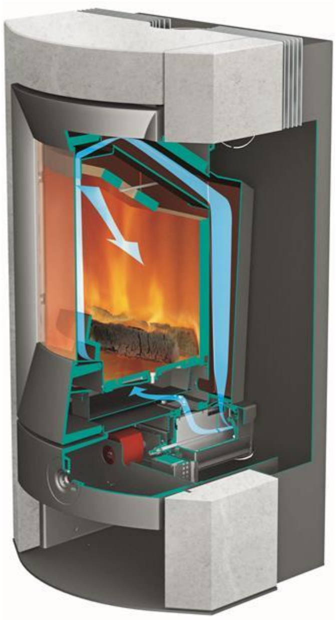
Guidelines for automated control systems for stoves



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Report within the scope of the ERA-NET Bioenergy Project "Woodstoves2020" – Development of Next Generation and Clean Wood Stoves

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Preface

ERA-NET Bioenergy is a network of national research and development programmes focusing on bioenergy which includes 14 funding organisations from 10 European countries: Austria, Denmark, Finland, France, Germany, Ireland, The Netherlands, Poland, Sweden and the United Kingdom. Its mission is to enhance the quality and cost-effectiveness of European bioenergy research programmes, through coordination and cooperation between EU Member States. The project *Woodstoves2020* (Development of next generation and clean wood stoves) has been supported in the period between October 2009 and September 2012 by ERA-NET Bioenergy under 7th Joint Call for Research and Development of the ERA-NET Bioenergy from 2013.

Today small-scale biomass combustion is one of the most relevant bioenergy applications. Driven by EU-wide and national measures to promote the utilisation of biomass for energy production, the European market for biomass based residential heating systems is expected to substantially increase by about 130% until 2020 (based on 2009). Regarding the installed units stoves show the highest and steadily increasing numbers in Europe. According to market studies performed within the EU FP7 project EU-UltraLowDust (Project No. 268189), in 2020 in Europe a potential for an annual installation of almost 2,200,000 stoves (logwood and pellet stoves) is forecasted.

This additional potential for renewable energy production will of course contribute to a reduction of the EU greenhouse gas emissions. However, it is also well known that among the different residential biomass combustion technologies logwood stoves show the highest CO, OGC and fine particulate matter (PM) emissions.

Against this background, the project *Woodstoves2020* aims at the development of innovative measures and technologies in order to further reduce emissions from wood stoves, to increase their thermal efficiency and to expand their field of application from solely single room heating to central heating. The latter could especially be of relevance for future applications in low energy buildings.

Accordingly, the detailed objectives of the project proposed can be structured as follows.

Objectives related to emission reduction

- Development and implementation of automated control systems for stoves as a feature of new stoves but also as retrofit units for existing models. Automated control systems can help to widely eliminate user induced operation errors and therefore have a huge potential for emission reduction.
- Evaluation and test of new high-temperature catalysts specially adapted to wood stoves for efficient CO, OGC and soot emission reduction. Catalysts should be implemented in new stove concepts as a basis for an ultra-low emission operation which could be comparable to the emission level of automated small-scale boilers.
- Evaluation and test of foam ceramic materials for efficient PM emission reduction.
- Evaluation of the implementation of modern chimney draught regulators.

Objectives related to increasing efficiency and new fields of application

- Development and evaluation of efficient and novel heat storage options for stoves such as the application of PCM (phase change material) with high heat storage potential.

- Investigations regarding efficient heat recovery from stoves (increase of efficiency by the implementation of heat storage units or measures to stabilise the draft or to reduce standing losses).

Objectives related to the implementation and evaluation of the different measures

- Test of the most promising concepts by performing test runs with prototypes.
- Development of design guidelines for stove manufacturers based on the evaluation of the new technologies tested towards a clean stove technology 2020.
- Development of guidelines for the implementation and retrofit of selected measures for old stoves.

With the new technologies developed within the project an emission reduction between 50 and 80% and an increase of the efficiencies in a range above 90% shall be possible. If in future all newly installed wood stoves in Europe would be equipped with these new technologies, a PM emission reduction of 60 - 90% could be achieved.

In order to reach these objectives, a consortium of 4 research organisations and 4 industrial partners from 4 European countries collaborated within Woodstoves2020 (see next page).

This document summarises the outcomes of the investigations regarding the improvement of wood stoves by the application of automated control concepts as a primary measure for emission reduction. It should support stove manufacturers concerning the optimisation of their products and the development and design of new products with its recommendations which have been worked out based on scientific investigations as well as comprehensive test runs.

Woodstoves2020 project partners

Project coordinator

Technologie- und Förderzentrum	Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ) Straubing, Germany

Project partners (R&D)

BIOS	BIOS BIOENERGIESYSTEME GmbH Graz, Austria
RI. SE	RISE Research Institutes of Sweden AB Borås, Sweden
DTU	Technical University of Denmark, Department of Chemical and Biochemical Engineering, Lyngby, Denmark

Industrial partners

RIKA	RIKA Innovative Ofentechnik GmbH Micheldorf, Austria
KW KUTZNER + WEBER	Kutzner + Weber GmbH Maisach, Germany
NIBE	Nibe AB, Markaryd, Sweden
HWAM intelligent heat	HWAM A/S, Hørning, Denmark

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1 Introduction and objectives

All over Europe there is a growing awareness that residential wood fuel appliances are potentially responsible for a great deal of environmental hazards. The complaints are manifold: particle emissions are dangerous to health, bad smell is annoying, wood is used inefficiently, sometimes illegal fuel (waste) is burnt, regional particle emission limits are violated, etc. Consequently, regulations and restrictions for wood combustion are now being revised in many European countries.

At the same time the performance of stoves and knowledge about proper stove operation are progressing and there are various technical measures which can be undertaken to avoid the problems described above. The end user can today choose between much better stove products than in the past. But above all it is the end user's heating behaviour (i.e. fuel selection, stove operation and maintenance) which is most decisive for achieving high efficiency and low emissions.

Advanced automated control systems provide the basis for a low emission stove operation at increased efficiency since they contribute to a minimisation of user induced operation errors. Therefore, the introduction of such systems, which are presently not widely-used, can have a huge impact on emission reduction from stoves. Moreover, retrofit control units for existing stoves open a wide field of application with an even larger potential for emission reduction.

Therefore, this guideline is intended to improve the combustion performance of chimney stoves which represent todays largest group of appliances. The guideline aims at supporting manufacturers in the development and optimisation of their stoves by means of automated control systems.

1.1 Target group

This guideline is intended primarily for developers and manufacturers of chimney stoves to use the presented control systems for the design and optimisation of automatically controlled low-emission appliances. But it is also meant for professional users such as associations or public bodies. They are invited to make the guideline available either as a complete paper or by using fragments in their own brochures or product-specific manuals. Therefore, all text, photos and images are cleared for publication by third parties without extra inquiry. We only request that a reference to this guideline is made.

2 Definitions and limitations

2.1 Definition of chimney stoves

The following features apply to a chimney stove (Figure 1).

- It is a free standing room heater, not walled, and usually with a front window.
- Only a relatively small amount of heat storage is possible due to the low mass of the stove, but storage devices could be added to the stove to increase its efficiency.
- Fuel is charged in a single layer onto the bed of embers.
- Therefore: frequent re-charging is required.

- Heat is released by radiation from the window or from other surfaces and by convection via air ducts and outlets.

Figure 1: Examples of chimney stoves (from left to right: Contura, Rika, HWAM A/S)

2.2 Limitations

Much of the technical information in this Guideline also applies to slow heat releasing stoves (e. g. tiled stove inserts, closed fire place inserts), but such stoves are not the main focus in this document. This is due to the high variation of their designs and features which would make it difficult to give generalized recommendations. Consequently, tiled stoves, open fire places, cooking stoves, all stoves with water jackets, pellet stoves and sauna stoves are not covered in this guideline.

Apart from all practical questions concerning the proper selection and operation of stoves, further technical improvements are also possible, e. g. by a better stove design or by special flue gas treatment. But such primary and secondary measures are separately presented in other guidelines which have also been prepared during this ERA-NET-project (see [1] and [2]).

3 Basics/fundamentals of automated control systems for stoves

Advanced automated control systems provide a basis for a low emission stove operation at increased efficiency since they also contribute to a minimisation of user induced operation errors. Therefore, the optimisation and introduction of such systems, which are presently not widely-used, can have a huge impact on emission reduction from stoves. They shall provide a basis for achieving low emissions during operation not only at test stand conditions but also in real life operation. Moreover, retrofit control units for existing stoves open a wide field of application with an even larger potential for emission reduction. An automated control system for a stove can control and optimise the operation of the stove but cannot influence the fuel used. Therefore, it is very important that an appropriate fuel quality needed for an efficient and clean operation of the stove is ensured by the user. Appropriate guidelines regarding suitable fuel qualities as well as ignition manuals are available (see [3]).

3.1 Advantages and potentials of integrated automated control systems

The implementation of automated control systems shows the following advantages and potentials:

- reduce user influences (operating errors)
- provide the possibility to react on the changing process conditions throughout the entire batch
- reduce emissions (see Figure 2) and increase the thermal efficiency
- operation comfort
- reduce standing losses (by closing air flaps)

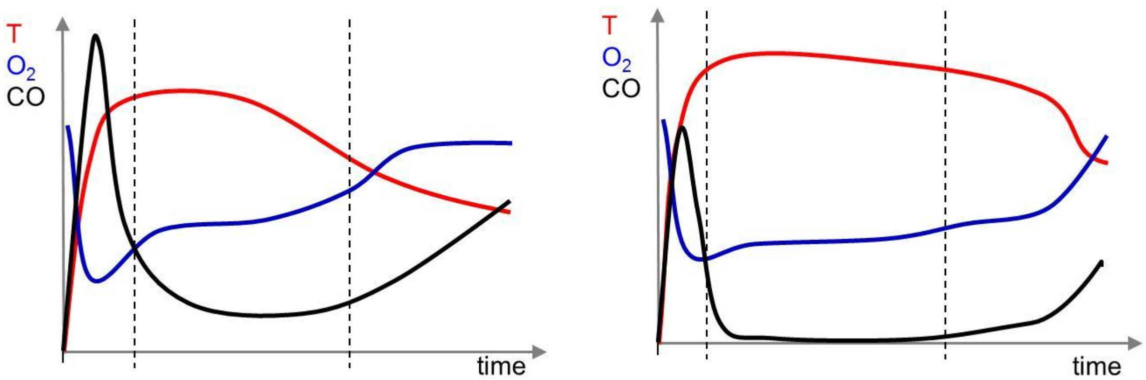

Figure 2: Schemes of a combustion batch for a conventional uncontrolled stove (left side) and an automatically controlled stove (right side)

The differences between the graphs shown in Figure 2 illustrate the advantages of an automatically controlled stove. The combustion chamber temperature (T) is more stable and is kept on a higher level. The O_2 level is more even and shows lower values during the main combustion phase as well as during the burnout phase resulting in higher combustion chamber temperatures and therefore in lower CO emissions with only one peak during the ignition phase of the batch.

3.2 Advantages and potentials of retrofit control systems

The implementation of retrofit control systems shows the following advantages and potential:

- reduce user influences (operating errors)
- provide the possibility to react on varying process conditions throughout the entire batch
- reduce emissions (only gaseous) and increase the thermal efficiency
- increase of operational comfort
- reduce standing losses (by closing air flaps)

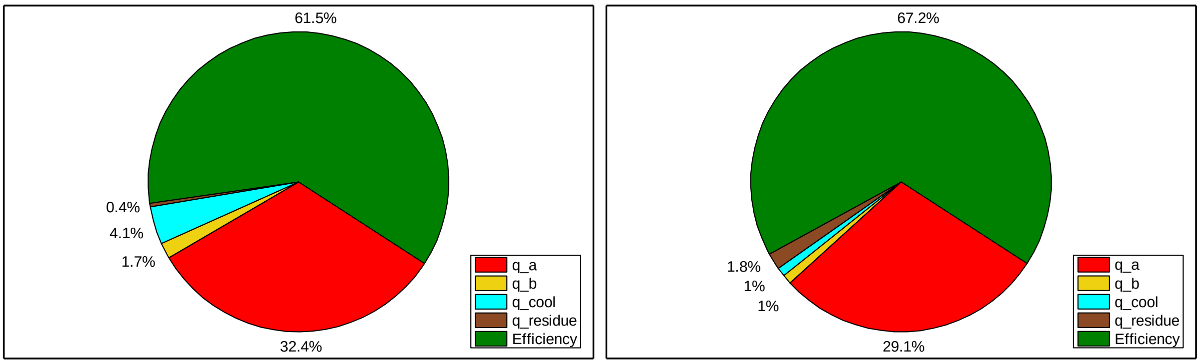

Figure 3: Efficiency and heat losses in manual operation with air flaps remaining in last position (left). Efficiency and heat losses with retrofit controller installed at the air socket (right). ***Efficiency=100%-losses; q_a=thermal losses; q_b=chemical losses of the flue gas; q_cool=standing losses while cool down; q_residue=energy content of the residues.***

The pie charts shown in Figure 3 shall give an idea of the differences in efficiency and losses by manual operation, when the air flaps are not adjusted after heating operation compared to the operation using a retrofit controller installed at the air socket of the stove. When comparing the two pie charts it becomes obvious that efficiency can be improved by up to 5.7 percentage points. This is due to the prevention of heating losses during the cool down phase by 3.1 % and higher CO_2 resp. lower O_2 levels during combustion (see Figure 2) which leads to reduced thermal losses (q_a).

Furthermore, the combustion tests during the project suggest that CO emissions can be reduced by up to 55 % and OGC emissions by up to 37 %, but the particle emissions remain in the same range if the controller is well adjusted to the stove. However, if the controller is not specifically adjusted to the particular stove model or no adjustment is possible, the particle emissions from stoves with retrofit controllers can be higher than by manual operation.

Therefore, it is highly recommended that a retrofit control unit is either sold and installed by the stove manufacturers themselves, or by qualified personal, able to adjust the controller settings to the particular stove model and to installation conditions on site (draught, external air supply etc.). Another prerequisite for retrofitting a stove with a combustion air controller is an external air supply socket which has to be air-tight to ensure low leakage air.

3.3 Challenges and requirements of automated control systems

Besides the advantages and potentials shown also challenges and requirements are given which have to be considered.

- robust sensors are needed
- the technical solution has to be economically competitive
- a 230 V electrical connection is required
- the automated control concept needs to be suitable for different fuel qualities and loads

- The control concept/unit needs to be safe and fulfil the national safety regulations if the air supply shall be closed completely.

3.4 *State-of-the-art of automated control systems*

Common logwood stove concepts are usually manually controlled (by a control switch). Therefore, process control efforts are usually limited to a change of the combustion air distribution at the end of the ignition phase. Recent technical solutions towards stove automation can be divided into automatically controlled stoves and stove add-ons, which feature an automatic control.

- Automatically controlled stoves
  - Thermo-mechanically operated air flaps (HWAM automatic™, Wodtke Air control)
  - Electronic sensor driven automatic control concepts (RIKATRONIC™, HWAM Autopilot IHS™, Hark 44 GT ECOplus SC)
- Stove add-ons and retrofit systems, which feature an automatic control
  - Chimney draught stabiliser and flue gas fans (K+W draught stabilizer, ATEC Florian)
  - Air and flue gas flaps (K+W Compact, Schmid SMR, TATAREK RT8OS-G-TD, Brunner EOS, OCOntrol) – see Figure 4
  - Electronic air distribution systems (ATEC Airmaster)

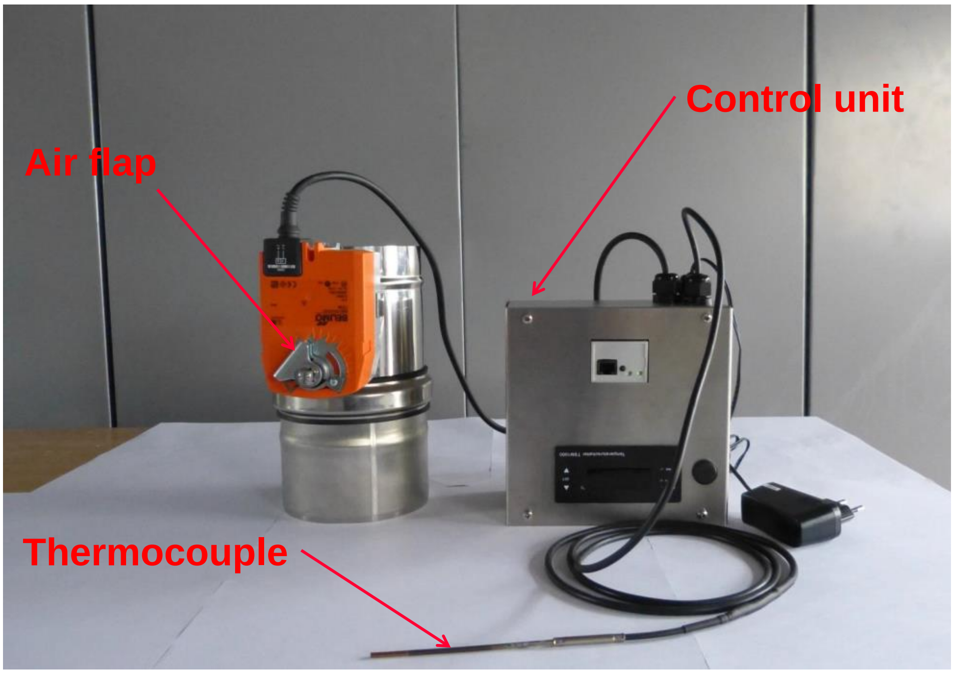

Figure 4: Picture of the retrofit automated control system LKF of K+W based on a temperature controlled air flap (Source: K+W)

3.5 Sensors for automated control systems

For implementing a reliable automated control system based on electronic sensors the choice of sensors is crucial. In the selection process certain specific criteria should be considered, such as price, availability, life span, temperature resistance, signal selectivity, stability & processing.

The most important criterion of course is ensuring an acceptable price level for sensor & peripherals, since the costs for implementing sensors will result in a higher relative market price increase than compared to conventional stoves.

Regarding availability it is essential that the sensor's development status is commercially ready. The sensor should be available in sufficient numbers and consistent quality since it is intended to implement it in a commercial product.

Similar requirements are also valid for the life span expectation – ideally it should be unnecessary to replace the sensor during the stove's normal life time.

The criterion resistance ability to temperature and other ambient conditions has impact on the sensor location possibilities. The sensors must be able to be placed in representative locations to give a fast and suitable signal for the control system to act on. For example, the positioning of a temperature sensor in the flue gas socket provides a less sensitive and less dynamic control signal compared to a sensor located in a suitable location in the combustion chamber, thus would weaken the control system's potential.

The signal selectivity, stability & processing influences the control systems overall operation properties and the effort in implementing the system. Ideally the signal of the sensor can be directly processed, which helps to minimize control peripherals. Furthermore, it should accurately and stable reflect the desired parameter to be measured with minimal cross sensitises to other ambient conditions.

Depending on the kind of automatic control system different sensors can be used, as for example:

- Temperature sensors
  - Thermocouples are the cheapest sensors available and also rather robust, therefore they are an excellent choice for stove control
- Gas sensors
  - In terms of aiming for high efficiency and low emissions the most useful sensors would be oxygen or carbon dioxide sensors as well as sensors for unburnt components such as carbon monoxide and hydrocarbons.
  - Online oxygen sensors are commonly used in combustion appliances, especially in form of lambda probes respectively similar sensors based on the same measurement principle (example for manufacturers: NGK Spark Plug Co., LAMTEC, J. Dittrich Elektronic). According to literature they have been proven to be reliable and durable for use in biomass combustion appliances with general good accuracy and little cross sensitivity. Long-time evaluations (several hundred hours) within the Woodstoves2020 project with two different lambda probe models (switching & broadband type) confirmed that statement.

Both types delivered a fast and reliable signal with no observed long term effect on stability and accuracy and have therefore been found to be suitable for usage in automated stove control systems.

- Sensors for carbon monoxide usually detect all unburned components, therefore provide a combination signal for CO and Hydrocarbons (example for manufacturers: LAMTEC, FIGARO Engineering inc). According to literature, development has significantly improved within the last years in terms of availability, accuracy and stability. Their utilization in control concept has been successfully proven in some projects, at least with providing usable and reliable trends. On the downside, they are still more expensive than for example oxygen sensors.

- Combination sensors for oxygen and unburnt components provide a compact opportunity for generating a high-end control concept aiming for best efficiency with lowest emissions (example for manufacturers: LAMTEC, Sensic). Regarding their current development status the same conclusion is valid as for CO sensors. They are still quite expensive, but their performance has been improved during the last years. Specific test runs (up 250 hours) with the combination probe KS1D of LAMTEC at a low-emission logwood chimney stove within the Woodstoves2020 project have been performed. Generally, the combination probe KS1D seems to be suitable for the implementation into an automated stove control concept based on the results achieved so far. The sensor can well reproduce the O_2 trend over the entire range of operation of a wood stove. Regarding CO some deviations, especially at higher CO levels (> 1,000 ppmv), occur. If the internal compensation function of the sensor would be determined for biomass combustion systems at different CO and O_2 levels then the deviation could most probably be reduced (according to the manufacturer). However, the CO trend is sufficiently well predicted. Due to the recent high costs the combination probe KS1D is currently not recommended for the integration in the automatic control system of stoves.

- Pressure sensors
- Other sensors, as for example detectors for recognizing flame or door opening

Before using a sensor in a commercial product, its suitability to be used in such an appliances should be reviewed through market & literature study or if necessary through own evaluation. See chapter 9 for information regarding manufacturers of sensors.

4 Proposed automated control systems for stoves

4.1 Design and function of a modern chimney stove

In the following, a typical design and functioning principle of a modern chimney stove is described. For better understanding the following definitions apply:

- Primary air: It provides the oxygen needed to gasify the wood fuel and to burn the remaining char. Primary air is directed to the space where the solid fuel is pyrolysed (bed of embers).
- Secondary air: It is needed to provide oxygen to be mixed with released pyrolysis gases which burn as visible flames. It is usually applied as window purge air but it can also be supplied as a combination of window purge air and additional secondary air supplied through additional nozzles.

Figure 5 shows the flow of air and flue gas in a chimney stove. For air tight buildings it is required that a combustion air conduit (pipe) can be connected to the chimney stove via a central air inlet socket (1). Such an air inlet socket can also enable the retrofitting of an electronic combustion air control system via a motor driven flap.

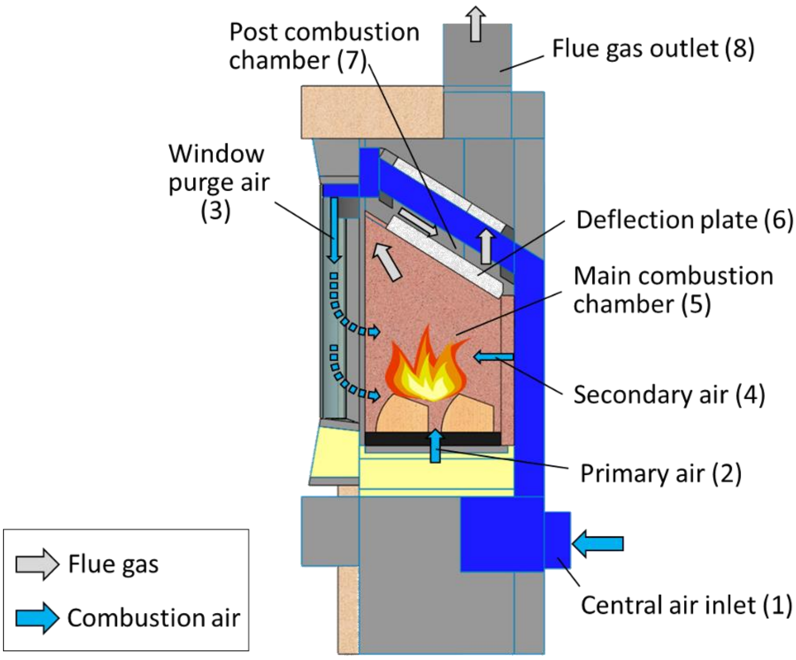

Figure 5: Typical design of a chimney stove (here: stove with central air supply socket and primary air via grate)

The combustion air flow into the chimney stove (blue area in Figure 5) is divided into

- a primary air stream (2) which passes through the grate into the firebox and
- a window purge air flow (3) which is conducted to the window top and is then directed through nozzles or slots downwards along the window. It flushes the window to prevent tar, soot or particle depositions. But it also serves as combustion air. One part of it usually reaches the bed of embers and can provide primary air to the wood fuel if either the grate is closed (e. g. by a rotation rosette) or if the grate air damper is

locked or if no grate exists at all. Another part of this air stream is directed above the bed of embers into the combustion chamber (5) to provide oxygen for the gas phase combustion (serves as secondary air).

- Some stoves are equipped with an additional secondary air inlet at the back of the stove wall (4) (this air flow is sometimes also called "tertiary air"). Such an inlet may improve the turbulent mixture of oxygen with the pyrolysis gas released from the solid fuel. The portion of this air stream is usually smaller than the window purge air.

The heat produced in the firebox (i. e. combustion chamber) is conserved by a heat resistant mineral insulation layer made of fire clay or chamotte. This ensures high temperatures for complete combustion reactions. In the post combustion chamber (7) combustion is completed, therefore high temperatures are here still maintained by refractory lining (fire clay, chamotte or vermiculite insulation). Also high turbulence is achieved here through the deflection plate (6) which leads the hot gases to the narrow entrance of the post combustion chamber. The gases are finally burnt out here and are conducted to the flue gas socket from where they exit to the chimney (8) via a connecting pipe.

4.2 Overview of proposed automated control systems

Several different systems of automated controls for logwood stoves have been evaluated within the ERANET project Woodstoves2020. However, other systems will be considered within this guideline as well. In the following some examples for integrated, add-ons and retrofit systems are presented.

4.2.1 Automatically controlled stoves

- Electronic sensor driven automatic control concepts based on
  - Flue gas temperature measurement in the combustion chamber
  - Oxygen measurement in the exhaust gas
  - Combinations of temperature measurement and oxygen measurement

4.2.2 Stove add-ons and retrofit systems for semi-automatic stove control

- Chimney draught stabiliser
- Automatic combustion air valve based on
  - Flue gas temperature measurement in the combustion chamber
  - Oxygen measurement in the exhaust gas
  - Combinations of temperature measurement and oxygen measurement

4.3 Electronic sensor driven automatic control concepts

Electronic sensor driven automatic control systems are more efficient but also more costly. The temperature (for example in the post combustion chamber) or the oxygen concentration of the flue gas, as well as a combination of these, can be applied as guiding parameters for automated adjustments of the combustion air flow and combustion air distribution by flaps over time.

4.3.1 Stove control based on temperature measurement

This automated control system is based on a temperature measurement in the combustion chamber and flaps for the combustion air supply control. The different combustion phases can be identified by temperature changes and since temperature sensors are the cheapest sensors available and also rather robust, they offer a suitable opportunity for stove control.

The basic control strategy can be described as follows:

- Ignition phase
    - Mainly primary air and a low amount of window purge air is supplied in order to facilitate a quick ignition and rapid increase of the combustion chamber temperatures
- Transition to main combustion phase
    - As soon as the temperature in the combustion chamber exceeds a certain level the primary air damper is closed to avoid excessive burning rates
    - At the same time secondary air and window purge air flows are increased to maintain adequate combustion air supply
    - During the main combustion phase the secondary and window purge air flow should be kept rather constant. The distribution between these two flows depends on the furnace design (combustion chamber and air injection nozzle geometries) and should be experimentally optimised for a specific stove type.
- Transition to charcoal burnout and charcoal burnout phase
    - when the furnace temperature starts to drop below a certain value, the amount of secondary and window purge air should be reduced to keep the temperature at a reasonably high and nearly constant value until the end of the batch
    - Thereby, excess oxygen is kept low and too much cooling of the combustion chamber is prevented.
    - As soon as the flames extinguish the CO and OGC emissions strongly increase. Thus, re-charging of fuel should be performed as soon as the flames extinguish.

Following this approach

- a shorter ignition phase can be achieved
- with combustion air flow control during the main combustion and burnout phase more stable O_2 concentrations in the flue gas can be achieved
- generally lower O_2 levels as well as sufficiently high temperatures (relevant for improved burnout) can be achieved

resulting in lower emissions and higher efficiencies.

Basically, the combustion air flows (primary, secondary and window purge air) are controlled in dependence of the furnace temperature (measured by a flame temperature sensor) and a calculated time dependent temperature gradient (see Figure 6).

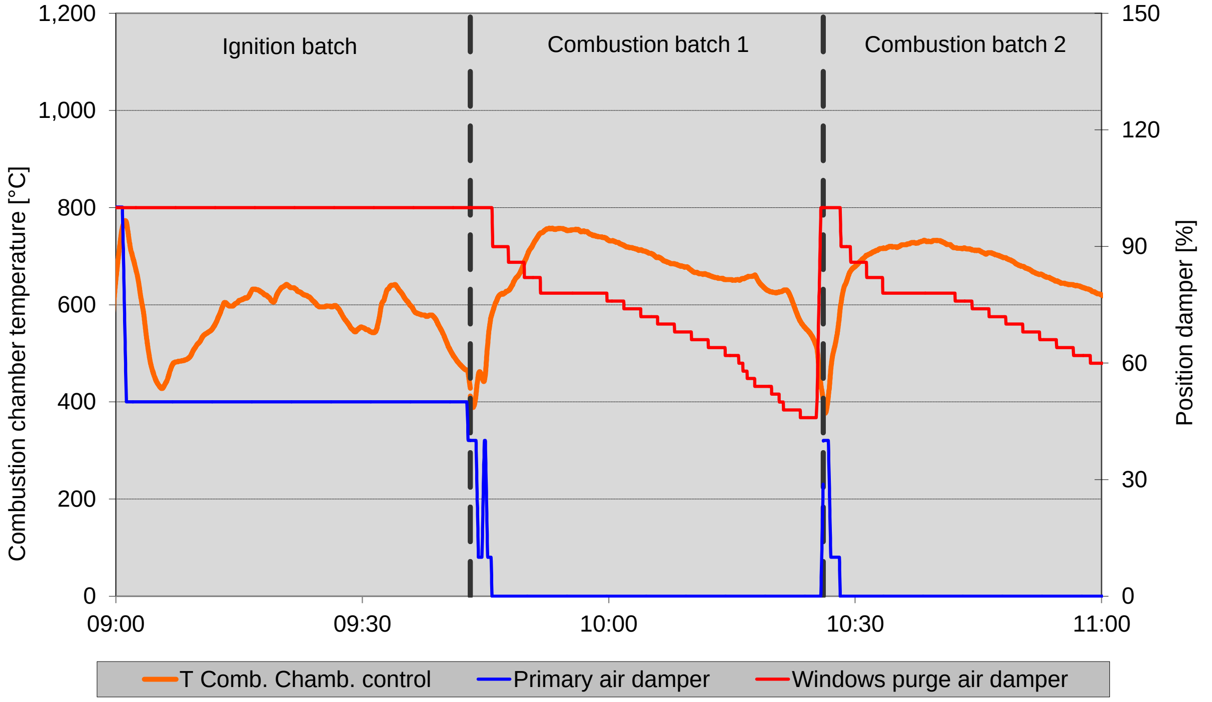

Figure 6: Trends of the combustion chamber temperature and damper positions of a test run with a logwood fired stove with automated control system based on temperature measurement (dashed lines mark the beginning and the end of a batch)

At the stove the primary air through the grate as well as window purge air and secondary air (if applied) are supplied. The combustion air flows have to be separately controlled by electronically driven dampers and the furnace temperature is measured by a flame temperature sensor located in the main combustion chamber (see Figure 7).

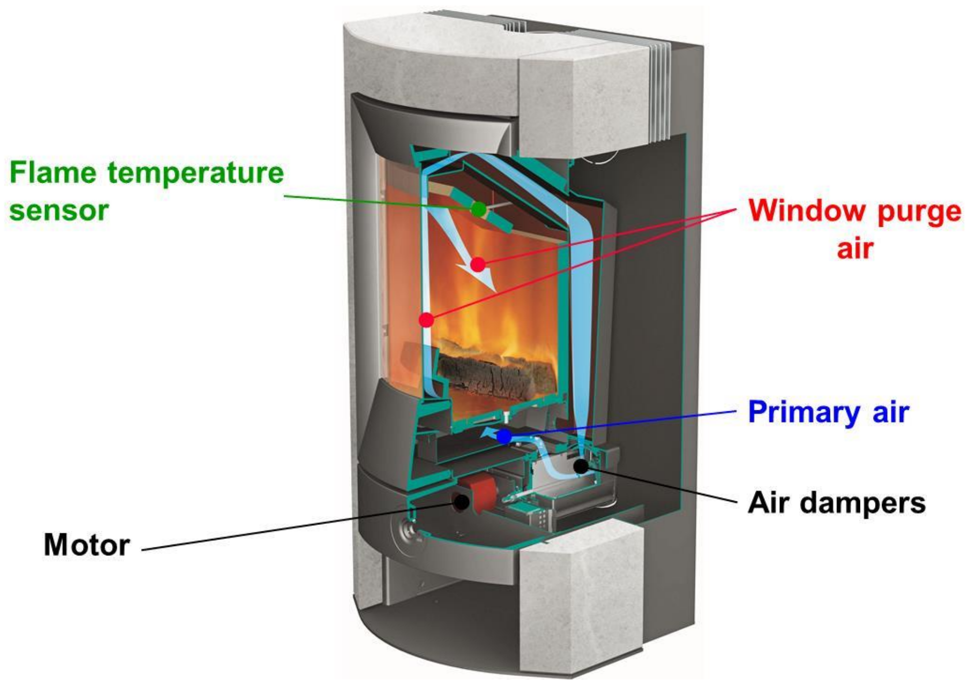

Figure 7: Scheme of a logwood fired stove with automated control system (source: RIKA)

4.3.2 Stove control based on a combination of temperature measurement and flue gas sensors

These automated control systems identify different combustion phases with the help of gas sensors and adjust the air dampers accordingly. The combination with additional sensors, such as temperature and pressure sensors is also possible and provides further information for the control system. Such control systems are more complex and expensive than systems based on temperature sensors alone but also create opportunities to further improve efficiency and flue gas emissions as well as deal with unexpected events.

An automated control system based on an oxygen & temperature sensor (assisted by a sensor that recognizes door opening) would identify ignition & refueling, main combustion phase and charcoal burnout and adjust the damper settings for primary, secondary and tertiary combustion air accordingly. The basic control strategy for these main operating phases is as follows:

- Ignition phase
    - The aim is to ignite the wood and increase the temperature in the combustion chamber as quickly as possible to avoid unnecessary release of unburnt components. In order to achieve that a high air flow is needed and therefore air dampers are opened when the ignition signal is triggered.
    - During ignition the oxygen content in the flue gas is reduced while temperature increases. When both signals reach a certain lower respectively upper value the primary air damper is closed. This marks the transition to the next operation phase.
- Main combustion phase
    - With the primary air damper closed the fuel gasification rate is slowed down in order to avoid insufficient oxygen supply in the gas combustion zone.
    - In the following the automated control adjusts secondary and tertiary air to keep the temperature and the oxygen in the flue gas within defined ranges. Secondary air damper setting is thereby based on temperature and tertiary dampers on oxygen content. In order to achieve a smooth combustion, rapid and too large changes in damper settings should be avoided.
    - In the end of the main combustion phase when less volatile matter will be released from the fuel and mainly charcoal remains, the oxygen signal will increase above the defined range despite having the corresponded air damper adjusted to its minimum position. This marks the end of this main combustion phase and the transition to the next operation phase.
- Charcoal burnout towards refueling or final burnout
    - The control during this phase is based on oxygen signal and adjusts primary and secondary air dampers accordingly to keep the oxygen level within a defined range. Enabling primary air accelerates charcoal burnout in the bed of embers and generates heat to avoid a rapid drop in combustion chamber temperature.

- When the oxygen content rises above the desired range despite dampers at their final positions, the stove will signal for the next batch
- If the user follows this refueling signal the stove will switch back to ignition phase with air dampers open for rapid ignition until defined oxygen & temperature levels are reached, marking again the begin of the main combustion phase
- If the user refuses to refuel, the stove switches to final burnout with fully open primary air, at which end, when reaching the final levels for oxygen and temperature, the dampers are closed to minimize standing losses

The different control parameters such as oxygen & temperature ranges, damper positions as well as primary/secondary/tertiary air ratio and amount should be experimentally optimized for the specific combustion chamber.

This control concept aims for achieving short ignition and charcoal burnout phases in order to minimize emissions of unburnt components while optimizing efficiency by avoiding unnecessary excess air. The control system shall ensure constant and optimal temperatures and oxygen concentrations throughout a whole combustion cycle (see Figure 8) which makes it very robust to different ways of operation.

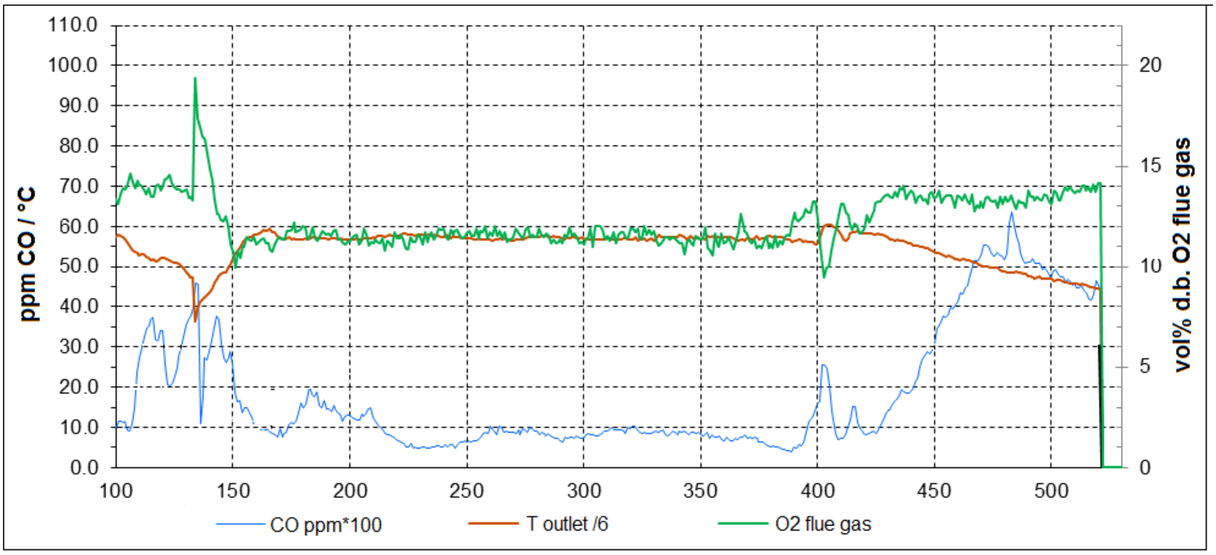

Figure 8: Trends of the combustion chamber outlet temperature and O_2 concentrations of a batch with a logwood fired stove with automated control system based on temperature and oxygen measurements (Source: DTU)

For situations where a flue gas fan is necessary (e.g. insufficient draft due to installation limitations, weather conditions, secondary measures such as filters or catalysts) the implementation into the automated control concept is possible either for continuously draft depended operation (based on for example a pressure sensor) or intermittent operation for certain operation phases (as for example cold ignition or refueling).

4.4 Stove add-ons and retrofit systems, *which feature an automatic control*

Also for retrofit control systems it would be preferable to control primary and secondary air in the way described in chapter 4.3. In practise it is only possible to adapt the controller as an air flap on a central air inlet socket. Furthermore, it is required that the stove is air-tight when oxygen supply via the air flap is shut down. Sensors for retrofit control systems can only be located behind the stove in the flue gas pipe, this is because manipulation of the stove itself is not allowed without approval by the manufacturer.

4.4.1 Control strategy

For universal retrofit systems certain specific parameters, like flue gas temperatures or O_2 levels, are not given, only a conservative air control is possible as shown in Figure 9.

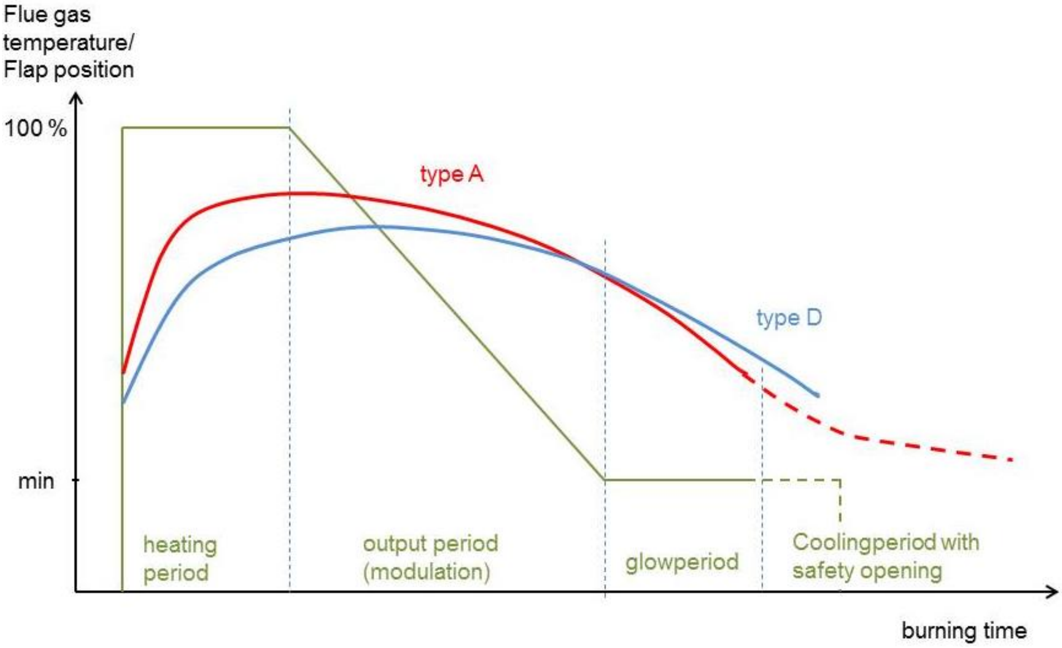

Figure 9: Function of air supply compared to temperature trends of two different stove types (Source: K+W)

The first part (heating period) of the batch is characterized by a high combustion air demand. To supply enough air for all cases the air flap is totally open so that the stove works comparable to a manually operated system. In the subsequent output period which can be identified by a certain temperature-criterion, air supply can be stepwise reduced in order to keep the combustion temperature on a higher level. After the charcoal burnout phase (glow period) the standing losses can be reduced by closing the air supply completely. Apart from the prevention of failures in user operation such loss reduction represents one of the main benefits of a retrofit air control device.

4.4.2 Implementation / technical solution

A typical retrofit controller is shown in Figure 10. It consists of a control unit, an electrically driven air flap and a sensor for flue gas temperature. To guarantee a proper stove operation in combination with the controlling unit the following points should be considered.

- The temperature sensor shall be installed as close as possible to the flue gas socket (centrally placed) in order to avoid any additional delay due to given thermal inertia and to ensure a quick reaction of the controller to the current stove behaviour.
- The installation of the air flap at the air inlet socket of the stove shall be performed with absolute air tightness. In the same way high air tightness is required for the stove

itself. Both requirements aim at avoiding leakage air passing around the air flap to the stove.

The findings in this ERANET-project had shown that there can be an increase of particle emissions by installing a retrofit controller without correct stove specific adjustment of the control parameters and draught conditions (or when sufficient adaptation is not possible at all). Therefore, it is highly recommended that the distribution and installation of retrofit controllers should only be executed by the stove manufacturer or by an original equipment manufacturer in cooperation with the stove manufacturer.

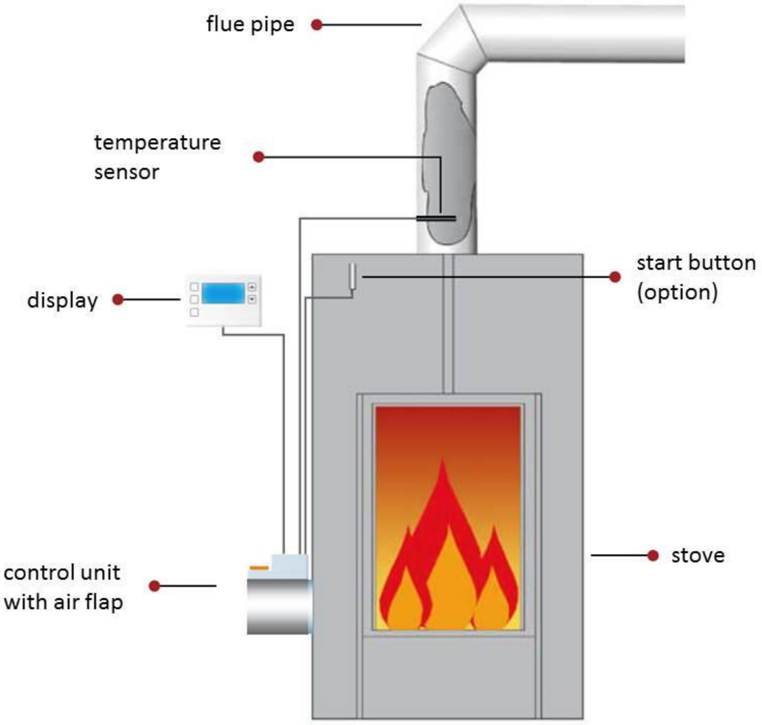

Figure 10: Typical retrofit controller mounted on the central air inlet socket with flue gas temperature sensor and display.

5 Troubleshooting

In the following relevant failures/malfunctions that may happen are described which are of relevance for an automatic control:

- Power blackout
    - Manual control of stove must still be possible
    - Restart of automated control when stove is cooled down
- Flap got stuck
    - Consult the user manual for the stove!
- Sensor failure
    - Manual control of stove must still be possible
    - Consult the manufacturer of the stove!

6 Safety requirements and legal frameworks

Regarding the safety requirements for automated stoves and retrofit controllers, some critical requirements need to be met if the air supply will be closed completely after stove operation (as recommended here) in order to prevent standing losses. In this case it has to be ensured that there is no release of pyrolysis gases or exhaust fumes into the heated room. It also must be ensured that no dangerous concentrations of unburnt gases can occur in the flue gas. Therefore, the stove shall be highly air tight, and it shall be ensured by appropriate criteria that the flames are extinguished when oxygen supply is shut down completely. Such criteria can be the achievement of a certain temperature or oxygen level in the flue gas.

Another crucial point is that there should be a distinct detection of door openings before, during and after stove operation. This could either be done by door switches or by a certain sensor signal (temperature, O_2 etc.), but the use of a door switch (perhaps as additional feature) is highly recommended, because the other signal indications are less reliable and may thus be more error-prone.

Regarding the framework for market introduction, there is European standardisation work ongoing within CEN TC 295, where the upcoming EN 16510-standard shall be amended by adding a separate part which shall specifically deal with requirements for automated combustion control systems in room heating appliances.

Until this new European standard is achieved there is another option which allows manufacturers to affix the CE marking onto products which are not (yet) based on a harmonised standard. This possibility is given by the ETA (European Technical Assessment) procedure (see Figure 11). More information can be found in the cited download link.

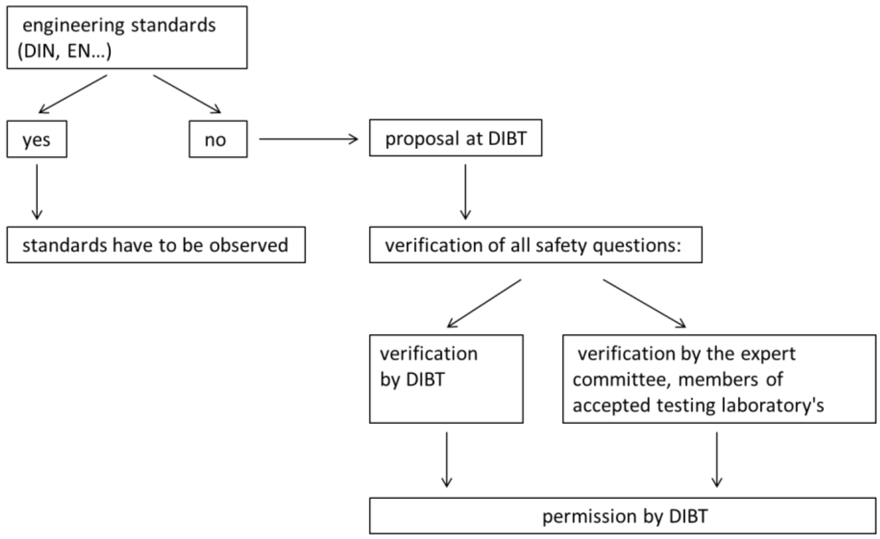

Figure 11: ETA permission procedure (Source: https://www.dibt.de/en/dibt/data/ETA_brochure.pdf, Download date: 30/05/17)

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	Swedish Energy Agency

8 Related literature

1. HARTMANN H., MACK R., OBERNBERGER I., MANDL C., SCHUESSLER I., 2017: Guidelines for Optimized Stove Concepts. Report within the scope of the ERA-NET Bioenergy Project “WoodStoves2020”, July 2017 www.tfz.bayern.de/mam/cms08/en/dateien/stoves2020-guidelines_low_emission_concepts.pdf

2. MANDL C., OBERNBERGER I., 2017: Guidelines for heat storage units based on Phase Change Materials (PCM). Report within the scope of the ERA-NET Bioenergy Project “WoodStoves2020”, July 2017 www.tfz.bayern.de/mam/cms08/en/dateien/stoves2020-guidelines_Phase_Change_Materials_pcm.pdf

3. HARTMANN H., SCHÖN C., TUROWSKI P., OBERNBERGER I., BRUNNER T., BIEDERMANN F., BÄFVER L., FINNAN J., CARROLL J.; 2012: Low Emission Operation Manual for Chimney Stove Users. Report within the scope of the ERA-NET Bioenergy Project “FutureBioTec”, October 2012

4. VIRÉN, A.; LAMBERG, H.; TISSARI, J.; SIPPULA, O.; JOKINIEMI, J.; OBERNBERGER, I.; BIEDERMANN, F.; BRUNNER, T.; HARTMANN, H.; SCHÖN, C.; TUROWSKI, P., 2012: Guidelines for Low Emission Chimney Stove Concepts. Report within the scope of the ERA-NET Bioenergy Project “FutureBioTec”, October 2012.

5. OBERNBERGER I., BRUNNER, T.; 2015: Guidelines and relevant issues for stove development. Workshop on Highly Efficient and Clean Wood Log Stoves within the IEA Bioenergy Conference, October 2015, Berlin, Germany; http://www.ieabcc.nl/workshops/task32_2015_Berlin/index.html

6. MANDL C., BRUNNER T., OBERNBERGER I., KOESSL M., 2013: Optimisation of Logwood Fired Stoves by Means of Innovative Primary Measures. In: Proc. of the 21st European Biomass Conference and Exhibition, June 2013, Copenhagen, Denmark, ISBN 978-88-89407-53-0 (ISSN 2282-5819), pp. 562-567, (paper DOI

10.5071/21stEUBCE2013-2CO.4.4), ETA-Florence Renewable Energies (Ed.), Florence, Italy

9 Useful sources for further information

Manufacturers of sensors:

- LAMTEC Meß- und Regeltechnik für Feuerungen GmbH & Co. KG:
  https://www.lamtec.de/de/

1. NGK Spark Plug Co., Ltd.)
   https://www.ngksparkplugs.com/
   http://www.hs-kabeltechnik.at

- LogiDataTech electronic GmbH und LogiDataTech systems GmbH & Co. KG (formerly J. Dittrich Elektronic GmbH & Co. KG)
  https://logidatatech.com/de/
- SenSiC AB:
  http://sensic.se/
- Scan Tronic Aps:
  http://www.scan-tronic.dk/

Certification schemes and labels for stoves:

- Nordic Ecolabel for stoves (Scandinavian countries):
  http://www.svanen.se/en/Find-products/Product-search/?categoryID=100067
- DIN_{plus} label for stoves (Germany)
  http://www.dincertco.de/de/kaminoefen_pelletoefen_heizeinsaetze_herde_und_sonstige_haeusliche_heizgeraete.html
- Austrian Umweltzeichen UZ 37
  https://www.umweltzeichen.at/cms/de/produkte/gruene-energie/content.html
- Ecodesign and Energy Labelling (Directive 2009/125/EC) – Local space heaters:
  https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/ecodesign/solid-fuel-local-space-heater_en