# STANDING LOSSES VIA CHIMNEY WHEN USING LOG WOOD STOVES

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ABSTRACT: Two types of standing losses were investigated: heat losses though the chimney without any heating operation (cold standing losses) and the post heating losses (losses during chimney cool down).
Keywords: wood stove, efficiency, heat losses, chimney, small scale application.

## 1 INTRODUCTION

### 1.1 General

Efficiency is a well investigated performance parameter of room heaters for wood fuel. In a combustion test it is usually quantified by determining the thermal flue gas losses through the flue outlet of the stove, and efficiency is then calculated as the useful heat output versus the fuel energy input. Heat losses which may occur during the cooling phase or during cold phases without any stove operation are usually not regarded or they are considered negligible in stove testing. But new technological features of stoves sometimes include automatic air control or air inlet flaps which could minimize such losses. Additional investment costs for such features could be compensated by fuel savings, but sound data for such calculation is missing.

### 1.2 Definition of standing losses

In stove combustion, flue gas transport is propelled by the chimney draught as created during the combustion phase. However, in practice the chimney draught still remains active over a long time after termination of combustion. This is due to the fact that both, stove and chimney,still remain warm for several hours. Furthermore, the temperature gradient between the inside of the building and ambient air persists even though stove and chimney may both have cooled down completely. As a result,a certain chimney draught is sustained throughout the complete heating season even if the stove is not used at all. If air supply is then not shut down – as given for most stoves – continued heat losses are inevitable as the building remains heated (e.g. by central heating).

Hence, two types of standing losses can be identified: heat losses though the chimney without any heating operation (cold standing losses) and the post heating losses (losses during chimney cooling).

### 1.3 State of knowledge

For room-air-dependent gas fired water heatersmany experimental data about streaming behaviour, average operation hours and the different power statusare available. Rawe et al [1] estimated theheating losses using a calculation model based on experimental data and some meteorological calculations. With an average chimney length of 10 m the losses are estimated to be between 1000 and 1500 kWh/a for small duct diameters (0.11 m) between 3000 and 5000 kWh/a forlarger diameters (0.2 m) [1].

However, for wood stoves the situation can be different. Stoves are sometimes particularly built to store and to slowly release certain portions of the produced heat. Furthermore, flue gas temperaturesare usually also largely higher than for gas boilers and thus the chimney is heated up to a higher level. For both reasons, the period of high chimney draught is expanded compared to other heating sources. Thus, there is a suspect, thatwith wood stoves the magnitude of the created "standing losses" should be higher and measures for their reduction could be promising for energy saving in wood heated buildings.

### 1.4 Aim

With approximately 10 million room heating appliances only in Germany the standing losses of wood stoves due to open air dampers or non air tight stoves may be high in total. It was the aim of this research to evaluate the fuel saving potential of modern chimney stoves which prevent such standing losses by automatically closing the air inlet flap of a central air socket.

## 2 MATERIALS & METHODS

### 2.1 Equipment used

Three log wood stoves were chosen for measurements of cold standing losses, all were equipped with a central air inlet socket.

Stove A was a room sealed stove Hark44 GT ECOplus with 8.0 kW nominal heating power. It was equipped with an integrated foam ceramic element for particle emission reduction. Three dampers allowed for manual adjustment of either primary or secondary air, or enabled the opening of a bypass around an integrated foam ceramic filter element; this was to ensure a safe ignition and an operation during phases of low chimney draught or filter clogging.

Stove B was a log wood stove Scan 85 2013,type 85-2, with 8.0 kW nominal heating power.Air dampers were adjusted by a single-lever mechanism for combined primary and secondary air adjustment.

Stove C was a log wood stove BuderusBlueline, type No. 10, with 8.0 kW nominal heating power. Air dampers were adjusted individually for primary and secondary air supply.

All 3 stoves were mounted to a chimney of 130 mm inner diameter. It was made of stainless steel and had a total height of 12.5 m with 1.7 m in outdoor environment. The chimney was equipped with several sensors (Fig.1).

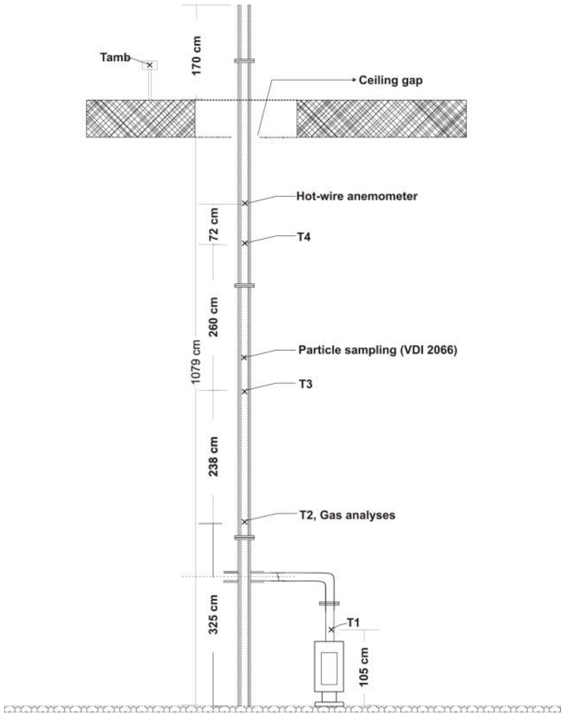


**Figure 1:** Dimensions of test rig and sensor positions in chimney

For temperature measurement five thermocouples of type K (NiCr-Ni) class one (-40°C to 375°C ± 1.5°C),were used. A high-precision hot-wire anemometer SS 20.650 (Schmidt Technology GmbH), (± 1 % of m.v. +0.4 % of u.r.v.)were positioned at 8.95 m. Several climate data parameters were logged simultaneously: ambient and indoor temperature using thermocouples of type K (NiCr-Ni) class one (-40 °C to 375 °C ± 1.5 °C), wind speed. Chimney draught was recorded using a differential pressure transducer P26-500Pa (Halstrup-Walcher GmbH), (± 0.2 % from u.r.v).

2.2 Procedure for cold standing losses

Stove A was monitored over several weeks on a cold natural draught chimney. Four different damper positions of the stove were applied sequentially:

1= Primary air: max; secondary air: max; bypass open

2=Primary air: min; secondary air: max; bypass open

3=Primary air: min; secondary air: max; bypass closed

4=Primary air: min; secondary air min; bypass closed

During this time the usual fluctuation of the natural draught conditions was accepted. A recording of the conditions during the monitoring phase is presented in Figure 2. It shows, that ambient temperatures were usually between 0 and 10 °C and wind velocity fluctuated between 0 and 4 m/s. As consequence the natural chimney draught was largely determined by these factors, while it hardly fell below -4 Pa it could easily reach peaks of -40 Pa, particularly during periods of elevated wind speeds. As a result the measured volume flow

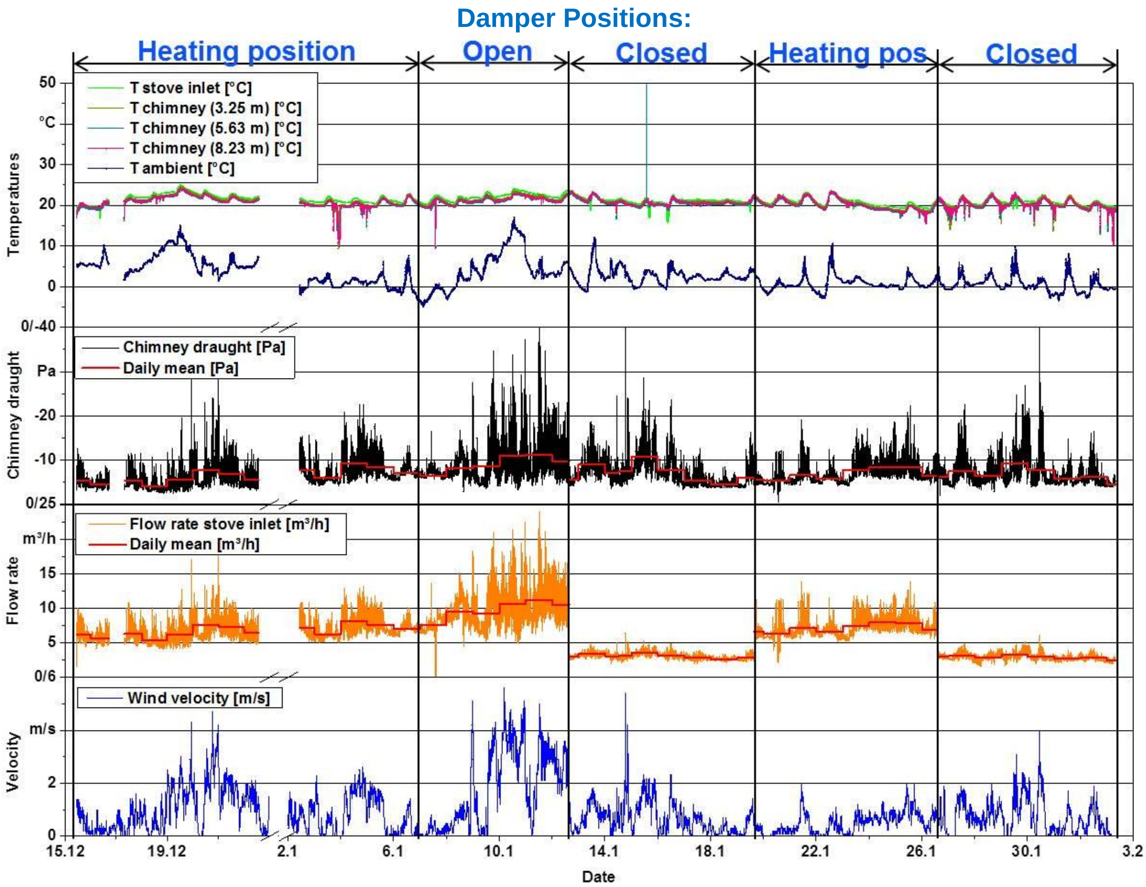


**Figure 2**: Measured parameters during monitoring program for cold standing loss estimation at the four damper positions applied with Stove A

though the cold chimney follows the same pattern as given for the chimney draught (Fig. 2).

With the twootherstovesthe procedure wassimilar. For Stove B threedifferentdamper positions werechosen

1 = fully open

2 = intermediate position (normalcombustion)

3 = fullyclosed

and for Stove C the damper positions were:

1 = Primary air: max; secondary air: max

2=Primary air: min; secondary air: max

3=Primary air: min; secondary air: min

The duration of each test is given in Table I. All monitoring periods were conducted under quite similar climatic conditions during mild winter days in 2015.

**Table I**: Monitoring duration of cold stoves at natural draught chimney (duration in days)

| Stove A | | Stove B | | Stove C | |
|---|---|---|---|---|---|
| Damper position | Duration | Damper position | Duration | Damper position | Duration |
| 1 | 4.0 | 1 | 30.1 | 1 | 8.8 |
| 2 | 4.2 | 2 | 5.0 | 2 | 3.1 |
| 3 | 5.8 | 3 | 8.6 | 3 | 2.5 |
| 4 | 2.8 | -- | -- | -- | -- |

2.3 Procedure for losses during chimney cooling

For measuring the losses during chimney cooling the same setup was used but tests were executed with only one log wood stove (Stove A). A heating cycle of 5 full load batches followed by 3 partial load batches was applied. This heating cycle was repeated over 13 testing days.At the end of each such heating cycle the air flaps were either fully closed (in 6 tests) or they remained in the last heating position (in 7 tests). The monitoring period of the cooling phase lasted over 12 hours (i.e. overnight).

2.4 Calculation

Mean chimney temperature $\bar{T}_{chimney}$was calculate as mean value from the three sensor positions T2 to T4 as indicated in Figure 1. Cold standing losses via chimney were calculated according to the following equation:

$$\dot{Q}_{chimney} = \dot{V}_{air} * \bar{\rho}_{air} * \bar{c_p}_{air} * \left(\bar{T}_{chimney} - T_{ambient}\right)$$

where$\dot{Q}_{chimney}$ is the calcuated heat loss rate through the cold chimney (in W), $\dot{V}_{air}$ is the air volume flow in the chimney (in Nm³/s), $\bar{\rho}_{air}$ is the mean density of air (in kg/m³) calculated at given temperature (calculated as mean value of$\bar{T}_{chimney}$ (i.e. the mean chimney temperature) and $T_{ambient}$(i.e. the ambient air temperature measured at the rooftop) in °C.

The calculation regarding the standing losses for the hot chimney are calculated using the same equation.

3 RESULTS& DISCUSSION

3.1 Cold standing losses

During the relatively mild winter period 2015 the measured the average cold standing losses of the log wood stovesvia the cold chimney was between 19 and 75 W (Stove A) or it was between 27 and 56 W for Stove B.For stove C the range was from 17 to 44 W. This is shown in the results presented in Table II.

**Table II:** Cold standing losses using Stoves A, B and Cwithout heating operation, calculated over full the measurement duration(n.a. = not available)

| Stove/ damper position | Chim-ney draught [Pa] | Flow rate $\dot{V}_{air}$ [m³/h] | $\bar{T}_{chimney}$ [°C] | $T_{ambient}$ [°C] | $\dot{Q}_{chimney}$ [W] | Monthly heat loss (calcu-lated) [kWh] |
|---|---|---|---|---|---|---|
| A/1 | -4.5 | 13.9 | 19.0 | 2.8 | 74.7 | 53.8 |
| A/2 | -5.8 | 11.5 | 19.4 | 3.5 | 60.7 | 43.7 |
| A/3 | -6.0 | 11.9 | 21.3 | 4.2 | 68.3 | 49.2 |
| A/4 | -6.2 | 4.3 | 21.8 | 8.4 | 19.0 | 13.7 |
| B/1 | -9.7 | 10.1 | 21.4 | 5.0 | 55.5 | 40.0 |
| B/2 | -6.8 | 7.0 | 20.5 | 4.4 | 37.6 | 27.1 |
| B/3 | -9.6 | 4.5 | 20.6 | 2.5 | 27.1 | 19.5 |
| C/1 | n.a. | 8.3 | 20.2 | 4.3 | 44.0 | 31.7 |
| C/2 | n.a. | 4.4 | 21.2 | 7.1 | 20.9 | 15.1 |
| C/3 | n.a. | 2.8 | 21.3 | 3.2 | 16.7 | 12.0 |

Maximum heat loss flow was recorded when all dampers were kept open (see A/1, B/1, C/1 in Tab. II). For Stove A differences were low when either primary or secondary air were kept open (Positions 2 and 3); only when all dampers were closed there was always a significantly reduced air flow which created only low loss rate of between 17 and 27 W in average.

Calculated on a monthly basis this lowest loss rate of Stove A would amount to a heat loss of approximately 14 kWh. An equivalent of about 4 kg of wood fuel would be required to compensate for this monthly loss. For the highest loss rate (Stove A at damper position 1) an aggregated monthly cold standing loss of 54 kWh is calculated, it would be compensated by the use of about 16 kg of wood fuel.

3.2 Losses during chimney cooling

If the stove is operated occasionally, additional heat losses will occur. This was tested by the use of Stove A only. InFigure 3from two testing days are displayed, it shows the differences between an operational mode with and without a closure of both air dampers after the last batch. When both dampers remain in the same position as during combustion, the temperature of both, stove and chimney, rapidly declines(see dotted line) while a closure of dampers will immediately reduce the flow through the chimney (continuous line) and as a consequence this will prevent convection losses.

In Table III the results from all 5-h-cooling phases observed during 12 testing days are compiled and sorted in ascending order of the respective chimney draught. It shows that the range of climatic conditions during the tests were quite similar for both settings; they are thus reflecting a typical range of heating days in Germany. It is also shown that the level of mean chimney flow velocity is drasticallyreduced by about 60 to 70 % when all dampers are shut after combustion. However, there is still a remaining flow, which is either a deliberately realised flow (for safety reasons) or it can be attributed to leakage air intake from an untight stove construction.

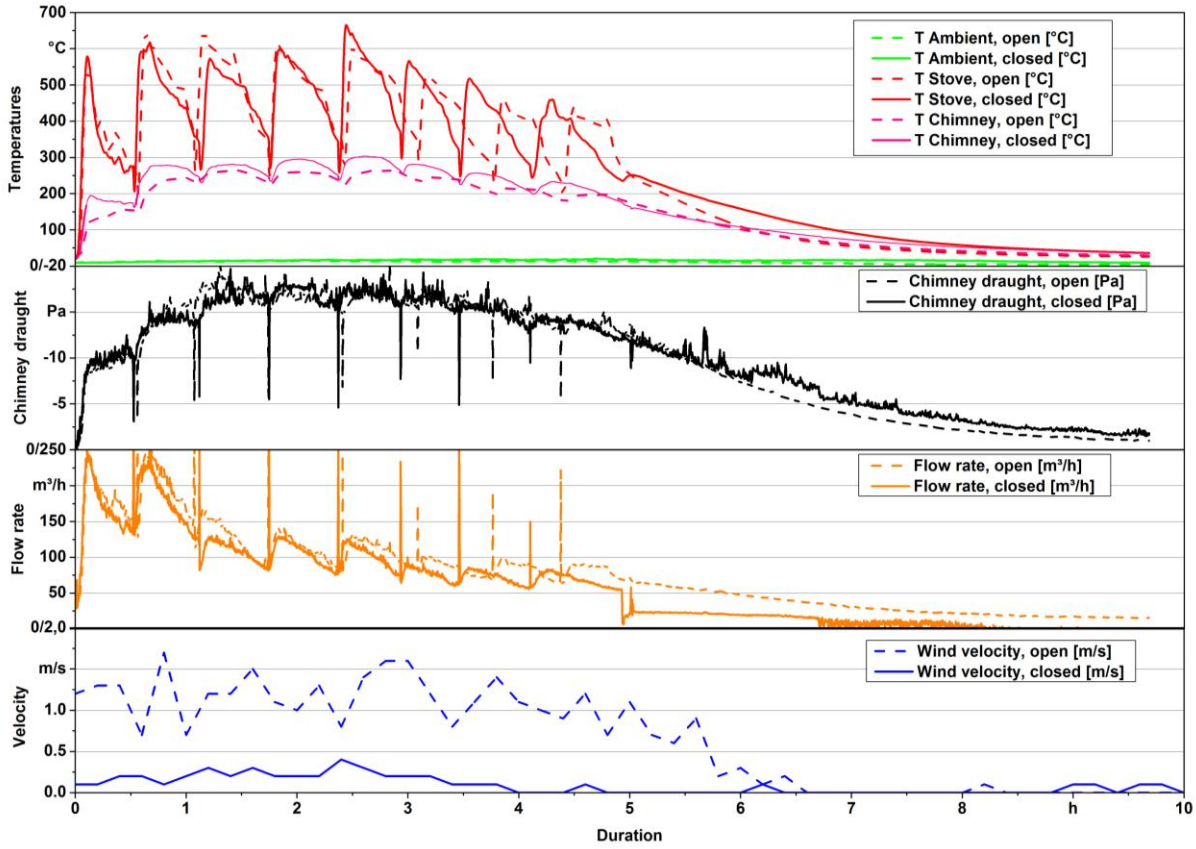


**Figure 3**: Cooling performance of Stove A at operational mode "closed" (= both dampers are closed after batch 8) and "open" (both dampers are left open after batch 8)

The post heating losses within the assumed 5-h-cooling phase are shown in Figure 4as a function of the respective chimney draught. There is a clear correlation which follows a similar pattern as also given for the correlation between chimney flow velocity and chimney draught (see data in Tab. III). The fact that the heat losses in Figure 3 did not follow a steady linear increase can be attributed to chimney draught fluctuations which are not easily reflected by the calculated mean value over the 5 h observation period. Additional sources of variation could be either an inconsistencyof stove tightness or of the damper positions at closure.

From Table III the mean post heating losses are 4.6 kWh (damper settings "open") and 1.9 kWh (damper settings "closed"). Thus, with Stove A the total directly avoidable post heating losses are around 2.7 kWh. It can be assumed, that there is a high potential for further reducing the avoidable postheating losses. Such reduction

**Table III:**Operational conditions and measurement results with Stove A on heat losses during cooling phase (5 h) after combustion (trials sorted by natural chimney draught under given climatic condition)

| | | Damper settings after heating operation: **"open"** | | | | | | Damper settings after heating operation: **"closed"** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | O1 | O2 | O3 | O4 | O5 | O6 | C1 | C2 | C3 | C4 | C5 | C6 |
| Mean heating powerlosses in post heating phase (5 h) | kW | 0.6 | 0.8 | 1.0 | 0.9 | 1.1 | 1.1 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.7 |
| Total of post heating losses | kWh | 2.8 | 4.0 | 4.9 | 4.7 | 5.6 | 5.4 | 1.1 | 1.5 | 1.5 | 2.1 | 1.9 | 3.7 |
| Mean ambient temperature while cooling (5 h) | °C | 6.6 | 24.3 | 13.8 | 16.7 | 4.8 | 10.7 | 14.3 | 14.6 | 17.4 | 11.2 | 17.9 | 5.3 |
| Mean chimney temperature while cooling (5 h) | °C | 62.1 | 96.3 | 92.3 | 88.6 | 82.5 | 79.8 | 74.6 | 85.2 | 94.5 | 96.0 | 93.4 | 87.1 |
| Mean stove temperature while cooling | °C | 64.4 | 120.9 | 121.2 | 110.1 | 95.7 | 85.1 | 99.8 | 106.5 | 140.8 | 155.1 | 132.1 | 102.2 |
| Mean chimney flow velocity | m/s | 0.63 | 0.8 | 0.92 | 1.0 | 1.09 | 1.24 | 0.19 | 0.26 | 0.2 | 0.3 | 0.4 | 0.58 |
| Meanchimneydraught | Pa | -3.9 | -20.3 | -23.3 | -27.7 | -33.1 | -42.5 | -5.3 | -6.9 | -21.3 | -26.3 | -29.3 | -38.6 |
| Meanatmosphericpressure | mbar | 974 | 978 | 991 | 988 | 970 | 962 | 984 | 969 | 985 | 994 | 987 | 976 |

could be achieved by applying fully tight air flaps on a central air intake socket while at the same time the stoves should also be highly airtight towards the heated room.

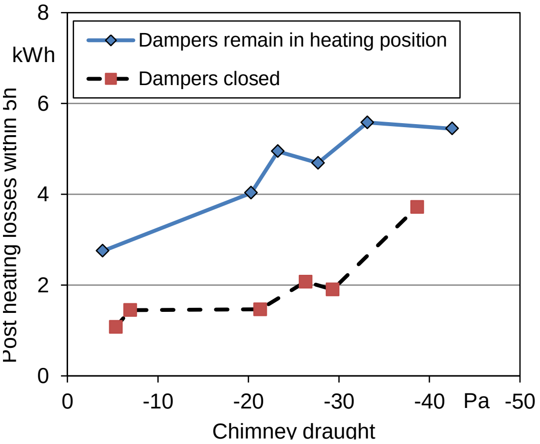


**Figure 4**: Post heating losses as a function of respective chimney draught

3.3 Techno-economic evaluation of standing losses

A model calculation was performed using the measured post heating losses as presented in Chapter 3.2. It was assumed, that the heating period will last from October until April (i.e. 213 days). For Stove A the usual damper position aftera heating cycle would be Position 3 (see Chapter 2.2). In this position cold standing losses of 68.3 W were determined (see Tab. II) and post heating losses are 4.6 kWh per heating cycle (average of damper setting "open" in Tab. III). In an operation with air dampers closed (Position 4) after terminating the heating cycle,a cold standing loss flow of 19 W was assumed while the mean post heating losses were 1.9 kWh per each heating cycle.

With these input data the total standing losses were calculated as shown in Figure 5.

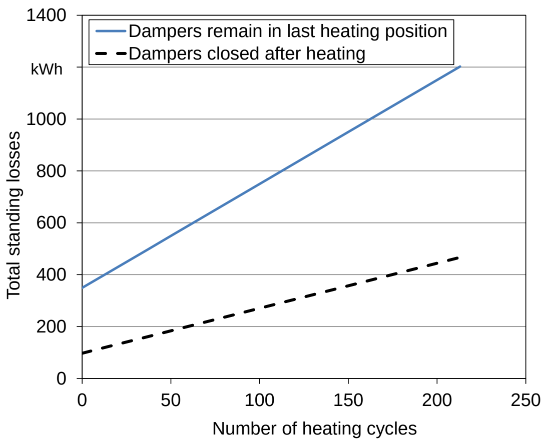


**Figure 5**: Aggregated total standing losses as a function of the number of annual heating cycles (calculated on measurement results for Stove A)

Figure 5 shows that, given the assumption of the air dampers remaining in the last heating position (which may be regarded as a highly probable case in practice), and with an estimated number of 100 heating cycles per year, the annual heat loss using Stove A amounts to 750 kWh. The heat loss in this example corresponds to approximately 0.5 m³ of staked hard wood logs. If this heat loss shall be replaced by an ordinary heating oil boiler, having an annual efficiency of 85 %, Stove B would then cause additional heating costs in the order of around 62 €/a due to leakage flow through the chimney (at an assumed oil price of 0.66 €/l).

Significant reduction of two thirds of these losses were demonstrated by closing the air dampers after heating operation (Fig. 5), although this closure seems to be rather unlikely in practice as the stove burnout usually happens overnight. But even then some losses would remain, they must be accounted to a non air-tight stove construction and to the fact that even with fully closed air dampers some air may be allowed to enter the stove via the air inlet socket (e.g. for complete coal burnout). Thus, further reduction potential is given by a fully automatic shutdown of the air supply. This could be performed by control systems or also be realized by retrofit flaps with electronical control.

## 4 CONCLUSION

Both, room heat and such heat which is still stored in a stove can easily be exhausted through the chimney of a log wood stove; this can account for notable heat losses which are usually not evaluated in stove tests. Modern stoves with automatic combustion air inlets can reduce such heat losses to a minimum by closing the air supply or the flue gas connection when the stove has cooled down to a given temperature level.

Heat losses through chimneys after termination of heating operation should generally be regarded in economical viability calculations for additional stove features such as automatic air inlet flaps. However, it should also be clarified if a complete closure of air inlet flaps is compliant with given legal safety restrictions.

## 5 REFERENCES

[1] Rawe, R. et al., Energieverluste von Gebäuden infolge Luftströmungen durch Abgasanlagen Einsparungen durch Abgasklappen,Fachhochschule Gelsenkirchen (2004)

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