Increase of Efficiency of Energy System with Heat Pump Using Solar Radiation

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Abstract: Present energy policy of European Union appears to be in a period of dynamic progress. Currently the primary aim is to ensure the energy stability of European Union member states mainly with the usage of renewable power sources. Great attention is paid to increase of efficiency of energy systems operation. The paper presents the results of research in the filed of alternative power sources utilization. The possibilities of increasing the alternative power sources operation in terms of its mutual cooperation are mentioned above all. The research is focused mainly on new possibilities of utilization of heat pumps in connection with active solar system. Aspects of such connections are reviewed mostly from the energy point of view but the economic parameters of this assembled system are pointed as well. The results of long-term measuring on the active solar system assembled in the university laboratories are presented in the paper. The research showed that the new approach to a cooperation of heat pump and solar system working in a common power unit leads to increase of heating factor of heat pump and high efficiency of solar system which finally decreases the demands on primary energy.
The results presented in this paper were elaborated thanks to Grant Agency and Ministry of Education of Czech Republic. The results and conclusions are based on the measuring on existing combined system assembled at the Department of Electrical Power Engineering, Brno University of Technology, Czech Republic.

Key-Words: solar system, combined heating system, heating factor, heat pump, renewable energy, environment

1 Introduction

Over the recent years the issue of using the alternative power sources has become much more important. There are several reasons why it is so. The most obvious reason is ecology but no less important is the energy and economy aspect. The aim of contemporary energy policy is mainly decreasing the consumption of primary power sources while keeping the growing energy production. Consequently the development and research is focused on increasing the efficiency of energy systems and on integration of renewable power sources into the energy production.
Europe shows great interest in alternative power sources such as solar energy, heat pumps, wind energy etc.
The aim in here presented research is to explain new possibilities of active solar system cooperating with heat pump. New connection of these power sources allows to increase the efficiency of its operation.
It is generally known that both the solar system and heat pump can work fully separately as equivalent power sources. The efficiency (or more precisely heating factor) of both systems depends on the input parameters. And therefore the possibility of influencing the input parameters by the help of solar system leads to the idea of optimalization of heat pump and solar system cooperation.
The optimalization of such cooperation itself is solved from several points of view at once. The optimalization is not evaluated only based on the energy balance but also based on the operational economy parameters. The principle in this case is to use the solar system for increasing the input temperature in the heat pump whereas the solar system works as a bivalent power source.

2 Connection of solar system and heat pump

At present within the technical field there appear common installations of active solar system and heat pump, however both systems in such connections work generally separately. This fact means that the systems have common storage reservoir and solar system „only“ increases the temperature of heating medium in the reservoir. [1, 3]
Disadvantage of such designed system is that the solar system has to work with the temperature of medium that is useful for heating (temperature on the input of heating

system). This fact fundamentally lowers the efficiency of solar system itself during winter time. Another disadvantage of the system described above is its price. Whole system has to be over-dimensioned which is the cause of higher costs. Over-dimensioning also results in a very long payback period caused by improper usage of solar panels over the year namely thaks to both the high output temperature and insufficient (fluctuating) value of solar radiation intensity.

2.1 Optimized connection of solarsystem and heat pump

The main contribution of optimized connection is high operational efficiency of solar system and increased heating factor of heat pump. These facts influence positively decreasing the consumption of primary energy necessary for operation of heat pump.

In the system there is used the combined solar collector which provides to use air and water as heat carrier. This appears as a great advantage. The optimalization is realized on the system assembled thanks to grant support of Ministry of Education. Functional model of air-to-air heat pump together with added solar system has been assembled so the original hypothesis of proper cooperation of these power sources. Optimized system (see Fig. 1) works on following principle.

- During the heating season the solar system is activated when the temperature falls below the temperature of bivalention. The solar system is then used for increasing the temperature at the heat pump input. Increasing the input temperature causes increasing the heating factor of whole system and at the same time it lowers the demands on primary energy necessary for heat pump operation.
- Solar system is used for heating water beyond the heating season. Combined solar collectors allowing fluent conversion between heat carriers (air and water) are used.

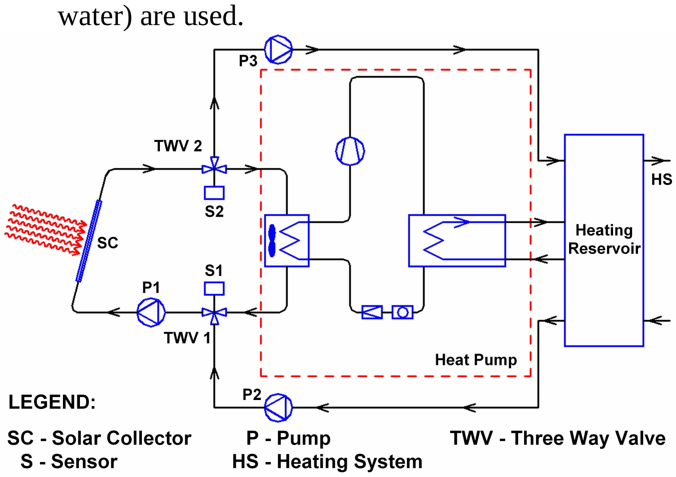

Fig. 1 [1, 2]

As it is mentioned above, the basic idea is to use the solar system for pre-heating the input medium (air) of heat pump during the heating season and therefore achieve better operational parameters of the system. The presumption is the input temperature increase within the limits of $_\Delta T = 5 – 10°C$.

Within the applied research there is for the defined input temperature gradient determined the optimal area of added solar system and its direct influence on heating factor. The area of solar system is determined on the basis of applied analysis of measured data on combined system of heat pump (air-to-water) and allocated solar system and on the basis of long-term measuring of solar radiation intensity in Brno, Czech Republic. Evaluation of combined system is completed on the basis of energy-economic analysis of the operation.

3 Results of long-term measuring on combined system

The main idea of the research is to determine the influence of allocating the solar system on heating factor of heat pump. The goal is to use solar system for pre-heating the temperature of input medium (air) in heat pump.

Bivalent source in designed connection (see Fig. 1) is solar system. The primary task is to determine the operational parameters (such as efficiency, temperature gardients, operating temperatures) of solar system for required working conditions. The demand is increase the temperature of heat carrier within the limits of $_\Delta T = 5 – 10°C$. To determine these parameters it is essential to ensure long-term measuring of operation states.

It is very imporatnt to determine the distribution of solar radiation intensity during the day for area in view. For this purpose the methodics based on period of sunshine is used. Information about sunshine serve as input data for setting radiation characteristics.

This method consists in determining the average month amount of global, difussion and direct insolation. After determination of these characteristics it is possible to provide daily amount and subsequently average daily behaviour of global, diffusion and direct insolation flow.

Figures 2 – 5 show behaviour of solar radiation intensity for monthly (November – February 2005) middle days. For each day there is marked out average air temperature T_{ave} and average intensity of solar radiation I_{ave}. [4, 1]

According to provided temperature rise of input medium in heat pump ($_\Delta T = 5 – 10°C$) there is the average efficiency of solar system η_{ave} determined. Measured and calculated values are mentioned in Table 1.

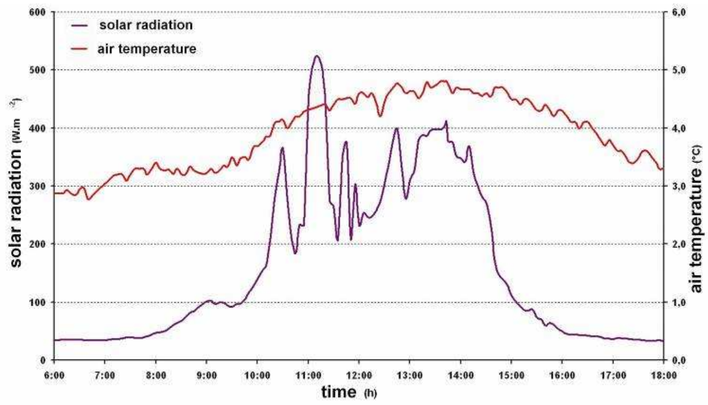

Fig. 2 Behaviour of solar radiation intensity in November 2005

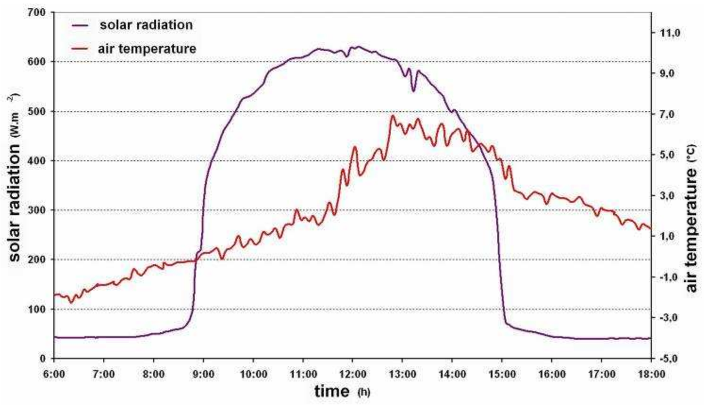

Fig. 3 Behaviour of solar radiation intensity in December 2005

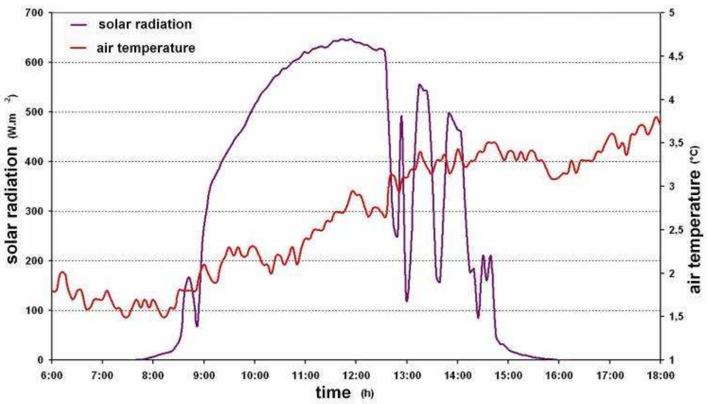

Fig. 4 Behaviour of solar radiation intensity in January 2006

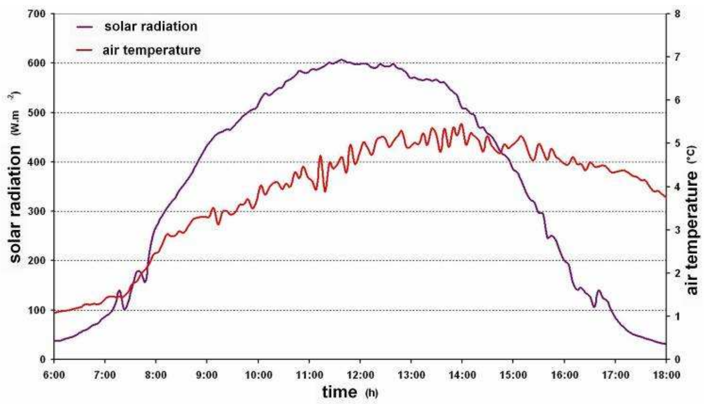

Fig. 5 Behaviour of solar radiation intensity in February 2006

month	day	T_{ave}	I_{ave}	$^*T_{A1}$	T_{A2}	T_{A3}	η_{1ave}	η_{2ave}	η_{3ave}
		°C	$W.m^{-2}$	T_{ave} + 5°C	T_{ave} + 8°C	T_{ave} + 10°C	%	%	%
November	16.11.2005	3,9	159	8,9	11,9	13,9	66	55	47
December	16.12.2005	2,1	292	7,1	10,1	12,1	75	69	64
January	16.1.2006	2,7	336	7,7	10,7	12,7	76	71	67
February	16.2.2006	3,9	350	8,9	11,9	13,9	76	71	68

$^*T_A$ – temperature of air at output of solar system

Table 1

3.1 Influence of solar system on heating factor

As the results of measuring prooved, the added solar system in combined connection has positive influence on operational characteristics of heat pump mainly on its heating factor. This fact is most apparent in Figure 6.

The picture presents percentage growth of heating factor ($_\Delta$COP) which is valid for particular area of added solar system S = 10, 14, 20 and 24 m^2.

In the Figure 7 can be seen the behaviour of heating factor (COP) depending on the input temperatures in heat pump measured on assembled combined system. Parameter of displayed characteristic is output temperature from heat pump (temperature of heating system).

Operational characteristics pointed in Figure 8 explain the influence of added solar system on heating factor. Characteristics are valid for the output temperature from the heat pump T_{out} = 16°C and the parameter of each course is the area of added solar system (S = 10, 14, 20 and 24 m^2).

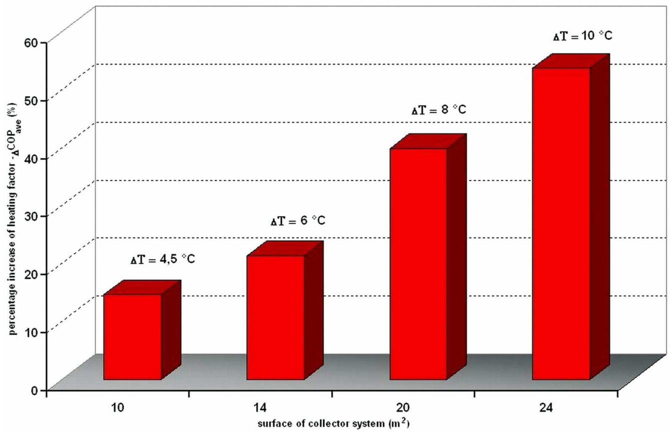

Fig. 6 Percentage increase of heating factor [1]

Introduced heating factor COP (*Coefficient of Performance*) result from real energy flows measured on combined system and it is determined according to the equation pointed below (1).

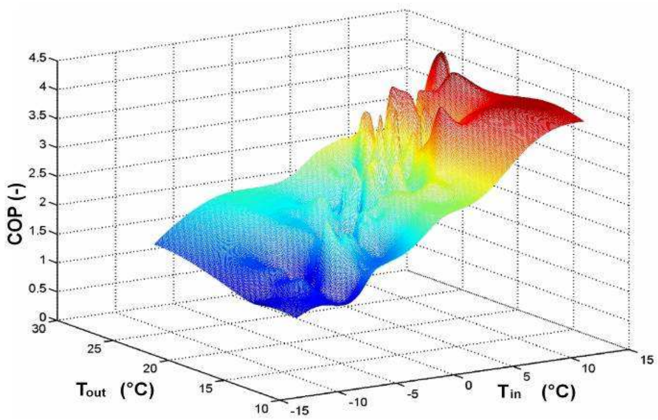

Fig. 7

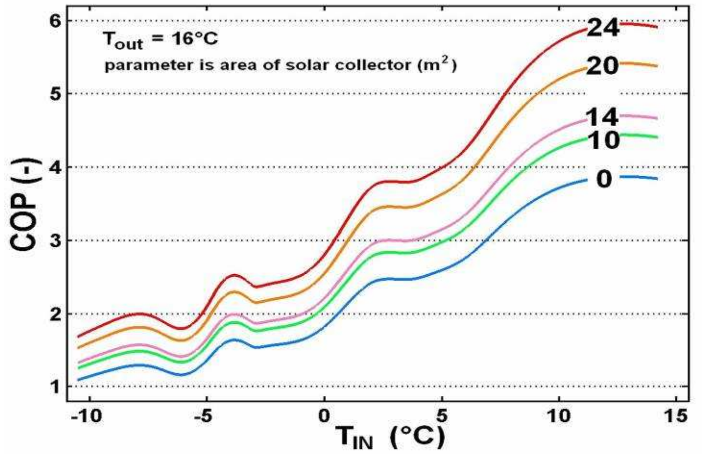

Fig. 8 Influence of added solar system on heating factor

$$COP = \frac{_{\Delta}T \cdot Q_m \cdot C_p}{P_p} \quad (-) \qquad (1)$$

4 Economical-technical evaluation of operation of combined system

Economical-technical evaluation of operation of combined heat pump and solar system is based on the analysis of operational parameters. Energy evaluation results from measured values on the combined system.

Economical evaluation is an integral part of the general evaluation.

The result of economical-technical analysis is to find the optimal area of solar system for incresing the medium temperature on the input of the heat pump in required range $_{\Delta}T = 5 - 10°C$.

To compare heating with the heat pump and other possible power sources, the existing family house project in Brno is used. The newly built-up low-energy house of 8,4 kW heat loss and of Q_{aneed} = 22,4 MWh.year^{-1} total energy demand (heating - $Q_{Heat, year}$ and hot service water $Q_{HW,year}$).

For the calculation of heat demand of the building the standard ČSN EN 832 „Thermal Behaviour of Buildings – Calculation of Heat Demand – Residential Buildings“ and the norm MPO no. 291/2001 Sb. „Determination of Energy Usage for Heat Demand in Buildings“.

The analysis itself elaborated for two different variants of heat pump connection within heating system. [4, 1]

4.1 Heat pump without solar system

The heat pump air-to-water in bilvalent connection with 7,7 kW heat rate is designed in the first case. The heat rate of heat pump at the temperature of primary source 2°C and output temperature 35°C is P_t = 8,3 kW and heating factor ε = 3,5. This power source covers the heat demands of the building approximately up to 98%. For complete coverage of heat demands of the building the air-to-air heat pump with 2,5 kW heat rate has been added to the system.

These two sources fully cover the heat loss of the building. The low-temperature floor heating has been installed in the monitored building. Such heating improves the parameters of whole heating system. The investment costs of this system are mentioned in the table 2.

HP without solar system	
HP	7.320,-EUR
air condition	3.215,-EUR
installation	1070,-EUR
heat reservoir	630,-EUR
total	**12.235,-EUR**

Table 2

4.2 Heat pump with solar system

The heat pump air-to-water in bilvalent connection with 5,3 kW heat rate is designed in the second case. The heat rate of heat pump at the temperature of primary source 2°C and output temperature 35°C is P_t = 5,8 kW and heating factor ε = 3,6. The type of the heat pump is designed so the ratio of heat pump performance to heat loss of the building is 63% that correspond to 90% of supplied thermal energy for heating the building [3].

The remaining thermal energy necessary for heating and hot service water is ensured by the cooperation of heat pump and solar system.

As it is mentioned above, the solar system is for a faction of a year used as a bivalent power source to the heat pump where it increases the temperature at the input of the heat pump. In this case air is the working medium. In case it is not necessary to increase the heat pump performance then the solar system is used for heating hot service water. Water is the working medium in such case.

Investment costs of combined system are pointed in Table 2. The level of costs depends on the area of added solar system. Very important issue when regarding operation of the system is the comparison of yearly costs of heating for each case described above. The advantage of combined system can be seen in Figure 9.

As it is mentioned in the begining of this paper, the heat demand for the monitored building is 17,0 $MWh.year^{-1}$ and the heat demand for heating hot service water is 5,4 $MWh.year^{-1}$. The heat pump covers the heat demand up to 90% which conform to 15,3 $MWh.year^{-1}$. To cover the entire heat demand for heating and hot service water it is necessary to supply 7,1 $MWh.year^{-1}$ from the solar system.

combined system (HP + solar coll.)	**price without capital grant** EUR	**price with capital grant $^{(I)}$** EUR
HP + $2m^2$	9.125,-	6.170,-
HP + $4m^2$	9.850,-	6.530,-
HP + $6m^2$	10.595,-	6.905,-
HP + $8m^2$	11.305,-	7.260,-
HP + $10m^2$	12.045,-	7.630,-
HP + $12m^2$	12.925,-	8.070,-
HP + $14m^2$	13.645,-	8.735,-
HP + $16m^2$	14.370,-	9.460,-
HP + $18m^2$	15.100,-	10.190,-
HP + $20m^2$	15.845,-	10.935,-
HP + $22m^2$	16.605,-	11.700,-
HP + $24m^2$	17.300,-	12.390,-

Table 3

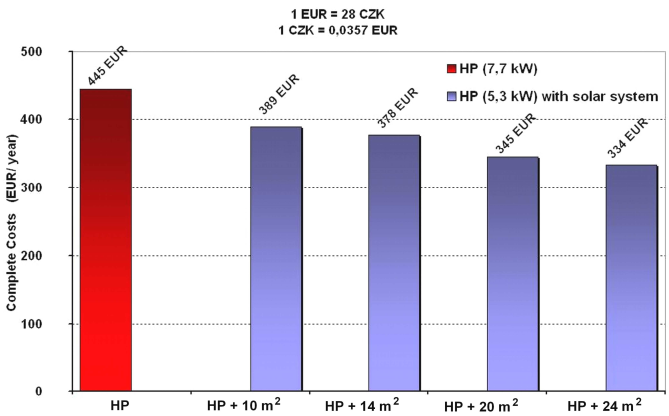

Fig. 9 Confrontation of operating costs

4.3 Final analysis of combined system

Economical-technical evaluation regards the energy demands of the building and the economic parameters as well. The results of the analysis are presented in the Figure 10.

The results clearly define the possibility and the field of energy and economic usage of a solar system in connection with a heat pump for monitored building with total heat loss Q_c = 8,4 kW determined on the basis of average monthly values of solar radiation intensity measured in the laboratories of Unconventional Transformations at the Department of Electrical Power Engineering, Brno University od Technology, Czech Republic.

The required amount of thermal energy for the building is in the graph marked with red line. The amout of reqiured energy is $\mathbf{Q_r}$ = 22,4 $MW.rok^{-1}$ including the energy necessary for heating hot service water. As it can be seen in the graph, the combined system of heat pump and solar system covers the energy demands of the building when the area of collector field is larger than S = 11,4 m^2 (this fact is marked with yellow area in the graph). This area is from above limited with the spline which conform to the enrgy supplied by the combined system providing that the solar system is during the period from September till April (heating season) used for increasing the temperature of incoming air in the heat pump within the interval $_{\Delta}T$ = (5 ÷ 10°C). This fact positively influences the value of heating factor of heat pump which after that ensures required supply of thermal energy. The evaluation regards two options: with and without obtaining the state dotation. The areas in the Figure 10 marked as „**A**“ and „**B**“ present situation in which – regarding the internal rate of return (IRR) and cash flow – the combined system is preferable to original project with heat pump – („A“ – without state dotation, „B“ – with state dotation).

4.3.1 Evaluation of the system without state dotation

Green area in the Figure 10 specifies possible area of added solar system regarding energy and economic demands without obtaining the state grant. In such case the IRR moves above 5% (green splines) for the areas of the solar system from 11,4 to 17 m^2 on condition that designed system covers the energy demands of the building. The project appears to be inconvenient from the economic point of view for larger areas of solar system.

4.3.2 Evaluation of the system with state dotation

The IRR of the project with heat pump in bivalent connection is 8% in the case of obtaining the state grant. The IRR value differ from 11% to 7% for the combined system. The area of added solar system is limited with blue splines in this case and varies from 11,4 to 20,3 m^2 (light yellow area). The combined system appears much more convenient when obtaining the state grant.

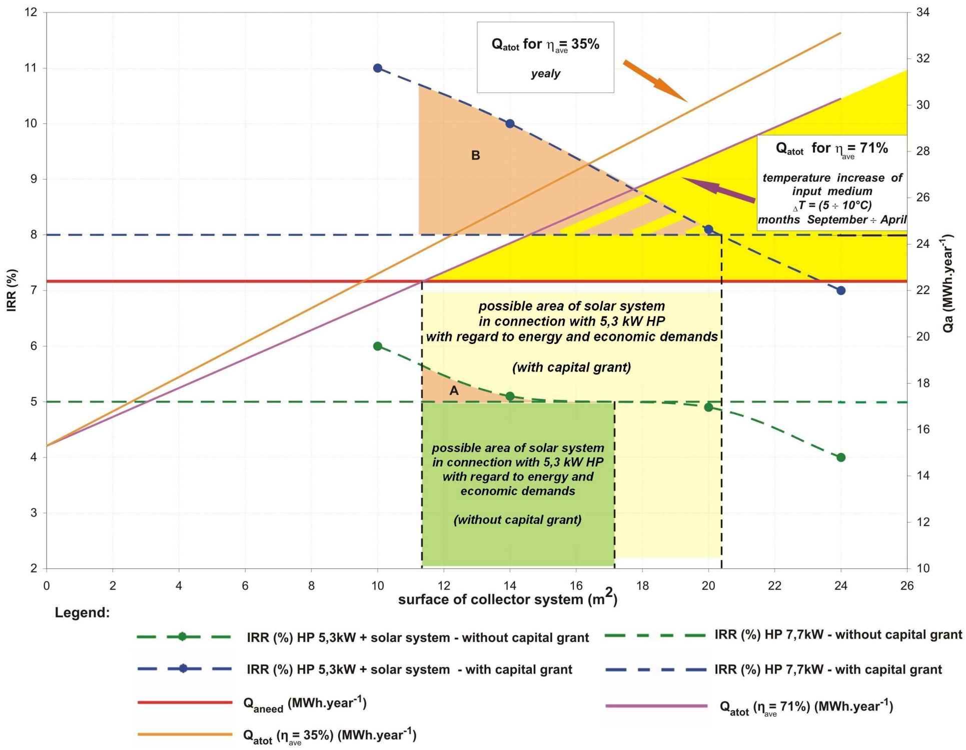

Fig. 10 [1, 2]

5 Conclusion

The results of the research pointed in this paper, which is focused on incresing the efficiency of operation of alternative power sources, present new possibilities of alternative power sources cooperation. The reasearch is focused on the cooperation of active solar systems and heat pumps. As the presented results explain, the cooperation of these sources is well-founded from the energy and economic point of view. In comparison with presently used system, the new connection of these sources is much more effective. Solar collectors in the new connection work with high efficiency which moves around 70%. The reason for such favourable operational parameters is mainly the new system of connection. Another important result is high heating factor of cooperating heat pump.

The measuring system has been designed for the purpose of measuring on the assembled combined system. The measuring system allows on-line monitoring of measured characteristics on both the solar system and the heat pump.

The essential contribution of this research is the increase of operational efficiency of combined system. This fact has direct influence on the consumption of prime energy of combined system. New connection allows to use heat pump with lower load which decrease the consumption of prime energy. This fact positively influences reducing the CO_2 concentration. The whole research follows the demands of the EU on the usage of alternative power sources. And it is supported by the Ministry of Education of the Czech Republic.

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(I) possible acquired state grant is considered at the maximum amount according to the conditions pointed in records (see [5]) for providing the state grant – scheme 1.A and 4.A