OPTIMISATION OF A HYBRID WALL FOR SOLAR UTILISATION IN AGRICULTURE

J. Radon[1], W. Bieda[2]

Dept. Of Rural Building, Agricultural University of Cracow,
Al. Mickiewicza 24-28, 30-059 Krakow, Poland,
Phone: (048)-12-654-5683, Fax: (048)-12-633-6245
E-mail: [1]rmradon@cyf-kr.edu.pl, [2]rmbieda@cyf-kr.edu.pl

ABSTRACT

A concept of a system has been prepared for obtaining hot water from the so-called hybrid wall (i.e. outer wall with build-in piping system, covered with transparent thermal insulation) integrated into living quarters or a livestock building structure. With the help of a special computer programme, a number of simulation calculations have been conducted of the system operating in a natural environment, and the calculated results have been compared with the experimental data. The impact of specific system parameters has been described, as well as the wall surface and construction, pipe spacing, water tank capacity and the yield of the water pump on passive and active solar heat gain. Results of the calculations showed that it was possible to optimise the hybrid wall through calculation.

Key words: Solar radiation, hot water, hybrid wall, transparent thermal insulation, optimisation.

INTRODUCTION

Solar radiation absorbed by building facades is almost completely lost through convection into the atmosphere. It is differently if the wall becomes covered with a transparent thermal insulation which passes solar radiation through it and retains the heat absorbed inside the wall thus preventing its escape into the atmosphere. The storage of the heat in the wall, allows for both the passive and active solar energy gain through the so-called hybrid system. Studies on the deployment of such systems have recently been conducted, among others, at the Fraunhofer Institute of Building Physics (IBP) in Holzkirchen (Germany). The authors of the paper actively participated in the preparation of the concept of employing a hybrid wall in agricultural buildings, using the results of the experimental studies conducted at IBP in Holzkirchen (Radon, Leonhardt 1996, Bieda, Radon 1997).

The authors have prepared a concept for a system for obtaining hot water and passive heating of buildings, and they also attempted to fully define the impact of the key parameters on the system's operation. A more complete definition of the applicability of the solutions proposed, is possible only after the thermal and energy properties of the hybrid system in relation to the climate, constructional solutions and steering have been completely determined. Such recognition is not fully feasible experimentally but could be theoretically, and the literature lacks further information on the subject.

Radon, J. and W. Bieda. "Optimisation of a Hybrid Wall for Solar Utilisation in Agriculture". Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Vol. II.

THE CONCEPT OF THE HYBRID SYSTEM FOR AGRICULTURE

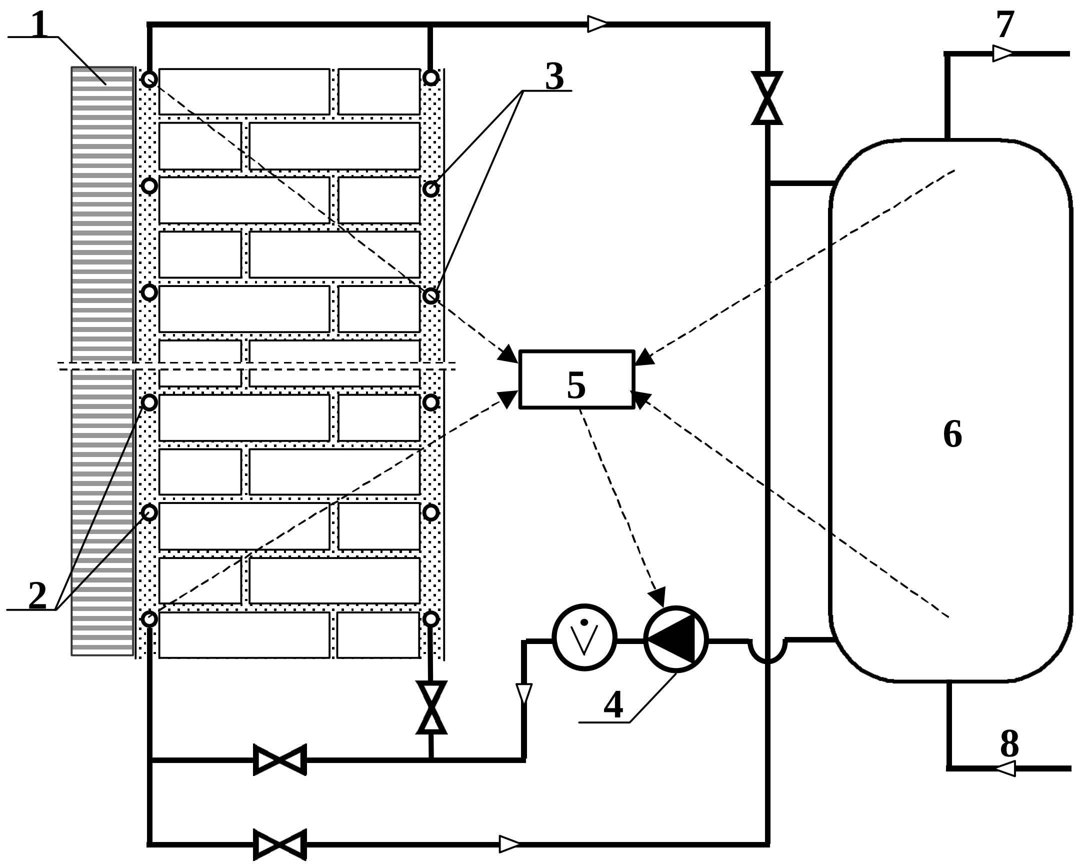

Figure 1. Hybrid wall scheme: 1- transparent thermal insulation, 2 – outer piping, 3- inner piping, 4- water pump, 5 – pump controller, 6 – water tank, 7 – hot water outlet, 8 – cool water inlet.

Figure 1 shows a simplified concept of the hybrid system. The most important elements of the system are the wall covered with transparent thermal insulation, the piping system, water tank, water pump and its controller. The piping is outlined so as to allow for a variety of system operational modes: water circulation within inner and outer piping or either inner or outer piping. Such control is exercised through four valves, in various combinations of which, two are open and the remaining two are closed. Pump control is conducted through monitoring of the water temperature at the pipe outlet from the wall, and comparing it with water temperature at the top of the tank (maximum of temperature) or at the bottom of the tank (maximum of energy). If cost reduction is necessary, it is possible to simplify the system using only the outer piping system and controlling the temperature through only one measuring point.

METHODS AND SCOPE OF THE OPTIMISATION CALCULATIONS

In order to simulate of the thermal performance of the system, a special computer programme was utilised, written in Delphi for a PC computer. The problem of heat flow within the wall, solved by a method of elementary balances (Radon, 1997), was simplified to a two-dimensional, non-stationary heat transfer and exchange, using the symmetry of the wall. In the water tank, the so-called stratification model was accounted for, which consists of hot water accumulation at the top of the tank, with the cooler water remaining at the bottom. In the calculation model accepted, it was assumed that the tank was of a cylindrical shape. Vertically, the tank interior was divided into horizontal water layers of temperatures constant in a given calculation step. Water layers exchange heat directly through conduction and indirectly through the tank walls, while heat exchange with outer air is linear, perpendicular to the side and top walls (Sauer, Zeise, 1982).

The validation of the programme was done through comparing the measurement and calculation results. A comparative analysis showed that the maximum difference between the average measurement values and the calculation values (i.e. temperature, energy and flow) did not exceed 11 %. Figure 2 presents measured boundary conditions (solar radiation, outer and inner air temperature, water flow) and measured and calculated water flow off temperature for seven days during experimental period.

Calculations conducted to optimise of the system accounted for the following parameters:

- surface, construction, thermal properties of the hybrid wall, and pipe spacing;
- flow of water within the wall (maximum yield of the water pump);
- water tank capacity, as well as the quantity and time profile of hot water consumption.

The pump is turned on when water at the outlet from the wall reaches 40°C, and turned off when the temperature falls to 26°C. The temperature is additionally controlled at the bottom of the tank, so as to prevent the cooling of water in the tank, in a situation when the water temperature at the bottom of the tank is higher than the wall-outlet temperature. As simulations were conducted for the summer period, water circulation used first the inner piping, and later the outer piping. As the water temperature at the bottom of the tank is usually lower than the inner wall surface temperature, one can gain additional heat through initial heating of the water while the inner wall surface is cooled, which gives a certain protection against overheating of the building in summer.

For boundary conditions, the real weather data was used, measured during the period between 15 July 1996 – 15 August 1996 at the IBP in Holzkirchen. This allowed for additional control of the calculation results and comparison with experimental data. Additional comparative calculations were conducted using statistical climate (TRY) for two summer months (July, August), where similar results were achieved.

CALCULATION RESULTS AND ANALYSIS

The key elements of the hybrid system were taken into consideration, and particular data were changed so as to account for the most probable combinations of system forming. When changing certain parameter, the other ones remained unchanged in order to see it’s impact on the possible gains or losses of heat. Table 1 presents the basic parameters assumed when calculating.

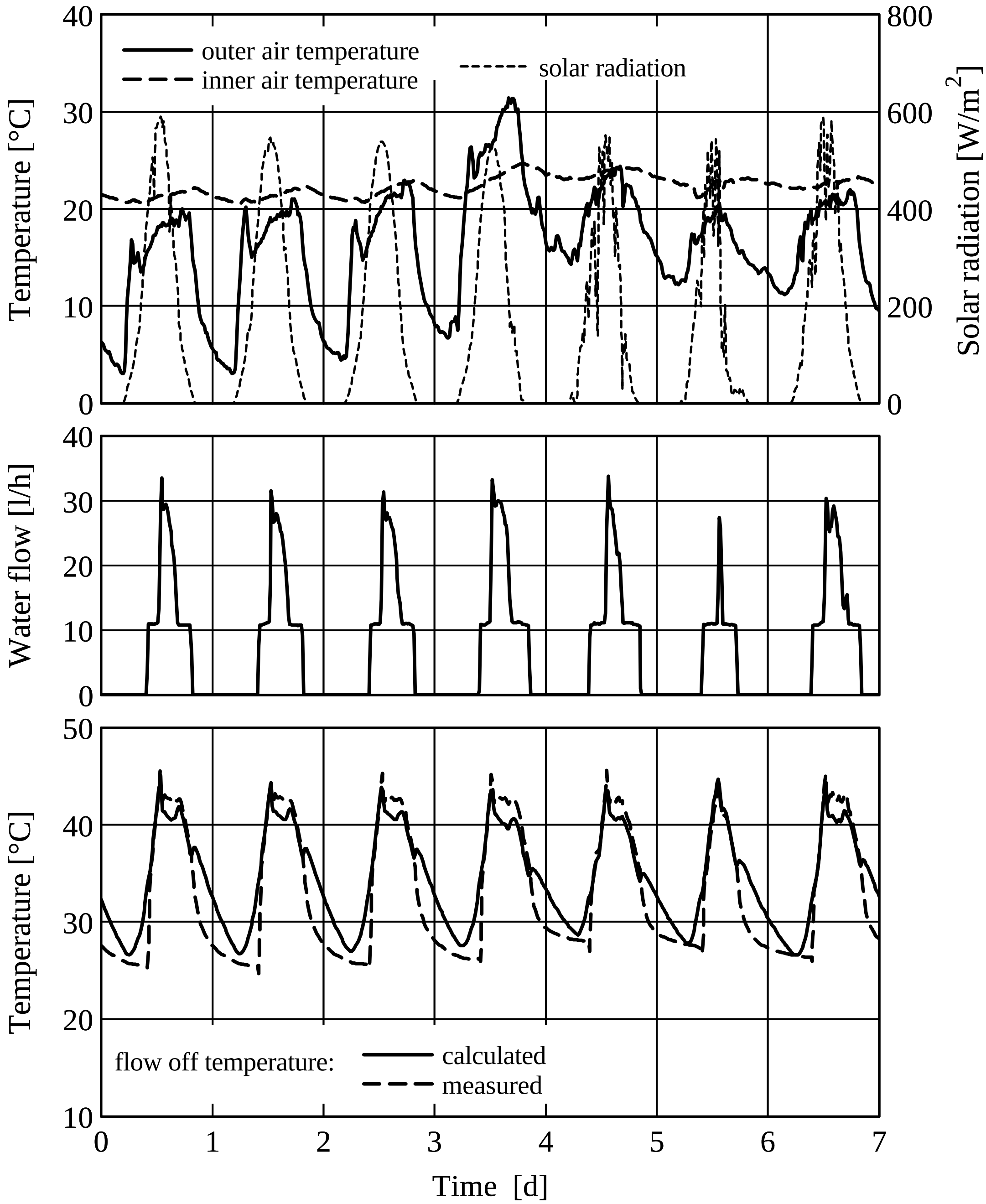

Figure 2. Boundary conditions (upper diagram), measured water flow (middle diagram) and measured and calculated water temperature at the outlet, in the period between 20 July – 26 July 1997.

A basic optimisation criteria is the maximising of heat gain to the heating of water. Heat not used for water heating is partially lost, and partially used for the passive heating of internal air. The average heat power for water heating and the average passive heat gain on the inner surface of the hybrid wall are thus the basic parameters, which characterise the energetic yield of the system.

Table 1. Basic system parameters assumed for calculations.

Enumeration / unit	Value
Transparent insulation	
Thickness [m]	0.08
Solar energy transmittance [-]	0.35, 0.50, 0.65, 0.80
Thermal conductivity [W/mK]	0.08
Wall	
Height [m]	2.30, 3.30, 4.00
Width [m]	2.40, 3.33, 4.12
Construction layer thickness [m]	0.24
Plaster with pipes layer thickness [m]	0.03
Pipe diameter [m]	0.022
Pipe spacing [m]	0.0416, 0.0833, 0.125, 0.2083
Thermal conductivity of construction layer [W/mK]	0.20, 0.42, 0.79, 2.10
Construction layer volumetric density [kg/m³]	400, 900, 1600, 2400
Wall and plasterwork heat capacity [kJ/kgK]	1
Thermal conductivity of plasterwork [W/mK]	0.87
Plasterwork volumetric density [kg/m³]	1800
Water tank	
Capacity [l]	100, 300, 500, 750, 1000
Height [m]	1.53
Diameter [m]	0.50
Wall thickness [m]	0.003
Thermal conductivity of wall [W/mK]	200
Insulation thickness [m]	0.08
Thermal conductivity of thermal insulation [W/mK]	0.04
Hot water consumption [l/d]	120, 200, 280
Other	
Solar absorption coefficient [-]	0.95
Pump turn on/off temperature [^{o}C]	40/26
Max. yield of water pump [l/h]	5, 10, 15, 20, 25, 50, 100

Impact of surface and hybrid wall construction on heat gain

A number of studies were conducted using data from Table 1, taking variable thermal properties of the wall layer, and additionally changing the spacing of the pipes. The results are illustrated in Figure 3. Its analysis shows that the heat gain used for water heating significantly lowers, with the increasing volumetric density and thermal conductivity for the construction layer of the hybrid wall. In extreme conditions, the difference between the light wall (e.g. of cellular concrete) and the heavy wall (e.g. of regular concrete) reaches 23 % in relation to the maximum gain (with a minimum pipe spacing of 4.16 cm) and slightly decreases – to 18% with the increased pipe spacing (with a maximum spacing of 20.83 cm). The difference in gain for maximum and minimum spacing is ~20% (light wall) and ~15% (heavy wall). Passive gain behaves in a manner opposite, as these gains increase with the volumetric density and the heat conductivity of construction layer of the hybrid wall. The differences are approximately 85%, regardless of the wall type. The gains are almost linearly proportional to the increase in pipe spacing and amounts to 70% (light wall) and 23% (heavy wall).

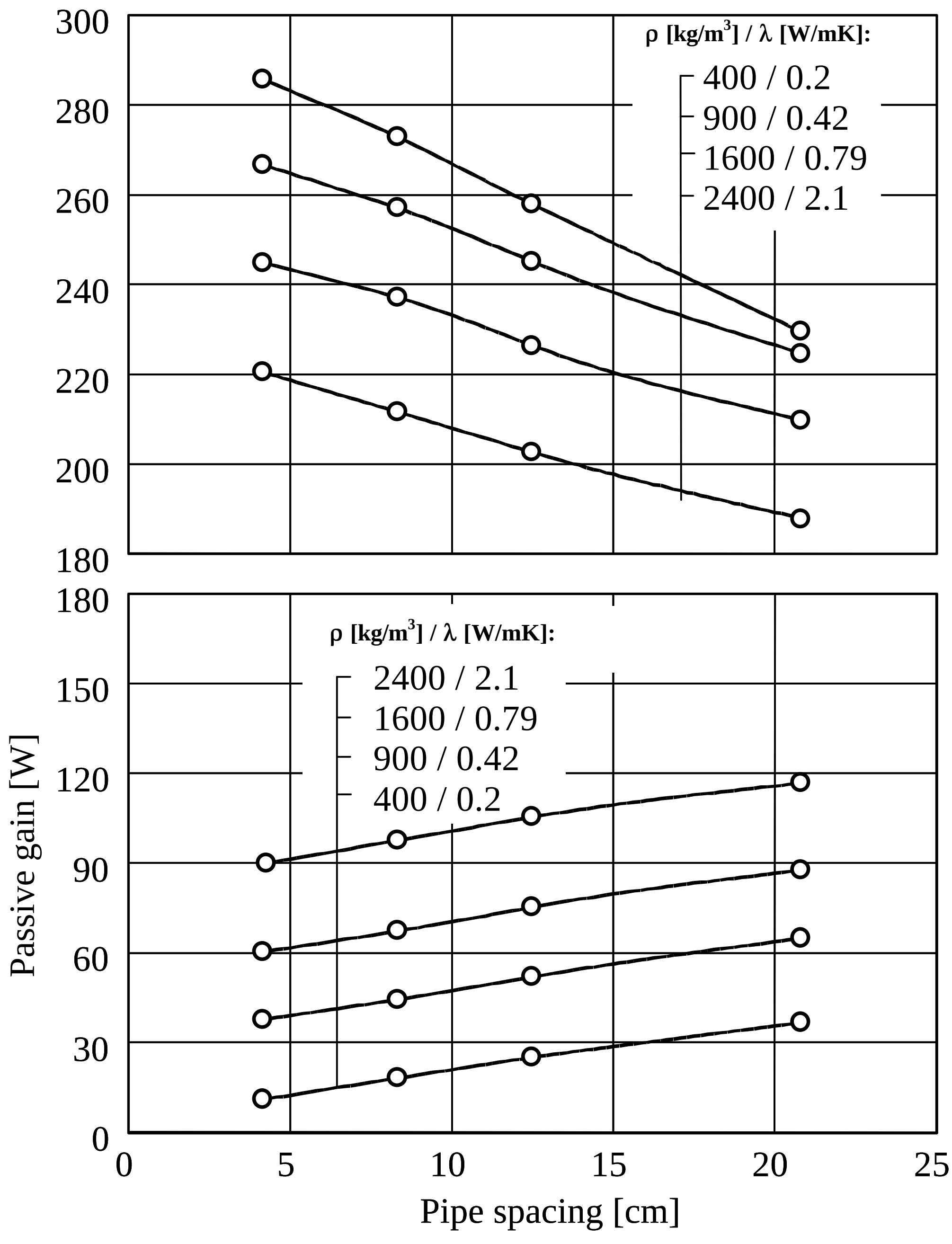

Figure 3. Amount of active gain (upper diagram) and passive gain (lower diagram), dependent on thermal properties of the wall and pipe spacing.

The doubling of the wall surface, whilst keeping the other parameters, results in the increase of active gains by 27 %, while tripling the wall surface – by 44 %. The remaining heat is used in a passive way. A more effective use of active gains is possible though increasing the tank capacity or increasing the hot water consumption.

Impact of water tank capacity and pump yield

Water tank capacity limits the ability of the system to accumulate irregularly produced heat and supply it when hot water is needed. As Figure 4 shows, the increase in tank capacity leads to the growth of active gain. Yet increasing its capacity above a certain value seems pointless, as the active gain grows very little. Too small capacity of the tank, however, causes a lowering of heat gain and its partial loss for passive gain, which is not desired in summer. The optimal size of the tank thus depends directly on other parameters of the system, especially on the size of the wall surface and water consumption. The increase in input from 200 to 280 l/day, with a tank of 500 litre capacity, increases the energetic yield of the system by 13%. Further calculations indicated that the impact of the time profile of the water consumption (constant or only at certain times of a day) is slight, and decreases as tank capacity increases.

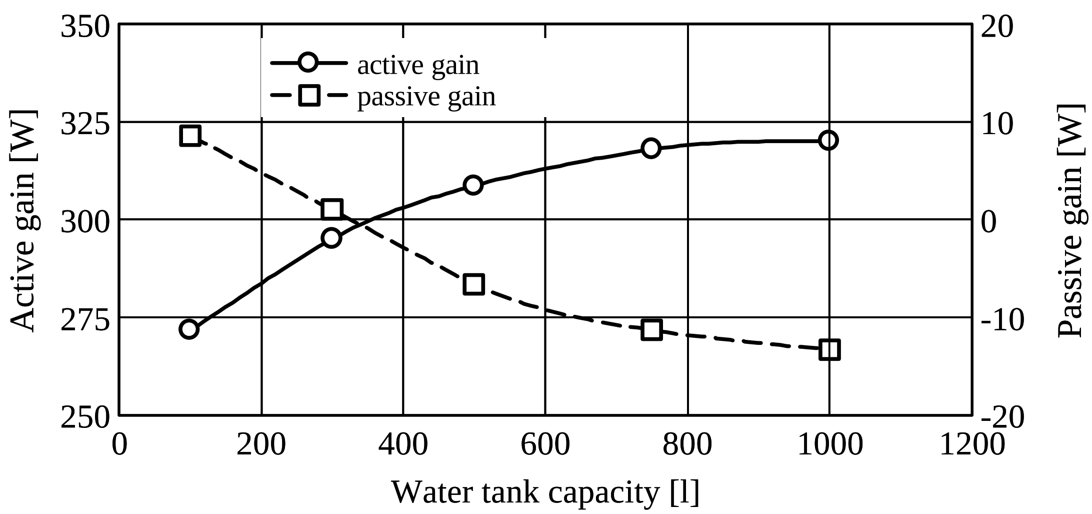

Figure 4. Relation of passive and active gain to water tank capacity.

Another interesting problem is the defining of the optimal pump yield. As Figure 5 depicts, there is a visible extreme, at which the heat gain is maximal.

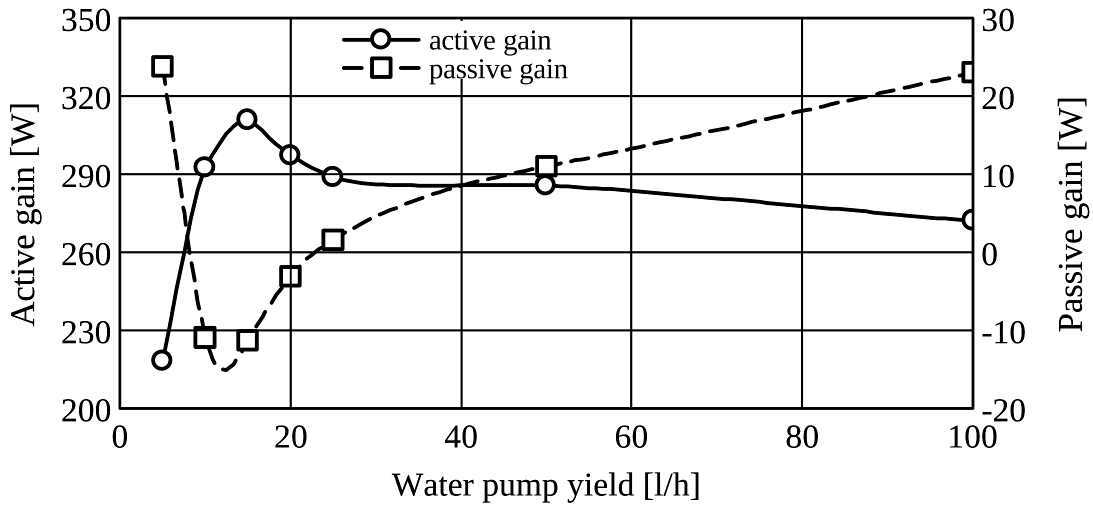

Figure 5. Relation between water pump yield and amounts of active and passive gain.

Too small a water flow allows temperature in wall to grow higher, what causes higher losses to outer and inner air. The increase of pump yield, however, over the optimum point causes a slow decrease of heat gain for water heating. If in doubt, it is better to employ a pump of greater yield, as its bigger dimension causes smaller losses than a pump of smaller dimension. As further studies have proved, the optimal efficiency of the pump significantly changes depending on the wall size and construction, yet there are no significant changes resulting from water tank capacity. For exemplary wall (see Table 4) the optimum pump efficiency totals approximately 12.5 l/h.

CONCLUSIONS

- Thermal properties of the wall have a decisive impact on heat gain levels. A higher active gain may be achieved in a so-called light wall, made of a material of lower volumetric density and low thermal conductivity. A passive gain, however, increases with the increased volumetric density and thermal conductivity. The calculated difference in active gain levels between light and heavy walls is estimated for ca. 23% (for pipe spacing of 4.16 cm) and decreases slightly with increased line spacing
- Increased pipe spacing causes a visible decrease in active gain and increase of passive gain. Quadrupled increase in pipe spacing decreases active gain only by ca. 20% (light wall) and ca. 15% (heavy wall)
- Water tank capacity should be chosen depending on the collecting wall surface and hot water consumption. Too small a tank limits the system accumulation abilities, while increasing its volume beyond a calculable value is pointless, as growth in active gain is insignificant when compared to incremental growth of tank capacity

- During calculation, it was noticeable that the time profile of the water consumption from the tank had a small impact on the level of the passive gains
- Calculation results showed a visible relation between the pump yield and active gain levels. The optimum pump yield, dependent almost solely on the hybrid wall construction and surface, as well as on pipe spacing, may be defined by calculation
- Regarding the numerous varied parameters with a significant impact on the hybrid wall operation, it is impossible to generalise rules for system lay-out. However, for specific architectural and constructional conditions, climate, production technology and hot water needs, it is possible to optimise the water tank capacity and define the optimal pump efficiency through calculation.

REFERENCES

1. Bieda, W, Radon, J (1997). Wall with transparent thermal insulation in building for boilers. Scientific Papers of Agricultural University in Cracow, Vol. 49, 7 – 16
2. Radon, J, Leonhardt, H (1996). Passive und aktive Nutzung solarer Wärme mit TWD-Außenwänden für Ställe in der Landwirtschaft. IBP-Bericht, REB-7
3. Radon, J (1997). Calculation of active heat gains in wall with transparent thermal insulation. Scientific Papers of Agricultural University in Cracow, Vol. 49, 93-102
4. Sauer, E, Zeise, R (1982). Energietransport, - speicherung und, -verteilung. Band 11, Handbuchreihe Energie, Köln – Technischer Verlag Resch, 49-66