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Design and implementation of sustainable solutions in rural Mexico

MASTER THESIS

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Design and implementation of sustainable solutions in rural Mexico

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Objectives of thesis

Aim – define the best suitable design for cooking stove in Jaltepec community in Mexico.

Methodology

Objectives – Literature review about indoor air pollution, stove design and measuring of fumes

Workshop held in Mexico

Testing the stove in Mexico

Amending the stove based on testing

Find the best suitable design reducing indoor air pollution and wood consumption

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- Duany, Andres, E. Plater-Zyberk, and Jeff Speck. 2000. Suburban Nation: The rise of sprawl and decline of the American dream. New York: North Point Press. Read Pages 1-37.
- Spatial planning in the Czech Republic and international cooperation. By Martin Tunka, Director of Spatial Planning Department, Ministry for Regional Development for the Czech Republic
- Town and Country Planning in the Czech Republic: Ministry for Regional Development, Institute of Spatial Development.
- Waldheim, Charles. “Landscape as Urbanism”, in The Landscape Urbanism Reader, Charles Waldheim, Ed. 2006, Princeton Univ. Press. NY.

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I hereby declare that I wrote this diploma thesis independently. I have listed all literature and publications from which I have information.

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ABSTRACT

In the community of Jaltepec, located in San Jose del Rincon in the State of Mexico, health complications are caused by poor cooking practices leading to dangerous levels of in-house air pollution. Women and children spend majority of their time cooking and collecting water and firewood due to lack of facilities in rural communities. Considerable time spent in cooking areas and carrying heavy loads result in respiratory and other health issues.

These issues have been analysed and design tools used to develop potential solutions. This report describes the second part of phase two of an ongoing project to improve the living conditions of women in the community of Jaltepec. Firewood cooking stove design was taken further from the first part of the second phase. The design was amended following international chimney standards. The first part of the second phase was presented to women from the Jaltepec community, people from the Tlaloc Foundation, representatives of World Vision and partner university Universidad Autónoma del Estado de Mexico. The prototype was built at the university campus in its actual size

Experiments were designed and instructions were sent to the partner university. When the experiments will be conducted, the values will be compared to Mexican air quality standards to indicate stove safety. Stove efficiency will be compared to stoves in the Jaltepec community. The results of these experiments will dictate further approach. This could entail either change of the design of the stove or teaching people in the community how to build and use the stove.

Keywords:

Design, stove, indoor air pollution, experiment

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1 INTRODUCTION

The rural community Jaltepec belongs to the municipality San Jose del Rincon and is located in the western part of the State of Mexico. The community counts 1400 inhabitants (Analysis, 2005).

Fig 1-1 Location of San Jose del Rincon

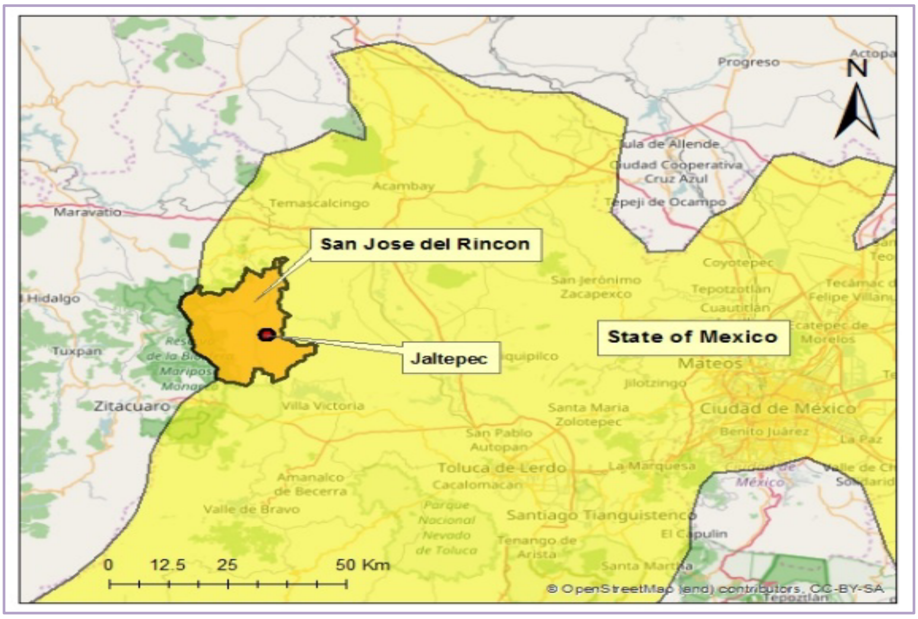

Fig 1-2 Location of Jaltepec

Mazahua, one of the biggest indigenous communities in Mexico forms the majority of the community in San Jose del Rincon (City Population, 1998; Whaites, 2015). Nearly half of the population is considered extremely poor, living with lack of basic infrastructure such as, electricity, access to clean water and drainage (Coneval, 2015).

Health issues, indoor air pollution in levels not complying with Mexican air quality standards and the need for wood for daily cooking are key problems the community is facing due to poor cooking practices. Moreover, the health issues from daily collecting and carrying heavy wood are burdening the community (Zarza, 2017).

The issues mentioned above were collected in ethnographic study of the Jaltepec community. It created the base for a group project focused on finding solutions to the problems introduced. The solutions were found and turned into prototypes for further development.

Firewood, for example oyamel and pine is commonly used as fuel for cooking. Other possible fuels and sources of energy for cooking are usually very expensive and not accepted by the community (Zarza, 2017). The firewood stove is used as well for heating the houses, as temperatures in the location of the community can go down to 0°C (INEGI, 2009). Use of firewood for cooking may result in respiratory diseases. Moreover, pneumonia is the main origin of child mortality in developing countries (WHO, 2006).

People in the community are spending most of their time cooking in poorly equipped kitchens on inefficient stoves and carrying heavy resources as firewood and water (Zarza, 2017). The inefficiency of the process forces the community to make children help out. Therefore, children are kept out of schools which cause the community to suffer from a lack of education, and a lack of social and cultural growth possibilities (Danielsen, 2012). It is common that 12 year old children do not attend school and help their mothers in the house (Zarza, 2017). Children usually accompany their mothers to carry out household work. Because mothers and children are most likely to spend time in the exposure area, these two groups are most vulnerable to air pollution from open fire (Zarza, 2017). Pain in the eyes and respiratory problems were reported by many women in the community (Zarza, 2017). Exposure throughout the day to harmful air pollutants is present in the study done by Zuk (2007). It shows that concentrations of pollutants are ten times higher in kitchens with an inefficient fire place than outdoor air pollutant concentration standards in Mexico. Studies on health effects caused by indoor air pollution introduce eye irritation, respiratory illnesses, chronic diseases as pneumonia, tuberculosis, cancer, low birth weight and in the worst case infant mortality (Jones, 1999; Bruce, Perez-Padilla and Albalak, 2000; Fullerton, Bruce and Gordon, 2008; Sulaiman *et al.*, 2017). It is stated by The World Health Organisation (WHO, 2016) that four million people die prematurely due to the sicknesses developed from Indoor air pollution. Moreover, 50% of deaths of children under 5, related to pneumonia are caused by solid fuel cooking.

Firewood traditional stoves have been used in the Jaltepec community for generations. Most of the community has access to electricity as well as gas, however the expenses and especially the cultural heritage does not allow women to cook on other sources of energy than firewood, as these make food, mainly tortillas, taste different (Zarza, 2017). Proper design of the stove could protect the health of the people in this community, decrease the consumption of wood and mitigate the need of collection of wood; thereby, limiting the exposure of non healthy carrying of wood (Wastling, 2017). The Mexican government has deployed a firewood cooking stove recently, called the Patsari stove. It was successfully tested for safety and efficiency (Berrueta, Edwards and Masera, 2007). A small number of these stoves were deployed in Jaltepec community. However, there were issues with the use, as is described further in the text.

Development is using design tools for decades (Pilloton, 2009). The solutions produced by Design for Development or Humanitarian Design are usually focused on new technologies and novel products; these products typically focus on one area of the issue, but do not fix the whole issue (Johnson, 2011). Design Thinking is an approach focused mainly on the end user (Design

Thinking, 2002). The design used in the project is rooted in Design Thinking Approach and Development Design, which is used in Spatial Planning. Both approaches share the idea of understanding the location, end user and the situation. The design takes in consideration the possibilities of the community, tries to find sustainable solutions, created locally from local materials.

The aim of the project is to improve the design for cooking stoves in the Jaltepec community and thereby reducing the need for wood. The report describes the second part of phase two of an ongoing project, improving living conditions of women in the Jaltepec community in Mexico. Phase one of the project was an ethnographic study conducted in the community by Universidad Autónoma del Estado de Mexico (Zarza, 2017). Problems with water and energy on a local scale were indentified in the ethnographic study. Based on the study, the first part of phase two was developing sustainable solutions for the problems in the community Jaltepec. The second part of phase two described in this work is focused on one of the solutions from the first part, i.e. a prototype of the firewood stove; further development following international standards of simple sustainable design of the stove.

1.1 Aim and objectives

The aim of the project was to improve the design for cooking stoves in the Jaltepec community, thereby reducing wood requirements.

Specific objectives to fulfil the aim were:

1. Literature review about indoor air pollution, stove design and materials, measuring of fumes and relevant standards and regulations.

2. Building and basic testing the stove in Mexico.

3. Analysing of combustion and hot flue gases for identifying key parameters.

4. Designing experiments to prove stove safety and efficiency.

1.2 Stove design

For accomplishing stove sustainability, safety and efficiency specific design elements and materials were used. The stove design originates in the Patsari stove, deployed into central-western Mexico since 2003 by the Interdisciplinary Group on Appropriate Rural Technology (Berrueta *et al.*, 2015). The Patsari stove relatively reduces exposure to indoor air pollution and was found efficient in firewood conservation compared to traditional stoves (Berrueta, Edwards and Masera, 2007). The ethnographic findings show problems with the installation of a chimney. Further issues include limited deployment and the communities' dependency on the federal government for the Patsari stove. Even though women in the community were satisfied with the stove (Zarza, 2017), rainwater enters the houses through ceilings due to shortcomings with its installation (Whaites, 2015). Improper installation of the chimneys and inefficient technical skills of people in the community to solve basic issue with water entering the house, lead to the removal of the chimney and in some families even the removal of the stove (Wastling, 2017). Methods respecting the design thinking approach (Sato, 2009) were used to develop the solutions and prototypes in the group project. With the design thinking methods in mind and following the design of the stove in the group project, where the stove was prototyped after deep analysing, the design of the stove was improved and sent to Mexico for discussion. The design was based on both 17th century stoves and modern stoves and fireplaces. This design was confirmed and forwarded to Dr Ramon Gutiérrez, architect and teacher at the Universidad Autónoma de Estado del Mexico in Tolluca. Dr Gutiérrez created bricks, which can be manufactured without the need of a furnace. The bricks were used to build an improved stove in the campus of the partner university. The design of the stove used specific described below.

Fig 1-3 Specific stove elements

1.2.1 Double door system

Double door system works on the principle of air draft. The system was designed based on systems utilised in home barbeques and fireplaces. The stove design is not fit for all weather conditions. The latter can be explained using an example of a windy day and a day without wind. If the stove would be perfectly designed for certain conditions on a day without wind, during the windy day the draft would increase because more air would get blown into the combustion chamber; therefore the fire would increase and so would the firewood consumption. The door in front of combustion chamber reduces air input and leaking of fumes. The purpose of the door is enabling loading of the firewood into the combustion chamber.

The bottom door under the combustion chamber acts as a draft regulator. The air enters the stove through this door. The position in which the door is opened changes with changing stove use, for example, cooking, heating, in between phases, or just leaving it over night with firewood inserted, will benefit from a different position of the door. A widely opened door provides maximum air input and maximum draft. It provides maximum cooking and heating conditions with maximal firewood consumption. Closing the door decrease the air input and fire, it is an important step in saving wood. A closed door minimises the fire and could cause the fire to extinguish. With decreasing of the fire intensity, more fumes are expected. The bottom door provides access to ashes produced during combustion that fell through a grid from the combustion chamber to the bottom of the stove.

Fig 1-4 Double door system

1.2.2 Grid

The grid is a commonly used compound in stoves and fireplaces. It provides support for the combustion by supplying air from the bottom. Air blowing from the bottom of the combustion chamber promotes the combustion process as it mixes the air through all fire. This mixing is more efficient than another kind of air input in the fire, for example an open fire place. Through the grid, ash from the combustion falls in the bottom of the stove.

Fig 1-5 Grid

1.2.3 Chimney cowl

The chimney cowl is the least important element of the stove. It protects stove from rainwater entering, thereby prolonging its lifespan. The cowl could be manufactured using metallic plates connected to the chimney by metallic stands. There is large spectrum of designs of the cowl. There is no essential need for the cowl to be built.

Fig 1-6 Example of chimney cowl (*Pragoflorservis*, 1991)

1.2.4 Metallic cooking plate

The metallic cooking plate is the place where food is cooked. It is heated from the bottom directly by fire in the combustion chamber. The cooking plate is one of the compounds of the stove, which will most probably vary the most on each stove design in each family. The plates could have a different shape, size, material and even the number of plates on the stove could differ. The Patsari stove has three separated cooking plates. The one in the front is bigger than the two in the back. The stove designed for the Jaltepec community has one big cooking plate. There are no restrictions for the design, material or amount of plates. The principle of the heating plate is to be cheap and to be able to heat pots or pans. As the design contained only one cooking plate it is simpler and easier to build. The thickness of the cooking plate is crucial, as very thin cooking plates could get twisted by heat. Moreover, the cooking plate has to be installed thoroughly to seal the stove and to prevent fumes leaving by holes.

Fig 1-7 Cooking quesadillas on metallic plate

1.3 Stove presentation

The group project was presented and the stove with elements listed above was built and shown to the community, personnel of the university and people from the Tlaloc Foundation and representatives of World Vision involved in Mexican community development. Feedback from participants regarding the prototypes was collected. Discussions were held with the community about possible amendments to the stove. For example the idea of adding chairs on the side of the stove was discussed. It was explained that the goals were to develop a safe design of the stove, explain the main principles and teach the community how to build it. Then the people would be able to change anything to their priorities. Moreover, the height of the work place of the stove, 80 cm, was confirmed as suitable by the community.

The height of 80 cm was chosen based on ergonometric kitchen standards and recommendations (Richtar, 2017). The right height is recommended as shown in the table 1-1. Women in Jaltepec have an average height of 150 centimetres (Zarza, 2017). The height of the stove (cooking desk) should vary between 70 and 80 centimetres depending on the height of each women. This will mitigate possible back issues.

Tab 1-1 Ergonometric standards for working desk in kitchen

Height of worker in centimetres	Height of working desk in centimetres
150 – 160	82
160 – 170	86
170 – 180	91
180 - 190	94

The stove was functional, efficient and accepted by the leader of the community. The most important part of the introduction of the project was to make sure that the community accepted the stove. The next step in the project is measuring pollutants leaving the stove and making sure, the stove is not harmful. Furthermore, consumption and efficiency of the stove needs to be measured.

Fig 1-8 Stove presentation

2 LITERATURE REVIEW

The literature review section focuses on chimney standards, combustion and hot flue gas analysis, which influenced the improvement of the design and standards regarding carbon monoxide. This section describes as well bricks created from soil without firing.

2.1 Chimney

The chimney works on the principle of rising hot air as it has less density than cold air (Greenway, 2017, Voorburg, 1979). Critical for function is to select correct design, size and layout of the chimney (Greenway, 2017). Tracing back to analysis of the current state in Jaltepec community, one issue is mentioned in the next advice of Greenway (2017), there is save and correct function of the wood stove or fireplace only, when the chimney is connected. As Greenway (2017) experienced, majority of issues with heating system are found in chimney not actually in the system itself.

Chimney works on principle of rising less dense hot air than cold air. Based on this principle, chimney removes hot gasses from heating and burning firewood and they are expelled outside of living are (Greenway). Hot air, gas created by combustion, rising up through the chimney creates a pressure difference known as draft (Solid Fuel Association, 2017). Draft depends on temperature differences. The higher the difference between the outside temperature and the gases in the combustion chamber, the stronger the draft will be (Greenway, 2017).

The purpose of the chimney is to generate draft, pulling air with oxygen to the combustion chamber and to discharge products of combustion out of living areas, keeping the air in living areas clean and safe (Greenway, 2017). Air blowing around the roof or trees can affect the draft; therefore, the chimney should be designed more than 60 cm over the roof (Greenway, 2017). The draft is affected by the height of the chimney. Taller chimneys provide stronger drafts due to the pressure differences in the combustion chamber and the atmosphere (Voorburg, 1979, Greenway, 2017). Flue venting for the stove is recommended between 17 and 21,5 cm (Greenway, 2017). Flow, fresh air volume entering combustion chamber, depends on chimney draft. Stronger draft and stronger flow results in hotter and cleaner fire (Greenway, 2017).

2.2 Standards and regulations

The design of the stove has to respect air quality standards, regulations and guidance before deploying it into the community. International standards listed in the table below were studied to provide the necessary base for identifying key pollutants while assisting the design of the stove safety experiment. Moreover, the standards dictate security measures during conduction of the experiment. The measures are explained in the experiment design section. The standards and regulations listed below determine the targeted values during stove safety test; and served as guidance for designing of experiments.

Tab 2-1 Air quality standards and criteria followed during designing of experiments

Air Quality Criteria for Carbon Monoxide 1999 and 2000
Air quality guidelines for Europe
Indoor air quality and allergic rhinitis among office workers in a high-rise building
Occupational Health and Safety Agency for Healthcare in BC
UK and EU air quality limits
Criteria air pollutants, United Stated Environmental protection agency
Clean air act, United Stated Environmental protection agency
Normas oficiales Mexicanas de Calidad del Aire (Air quality Mexican official standards).

2.2.1 Carbon Monoxide

Carbon monoxide (CO) is an odourless, tasteless, colourless, and no-irritating gas. CO is produced by incomplete combustion of carbon-containing fuels. Carbon monoxide is produced as well by living organisms. Very high levels of carbon monoxide could result in death. Carbon monoxide is produced by natural processes and human activities. Concentration of CO in urban areas can exceed natural background levels. Ambient CO could be harmful to human health. It depends on levels where humans live and work and on exposure to individuals (EPA 2000). EPA (2000) stated levels for The United States of America not to be exceeded than 10 mg/m3 (9 particles per cubic meter) for an 8 hours average, and 40 mg/m3 (35 particles per cubic meter) for a 1 hour average once in the year. These numbers differ from standards for Mexico (Normas oficiales Mexicanas de Calidad del Aire), where is allowed 11 particles per meter for an 8 hours average.

Tobacco smoke, improperly installed or unvented or malfunctioning combustion appliances and vehicle start-up are major sources of carbon monoxide in urban environment. There are many factors affecting CO emissions in houses, fuel type, appliance design, source operation condition, and fuel consumption rate. Indoor CO concentration vary on source emission rate, ambient CO concentration, air exchange rate, and air mixing within the building, building volume, and use pattern. Fireplaces and woodstoves produce carbon monoxide during start-up, through leaks, during maintenance and from back drafting. The highest volume of carbon monoxide produced by wood combustion is during start-up, as the combustion temperature is lower and there is imperfect combustion (EPA, 2000).

Primary source of carbon monoxide indoors is represented by improperly vented combustion appliances, water heaters, furnaces, fireplaces and woodstoves. Primary source of heating together with unvented space are most likely places, where the highest CO concentrations would be found. Exposure of carbon monoxide is the most significant indoor. Carbon monoxide occurs indoor indirectly as a result of ventilation or infiltration from outdoor sources. In absence of sources indoors, the concentration of carbon monoxide indoors equal concentration in surrounding ambient air. Second possibility of carbon monoxide occurrence indoor is the combustion sources. Carbon monoxide emissions occur indoor only, if combustion appliance as, furnaces, dryers and water heaters, are malfunctioning. Improperly installed or maintained combustion appliances together with poor ventilation, insufficient draft during different weather conditions operations with fireplaces and woodstoves may contribute to higher indoor CO concentration. Wood burning in residential areas is an important source of CO indoors. Fossil and biomass fuels incompletely combusted produce carbon monoxide. Human activity produces approximately 70% of total carbon monoxide (EPA, 2000).

More efficient burning appliances produce less carbon monoxide than less efficient appliances. Carbon monoxide could rise to dangerous levels, while the unit is malfunctioning, it is improperly installed or the ventilation system leaks. Alright fireplaces and woodstoves usually do not produce carbon monoxide, except during start-up phase, leaks in ventilation system, maintenance and back draft (EPA 2000). Back draft can occur due to different pressures or as well by stronger blowing of the wind outside. It could be prevented by increase height of chimney.

CO exposure can decrease oxygen carrying capacity of blood. CO is binding with haemoglobin, it produces COHb. Creation of COHb can cause tissue hypoxia and end in identifiable health effects. Health issues caused by carbon monoxide could result in death (EPA, 2000).

Carbon monoxide acts as an important factor in atmospheric photochemistry in urban and regional areas. CO can destroy or produce ozone in urban environments. It depends on concentration of hydrocarbons and nitrogen oxides. Carbon monoxide was found in concentration between 10 and 20% of ozone in urban air shed (EPA, 2000). Carbon monoxide affects ozone and abundance of hydroxyl radicals (OH). Hydroxyl radicals influence cycles of many anthropogenic and biogenic trace gases, which are affecting stratospheric ozone. These affects may contribute to changes in atmosphere chemistry; therefore can affect global climate (EPA, 2000).

2.3 Fuel combustion

Combustion occurs by the reaction of oxygen in the air with fuels such as wood, oil, coal, natural gas or gasoline to produce heat (TSI, 2004). Biomass fuels are hydrocarbons primarily compounded of hydrogen and carbon. Burning biomass fuel generates two principle products: carbon dioxide and water formed from oxygen in air and carbon and hydrogen in fuel (TSI, 2004).

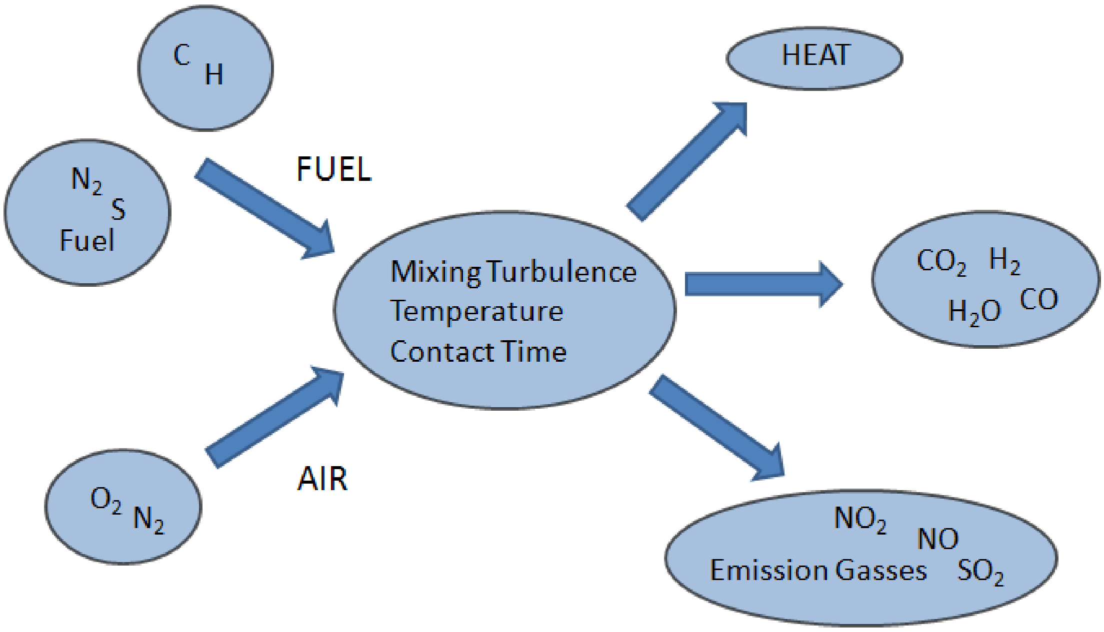

Fig 2-1 Combustion diagram (TSI, 2004)

The complex process of generating heat by the reaction of carbon in the fuel and oxygen in the air requires sufficient activation temperature, mixing turbulence and enough time for the reaction to occur (TSI, 2004). There are two ways to burn wood, perfectly/completely and imperfectly/incomplete. Perfect and clean burning of the wood harvests all the energy of the wood (Perfect Combustion, 2017). Carbon perfect combustion is divided into two phases. Phase one, is the fusion of carbon and oxygen (O_2) in the air, which produces carbon monoxide (CO). Carbon monoxide is an odourless, invisible, very toxic gas. Carbon ignites at 800 degrees Celsius, which is the required combustion temperature for phase one. Igniting carbon in 800 degrees Celsius transforms 28% of carbon's energy into heat. in phase two combustion temperature is increased to 850 degrees Celsius, which leads to carbon monoxide being burned. In this phase, the remaining 72% of the energy is harvested, and carbon monoxide is transformed into carbon dioxide (CO_2). The wood is converted into clean gray ash formed from incombustible materials in solid fuels (Perfect Combustion, 2017).

The moisture content in biomass fuels is relatively high, typically 30 to 55%. Temperature, time and air turbulence has to be sufficient to start and maintain not only combustion, but also the reaction between oxygen in air and the wood components (carbon, hydrogen and water) producing light and heat. There are three stages in biomass combustion, drying, volatiles release and burning, and char combustion displayed in fig 2-2 (Verloopa, 2017). The drying stage entails evaporating of water from wood. The volatiles release and burning stage releases oxygen, hydrogen, water, carbon monoxide, carbon dioxide and volatile organic compounds. The release of these elements and in addition of oxygen is needed for combustion of volatiles. In the last stage, char combustion, by the assistance of oxygen, heat is released, particle size is reduced and residual ash is left (Verloopa, 2017).

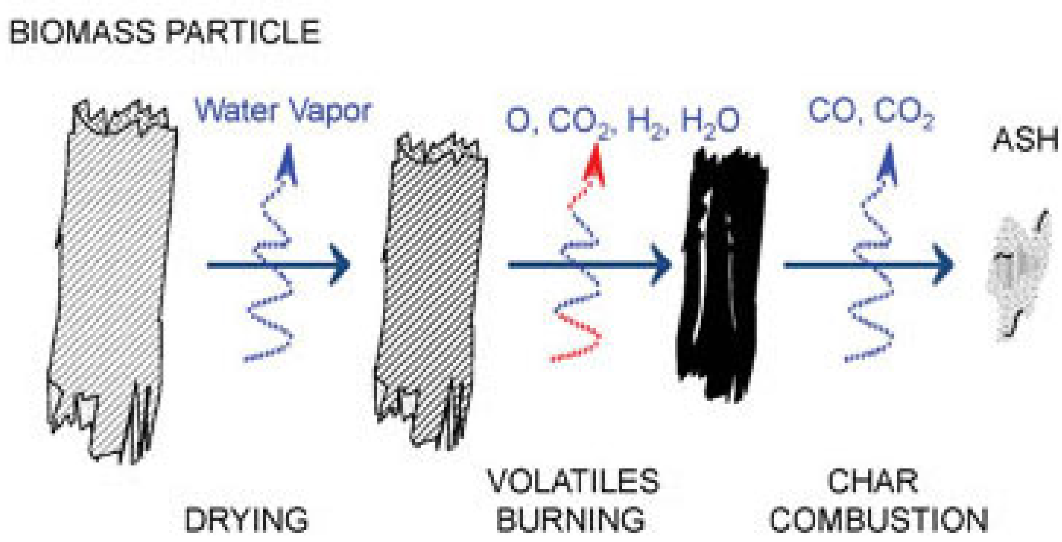

Fig 2-2 Three stages of combustion (Verloopa, 2017)

Proper control of the combustion minimizes forming of undesirable products. Soot and carbon monoxide are formed in combustion with insufficient air input or poor mixing of air and fuel. On the other hand, excessive amount of nitrogen oxides (NO, NO_2) is formed if the flame temperature is too high. If fuel forms contain sulphur, sulphur dioxide (SO_2) is formed during combustion (TSI, 2004). For the control of the combustion, specific elements were designed. For instance, the grid, the double door system and valve are main factors for stove settings and combustion control.

2.3.1 Combustion analysis

Combustion analysis improves fuel economy, safety and exhaust emissions. Measurement of flue gas concentrations, draft pressure and gas temperature is the key base for combustion analysis (TSI, 2004). The collected data from measurements is used in calculations for determining combustion efficiency (TSI, 2004).

2.3.2 Indoor air pollution

Burning biomass fuels can produce undesirable air pollutants such as, carbon monoxide, particulate matter, sulphur dioxide and nitrogen oxides. These toxic compounds contribute to smog, acid rains and cause respiratory problems (TSI, 2004). Pollutants and their maximum permissible limits are listed in Mexican air quality standards to which the measured values will be compared (Normas de Calidad del Aire). The limits are similar to air quality standards in The United Kingdom and The United States. Information and limits provided by deep analysis of standards and regulations were key attributes for designing the stove safety experiment described in the results section.

Tab 2-2 Limits stated by Mexican air quality standards (Diario Oficial de la Federacion, 2017)

Contaminant	Acute values in time	Chronicle values in time	Official Mexican norms
SO_2	288 µg/m^3 or 0.110 ppm (24 h)	66 µg/m^3 o 0.025 ppm Year average	NOM-022-SSA1-2010 (DOF, 2010)
NO_2	0.21 ppm or 395 µg/m^3 (1 h)		NOM-023-SSA1-1993 (DOF, 1994)
CO	11 ppm or 12,595 µg/m^3 (8 h)		NOM-021-SSA1-1993 (DOF, 1994)
PM_{10}	75 µg/m^3 (24 h)	40 µg/m^3 Year average	Modificación a la NOM-025-SSA1-1993 (DOF, 2014)
$PM_{2.5}$	45 µg/m^3 (24 h)	12 µg/m^3 Year average	Modificación a la NOM-025-SSA1-1993 (DOF, 2014)

The values are indicated in particles per cubic meter or in micro meters per cubic meter.

2.4 Bricks

One of the key achievements of the group project was manufacturing bricks from soil and water for a small prototype. The bricks were dried and fired in a furnace to ensure their physical properties and longer lifetime. The fact that the bricks were produced in the furnace was the main shortcoming of the project, as the cost, maintenance and skill needed to operate the furnace were too high. It was discussed to provide the furnace to the Jaltepec community and teach people how to operate it. Fortunately, architect Dr Ramon Gutiérrez joined the project and introduced his bricks created with no need of a furnace. These bricks only required a press. The bricks for the stove were created from local soil in the State of Mexico. Architect Dr Ramon Gutiérrez invented a new technology for brick creation. Twenty parts of soil mixed with one part of cement inserted into machine press, Adobera Adopress 5000, which creates bricks with no need for firing. The process is simple with the use of Adobera Adopress 5000 with estimation cost MXN 500,000,-, approximately USD 28,300,-. The capital cost could be provided to the community by project leaders. The press machine is cheaper than a furnace for firing bricks. Moreover, the process is easier to learn. The size of the bricks was 10x20x40 cm. The bricks were cascaded together and bound by a thin layer of cement mixed with water.

Fig 2-3 Adobera Adopress 5000

Fig 2-4 Building of the stove with a detail on bricks and adhesive

2.5 Methodology difficulties

There were difficulties during the project mainly caused by distance between the student and the stove. The experiments were not conducted as expected. Therefore, the project's aim and objectives had to be changed.

3 APLICATION AND RESULTS

3.1 Improved design

The final design of the stove includes specific elements such as the double door system, cooking plate and grid. These elements were discussed during a group project and were tested by a cooking experiment, carried out in the beginning of the project in Mexico. Extra elements were designed during the improvement stage of design, i.e. the valve in the chimney and extra bricks.

Extra bricks were added into stove design following analyses of documents assessing hot flue gases behaviour. The bricks are inserted into the gas flow prolonging its pathway which increases the time for energy transformation (Voorburg, 1979). The element increase stove efficiency.

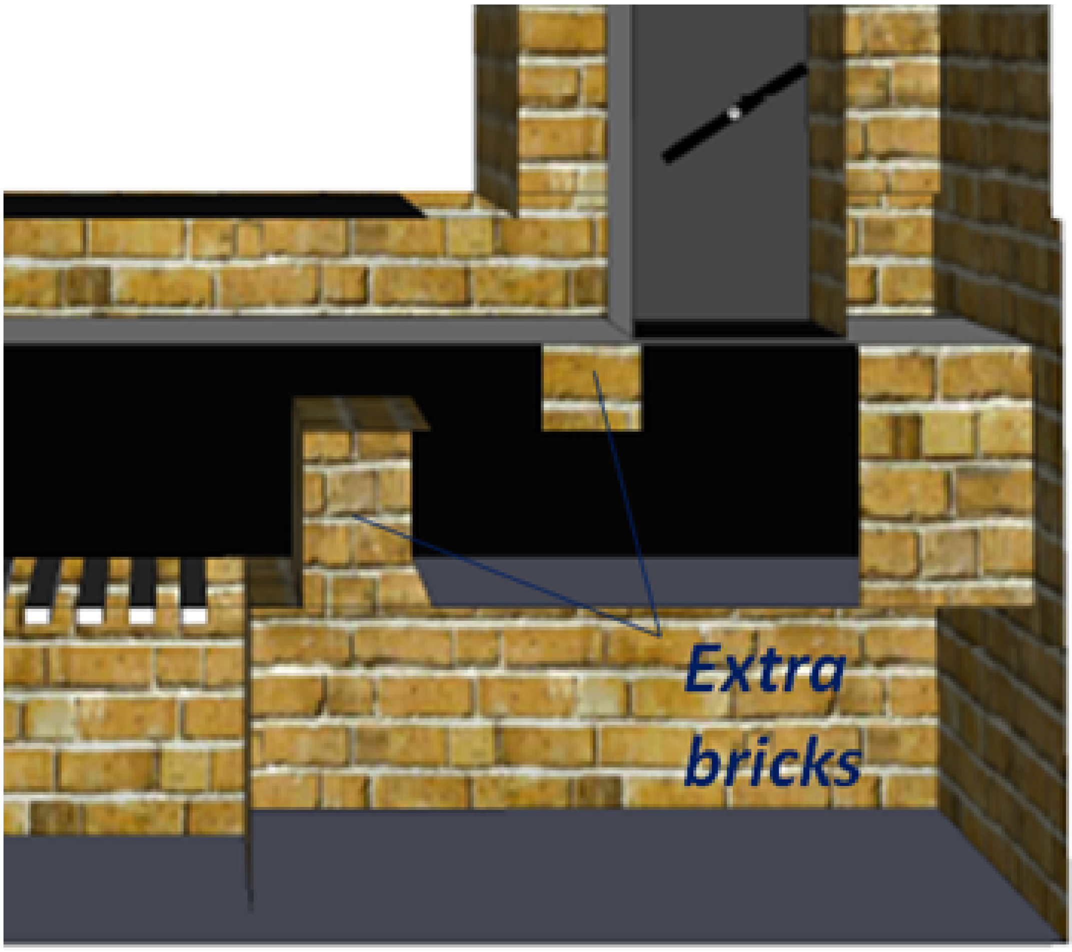

Fig 3-1 Extra bricks

The valve is a new element of the stove designed during its construction in Mexico. The chimney of the prototype in Mexico was constructed too wide. The valve was introduced as a solution for an increased diameter of the chimney. A wide chimney diameter could cause the draft to be too strong and even with double door system, this could increase firewood consumption. The valve is a metallic plate connected to metallic bar inside of the bottom of the chimney. The bar is connected to one of the chimney for stability leaves the chimney through another side, where a handle is placed. This easy controllable system allows closing and opening of the chimney diameter to decrease or increase the draft and firewood consumption.

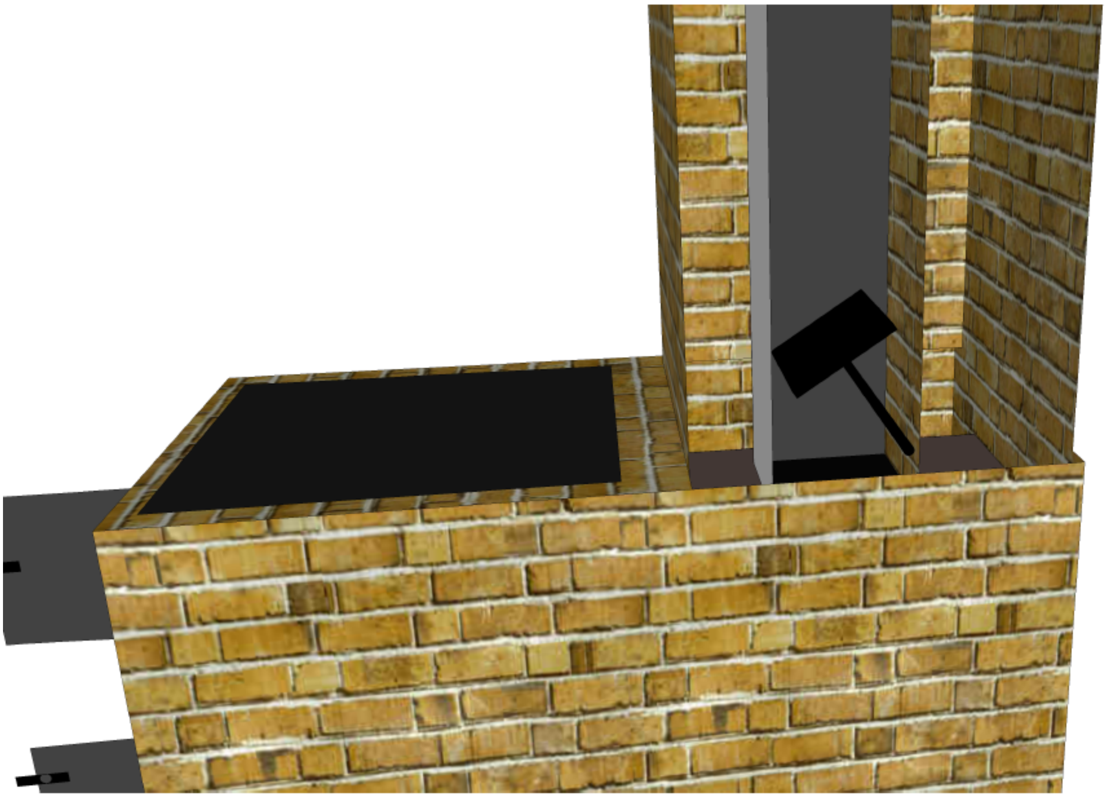

Fig 3-2 Chimney cross section with detail on valve

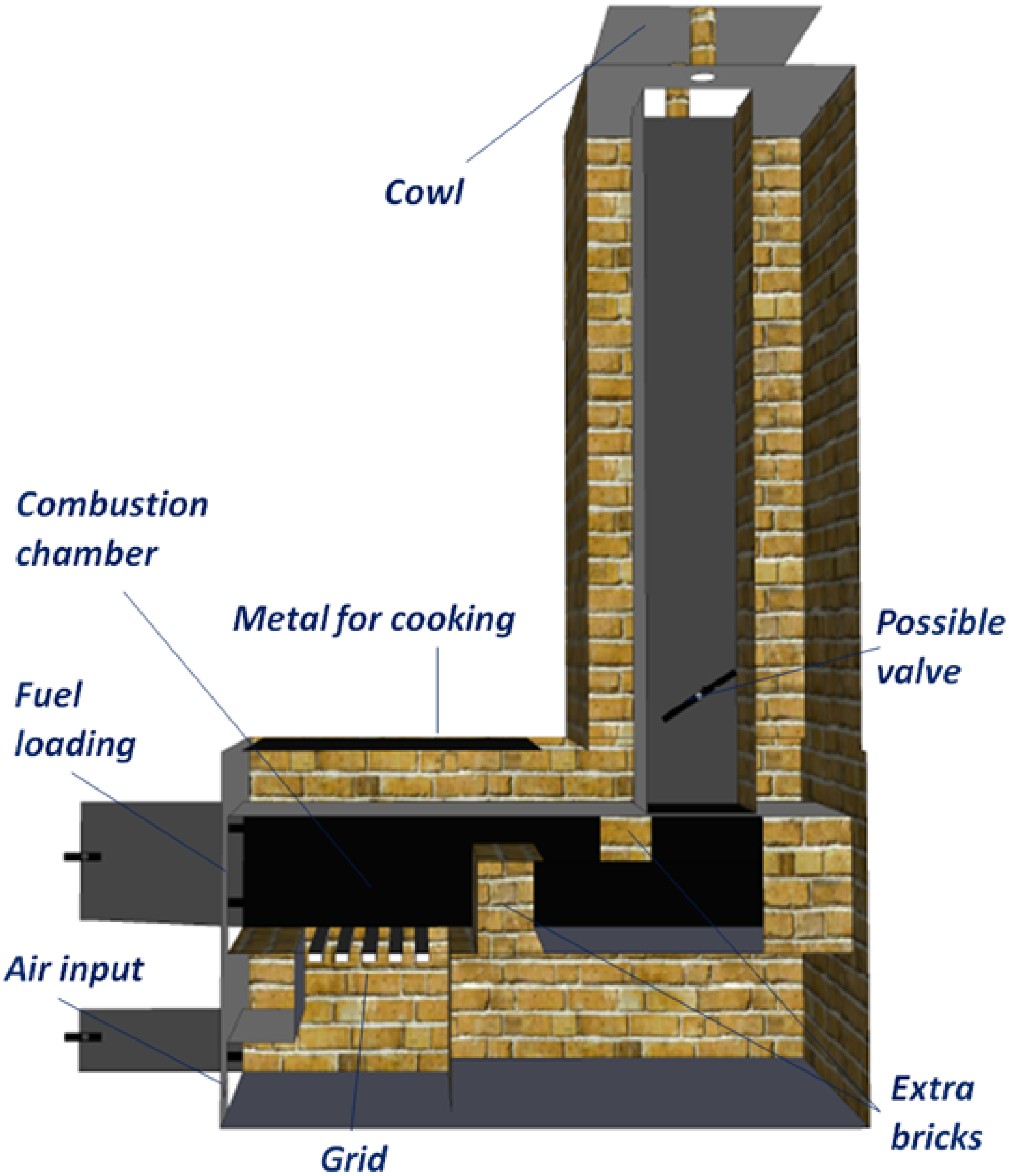

Fig 3-3 Final stove design

3.2 Cooking test – tests design

A cooking test was designed to prove stove efficiency and design. The efficiency was assessed by observing if the fumes went through the chimney. No measures were taken. The stove was finished after three days of building in the campus of Universidad de Autónoma del Estado de Mexico. The stove was set into cooking mode. The door under the combustion chamber was opened. The fire used small branches of wood collected nearby. The door in front of the combustion chamber was closed. The valve was not yet inserted in the chimney, as the fabrication of the valve needed more time. The stove was set in maximal cooking conditions. The metallic cooking plate was cleaned. In less than ten minutes, the cooking plate was ready for cooking. Quesadillas were distributed the on metal plate. The fire was controlled by a door under the combustion chamber. The fire in full cooking conditions was unnecessarily big; therefore the bottom door was partially closed to decrease the fire, it tested the system and saved some wood. While the fire was still big, the bottom door was closed. When the fire decreased to its minimum and the metallic plate started to cool down from optimal cooking condition for quesadillas, the bottom door was partially opened and more wood inserted into the combustion chamber to promote combustion and increase fire for better cooking conditions. One batch of quesadillas was done in approximately ten minutes. Cooking of quesadillas took approximately one hour.

Fig 3-4 Cooking of quesadillas

3.3 Stove safety test

Stove safety and efficiency experiments were designed as one complex test to save time and wood. The test was simulated as regular day in the Jaltepec community. The experiment last from morning until evening with the stove running all day based on the interviews conducted in ethnographic studies.

After the cooking test, a safety experiment had to be designed to prove stove safety before deploying it into the community. Statements that the stove is safe resulted from the cooking test. Next, this had to be proven by measurements. Based on literature review, main pollutants were identified as carbon monoxide and particulate matter. Standards, experiments and relevant documents were analysed and a safety experiment designed. Carbon monoxide and particulate matter have to be measure nearby the stove, where the highest possibility of inhalation during cooking is. Measurements are recommended to be placed at 1.3 meters above ground level (VAISALA, 2012, EPA - NCEA, 1999). 1.3 meters is chosen for measuring carbon monoxide and particulate matter based on estimation that the women in the community have average approximate height of 150 centimetres (Zarza, 2017); therefore the respiratory organs, such as nose and mouth, are located approximately in range of 1.3 meters (An Ergonomics Guide for Kitchens in Healthcare, 2003). A possible device for measuring is TPI 709R Combustion Efficiency Analyser - Standard Kit. It is able to measure O2, CO, CO2, pressure, temperature, etc. Measuring of particulate matter could be done by The Series 8500 FDMS™ unit, flue gas analyzer or others. The equipment depends on the market and has to be able to measure values represented in standards. Particulate matter is divided into two categories, $PM_{2.5}$ and PM_{10} representing the size of the particles. $PM_{2.5}$ has particles of 2.5 micrometers in diameter or less. PM_{10} has particles of between 2.5 and 10 micrometers in diameter (WHO, 2000). Both kinds of particles have to be measured.

The experiment is designed to simulate a regular day in Jaltepec. It is recommended to close the stove in a tent in order not to spoil measured values wind interference. The size of the tent is estimated to be 40 cubic meters representing the approximate size of kitchens in Jaltepec (Emmerich *et al.*, 2014). The tent needs to have an air input opening for oxygen needed for the combustion. This would simulate the situation when the kitchen door or window would be partially open during cooking. The opening should not be bigger than expected in the community, as the air exchange should not be faster in a tent then in Jaltepec houses. The precise air input cannot be identified due to differences in house designs. It is recommended to leave the air input into the tent no bigger than one square meter.

The test is divided into sections: starting conditions, cooking (peak) conditions and not cooking (turndown) conditions. The experiment is explained in more detail in Appendices A.2 and A.3. Stove safety will be proven when the pollutants measured in all phases fit into values indicated in Mexican air quality standards displayed in table 2-2. Moreover, fumes leaving the chimney including carbon dioxide (TSI, 2004) will be measured to display pollutants leaving the stove into the atmosphere and stove environmental impact.

Safety security measures during the experiment were considered. Based on Mexican air quality standards (Diario Oficial de la Federacion, 2017) and air quality guidelines for Europe (WHO, 2000), the safety measures were stated. As soon as the CO is within the values assorted below in table 3-1 (WHO, 2000), no harm needs to be considered and the stove can be safely approached during closing of the tent. If the values would however exceed 100 milligrams per cubic meter, the tent needs to be open for air to be able to enter and not to be exposed to high amounts of carbon monoxide. If the latter occurs, the data can be used. However, the test has to be repeated again.

Tab 3-1 Values limiting access to stove during experiment

• 100 mg/m^3 (90 ppm) for 15 minutes
• 60 mg/m^3 (50 ppm) for 30 minutes
• 30 mg/m^3 (25 ppm) for 1 hour
• 10 mg/m^3 (10 ppm) for 8 hours

3.4 Stove efficiency test

To prove stove design, the efficiency of the stove needs to be tested. Based on experiments and relevant documents, the experiment was designed. Carbon analysis basic (2004) explains the main principle of stove efficiency testing and combustion analysis on an international level. It is recommended to measure data following the instructions in Appendix A.2 and to use the data in equations in the experiment explained in Carbon analysis basic.

The basic principle of combustion is a reaction of carbon and hydrogen in fuel and oxygen in the air producing water, carbon dioxide and heat. Ideal combustion (perfect combustion) creates only gases water vapour, carbon dioxide and nitrogen (TSI, 2004).

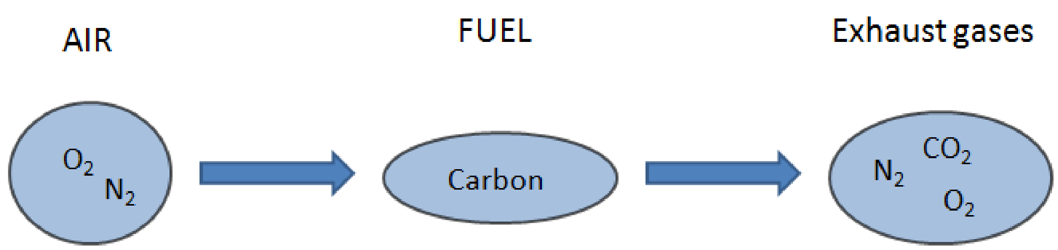

Fig 3-5 Simplified combustion diagram with more oxygen than needed

The appearance of oxygen in exhaust gases means that more air than needed is present in the combustion. On the other hand, if there is not enough air entering the combustion, there is not enough oxygen to complete the formation of carbon dioxide from the carbon in fuel. Instead of carbon dioxide carbon monoxide is created. This is a highly toxic gas. Theoretically, the most efficient combustion produces carbon dioxide and some nitrogen. If the latter is true, the reaction uses optimal amounts of oxygen (TSI, 2004). The concentration of carbon dioxide depends as well on firewood.

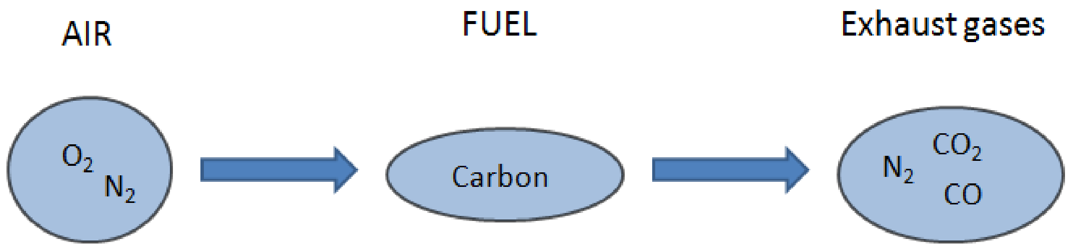

Fig 3-6 Simplified combustion diagram with less oxygen than needed

Exhaust heat is not useful. The higher the temperature of the fumes leaving the stove is, the less efficient the stove and its use of temperature is. Heat loss cannot be avoided. However, the stove efficiency can be increased by additional design elements, such as additional bricks increase the gas flow pathway. Therefore, this increases time for energy exchange (Voorburg, J., 1979).

Draft pulling air into the combustion chamber and releasing fumes into the atmosphere works on the principle of pressure differences (Voorburg, 1979). The top of the chimney is a typical place for measuring the pressure to verify the draft. Environmental influences, such as ambient temperature and barometric pressure can influence the flow (TSI, 2004). The draft influenced by the environmental conditions can affect flow temperature and the efficiency of the stove.

Tab 3-2 Values needed to be measure based on the analysis above

- Oxygen entering the stove through the bottom door
- Oxygen leaving the chimney in the fumes
- Pressure of the air entering the stove through the bottom door
- Pressure next to the top of the chimney and in the fumes near the top of the chimney
- Temperature in the combustion chamber
- Temperature in the bottom of the chimney
- Temperature of the fumes in top of the chimney
- Carbon dioxide leaving the chimney in the fumes

3.5 Firewood combustion test

The firewood consumption test was designed to determine minimal and maximal stove wood consumption. All the values mentioned above in the stove efficiency test will be measured as well during the wood consumption test. The firewood consumption test should operate with open valve, as the valve is not an essential element of the stove in every family. Maximal wood consumption will be reached when the stove is set to cooking (peak) conditions. The bottom door should be opened, fuel should be inserted, the top door closed and the bottom door should be left opened. With an opened bottom door, the air enters the stove maximally and promotes maximal fire. The fire wood is inserted into the stove and wood in the combustion chamber is mixed during every load.

The minimal wood consumption test simulates not cooking (turndown) conditions. The entails that the bottom door is opened, fuel is inserted, the top door is closed, and if the fire is sufficient, the bottom door can be closed. The key points in this phase are the amount of wood in each load and the amount of air entering the combustion chamber. The fuel should be loaded only in amounts to keep the fire going in minimal flames for about one hour. This can be done by judging visually if more wood is needed, and if so adding another pile. The bottom door should be closed in the beginning of the test and partially opened, if needed, to promote some air to the combustion, not to extinguish the fire. This phase is potentially the most polluting phase. The experiment could provide a variety of information about firewood consumption and pollutants created during combustion.

3.6 Open top door test

Consulting people involved in the project about the time families spend near open fires, and the need of heating the house as well as cooking on the stove were the reasons to test stove safety when the top door is opened. The open top door test will prove stove design and safety even, with the top door opened during cooking. It is assumed that the design of the stove is efficient enough to pull the pollutants through the chimney out of the stove without polluting the living area. This test could also show heating possibilities with opened door during winter. The stove setting is similar to cooking (peak) conditions – bottom door opened, fuel inserted; leave the bottom door opened with the top door opened. When the fire is started, the fumes should go to the chimney naturally. These conditions are the most wood consuming, as the air is entering the stove by both doors. The goal of the test is to prove that even if the top door is opened, the stove is safe. Based on conversations with the Jaltepec women, they sometimes want to watch the fire while waiting for their food to be ready. It is necessary to prove stove safety before instructing the women how to use it. Elements will be measured the same way as during stove safety and efficiency tests.

4 DISCUSSION

4.1 Design

The new stove focuses on the key factor introduced in the group project, namely the focus on building the stove locally using local materials. This focus allows people in the community to build their own stoves, amend the design following their needs and change or repair anything if needed. Moreover, as the community would have knowhow, they could use building of the stoves as a job opportunity and a source of income. This design could solve many problems in the community. The original design from the group project had one essential shortcoming, the manufacturing of the bricks. The bricks interpreted by Dr Gutiérrez, described in the materials and methods section, were used for building of the stove and the press for their production is considered to be subsidized by the project budget. It would give people in the community opportunities for creating their own bricks from the soil nearby. The size of the bricks can vary. This size was chosen as suitable by Dr Gutiérrez.

The design of the stove has weak points as well as great opportunities. One of main weak points is double door system. It is easy to operate. However, is has to be properly explained to the user, as it is the main parameter for stove settings. With incorrect settings of the double door system, the stove could pollute the living area. For example, when the valve in the chimney and the bottom door would be closed and the top door in front of the combustion chamber opened. The fumes would most probably leave the stove by the top door and pollute the surrounding area. The stove could have been designed with only one door as the Patsari stove is designed. This system should not promote the same combustion environment as with double door system and the grid due to air turbulences supported the fire from bottom in the second option. Moreover, the ash from combustion would be staying in the fire until the end of the fire to be taken out. The doors are hot and serve as a heater during winter. The heated door could also cause problems, as happened during the cooking test. The doors got hot, metal expanded its size and the doors could not be manipulated properly. This has to be considered during manufacturing.

Furthermore, the fire could be done in the bottom of the stove under the combustion chamber and the combustion chamber could be used as an oven. Moreover, the food can be inserted into the bottom door during regular cooking conditions to keep it warm. The stove does have the opportunity for heating water and food. It is possible to amend the design of the chimney following old European stoves and inserting in the chimney a heating box for water. Similarly, there could be two boxes in the chimney to heat water and food. This design should be considered for further design of the stove, if the stove would be considered as safe and efficient.

4.1.1 Valve and extra bricks

The valve is a new additional setting element of the stove. Options during the stove building were discussed. It was possible to build the bricks in the chimney like steps to prolong the pathway of the fumes and increase stove efficiency for heating. However, it would not have big impact on stove cooking efficiency as the hot fumes would already leave combustion chamber and get slower in the chimney part. It could also cause undesirable cumulating of soot in the beginning of the chimney. Other option was to put extra bricks into the bottom of the chimney to decrease the diameter of the chimney. This would be simple and permanent solution. In the end system with the valve was chosen for easy manipulation and joining double door system for setting of the stove based on conditions desired. The ideal setting is same air input as chimney output; respectively have the same opening in the bottom door as diameter of the chimney reduced by valve.

Extra bricks are added as elements prolonging hot gas pathway. Different solutions could have been chosen, as well as the design of the stove could have been changed. Adding the bricks is very simple solution, easy to proceed with no need for extra material. This solution could have as well minor impact on firewood consumption.

4.2 Cooking test

The design of the cooking test was taken from (Bussmann, 1988). The cooking test is very useful, as it shows stove efficiency and design in practice without a need of special devices. It could show bad function of the chimney by small draft, when the fire would not be promoted by enough air entering the combustion chamber and especially not enough draft pulling the fumes to the chimney. Cooking test could also indicate possible backflow, when the air enters chimney form the top and push the fumes to living area. Backflow can occur in shorter chimneys and it was discovered as shortcoming of the stove developed in the group project. The fumes could be also leaving by one of the doors instead of the chimney. It would indicate wrong design of the stove, with inappropriate draft. If the heating desk would not get warm, the combustion chamber would be most probably too high and the fire would not be able to heat the desk from distance. The cooking desk could also get twisted. This phenomenon would mean that the material is not suitable for the presence of high temperatures and it would need to be reconsidered. A disadvantage of the cooking test is its simplicity; the data are only collected visually.

4.3 Stove safety test

Stove safety test was designed based on international standards. The experiment is combined into one test together with the stove efficiency test to save time, firewood and the environment. Values proving stove safety are carbon monoxide and particulate matter. The advantages of the test are its simplicity for measuring the values and ease of explaining to people without expertise. The test could be conducted easily by persons with the right equipment. Disadvantages and key problems slowing the project for a few months is the equipment. The tests were designed and ready to be conducted in the beginning of July. However, the equipment was not obtained. The stove was not tested for its safety; therefore, the project could not move from the testing phase to the development phase to find the best suitable design, as was essentially planned. The stove safety test is the most important step in the project and it was not possible to fulfil it. It is recommended to do the stove safety test, compare the values with Mexican air quality standards and continue with the project as planned.

4.4 Stove efficiency tests

The complicated stove efficiency test, explained in carbon analysis basic (2004) and other stove efficiency tests were deeply analysed, and the experiment proving stove safety and efficiency on international comparable level was designed. An advantage of the experiment is its comparable level. The test is complicated, needs several valuables to be measured, such as temperatures in the combustion chamber, in the bottom of the chimney and in the fumes at the top of the chimney, levels of oxygen entering the combustion, pressures of the air entering the stove in the bottom and in the top of the chimney and carbon dioxide in the combustion chamber and in the fumes. These values should have been measured, and subsequently inserted in formulas explained in Combustion analysis basic (2004) and exact values should have been calculated. For example, the combustion efficiency (%) should have been calculated.

The test could be approached from a different angle, for example leave the stove running for several days under different setting conditions and average the values. The tests would then be easier and need less human attention. Moreover, the values would not have to be measured in that limited time frame. The test was design based on interviews with women from the community and possibility to compare results internationally.

The complexity of the test is one of the disadvantages; however, the results would be useful. The second and crucial disadvantage of the experiment was the equipment. The instructions how to conduct the measurements were sent to Mexico in the beginning of July, the equipment was described and assistance of finding the right equipment was provided. However, no equipment necessary for the experiment was obtained. The latter was also true for the stove safety test equipment. The stove efficiency test could have been explained and discussed more deeply in this report. Details of all the equations, outcomes etc. could have been provided. However, as the explanation of the test is very complicated, it is recommended to read the article Combustion analysis basic listed in references. Measure the data following instructions in appendixes and use the data in equations explained in Combustion analysis basic.

If the possibility to conduct the stove efficiency test would not be viable due to unskilled personnel, it is possible to discuss stove efficiency by simpler tests based on the Patsari stove efficiency test described in Energy performance of wood-burning cook stoves in Michoacan, Mexico by Berrueta (2007).

The stove efficiency experiment could be simplified. If the decision to continue the project would be made, the stove safety test is required. The stove safety test should have been done as a first test to prove stove safety. If it would be proven that the stove is not safe, the design would have to be changed before other tests would be conducted. If the stove would be considered safe, it is recommended to conduct the simple stove efficiency test before continuing. The simplified stove efficiency test is a cooking test where conditions similar to real-life cooking circumstances are simulated. Ideally three types of cooking practices would be compared, regular cooking in the community on an open fire, cooking in the community on the Patsari stove and cooking on an improved stove in the campus of Universidad Autónoma del Estado de Mexico. The cooking test would last one day. All three practices would cook the same meals. Time of cooking and wood consumption would be measured. Crucial would be to measure firewood consumption by weight. Consumption of wood would be compared and the decision could be made to deploy the stove or change the design of the stove based on the results.

4.5 Firewood consumption test

The firewood consumption test shows maximal and minimal consumption of the wood. The test provides data of quantity of wood consumed by certain settings of the stove. It is simple and the results are easily comparable to other cooking practices.

4.6 Open top door test

The open top door test is done to prove stove design, as if there would not be any or minimal figures of polluting gases measured in the cooking area, the stove could be used during the winter with opened top door to increase heating of the living area. This test was designed considering possibilities of alternative stove uses.

4.7 Test limits

Limitations of the tests are the equipment required and a lack of skills of test examiner. The tests were designed by non-professional and could have been conducted following international standards and relevant documents.

4.8 Cost

The cost of the stove was not estimated. There are many factors to influence the cost. The machine for the manufacturing of the bricks costs approximately USD 28 300,-. There is a need for cement with a cost around USD 7- for a bag of 25 kilograms. The metals for the cooking plate, door, grid, valve and chimney cowl could be found in the community and reused from other items. If the items would not be found, the estimated cost is USD 15,-. The price of the stove has to be confirmed in the community. However, it could be stated that the stove could cost approximately USD 20,- in the worst case scenario. Given the press machine would be supported by external source, project funding, as discussed earlier.

4.9 Project limits

The original aim of the project was to find the best suitable design for a cooking stove in the Jaltepec community in Mexico. Objectives of the project were to improve the design of the stove developed in the group project, keeping in mind hot flue gases behaviour, build the prototype in its actual size in Mexico, test the stove, amend the design if needed and continue until the design of the stove was safe and efficient. Unpredictable difficulties experienced by the Mexican partner lead to delayed purchasing of necessary equipment for successfully conducting the tests designed by the author. Therefore, the methodology of the project was changed and the results are designed experiments. Further steps are described in the recommendations section.

5 CONCLUSION

The stove design developed in the group project and improved in the beginning of the individual project by implanting adjustments to deal with hot flue gas behaviour and chimney standards was presented to the community and built in Mexico. The stove was tested by conducting a cooking test.

Positive results concerning mitigating indoor air pollution were expected based on visual confirmation of stove functioning during the cooking test. The fumes were leaving the stove by chimney. The safety of the stove had to be proven before deploying it into the community. Moreover, stove efficiency had to be clarified, given comparability to other cooking practices in the Jaltepec community. Experiments testing stove safety and efficiency including firewood consumption were designed.

The aim of the project was to improve the design for cooking stoves in the Jaltepec community, thereby reducing wood requirements. The aim could not be confirmed by measurements; therefore, the aim was not met. The design was improved following international standards, regulations and relevant documents. However, the amount of wood required is not known. Neither is the stove's safety and efficiency.

The partner university will carry on measurements. The main achievements of this project are an explanation of essential design elements of the stove, an approximation of advanced stove experiments for non-professional testers and experiments developed for comparison of cooking practices in the community. Disadvantages of the project are equipment needed for fulfilling the measurements and machine for bricks manufacturing. These devices are very expensive and need to be supplied by external source.

6 RECOMMENDATIONS

The improved stove design should mitigate harmful indoor air pollution by minimizing exposure to smoke. The stove is designed to be easily built in the Jaltepec community by use of soil and affordable cement. The tests need to be carry out in Mexico. Further changes of the design have to be done, if the stove will not be found safe or efficient. It is recommended to do a safety test. If the stove will be declared safe, simple efficiency test comparable with the Jaltepec way of cooking are required. If both these tests will be positive then the complex stove efficiency test should be carried out. If the stove is safe and efficient compared to Mexican air quality standards and the combustion model, people in the Jaltepec community should be thought how to build the stove, thereby ensuring long term sustainability. Open basic design respecting safety and efficiency standards should be tought to people in the community to understand the design and to be able to build the stove and amend the stove themselves. It is recommended to declare affordability of the stove while manufacturing in the community. The stove was designed to make starting a fire easy, it is recommended to turn on the stove for each cooking and not to leave it running all day long. It would save the firewood as well as prevent harmful substances from entering the environment.

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