ANNUAL CO-EMISSIONS OF COMBINED PELLET AND SOLAR HEATING SYSTEMS

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ABSTRACT

Emissions are an important aspect of a pellet heating system. High carbon monoxide emissions are often caused by unnecessary cycling of the burner when the burner is operated below the lowest combustion power. Combining pellet heating systems with a solar heating system can significantly reduce cycling of the pellet heater and avoid the inefficient summer operation of the pellet heater. The aim of this paper was to study CO-emissions of the different types of systems and to compare the yearly CO-emissions obtained from simulations with the yearly CO-emissions calculated based on the values that are obtained by the standard test methods. The results showed that the yearly CO-emissions obtained from the simulations are significant higher than the yearly CO-emissions calculated based on the standard test methods. It is also shown that for the studied systems the average emissions under these realistic annual conditions were greater than the limit values of two Eco-labels. Furthermore it could be seen that is possible to almost halve the CO-emission if the pellet heater is combined with a solar heating system.

1. INTRODUCTION

The dramatically increased prices for oil and electricity over the last few years encourage many house owners with electric heating or and oil heating systems to convert their heating systems. Today in Sweden mainly heat pumps are installed but also pellet heating systems become more and more popular. Studies have shown that the combination of conventional boiler heating systems with solar heating is beneficial in terms of fuel savings and lower emissions since the boiler usually in the summer can be turned off when it's efficiency is low (11; 14).
Emissions of harmful gases are important parameters in addition to the efficiency and the thermal performance of pellet heating units. The national building codes and emission regulations include limits of allowable emissions of noxious gases for wood pellet boilers. More stringent limit values are applied by the Swedish Testing Institute (SP) and eco-labels such as the Svanmark (7; 13). The limit values can be expected to further sharpened when comparing the limit values from other European regulations and eco-labels (1; 12). More stringent limit values have also been proposed by the Nordic eco-label Svanmark (6). In Table 1 the official limit values for emissions and efficiencies for pellet boilers and pellet stoves are compared with the current limit values from eco-labels and other regulations in Sweden and Germany.

Table 1. Limit values for emissions from automatic fed pellet heating units with a nominal combustion power smaller than 50 kW, CO-carbon monoxide, OGC-organic gaseous carbon.

Regulation		**Limit value for emission**			
		NOx	CO	OGC	Particles
		mg/m^3 dry flue gas with 10 vol-% O_2, 0°C, 1013 mbar			
EN 303-5 (class 3)		-	3000	100	150
SP-Swedish testing institute, P-mark		-	2000	75	-
Svan-mark		-	1000	70	70
Svan-mark, proposed 2006		340	400	25	40
Blauer Engel (To be measured with 13vol-% O_2)	Pellet stoves	150	200 - 400	10-15	35
	Pellet boiler	150	100-300	5	30

In this study the emphasis has been on CO-emissions released from different pellet heating systems with different operating strategies combined or not combined with a solar heating system. CO-emissions from pellet stoves/boilers are highest during the start and stop phase. By operating the burner with modulating combustion power the number of starts and stops and consequently the start/stop CO-emissions can be reduced. On the other hand, the longer operation time leads to higher total CO-emissions during normal combustion. Both these effects are simulated in this study, and results are given for complete annual simulations with sub-hourly time step.

2. METHOD

This work compares and analyses the simulation results of six combined solar and pellet heating systems that have been

chosen from a variety of design variants. Four of them were chosen to represent the range of commercially available solutions found in Sweden. The systems contain: a water mantled stove; an air cooled pellet stove; a store integrated pellet burner; and a standalone pellet boiler. The fifth system is similar to the system with the standalone boiler but uses a boiler with an adequate size of 12 kW. The sixth system is based on a completely new system concept using a very efficient Austrian pellet boiler. The pellet heating units in these systems had been previously tested at the Solar Energy Research Center, Borlänge (10). A detailed description of the systems can be found in (3) and (11).
The systems were modelled in the simulation environment IISiBat/TRNSYS (5). The systems have been simulated for one year for the same boundary conditions. Particularly design parameters such as the boiler combustion control have been varied to study the effect on the CO-emissions of the systems. For comparison one system has also been simulated with only the boiler as main heat source and without solar heating system.

4. MODELLING IN TRNSYS

The modelling of the systems in TRNSYS is based on the system models and boundary conditions used in IEA-SHC Task 26 Solar Combisystems (2), which includes both the building (single node in type 56) and heat distribution using a radiator and PID controller modelling the thermostatic valve. For the system with air cooled pellet stove, no radiator was used. The boundary conditions for the systems are defined by the climate, in this study Stockholm, the domestic hot water (DHW) load and the space heating demand. The DHW load has been modelled with a load profile developed by Jordan et al. (4) assuming a daily hot water demand of about 200 litre (~3100 kWh/year). The space heating demand is modelled by an one zone building model developed for IEA-SHC task 26 giving a yearly heat demand of approximately 12200 kWh (87 kWh/m^2) for Stockholm.
Modelling of pellet stoves, burner and boiler were implemented with TRNSYS-component type 210 (8). This dynamic model can be used to simulate pellet stoves, pellet burners and pellet boilers and gives flue gas losses during operation and in standby mode (leakage losses), as well as heat supplied to water in a mantle and to the surroundings. The model also calculates the CO-content in the flue gas, including the emissions during the start and stop phases. The parameter values used in this study were derived from parameter identification using measured data from the stoves/boilers, and have been verified against measured data (3; 10). The parameter values for each of the pellet heaters used to simulate the CO-emissions of the pellet heaters can be seen in Figure 1. The model calculates the CO-emissions as the sum of a power dependent part during normal operation and a lumped constant amount per start and stop.

System	1	2	3	4	5	6
CO-emission start and stop (g)	1.85	2.2	7.7	7	23.2	5.8

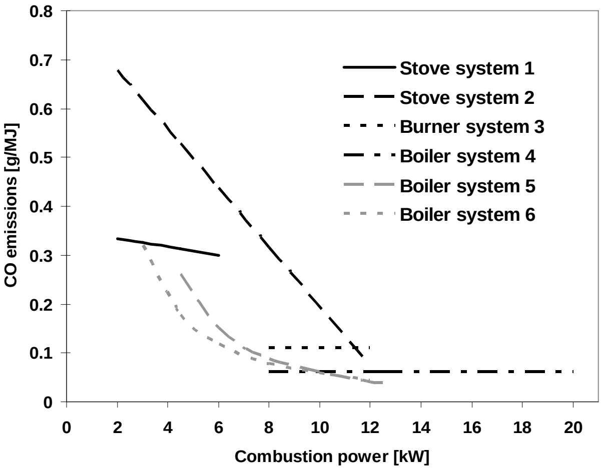

Fig. 1: CO-emissions during operation (graph) and start/stop (table) of the six pellet heating units.

Two variants of operating strategy were chosen for simulations of each system. On/off control using the full power of the heaters and modulation control was used with the measured modulation range for the specific heaters simulated in the systems. For comparison, system 5 has also been simulated with only the boiler or stove as main heat source and without solar heating system (solar collector loop and combistore).

5. RESULTS

Figure 2 shows the CO-emissions for the six systems in kg divided in start/stop emissions, emissions during operation and standby emissions. The latter occur only for the boiler in system 4 which has an option to operate in a standby mode when there is no heat demand. Keeping the boiler in this standby mode (by constantly combusting a little amount of pellet) increases the CO-emissions dramatically. The assumption here is that the start emissions are the same as if the boiler would not kept in standby. This has not been investigated in detail and the standby operation has not been included in the system simulations. Instead, the standby emissions in Figure 2 have been determined by separate calculations based on measurement of the boiler during standby operation.
From Figure 2 it can bee seen that the amount of emitted CO varies significantly for the different systems. The boiler systems have large start/stop emissions whereas the start/stop emissions for the stove systems are very low. The pellet stove in system 2 emits with 7 kg in on/off mode the lowest amount of CO per year whereas the boiler in system 5 emits 37 kg CO per year if on/off operated. The stove systems (system 1 and 2) emit most CO during operation whereas the

combisystems (system 3-6) emit most CO during start and stop when on/off operated. For system 3, 4, 5 and 6 the start/stop emissions decreases drastically if controlled with modulating power. The CO-emissions of system 2 are much higher when operated with modulating power. The CO-emissions for system 1 are almost the same regardless if the stove is operated with on/off or modulating combustion power.

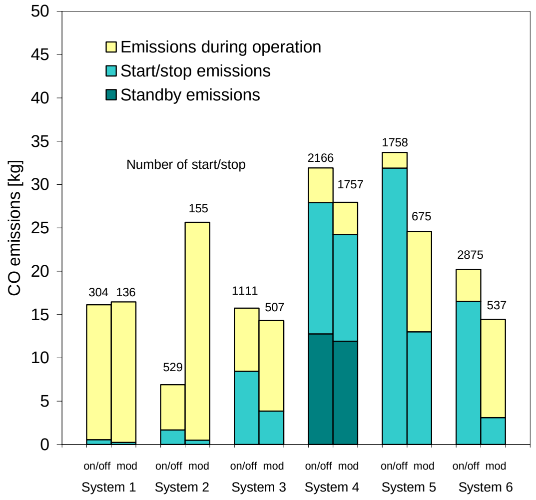

Fig. 2: CO-emissions for start/stop, normal operation and standby of the pellet heaters in the systems for on/off and modulating operation.

The pellet consumption is not the same for all systems. For a qualitative CO-emission comparison of the different systems it is therefore necessary to express the CO-emissions in a specific form, in kg per MJ pellet (Figure 3).

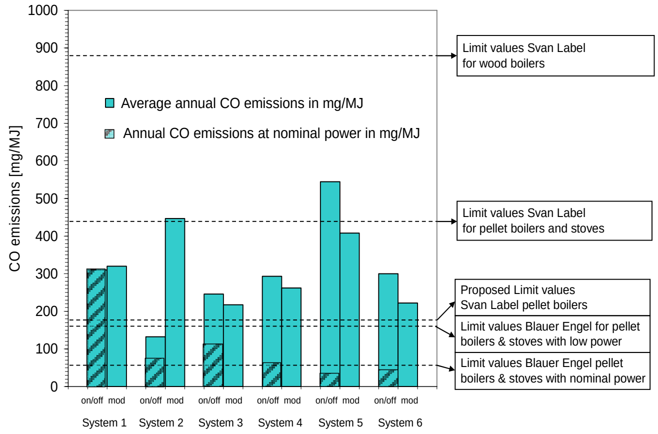

Fig. 3: Average annual CO-emissions in mg per MJ pellet in comparison with limit values of the Eco-labels Svan-mark and Blauer Engel-mark.

Together with the specific emissions of each system the limit values for CO from two eco-labels are indicated. The relative high limit value of the Standard EN 303-5 of 13214 mg/MJ is not indicated. It can be seen that only system 2, if on/off controlled, would fulfil the recently proposed limit values for the Svan-mark if the start and stop emissions and realistic conditions are taken into account. None of the stoves and boilers would fulfil the requirements for the Blauer Engel-mark. The dashed area shows the emissions of the stoves and boilers from lab measurements at constant nominal combustion power. These are much lower than the average annual emissions except for the stove in system 1 that has very little start and stop emissions. Note that for system 4 only the emissions for start/stop and normal operation are included but not the emissions for standby. These emissions have been excluded because no measurement data for the pellet consumption during standby were available.

In Figure 4 the annual CO-emissions of the pellet boiler used in system 5, with and without solar heating system, and the CO-emission of system 6 (with a solar heating system) are compared. It can be seen that the CO-emissions of system 5 can be reduced by almost the half by adding a solar system. This is mainly due to the reduction of the number of starts and stops from 3352 (on/off controlled) and 1601 (modulating power) to 1758 (on/off controlled) and 675 (modulating power). For system 6, that uses an Austrian pellet boiler with relatively low start/stop emissions, the annual CO-emissions would be only a third of the boiler used in system 5.

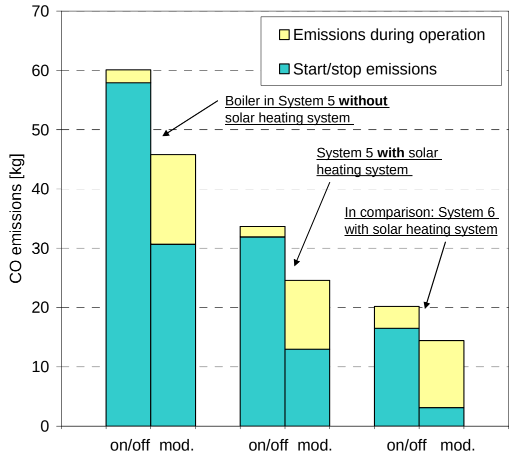

Fig. 4: Average annual CO-emissions in kg for system 5 including and not including a solar heating system in comparison with system 6 (with a solar heating system).

6. DISCUSSION AND CONCLUSION

Figure 2 and 3 show that the amount of emitted CO varies significantly for the different systems. There are several reasons for these differences. Each pellet heater has its own CO-characteristic for the operation with a particular combustion power and during start and stop (Figure 1). The pellet heaters vary also in their nominal power from 6 kW to 20 kW which of course together with the size of the buffer volume, the boiler control mode and the way the heat is transferred to the building influence the number of starts and stops.

The boiler systems have large start/stop emissions whereas the start/stop emissions for the stove systems are very low. This is due to the much lower total number of starts and stops of the stoves using the complete building as heat storage. This is a simplification which provides that the heat can be freely distributed to the building. A more advanced multi zone building model for simulations of stove systems has been used by Persson. Perssons studies showed that stove systems have similar number of starts and stops as boiler systems if the convective and radiative part of the heat from the stoves can not be freely distributed to the complete building (see table 3.2 in (9)).

In Figure 3 the specific CO-emissions for each system are compared with the CO-limit values for two Eco-labels. All systems are below the rather high limit value of the Standard EN 303-5 of 1314 mg/MJ which is not indicated in this figure. However, it can be seen that only system 2, if on/off controlled, would fulfil the recently proposed limit values for the Svan-mark if the start and stop emissions and realistic conditions are taken into account. None of the stoves and boilers would fulfil the requirements for the Blauer Engel-mark. The dashed area shows the emissions of the stoves and boilers at nominal combustion power. Testing institutes usually use a mixture of the measured CO-emissions at nominal and minimal load to specify CO-emissions of the tested pellet heater. The comparison shows that this leads to a drastic underestimation of the real annual CO-emissions due to the fact that the start/stop emissions are not included. It is therefore suggested to revise the methods to determine the CO-emissions for pellet stoves and boilers in the current norms and eco-labels and to include an estimation of total annual emissions based on the operation of the boiler and the average load.

Combining solar and pellet heating systems can reduce significant CO-emissions compared to operating a single pellet heating system. This combination prevents the summer operation of the pellet heater with low efficiency and high emissions. Simulations for one system have shown that the CO-emissions can be reduced by almost the half compared to a single pellet heating system using the same boiler.

4. ACKNOWLEDGMENTS

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