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Investigation of user behavior and assessment of typical operation mode for different types of firewood room heating appliances in Austria

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ABSTRACT

Firewood heaters like firewood roomheaters, tiled stoves and residential biomass cookers are commonly used for supplying the residences with renewable heat. However, these kinds of appliances were identified as responsible for relevant amounts of gaseous CO and OGC as well as particulate emissions causing negative health effects. Beside technological reasons, the operating conditions and the user behavior are essential reasons for increased emissions, especially in real life operation.

Therefore, this study aimed at an investigation and assessment of typical real life user behavior by a survey. Based on the findings effective and customer friendly technological and non-technological optimization approaches for a better and more environmental friendly real life performance were defined.

The results of the study showed principally similar user behavior of all considered types of appliances regarding most relevant operation characteristics, i.e. kind, properties and amount of used fuels, ignition procedure and air valve settings. Most effective non-technological optimization approaches were found for an enhancement of external training arrangements and the development of user friendly manuals that aimed mainly at an improvement of the ignition procedure from bottom–up to top–down ignition method. The use of devices with an automatically controlled combustion air supply was identified as promising technological measure.

1. Introduction

Most widespread residential wood combustion heaters are batch-wise operated direct room heating devices such as open fireplaces, closed fireplaces, insets, roomheaters and cookers operated with firewood. In Europe the stock of this kind of direct room heaters is estimated to be more than 65 million appliances [1], in Austria it is around 1.4 million appliances [2].

However, these types of appliances were identified to cause high amounts of gaseous as well as particulate emissions [3–5] which can seriously affect public health [6–10]. Especially for fractions of harmful fine particle emissions with aerodynamic diameter smaller than 10 μm (PM10) residential wood combustion has been identified to be a major source of local air pollution, especially in the winter half year in Europe [11–14].

Emissions from firewood combustion in room heating devices have a high health impact, because of the emitted respirable dust. Additionally, PM emissions include carcinogenic compounds, e.g. polyaromatic compounds (PAC) like benzo(a)pyrene. An exposure to those emissions can lead to irreversible health diseases till premature death [5–8].

In Austria residential wood combustion has been identified to be responsible for around 25% of PM10 emissions in 2013 [15]. Hence, PM emissions have become an important topic in the European Union since several studies present a regular violation of the European thresholds for PM10 in ambient air, which means an maximum annual average value of 40 μg/m^3 or at maximum 35

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times of exceedance of daily average value of 50 μg/m^3 per year [16–18]. Consequently, public authorities are forced to implement effective measures for emission reduction. To best possibly guide the respective policy measures, there is a need to understand the reasons for the currently high emission level of batch-wise operated firewood room heating appliances in real life operation. Consequently, the implementation of effective primary and secondary measures for emission reduction is required.

Generally, the reasons for increased gaseous and particulate real life emissions compared to expectations according to current standard type test results can be categorized in four different groups:

- Technological reasons
- Type testing reasons
- Reasons referring to operating conditions
- User behavior reasons

- *Technological reasons*
  The used technology has a strong impact on the emission level regarding gaseous carbon monoxide (CO), organic gaseous compounds (OGC) and polycyclic aromatic hydrocarbons (PAHs) as well as particulate (PM) emissions [4,9]. Conventional combustion technologies without implemented primary optimization measures, like air staging and well dimensioned combustion chamber [19,21], have higher gaseous and particulate emissions. According to KELZ et al. [9] and BRUNNER et al. [20] old technologies emit around two times higher gaseous CO and OGC emissions and about 40% higher PM1 emissions. The difference regarding PAH emissions was even higher by a factor of 18.
  Unfortunately, the stock of firewood room heating appliances in Europe is dominated by old and not state-of-the-art combustion systems [4,9]. The use of secondary emission abatement technologies like filter precipitators, electrostatic precipitators (ESP) as well as catalysts is one possibility for reduction of emissions of old types of technologies. However, since up to date there is no legal requirement in most European countries for using such secondary abatement technologies they are only rarely used. Additionally, most of these secondary emission abatement technologies are still under development and are not yet commercially available [22].

- *Type testing reasons*
  Current European standard type test methods for firewood room heating appliances do not sufficiently reflect real life operating conditions as well as user behavior aspects in their testing procedures. This leads to type testing results of emission and efficiency performance that are only reachable under optimal steady-state or nearly steady-state operation, but are far away from real life operation performance [23,24]. However, the need for advanced standard type testing procedures that better reflect the real life behavior and are less endangered by manipulation and rooms for interpretation has reached the awareness of the European public administration [25].

- *Reasons referring to operating conditions*
  Operating conditions define parameters referring to the infrastructure of the heating appliance which cannot be directly affected by the user during operation. Relevant operating conditions concerning emissions and efficiency are mainly the flow conditions induced by natural draught. A high flue gas draught level leads to a lower efficiency [24,26]. Although it seems that draught conditions have limited correlation with gaseous and particulate emission concentrations in the flue gas the absolute emission level is increased indirectly. This means that for reaching a certain room temperature more fuel is necessary for combustion at a lower efficiency level. Consequently the total emission release is higher even if the emission concentrations are on the same level compared to combustion at a lower chimney draught conditions.

- *User behavior reasons*
  All parameters of the operation which can be directly affected by the user are defined by the term user behavior including following aspects:

  - Physical and chemical fuel properties
  - Ignition method
  - Fuel amount per batch
  - Adjustment of air valve settings for combustion air supply
  - Number of batches performed during one heating operation cycle

  The above listed aspects, comprising the user behavior, can seriously affect the emission level during the combustion process [27–33].
  However, currently there is a lack of systematic studies about the user behavior in real life operation and the influence of incorrect operation mode on real life emissions. Consequently, there is a need for an assessment of more reliable data about user behavior referring to different types of batch-wise operated firewood room heating appliances.
  Therefore, in Austria a survey on investigation of common user behavior of most relevant types of batch-wise operated room heating appliances, for firewood roomheaters, tiled stoves and residential biomass cookers respectively, was conducted. In addition to already available data about real life user behavior for firewood room heating appliances [34], further essential aspects for real life emission and efficiency performance were investigated and evaluated. Based on an assessment of similarities as well as differences the typical user behavior for all three classes of technology was defined. The gained information provides a useful basis for development and implementation of technological and non-technological primary measures for improvement of user behavior regarding emission minimized and efficiency optimized real life operation. Further, the results of the survey provide a useful basis for standardization or labeling purposes, especially for the development of new test methods focusing strongly on real life operation.

2. Materials and methods

2.1. Survey

The survey based on a questionnaire was conducted at the tradeshow “Buildings and Energy” in Lower Austria in September 2012. The survey was performed by face-to-face interviews with attendees of the tradeshow who are users of firewood room heating appliances. In total 108 randomly selected persons met this requirement and agreed to take part in the survey. No personal data, like name, age, education level or gender, were recorded. Further, no questions regarding specific living conditions were asked. In advance of the interviews all respondent users were informed that no personal data will be published and that all data analysis will be done anonymously. This was done in order to fulfill data privacy protection requirements.

The questionnaire consisted of 15 multiple-choice questions. All questions as well as the specific answer options were defined by