Final report

1.1 Project details

Project title	Intelligent Burner
Project identification (program abbrev. and file)	64015-0579
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	Danish Technological Institute Kongsvang Alle 29, 8000 Aarhus C
Project partners	NBE
CVR (central business register)	56976116
Date for submission	28th of February 2018

1.2 Short description of project objective and results

The project objective is to develop an intelligent burner by incorporating components and software that can lead to efficient combustion of biomass, taking parameters such as weather, chimney draft, combustion airflow and fuel supply into consideration. A number of different technologies have been combined in to an 'Intelligent Burner' where costoptimal components have been applied along with an improved controlling system. Through the project, it has been demonstrated that it is possible to develop a biomass boiler with significantly lower emissions and higher efficiency both at test conditions and in real life simulations.

Projektet formål er at udvikle en intelligent brænder ved at kombinere komponenter og styring således, at der opnås en effektiv forbrænding af biomasse med hensyntagen til parametre som vejret, skorstenstræk, luft flow og brændselsdosering. Teknologier er blevet koblet i projektet, hvor kostoptimale komponenter er blevet kombineret med et nyt og forbedret styringssystem. På denne måde har det vist sig muligt at opnå en biomassekedel med signifikant lavere emissioner og højere virkningsgrader i såvel testsituationer som under simuleringer af årsdrift i danske hjem.

1.3 Executive summary

In the project, an intelligent burner has been developed during a number of steps by combining various different techniques and software/controlling to obtain better combustion with lower emissions.

Firstly, evaluations were made based on theoretically and preliminary experimental tests on which techniques to move forward with, related to mass determination of air and dosing of biofuel. Promising techniques were considered to be a venturi flow meter for the air measurements and sound measurements for the fuel dosing. Furthermore, it was decided to isolate the burner with vermiculite and ceramics to evaluate advantages and disadvantages of each possibility. See details regarding the preliminary choice of techniques in Appendix 1.

In the next step, work was initiated to develop components to optimize dosing of air and wood pellets and to look into the impact of insulation material around the burner on the emissions. Components for air regulation were developed in form of a venturi flow meter and a difference pressure measure unit. Furthermore, a security component measuring CO (gas detector method) at the entrance of the burner was developed to detect if CO concentrations were too high. The security component can indicate blockage of chimney or other malfunction of the system. This way it will be detected if the airflow is running in the wrong direction, which could otherwise go unnoticed and result in a false air value measured by the venture.

Related to development work of wood pellet dose, a mass measurement method was developed using sound and relating this to mass. In order to bring the technology to a height where it can be used in a prototype/real life boiler, additional work with e.g. digital storage oscilloscope must be carried out. It was decided to work for an easier applicable alternative in terms of a combined two-auger system and regulate the air according to this. Analysis showed that a two-auger system is reducing the deviation between the doses of wood pellets added to approximately half the size compared to having a traditional one auger system. The deviation between dosing with a traditional auger and a two-auger system is displayed in Figure 1, where it can be seen that the dosing is becoming more stable when using two-auger system compared to the traditional one auger.

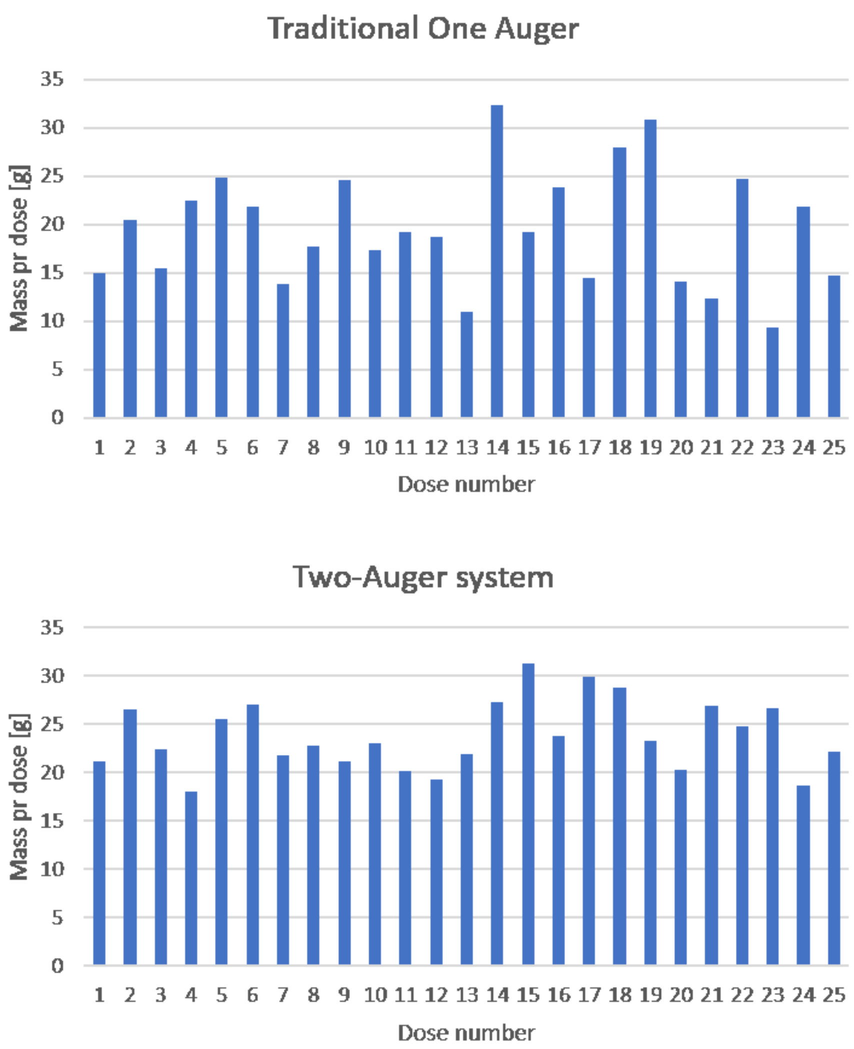


Figure 1 Deviation in dosing of wood pellets at respectively a traditional one auger system and a coupled two-auger system

To investigate the impact of the fuel chosen for tests and the isolation of the burner a study was carried out. Five different wood pellets A-E were examined by combustion in a biomass boiler with isolation of the burner itself using, vermiculite, s; and ceramic material, k. A, B, C and E respectively, consists of softwood while D consists of hardwood. A, C, D and E are 6 mm pellets, while B is an 8 mm pellet. The results are summarized in Table 1.

Tabel 1 Emissions and chemical properties for various wood pellets when investigating the combustion at burner isolated with respectively ceramics (k) and vermiculite (s)

	As	Ak	Bs	Bk	Cs	Ck	Ds	Dk	Es	Ek
CO_2 @10% O_2 [mg/m³]	13.5	13.1	13.8	13.8	12.9	12.9	13.3	13.6	13.1	13.1
CO [mg/m³]	122	113	818	659	182	155	421	364	166	189
NO_x [mg/m³]	145	142	198	195	151	150	213	216	258	267
OGC [mg/m³]	7	6	16	16	6	6	8	7	8	10,3
Dust [mg/m³]	22	21	53	50	24	23	55	54	27	26
Effect [kW]	15	15	15	15	15	15	15	15	15	15
N [mg/kg]	400	400	780	780	480	480	990	990	1180	1180
Net calorific value [MJ/kg]	19.2	19.2	18.7	18.7	19.1	19.1	18.4	18.4	19.1	19.1
Ash [%]	0.3	0.3	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.3

The different insulation materials did not result in significant differences in dust emission nor in any other emissions such as NOx, CO or OGC. In fact, the emissions were shown to be considerably more dependent on the wood pellets – it was for example demonstrated that a linear correlation existed between nitrogen content in the wood pellets and the NOx emissions. This is shown in Figure 2.

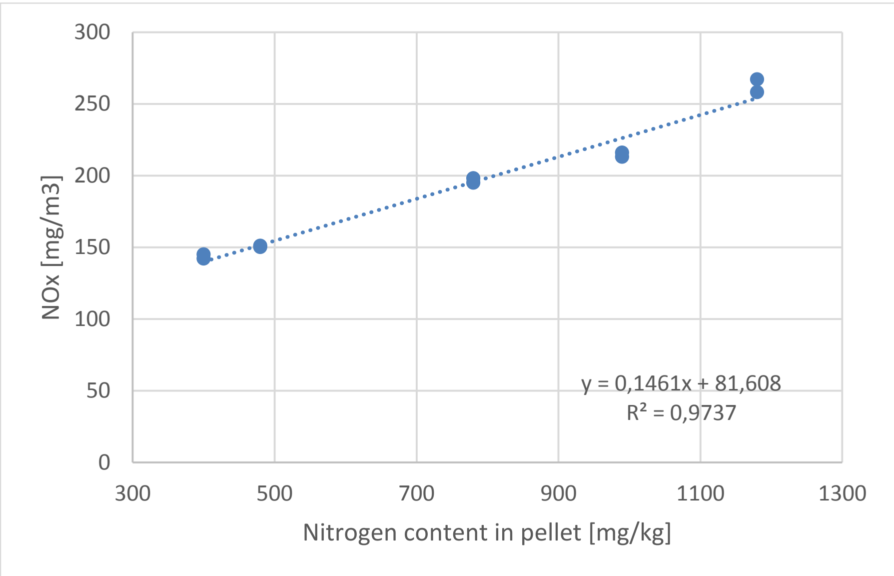
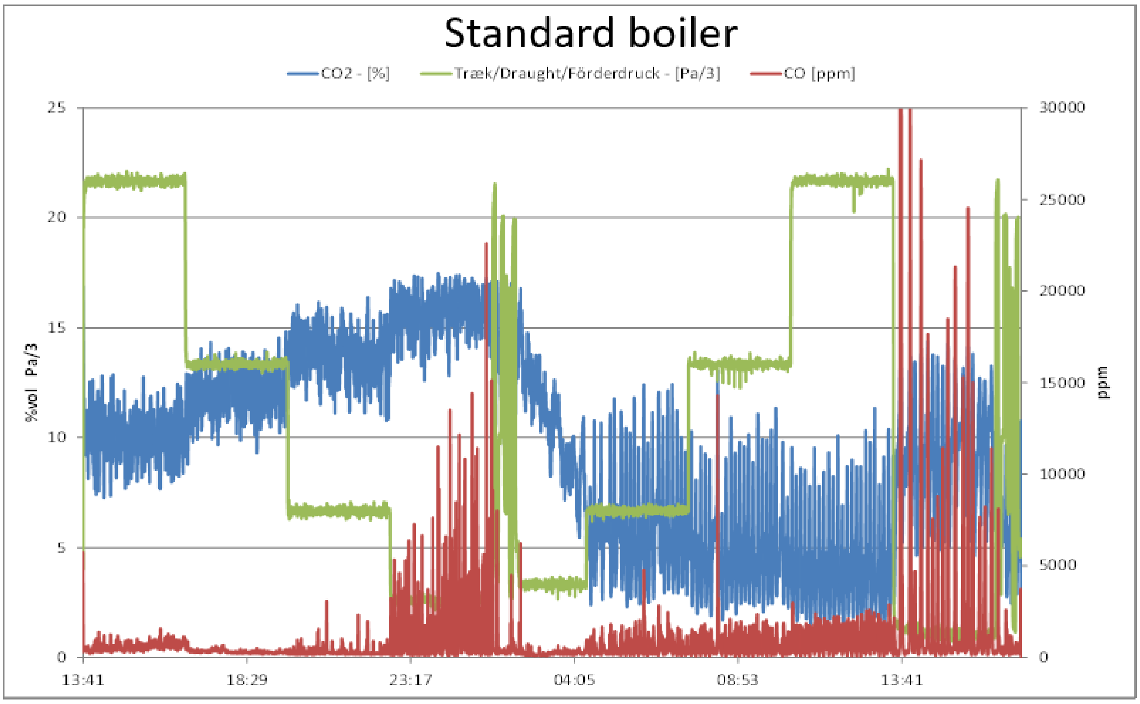


Figure 2 NOx emissions versus nitrogen content in wood pellets

The off-set could be ascribed to thermic NOx, showing that this was as good as identical in all conditions also independent on insulation material, as long as the burner was insulated. See more details in Appendix 2.

With respect to boiler development, firstly, insight into combustion properties was gained and then a number of single components to regulate the combustion better were developed. Thereby a better performance of the boiler was obtained. The various components were integrated and software and algorithms were developed as to obtain an overall intelligent burner. It was demonstrated that the new components and software resulted in an intelligent burner with lower emissions. CO was reduced with 53 % and OGC with 40 % under a test cycle where chimney draft was varied from 10-60 Pa in order to see how the boiler could compensate for this for in the standard system and the new developed system respectively. The difference in selected parameters between the traditional boiler and the intelligent burner is displayed in Figure 3.



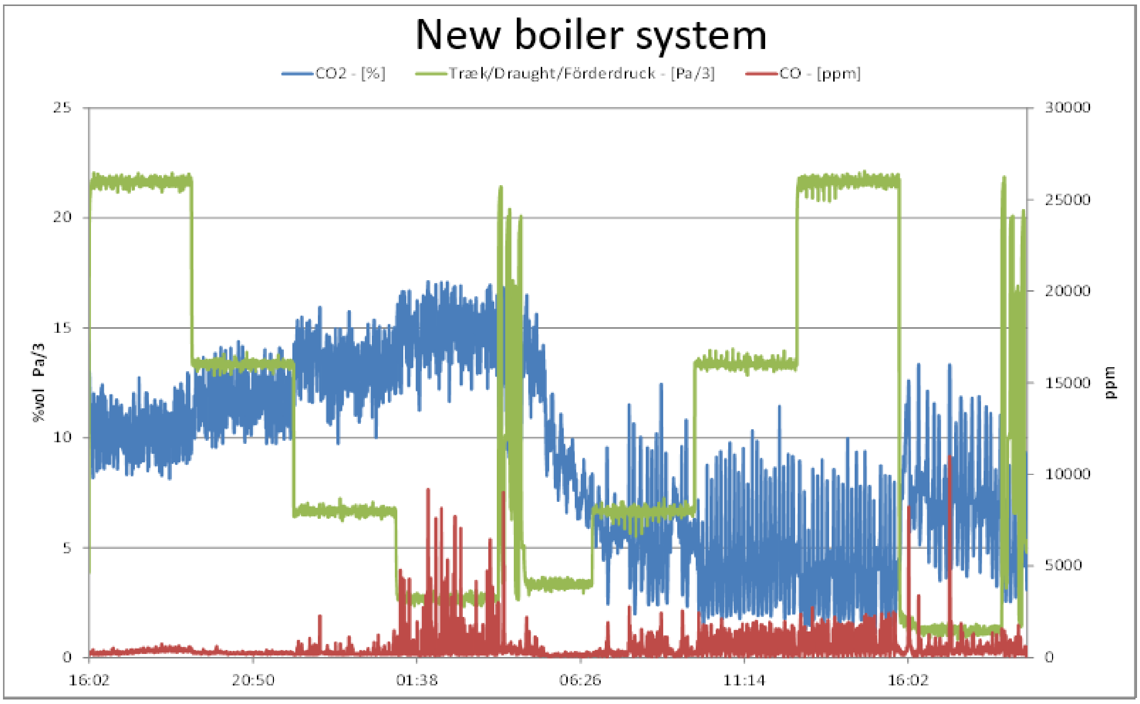


Figure 3 CO emissions from traditional boiler and intelligent burner under various draught simulations

Figure 3 clearly shows that the CO is considerably lower for the new boiler system than before improvement. See more details in Appendix 3.

Finally, a load cycle test was developed in order to evaluate biomass boilers performance in a simulated real-life operation instead of comparing under only laboratory standard test conditions. The load cycle test was developed in such a way that an average user's daily usage of the boiler was simulated. This was done for respectively winter days, days representing autumn/spring and summer days. The simulated real-life season days are displayed in Figure 4.

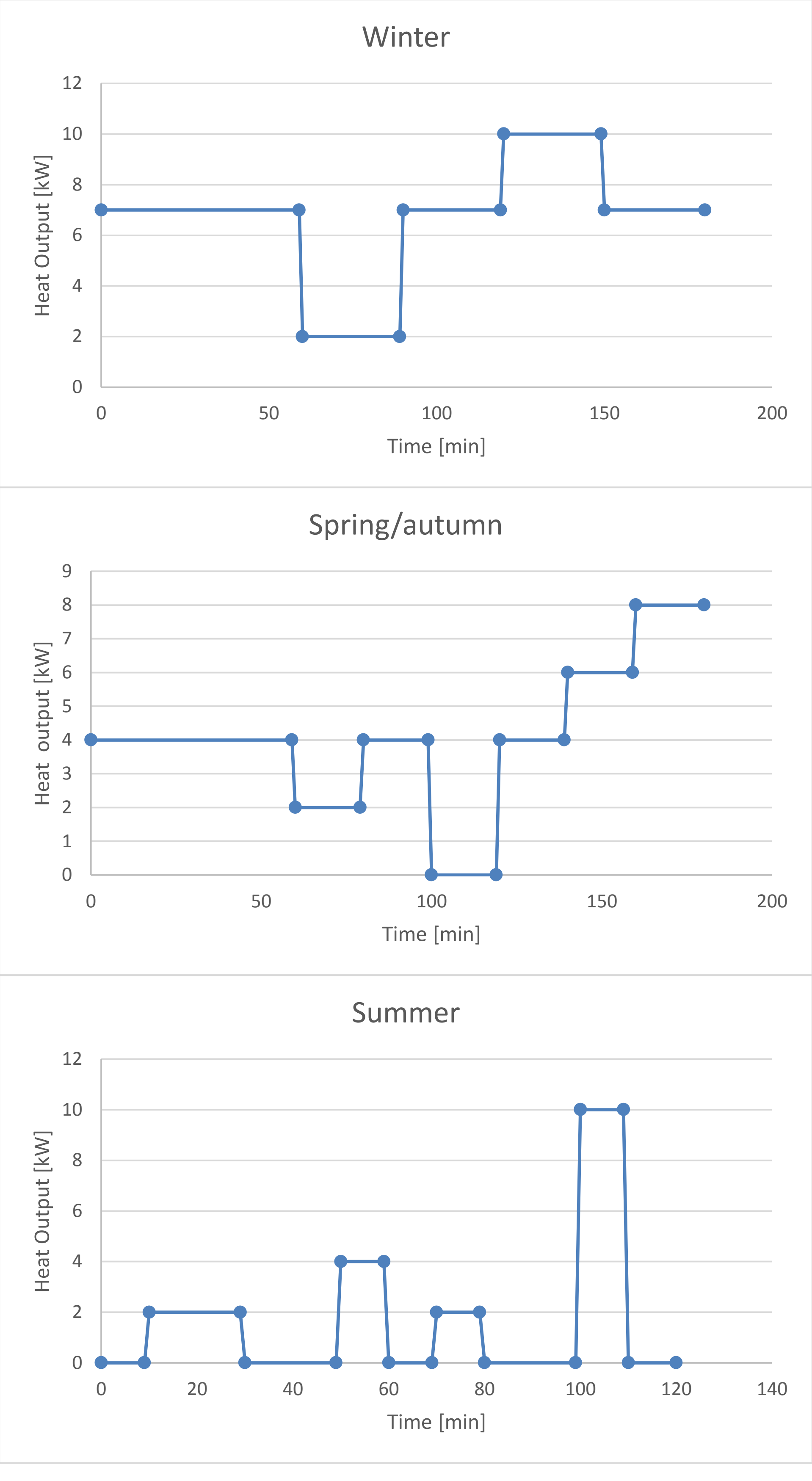


Figure 4 illustration on heat output settings on the simulated days during various seasons

The load test was carried out so that each day, displayed in Figure 4, was run twice (reproduction) at three different chimney draft conditions namely 12, 6 and 24 Pa to simulate the variety on this parameter. This means that 6 days of each season was run starting from winter to spring to summer. In the end two winter days, with draft 12 Pa was run to check if any

change in performance had happened during the ‘one year’ operation. A total of 20 days were simulated.
The developed test was used to evaluate and compare the intelligent burner with a standard burner, to see what had been gained by the development work. In Figure 5 the flue gas temperature and the emission of OGC are displayed for the standard burner and the intelligent burner.

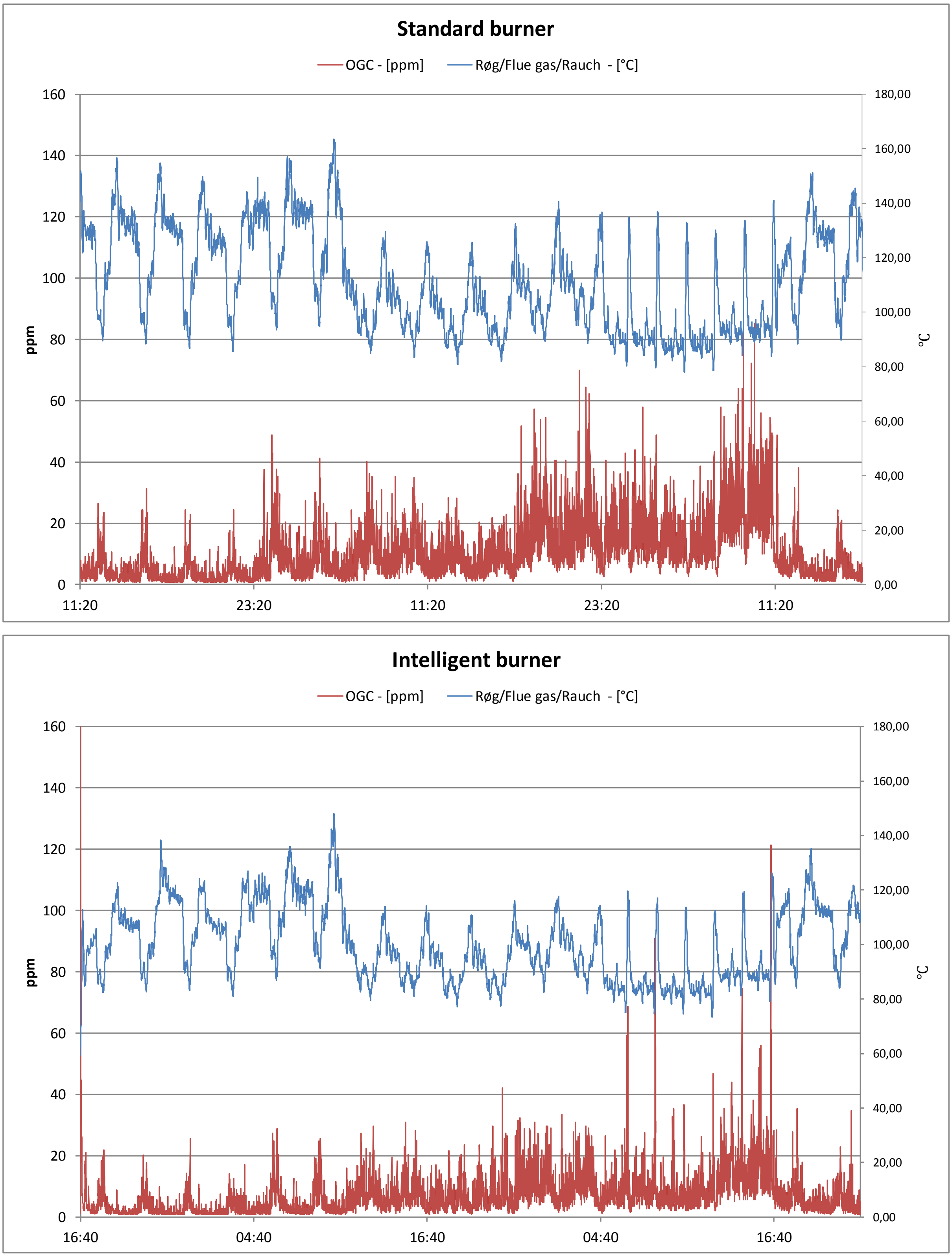


Figure 5 Flue gas temperature and OGC emissions during load cycle test for the standard burner and the intelligent burner

The individual days in the load cycle test can be distinguished by the peaks when evaluating the flue gas temperature. In general, it can be seen that the peaks are higher for winter days than autumn/spring day which again are bigger than the peaks for the simulated summer days. When comparing the standard burner and the intelligent burner it can be seen that peaks of a given season are defined in a smaller temperature range than the standard boiler. This suggests that the burner is regulating fine and adapting faster to the changes during a given day. From Figure 5 it is also seen that the OGC signal is lower for the intelligent burner throughout the load cycle test. By looking at the data from the tests, it was found that the efficiency was increased from 90,4 % with the old burner to 92,1 % with the intelligent burner. CO was reduced from at average value of 716 ppm to 492 ppm and OGC from 26,2 ppm to 15,2 ppm. Dust evaluated with opacity was in both cases at a comparable low level. See more details in Appendix 4.

1.4 Project objectives

Danish climate and energy politics focus on security of energy supply, independence of fossil fuels and insurance of a clean environment. 70 % of Danish renewable energy origins from biomass. The amount of wood pellets used in private homes for heating amounts to approximately 500.000 tons annual. This contributes to reducing CO_2 as opposed to using a traditional oil boiler.

Since biomass boilers in Denmark and EU are required to fulfil limit values for emissions in order to be approved for distribution and sale. These values given by legislation is getting ever stricter. Therefore, it is necessary, to develop modern efficient and low-emission biomass boilers in order to continue utilizing biomass as heating source in smaller units.

The overall objective of the project is thus to develop a modern ‘intelligent’ biomass burner that can fulfil the requirements to performance with respect to efficiency and emissions in the future. This will first of all allow that biomass boilers can continue being used in Denmark to help contribute to green and sustainable energy and heating especially in areas outside district heating. In order to do so, the project’s goal is to clarify the influence on combustion parameters on the flue gas.

In this project, more specific technical objectives are to develop a boiler where

- Air supply is optimized
- Biomass dosing is optimized
- Software and controller unit is further developed ensuring interplay for optimal boiler performance

Furthermore, it was desired to ensure that the boiler was not just performing under test conditions but also under real life conditions. In order to establish this, an objective was to develop a load cycle test that can simulate yearly performance in Danish homes.

Lastly, it was an objective of the project to ensure that the new boiler system and software was compatible with the NBE cloud system. The principle behind the cloud system is displayed in Figure 6.

Figure 6 Principle behind NBEs StokerCloud

The NBE cloud system records data from the boilers and how they perform in the Danish houses. Based on these data logs it is possible to spot challenges and problems and solve them before they become an issue qua security or too high emissions.
Figure 7 shows the interface which the user can see and the data which NBE can collect to evaluate the boiler performance.

Figure 7 User interface for NBE boiler system

This use of Stokercloud can and will also be done for the new product developed by NBE based on the project.

1.5 Project results and dissemination of results

1.5.1 Results

During the project, a number of results have been obtained. In the first stage of the project it was investigated, how different combustion parameters influenced the emissions in the flue gas namely

- Insulation of burner
- Biomass dosing
- Air regulation
- Safety

It was found that insulation of the boiler is important to obtain good combustion. However, the nature of the material whether ceramics or vermiculite played as good as no role on emissions of dust, NOx and OGC. Based on these findings, it was decided to use vermiculite in the rest of the project, as the material is Danish, relatively cheap and easy to work with. In this way, insulation can be placed correctly around the burner.

The biomass dosing was studied with respectively a normal auger and a combined two auger system used to flatten the dosing out, to make it more continuous. The system is displayed in Figure 8.

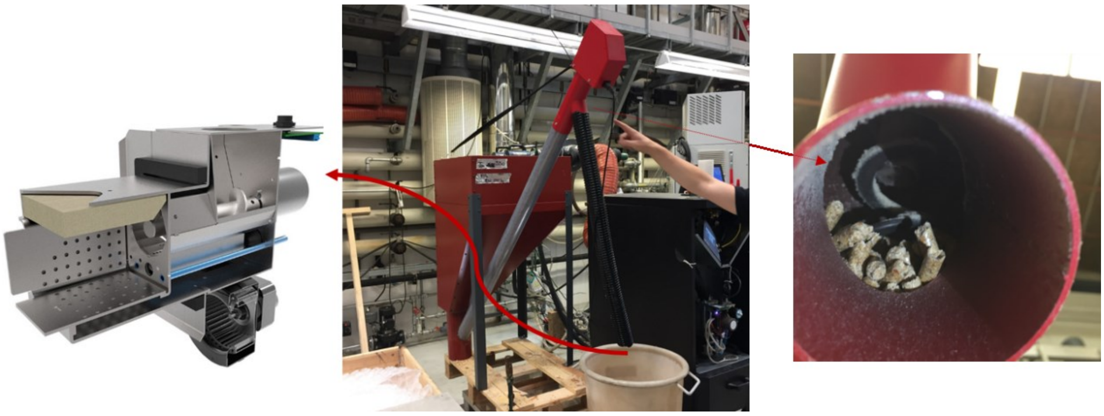


Figure 8 Two-auger system

It was found that at nominal heat output, the deviation between the different doses was reduced to half size by a two-auger system compared to a traditional auger. A two-auger system is thus contributing to making the addition of wood pellets to the burner smoother whereby the air easier can be adjusted to the desired amount for the combustion, leading to reduced emissions. A sound measurement system was studied during the project and it was found possible to detect a signal of different size depending on the mass of the wood pellet(s) added. However, the technological readiness level of this system is still too low to incorporate it to an intelligent regulation system in the boiler. Instead, air regulation has been optimized to regulate the dosing of wood pellets with the two-auger system.

It was found possible to optimize the air regulation in the biomass boiler by adding a venturi flow meter, combined by adjusting the air based on a given amount of air to a given output. This is done by difference pressure measurement. It was proven possible this way also to regulate flow according to draft in the chimney. The venture system is shown in Figure 9.

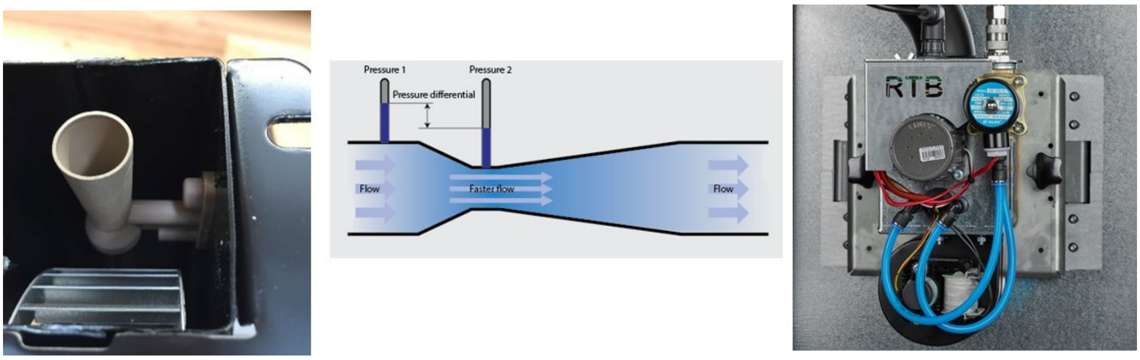


Figure 9 Venturi system for air regulation

Furthermore, it was found that a CO sensor could be installed to increase safety. The system was measuring the CO level right before the combustion chamber, where the value should be very low if the combustion is taking place as it should and the chimney is functioning. The CO sensor was constructed so that the boiler was automatically switched off by too high CO values indicating smoke moving backwards as for example in the case of a blocked chimney.

The air regulation system is displayed in Figure 10.

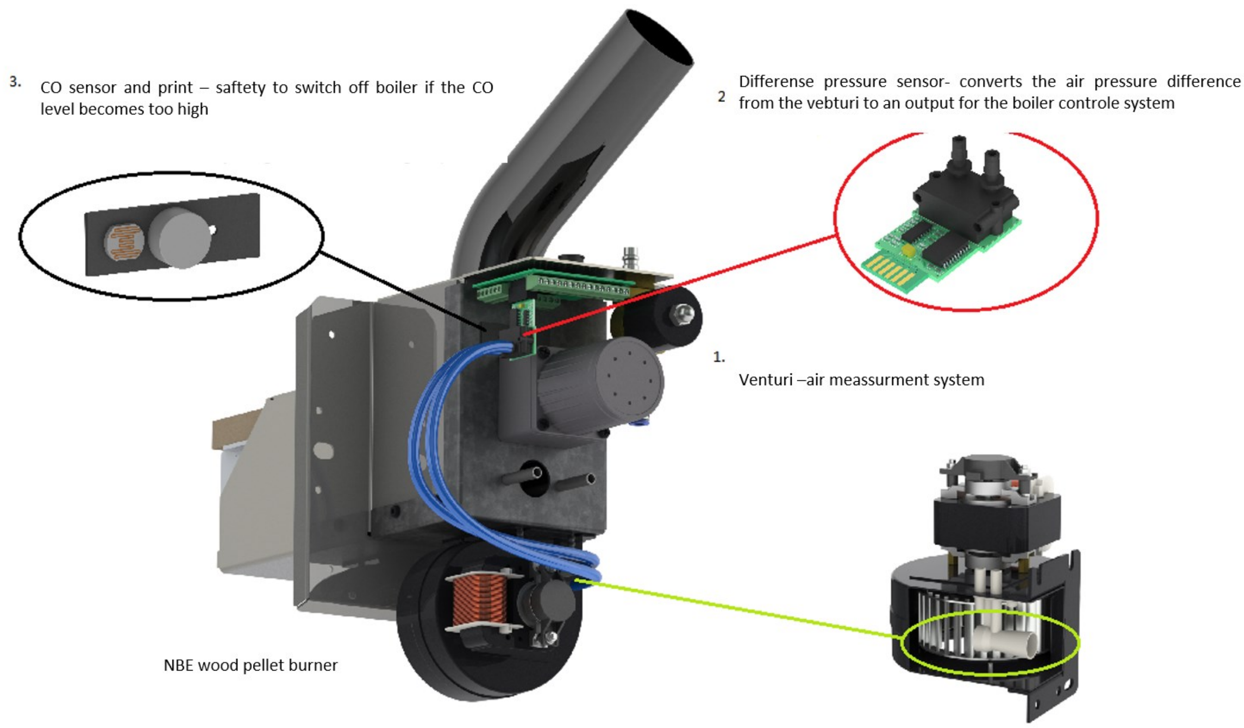


Figure 10 Optimized air regulation system

In the second stage of the project the technologies described above were combined and new software was installed for controlling the overall biomass boiler in an intelligent way with proper algorithms ensuring this. This has resulted in the development of an intelligent burner displaying reduction of CO emissions of 46 % and OGC of 60 % compared to a traditional corresponding boiler before optimization and development work under tests evaluating performance at different draught conditions.

A load cycle test has successfully been developed. From the load cycle test demonstrating how the biomass boiler perform under simulated real-life operation.

It was found that the efficiency was increased 1.5% point with the intelligent burner. CO was reduced for the intelligent burner with 69 % and OGC (organic gaseous compounds) was reduced with 58 %.

Outside of this project, the load cycle test can generally be used as a tool in the future for testing of biomass boilers to get a more realistic view on how the boiler performs under real life application, and thus become a parameter for the consumer to choose an energy efficient and low emission boiler.

1.5.2 Dissemination

Dissemination of the results have been considered a very important part of the project. Therefore, selected results have been presented at various national and international conferences with poster as well as oral presentations. Furthermore, an article has been written. The contributions are listed in the following publication list:

International Journals

Gottlieb Jespersen, M., Pødenphant, A., Frey, A.M. "Smart boiler: combustion optimization and emissions reduction" Biomasa News (2017)

Oral Contributions

Gottlieb Jespersen, M., Pødenphant, A., Frey, A.M. "Smart boiler: combustion optimization and emissions reduction" ExpoBiomass, Spain, September 27st, 2017

Frey, A.M., Gottlieb Jespersen, M., Pødenphant, A. "Load cycle test" Branchedag, Teknologisk Institut, March 6th, 2018

Poster Contributions

Frey, A.M., Hastrup Jensen, A., Gottlieb Jespersen, M., Pødenphant, A., "Minimizing NOx and dust emissions from pellet-fired biomass boiler by optimizing the combustion" European Biomass Conference, Stockholm, June 15, 2017

Frey, A.M., Hastrup Jensen, A., Gottlieb Jespersen, M., Pødenphant, A., "Intelligent burner – a way to minimize NOx and dust emissions from pellet-fired biomass boilers" Annual Meeting in the Danish Chemical Society, Odense, June 15, 2017

1.6 Utilization of project results

Based on the outcome of the project, NBE will be able to produce a new biomass boiler with improved combustion and thus higher efficiency and lower emissions – not only under test conditions but also under real life conditions as explained under paragraph 1.5. Costoptimal components have been chosen during the development work in such a way that it will be possible to sell the intelligent burner as a new system at a favourable price. In the new produced NBE boilers, the new system will be incorporated and sold for the same price as the old boiler system is sold today. This way the project has contributed to be able to see quality products at low cost which fits in NBE's business model.

Furthermore, the new developed components, can be incorporated into NBE boilers already in use in Danish homes, due to the compatibility of the new developed parts with already existing NBE systems. It will require software updates to make use of added components, just as the air flow measurement component (difference pressure sensor part) need to be equipped with proper hardware. Such updates could possibly be implemented via the StokerCloud. For boilers, already at the market NBE expect to be able to sell the add on system to a total price of around 1200 DKK.

1.7 Project conclusion and perspective

It has been possible to develop an intelligent burner by combining various technologies and software. The new biomass burner is displaying higher efficiency, lower emissions and higher security as it switches off automatically, if problems such as blocking of the chimney occur. The new boiler performed better during test conditions as well as under simulation of yearly performance in real life use, determined by using a load cycle test developed within the project. The efficiency was increased from 90.4 % with the old burner to 92.1 % with the intelligent burner. CO and OGC was reduced with 69 % and 58 % respectively. Furthermore, the new system can be connected to NBE StokerCloud. This provides the possibility to make trouble shooting on a distance, thereby preventing that a boiler is performing poor in real life application without the problem being detected and possibly solved.

Regarding perspectives, a wide range of further improvements are found, both within technical development and within use of software and StokerCloud.

With respect to technical development further development work could be carried out in order to find an applicable way to use microphone/sound.
With respect to software it is expected to be possible to optimize that further, by making the optimization based on real life condition simulation such as the load cycle test, whereby the boiler performance will be better during daily operation.

With respect to StokerCloud, a great perspective would be to further develop the system making it possible from a distance to change algorithms in the control system and thereby improve the performance of the boilers in Danish homes. Furthermore, the system can be improved in smart ways. Wood pellets could be ordered when supply calls for this, so the user does not have to spend time and energy keeping track of the supply. Based on analysis of the data logged in the system, it might be possible from the energy consumption in individual houses to propose more optimal solutions for the total energy system such as evaluating whether combination of a boiler and a heating pump would be advantageous based on the usage pattern.

Annex

Technical reports (in Danish) are attached, describing the technical and technological findings throughout the project
Appendix 1: 'Grundlag for valgte teknologier'
Appendix 2: 'Komponent udvikling og deres betydning for forbrændingen'
Appendix 3: 'Designforslag til integration af teknologier i en Intelligent Brænder'
Appendix 4:' Årsvirkningsdrift – effekt i den virkelige verden, potentiale områder og vurdering af fremtidige indsatsområder'