SOLAR COMBISYSTEMS

Task 26

Industry Workshop

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Compiled by Werner Weiss

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

Industry Workshop

Task 26 - Solar Combisystems

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Solar Heating & Cooling Programme

13:00 h	**Welcome Address** *Lars Broman, Chris Bales*
	STAGNATION BEHAVIOUR OF SOLAR COMBISYSTEMS
13:15 h	**Requirements of the international Standardisation to avoid overheating problems** *Jean-Marc Suter, Büro n+1, Switzerland*
13:45 h	**Stagnation behavior of solar combisystems – monitoring results** *Robert Hausner, AEE, Austria*
14:30 h	**Stagnation - Effect on anti freeze** *Dr. Hillerns, Tyforop, Germany*
15:00 h	***COFFEE BREAK***
15:30 h	**Strategies to avoid stagnation problems** Presentations of strategies used in Task 26 combisystems
16:15 h	**Discussion + Questions**
16:30 h	***COFFEE BREAK***
	BIOMASS – AUXILIARY ENERGY FOR SOLAR COMBISYSTEMS
17:00 h	**Exhaust emissions from small biomass boilers** *Lennart Gustafsson, SP Swedish National Testing & Research Institute*
17:25 h	**Health effects of biomass boiler emissions** *Katarina Viktorin, National Institute of Environmental Medicine, Sweden*
17:50 h	**Swiss experiences with solar heating and biomass** *Jean-Marc Suter, Büro n+1, Switzerland*
18:15 h	**Results from measurements of an integrated pellets burner in store** *Stefan Larsson, Vattenfall, Sweden*
18:35 h	**Presentation of a Danish study of solar and biomass heating systems** *Klaus Ellehauge, DTI, Denmark*
18:55 h	**Solar heating system for a new single family house** *Jan-Olof Dalenbäck, Chalmers Technical University, Sweden*
19:15 h	**Discussion**
19:30 h	**End of workshop – Dinner and informal discussions**

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TESTS ON THE STAGNATION BEHAVIOUR OF SOLAR COMBISYSTEMS

Robert Hausner, Christian Fink
Arbeitsgemeinschaft ERNEUERBARE ENERGIE – AEE
A-8200 Gleisdorf, Feldgasse 19
Tel.: +43-3112-5886, Fax: +43-3112-5886-18
e-mail: r.hausner@aee.at, c.fink@aee.at

The standstill behaviour is very important for the long-term, reliable and low-maintenence operation of thermal solar plants. Particularly when it comes to applications for the support of solar heating systems, the standstill behaviour becomes important for manufacturers and operators since these plants are very frequently shut down in the summer since their capacity cannot be fully utilised. This operating state places all the components in the collector circuit under considerable stress, a stress quite different to that encountered in normal operating conditions.

T he behaviour of thermal collector systems in a shut-down state was, therefore, the subject of an examination within the framework of the project supported by the EU »Stagnation Technology for Thermal Solar Systems«" (CRAFT-JOULE programme) with the companies Sonnenkraft, Solvis, Technische Alternative, Tyforop und Scherzinger Pumpen in co-operation with Fraunhofer ISE and the AEE - Arbeitsgemeinschaft ERNEUERBARE ENERGIE. These tests aimed at finding out more precisely how temperatures and pressures develop in the system in standstill conditions. The aim was to support companies to further develop their plants and components in terms of unproblematic and reliable standstill behaviour. To this end, measurements were carried out by the Fraunhofer ISE on test systems and the AEE carried out „in-situ" measurements on three field plants covering two summer periods.

The following report gives the results and findings from the first measurement period from the measurement series conducted by the AEE on the three field plants.

Selection of plant and measurement concept

Three problematic combi-systems were selected in one-family homes of a representative size and with a representative plant hydraulic system, but with a different collector hydraulic system, and fitted with a measuring system. Initial measurements (first measurement period) were then carried out over a few months in the summer. In this respect the following were recorded:

- solar radiation at the collector level and the ambient temperature
- The distribution of temperature in the collector field, numerous temperatures in the inlet and outlet lines, on the expansion vessel and on the heat exchanger in the secondary circuit
- The pressure in the inlet and outlet and on the expansion vessel
- The flow speeds in the inlet and outlet.

Figure 1 gives the example of a hydraulic circuit (correct scale geodetic heights) of a plant measured with a gross collector area of 44 m² (flat collectors) and a storage tank of 4,5 m³ with the measuring points sketched in. Figure 2 gives the Southern view of the building belonging to this.

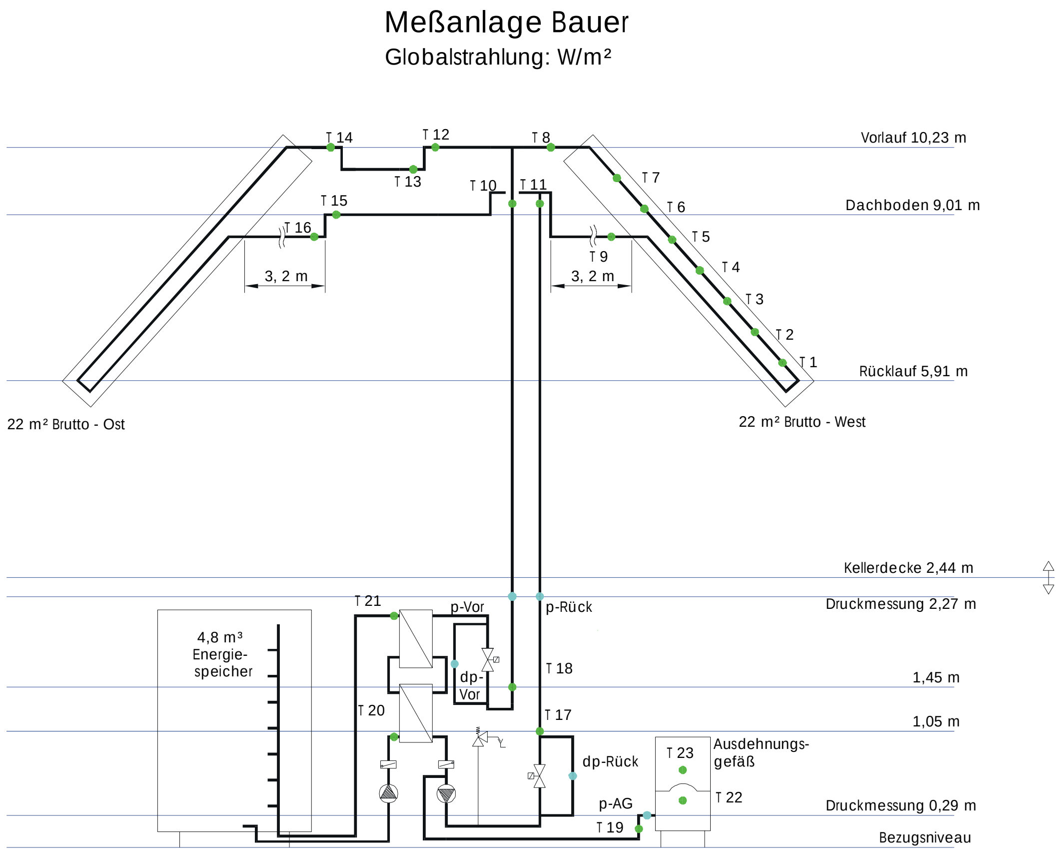

Fig. 1: Hydraulic and measuring concept of a plant with a collector area of 44 m² and an energy storage tank volume of 4,5 m³.
Measuring line Bauer/global radiation: Wm^2
inlet, roof/attic, outlet, gross – East /West, cellar ceiling, energy storage tank, pressure measurement, expansion vessel, pressure measurement, reference level

Figure 2: Southern view of Bauer one-family home

The goal of these measurements was to quantify respectively explain the standstill phenomena observed such as

- High temperature loads through to areas in the pilot plant area and any malfunctions of system components resulting from this as well as any possible leaks
- Opening of the pressure control valve although the usual design guide-lines have been adhered to with regard to the size of the expansion vessel and the pressure conditions
- Condensation pressure shocks in the primary and secondary circuit of the solar plant

As well as to elaborate adjusted/adapted planning and design guide-lines.

Description of procedures during stagnation

On the basis of the measurements performed, the stagnation procedure generally takes the form of the scheme which follows, divided into several phases, apart from differences arising from differences in the type of plant, that the arrangement of the flap trap in the evaporation process allows the expansion vessel to be filled with liquid both from the inlet as well as from the outlet line.

Phase 1 Liquid expansion

After disconnecting the collector circuit and the secondary circuit pumps from the normal operating condition, the collector temperatures rise again quickly in a regular manner until such time as the evaporation process begins in the upper area of the collector on one part of the absorber strip. Up to this point, the increase in the system pressure is only very slight.

Phase 2 Pushing the collector empty

The beginning of evaporation complies with the boiling point which results from the local pressure predominating at this point on the collector. Initially the boiling point is relatively low. A small portion of the medium evaporates and pushes a larger share of the liquid content of the collector out until such time as the inlet and outlet lines are immersed in saturated steam. The pressure rises relatively quickly as a result of this since large amounts of liquid are pushed into the expansion vessel. With a simple collector hydraulic system with – in the direction of flow – only horizontal or rising pipe pieces, the larger share flows via the outlet line (return line) (content of collector) and the smaller share via the inlet line (communicating vessels). With more complex collector hydraulic systems – a mixture of rising, horizontal and falling pipe pieces – the emptying behaviour also becomes more complex.

The system pressure rises rapidly in this phase as does the boiling point in the area filled with saturated steam. This phase lasts for only a few minutes.

At the start the temperatures of the outlet and inlet lines in the heating room and the inlet line to the expansion vessel are low (cooled down following the pump standstill) and then later on they rise (hot collector content), however, they never reach the original high collector temperatures due to cooling down losses in the lines. If these lines are short and have low cooling down losses then non-permissible high temperature loads can occur in the expansion vessel and other system components particularly when with a highly selected system pressure evaporation does not start until the temperatures are higher. Long and non-insulated lines to the expansion vessel reduce the temperature load of the latter quite considerably.

Phase 3 Emptying of collector by boiling - phase with saturated steam

This is the phase when the rise in pressure slows down. A smaller but not insignificant share of the content of the collector is still present in the absorber and collecting pipes in liquid form. In this phase either a liquid medium, or saturated steam in equilibrium with liquid are observed at all measuring points. The inlet and outlet lines are increasingly pressed empty downwards in the direction of the heating room with about the same level of liquid (communicating vessels) and the heat exchanger can be reached by steam. This also causes steam to form on the secondary side of the heat exchanger. The pressure on the expansion vessel reaches its peak value and thus also the temperature of ebullition.

The energy led off from the collector by means of steam (this results from the collector efficiency rate at high temperatures and with due consideration to the stored energy) is always in equilibrium with the heat losses of the area under steam in the pipelines, fittings and on the heat exchanger. In line with the principle of the heat pipe energy is hereby transported very effectively at what is almost a constant temperature from the source of heat to all heat sinks whereby the steam condenses again here and runs off down the way in liquid form. The differences in temperature between the source of heat (collector) and the heat sink (e. g. heat exchanger) are small (on a scale of a few K) since there are only slight differences in pressure (flow pressure losses with regard to steam, but differences in concentration also exist in the system water-glycol – fractionated distillation). This means that the maximum pressure reached (on the phase border between steam - liquid) determines the maximum temperature load of the plant components reached by the steam in accordance with the relation of pressure – temperature of ebullition.

At the beginning of this phase the temperatures of the outlet and inlet lines in the heating room and the inlet pipe to the expansion vessel fall since the steam area now increases in size much more slowly and the lines filled with liquid cool down. A sudden rise in temperature up to the boiling point occurs only when steam occurs in these places.

Phase 4 emptying of the collector by boiling - phase with saturated steam and superheated steam

The liquid begins to completely evaporate in the upper collector area. These areas superheat. As a result the collector efficiency rate decreases even further and the amount of energy to be transported away by steam decreases so that the energy amount also drops and so that the ”loss area” in the plant can also decrease. The steam volume decreases even if the solar radiation remains the same. The pressure in the plant drops (which also means the saturated steam temperature) and liquid is pushed slowly out of the expansion vessel into the outlet line (return line). The back flap prevents the latter on the inlet side. If the superheating areas in the collector continue to expand, the plant pressure falls even further and the liquid level of the outlet reaches the collector inlet. The inlet fills up slowly with condensate.

The superheating phase can take a few hours on cloudless days and ends when irradiation is on the decline.

Phase 5 Refilling the collector

The collector is refilled via the outlet lines whereby the temperatures drop quickly. The refilling of the inlet line takes place in a slightly delayed manner as a result of the condensate.

Additional comments

With more complex plant and collector hydraulic systems, more complex as well as periodic procedures overlap the behaviour described (sinus or saw tooth like pressure and flow fluctuations with periodical lengths of some seconds up to a few minutes) which are in part explained by the pipe guidance (up and down) within and outside the collector.

Maximum temperature and pressure loads occur in the plants on clear days with intermittent clouds rather than on cloudless days. The latter results in a very high diffuse share of the radiation and global radiation at the plain of the collector reaches extreme values in the short-term.

THE BEHAVIOUR OF HEAT TRANSFER MEDIA IN SOLAR ACTIVE THERMAL SYSTEMS IN VIEV OF THE STAGNATION CONDITIONS[1]

Dr.rer.nat. Frank Hillerns
Tyforop Chemie GmbH
Hellbrookstr. 5a, 22305 Hamburg
Phone/Fax: ++49-40-61-2169/5299
e-mail: hillerns.@tyfo.de

Dipl.-Ing. Hans Schrimpf
BASF AG
ESB/AV-J550, 67056 Ludwigshafen
Tel./Fax: 0621-60-42468/20995
e-mail: hans.schrimpf@basf-ag.de

Abstract

On-going technical development of solar collectors significantly raise the demands to the heat-transfer medium regarding its ability to take thermal stress. However, stagnation temperatures of up to 200 °C in flat plate collector systems still can be mastered by *conventionally inhibited* solar fluids. In contrast to this, absorber temperatures of up to 300 °C as reached in evacuated tubular collectors require the application of a more advanced medium containing *reversibly evaporizable* corrosion inhibitors. Practial application experiences concerning such a recently developed fluid are in the meantime available.

1. Introduction

Water is predestinated to function as a heat-transfer medium in solar active thermal systems. This is on the one hand due to its outstanding thermophysical properties, e. g. highest specific heat and thermal conductivity, and lowest viscosity of all the fluids considered for heat carriers. On the other hand, water is non-toxic, non-flammable, cheap, and easily available. However, parameters that reduce its general suitability are: corrosivity to metals and alloys, precipitation of hardness constituents at higher temperatures, and a relatively small temperature range of operation determined by its freezing and boiling point, respectively.

It is well known that this application range can be extended when aqueous solutions of inorganic salts, monohydric alcohols, or dihiydric alcohols (glycols) are used. In spite of very effective freezing-point depression and good thermal transport properties, salt solutions are not applicable for solar systems due to uncontrolable corrosivity at temperatures > 0 °C. On account of better material compatibility, favorable viscosity, and low costs, methyl and ethyl alcohol solutions have been widely used since 1920 till the early seventies in automotive cooling as well as in many other applications. Unfortunately, methanol and ethanol are toxic and readily volatile due to low boiling points (meth: 64 °C, eth: 78 °C) [1], hence depressing the boiling points of its aqueous solutions.

In comparison with monoalcohols, ethylene and propylene glycol (b. p. 197 °C, 188 °C) [2], cause similar freezing-point depressions, but simultaneously raise the boiling points of its mixtures with water. Regardless higher costs and inferior thermophysical properties, nowadays non-toxic propylene glycol is exclusively used as the basic compound for solar heat transfer media instead of „injurious-to-health“ classified ethylene glycol.

2. Solar Media - General Demands and Composition

Heat transfer media have to meet a variety of challenging requirements to ensure trouble-free operation of the solar system over a long period of time:

[1] Based on a presentation held at 9. Symposion Thermal Solar Energy in Staffelstein, May 5-7, 1999

- Frost resistance down to -50 °C maximum
- Thermophysical properties equivalent to water
- Non-inflammability
- Corrosion protection for metals and alloys
- Compatibility with sealing materials
- Endurance under thermal stress conditions
- Prevention of deposits and foaming
- Low ecotoxic potential, biological degradability
- Long-term stability
- Reasonable price

As already stated above, water is in general corrosive to metals. Factors that strongly govern the grade of corrosivity are the content of oxygen, pH value, temperature, and presence and concentration of dissolved chemical substances. The latter point is of great importance regarding practical use of „pure“ propylene glycol / water solutions: compared to neat water as well as to neat propylene glycol the corrosivity of those mixtures is significantly enhan-ced - in inverse proportion to the glycol concentration. Hence this effect must be compen-sated by addition of inhibitors, which predominantly prevent corrosive attack by forming thin protective layers on the metal surfaces.

Solar systems typically consist of different materials like copper, brass, solder, steel, grey cast iron, and (rarely nowadays) aluminium. Unfortunately there is no universal inhibitor available hitherto. Thus several organic and inorganic compounds possessing metal-spe-cific protective potentials have to be combined to an efficient, low-toxic and environmen-tally friendly *inhibitor package*. Table 1 displays the composition of a conventional solar fluid concentrate based on propylene glycol, suitable for common solar installations (equipped with flat plate collectors, stagnation temperature 200 °C max.).

Compound	**% w/w**	**Function**
Propylene glycol	92 - 94	Frost resistance
Salts of organic acids	3 - 4	Ferrous metal protection
Silicates	< 1	Aluminium protection
Triazoles	≤ 0.2	Yellow metal protection
Borax	1 -1.5	Reserve alkalinity
Potassium hydroxide	< 1	Reserve alkalinity
Water	3 - 4	Solvent for inhibitors
Stabilizer, dispersant, defoamer, dye	0.1 - 0.3	Stabilization of water hard-ness, defoaming, coloration

Table 1: Composition of a conventional Solar Fluid (Concentrate)

3. Conception and Design of Solar Systems

The life-span of thermal solar systems strongly depends on the grade of corrosion stress the several components are subjected to. To minimize corrosion problems and hence reach the aim of long-term and trouble-free operation, both installation and fluid must be optimally adapted to each other. Assuming correct application and performance of the heat transfer medium, important plant technology parameters in this respect are operation temperature, heat flux, flow conditions, and electrochemical effects caused by mixed installations or external voltages. Special attention is to be paid to keep the internal metal surfaces free of encrustation or scaling. Inhomogeneously covered surfaces implicate lower heat transfer efficiency giving rise to locally increased temperatures, which cause thermal stress to the medium and accelerated corrosion in those areas. Explicitely to be mentioned in this con-text is black cupric oxide which forms at high temperatures in the course of component production or system assembly (hard-soldering) due to local overheating of copper surfaces in presence of oxygen. Such insoluble scale can be mechanically detached by the hot solar fluid, but this occurs slowly and in most cases only partially. Subsequently, those dispersed particles often sedimentate in low flow areas and may lead to blocking of collector tubes and filter elements as well as to pump malfunction.

4. Increased Collector Efficiency - Increased Thermal Stress to Solar Fluids

4.1. Systems equipped with Flat Plate Collectors

Dynamic development of solar technology over the last decade has led to improved corrosion resistance of components like pumps, membrane expansion vessels, and of course collectors. Consequently, corrosion damages in flat plate collector systems are nowadays rarely to be observed. Simultaneously achieved enhancement of collector efficiency on the other hand causes remarkably increased thermal stress to the heat transfer medium due to now possible stagnation temperatures of up to 200 °C.

Propylene glycol / water based solar fluids are subject to premature aging at such temperatures, indicated by darkening of the fluid and a slowly decreasing pH value. Chemically speaking, propylene glycol then undergoes decomposition in the course of oxidation reactions. Acidifying organic compounds, e. g. lactic, oxalic, acetic, or formic acid [3] are formed, which initially can be neutralized by the reserve alkalinity (ref. table 1) to a certain extent. But due to limited concentration of buffering substances, repeated overheating finally brings the pH of the fluid down to values < 7, hence the system is not protected against corrosion anymore. It can be said in general that velocity of propylene glycol degradation is proportional to temperature stress and oxygen concentration. Further acceleration effects caused by the presence of unprotected copper surfaces and heavy metal ions have been reported [3].

Taking the above mentioned facts into consideration, it becomes essential to prevent the medium from exposure to excessive temperatures over longer periods of time, especially during stagnation state. A precautionary measure proven to be worthwile in practice is to install expansion vessels of suitable size to ensure that all of the medium can drain out of the collector when stagnation temperature is reached. The „stagnation scenario“ can be described in a simplified way as follows: locally formed vapour bubbles - in fact a small quantity of vaporized propylene glycol / water - are pushing the main quantity of still liquid medium out of the collector when evaporation starts. Recalling that conventional heat transfer fluids consist of water, propylene glycol *and* dissolved solid inhibitors, it is evident that small amounts of those non-evaporizable components will remain on the hot tube walls. Hence another important quality feature of conventional heat transfer fluids is reversible dissolvability of such residues when stagnation has terminated and cooled fluid streams through the collectors again. On the one hand, insufficient or lacking re-dissolvability may incur deteriorated performance up to blocking of the collector. Corrosion risk on the other hand is enhanced due to depletion of inhibitor concentration in the fluid.

4.2. Systems equipped with Evacuated Tubular Collectors

Stagnation conditions in flat plate collectors still can be mastered by using conventional solar fluids with suitably formulated inhibitor packages to meet the above described requirements. Anyway, such media reach its limits of application when it comes to evacuated tube collectors. Here absorber temperatures up to 300 °C can be reached, thus causing accelerated propylene glycol degradation, indicated by darkening and pH drop already after several hours. Under permanent stagnation, irreversible fluid damage takes place within two to three weeks, meanwhile considerable amounts of dark insoluble residues were builded.

It became evident that further improvement of the inhibitor package was necessary to avoid formation of deposits as well as to offer enhanced buffer capacity to control the glycol decomposition even under such extraordinary thermal stress. A theoretically simple, but in view of its development nevertheless sophisticated remedy is the use of a *liquid* inhibitor package. In case of stagnation those components will be evaporized together with propylene glycol and water, thus the collector remains completely emptied and no damaging insoluble residues may lead to flow obstruction or blocking.

In practice, recent experiences obtained from properly designed solar systems equipped with evacuated tubular collectors show that even temperatures up 300 °C can be mastered by this new medium. Anyway, it must be emphasized again that under those conditions the lifetime will be generally reduced. Annual lab check concerning e. g. density, concentration, inhibitors, and pH is therefore highly recommended. Supposing that one of the mentioned parameters is found to deviate from the required values during analysis, the solar fluid must be replaced immediately.

6. References

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[2] Ullmanns Encyclopedia of Industrial Chemistry, 5th ed. Weinheim, Volume A 10 (1987) 101-115, Vol A 22 (1993) 163-171

[3] W. J. Rossiter Jr, P. W. Brown, McClure Godette, The determination of acidic degradation products in aqueous ethylene glycol and propylene glycol solutions using ion chromatography. Solar Energy Materials 9, 1983

EMISSIONS FROM SMALL BIOMASS BOILERS

Ph. D. Lennart Gustavsson
Swedish National Testing and Research Institute
Box 857, SE-501 15 Borås, Sweden
Tel. #46 33 165523
Fax #46 33 191979
e-mail: lennart.gustavsson@sp.se

Abstract

Small-scale combustion of biomass may be an important part of a sustainable society. Biofuels are considered to be CO_2-neutral and hence do not in principle contribute to the green-house effect. However, all combustion give rise to some emissions. In this case, the range of emission levels is very broad, depending on which kind of fuel quality and which kind of combustion equipment that is used. In this paper, an overview of today´s emission levels is given. Also, a discussion of what can be considered as long-term sustainable levels are included.

Introduction

Small-scale combustion of biofuels is not by definition environmentally acceptable. Products of incomplete combustion (PIC), e.g. carbon monoxide, methane, volatile organic compounds (VOC), polycyclic aromatic hydrcarbons (PAH) are emitted at different levels. In addition, particulates as well as nitrogen oxides occur in the flue gases. These emissions have both environmental and health effects.

Today´s emission levels

Emission levels of PIC´s differ very much depending on which kind of combustion equipment that is used. During the last ten years, a dramatic technological development for wood-fired domestic heating boilers has taken place. The introduction of down-draught combustion, ceramically insulated combustion chambers and staged air supply has decreased the emissions of hydrocarbons with more than 90 %, see Fig 1. However, most of the boilers used in Sweden is still of the old type, meaning that the emissions are very high. Emissions of methane from such an old boiler contributes to the green-house effect nearly as much as would the use of oil do [1]. In addition, certain VOC´s as well as PAH´s and particulates have adverse affect on man´s health. It is therefore most important that these old boilers are replaced with boilers with new technology as soon as possible.

In Table 1, a comparison of emissions from different heating systems for a one-family house is made.

Table 1: Emissions from different domestic heating systems per net kWh

Type of combustion	Tar, mg	VOC, mg	NOx, mg	Particu-lates, mg	CO_2, mg
Gas firing	-	-	200	-	200 000
Oil firing	-	80	200	120	360 000
Traditional wood boiler	2 500	10 000	350	1 800	-
Modern wood boiler	30	300	520	80	-
Modern wood stove	50	700	n.a.	80	-
Pellet boiler	20	160	240	160	-
Pellet stove	20	120	n.a.	n.a.	-

n.a.: data not available

Again, the most important fact is the high emissions from old, traditional boilers. But still, even modern boilers and stoves emit PIC´s (tar and VOC). Mainly this is due to the large fuel size compared to e.g. oil which is atomised prior to combustion. Also the batch-wise combustion of wood makes optimisation of air supply etc. difficult. To overcome the fuel size problem, pellets combustion may be a solution. As seen from Table 1, PIC´s from pellet combustion is lower than from wood combustion. The pellet combustion technology is still in it´s infancy, and technological developments may well lead to even lower emissions.

NO_x emissions are higher from modern boilers than from old ones. This is a result of the higher combustion temperatures used. The problem should not be exaggerated, since small-scale combustion of biofuels only contributes to 0,5 % of the total NO_x emissions in Sweden. However, if small-scale combustion of biofuels should play a major role in a future more sustainable society, replacing oil combustion, the problem must be adressed seriously.

Particulate emissions from small-scale biomass combustion is not very well known. Also in this case, modern wood boilers should emit significantly less than old ones. Pellet combustion in turn may emit more than modern wood boilers. However, it is perhaps not the absolute emission levels which are of prime interest, but the particle size distribution. Preliminary experiments indicates that particulates from biomass combustion are small, <1 µm, which makes them adverse to man´s health, since they can penetrate deeper into the lungs.

Future´s demands

Biomass combustion is in principle an important part of a sustainable society. For small-scale devices, a tremendous decrease in emissions has been achieved during the last ten years. However, further technological development is needed, especially if small-scale biomass combustion should increase in densely populated areas.

Emissions of PIC´s from wood-fired boilers and stoves may be reduced by 50-75 % with the aid of better combustion chamber geometry and advanced control technology (new cheap sensors etc). Incorporating catalyzers in boilers and stoves may well lead to a further reduction of 50-75 % of PIC emissions within 10 years.

Concerning pellet combustion, new products where the VOC emissions are about 25 % of the values in Table 1, are now introduced on the market. Assuming the same technological development as above, which should be easier for pellet burners, products with VOC emissions of about 10-20 mg/kWh may be on the market within 10 years. This means that small-scale biomass combustion should be very near really sustainable emission levels of PIC´s.

Not much has hitherto been done concerning NO_x optimization in small-scale devices. Since the knowledge is there in larger scale applications and in fuel oil burners, it should be rather easy to decrease NO_x emission levels by a factor 2. For pellet combustion, the fuel quality is strongly influencing emission levels, and must be seriously adressed in the future.

The most important question concerning sustainability for biomass combustion is emission of particulates. On one hand, the particles are small, penetrating deep into the lungs; on the other hand particles may contain substances which possibly make the particulates less dangerous to health [2]. What is definitely clear is that much more research in this area is needed, both concerning levels and characteristics of the emissions as well as concerning health effects. Such research has recently been initiated and may give some answers within the next years.

References

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[2] Kjällstrand., J.: Methoxyphenols in Smoke from Biomass Burning. Licentiate Thesis, Chalmers University of Technology, Dept. of Chemical Environmental Science, Gotheburg 2000.

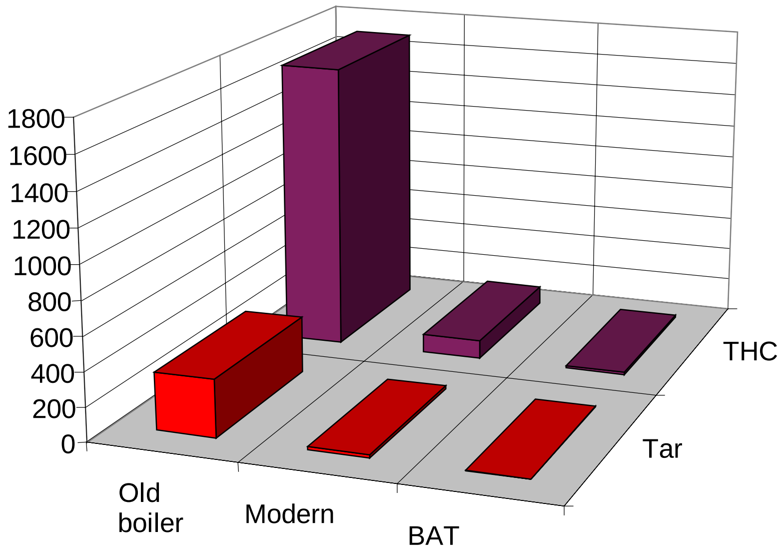

Fig. 1: Comparison of emission from different types of wood boilers

SOLAR COMBISYSTEM WITH INTEGRATED PELLET BURNER IN STORE

Stefan Larsson
Vattenfall Utveckling AB
Älvkarlebylaboratoriet
814 26 ÄLVKARLEBY
SWEDEN
Tel: +46 26 838 01
Fax: +46 26 838 10
Email: stefan.larsson@utveckling.vattenfall.se

Abstract

A small combisystem with an integrated pellet burner in store has been monitored during a one year period. The purpose of the project was to join solarheating with a biofuel burner and a store in the same system making a attractive concept for the Swedish market. One main concern was the store heat losses in the solar-pellet system. Therefore the system was equipped with high grade insulation in a thicker layer then previously manufactured stores has been made. Measurements of the prototype system showed that the internal combustion chamber for the pellet burner is giving extended heat losses in the area of the exhaust connection and around the lid of the combustion chamber when compared to the same storage tank used without pellet burner (allthough the lid itself are well insulated). This means that thick insulation with low losses at the store is not enough in this type of system. Additional developments have to be made to insure low total losses.

1. Introduction

In the Swedish R&D program (FUD Solvärme 1996-99) a lot of effort has been made to achieve lower costs in both solar collectors and system components (i.e. store, pumps, controllers, tubing). Due to the need of supplementary energy from other heat sources and the fact that gas is not avaliable in all of Sweden biofuel and oilfuel systems are more common than gas. The typical system in Sweden is often a solar SDHW system with a biomass boiler of some kind. If this system type is to be cost effective considering the Swedish level of energy costs all unnessesary components and heat losses should be eliminated. The typical Swedish biomass boiler usually have a separate storage tank. In use the heated water is then pumped from the boiler to the store with some cind of control system in between. This means that the system has two hot bodies with a relativeley large surface area, with pipes and valves giving extra heat losses. A few biofuel boiler manufacturers in Sweden has developed a single body system where the boiler and the store share the same water container. Experience from these solutions indicates that the annual effeciency is higher than the standard system due to lower heat losses in the single body system. The cost of the single body system is reduced mainly because no pumpsystem between the boiler and store is needed.This is also reducing the installation cost. One parameter that is difficult to predict exactly is how large the systems total specific heat losses will be due to the increased conductive heat losses around the combustion chamber and exhaust pipe connection (whitch is made of stainless steel). The Swedish company Stocksbroverken AB manufactures heat stores mainly for use in solar and biofuel systems for the domestic market. Stocksbroverken AB has developed a solution where the combustion chamber is mounted in a standard store of 750 litres hence giving around 640 litres of water avaliable for storing heat. The system is equipped with a patented combustion chamber designed with adjustable heat exchanger surface area (i.e. it is possible to adjust the amount of heat extracted from the gases to a specific power level or to fit different pellet burners).

2. The combined Solar- & Pelletsystem – general design

The system consists of a flat plate solar collector of 7,5 m², and a 750 l storage tank. The store has a insulation layer of 90 mm Polyurethane (λ 0,028 W/mK). One solar loop heat exchanger is located in the lower part of the store. The solarloop is protected against freezing with a mixture of propylene glycol and water. The collector itself is internally connected as a serpentine absorber designed for low flow (approx 2 litres/m²minute) and the solarloop heat exchanger is extracted physically between the bottom of the store up to 2/3 from the top. A differential temperature controller equipped with overheating protection is used for start/stop of the solarloop pump. In addition to solar collector and pellet burner there is an electrical immersion heater located near the top of the store used as a supplemental heating source during the summer period when the pellet system works with lower effiency. Two heat exchangers made of finned copper tubes are used for DHW preparation. The pellet combustion chamber and heat exchanger tubes are located in the top region of the store heating 35 % of the total water volume when its active.

3. Measurement setup

In fig. 1 the solar – pelletsystem measurement setup is illustrated in principle. The annual DHW and heating load was monitored and controlled with a Campbell Scientific CR10 module. Magnetic valves controlled the hotwater outlet to a specific daily pattern, see fig. 2. This setup has been used in several other projects in the Swedish R&D program [1] with the same load pattern except for the heating load that was used.

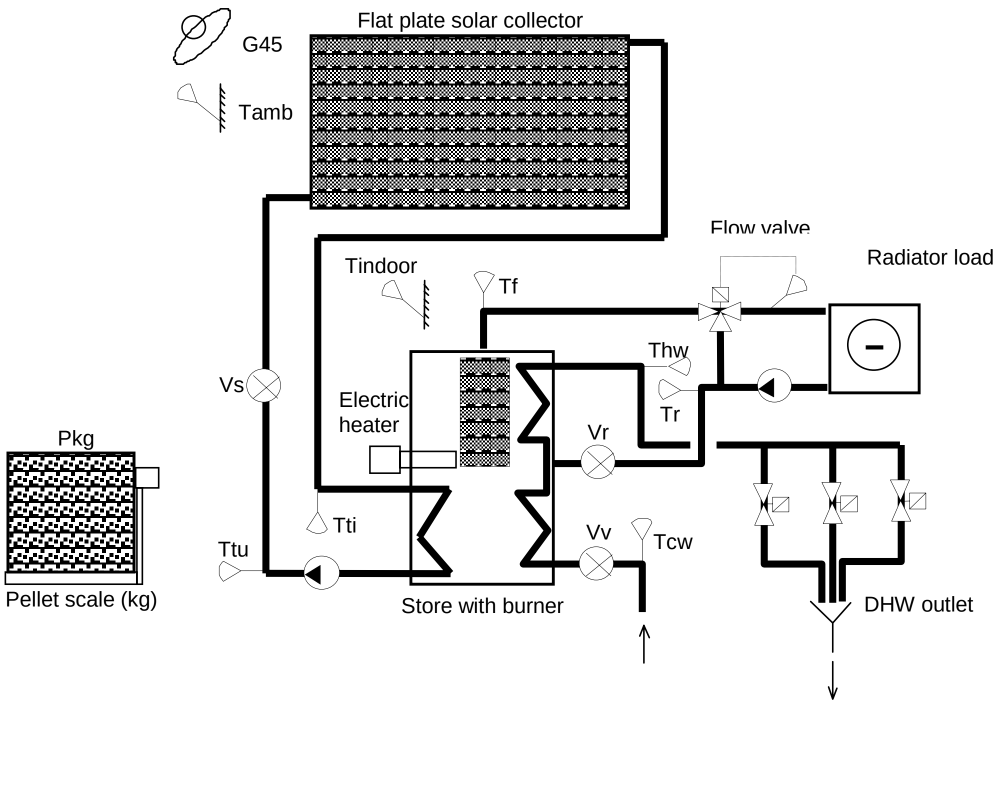

Fig. 1 Principle drawing of the system with sensors included

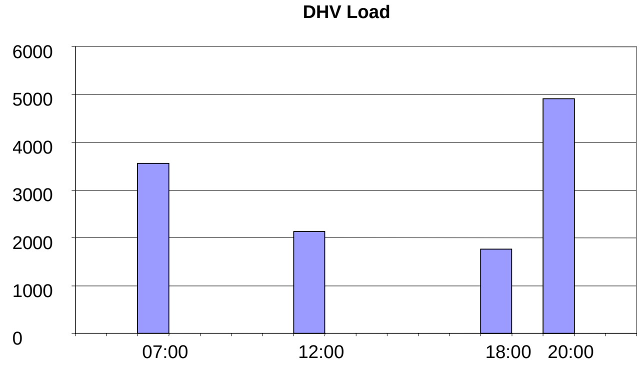

Fig.2 Daily DHW load used in the setup (i.e. 4 individual tappings per day).

4. Results

In fig. 3 the annual balance of delivered energy to the system is presented in a diagram. With a total heating load of 25000 kWh the monitored systems annual solar fraction was 11 % of the total energy used and 58 % of the annual DHW load (i.e. DHW load 12 kWh/day or 4380 kWh/year). The solar collector total energy output was 2542 kWh and with 7,5 m² apperture used it equals 339 kWh/m². The annual insolation (total at 45 degrees apperture angle) during the same period in Älvkarleby was 969 kWh/m².

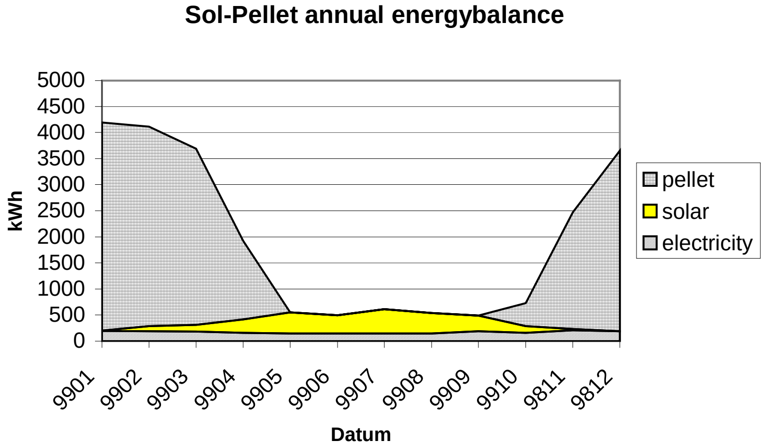

Fig 3. Diagram shows the annual energybalance of the system during the period

Typical for the system function is the presence of electrical heat used during periods where the solar collector is giving more power then the heating load requires. The system also uses some electrical heat during the winter period when pellet normally is to be used. This unnessesary use of electrical energy was primarily caused by the use of two separate control units for the electrical immersion heater and the pellet burner. By using a different control strategy this could be prevented and as a result maximising the use of biofuel. A secondary cause was times when the burner flame went out (the burner can not automatically fire itself up again). The control unit for the solarloop had no significant features apart from the standard differential control function when analysing results in the time scale of single days the system is working properly. An example of the solar output at a single day is presented in fig. 4.

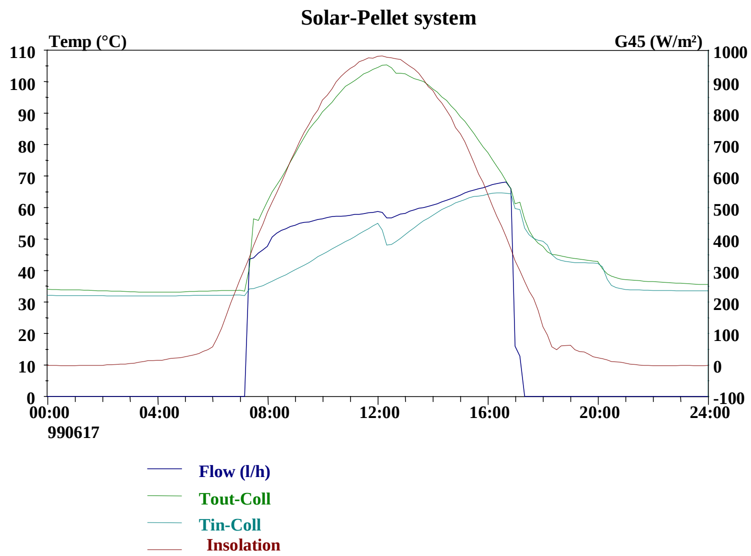

Fig. 4 The diagram shows the daily input/output from the collector

The effiency of the pellet burner was 85% during the half year winter period it was used. The amount of pellet used during the period was 4.042 kkg (tons). Both at the beginning and near the end of the period measurement of the pellet burner emissions was made. There was some differences between the two (i.e. the level of CO and HC) and the results is here shown as average from the latter measurement in fig.5. In this diagram results from the pellet burner emissions from a test made at the Swedish National Testing and Research Institute (SP) is also shown.

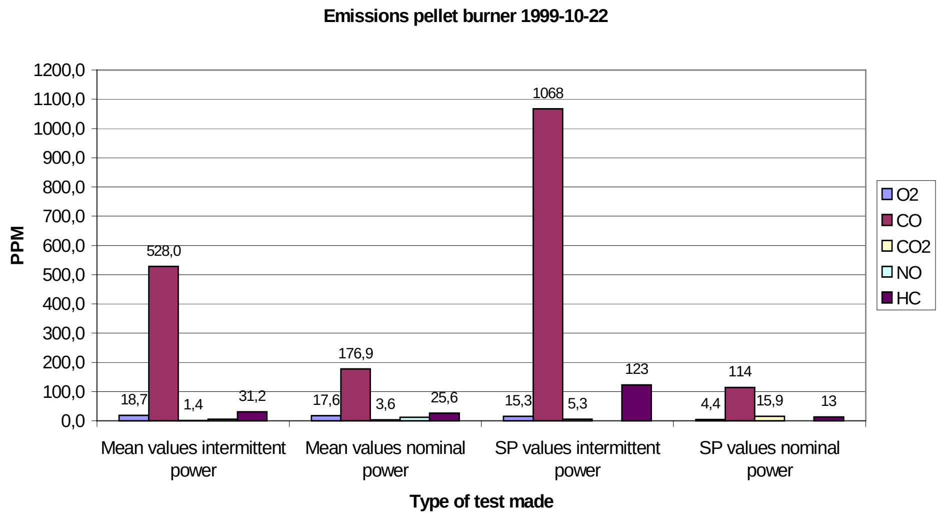

Fig. 5 The diagram shows results from pellet burner emission tests.

The pellet burner controller is operating as a on/off device. As a result of the control strategy the burner is giving extended exhaust emissions when at stand by between firing periods. During each period of nominal power the emissions are low. This means that the average emissions over time is greatly dependent of the systems load, store capacity and nominal power of the burner. In fig. 6 a diagram with short time window is presented were all the parameters are sampled once every second and stored once every minute. First in the left in the diagram there is a period with no power and the burner is only feeding fuel and air once every 10 minutes (could be varied if nessesary). Next (middle section of the diagram) there is a period of nominal power with the burner working under near optimal conditions. And at last to the right in the diagram there is another ”no power” period (stand by mode).

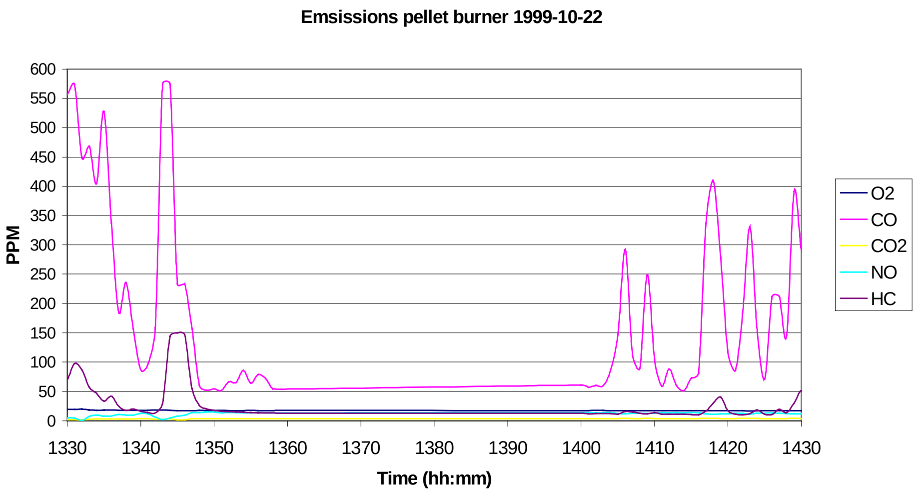

Fig. 6 The diagram shows emissions during different types of load with on/off control strategy

Tests to determine the power of heat losses in the store was performed by using the internal electrical immersion heater as energy source. By heating the store to a fixed temperature and simultaniously monitoring the amount of energy input needed to maintain the temperature the average heat losses (i.e. as continous power consumtion) was calculated. In the test power input (P_{loss}) the store temperature (T_{store}) and ambient temperature (T_{amb}) was monitored during a 5 day period. The store temperature was 65°C and ambient around 20°C during the heat loss test. In total the store losses was 290 W in average as shown i fig. 7.

$$q_S = \frac{P_{loss}}{T_{store} - T_{amb}}$$

With the formula used:

The specific heat loss was caculated to be 6,4 W/°K. Assuming that half of the store is heated with the electric immersion heater. In summer conditions all of the store is heated by the solar collector thus giving a assumed specific heat loss of 12,8 W/°K. Calculations of the store heat loss with insulation λ 0,028 (W/m°C) and thickness 90 mm around the whole storage surface was made and the results indicates values around 65 W total without pipe connection losses included and approximatly some 115 W with pipe connections included. If so the additional heat losses due to the presence of the combustion chamber lid and exhaust outlet connection raises the losses with approx. 175 W.

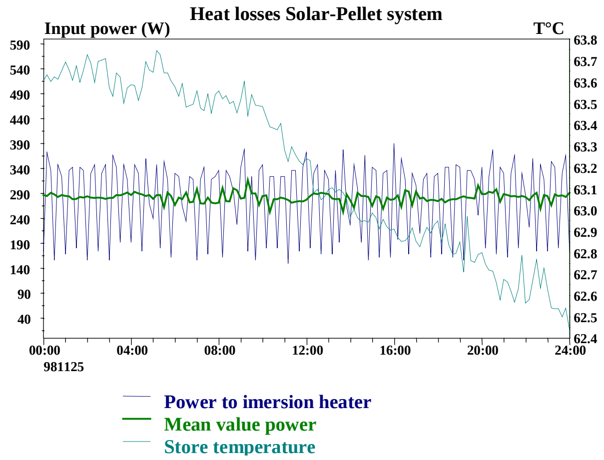

Fig. 7 Store heat losses at 45 degrees Δt (°K)

The final prototype of the store with its pellet burner used in the test is presented in fig. 8 The pellet burner is mounted and shows in the front end of the store.

Fig. 8: The final prototype used in the test with the burner

5. Discussion

According to recently made tests of other other biofuel systems with external store [2] a typical value of the specific heat loss is ranging from 3,5 to 9,9 W/°K. The result of 6,4 W/°K shows that the heat losses is lower then many of the other tested systems of standard configuration with external store. Hoewer if the lid of the combustion chamber and exhaust connection was to be better insulated the calulations indicates that it could be possible to achieve a specific heat loss around 3,5 to 4,0 W/°K. The results also indicates that further simulations and sensitivity analysis could give som additional information of the optimum relation between load, store capacity and nominal burner power. Another key feature of importance is the possibility to increase the annual solar fraction at the used heating load. Due to the lack of monitored data of systems at the same load the conclution made so far is that the system performance is as could be expected, concidering the system technology used.

References:

[1] Helgesson A., FUD Solvärme 1996-99, Annual report 1999 UR 99:03, Vattenfall Utveckling AB, Älvkarleby 1998.

[2] Kovacs P. and Sandberg M., Testing of store systems for biofuel boiler systems with solar heat, SP AR 1998:13, Swedish National Testing and Research Institute

STUDY OF COMBINED SOLAR AND BIOMASS HEATING SYSTEMS IN DENMARK

Klaus Ellehauge
Solar Energy Center Denmark
Technological Institute, Energy
Teknologiparken, DK-8000 Aarhus C, Denmark
Tel: +45 89 43 85 13/+45 72 20 13 70
Fax: +45 89 43 85 43/+45 72 20 12 12
E-mail: klaus.ellehauge@teknologisk.dk

Abstract

Since 1998, a study of combined solar and biomass fired heating systems for one family houses has been carried out in Denmark in order to investigate problems and advantages of the combination.

12 systems have been inspected and among these 3 systems have been monitored.
Problems experienced at some of the inspections have been:

- oversized boilers compared to heat demand
- undersized storage volumes compared to boiler
- safety problems at some boiler installations (illegal installation)
- too small or too large solar collectors
- insufficient insulation

Some systems seem ok.

The monitoring has shown big differences in heat losses from installations and differences in solar gain. One of the systems has a considerable heat loss from the circulation piping for the domestic hot water. This means that the solar heating system has not been able to deliver enough energy at any time of the year, while at the other two systems the boiler has been turned off for 18 weeks in summer.

1. Introduction

Within the past couple of years we have in Denmark experienced an increasing number of heating systems combining solar and biomass. A large number of these systems are fired automatically with wood pellets, while others use manually fired wood boilers. The systems using wood pellets could be considered as a combination of a separate boiler and a separate solar heating system. However, the systems with manually fired boilers are often designed to use the same storage for the solar heat and the heat from the boiler.

Especially the latter combination appears in a number of different designs and a study to obtain the first experience from such systems in Denmark has therefore been carried out and is about to be finished.

12 systems have been inspected and among these 3 systems have been monitored for a year while monitoring of a fourth system has just started.

2. Experience gained from inspections

Most of the systems have been with two tanks. There are a few "tank in tank" storages in the Danish market. However, they are too small for most boilers so most designs combine a "tank in tank" with an extra tank in parallel or they have a large storage combined with a domestic hot water tank.

A general problem at most inspections has been oversized boilers compared to the heat demand.

This gives rise to low efficiencies in spring and autumn (and in summer if not turned off) and often the storage is not large enough to contain the heat from one combustion period.

Further problems have been safety problems at some boiler installations (illegal installation). In Denmark, closed expansion in connection with the boiler is not allowed and it is not allowed to have valves between the boiler and expansion.

Other problems are e.g. too small or too large solar collectors (not allowing the boiler to be turned off during summer or overheating problems) and insufficient insulation together with many piping connections causing large heat losses.

3. Experience gained from monitoring

At first, 3 systems were chosen to be monitored. For reference purposes one of the monitored systems (Øster Hornum) did not have a combined storage, but an automatically fired wood pellet burner and a storage only for solar.

Late in the project period a new system - inspired by already gained experience - was installed at Samsø. This system had one tank combined with a heat exchanger for hot water preparation and was combined with a combined wood boiler and oven (5 kW for the water side and 5 kW for radiation and convection to air). The monitoring of this system has just been started.

Data of the systems are:

	Area of house	**Collector area**	**Tank volume**	**Boiler capacity**	**Boiler type**
Hadsund	250 m²	12 m²	750 + 1000 liter	31 kW	manual
Helsinge	240 m²	12 m²	500 + 1850 liter	24 kW	manual
Øster Hornum	180 m²	12,5 m²	500 + 160 liter	48 kW	automatic (pellets)
Samsø	200 m²	15,6 m²	750 liter	10 kW	manual + oven

Monitored results during 1999 have been:

	Heat demand	**Solar gain (brutto)**	**Boiler**	**Heat losses**	**Period boiler turned off**
Hadsund	23200 kWh	1490 kWh	22250 kWh	1000 kWh	18 weeks
Helsinge	40700 kWh	4803 kWh	45700 kWh	9750 kWh	0 weeks
Øster Hornum	32100 kWh	4750 kWh	27840 kWh	1020 kWh	18 weeks

As it appears there are big differences in the heat loss from installations and there are also differences in solar gain. The poor solar gain in Hadsund is mainly due to a less efficient collector facing west. The system in Helsinge has a big heat loss from the circulation piping for the domestic hot water. This has meant that the solar heating system has not been able to deliver enough energy to turn off the boiler at any time of the year.

SOLAR HEATING SYSTEM FOR A NEW SINGLE FAMILY HOUSE

On the Performance and the Economy of a New Combined Storage and Boiler

Jan-Olof Dalenbäck
Building Services Engineering, Chalmers University of Technology, Göteborg
Tel.: +46-317721153 - e-mail: jod@vsect.chalmers.se

ABSTRACT

The study is concerned with a solar heating system connected to a new combined storage tank and pellet boiler for new single family houses. The modelling was carried out by using TRNSYS. The total average heat supply of a typical Swedish single family house (A-Hus 'Samarkand'), located in Göteborg and using heat recovery on ventilation air, is estimated to about 8 500 kWh/a, incl. 3 000 kWh/a for heating of domestic hot water. A standard solar heating system, i.e. using a boiler connected to a separate solar tank, will contribute solar gains with about 1 500 kWh/a, or 17 %, using 5 m² of solar collectors and 300 litres of storage volume. The performance of the studied system, comprising 5 m² of solar collectors and a combined storage/boiler vessel with 270 litres of water volume, is slightly worse in comparison to the standard solar heating system. However, a slightly improved collector or a small increase in collector area will generate the same performance in terms of solar gains.

The study also comprises an economic comparison between present heating system alternatives in typical Swedish single-family houses. The total annual costs for common combinations of heat supply, space heating and ventilation systems, are all about 1 450 Euro/year incl. VAT. The permissible marginal cost for the studied solar heating system varies between 350 and 3 200 Euro, depending on the circumstances. The studied system shows a marginal cost of the order of 1 700 Euro.

INTRODUCTION

This paper relates to development project no 16227-18 carried out by TeknoTerm Energi AB and Derome AB with part financing from the Swedish National Energy Administration and Vattenfall AB (Dalenbäck, 1999). The studied system is now marketed by Effecta-Pannan AB.

The project comprises three parts. First, development and testing of a pellet boiler with integrated heat exchangers for solar circuit and preparation of domestic hot water together with the sizing of a roof-integrated collector unit. Second, a study on the thermal performance in a new single-family house (using TRNSYS) and third, an economic study regarding the economic prerequisites in a new single-family house. The study is based on "Samarkand"; a typical house with 118 m² heated living area (A-hus).

SYSTEM DESCRIPTION

"Pellet boiler"

Based on a questionnaire to single-family house owners it was decided to evaluate a system that is less space demanding than an ordinary solar system. Thus, the system comprises a "pellet boiler" with integrated heat exchangers for the solar circuit. The system is created by putting a pellet burner chamber and inside heat exchangers in a standard wood boiler. The resulting water volume is 270 litre.

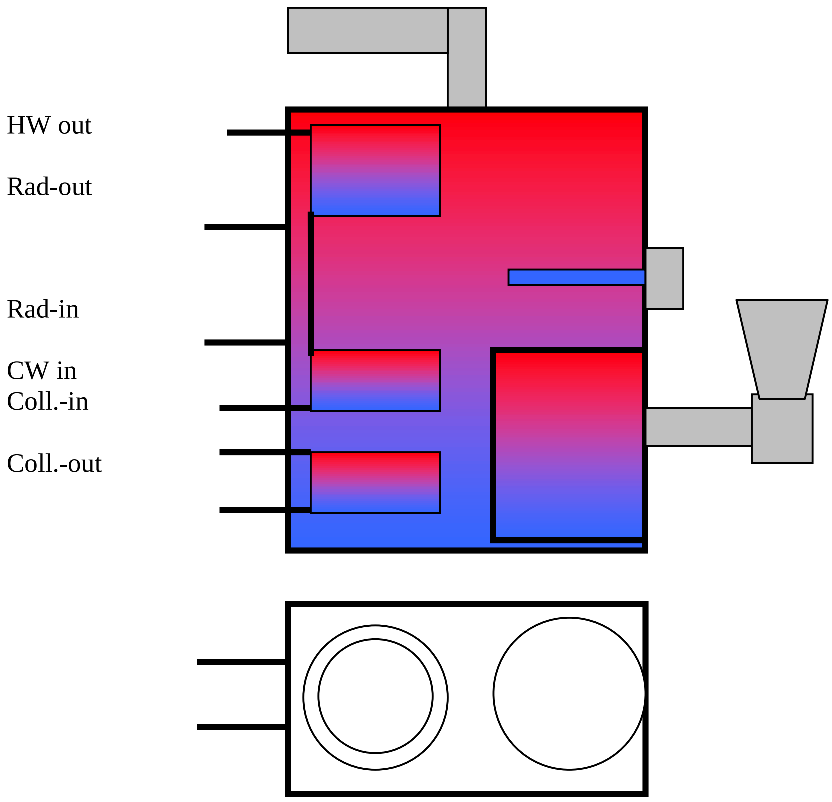

Fig. 1 Pellet boiler with integrated heat exchangers for the solar circuit and domestic hot water preparation.

The boiler is also equipped with an electric heater mainly to be used together with collector operation and no space heat demand. The boiler has a restricted storage volume that puts restrictions on the collector area as well as the solar fraction. However, using wood pellet makes it less important to achieve a high solar fraction.

Space heating and ventilation system

The thermal performance of the solar system as well as the total cost of all other equipment depends on how the house is designed (size, overall U-value, orientation, etc.) as well as how the space heating and ventilation systems are chosen and designed.

The use of a pellet boiler makes it interesting to use a radiator system designed for e.g. 80/40°C (instead of 55/45°C), which should lead to a reduced investment cost. This can than be compared to the improved thermal performance using a floor heating system with lower temperature demands. Furthermore, it is interesting to study the influence of heat recovery (on ventilation losses) on the overall heat demand and the solar fraction.

The thermal performance analysis is performed in the way that the boiler is placed in the house and that the boiler losses will make up a part of the heat demand during times with heat demand.

Thermal performance

The study on the thermal performance was carried out as a 'studienarbeit' by Kai Albers, TU Berlin, at the department of Building Services Engineering, Chalmers University of Technology (Albers, 1999). The study is concerned with the detailed modelling of a solar heating system connected to a combined storage tank and pellet boiler for new single family houses.

The modelling was carried out using TRNSYS in two major steps. First, the thermal performance of the building, a single-family house (A-Hus 'Samarkand'), with its heating and ventilation systems and window area orientations, was simulated. The output heating load files were then used as input for simulations regarding the performance of the solar heating system, using the same weather data.

The total average heat supply of this typical Swedish single family house, located in Göteborg and using heat recovery on ventilation air, is estimated to about 8 500 kWh/a, incl. 3 000 kWh/a for heating of domestic hot water. A standard solar heating system, i.e. using a boiler connected to a separate solar tank, will contribute solar gains with about 1 500 kWh/a, or 17 %, using 5 m² of solar collectors and 300 litres of storage volume. The performance of the studied system, comprising 5 m² of solar collectors and a combined storage/boiler vessel with 270 litres of water volume, is slightly worse in comparison to the standard solar heating system. However, a slightly improved collector or a small increase in collector area will generate the same performance in terms of solar gains.

Solar and boiler system cost

The cost for the combined boiler and storage is estimated to about 3 000 Euro which is about the same as for a separate (smaller) pellet boiler and a separate storage tank with 300 litre. The cost for the pellet burner adds up another 1 800 Euro which makes a total system cost of 4 800 Euro (excl. VAT).

The cost for the roof-integrated collector, actually a roof module with an integrated collector, varies from 140 to 200 Euro/m² aperture area (excl. mounting and VAT) depending on the size. Here we are considering a slightly improved collector module (improved insulation, anti-reflex coated glass) with 5 m² of aperture area or a slightly larger collector with 6.5 or 7.8 m² aperture area. The cost is in both cases estimated to come below 1 200 Euro (excl. mounting and VAT) in a first test series. Taking ancillary equipment and mounting into account the total marginal cost for the solar system is estimated to about 1 500 Euro (excl. VAT).

Furthermore, this system is planned to have a pellet storage situated in the cold attic. With pellet data as follows: 1 m³ - 3 000 kWh - 650 kg, the storage should contain 3.5 m³ or 2 300 kg pellet in order to cover the annual requirements, 8 500 kWh in this case, with 80% boiler efficiency.

ECONOMIC PREREQUISITES

System combinations

The study is based on a comprehensive collection of component costs including installation in the actual house (A-Hus, Samarkand) carried out by Andersson & Hultmark Ing.byrå AB. The study comprises different heat supply (i.e. boilers, etc.), space heating and ventilation systems. The design heat demand (at –16 °C ambient temp.) amounts to 5 kW without and 3 kW with heat recovery on ventilation.

Heat supply
Electr. boiler (3 and 5 kW)
Pellet boiler (ca 7 kW)
Exhaust air HP (incl. electr. boiler 3 and 5 kW)
Exhaust air HP (incl. mech. supply air fan and 3 kW electr. boiler)

Space heating system
Radiators 80/40 °C design temp. (designed for 3 and 5 kW)
Radiators 55/45 °C (3 and 5 kW)
Floor heating 45/30 °C (3 and 5 kW)

Ventilation
Mech. exhaust (ME)
Mech. exhaust with heat recovery (MEX)
Mech. exhaust and supply with heat recovery (MESX)

The total investment costs for 10 realistic combinations are put together using the component costs, see Table 1. Oil and gas boilers are seldom used in new single family houses in Sweden and are excluded.

Comb.	Heat supply	Radiators	Ventilation
1	El.boiler - 3 kW	55/45 - 3 kW	MESX
2	El.boiler - 3 kW	80/40 - 3 kW	MESX
3	El.boiler - 3 kW	55/45 - 3 kW	MEX + kitchen fan
4	El.boiler - 5 kW	55/45 or floor heating - 5 kW	ME + kitchen fan
5	El.boiler - 5 kW	80/40 - 5 kW	ME + kitchen fan
6	HP (El.boiler 5 kW)	55/45 or floor heating - 5 kW	ME + kitchen fan
7	Pellet boiler	80/40 - 5 kW	ME + kitchen fan
8	Pellet boiler	80/40 - 3 kW	MESX
9	Pellet boiler	80/40 - 3 kW	MEX + kitchen fan
10	HP (El.boiler 3 kW)	55/45 - 3 kW	MES + kitchen fan

Table 1. Studied combinations for A-Hus, Samarkand.

Here a radiator system designed for 55/45 °C and 5 kW shows about the same cost as a floor heating system (typical 80 W/m² floor area) and can be considered as equal (see comb. 4 and 6). A radiator system designed for 80/40 °C is less expensive than a 55/45 system, thus all combinations with pellet boiler (comb. no 7-9) include a radiator system designed for 80/40 °C. It should be noted that radiators designed for 80/40 °C are usually not allowed according to the Swedish building code as the maximum allowed supply temperature is 55 °C.

Cost comparison

The total investment costs regarding chosen combinations are shown in Figure 2. Combination no 5 with electr. boiler, radiators 80/40 and a simple ME-system is the least expensive, below 6 000 Euro excl. VAT, while combination no 8 with pellet boiler, radiators 80/40 and an MESX-system is the most expensive, about 10 600 Euro.

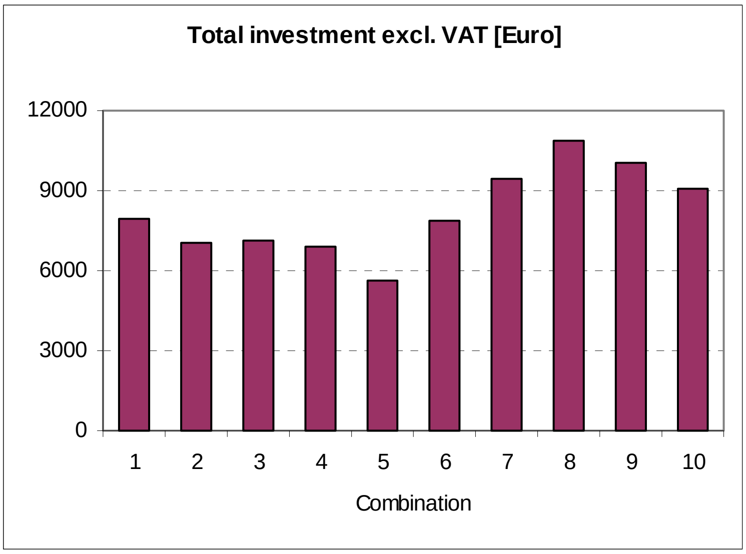

Fig. 2 Total investment costs for combinations shown in Table 1.

The different combinations have different heat demands depending on ventilation system and different energy demands depending on type of heat supply system. Based on Albers work and the assumption that the Seasonal Performance Factor (SPF) is 3 for the heat pump alternatives the heat and energy demands are as shown in Figures 3 and 4.

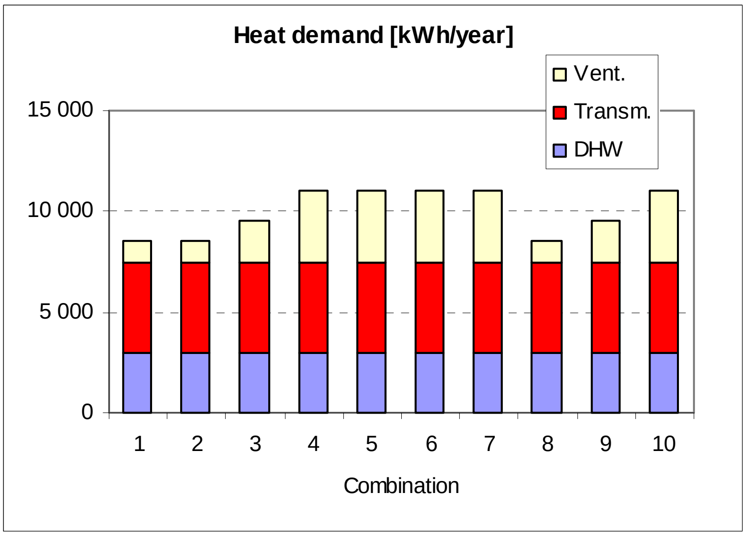

Fig. 3 Heat demand for combinations shown in Table 1.

Combinations no 1, 2 and 8 show the lowest heat demand as they include MESX-systems and combinations no 6 and 10 show the lowest energy demand due to the heat pumps. Combinations no 7-9 uses mainly pellet while all other combinations are based on electricity. All combinations are assumed to cope with the Swedish building code regarding energy demand, but combinations no 4, 5 and 7 may be close.

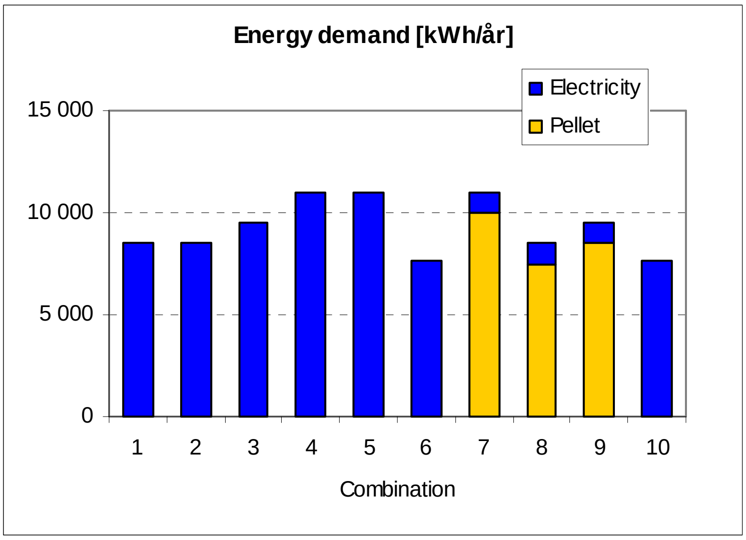

Fig. 4 Energy demand for combinations shown in Table 1.

In order to evaluate combinations which are the most favourable from an economic point of view we apply the following assumptions. The annual capital costs are based on an average depreciation of 20 years and 6% interest rate (annuity 0.09), electricity price 0.07 Euro/kWh and pellet price 0.03 Euro/kWh (incl. VAT). The total heat costs are shown in Figure 5.

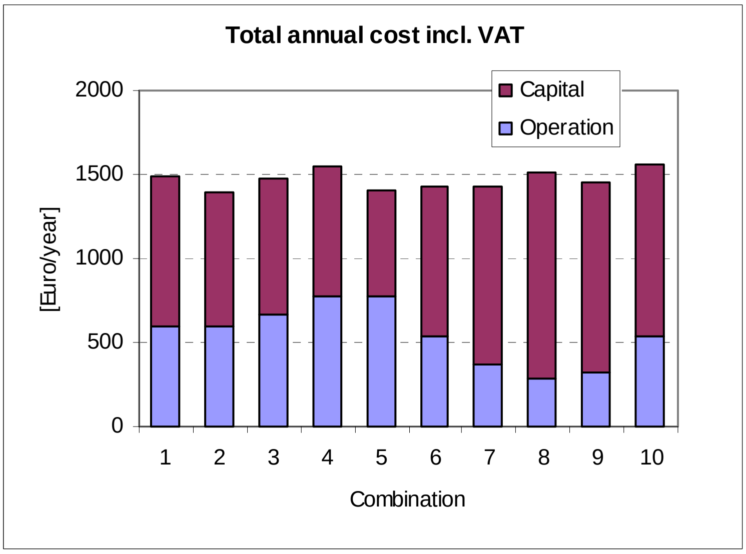

Fig. 5: Total annual costs using annuity 0.09, pellet price 0.03 Euro/kWh and electricity price 0.07 Euro/kWh for combinations shown in Table 1.

We can see that capital and operation costs are different, but the total annual costs are about the same, i.e. around 1 500 Euro/year, for all combinations. The resulting 'heat price' is thus about 0.14 Euro/kWh related to the total annual heat demand of 11 000 kWh/year.

In practice the choice between different combinations depends on the local circumstances, the actual cost in the specific case and usually the opinion that the electricity price will stay low. Today combination no 6 with exhaust air HP is the most common choice, although it shows about the same total annual cost as all other combinations in our study.

Shown heat demands take solar radiation and internal gains from persons, lighting and equipment into account, while electricity for pumps and fans is neglected (makes MESX-systems more favourable than they are). Furthermore existing tax reductions on interest rate are not taken into account, which makes combination with high capital costs (e.g. comb. with pellet boiler) less favourable than they are.

Marginal cost for the solar system

The studied solar system will replace operation costs related to 1 500 kWh with capital costs. With the prerequisite that we should keep the total annual cost the same, the allowed marginal cost for the solar system can be calculated as follows:

- appr. 1 200 Euro in combination with electric boiler (comb. no 1-5),
- appr. 700 Euro in combination with pellet boiler (e.g. comb. no 7-9, assuming that the system replaces 33% electricity and 67% pellet) and
- appr. 350 Euro in combination with a heat pump.

The aim here is to evaluate the prospects for a future alternative with a pellet boiler and a solar system. Thus we apply the following assumptions. We assume a future electricity price of 0.09 Euro/kWh, take existing tax reductions into account by using annuity 0.07 instead of 0.09. Furthermore we assume that our system, i.e. comb. no 9 complemented by our solar system, has to show the same total annual cost as combination no 6 in order to be competitive. The result is shown in Figure 6.

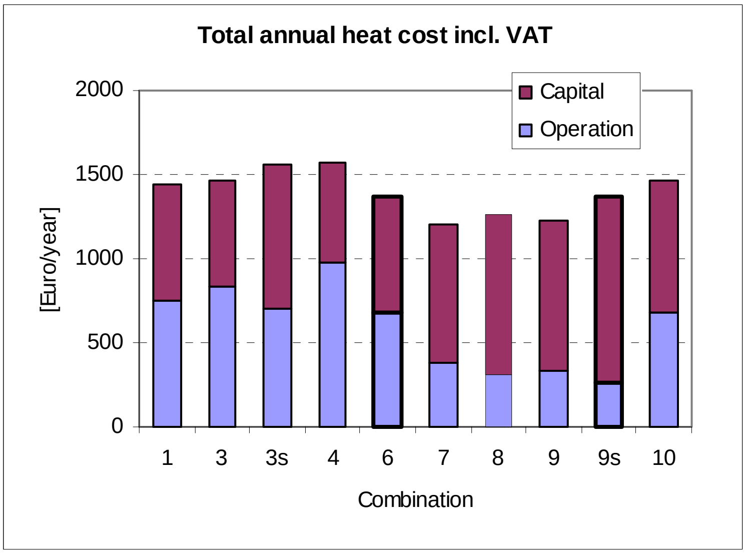

Fig. 6 Total annual cost with annuity 0.07, pellet price 0.03 Euro/kWh and electricity price 0.09 Euro/kWh for combinations shown in Table 1 complemented with two solar alternatives, 3s and 9s, replacing comb. no 2 and 5.

Combination no 3s in Figure 6 shows combination no 3 complemented with a similar solar system as comb. no 9. NCC has recently chosen such a system in a new residential area with 70 two-family houses for Partillebo, Göteborg.

With the prerequisite that the total annual cost in combinations no 6 and 9s should be the same, the allowed marginal cost for the solar system amounts to 3 200 Euro incl. VAT. To summarise, we can conclude that the allowed marginal cost for a solar system replacing 1 500 kWh/year varies between 350 and 3 200 Euro, depending on our assumptions.

DISCUSSION

First, it is essential to apply a comprehensive system approach, i.e. to consider heat supply, space heating as well as ventilation, and second it is essential to assign prerequisites and assumptions, when one wants to discuss prospects for solar systems. The total annual cost is about the same for a wide range of combinations and the most economic combination of heat supply, space heating and ventilation system for a new single-family house relates to prevailing conditions.

The studied solar system with a combined pellet boiler and storage shows a slightly worse performance than a traditional solar system with a separate storage tank, but is less space demanding which is an advantage in new small single-family houses. A slightly larger collector area can easily compensate the difference in performance. Further possible improvements are to apply a smaller pellet burner chamber (placed apart from the bottom) together with a control that only allows burner operation during space heat demand and blocks the electric heater during collector operation.

A combination with radiators designed for 80/40 °C shows similar solar gains and lower costs compared to a system with radiators designed for 55/45 °C. A radiator system designed for 60/40 °C or a floor heating system might be the alternatives in practice. An MEX-system might be an interesting alternative to an MESX-system.

The Swedish building code stipulates energy savings of the order of 50% of the ventilation losses compared to a reference house (outside district heating areas). This is satisfied by an MESX-system, an exhaust air HP or an improved overall U-value. A solar system should be treated in a similar manner as it shows similar energy savings.

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