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Solar Assisted Ground Source Heat Pump Performance in Nearly Zero Energy Building in Baltic Countries

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Abstract- **In near zero energy buildings (NZEB) built in Baltic countries, heat production systems meet the challenge of large share domestic hot water demand and high required heating capacity. Due to passive solar design, cooling demand in residential buildings also needs an assessment and solution. Heat pump systems are a widespread solution to reduce energy use. A combination of heat pump and solar thermal collectors helps to meet standard requirements and increases the share of renewable energy use in total energy balance of country.**

The presented paper describes a simulation study of solar assisted heat pump systems carried out in TRNSYS. The purpose of this simulation was to investigate how the performance of a solar assisted heat pump combination varies in near zero energy building. Results of three systems were compared to autonomous (independent) systems simulated performance. Different solar assisted heat pump design solutions with serial and parallel solar thermal collector connections to the heat pump loop were modelled and a passive cooling possibility was assessed. Simulations were performed for three Baltic countries: Lithuania, Latvia and Estonia.

Keywords – combined renewable systems, near zero energy buildings, passive cooling, solar assisted heat pump, TRNSYS

I. Introduction

According to EU directive 2010/31/EU near zero energy building (NZEB) is required to consume zero or near zero primary energy [1]. While the reduction of energy use through the decrease of heat loss in the building envelope is limited due to economic reasons, solutions for primary energy demand reduction on heat production systems is the next action. Heat pumps are a widespread sustainable solution for heat production in NZEB. These systems can produce more final energy than consume primary, by using renewable heat from air, ground or water sources. Heat pumps perform better in close to room temperature (low temperature heating and high temperature cooling) applications, while running in a higher temperature mode to produce domestic hot water decreases the coefficient of performance (COP) values. In typical buildings, the main purpose of solar thermal collector use is domestic hot water (DHW) preparation for the summer season. The possibility to reduce heat pump running time for DHW preparation by using solar collectors is one solution which can meet the seasonal performance (SPF) requirements for heat pump systems according to EN 15450:2007 Annex C [2].

In this paper, the solar assisted heat pump system is analysed to serve a NZEB for DHW and space heating. The performance of five different systems is studied using TRNSYS software. The results of this study represent the situation in three Baltic countries.

II. Literature review

Combining heat pumps with solar thermal collectors results in increased costs and complexity of the system assuring comfortable indoor conditions and provision of DHW. These systems lead to changed SPF of the overall system and to a reduced consumption of electrical energy [3]. In most cases, reduction of electrical energy consumption depends on the chosen operational strategy [4].

Previous studies examined typical buildings without detailing the components of heat balance. Mainly space heating demand was based on specific heat losses [4–6]. In studies where more detailed building models were used [7, 8], performance of envelope elements fit regular buildings – and solar assisted ground source systems were not widely examined in high performance buildings like Passive houses and NZEB.

Biaou and Bernier [9] examined four alternatives for DHW with renewable energy in zero net energy homes. The results showed that heating DHW with thermal solar collectors and an electrical backup is the best solution for such buildings. However, the opportunity to cover space heating demand was not assesed.

Kapsalaki et al. [10] presented a methodology of assisting in the choice of economically efficient NZEB solutions including various energy transformation technologies. Assessing the influence of different climate contexts in the economic-efficient design of NZEBs, indicated that the ‘optimal’ design solutions for mild winter climates can be significantly cheaper than for cold winter climates.

Rad e al. [11] demonstrated that the hybrid ground source heat pump system combined with solar thermal collectors is a feasible choice for space conditioning for heating dominated houses. It was shown that the solar thermal energy storage in the ground could reduce a large amount of ground heat exchanger length.

Kjellsson [12] in her thesis investigated six solar assisted heat pump systems which can be classified by connection type. This classification could be found in IEA task papers [3]. When connected to the cold side of the heat pump, solar collectors increase source temperature and regenerate borehole when the heat pump is not operating.

The purpose of solar collectors at the hot side of the heat pump mainly is to reduce its running time by partially covering heat demand.

III. MOTIVATION OF STUDY

While building envelope properties are widely examined and analysed in the NZEB case, there is a lack of studies for mechanical systems in high performance buildings. According to European Union's directives [1], national regulations must be adapted to fit the roadmap to year 2020: heat demand will be minimized with highly insulated envelopes, but DHW demand seems to be stable. The use of heat pumps helps to reduce primary energy. Due to the high fraction of DHW demand, heat pumps used in NZEB have a higher risk of not meeting the requirements of EN 15450:2007 [2]

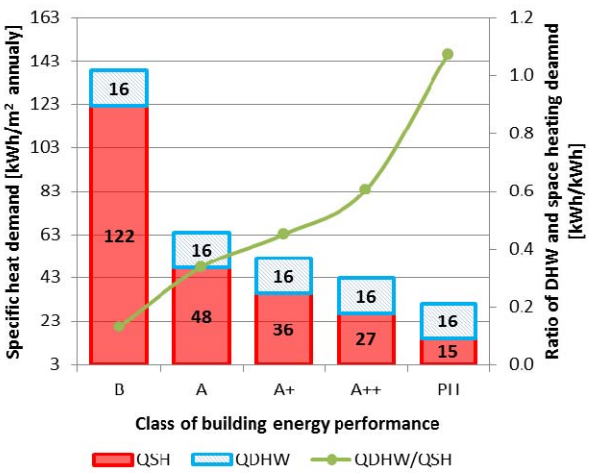


Fig. 1. Energy consumption for space heating and DHW preparation.

In the figure above, parts of specific heat demand for hot water preparation and space heating (SH) for different energy performance classes are shown. These demand values are calculated for typical 180 m^2 dwelling according to Lithuanian national law [13]. The line in the figure represents the ratio between DHW and space heating. Keeping in mind that energy performance class must be calculated from primary energy (PE) demands, inefficient (from PE use perspective) DHW preparation might be a cause of the failure to reach a better energy performance class.

In previous studies [3-8,14], the scenario of equal or higher DHW demand was not widely examined. During the spread of NZEB and Passive house concepts, this scenario appears realistic in Baltic countries too. The tendency of specific heat demand (Q_{SH}) and the ratio of DHW and space heating demand is shown in Fig.1. It can be observed that hot water demand (Q_{DHW}) has higher influence for heat pump annual performance when ratio of DHW and space heat demand increases. When a heat pump runs on lower COP for DHW preparation for a longer time, it is difficult to achieve higher SPF values than in a typical building, where heat production for low temperature heating system (max 35 ^{o}C) makes most of the demand.

Using a weighting method, COP values were calculated for a heat pump which has the performance characteristics of B0W35 – COP=4.3 and B0W55 COP=2.9. The dashed line (in Fig. 2) shows predicted COP values for a parallel solar assisted heat pump system which covers 50 % of DHW demand.

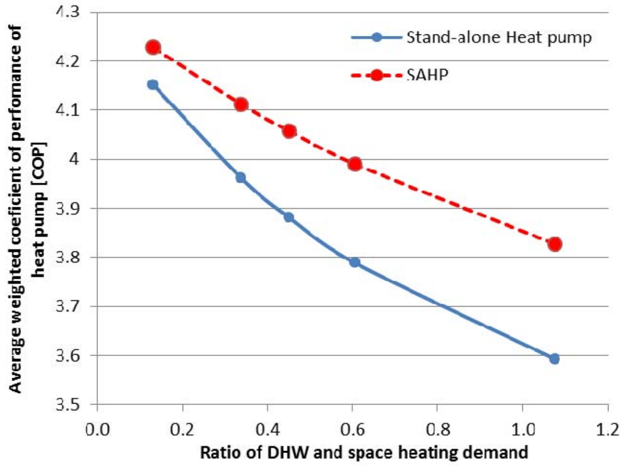


Fig. 2. Demand weighted COP value for stand-alone and solar assisted heat pump systems dependence on ratio of DHW/SH

A solar assisted heat pump should perform better in NZEB cases when the ratio of DHW and space heating demands are high. This effect appears due to reduced heat pump running time on low COP values.

The aim of the presented work is to examine different solar assisted heat pump schemes which allow to cover all heat demand in NZEB without a decrease of SPF value.

IV. ENVIRONMENTAL CONDITIONS IN BALTIC COUNTRIES

Meteorological data shows that average temperatures and average annual solar radiation has minor variations for the capital cities of the three Baltic countries studied. Those meteorological conditions reflect on heating and cooling demands for NZEB building used in simulation at TRNSYS environment. Simulated demands are shown in Table I.

TABLE I

SIMULATED HEATING AND COOLING CONSUMPTION FOR STUDIED BUILDING

	Heating consumption, kWh/m^2	Cooling consumption, kWh/m^2
Tallinn (Estonia)	17.3	8.2
Riga (Latvia)	18.8	12.9
Vilnius (Lithuania)	16.2	15.2
Average	17.4	12.2

From data shown in Table I, it is clearly visible that for the near zero energy buildings used in this case, heating consumptions are quite similar in numerical values.

While NZEB energy consumption is highly influenced by solar radiation and sunshine duration in cold periods, the Climate Severity index (CSI) [16] could be used for meteorological condition comparison. Comparison of CSI criteria and solar radiation comparison is shown in figure below. (Fig. 3)

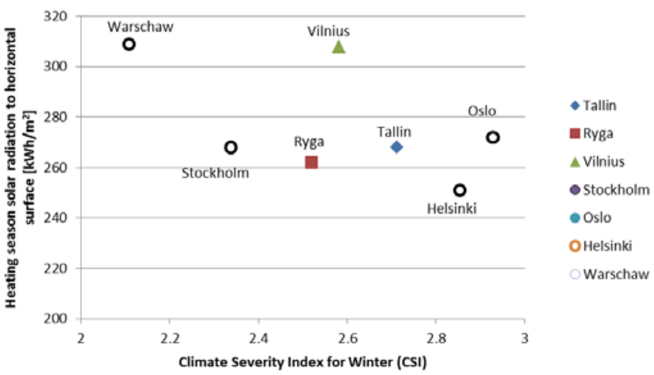


Fig. 3. Solar radiation and climate severity index for capital cities

CSI takes into account astronomical and measured sunshine duration, solar radiation (data from Meteonorm [17]). Degree days of the heating season are also included (5 year averaged data [18]). Geological conditions of surface layers are similar due to the same origin and ice age forces that created them (Fig. 4).

Fig.4. Geological situation of Baltic countries [19]

According to the meteorological data sets aggregated and presented above, one can conclude that climate and geological conditions are quite the same in all three Baltic countries and the heat demands for NZEB are also very similar.

Since particular site situation could vary due to local geological conditions, an average value of 1.8W/mK of ground thermal conductivity was used.

Results are mainly presented for Vilnius case due to this city holding the average CSI value among the assessed capitals and the highest risk of overheating in summer (with passive prevention systems).

V. Simulated Cases

All the simulated systems supply heat for NZEB. Building model is designed close to Passive house standard requirements. Validation of building design was performed with the PHPP [15] tool by using Vilnius meteorological data set. The floor area of the building is 180 m^2. A DHW demand calculation is based on Jordan & Vajen methodology [20], by taking into account 4 people with 35 l/person daily hot water use.

Since DHW demand has a high influence on solar collector fraction of covered heat demand, a detailed water drawn profile was used in simulation. Figure 5 shows probability driven load generation results, which take seasonal, monthly, daily and hourly water drawn probabilities into account.

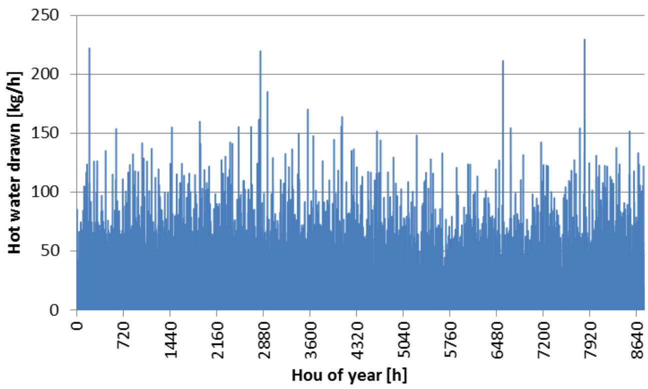


Fig. 5. Hot water drawn profile

Cold water temperatures are calculated by sinusoidal law variation, with a minimum temperature of 6 ^{o}C in the winter time and 12 at the summer's end (Fig. 6).

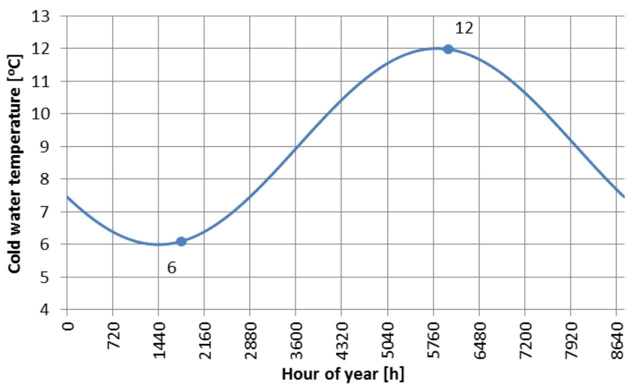


Fig.6. Cold water temperature annual variation

Water temperature is based on the annual variation of terrene temperature. That variation directly reflects on water temperature due to heat transfer from supply piping and water flow.

Required heat pump capacity was determined for single zone passive house model (Fig. 7). This model was used in previous studies [21,22] and reused for this study. This building has typical architectural features used for passive solar design and balance solar heat gains for heating and cooling seasons.

The simulated building is characterized by specific heat losses. Effect of heat storage is taken into account when heat capacity is calculated using simplified rules [13] for heavy construction buildings. Varying characteristics of differently orientated window area are also taken into account in loss-gain calculation.

The building has shading protection from sun: overhangs are used to reduce the risk of overheating due to solar heat gains.

Cooling loads are calculated with fixed internal heat gains (2.1 W/m^2 caused by auxiliary and domestic electricity use) and various solar gains are reduced via shading devices. The air change rate stays constant for the whole year. Internal gains caused by the occupant are not included in the calculation (according to PHPP [15] calculation rules) while this part of heat balance has high uncertainty.

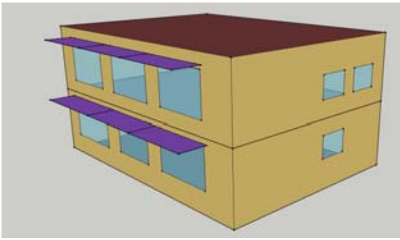


Fig.7. Simulated building

The building envelope has a specific heat loss coefficient of 60W/K. Window to floor area ratio is 20 % while most of the glazing is facing south. Design air tightness at 50 pressure difference is 0.5 h^{-1} Ventilation heat recovery efficiency value - 85%. Design flow rate of air supply fixed to 150 m^3/h.

Mechanical system components were sized according to the standard rules to meet heating capacity requirements and provide stable long term running conditions for the heat pump.

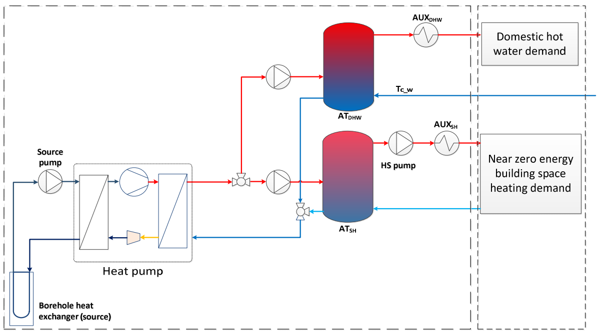
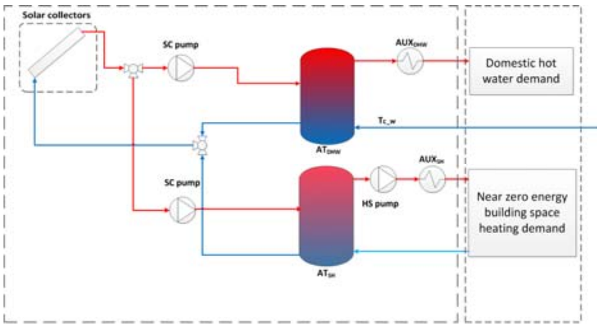
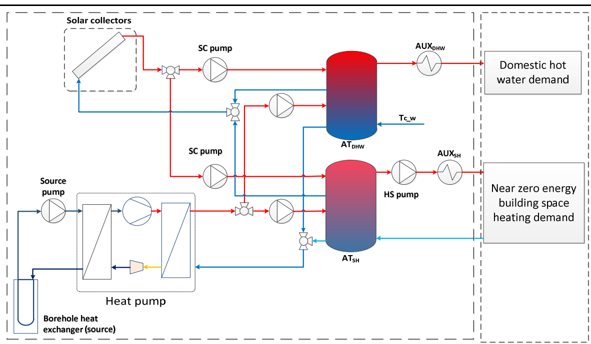
Solar thermal collector sizing is based on the f-chart method [23] according to EN 15316-4-3 [24]. The predicted solar fraction for 7.12m^2 flat plate collectors varies from 48 % to 52 % of heat demand fraction for various countries.

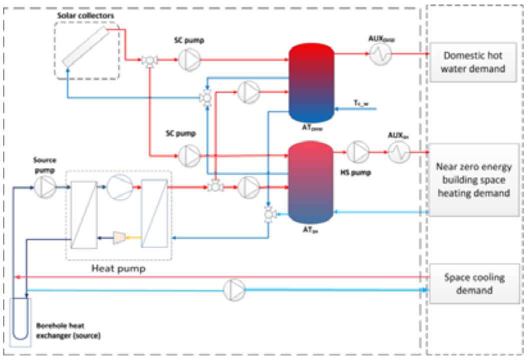
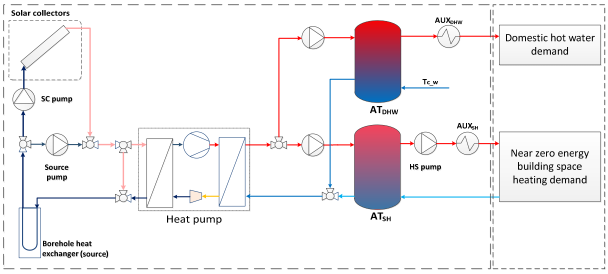
Accumulation tanks were selected to achieve 50 % of solar fraction according to the f-chart method. A buffer tank for the heat pump was chosen to ensure 1 hour running time of the heat pump on nominal capacity at any conditions for covering heating demand.

The simulations of systems performance are conducted using TRNSYS software. The systems are described below and presented schematically in Table II.

TABLE II

SIMULATED HEAT PRODUCTION SYSTEMS

	STAND-ALONE GROUND SOURCE HEAT PUMP SYSTEM • Typical heat pump system with separated accumulation tanks for space heating system and DHW preparation • Back up heaters provide additional heat if set point value is not meet for DHW and SH flows • Space cooling demand is not covered by this system
	SOLAR COMBI SYSTEM WITH ELECTRICAL BACK UP • Main heat supply system is solar collectors • Solar system is controlled by temperature difference between solar collector outlet and accumulation tank top section temperatures • Additional electrical heaters support and add heat if set point temperature is not reached for DHW and SH flows • Space cooling demand is not covered by this system
	PARALLEL SOLAR ASSISTED GROUND SOURCE HEAT PUMP SYSTEM • Main heat source is heat pump which provides heat supply for space heating and domestic hot water preparation • The purpose of a solar collector is to reduce heat pump running time for DHW preparation in summer • Space cooling demand is not covered by this system

<table>
<tr><td>
</td><td>PARALLEL SOLAR ASSISTED GROUND SOURCE HEAT PUMP SYSTEM WITH PASSIVE COOLING OPTION
• Main heat source is heat pump
• Solar collectors connected in hot side of heat pump reduce running time of heat pump
• In passive cooling mode borehole heat exchanger works as heat sink for removed heat
• The assumption is used that low temperature surface heating system works as high temperature cooling system</td></tr>
<tr><td>
</td><td>SERIAL SOLAR ASSISTED GROUND SOURCE HEAT PUMP SYSTEM
• Main heat source is heat pump
• Solar collectors connected in cold side of heat pump provide additional heat to condenser and regenerate ground when heat pump is not operating.
• Cooling demand is not covered</td></tr>
</table>

VI. TRNSYS SIMULATION

The simulation of solar assisted heat pump systems was performed with the TRNSYS simulation program [25]. This completely extensible simulation environment is a widespread tool for complex renewable energy system simulation. The models were created with the main system elements as Types: *Type 12C* – Energy/Degree-Hours House model with temperature level control is used for weather influenced space heating load generation. The additional heat gains and losses from windows were added with *Type 35A*. The influence of shading devices was taken into account with *Type 34*.

Type 927 – Water to Water Heat Pump. This Type uses normalized data file interpolation for the performance modelling based on the user-supplied data files containing catalogue data for the normalized capacity and power draw. The content of this file was custom made from the performance data for the heat pump as supplied by the manufacturer *STIEBEL ELTRON*.

Type 557 – Vertical U-Tube ground heat exchanger. This Type provides the possibility to calculate heat rejection and absorption depending on temperatures of heat carrying fluid and the ground. This type uses calculation model created by Hellstrom [26].

Type 1 – Solar Collector model which calculates solar collector performance using quadratic efficiency formula where 2nd order incidence angle modifiers are taken into account. Optical efficiency of solar collectors is 0,78. Heat loss coefficients (a_1 and a_2) of 4,12 W/m^{2}K and 0,0064 W/m^{2}K^2 were used.

The simulation was performed with the integration and convergence toleration of 0.001. The balance between the elements is checked manually in the MS Excel environment. The highest errors fit in 2 % mismatch value. The flow temperatures values fit the margins of a real system according to the authors' experimental experience.

Due to the assumptions made during the simulation (neglected piping heat loss, constant power use in pumps and ideal heating system control) the results are not suitable for real system performance prediction, but are appropriate for the comparison. The results clearly show differences among systems. All cases are simulated using the same conditions and assumptions.

Component size and main characteristics are shown in Table III.

TABLE III

COMPONENT SIZES IN SIMULATED HEAT PRODUCTION SYSTEMS

Component/Characteristic	Value
Heat pump nominal power	5,80 kW (B0W35) 5,40 kW (B0W50)
Borehole length	2X42m
Space heating accumulation tank	300 L
DHW tank (with solar collectors)	200 L
DHW tank (without solar collectors)	600 L
Solar collector area	7.4 m^2

In loops where there is a risk of icing due to low temperatures, an antifreeze solution - heat capacity and density properties of 30% propylene glycol - was used in simulation.

VII. ASSESSMENT METHOD

The seasonal performance factor (SPF), as calculated according to LST EN 15450:2007 [2], takes into account the power consumption of the heat pump and the source circulation pump; auxiliary energy (E_{aux}) need; heat output for the space heating (Q_{SH}) and the heat output for the domestic hot water preparation (Q_{DHW}). Usually the SPF is calculated only for the boundary of a heat pump system to express the rate of the total seasonal energy use and production. In this case, SPF_{HP} shows how a heat pump system is influenced and

SPF_{sys} expresses overall solar assisted heat pump system performance.

For the analysis, yearly SPF values are used to compare systems. Parallel system, seasonal performance is calculated by formula (1) which takes into account the electricity use of the heat pump (E_{HP}) and the source pump ($E_{s.p.}$).

$$SPF_{HP} = \frac{Q_{SH} + Q_{DHW}}{E_{HP} + E_{s.p.} + E_{aux}} \quad (1)$$

In this formula (1) only the amount of energy that is produced by the heat pump is taken into account. Solar energy gain is not accounted for in seasonal performance calculation for heat pump boundaries. Circulation pump consumption is calculated only for heat pump working periods.

According to the standard [2] with the chosen boundaries of the system, SPF factor for the yearly period is calculated as presented in formula (2). In this case, the energy consumption of the solar collector system circulation pump was added as E_{pumps}:

$$SPF_{sys} = \frac{Q_{SH} + Q_{DHW}}{E_{HP} + E_{s.p.} + E_{pumps} + E_{aux}} \quad (1)$$

For the parallel system, both heat pump and overall system SPF values were calculated. Due to the solar collector connection to the cold side of heat pump in a serial system, SPF_{HP} value would be equal to SPF_{sys} and annual performance if energy consumption for ground regeneration is not taken into calculations. While the purpose of ground regeneration via solar heat and passive cooling is mainly for source temperature increase – circulation pump electricity consumption is taken into account in SPF_{SYS} calculation.

VIII. Seasonal performance factors

The seasonal performance factor shows simulated system performance for the 5th running year. This makes no sense for solar combi system, but for heat pump systems the running period of the first 5 years is enough to get temperature equilibrium conditions with surrounding ground.

Performance values of the whole system (heat pump and solar collectors) are presented in the following Fig. 8.

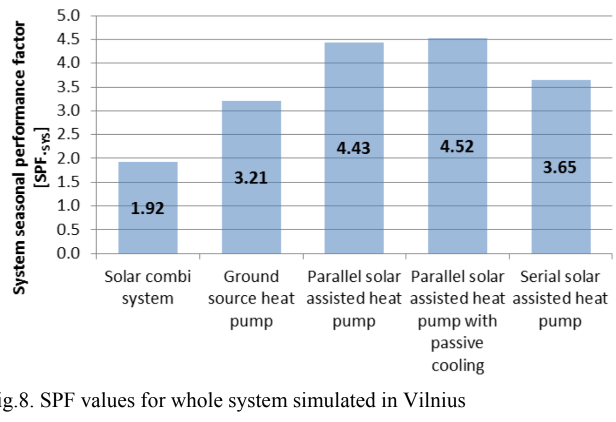


Fig.8. SPF values for whole system simulated in Vilnius

Solar combisystem has the lowest SPF value because of high fraction of heat demand that is covered with direct electric heating in winter months. Pumping electricity needs makes influence to overall system performance when the system over-produces heat in summer. In this period higher part of energy (compared to winter months) is lost due to transmission loss in accumulation tanks.and not propertly used while there is small heat demand.

Stand-alone heat pump at simulated conditions has SPF value of 3.2 for the analysed case. This system does not have overheating of DHW tanks due to easily achievable set point.

Parallel solar assisted heat pump has highest SPF of all simulated systems due to reduced heat pump running time and high fraction of DHW produced. Solar collectors create overheating effect in DHW tanks by raising temperatures for higher than 80°C and contributing to higher losses from tanks in summer season in comparison to stand-alone heat pump system.

Parallel solar assisted heat pump with a passive cooling option has the same operating specifics as a parallel system. Despite the fact that increased ground source temperature ensures higher heat pump COP value, SPF decreases due to circulation pump electricity consumption on passive cooling mode.

For **serial solar assisted system** heat pump runs higher COP values, but electricity consumption appears to be the highest due to increased running time of circulation pumps. While this system do not use solar heat for direct DHW heating, indirect use of solar heat thru heat pump leads to lower operation efficiencies in summer time. For this system SPF_{SYS} value appear 18-60 % lower than in parallel cases.

It is clearly seen that combinations have better performance than stand-alone systems. Presented values are similar (with ±3 % deviation) for all assessed cases in Riga and Tallinn.

IX. Monthly SPF values for heat pump and system boundaries

While the whole system SPF_{SYS} shows the heat pump and solar collectors overall performance, heat pump performance could be expressed by SPF_{HP} value.

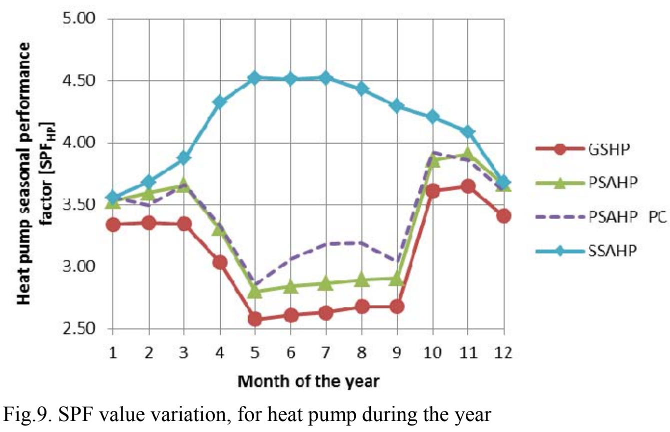


Fig.9. SPF value variation, for heat pump during the year

Fig. 9 shows that the serial system has the highest monthly SPF_{HP} values due to added solar heat to source flow. While there is a 30°C limitation for incoming fluid (to prevent heat pump from overheating and achieve a longer life time) values might be greater, but due to technical reasons SPF could be 27-34 % higher than in a stand-alone heat pump system.

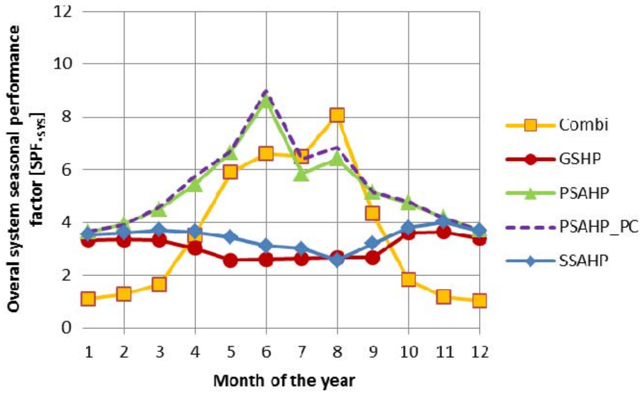


Fig.10. SPF value variation, for the whole system during the year

The parallel system with a passive cooling option has from 12 to 19 % higher monthly SPF_{HP} values. It was not assessed, but these numbers might vary due to heat delivered from cooled building, while increase is caused by a higher heat source temperature.

All systems have from 6 to 76 % higher SPF_{HP} value than a stand-alone system most of the time, due to higher source temperatures. SPF_{SYS} values are 6 to 230 % higher than a stand-alone system.

Systems with solar add-on have slightly greater monthly performance factor values in summer months due to high electrical efficiency of solar radiation transformation to heat. Serial system suffers high electricity consumption for ground regeneration, while heat production process (as shows SPF_{SYS} in Fig 10) has the highest efficiency of all systems.

X. Running Time of Heat Pumps

One of the benefits of solar collector's connection is reduced heat pump running time. This may cause longer life time if hourly start up settings is adjusted properly. In the figure below (Fig 11) running time hours are presented for different systems.

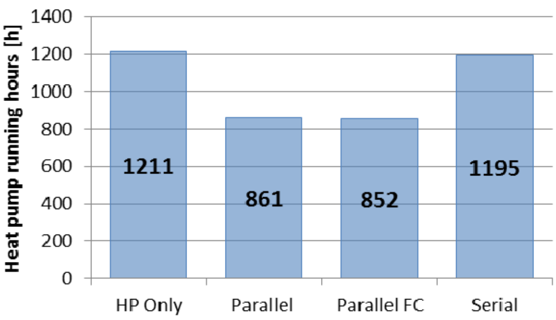


Fig.11. Running time of heat pump in different systems

As shown in figure above, parallel systems have 29-28 % shorter annual running time. Serial system has better heat pump performance factor which could cause a small reduction of running time. In the simulated case, running time reduction is about 1 %.

XI. Ground Temperatures for Long Periods

Quality of heat pump system could be expressed as short and long term temperature decrease intensity. According to good practice rules and manufacturers' recommendations, borehole heat exchangers should be designed with an intention to keep source temperature constant for the long term. In the first five years ground source temperature decreases- after this period, temperatures drop is relatively small. . In combined solar assisted systems, this temperature may be different from that of a stand-alone system. (Fig.12).

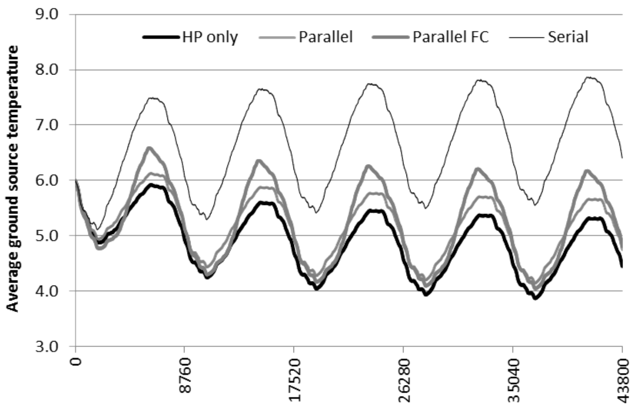


Fig. 12. Ground source average temperature variation

The observed variations could be classified as:

- Natural regeneration – short term (HP only)
- Natural regeneration – long term (Parallel)
- Active regeneration by passive cooling and natural regeneration (Parallel FC)
- Active regeneration/accumulation by heat supply (Serial)

Heat pump performance directly depends on long time ground source temperature, so the prevention of long term temperature decrease keeps annual heat pump performance stable for the whole period of usage.

Average temperature difference from stand-alone heat pump case:

- Parallel system by 0.32°C
- Parallel system with passive cooling option by 0.42°C
- Serial system by 2.14°C

Serial system has highest temperature difference from base case (stand-alone heat pump system) due to active regeneration. But this action causes high electricity consumption and it reflects on the SPF values negatively.

The more rational option – a parallel system with passive cooling has increased long term temperature, but the SPF value for heat production stays constant (in comparison to parallel case without passive cooling) and has a relatively small decrease of annual SPF value due to passive cooling consumption.

XII. Indoor comfort

Since Vilnius has the highest cooling demand and highest risk of unsatisfied comfort conditions, duration of temperatures is presented for system simulated in Vilnius.

For NZEB that is designed according to Passive house standard, passive cooling via floor heating system could not satisfy high loads due to low specific capacity (W/m^2) – priority for shading devices must be taken, to reduce cooling loads to acceptable range.

Quality of comfort was interpreted as temperature duration in building. In figures presented below (Fig. 13 and Fig. 14) temperatures are separated for heating and cooling season. While set point for heating season is 20 °C (with ±1 dead band), higher temperatures appear due to solar heat gains. In summer season the set point is 25 °C (with ±1 dead band). Main cause of overheating is solar heat gains. Temperature durations are shown in Fig. 13.

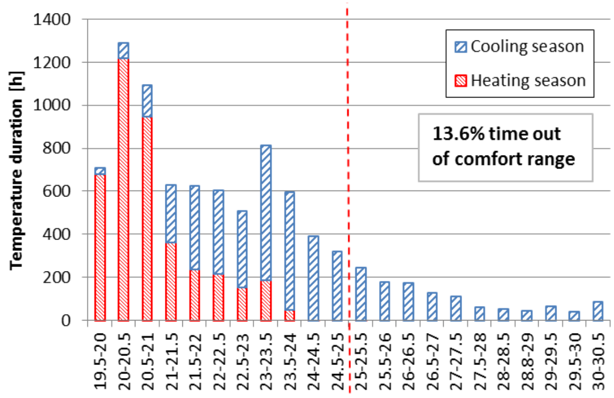


Fig.13. Temperature durations in building without passive cooling

For a system without passive cooling, the length of time whereby the building is overheated may reach up to about 13 % of the year. This result holds true if no actions like increased air change are introduced and heat gains stay stable.

In a passively cooled building, indoor temperatures fit in comfort range almost all year long, except 2.5 % of year, comfort criteria is unsatisfied(Fig 14).

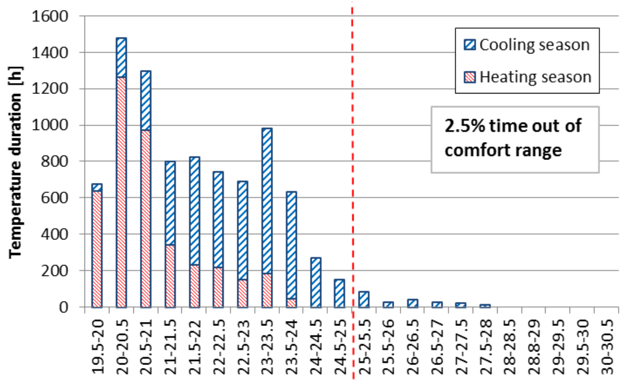


Fig.14. Temperature duration in building with passive cooling

With passive cooling, building internal temperature fits in comfort range, but this option limits usage of other passive cooling strategies like night time ventilation, because it may cause condensation on cooled surface if dew point temperature is reached. According to EN 7730 [27], the indoor floor surface must not fall below 19ºC to stay in a comfortable range. If these conditions are easy to sustain, passive cooling is one option which is available to reduce PE use for building cooling.

Possibility to reduce indoor temperature by using ground source as a heat sink with passive cooling option, creates possibility to reduce energy use for building cooling. This mode has a higher cooling COP than a mechanical cooling process via the heat pump.

For the other cities (Riga and Tallinn), the situation is much better while predicted cooling demands are lower. In some cases when summer heat balance is highly influenced by internal heat gains, this solution could be used.

XIII. Conclusion

1. A combined system performs better than a stand-alone heat pump system. The synergy effect could be clearly seen at parallel connection cases when solar collectors reduce heat pump running time and ground source regenerates naturally.

2. Active ground regeneration can result in lower SPF value due to specifically high electrical energy consumption for ground regeneration. This negative factor could be reduced by optimizing system control strategies. While system performance is not optimized to meet the highest SPF value, seasonal performance seems to be 21 – 26 % lower than in parallel cases, but about 11% higher than for stand-alone heat pump system.

3. Combined systems have more stable long term performance due to passive natural and active ground regeneration. Long term temperature variation proves that combined systems have more stable operation and a possibility to minimize long term temperature decrease in heat source.

4. While cooling demand does not make high influence to energy demands (according to low cooling degree days) it is not recommend installing additional mechanical cooling units due to additional costs. In such situation, passive cooling option with ground source as a heat sink for high temperature cooling seems to be working and cost efficient solution if a condition to use this solution is met.

5. According to similar weather and geological conditions of all Baltic States capitals, same solutions for NZEB buildings could be used to obtain higher SPF value for ground source heat pump systems by adding solar collectors and using passive cooling option.

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