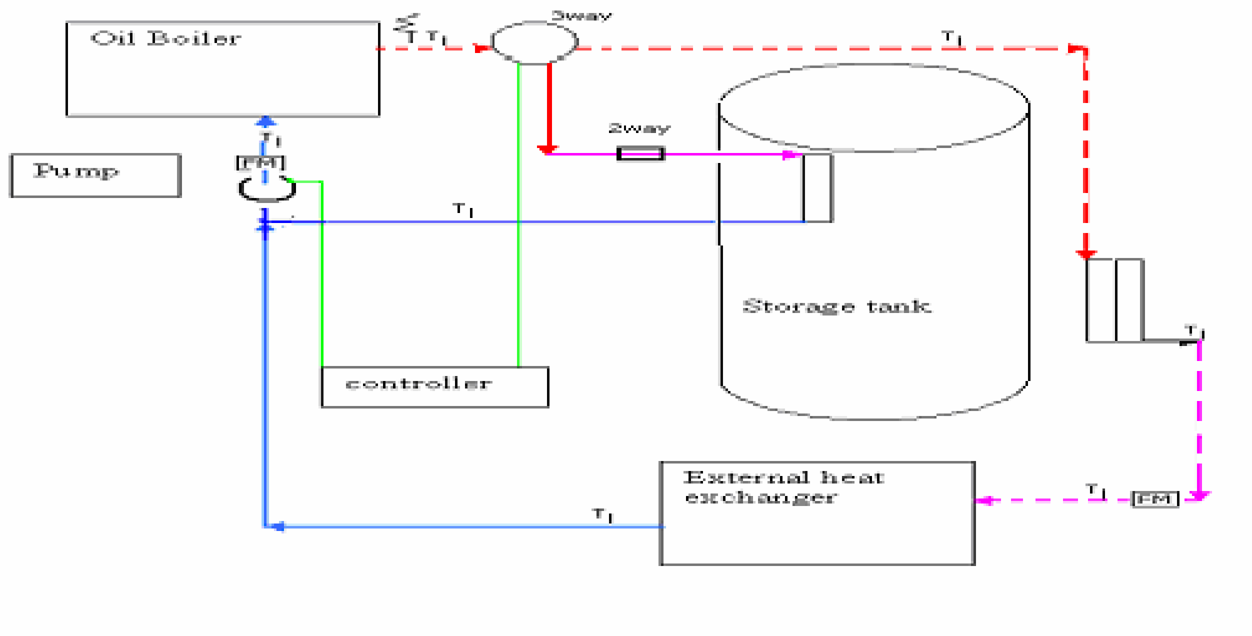

Fig.2 Boiler loop of Renewable Energies Laboratory installation (FM are flow meters and T points of temperature measurement)

3 Control strategy and philosophy

The control decisions affect drastically the operation of the system. The selection of incoming signals to the control system and the priorities for the use of the delivered energy can justify or not the operation of a solar combisystem.

One basic approach in all control strategy is that our primary priority is to secure the DHW load, thus to keep the DHW temperature at a desired level. If this priority is satisfied then we can satisfy any other needs (if exist).

Another very important priority is that with the configuration we built, both in model and in experiment, we want to use solar energy in winter mainly for space heating purposes. This can be done using boiler to cover DHW needs first and then space heating.

3.1 Control in the collector loop

We accept that the temperature at the collector outlet have to be higher than the temperature at the bottom of the tank – and more specifically at the outlet of the solar loop immersed heat exchanger- in order to operate the pump of the collector loop. This is a classic approach, as we don't intend to transfer heat from storage tank to the collector fluid through the immersed heat exchanger. If collector's outlet temperature doesn't satisfy this limitation, it doesn't matter in which position the 3-way valve (Figure 1) is directed. For the shake of control decisions we can select that the position is to Mode 1 (through the external heat exchanger), as "resting position". The position of collector's loop 3-way valve, when pump is operating of course matters. This is regulated after a second check (the first is that the temperature at the collector outlet is higher than that at the outlet of the solar loop immersed heat exchanger). Specifically, we check if DHW temperature has succeeded the desired value (50°C). If not, a command is sent to the 3-way valve to be positioned in such a way, to feed the immersed heat exchanger and through it the storage tank. If we have succeeded this temperature level the 3-way is positioned to deliver heat to the space heating through the external heat exchanger. There is a situation where this last command seem to be useless and that is if there is no need for space heating and that is possible to happen during the summer. However if collector area is not so large (and the combisystem is not do expensive) we see that it never happens. If also combine the use of solar air conditioning we can solve definitely this (and many other) problem.

Thus, the control in collector loop, is managed by comparing the following 4 temperatures:

T_o: Temperature in collector (at outlet)
$T_{store,b}$: Temperature in bottom of store
T_{DHW}: Temperature at tank delivery point for DHW
T_{set}: Set temperature for DHW (50^0C)

3.2 Control of boiler and space heating circuit

We have again here two categories of devices to control. One is the boiler and the boiler pump (and possibly a two way valve acting as no return valve). The other is the boiler loop 3-way valve.

The first group is activated during the heating period to cover DHW needs and space heating needs in that order. Thus there are two principles we accept

1. It is wintertime and simultaneously
2. There is need for DHW preparation (DHW temperature is lower than the desired value (50°C)) or for space heating (temperature at the outlet of radiators is less than a set temperature e.g. 55°C)

The second group is activated as follows: when there is need for DHW preparation (DHW temperature is lower than the desired value (50°C)) the 3 way directs the flow to the tank no matter if there is or not need for space heating. If there is no need for DHW preparation, the valve is shifted towards radiators.

3.2.1 Summer (no heating) period

In the summer period, for the climates we examine, there is no need for space heating. Thus the only possible load is DHW load. Thus, the boiler is turned off and the valves are shifted so the radiators only will get heat from the solar collectors. The last is accompanied with heat transfer only if there is large collector area. In the summer period, if the temperature in the hot water tank gets below the set temperature, the controller will turn on an electric heater to keep the top of the tank (delivery point of DHW) at the needed temperature. Theoretically this could be done also during wintertime. However, because at that time, boiler operates, with a small extra power we can face DHW needs with much lower economic and environmental cost, than the case we would use electric heater.

Thus, the control in boiler loop, is managed by comparing the following 4 temperatures:

T_{DHW}: Temperature at tank delivery point for DHW
T_{set}: Set temperature for DHW (50^0C)
T_{RAD}: Temperature at the return flow from radiators
T_{need}: Needed temperature for proper operation of space heating system (55^0C)

In reality 4 controllers control the system. One controls the collector pump, one the boiler and the boiler pump, one the 3-way valves and one the auxiliary electric heater. We use also a forcing function to “know” if it is winter or summer.

3.3 Details on control strategy

The control strategy is given in the following “truth” table. There are 8 valid modes.

Mode	$T_o >$ $T_{store,b}$	$T_{DHW} >$ T_{set} (50^0C)	$T_{RAD} <$ 55^0C	Collect Pump	Collect 3-way Valve	Boiler & Boiler Pump	Boiler 3-way valve
1	0	0	0	off	space h.	on	tank
2	0	0	1	off	space h.	on	tank
3	0	1	0	off	space h.	off	radiator
4	0	1	1	off	space h.	on	radiator
5	1	0	0	On	tank	on	tank
6	1	0	1	On	tank	on	tank
7	1	1	1	On	space h.	on	radiator
8	1	1	0	On	space h.	off	radiator

1: Logic expression true - 0: Logic expression false

Table 5.1 Truth table of the integrated control strategy

Note: When pump is off, no matter the criteria for 3way valve, it goes to space h., or radiator (depending on the circuit), as resting position

4 Results

The configurations of our system simulated by TRNSYS code [6] can result in two different values of an important efficiency indicator called Fractional Solar Consumption (FSC) [7]. FSC can be considered as the maximum theoretical fractional energy savings, which could be reached if the solar combisystem had no losses.

$$FSC = \frac{Q_{solar,usable}}{E_{ref}} \tag{1}$$

FSC is a dimensionless quantity, which takes simultaneously into account the climate, the building (space heating and domestic hot water loads), the size of the collector area, and its orientation and tilt angle, but which does not depend on the choice of any particular solar combisystem.

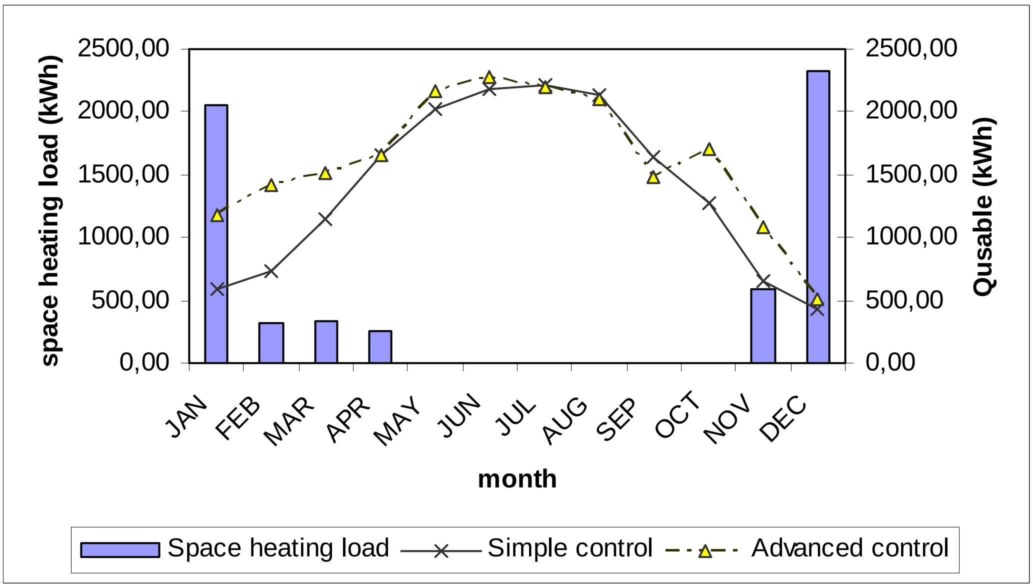

Fig. 3 Increase of FSC due to advanced control strategy

This indicator for the space heating loads, which represent the largest part of thermal load, rises from 0.43 using a simple diffrential thermostat to 0.54 using the control modes described in the last paragraph. This means an optimization of 25.6% with the relevant decrease in conventional energy and pollutants' emmissions.

5 Conclusions

The incorporation of integrated control strategies, tailored to the system used, that is the type of loads, climate conditions and operating units, offer the possibility of optimisation in terms of system efficiency which should not be ignored as the energy and environmental benefits are important.

6 Acknowledgments

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