CHAPTER 5

Biomass Pellet-Fired Boilers

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Abstract

Wood fire has been used as a heat source for thousands of years. Nonetheless, the methods for burning wood have progressed to very automatic and controlled combustion systems. The pressure to develop systems that minimize air pollution and maximize heating efficiency has led to imaginative and innovative new designs. Provided that firewood is grown in a sustainable manner and used in efficient combustion systems with insignificant hydrocarbon emissions, firewood is a renewable energy source. Already today, it is a significant heating source in most of the world. Due to its potential of being CO$_2$ neutral, an increased use of small-scale combustion can have a significant impact on reducing greenhouse gas emissions. The fuels in use are mainly wood logs, but the use of densified biomass in the form of pellets or briquettes is playing an important role, especially in the residential and public sectors. In this regard, it has to be noted that the use of traditional batch-fired systems burning firewood has been augmented because of the introduction of systems designed to burn pelletized wood wastes, agricultural grains or woodchips. Due to the fact that intelligent design and sophisticated technology have resulted in several types of biomass heating systems, the aim of this chapter is to provide the reader with an overview of the domestic pellet boilers.

Keywords: Biomass, pellet, boiler, efficiency, stoves, fireplace.

1 Domestic Pellet-Burning Appliances

In spite of its long history, biomass is the most difficult of the commonly used heating fuels to burn clean and efficiently, especially at a small scale. Residential wood-fired heating systems typically have considerable amounts of particulate, carbon monoxide and other unburned gaseous emissions compared with systems fired by natural gas and oil-fired systems. The more recent development of wood-fired
appliances has largely focused on the reduction of these undesirable emissions to retain the desirability of wood as a fuel source. The challenge in designing batch-fired heating systems is to provide a controlled rate of heat output over as long duration as possible, while capturing as much of the heat released by the fuel as practicable. Therefore, the development of efficient and clean-burning systems has preoccupied product designers for decades.

The use of wood pellets for domestic heating is a rather recent phenomenon. Pellet-fired appliances were developed in the 1980s but significant market penetration of pellet stoves has only taken place during the past 15 years. With the introduction of wood pellets and automatic combustion systems in recent years, it has become much easier to continuously adapt the heat output to variations in heat demand over time. Pellet burners for use in central heating boilers were developed during the 1990s and now have a significant share of the domestic heating market. In Austria, Germany and Denmark, complete pellet boiler units are the most common appliance types. In other countries, the interest in pellet heating is just awakening.

At present, there are several types of small combustion devices for biomass pellets, which can be roughly divided into the types described below [1].

1.1 Loose stokers with integrated hopper

One possibility for converting to wood pellets is to retrofit an existing boiler with a separate pellet burner (Fig. 1). This type of pellet burning system demands a lot of space in the boiler room. When the boiler is in good condition, the size and the geometry of the combustion chamber make it suitable for combustion of wood pellets, particularly where the existing boiler was used for burning coal. An important condition to be fulfilled to make a retrofit system work satisfactorily is

Figure 1: A pellet burner with an integrated hopper for wood pellets [2].
that the chosen pellet burner should be sized correctly so that it fits the capacity of the existing boiler.

1.2 Wood pellet boiler combined with oil-fired boiler

When installing a wood pellet boiler, it can be desirable to keep any existing natural gas fired boiler as a supplement to the wood pellet boiler in the coldest winter periods or as a spare boiler [3].

1.3 Pellet burners without hoppers

They are compact pellet burners, which resemble oil burners both in size and appearance (Fig. 2). These compact pellet burners were build upon differing principles of wood pellet firing of pellets than used in the traditional compact boiler.

This type of pellet burner has the advantage that it can be retrofitted onto an existing boiler and that the installation is simple and demands little space. However, there is a final demand that is the stoker must to have a size and shape that makes it suitable for the combustion of wood pellets [5].

1.4 Compact boiler systems

Compact boilers, also called stoker boilers, are characterized by having a boiler, a combustion system and a fuel hopper built together into one compact unit. The whole unit is designed so that the single elements fit together (Fig. 3). The hopper, combustion system and boiler are all designed to the same capacity, which is not always the case when installing a loose stoker on an existing boiler.

Some compact boilers are designed to burn wood pellets, wood chips and grain. However, shifting between different fuel types normally requires an adaptation of the operating unit to the fuel it is intended to use [6]. As with other boilers’ systems

![Figure 2: An example of a pellet burner that amongst others can be used for the retrofitting of an existing boiler [4].](image-url)
1.5 Pellet stoves

There are two main types of pellet stoves available: stand-alone pellet stoves and chimney integrated stoves. The only difference between these two types is that the latter is especially dimensioned to be placed in an open fireplace. The most common stove is the stand-alone stove. Stand-alone stoves usually have an integrated pellet storage, which allows storage of a limited quantity of pellets, usually enough for 1 or 2 days. Based on the wood stove, pellet-fired stoves designed for installation in the living room have been developed and have become increasingly popular in recent years. In comparison to normal wood stoves, pellet stoves are designed for house owners who emphasize a need for simple operation and a minimal need for maintenance (Fig. 4). Most pellet stoves are equipped with a thermostat and electronic ignition and therefore they do not demand manual intervention such as stoking or the controlling of their output.

1.6 Pellet stoves with back boilers

Some manufacturers have produced pellet stoves with an integrated back boiler. They produce 8–9 kW of heat, of which the water tank takes 35%–45%. This heat is used to heat other rooms in the house via the central heating system. The remainder heats the room in which the stove is placed. In comparison to wood
stoves, they are still relatively expensive, but in return, they have some of the advantages of pellet-fired central heating installations [8].

1.7 Wood pellet boiler with solar heating

The solar heater can either be implemented so that it only delivers domestic hot water or so that the solar panel delivers both hot water and space heating. As opposed to wood pellet boilers, a solar heater demands storage for the heat, which is produced by the solar panel during the day. The capacity of the storage tank has to correspond to the area of the solar panel and in many cases; the hot water tank will have sufficient capacity [9]. The advantage of combining a wood pellet boiler with a solar heater (Fig. 5) is that in the summer period, the solar heater can completely or partly cover the domestic hot water demand, so that the wood pellet boiler can be taken out of service [10].

2 Wood Pellet Boilers

2.1 Technical features

Pellet-fired boilers (Fig. 6) allow continuous automatic combustion of a refined and well-defined fuel, with the burning rate controlled by the rate of fuel supply rather than by restricting the primary air. The fuel is fed automatically into the
combustion chamber by means of an auger from a storage hopper. Some burners are equipped with a smaller pellet storage (enough for one or a few days of operation) that can be refilled manually or by an automatic system from a larger storage. The combustion air is supplied by an electric fan that may also provide a distinct secondary airflow. The fuel feed is typically by means of an auger from a storage hopper. The fuel delivery rate can normally be fine-tuned by on/off timers causing the auger to cycle over a short interval, with the percentage of on-time varied depending on the heat demand. Operation is normally controlled by a thermostat in the heated space, or by an aqua-stat in a boiler or heat storage tank. Ignition is by means of an electric device or by maintaining a pilot flame. Minimal maintenance is desired and the best burners can be in operation for more than a week without the manual removal of ash, etc. In fact, the most important development is perhaps to increase the availability and decrease the necessary maintenance. For instance, burners can be installed in boilers with automatic ash removal.
Modern wood pellet-fired systems are designed for automatic operation, so that the supply of fuel and combustion control only requires the minimum of manual intervention. Because of this, wood pellet boilers have advantages in terms of comfort compared with other solid fuel boilers. In full, a pellet-fired boiler consists of: fuel storage, fuel hopper, stoker or wood pellet burner, boiler, ash outlet and ash container, systems for controlling the supply of fuel and air, and flue gas exit and chimney.

2.1.1 Fuel storage
The design of the fuel storage system depends on the space the consumer has available for it and the wood pellet delivery method chosen.

- **Storage in bags**: Some domestic boilers use wood pellets that are delivered in bags with a weight of 10–25 kg. Even though the bags are made out of a plastic, they have to be stored dry because the pellets are able to absorb moisture from the air. If wood pellets are exposed to moisture, for example in the form of rain, they will decompose and become useless as a fuel. The bags, therefore, have to be stored in a dry place, for example in an annex or in the basement. From the storage room the bags are carried to the boiler room, where they are manually emptied into the fuel hopper.

- **Storage in loose weight**: Larger fuel stores where the wood pellets are delivered by lorry and blown into the storage room can be arranged in a room neighbouring the boiler room, in a silo or a room that is arranged in an attic above the boiler room. In such cases, special fire protection measures for the storage room must be taken. Storage of loose wood pellets by the consumer will typically take place in a pellet silo as can be seen in Fig. 7. A pellet silo will typically contain 5–6 m$^3$ of pellets. This type of storage gives the least

![Figure 7: Drawing of a complete boiler plant with an outdoor silo for wood pellets [4].](image-url)
possible amount of work and only demands an agreement with the supplier for the regular delivery of new pellets as the old ones are being consumed. The silo has to have steep side walls towards the screw conveyor. If the sides are not sufficiently steep, the pellets will roll down, but the dust will remain in the silo. This means that after a while the boiler will only be firing dust, which will increase the boiler temperature and reduce efficiency. The increased temperature also increases the risk of the ash clinkering.

Independent of the storage system selected, the room in which the pellets are stored has to be dry and the creation of dust has to be minimized.

The maximum content of moisture in the raw material at 15% is so low that dry rot and bacteria are not active. Because of this, wood pellets are in principle sufficiently dry to be stored for an indefinite amount of time without being decomposed by microorganisms.

An important objective when handling wood pellets is that the pellets should be exposed to as little physical stress as possible, because it can cause the creation of dust and small particles. During mechanical handling of wood pellets, small parts are loosened and thereby dust and small particles are created. Usually, pellet manufacturers remove dust and small particles with a screen or exhaust equipment. However, it is difficult to avoid the creation of dust during handling and storage. To reduce dust nuisance, it is important that bags and wood pellets are handled in a way that does not cause the wood pellets to break. If the fuel storage room is established indoors, it is recommended that a cyclone is mounted in the injection system to reduce the dust nuisance in the storage room. Low pressure in the fuel storage room during the injection of wood pellets furthermore ensures that the dust does not spread to other parts of the building. Dust is not only annoying and harmful to the health but can also constitute a fire risk and cause dust explosions. Thus, regular vacuum cleaning and removal of dust is important to reduce its associated problems such as: uneven combustion caused by uneven induction of fuel; low efficiency; high content of unburnt fuel in the ash and diffusion of dust.

2.1.2 Fuel transport

Transportation of wood pellets from the storage area to the fuel hopper usually takes place through a system consisting of screw conveyors. When choosing the conveyors, it is important that they are suited for the transportation of wood pellets, which mainly means that they rotate slowly. Quickly rotating conveyors act as whisks and break the wood pellets.

2.1.3 Fuel hopper

The fuel hopper acts as a store from which the wood pellets are automatically transported with a screw conveyor into the combustion chamber. The fuel hopper has to be made of non-flammable material and has to be able to be closed with an air tight lid. The fuel hopper normally holds an amount of fuel that corresponds to approximately one day’s consumption at full load.
2.1.4 Stoker or wood pellet burner
From the fuel hopper, the firing of the pellets happens via a stoker or screw conveyor (or a corresponding device) that conveys the wood pellets into the combustion chamber of the boiler. The stoker is driven by a motor that is controlled so that it delivers the amount of fuel that corresponds to the heat consumption from the boiler or to the wanted boiler output. Inside the stoker pipe, a temperature sensor is placed that activates a sprinkler device if the temperature in the stoker pipe gets too high, e.g. due to back firing. The sprinkler device is supplied with water from a water tank placed on the boiler or the stoker.

Pellet burners for domestic use are usually constructed for a nominal thermal output of <25 kW. Depending on the feeding system, three different types of pellet burners can be identified (Fig. 8) with the flame burning either horizontally or upwards. Perhaps, the most interesting burners are the horizontally fed ones, in which the gases are released within a combustion chamber (tube) during devolatilization and in which a primary combustion zone can be defined, in contrast to the other types of burners. To ensure minimal emissions, it important to obtain stable combustion conditions and minimal stand-by periods, i.e. by avoiding the number of start-ups or operation with a pilot flame. In addition, the overall emissions are generally reduced when using electric ignition rather than a pilot flame.

![Figure 8: Wood pellet burners: (1) underfed burners; (2) horizontally fed burner and (3) overfed burner [13].](image-url)
In some Nordic countries, it is quite common to replace an oil burner in an existing heating boiler with a pellet burner. In this case, it is important that the pellet burner is properly designed for the boiler. If the flame hits a cold surface, high emissions of soot and hydrocarbons and a low efficiency will result. In addition, the flue gas flowing from a pellet burner is higher than that of oil, and the installed thermal output of a pellet burner should therefore be less than that of a corresponding oil burner. This is important since the residence time in the boiler may otherwise be too short, resulting in flue gas temperatures that are too high and emissions of unburned hydrocarbons. This means that a consumer can get slightly less heat output from an oil-fired boiler converted to use a pellet burner. Normally, this does not cause any problems because, for technical reasons, oil boilers are normally over-sized for small houses. Some burners are equipped with an integrated smaller pellet storage (enough for one or a few days of operation) that can be refilled manually. Other burners may have an automatic system, connected to a larger storage. The fuel is usually fed to the burner by means of a screw, but other feeding systems also exist.

2.1.5 The boiler
The boiler consists of a combustion chamber with a water jacket around it. In the combustion chamber, the wood pellets are combusted, with air supplied from one or more fans.

The combustion chamber may be designed in various ways. In smaller boilers, it is fairly normal for the combustion to take place in a burner pipe on the stoker itself. The combustion air is supplied through a series of openings in the burner pipe. In larger boilers, combustion normally takes place on a grate.

The combustion chamber may have a lining made of a fire-resistant ceramic material or cast iron, which partly contributes to keeping a high temperature and is also more resistant to heat stress from the combustion. To ensure good combustion the air supply is very important. When combusting wood pellets, it is especially important that the air is supplied in such a way that the gasses produced during combustion get sufficient oxygen to be combusted completely and before they leave the combustion zone. Water from the radiator system of the house circulates in the water jacket around the combustion chamber. The heat that is generated during combustion is transferred to the boiler water through the heating surfaces in the boiler. A central heating pump pumps the heated boiler water to the radiators. In some cases, the heat is transferred to the radiator water via a heat exchanger. Another heat exchanger ensures the heating of domestic hot water.

2.1.6 Ash container and ash outlet
When wood pellets are combusted, the ash generated is generally low (0.5%–1%). A larger amount of ash than that may be a sign that the pellets are of poor quality. For example, they may contain an amount of impurities in the form of sand or other inorganic materials. If the ash creates burnt cakes or slag, it may either be because of impurities in the pellets or too high combustion temperature.

In pellet appliances, the ash is collected in an ash dump or in an ash container, which is emptied by hand. Large boilers have an automatic ash outlet where the
ash is transported to a container via a screw conveyor. To avoid the danger of fire, the ash has to be collected in a metal container with a lid. It may never be put into a rubbish bag or the like before, it is known for a fact that no embers are left.

2.1.7 Controlling air and fuel supply
Wood pellet-fired boilers are different from oil-fired and gas-fired boilers in one significant respect: fossil fuelled boilers operate in short heating intervals (on–off operation), as the supply of fuel and air is turned on and off momentarily. In oil-fired and gas-fired boilers, the combustion in the combustion chamber of the boiler stops at the moment that the supply of fuel is discontinued.

In wood pellet-fired boilers, on the other hand, the fuel is supplied in a steady flow. As long as fuel and air is supplied, the combustion of wood pellets will continue. If the supply is cut off, the combustion will continue until all the fuel in the combustion chamber has been converted. Heating with wood pellets thus gives longer start-up and shut-down times than is usual in oil or gas firing.

The purpose of the boiler control system is to control the fuel and air supply, so that the boiler delivers the desired heat to the heat distribution system, i.e. the radiators and supply of domestic hot water. The more heat that is needed, the more fuel has to be supplied and the more air has to be added to ensure clean combustion.

The control unit may be built upon a thermostatic control unit that registers the temperature of the boiler water at a suitable place in the system. When the temperature decreases beneath a certain level, a start-up impulse is sent to the motor that conveys the pellets into the boiler. At the same time, the control unit makes sure that the air supply corresponds to the amount of fuel that has to be combusted. Newer boilers are often fitted with an oxygen control unit based on a so-called lambda probe. This is a sensor that is placed in the flue gas duct and registers the oxygen content in the flue gas. The controlling system uses the signal from the lambda probe to ensure that a suitable amount of air is supplied into the combustion zone. The control unit is very often equipped with pre-settings that are activated when the boiler starts up and at different output levels (modulating control), for example, it can be pre-set for low, medium and high output, respectively. The control unit is of high importance. Precise control is important to obtain the optimal fuel economy and clean combustion. Finally, control is important for the sake of the easy operation of the boiler. Thus, the improvement of boiler control systems is an on-going process.

2.1.8 Flue gas outlet and chimneys
To obtain an efficient combustion, it is important that the flue gas outlet and chimney are dimensioned to ensure the ‘breathing’ of the boiler. If the chimney is blocked or wrongly dimensioned, it may lead not only to inefficient combustion but also in the worst-case scenario to the seepage of carbon monoxide [14].

The boiler must always be provided with flue gas ducts and chimney that comply with the requirements that the boiler manufacturer has stated and those of the relevant building regulations. These relate to both the diameter of the chimney pipe and the chimney height.
When the wood pellet boiler is being installed as a replacement for a previous oil-fired or gas-fired boiler, or when a loose pellet burner is installed to an existing boiler, attention must be paid to the fact that a wood pellet boiler demands a chimney diameter of no <15 cm, corresponding to a cross section area of 175 cm$^2$. To obtain the right exhaust conditions, it might be necessary to put up a new chimney, for example a steel chimney, or to rebuild the existing chimney for example by insertion of an insulated exhaust pipe.

Both the flue gas outlet from the boiler to the chimney and the chimney itself has to be kept clear of carbon depositions.

Problems can arise when house owners switch to a very efficient wood pellet boiler. Chimneys that have worked satisfactorily with old boilers are corroded by tarry soot when a more efficient boiler is connected. New, effective wood pellet boilers have a low smoke temperature. Thus, these boilers set demands just as high on the chimney in relation to insulation and diameter as an efficient oil-fired boiler. Tarry soot in the chimney is destructive and foul-smelling and may cause a chimney fire if not stopped in time. Tarry soot is a result of condensation that develops, when the water vapour in the flue gas is cooled down below approximately 50$\degree$C. Condensation happens in the coldest places of the chimney – typically at the top of the chimney or in the part that passes a cold, poorly insulated attic. The condensation is absorbed by the joints and bricks of the chimney and dissolves the carbon it meets. The dissolved carbon then migrates through the walls of the chimney. After some time, brown and black–brown discolorations will be visible on the outside of the chimney and in the attic at the horizontal divisions.

The reason for the carbon layer is typically a combination of a poorly insulated chimney, low flue gas temperature and incomplete combustion. When closing the air supply, the fuel lasts longer, but in return unburned flue gasses will settle in the plant and in the chimney as carbon deposits. When the air supply is shut off, the flue gas speed will decrease and the water vapours in the flue gas will stay in the chimney and mix with the unburned flue gasses. When this has happened, it is often seen in the chimney as a layer of carbon with a glossy surface (shining soot).

To prevent condensation, the chimney can be insulated on the inside by lowering an insulating interior into the chimney or casting an insulating interior inside the old chimney. It is also possible to lower a steel-lining into the chimney. Installing a chimney liner results in a chimney with a smaller diameter [15].

### 2.2 Safety requirements regarding back-burning

Preventing burn-back into the feed auger and storage hopper is a major safety concern for pellet-fired equipment. Burners and stoves can (and should) be equipped with a number of independent safety systems such as:

- A sprinkler system.
- A drop chute into the combustion chamber.
- A thermal sensor in the feed system.
• An airtight fuel storage hopper.
• A double auger feed system with a firebreak between the two augers.

2.3 Emissions

Emissions from residential wood burning appliances are in general influenced by combustion technology and process conditions and by fuel properties. Current appliances with low emission levels tend to have a clear delineation of primary and secondary air supply to maintain an air-starved condition in the fuel bed for output control, but still permit adequate burnout of combustible gases. Introducing secondary air under conditions of adequate temperature for ignition and burnout can markedly reduce emission levels, and various strategies have evolved to achieve this objective [16].

Good pellet burners show very low emissions levels of hydrocarbons and carbon monoxide. However, NO\textsubscript{x} emissions are significant despite the rather low nitrogen content in the pellets. In fact, the conversion of fuel nitrogen to NO\textsubscript{x} is in many cases close to 100% (Fig. 9).

The amount of excess air in the secondary zone is not only of importance for carbon monoxide (CO) and unburnt hydrocarbons (OGC), there is also a trade-off between these emissions and the emission of nitrogen oxides (NO\textsubscript{x}): too little air will result in increased emissions of CO and OGC, but will keep the amount of NO\textsubscript{x} in the flue gas small; with greater excess air, more NO\textsubscript{x} will be released from the burner. Since the emissions of NO\textsubscript{x} usually increase as the emissions of unburned hydrocarbons decrease (Fig. 10), the challenge is to balance efficient NO\textsubscript{x} reduction with low emissions of hydrocarbons. In addition, particulate emissions from small-scale pellet combustion can be significant.

2.4 Efficiency

The efficiency of pellet combustion devices is typically within the range 60%–90%, but the final value is largely dependent on its design and on the fuel properties.

Figure 9: The conversion of fuel nitrogen to NO\textsubscript{x} in wood pellet combustion [17].
Three types of losses are inherent: (1) latent heat losses from the moisture in the flue gas, (2) losses due to unburnt fuel and (3) sensible heat loss in the flue gas.

Maximizing efficiency has traditionally been dealt with by providing a large heat exchange surface area relative to heat output. While this results in adequate efficiency for many applications, it does not address high levels of unburned hydrocarbons and carbon monoxide, which reduce efficiency and result in high pollutant emissions relative to conventional heating systems.

A major impediment to the design of good appliances has been the lack of commonly accepted test protocols for determining the emissions and efficiency of these appliances. It is only since the 1990s that consensus standards for these evaluations have been developed, and they continue to undergo refinement as more experience with their use is gained [18].

2.5 Certification

A burner must fulfil a number of technical requirements as well as meet tough emission standards [19]. In North America, the manufacturers have developed a safety certification standard for pellet stoves. Certification bodies typically use this standard together with additional in-house requirements. Underwriters’ Laboratories of Canada is in the process of developing a consensus standard for pellet stoves for that country. Requirements for residential central heating systems and
larger pellet equipment are covered in the CSA (Canadian Standards Association) standards that also cover firewood-fuelled systems, and do not address efficiency or emissions. The US exempts most pellet stoves from emission requirements due to their high excess air level.

3 Wood Pellet Stoves

Special kinds of stoves have been constructed to combust only pelletized material. Contrary to conventional wood stoves, pellet stoves are dependent on electricity for their operation. An electric fan controls the combustion process by varying the supply of combustion air. This results in low CO and C$_x$H$_y$ emissions. Particulate emissions are generally low and consist mainly of inorganic material in contrast to wood stoves where particle emissions are dominated by soot and tar. Pellet stoves are typically provided with small fuel storage, fuel feeder, combustion air blower, burner shell and a flue gas discharge system. They are equipped with a rather extensive control system. Figure 11 shows the principle of a pellet stove with a maximum nominal power output of 10 kW and a turn-down ratio of a factor of 4 (2.5–10 kW).

Pellet stoves work using the same basic principles as pellet boilers. The pellets are combusted in an integrated burner, which is similar to the ones used in pellet boilers. Most pellet stoves use a fall channel from the integrated or external storage to feed the pellets to the burner pot. Through openings in the bottom of

![Figure 11: Diagram of a typical stove [20].](image-url)
the pot the primary air and the hot air for the automatic lighting is supplied [21]. The secondary air is usually preheated through the mantel of the pot and fed by many small openings of the mantle. The aspirator supplying the combustion air for the stove is placed below the burner. Sometimes an additional fan is used to improve the heat transfer from the stove to the ambient air. To simplify ash removal, the pellets are combusted on a manually or automatically operated moveable grate plate allowing the ashes to fall down in the ash container [22].

The fuel hopper is filled from the top. The burning time with a full hopper at nominal power output is in the order of 6 h. For transport of the fuel to the burner, a fuel-feeding system is used. The speed of the feeder is related to the heat demand. The burner of the stove consists of a shell-like pot in which the pellets are burned. Combustion air is drawn through slots in the inner wall of the shell by means of an exhaust fan, which reduces the pressure in the combustion chamber. The flue gases are discharged at the top of the combustion chamber and in this example flow down towards the chimney constructed in the bottom of the stove, passing through a heat exchanger on the way. Room air enters the stove near the bottom of the unit and leaves the stove at the top.

References