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Analysis of a Novel Solar District Heating System

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Abstract

This paper describes a new residential building area with a solar assisted block heating plant. The building area currently comprises 26 single family buildings, four small multifamily buildings, 6 terrace houses and a nursing home for elderly people with 64 apartments. All buildings are designed for a low heat demand (<45 kWh a^{-1} m^{-2}) and the total heated floor area is 14 000 m^2. The block heating system comprises a central 250 kW wood pellet boiler, about 700 m^2 of distributed roof-integrated solar collectors and a novel heat distribution system. An initial evaluation indicates that designed heat demands, as well as the overall system performance including expected solar contribution, is likely to be met. Reported measurements include annual (April 2013 – March 2014) heat balances for two substations with single family buildings, yearly solar energy gains (August 2013 – July 2014), and a monthly (March 2014) heat balance for the whole system.

Keywords: solar thermal, district heat, hot water circulation, passive houses

1. Introduction

EKSTA Bostads AB (municipal housing company) has built and operates a number of solar assisted heating plants in small residential building areas, the first ones from the 1980's. The heat supply is managed via small district heating systems based on wood chips and/or wood pellet boilers and roof-integrated solar collectors of different generations, i.e. 100% heating by renewables. The buildings, commonly small multifamily buildings, have always had a bit lower heat demand than required by the Swedish building code.

The new building area in Vallda Heberg comprises multifamily buildings, as well as single family buildings, with even lower heat demands than previous areas, and is thus a bit of a challenge for a central heat supply system.

The area is the result of a commercial "partnering" project (carried out together with NCC as the main building contractor). It is a great achievement for all involved stakeholders - housing company, architect, consultants and contractors - as it involves a number of innovative parts and has got a lot of attention in media.

2. System description

2.1. The area

Vallda Heberg comprises 26 single family buildings, four multifamily buildings (4 apartments per building), 6 terrace houses with in total 22 units and a nursing home for elderly people with 64 apartments, all together about 14 000 m^2 heated floor area. A preschool and a few commercial buildings will also be part of the area in the future.

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All buildings are designed as passive houses according to the Swedish standards, i.e. well insulated buildings with air tight envelopes, and supply and exhaust ventilation with heat recovery is applied in all buildings. Roof overhang and balconies provide sun shading to reduce solar gains in the summer period.

2.2. Heat supply

The local district heating system comprises one central heating plant (HP) with a 250 kW wood pellet boiler (and an oil boiler for back-up) and four sub-stations (SS1-4). Buffer storage tanks are installed in the central heating plant and in each sub-station. There are 108 m^2 evacuated tube solar collectors on the heating plant and 570 m^2 flat plate roof-integrated solar collectors in connection to the sub stations (see Fig. 1 and 2 respectively). Solar heat is targeted to cover 40% of the end-use of space heating and domestic hot water.

Fig. 1: Heating plant with evacuated tube solar collectors

Fig. 2: Multifamily buildings with roof-integrated solar collectors

The primary heat distribution between HP and SS1-4 comprises a 2-pipe system between the central heating plant and the sub-stations, using traditional pre-insulated steel pipes. The flat-plate collectors deliver heat to the storage tanks in each sub-station. The cold water inlet of the loop is supplied through the storage to be pre-heated. If the storage temperature is high, the DHW circulation will pass through the storage as well. The primary culvert delivers heat to the secondary distribution loop via a heat exchanger when the solar heat produced by the flat-plate collectors of the sub-station is not sufficient to maintain 57-60°C outlet temperature. A low supply temperature is possible, as the permitted minimum return temperature of a domestic hot water circulation loop is 50°C according to the Swedish building regulations.

The secondary heat distribution system between SS1-4 and the buildings is a so called GRUDIS 2-pipe system (Zinko, 2004) where hot water is circulated in plastic (PEX) pipes, similar to a standard DHW circulation system. Fig. 3 shows the secondary heat distribution system comprising the pipes in an insulating (styrofoam) box buried in the ground. The circulating hot water is also used to heat the buildings when there is a heat demand.

Fig. 3: Secondary heat distribution system

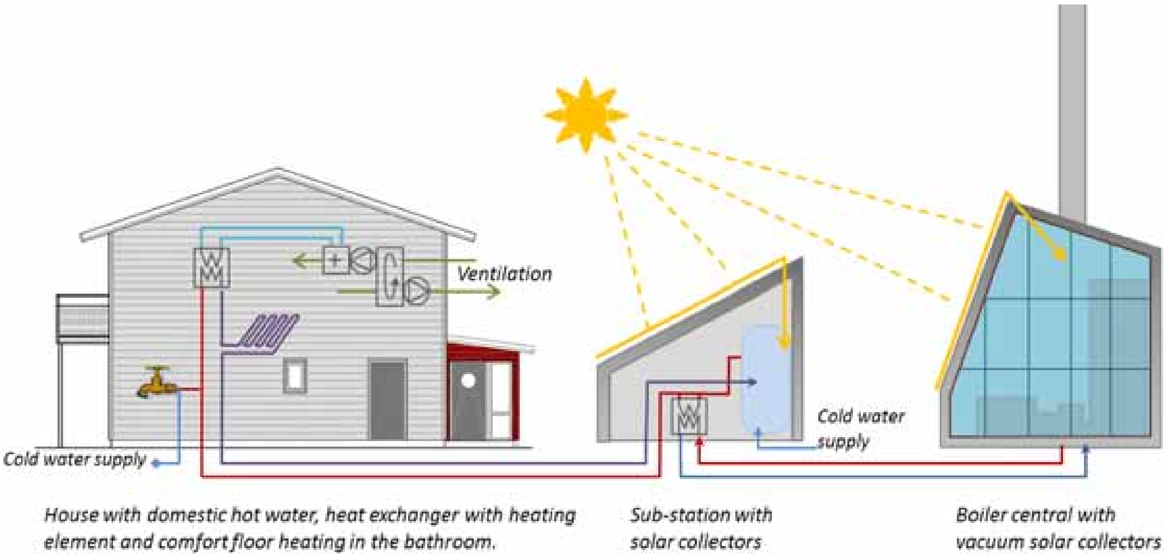

Fig. 4: Simple schematic of the technical system in Vallda Heberg

Fig. 4 shows how the heat for space heating and domestic hot water is delivered from the boiler central via a sub-station to the single family houses, in a simple schematic of the heating system. Sizing of solar system components for the sub-stations are based on the heat load design calculations to have a similar solar fraction (around 40%) in all sub-stations. Distribution of the solar collector areas and the buffer storage volumes in the heating plant and in the four sub-stations are found in Table 1.

Tab. 1: Solar collector aperture areas and storage volumes of the central heating plant and the sub-stations

	HP	SS1	SS2	SS3	SS4
Collector area [m^2]	108	142	48	64	324
Storage volume [m^3]	15	15	5	6	28

2.3. Single family houses

Heat for the single family buildings are supplied by sub-station one and two respectively. Each house has two floors, and a total heated area of 140 m^2. The hot water circulation of the secondary culvert is connected to each individual building. The hot water is delivered directly for tapping and for heated appliances (e.g. washing machines). The circulating flow is passing a heat exchanger for space heating and a floor heating loop in the bathroom and utility room before returning to the sub-station for re-heating. A water-glycol loop delivers heat from the heat exchanger to an air heating coil. Space heating is provided by the air heating coil to the supply air, which is pre-heated by the exhaust air using a rotating heat recovery unit. The schematic of the house units is shown in Figure 5.

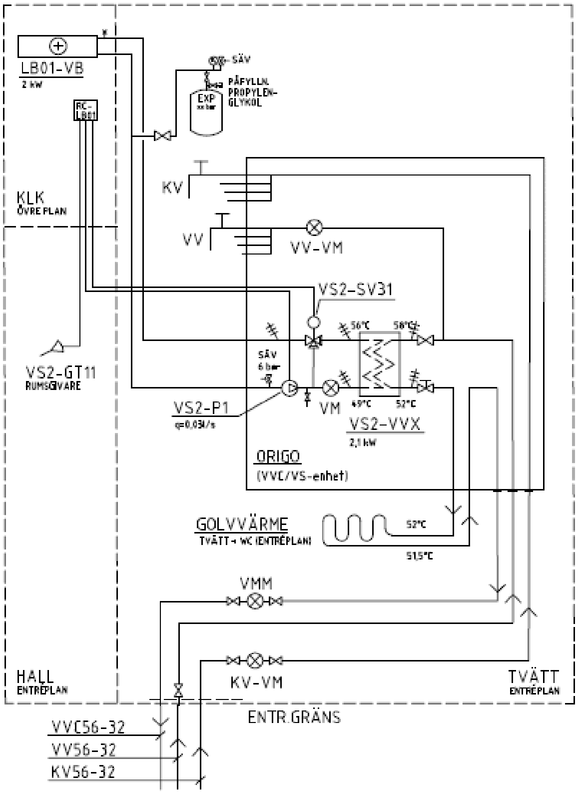

Fig. 5: Schematic for heating and hot water for single family houses. VS2-VVX is the heat exchanger from hot water circulation to the water-glycol loop, and LB01-VB is the air heating coil unit. “Golvvärme” is the floor heat.

2.4. Building area development

The residential area has developed over a period of 2 years. The single family buildings were occupied already at the end of 2012, while the other buildings where occupied late 2013. The heat supply system, including solar collectors, has been put into operation in steps in order to supply heat to occupied buildings. A few commercial buildings have been finished in the summer of 2014.

This paper is mainly focused on the operation of SS1 and SS2 for the period April 2013 to July 2014.

2.5. Design calculations

The buildings have, as mentioned, their heat supplied via four sub-stations (SS). Table 2 summarizes the heat demand for space heating and Domestic Hot Water (DHW) in all buildings connected in the initial building phase, as calculated during the design of the area.

Tab. 2: Calculated heat demands.

	Heat [kWh a^{-1}]	**Units** [-]	**Specific** [kWh $a^{-1}m^{-2}$]	**Total** [kWh a^{-1}]
Single family buildings	7 800	26	55	202 800
Flats in terrace buildings	3 400	22	52	74 800
Multifamily buildings	15 400	4	48	61 600
Commercial buildings	12 700	1	62	12 700
Nursing home	269 000	1	37	269 000
Total				**620 900**
SS1	7 800	19	55	**148 200**
SS2	7 800	7	55	**54 600**

Fig. 6 shows the whole building area with heat distribution systems between heating plant, sub-stations, solar collectors and buildings.

Fig. 6: Building area with central heating plant (right), four sub-stations (red), primary (brown) and secondary (violet) heat distribution, as well as the distribution system for solar heat (green) between the 4 multifamily buildings and sub-stations 1 (at bottom with 19 single family buildings) and 3 (top middle with 22 units in terrace buildings and the nursing home for elderly people). Sub-station 2 is in top left (see also Fig. 11). The 6-7 small buildings shown on the far left and 3 large buildings nearby the heating plant are not yet built.

3. System performance

3.1. The overall system

The connected buildings are designed to have low heat losses and about half of the heat demand is related to the single family buildings. The building area thus has a low heat density, i.e. a low heat demand per heat distribution pipe length, which requires a feasible (low-cost) heat distribution system.

Tab. 3: Measured heat balance for March 2014

	Heat [kWh]	Heat [kWh]	Share [%]
Wood pellet	79 700		86
Solar HP+SS	13 300		14
Heat supply		**93 000**	
Primary distr.	-17 100		
Secondary distr.	-9 300		
Distribution		**-26 400**	28
Heating	-52 100		
DHW	-14 500		
Heat demand		**-66 600**	72

It is not yet possible to have measurements for a complete year for the whole system. Table 3 thus shows the measured heat balance for one month in spring 2014 in order to get an indication of how it will look like for a complete year. The solar heat gains are measured on the primary side of the solar heat exchangers, which is (almost) equal to what is actually charged to the buffer storages. The net utilized solar energy will be less, especially due to storage heat losses.

The result show that solar heat covered 14% of the heat supply and that 72% of the heat supply was used in the buildings and 28% was used to cover heat losses in the heat distribution systems.

3.2. Annual performance of SS1

All sub-stations have their own solar collectors to pre-heat outgoing hot water. The difference between the heat demand in the buildings and the local solar heat is made up by heat from the main heating plant (HP). The heat from the HP includes solar heat from the collectors on the HP. Fig. 7 shows the heat (MWh/month) going into SS1 for the period April 2013 to March 2014.

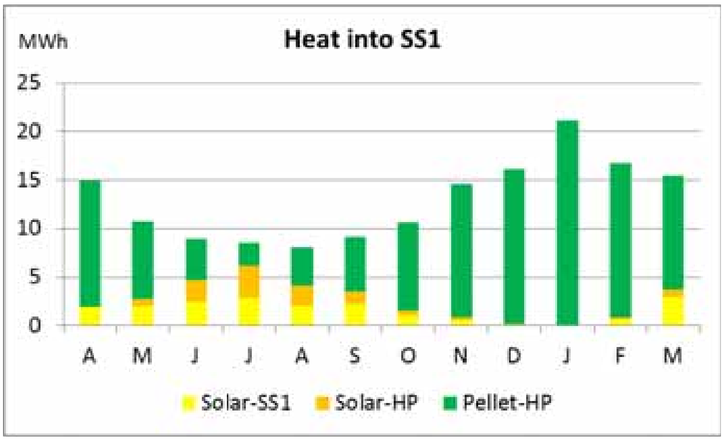

Fig. 7: Heat into SS1, April 2013 – March 2014.

Here it should be noted that Solar-SS1 was not in full operation until September 2013.

The heat (MWh/month) going out from the sub-station covers DHW and space heating in 19 single family buildings, as well as the heat distribution losses. Figure 8 shows the heat going out from SS1 for April 2013 to March 2014. The heat demand in June-August is mainly due to a comfort floor heating in the bathrooms, and is relatively large compared to both the DHW load and the winter load.

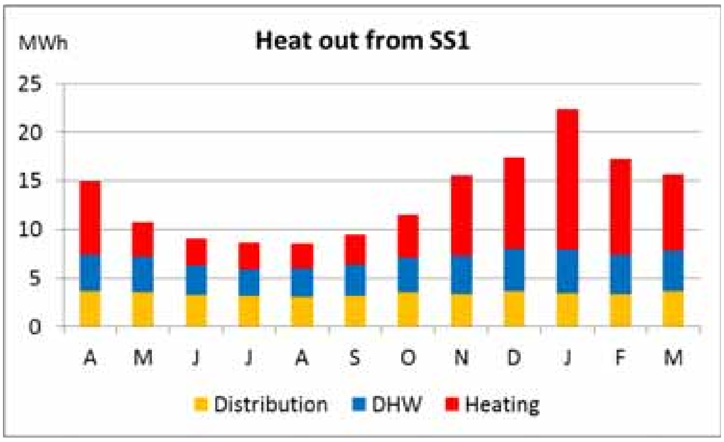

Fig. 8: Heat out from SS1, April 2013 – March 2014

The annual heat balance of SS1 is shown in Table 4. The difference between Heat supply and Heat demand (2%) is due to measurement uncertainties in SS1.

SS1 supplies heat to 19 single family buildings with 2 660 m^2 of heated floor area. That means a heat demand of 29 kWh $a^{-1}m^{-2}$, DHW of 16.5 kWh $a^{-1}m^{-2}$ and in total about 45 kWh $a^{-1}m^{-2}$, for the year measured.

Tab. 4: Measured annual heat balance SS1, April 2013 – March 2014

	Heat [kWh]	**Heat** [kWh]	**Share** [%]
Pellet - HP	124 540		80
Solar – HP	11 460		7
Solar – SS1	19 150		12
Heat supply		155 150	100
Secondary distr.	-40 560		25
Heating	-76 450		48
DHW	-44 010		27
Heat demand		-161 020	100

3.3. Annual performance of SS2

Similar to SS1, SS2 has its own solar system to pre-heat outgoing hot water. The difference between the heat demand in the buildings and the local solar heat is made up by heat from the main heating plant (HP). The heat from the HP includes solar heat from the collectors on the HP. Figure 9 shows the heat (MWh/month) going into SS2 for April 2013 to March 2014.

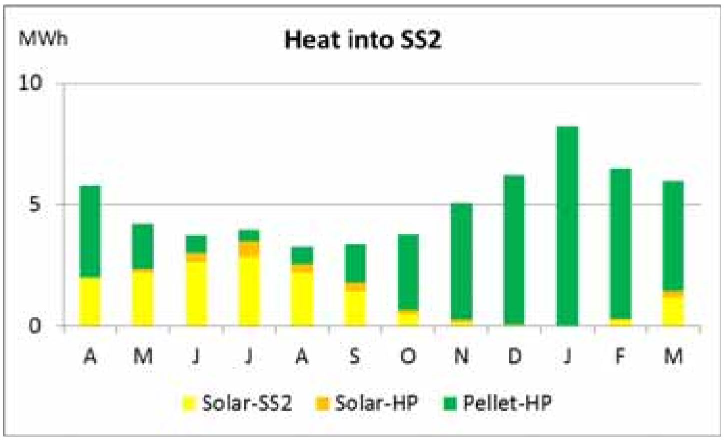

Fig. 9: Heat into SS2, April 2013 – March 2014

It should be noted that Solar-HP was not in full operation until June 2013. The heat going out from the sub-station covers DHW and space heating in 7 single family buildings, as well as the heat distribution losses. Figure 10 shows the heat (MWh/month) going out from SS2 for April 2013 to March 2014.

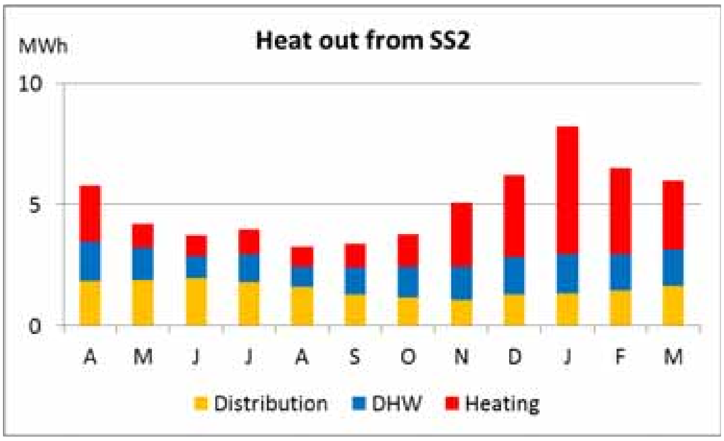

Fig. 10: Heat out from SS2, April 2013 – March 2014

The annual heat balance of SS2 is shown in Table 5. Here it should be noted that the heat distribution losses (including heat losses inside the sub-station) are calculated based on the difference between heat supplied to the sub-station and measurements in the buildings.

Tab. 5: Measured annual heat balance SS2, April 2013 – March 2014

	Heat [kWh]	**Heat** [kWh]	**Share** [%]
Pellet - HP	42 090		70
Solar – HP	2 610		4
Solar – SS2	15 450		26
Heat supply		60 150	100
Secondary distr.	-18 350		30
Heating	-26 140		44
DHW	-15 660		26
Heat demand		-60 150	100

SS2 supplies heat to 7 single family buildings with 980 m^2 of heated floor area. That means a space heat demand of 27 kWh $a^{-1}m^{-2}$, DHW of 16 kWh $a^{-1}m^{-2}$ and in total <45 kWh $a^{-1}m^{-2}$, for the year measured.

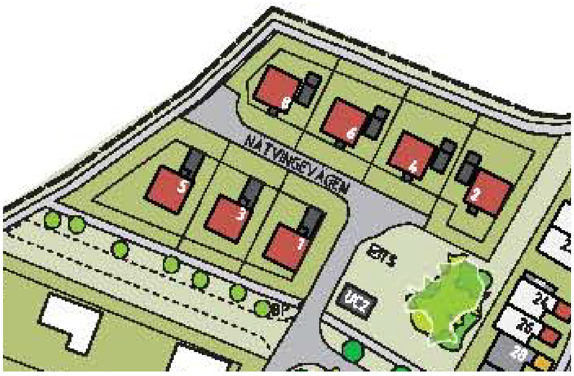

Fig. 11: SS2 (UC2) with 7 single family buildings (1-7)

The heat losses in secondary heat distribution system between SS2 (UC2 in Figure 11) and the buildings add another 19 kWh $a^{-1}m^{-2}$ (30% of total heat use).

3.4. Solar heat

The roof-integrated flat plate (FP) solar collectors are distributed on 7 buildings (see e.g. Figure 2) and inclined 27° (typical roof inclination). The evacuated tube (ET) collectors placed on the heating plant (see Figure 1) are inclined 70° (to reduce over-heating in summer).

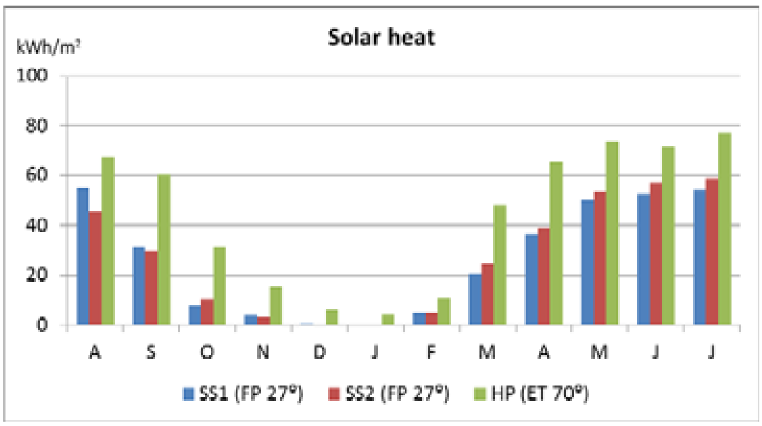

Fig. 12: Solar heat, August 2013 – July 2014

Figure 12 shows the area specific solar heat for SS1, SS2 and HP from August 2013 to July 2014. Solar-SS1 and Solar-SS2 have supplied about the same, around 320 kWh $a^{-1}m^{-2}$, while Solar-HP has gained more than 530 kWh $a^{-1}m^{-2}$, both values based on aperture area.

3.5. Heat distribution losses

The heat losses for the secondary culverts have been calculated based on an energy balance using measured energy entering houses and energy leaving the sub-stations during the period April 2013 – March 2014.

Tab. 6: Secondary heat distribution characteristics

	Length [m]	**Length** [m/unit]	**Heat loss** [kWh a^{-1}]	**Heat loss** [W m^{-1}]
SS1	469	24	40 560	9.9
SS2	215	31	18 350	9.7

Table 6 shows the secondary heat distribution length and heat losses for SS1 and SS2. The average heat loss power is around 10 W m^{-1} heat distribution length.

4. Discussion

The whole system has only been in operation with all residential buildings and solar collectors connected since autumn 2013, while parts of the system have been in operation since 2012.

An initial evaluation was carried out within a master thesis (Olsson and Rosander, 2014). A more detailed evaluation will be carried out by the main author within the Marie Curie "SHINE" project. The evaluation will include a more detailed analysis of the measured performance when data for the whole system for a complete year is available. System modeling will be performed for optimization of solar collector implementation and heat distribution system for similar areas.

4.1. Measurements vs. design heat demand

The initial evaluation based on annual heat balances of SS1 and SS2 together with a monthly heat balance of the whole system shows that the overall system performance is as expected.

Tab. 7: Measurements vs. design for SS1 and SS2

	Measurements Heating + DHW [kWh a^{-1}]	**Design calculations** Heating + DHW [kWh a^{-1}]
SS1	117 010	148 200
SS2	41 800	54 600

Table 7 shows a comparison between measurements for 12 months (Tables 4 and 5) and design calculations for one year (Table 2) for SS1 and SS2. The comparison shows that the measured heat demands in the single family buildings actually are significantly lower than the design heat demands. It should however be noticed that the measurement period was warmer than an average year and that the use of electricity (and thereby the internal gain) of the buildings was higher than in the design values.

The accuracy of the measurements has to be further evaluated. The uncertainty of the energy meter of the heat leaving SS1 is quite high. Due to constant pump flow rate the uncertainty of the measurements is substantial in the summer time, as the return temperature is only one degree lower than the outlet temperature of the sub-station.

4.2. Solar heat

The solar collectors are expected to supply about 400 kWh $a^{-1}m^{-2}$ as an average for all collector fields. The measurements (SS1 and SS2 about 320 and HP close to 530 kWh $a^{-1}m^{-2}$) indicate that the design will be met when all solar collectors are in operation as planned.

4.3. Heat distribution

The large share of heat distribution losses for the primary distribution system is partly due to some sections without buildings (see Figure 6). The share of heat distribution losses in comparison to the heat demand in the buildings will thus decrease as more buildings will be connected.

The building area has a low heat density and long heat distribution pipes in relation to number of units. The worst cases with single family buildings connected to SS1 and SS2, have 24 and 31 m heat distribution pipes per unit respectively. This is longer than recommended for district heating areas considering distribution pipe costs versus the cost of heat (Dahm, 1999).

4.4. Future work

Having domestic hot water circulation in a block heating system is unusual. It has proven to be unproblematic to provide hot water in a safe and stable way (i.e. always above 50°C return temperature). A future more detailed evaluation will show if the advantages with this type of block heating – 100% renewable heat supply including solar heat for a new small building area with low heat demands – will overcome the disadvantages, i.e. mainly relative large share of heat losses. The study will investigate if this solution is operationally and economically beneficial compared to more traditional 2- and 4-pipe block heating systems. It will also investigate whether the sub-station solution (which can also be used for new residential areas close to existing district heating networks) improves the potential of providing feasible solar heating.

5. Conclusions

The new residential area in Vallda Heberg presents a novel combination of low-energy buildings, heat distribution system and solar energy utilisation. As all buildings are passive houses, a large share (25-30%) of the supplied heat is lost in culverts and sub-stations. The system is designed with the intention to cover 60% of the (residential) heat demand by wood pellets and 40% by roof-mounted solar collectors. An initial evaluation shows that the (average) heat demands in the buildings, the solar heat contribution and the heat distribution losses are close to design values. The project shows that solar heat can play a big role in future residential areas connected to block or district heating systems. A more detailed evaluation will show how this type of system can be improved.

6. References

Dahm, J., 1999. Small District Heating System: Design and Performance of Heat Distribution Systems for Residential Areas with Low Heat Demand. Document D48:1999. Buildings Services Engineering, Chalmers University of Technology, Gothenburg, Sweden.

Olsson, H., Rosander, A., 2014. Evaluation of a New Passive House Area with Solar-Assisted Block Heating. Master thesis Report No 2014:14. Buildings Services Engineering, Chalmers University of Technology, Gothenburg, Sweden.

Zinko, H., 2004. GRUDIS-tekniken för värmegles fjärrvärme. Rapport Värmegles 2004:10. Svensk Fjärrvärme, Stockholm, Sweden. In Swedish.