Thermal Storage for Combined Solar and Pellet Heating Systems

M.Y. Haller
Institute of Thermal Engineering, Graz University of Technology, Inffeldgasse 25/B, 8010 Graz, Austria
email : michel.haller@tugraz.at

Abstract

The combination of energy from solar and from wood pellets to meet the demand for domestic hot water and space heating may play a crucial role in reducing the use of fossil and non-renewable energy use. A lot of synergies can be achieved by combining solar and pellet heating. Careful design, sizing, control and installation is of utmost importance for the efficient use of both, solar and pellet energy. Using the solar heat store as a buffer for the pellet boiler has to be done either very carefully or not at all. Higher heat losses from the store and lower chances for solar heat input into the store may well compensate the advantages of longer running times of the boiler. Oversizing of pellet boilers in order to be on the safe side with room-comfort is paid by lower efficiency and higher emissions of the system, and should therefore be discouraged.

Keywords: thermal storage, solar heating, pellet heating, energy efficiency

1. Introduction

Due to increasing concerns about climate change caused predominantly by the exploding concentration of CO_2 in the atmosphere, decreasing the use of fossil fuels has become one of the major tasks of todays societies around the globe. Saving fossil fuels in a sustainable way can be done by saving energy in general as well as by substitution through renewable sources of energy. For central European countries like Austria and Switzerland, energy use for room heating and domestic hot water (DHW) production accounts for about one third of total primary energy consumption [1][2]. Today, this energy need is covered predominantely by fossil fuels. Together with increased efficiency in room heating and DHW preparation, solar and pellet heating systems are assumed to play a crucial role in these countries to reach targets for CO_2 emission reductions set by the KYOTO protocol.

The potential for combined solar and biomass heating systems for domestic hot water preparation and room heating in Austria is large. The Austrian Ministry of Agriculture, Forestry, Environment and Water Management has set the goal to increase biomass heating from 81 PJ in 2000 to 130 PJ in 2020 [3]. Assuming the same total heat demand for domestic hot water and room heating in 2020 as for today, about 29% of it could be covered by biomass heating alone[1]. Following the trend of recent years, the largest increase is expected to be for pellet and wood chips heating systems, whereas the use of log wood heating systems is not expected to increase at all. If all biomass heating systems would be combined with solar thermal systems, the share of combined solar and pellet heating systems could cover more than 40%[2] of the total energy demand for domestic hot water and space heating in Austrian residential buildings (Fig. 1). This share could even be far higher, if the total need for room heating and domestic hot water will be reduced due to better insulation standards and technological improvements.

---

[1] Since the 120 PJ for heating in 2020 include other heat needs too, heat for residential buildings will be lower than 130 PJ. On the other hand, the total amount needed for domestic hot water preparation and room heating in the year 2020 is very uncertain too. As the insulation standard increases, the need for heating per meter square will certainly decrease. Whether this will lead to a decreased total heat demand for residential buildings in Austria, depends on the counteracting effect of population growth and increasing demand of comfort / living area per person.

[2] Assuming a realistic “fractional thermal energy savings” of about 30%, achievable with 15 m^2 flat plate collectors and about 950 liter storage tank and a total energy demand for DHW and space heating of 18.3 MWh [4].

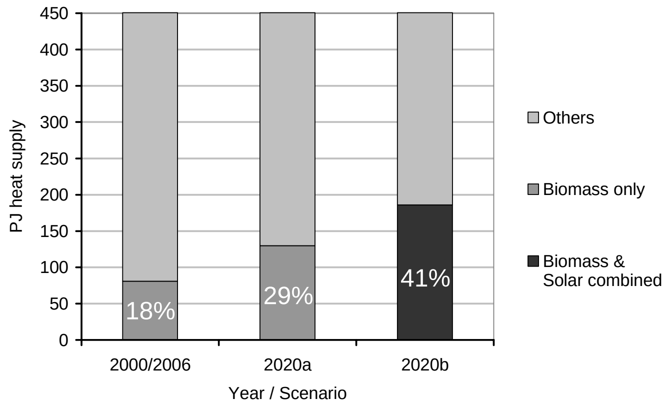


Fig.1. Assumed potential of combined solar and biomass heating for houses in Austria. “Others” includes other energy sources than biomass that may or may not be combined with solar. The current share of combined solar and biomass heating was not known. In Scenario “2020a”, all biomass heating is not combined with solar. In Scenario “2020b”, all biomass heating is combined with solar heating that reduces biomass need by 30% in each installation.

2. State of the Art of pellet heating

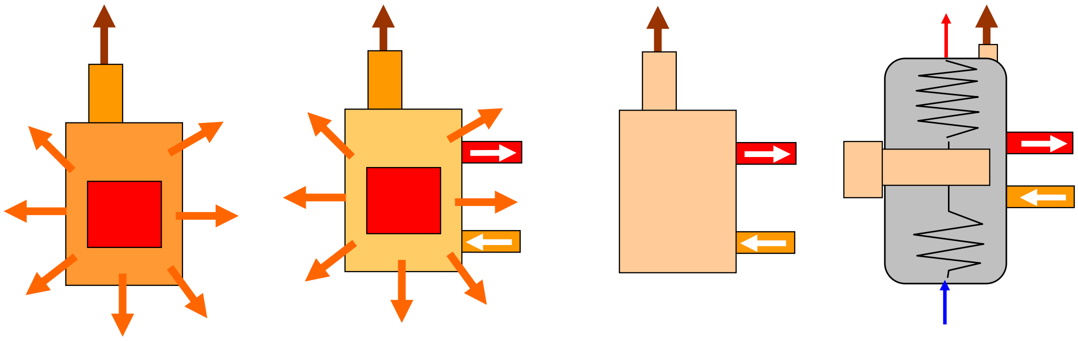
The combination of pellet and solar energy for room heating and DHW preparation today can be achieved in different ways that depend largely on the type of pellet heating system chosen (Fig. 2).

A ***pellet stove*** delivers heat only by direct radiation and convection from the stove unit. It can not be connected to a central heating system and can therefore only be used for the heating of one thermal zone, usually one room with some adjacent colder rooms. Preparation of DHW with a simple stove is not possible. It may be used together with a solar DHW system, but there is no direct interaction between the two systems. An additional heat source – usually electricity – is needed for DHW preparation in winter months when solar heat is not sufficient.

A ***pellet stove with water jacket*** delivers heat not only by direct radiation and convection, but also by heating up a fluid that may be used to serve DHW preparation and also room heating. Since there is a minimum share of heat that will always be transferred to the room of installation, also a stove with water jacket may only serve a limited heat demand outside this room that must be more or less in accordance with the demand of this one room. For example, DHW preparation in summer should not be done by the stove since this would cause overheating of the room the stove is installed in. Connecting the water jacket of the stove to the heat store of a solar thermal system offers several advantages in comparison to the system discussed before:

- DHW preparation during winter months can be done by the stove. Thus, expensive electric energy can be replaced by cheap renewable heat from pellets.
- DHW preparation outside the heating season can be covered by solar energy. Thus, no other auxiliary energy is needed to avoid the operation of the stove during summer.
- A small central heating system may be connected to the heat store to achieve better control of room temperatures in other rooms than the one the stove is installed in.

Both types of stoves, with and without water jacket, benefit from the fact that heat transferred to the room of installation is not waste heat, as they are installed in the living area and not in a technical room. This advantage may also be a disadvantage as there will always be a considerable heat input into the room of installation and thus distribution of heat to other rooms is restricted.



stove — stove with water jacket — boiler — burner integrated into a storage tank

room heating system or domestic hot water supply and return lines; radiative heat; exhaust / flue gas; cold and hot domestic water lines respectively

Fig.2. Different types of wood pellet heating systems

A ***pellet boiler*** is designed to deliver heat to a heating fluid only. The heated fluid can be used for space heating and DHW preparation. Unlike a stove, a boiler may also serve the increased heat demand of multifamily houses with one single unit. Boilers may be combined with solar thermal systems of any scale. They are installed in a technical room and therefore heat transferred to this room by radiation and convection from boiler surfaces and from pipes must be kept low. In contrast to the case of pellet stoves, this heat must generally be considered as waste heat.

A ***pellet burner integrated into a solar storage tank*** is a niche-product that is currently produced by only a few manufacturers in Europe. It competes with small scale pellet boilers and has the advantage that instead of two units – boiler and store - „losing“ heat to the technical room, only one unit – the store – is losing heat to the technical room. Additionally, installation requires less space and can be done easier because of the higher degree of prefabrication. This may also reduce the risk of installation errors. However, if burner integration is done without the necessary know-how and care, heat losses of a store with an integrated burner may be equal or even higher than for a system with boiler and heat store seperately. In a study performed at SPF Rapperswil / Switzerland, it was shown for integrated natural gas and oil burners that one system that was designed very carefully had a very high performance, whereas other systems with integrated burners performed much worse than their counterparts with separate boilers [6][7]. Reasons for poor performance were mainly:

- Insufficient insulation of the burner and the flanges where burner and exhaust pipe are connected to the heat store may lead to additional heat losses of the store. Thus, stored energy is lost not only during burner operation, but also during standby and at times where the store has been charged by solar energy.
- Leakage airflows through the burner chamber, the flue gas heat exchanger and up the chimney may cool out the whole store from the height of the burner chamber downwards during standby, and also outside the heating season (Fig. 3, Fig. 4).

[8] compared a system with separate pellet boiler and store with a store with integrated pellet burner. For the two systems studied, losses to ambient of the separated boiler that were saved by integrating the burner into the store where just about compensated by the higher heat losses of the store with the integrated burner.

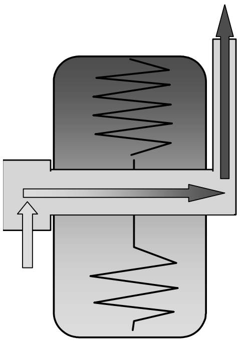


Fig. 3. Buoyancy (natural draft) driven leakage airflow through an integrated burner and its heat exchanger during standby

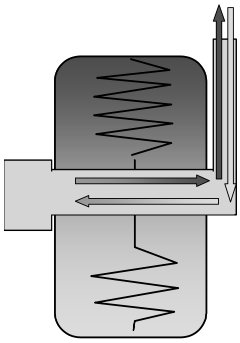


Fig. 4. Cooling out of store by buoyancy driven air circulation without net mass flow / draft through the flue gas heat exchanger of the integrated burner

3. General findings on boiler efficiencies and cycling behaviour

From previous investigations, some general findings concerning the efficient use of energy in pellet stoves and boilers can be summarized:

- Exhaust gas losses of stoves and boilers may be reduced by modulation. Lower rates of fuel burning lead to lower exhaust gas velocities. Thus, longer residence time in the area where the heat exchange between flue gas and water takes place is achieved, and more heat is transferred from the flue gas to the water. However, this effect is often counteracted by a higher excess air factor (lambda) at lower power that is often chosen deliberately to keep emissions of carbon monoxide low. Therefore, depending on lambda control, some stoves / boilers show lower exhaust gas losses at lower heat load whereas the opposite is true for others.
- Proper power modulation inevitably reduces the number of starts and stops. This may lead to decreased emissions of carbon monoxide and hydrocarbons [8][9]. Usually, thermal efficiency is not or only little improved by proper modulation. However, as electricity for the ignition at start can be saved, overall energetic performance is usually far better.
- If a boiler is operated within its range of modulation, exhaust gas losses are usually the predominant losses. However, if heat load is decreased far below nominal power, losses to ambient that depend on the temperature of the boiler water will remain constant, whereas the heat load and thus the useful energy is reduced. Thus, losses to ambient become more important and may easily exceed exhaust gas losses by far. Additionally, frequent on/off cycling increases electricity use for startup ignition considerably.
- Pellet boilers usually require minimum return and flow temperatures to avoid condensation of water vapor in the flue gas heat exchanger. The mass flow of heating water through the boiler is often fixed as well. These three parameters define the actual minimum boiler power that can be achieved without raising the return temperature further. For this reason, in a practical installation, boiler modulation may not go down to the minimum power the boiler is capable to provide without on/off operation, but only to the minimum given by the hydraulic setup.
- Oversizing a pellet boiler to be “on the safe side” for meeting comfort demands is always paid by lower overall efficiency. Oversizing not only increases thermal losses, but also leads to more frequent starts and stops of the burner. This again may increase electricity use and emissions of CO and particles substantially.

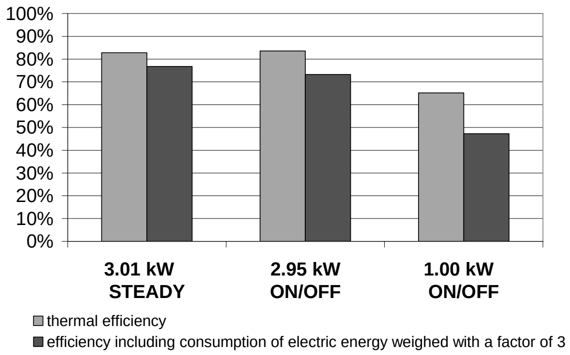


Fig. 5. Thermal and overall efficiency of a 10 kW pellet boiler as measured by [4]. Lowest steady state operation at 3 kW (30% of nominal power).

4. The combination of pellet boilers with solar stores

If a pellet boiler is connected to the heat store of a reasonably sized solar thermal system, about 25-32%[3] of pellet fuel may be saved in a moderately insulated single family house located in Central Europe [4]. It has been shown that pellet fuel savings may be far higher than solar gains. This is for various reasons:

- Energy contained in the pellet fuel is only converted to “useful heat” with an efficiency of 80-90%, whereas energy input from solar collectors usually suffer less losses.
- Annual boiler thermal efficiency is increased if it is combined with a solar thermal system. The reason for this is that the boiler can now be shut off completely during spring, summer and autumn if solar heat is sufficient during these seasons. As these are the seasons where the boiler is most inefficient because of little heat load and long standby times, the average boiler efficiency increases (Fig. 6).
- The number of starts and stops of the boiler is reduced much more than the fuel use, since the average running time of the boiler is increased by the solar system. This is also true for cases where the boiler is not using the heat store as a buffer. Thus, electricity consumption may well decrease after installing a solar thermal system since electricity spared by the reduction of burner starts and runtime is more than electricity needed to run the solar pump. For oil and gas boilers, the opposite is usually true.

Some special considerations have to be kept in mind when planning and installing a solar pellet heating system:

- Care has to be taken to choose the proper control of the heat input from the boiler to the heat store. A temperature sensor within the store is indispensable for proper control. A suitable hysteresis has to be chosen to switch the boiler on and off depending on the temperature in the store. The lower the hysteresis, the more the boiler will cycle. The higher the hysteresis, the more the temperature of the store will be raised and its heat losses increased. It has been shown that loading the solar heat store by the pellet boiler may decrease the overall thermal efficiency because of two effects caused by higher store temperatures: a) higher heat losses of the store, and b) reduced chances for input of solar heat [4]. Therefore, using the solar heat store for buffering heat from a pellet boiler is only necessary if the boiler is oversized with respect to the heat demand.
- Optimizing hydraulics and control of a combined solar and pellets heating system may reduce pellet fuel demand and boiler cycling considerably (Fig. 7).
- For all heat stores, proper pipe connections and insulations may save a lot of energy. Installers often pay too little attention to insulation, unwanted circulation and “in-pipe circulation”. Unwanted

[3] A maximum of 15 m^2 flat plate collector area and 950 liter heat store

circulation can be avoided by proper planning and placement of non-return valves. “In-pipe circulation” occurs in pipes that are connected to a heat store without a thermosiphon. Due to buoyancy driven “in-pipe circulation”, these pipes will be permanently at almost the same temperature as the store (Fig. 8). This long known effect has been quantified only recently [11]. According to these measurements, a steel pipe of 2 meter length and 1 inch diameter connected to the store without a thermosiphon, loses about 43% - 75% as much heat as if the water inside the entire pipe would be at the same temperature as the water in the heat store (Fig. 9).

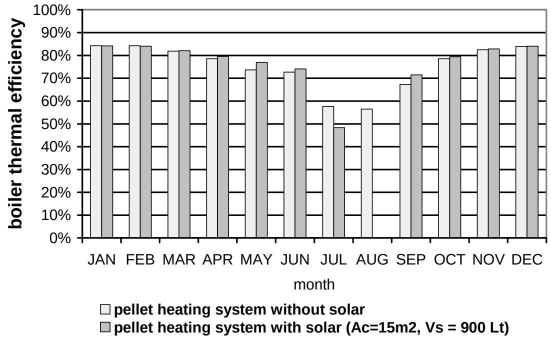


Fig. 6. Pellet boiler efficiency during different seasons of the year, with and without solar system / heat store. In July and August, only very little or no pellet fuel was needed for the system with solar / store. Figure adapted from [4].

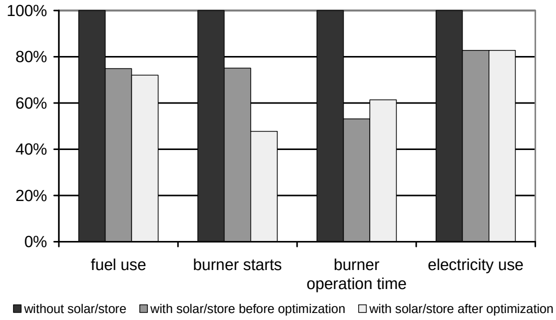


Fig. 7. Comparison of a pellet heating system without solar and two pellet heating system with solar and heat store before [4].

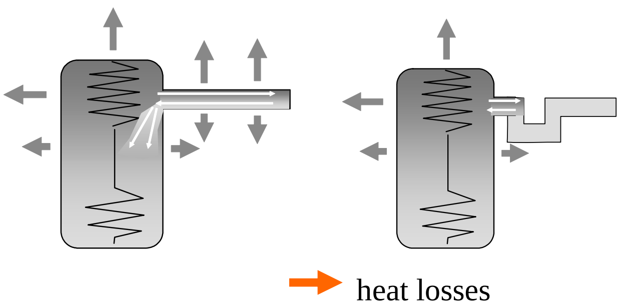


Fig. 8. Pipe connection to store without (left) and with (right) thermosiphon and the corresponding buoyancy driven “in pipe circulation” and heat losses

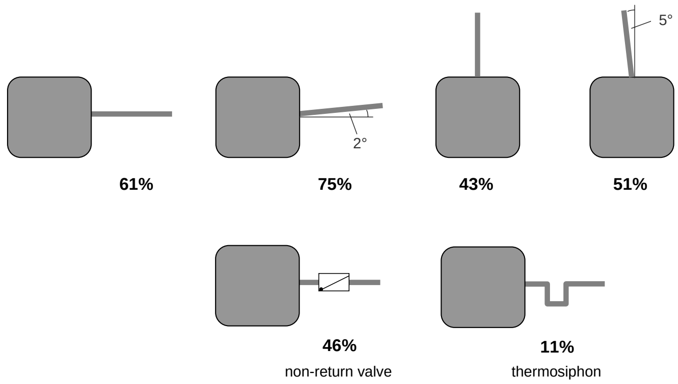


Fig. 9. Measured heat losses of an insulated steel pipe with 2 m length and 1 inch diameter. Heat losses are given in percent of heat losses of the same pipe that would be filled entirely with water at the same temperature as water in the store. Figure adapted from [11].

5. Conclusions

Increasing demand will push renewable pellet production to its limits sooner or later. Saving wood pellets in each installation by the use of solar thermal energy will make it possible to use the saved fuel in other installations, thus increasing the number of installations that can be based on energy from wood pellets.

Both, pellet stoves and pellet boilers, may be combined with solar thermal systems. For small and modern single family houses with suitable room concepts and matching preferences of the inhabitants, a stove with water jacket is likely to be the most efficient solution, since heat transferred to the room of installation is not wasted. Especially in the case of very low energy demand, a pellet boiler installed in a technical room is likely to lose a large share of energy to the room of installation. For these houses, pellet boilers with smaller nominal power than available today on the market would be needed. For larger buildings and/or higher heat loads however, a boiler or a store with integrated burner will most likely be the better choice as they offer more flexibility for the distribution of the heat.

The combination of wood pellet and solar energy for room heating and preparation of domestic hot water (DHW) offers excellent synergies. For example, due to solar energy, summertime DHW preparation with wood pellet or expensive electricity can be avoided. Furthermore, DHW preparation in winter can be covered efficiently and at low cost by heat from pellets instead of electric heating. Generally, the seasonal efficiency of the pellet boiler increases if it is combined with a solar thermal system.

The number of starts and stops of a pellet boiler or stove can be reduced significantly if it is combined with a solar thermal system in a smart way, even if the boiler is not using the solar store as a buffer store. Electricity demand and emissions of pellet boilers are higher during start and/or stop than they are during continuous operation. Thus, the combination with a solar thermal system has the potential to reduce electricity demand and contribute significantly to emissions reduction.

Integrating the pellet burner into a solar store offers the advantage of eliminating boiler heat losses to the technical room. However, integration inevitably leads to higher losses of the storage unit. With a thorough concept, this increase of losses can be kept small and a better system can be obtained than with the separate boiler. Without the necessary care and skills, integrating the burner may well result in a system with far higher heat losses than with a separate boiler.

Generally, pellet boilers should be better insulated. Solar stores should be insulated well, equipped with thermosiphons and controlled optimally to achieve higher energy efficiency.

More work is needed to find the best solutions for hydraulic setup and control of combined solar and pellet heating systems. For this reason, the Institute of Thermal Engineering of Graz University and Technology is involved in two research projects to study combined solar and pellet heating systems both in the laboratory and in the field. The final goal is to find the most energy efficient and environmentally friendly solutions for hydraulics and control of combined pellet and solar heating.

Acknowledgements

The work of the author is supported by the 6th European Union Research Programme's Marie-Curie early stage research training network Advanced solar heating and cooling for buildings – SOLNET.

References

[1] Energieverwertungsagentur - The Austrian Energy Agency. Energiefluss Österreich 2000, 2002

[2] Schweizerische Eidgenossenschaft, Bundesamt für Energie BFE. Schweizerische Gesamtenergiestatistik 2005, 2005

[3] Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMLFUW). Nationaler Biomasseaktionsplan für Österreich – Begutachtungsentwurf, 2006

[4] L. Konersmann, M. Haller, P. Vogelsanger. PelletSolar - Leistungsanalyse und Optimierung eines Pellet-Solarkombinierten Systems für Heizung und Warmwasser. Bundesamt für Energie BFE, UVEK, Schweiz, 2007

[5] T. Persson. Increasing efficiency and decreasing CO-emissions for a combined solar and wood pellet heating system for single-family houses, Proc on USB of Pellets 2006, 87-91, Jönköping, Sweden, 2006

[6] M. Haller, P. Vogelsanger. Combisystem performance investigation. In J.-C. Hadorn (Ed.) Thermal energy storage for solar and low energy buildings – State of the art by the IEA Solar Heating and Cooling Task 32, June 2005.

[7] M. Haller, P. Vogelsanger. Kombi-Kompakt+ - Schlussbericht, Dezember 2004, Korrektur: Dezember 2005. Bundesamt für Energie BFE, Schweiz, 2005

[8] F. Fiedler, S. Nordlander, T. Persson, C. Bales. Thermal performance of combined solar and pellet heating systems. Renewable Energy 31 (2006) 73-88

[9] A. Heinz, Application of Thermal Energy Storage with Phase Change Materials in Heating Systems, Ph.D. Thesis at the Institute of Thermal Engineering, Graz University of Technology, Austria , 2007

[10] F. Fiedler, C. Bales, T. Persson, S. Nordlander, Comparison of carbon monoxide emissions and electricity consumption of modulating and non-modulating pellet and solar heating systems. International Journal of Energy Research 31, 915-930 (2007)

[11] A. Lauber. Wärmeverluste durch rohrinterne Gegenstromzirkulation in Speicheranschlussleitungen, und deren Verminderung mittels Konvektionsbremsen, Konvektionssperren und Wärmesiphons – Quantifizierung der Effekte mittels Messung. SPF Solartechnik, Hochschule für Technik HSR Rapperswil, 2007