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A Wood-Burning Conversion Unit for Household Furnaces

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FOREWORD

THE wood-burning unit described in this bulletin is the fruit of cooperative research. Six years ago the Station joined with other forestry agencies to form the Marketing Committee of the Connecticut Forest and Park Association. The committee had concentrated its efforts on developing new markets for the low-grade material which should be taken out of the forest in the form of improvement cuttings. Some of the subjects investigated were the use of hogged wood for fuel, improved methods of fuelwood production, the preservation of fence posts, improved heating equipment using wood for fuel and the production of charcoal. The Station has worked on or cooperated in numerous phases of this broad study, but the work of most value to the current project was the development of a portable charcoal kiln, described in Station Bulletin 448. The reason is obvious, for charcoal is produced by the slow combustion of wood.

During the past summer, with a fuel crisis impending, the Marketing Committee helped to organize the Northeastern Wood Utilization Council, made up of research workers in forestry and allied fields from New England and adjacent areas. It was hoped that, by pooling ideas and coordinating effort, satisfactory wood-burning equipment could be devised before winter, especially for persons using oil furnaces. This hope was justified. At the first meeting of the Northeastern group, the past experience of the members was discussed and, as a result, several agencies began work with a helpful interchange of ideas.

The development of the conversion unit described in this paper was made possible through use of the facilities of the Department of Mechanical Engineering, Yale University, and the cooperation of Professor L. E. Seeley of that department. Valuable assistance was rendered by many agencies and individuals during the course of the work.

The principles made use of in the unit are not new, but the employment of these principles in an apparatus simple in design and built almost wholly of non-strategic materials is unique.

W. L. SLATE, Director.

A Wood-Burning Conversion Unit for Household Furnaces[1]

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IN THE light of the current fuel-oil shortage, which may last for a number of years, the necessity for the conversion of oil-burning heating equipment has been emphasized. In the popular mind conversion means the use of coal. It was believed, however, that wood might also be used as fuel to replace oil or coal under certain conditions. With this in mind it seemed advisable to investigate the possibilities of developing a wood-burning unit to replace the oil burner.

To accomplish this the Connecticut Agricultural Experiment Station initiated a project directed towards (a) a study of the general and specific problems involved in the combustion of wood and (b) the development of a device for conversion purposes.

To implement the study a cooperative arrangement was made with the Mechanical Engineering Department of the Yale School of Engineering. This provided the means for carrying on the work in a comprehensive manner.

Scope and Limitations of the Project

The urgency of the fuel situation obviously required that the major stress be placed on the second objective as the most timely contribution to public welfare and to the war effort.

The requirements, laid down in advance, which governed the development of the apparatus were as follows:

(a) It should provide a degree of comfort and convenience comparable to that of a hand-fired coal furnace. This means that the furnace capacity must be obtainable; that firing periods in severe weather must not be less than six to eight hours and, in mild weather, up to 24 hours; that the combustion must be clean and efficient at all times, and that control of combustion must be simple.

(b) It should require no major changes in the furnace itself.

(c) It should require little or no strategic material and be easily constructed without specialized labor.

(d) It should be adaptable to sizes of wood readily obtainable and to wood of varying degrees of moisture content from freshly cut to fully seasoned.

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[1] The term "furnace", as used in this report, includes both warm air furnaces and steam or hot water boilers.

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Method of Approach

The general background for the project was the experience of the several authors in the combustion of wood[1] and in the field of wood distillation[2]. Domestic and foreign literature was studied. Wood-burning equipment, principally stoves, which appeared to possess features that could be incorporated in the conversion unit were examined and, in some cases, tested.

Beyond this it was necessary to design and construct a conversion unit, within the limitations already stated, and to test it under as wide a variety of conditions as possible.

Two complete units were built. These were remodeled many times as the work progressed, principally to achieve control of air that would permit of low fuel-burning rates without the customary formation of tar, commonly called "creosote."

Many tests were run. Some of these were for the purpose of determining boiler output and efficiency under specific conditions while others were made to test new features or to furnish data on which to base rules of procedure during operation.

Much interesting and valuable information on the basic combustion of wood was secured during the course of the work. These data will not be included in this report which deals only with the construction and operation of the conversion unit.

Results

The unit described below has been used successfully at low-burning rates with both seasoned and freshly cut wood. It has been used also to obtain the full capacity of a medium-sized boiler. It is believed that, if constructed and operated as described below, it is an entirely feasible device to replace an oil burner and will require no more attention than a furnace hand-fired with coal. Moreover, it is simple and easy to build.

Adaptation

The conversion unit is directly adaptable to any furnace in which there is access to the heating surfaces by way of the ashpit which, in many oil burner installations, serves as the combustion chamber for the fuel oil. In warm air furnaces installation must be through the ashpit door opening. In steam or hot water boilers it may be either at the front, as for warm air furnaces, or at the side. In the latter case the wall of the ashpit must be pierced. By removing the grates and lining the ashpit with refractory brick the unit may be used for conversion from coal to wood. *For reasons of safety, only steam, gravity hot water and gravity warm air heating systems should be converted.*

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[1] Seeley, L. E. and F. W. Keator. Wood Burning Space Heaters. Mechanical Engineering, December 1940:864-870.

[2] Olson, A. Richard and Henry W. Hicock. A Portable Charcoal Kiln Using the Chimney Principle. Conn. Agr. Expt. Sta. Bul. **448**:483-514. 1941.

Preliminary Steps

The furnace should be clean and in good working order. The smoke pipe damper should be secured in the "open" position and the automatic draft adjuster and check damper fastened in a "closed" position. All joints should be inspected and, if necessary, filled with furnace cement to prevent leakage. The oil burner should be disconnected and removed. This is easily done and reinstallation is quite simple.

In oil burner installations the ashpit walls and floors usually are lined with refractory brick but, if they are not, this should be done. The floor area or hearth within the ashpit should be reduced to about one square foot. This is done by erecting a wall of uncemented fire brick as shown in Figure 4A.

CONSTRUCTION

The essential features of the conversion unit are a fuel chamber, a combustion tunnel, a built-in air duct system and a draft slide to control the air supply (see Figures 3A and 4D). With the exception of the cast-iron feed door and frame, construction is entirely of non-strategic materials.

The fuel chamber is 27 inches square inside and about 27 inches deep. It holds approximately one-tenth of a cord of wood cut in 2-foot lengths. An extension of the chamber to the front provides a housing for the draft slide frame (see Figure 3B).

The combustion tunnel provides a passage between the fuel chamber and the furnace ashpit. Its construction will vary with each installation.

When fully assembled the chamber, air ducts and combustion tunnel form the conversion unit. Hard fire brick in the sizes 2½ x 4½ x 9 inches (standard), 1¼ x 4½ x 9 inches (split), 2½ x 2¼ x 9 inches (soap) and 2½ x 4½ x 13½ inches (long brick) make up a major part of the material used. A few soft insulating brick, 2½ x 4½ x 9 inches, are used where special fitting is needed. It will be noted that two "soaps" laid side by side or two "splits" laid one on top of the other equal a standard fire brick in shape and volume and that a long brick is one and one-half times as long as a standard brick. An inspection of the measurements in Figures 1, 2 and 3 will show also that in many cases they are even multiples of some brick dimension or a combination of brick dimensions. In such cases the measurements need not be adhered to exactly. They are based on the quoted dimensions for brick which, in practice, vary somewhat in size. It is more important to use the right brick in the right place than to build to rigidly fixed dimensions.

These relationships among the several standard brick shapes are made use of extensively to avoid cutting hard fire brick, thus simplifying construction.

Building the Chamber Walls, Air Ducts and Combustion Tunnel

Figures 1 and 2 show the exact location and kind of brick used in laying up the first eight courses of the experimental conversion unit. These figures should be followed explicitly in shaping the air duct system and in building the four chamber walls, except where the combustion tunnel connects with the rear wall. Here the brick must be laid to fit the tunnel.

Bricks marked "t" in the above figures form the inner and outer walls of the combustion tunnel, the construction of which is described later.

To start construction of the unit, lay out line x-x on the cellar floor perpendicular to the ashpit opening (see Figure 1A). Lay out line y-y perpendicular to x-x and passing along the front edge of the ashpit opening. Line x-x will be the center line of the unit, the secondary air duct and the ashpit. Lay out lines a-a and b-b parallel to and 18 inches distant from line x-x. These lines define the outside of the side walls of the unit. Lay out line e-e perpendicular to x-x and 45 inches from the ashpit opening. This line defines the outside of the front wall of the unit. Lay out line d-d parallel to and 36 inches from e-e. This line defines the outside of the rear wall of the unit.

Now lay whole standard fire brick, numbers 1, 2, 3, 4, 6, 7, 9, 10, 11, 15, 16, 17 and 18 as shown, and cement to the cellar floor with fire clay (see paragraph below on laying fire brick). Lay whole bricks 19 and 20 with their ends 5¾ inches from the ashpit opening and their sides 2¼ inches from center line x-x. Lay whole bricks 21 and 22 with their ends abutting on 6 and 7 and their sides 2¼ inches from center line x-x. Lay whole bricks 23, 24 and 13 as shown. If the ashpit floor is not already lined, lay whole brick 25 just inside the ashpit as shown. Break standard fire brick to fit numbers 5, 8, 12, 14, 26 and 27. The above operations outline the chamber walls, draft slide housing and secondary air duct. Unnumbered spaces may now be filled in to complete course 1.

Now lay courses 2 to 5, inclusive, as shown in Figures IB, IC, ID and 2A, except for the bricks marked "t". Course 4 is laid entirely of brick splits. The space marked K in course 2 is the opening from the secondary air duct into the combustion tunnel. It should not be covered. Course 5 forms the chamber floor. The black rectangles are openings from ducts "a" and "b" into the chamber. The size and location of these openings are important and the dimensions given should be followed closely. See also Figure 3A.

The next step is to build the combustion tunnel. For this no specific instructions can be given because each tunnel must be shaped to fit the ashpit opening of the furnace which is being converted.

On the experimental unit, construction was accomplished by laying up double side walls (see Figure 4B and also bricks marked "t" in Figures 1 and 2) and casting a cap of refractory cement across the inner walls to serve as a cover. The cap was cast in place but was not allowed to bond as it should be removable for cleaning the tunnel and ashpit. Two holes were made in the cap for inspection purposes. When the walls and cap were completed, the holes in the cap were covered with a loose split brick, and flake asbestos was tamped in between the outer and inner walls and mounded over the cap as shown. This provided a tight seal and also insulated the tunnel. The inspection tube, made of a piece of one-inch iron pipe and a pipe cap, was then inserted. The location of this tube is shown diagrammatically in Figure 4B and indicated by arrows in courses 5, 6, 7 and 8, Figure 2.

The following points and suggestions will be found useful in constructing the tunnel:

High temperature insulating brick should be used in place of fire brick wherever special fitting is needed in the tunnel structure. These bricks are soft and spongy and may be shaped with a knife. They are also rather fragile and will not stand rough handling. They will be found particularly useful in fitting the tunnel to the ashpit and for the tunnel walls through which the inspection tube is inserted. By filing teeth in the end of the iron pipe, the latter may be used as a "core drill" to cut a hole through the soft brick.

The tunnel should be about 7 inches square, inside, as it leaves the chamber. It need not be the same shape throughout its length but its minimum cross-sectional area should not be less than 50 square inches at any point.

After completing the tunnel, lay courses 6, 7 and 8 as shown in Figure 2, B to D. Seven additional courses will be needed to complete the chamber. Diagrams for these are not shown. Course 9 spans the tunnel and is the first continuous course in the chamber walls. In laying course 9, first span the tunnel with a whole long fire brick and then place a piece of standard fire brick, 2¼ inches long, at each end of the long brick. Complete the course with whole standard fire brick. If this procedure is followed for course 9, courses 10 to 15 can be laid entirely of whole standard fire brick and "break joints" properly.

Brick used in the chamber walls should be well laid in fire clay of a medium creamy consistency. Dip the brick in water and then in the creamy clay before laying and then press firmly into position. There should be no surplus clay between bricks.

Brick forming the air duct system should be cemented tightly except for those in the layer which forms the floor of the chamber (see course 5, Figure 2A). These should be laid in place and wedged with small pieces of brick to facilitate replacement of any that may be broken. As the duct system is built up, fine sand should be brushed into crevices and voids as a seal. The side walls of the chamber may be built to any desired height but, for ease of loading with fuel, the top tier of brick should not be more than about 38 inches, or 15 to 16 courses, above the cellar floor. Two bricks cemented to the chamber wall at either side of the combustion tunnel (see Figures 2D and 3B) act as bumpers and prevent blocking of the tunnel with wood. After the chamber walls are completed and have thoroughly dried out they should be given a wash coat of very thin fire clay, both inside and outside, to seal leaks.

The side walls of the chamber should be insulated. This may be accomplished by using a double wall with dead air space or by the application of standard insulating materials directly to the chamber walls. If the double wall method is used, the air space should be closed at the top but vented near the floor. Common red brick may be used for the outer wall which should be "tied" into the chamber wall. This may be done by allowing an occasional fire brick to protrude endwise from the chamber wall and "locking" the red brick wall to it as the latter is built up.

The drawings show an extension of the chamber at the front for a distance of 9 inches (see Figures 1, A to D, 2A, 3A and 3B). The purpose of this is to provide a housing to which the draft slide frame may be fitted. The distance which this housing extends may be more or less than the 9 inches shown. It is important, however, that the other dimensions shown in the above figures be closely adhered to and that the vertical face of the housing should be smooth and flat. Otherwise the draft slide, described below and shown in Figure 4, will not fit the housing correctly or function properly.

The draft slide frame is fastened to the housing with three hooks and three screw eyes. The screw eyes should be bedded in a crevice, made by chipping off the edge or corner of a brick, as the housing is built up. Inspection of the draft slide drawings will indicate the approximate location of the screw eyes.

A strong platform, built to span the housing, will protect the latter and facilitate loading the chamber with wood.

Building the Draft Slide

The draft slide consists of a frame of wood, a fixed panel and a movable slide, the last two items made of either very hard pressed wood-fiber board or very hard pressed asbestos board. Construction is very simple but requires considerable care as the control of the air supply to the unit is accomplished wholly by manipulation of the slide.

The wood for the frame should be a good grade of white pine casing stock which runs about ¾ inch in thickness. It is recommended that the pieces listed below be sawed accurately on a power saw to the width shown. The lengths indicated allow for trimming.

1 piece	5	inches	wide	by	25	inches	long
2 pieces	3	"	"	"	12	"	"
2 "	1½	"	"	"	11	"	"
4 "	1½	"	"	"	25	"	"

The thickness of the wood fiber or asbestos board should be from $\frac{1}{8}$ to $\frac{1}{4}$ inch. A sheet 12 by 44 inches will then make both panel and slide. About 8 feet of weather stripping will be needed. The most satisfactory type is the one made by sewing fabric around a cord to form a soft roll.

The wood frame should be built around the front of the housing. It should fit fairly snugly but be easily removable. A clearance of about $\frac{1}{8}$ inch on all sides is recommended.

Figure 4D shows the completed assembly. Figures 4E and 4F are horizontal and vertical cross sections, respectively. Parts A to I are of wood. Parts J and K are of wood fiber board or asbestos board. The dimensions shown on the above figures and on Figures 4G and 4H are for a housing $11\frac{1}{4}$ inches high (See Figure 3A) by $22\frac{1}{2}$ inches wide (See Figure 1C) with air duct openings located as shown in Figures 1A, 1C, 1D and 3A. Allowance is made for $\frac{1}{8}$ inch clearance between the housing and the draft slide frame.

In building, nail parts A, B, D, F and G together lightly with all the front edges flush. Fit C and E, (see Figure 4D, 4E and 4F). Then nail B and A to C, and D and A to E, but do not drive the nails home. Try the frame on the housing. If it fits satisfactorily remove C and E and assemble A, B, D, F and G securely with wood screws.

Next shape panel J according to the template in Figure 4G and lightly nail this panel to the back edges of parts D, F, B and G and again try the frame over the housing. *If housing, frame and panel are in correct position, relative to each other, there will be a clear passage through the openings in panel J into the three air ducts.* If this condition is satisfied, nail or screw the panel and parts C and E securely in place.

Now shape slide K according to the template shown in Figure 4H and place in position in front of panel J. Parts H and I hold the slide K closely in contact with panel J (see Figure 4F). They should first be screwed tightly in place and then the screw holes should be slotted so that H and I can be moved in or out to adjust clearance of the slide.

To complete the apparatus, cement the weather stripping to the back side of panel J, as shown by the dot-dot-dash line in Figure 4G, to prevent air leakage between housing and frame and from one duct to another. Leakage under the frame, due to unevenness in the cellar floor, may be sealed with fine sand.

After completion, the draft slide should be tested as follows: With the slide K moved to the left in a fully closed position, the opening into duct "b" through panel J should measure $\frac{3}{4}$-inch wide by $2\frac{1}{2}$ inches high, and the openings into duct "a" and the secondary air duct should be closed. With the slide K moved to the right in a fully open position, the opening into duct "b" through panel J should measure 1 inch wide by $2\frac{1}{2}$ inches high; the opening into duct "a" through panel J, 3 inches wide by 3½ inches high; and the opening into the secondary air duct through panel J, 3 inches wide by 1¾ inches high. A 5 percent variation in these measurements is permissable.

An alternate method is to have a metal draft slide and frame built and fitted to the housing by a tinsmith. The precautions cited above should be observed in making the metal slide and frame.

The draft slide should be kept in good working order at all times. This means that panel and slide should be in close contact and that air leakage be as small as possible. This is important.

The Top and Feed Door

The feed door, through which wood is loaded, forms a part of the top of the fuel chamber. *This door was especially designed for the conversion unit and arrangements have been made whereby it may be procured at cost through the Connecticut Forest and Park Association, 215 Church St., New Haven, Conn.*

It will be noted in Figure 3B that the top is in the form of an "A" roof with sides of unequal pitch. The cast-iron feed door and frame form the front side and a refractory cement[1] slab, the back side. The two sides of the roof rest on a ledge of reinforced refractory cement which is cast on the top course of brick in the chamber wall. This ledge also forms the gable ends of the top.

The top is so designed that the cement slab can be removed to provide access to the interior of the chamber and, therefore, it is not bonded to the ledge. In order that the several parts which make up the top may fit and also that there be a minimum number of forms[2] to construct, casting of the refractory cement is done in place.

No metal reinforcing material should be used in the slab, but a loop of 10-guage wire should be cast into each corner to facilitate removal. Provision should be made for an inspection port in the slab. A suggested location is shown in Figure 5, A and B. The ledge should be well reinforced with 10-gauge wire, especially at the corners and peak. After the cement in the ledge and slab has dried out, all surfaces should be given a wash coat of very thin fire clay to close the pores. The surfaces of all wood forms which come in contact with the cement should be heavily coated with paraffin. The floor form (see Figure 5E), on which the slab is cast, may be left in place and burned out.

The flange of the door frame should be sealed to the ledge with fire clay to prevent leaks. A flat strip of woven asbestos, ½-inch wide, should be cemented into the channel of the feed door frame with water glass to provide a tight seal. Joints between slab and ledge

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[1] Refractory cement is a product made to withstand high temperatures. After mixing with water according to the manufacturer's specifications, it may be cast and otherwise worked in the same manner as ordinary cement.

[2] Drawings of the forms are not shown in detail but the sketches E and F in Figure 5 should be helpful to the builder.

and between slab and door frame should be sealed with flake asbestos or fine sand. The slab should be insulated with a 2 to 3-inch coat of flake asbestos or by using block insulation 2 inches thick. The depth of the cast iron feed door is sufficient to provide for 1 inch of insulation and 1 inch of refractory cement (see Figure 5C). Insulation of the block type, 1 inch thick, is first fitted in, and then 1 inch of refractory cement is cast on top of it. Bosses on the inner door surface are tapped to admit bolts, the heads of which project into the cement holding the latter in place.

Procedure in Building the Top

First remove burrs and other projections from the outer surface of the throat of the iron door frame and cover this surface with five to six layers of heavy kraft paper, cemented together and to the metal by brushing with hot paraffin (see Figure 5C). The paper will burn away allowing for expansion of the iron when heated.

Next, brace the door frame in place on top of the fuel chamber wall as shown in Figure 5B. When the top is completed, the frame will be in this position with its side and front flanges supported on the cement ledge, the casting of which should be done in one operation. The door frame serves as a part of the form but the balance must be made of boards properly fitted (see Figure 5F). It will be noted in Figure 5B that the part of the ledge which supports the front flange of the door frame cannot be poured because the flange overhangs. Therefore, when making up the wood form, shape the front board but do not nail it securely to the rest of the form. When ready to cast the ledge, fasten the front form board in position and push cement in back of it until the space under the flange is full. Then nail the rest of the form to the front board and pour the balance of the ledge. After 24 hours the form may be removed.

The next step is to cast the cement slab in place. The ledge and the door frame will serve as side forms, but it will be necessary to build a floor form of wood (see Figure 5E) on which to pour the cement. Before casting, line the surface of the ledge with heavily paraffined cardboard, ⅛-inch thick, and place paraffined brick splits as shown. The cardboard prevents bonding of slab and ledge. Removal of the splits will provide sufficient clearance for removal of the slab, should this be necessary.

OPERATION

Control of Combustion

Conditions within the fuel chamber change as the wood is consumed. They will vary also with the moisture content, size and kind of wood and the rate of combustion. Behavior of the unit will undoubtedly vary considerably with the type of furnace, draft conditions and other factors. For these reasons it is impossible to specify rules for operation which will fit all cases. The best that can be done is to explain the control system and indicate what results may be expected under certain circumstances. Beyond this the operator will have to develop such precedure as his own conditions warrant.

The rate of combustion is controlled by regulating the amount of air admitted to the fuel chamber and combustion tunnel through the air ducts. Regulation is accomplished by moving the draft slide (see K, Figure 4D) which is so designed that air will enter the ducts in approximately the correct proportions for any given setting.

The following brief description of the combustion processes which take place and of the relation of the air supply to these processes should be helpful to the operator in handling his fire.

The air which enters the fuel chamber is known as *primary air.* It supports limited combustion within the chamber. This means that gases and vapors are formed but are not burned, or are only partially burned, before passing into the combustion tunnel. It is desirable that these gases and vapors be burned as completely as possible in reasonably close proximity to the furnace heating surfaces, i. e., in the combustion tunnel or in the ashpit. To accomplish this it is necessary that they be mixed with sufficient air to support good combustion. This is known as *secondary air* and is supplied to the gases in the combustion tunnel. See Figure 3A. The gases must also be at a temperature sufficiently high to burn after they are supplied with air.

Primary air is admitted to the chamber through two separate ducts called "a" and "b" (see Figure 3B). At medium and fast rates of burning, both ducts are open and air enters through the chamber floor at four points (see Figure 3A). At a low or maintenance rate, only duct "b" is open and air is admitted through the chamber floor at one point near the combustion tunnel. Secondary air is admitted to the combustion tunnel only when operating at medium or fast rates, i. e., when ducts "a" and "b" are both open. The draft slide is so constructed that the fire may be increased slightly above a maintenance rate without admitting air through duct "a".

Duct "b" should never be closed. It functions to maintain a "hot spot" near the entrance of the combustion tunnel where the gases are heated sufficiently to burn as fast as they are made. The inspection tube (see Figures 2 and 4B) through the tunnel walls affords a view of conditions near the "hot spot". *A strong glow or slight flame should be visible through this tube at all times when operating with air through duct "b" only.* If there is no glow or flame, the opening in the draft slide leading into duct "b" should be enlarged to admit more air through this duct. When air enters through both ducts "a" and "b", a flame is always visible through the tube. The intensity of the flame varies with the amount of air admitted through the ducts. At medium to high rates flame is also visible in the ashpit.

The experimental unit was found to be reasonably sensitive to increase or decrease in the air supply but sudden changes in the draft slide, from closed to wide open or vice versa, are not recommended. It is better to bring the fire up gradually and to check it in the same manner.

Starting the Fire

This is done in the same manner as for any wood fire. Paper and kindling are placed in the chamber near the tunnel, lighted and fed with dry wood in rather small lots until the chamber is well warmed up and the furnace approaches operating temperature. The draft slide should be wide open during this period, the object being to build up a good bed of charcoal. When this condition is reached the chamber may be loaded with wood.

Loading

Loading should be done only after the previous charge has reached the charcoal stage. Before loading close the draft slide to avoid emission of smoke through the feed door and keep the door open no longer than is necessary. It is advisable to have a supply of wood near the unit before starting to load.

If the previous charge has been nearly all consumed, a trough will usually be burned out over the air inlets in the chamber floor. In loading, first fill this trough with wood and continue piling in this manner until the chamber is about half full. Then pile in the opposite direction (see Figure 4C). The wood should be packed as closely as possible and for this a sturdy long-handled poker will be found useful.

Periods between refueling will, of course, depend upon the demands of the heating system. However, the operator can to some extent regulate the length of these periods. After a little experience, he will be able to estimate fairly closely the length of time required to reach the charcoal stage at different rates of burning and for different amounts of wood. This will enable him to time the charcoal stage to suit his convenience by varying the amount of wood in the chamber. Fire may be maintained by throwing in a few sticks from time to time but, if any amount of heat is desired, the fuel mass should be above the top of the combustion tunnel.

It is desirable to maintain a good bed of charcoal at all times. This means refueling before all the charcoal is burned out, and is especially important with green wood.

A Precaution

The unit operates on the principle of slow combustion and there is never quite enough air in the chamber for the gases to burn freely. *Therefore, do not open the feed door as long as there is still uncharred wood present in some quantity.* To do so will cause the gases to burn in the chamber, and this is to be avoided.

An inspection port is provided for in the slab which forms part of the chamber cover (see Figure 5A). This may be covered with a piece of sheet metal overlaid with a piece of glass, preferably of heat-resistant type. For inspection, the metal sheet may be withdrawn from under the glass permitting a view of the inside of the chamber without admitting air. (The glass and metal covers are not shown in the drawings). If all or a considerable part of the charge is black, there is still much uncharred wood. If it glows all over, the wood has been reduced to charcoal and the door may be opened. If there is some doubt about the presence of uncharred wood, open the draft slide for a few minutes. This will cause the charcoal to glow more brightly, offering better opportunity for inspection.

Behavior at Low and High Rates

The behavior of the unit varies considerably with the rate of combustion. At low rates, when air is admitted through duct "b" only, it functions like a charcoal kiln, the wood being slowly reduced to charcoal with a shrinkage of 30 to 50 percent in volume. Settling of the fuel mass will be fairly even although it may be slightly more pronounced over the opening from duct "b" into the chamber. The length of time required to char the wood cannot be definitely stated, but it will probably be from 8 to 16 hours. By continuing to use duct "b" only, the charcoal will also be consumed. Combustion of charcoal under these conditions will be very slow and refueling will probably not be needed oftener than every 24 to 30 hours.

If the draft slide is opened up, admitting air to the deep charcoal mass described above, much heat will be generated for a short time, but soon diminishes. The reason for this is, apparently, that a channel is burned in the charcoal mass. Through this channel air passes to the tunnel and ashpit without coming in sufficiently close contact with the charcoal to cause it to burn strongly. If the charcoal is kept pushed down over the air inlets, it will continue to burn strongly until consumed. However, this is a tedious process and it is better to reload with wood if much heat is desired.

At high rates both ducts "a" and "b", as well as the secondary air duct, are fully open and air enters the fuel chamber at four points. Under these conditions rapid combustion takes place and after several hours a glow is visible near the combustion tunnel and over the air inlets into the fuel chamber. Charcoal is apparently burned as fast as it is formed and, when the fuel mass is almost consumed, will be found only along the chamber side walls. A full charge of wood will last for only six to eight hours under these conditions. This rate of fuel consumption will be necessary only in the most severe weather.

Cleaning

The amount of ash from wood is quite small and cleaning is not a heavy task. However, it should be done regularly. The best time to do it is just before reloading, when it causes the least disturbance to the air supply to the chamber. Most of the ash will accumulate in ducts "a" and "b". Those in the former are raked out the front after removing the draft slide frame. Special openings are provided so that duct "b" and the secondary air duct can be cleaned from the side. An additional clean-out opening is provided at chamber floor level on either side. These clean-out openings are plugged with brick and sealed with sand when not in use. It may be necessary, at infrequent intervals, to remove the ashes which accumulate along the side walls. A simple raking tool for ash removal may be made by bending a piece of 2 by 12-inch sheet metal (any guage from 12 to 20 will do) into an L with legs 2 inches and 10 inches long and fastening the longer leg to a piece of broom handle.

The entire unit should be inspected frequently to locate any leaks that may have developed at the junctions of the several parts or in the parts themselves.

The heating surfaces of the furnace should be inspected from time to time and the fly ash removed. If the unit is properly operated there should be no tarry deposit on the heating surfaces or flues.

Wood

The unit will accommodate 2-foot sticks. Cordwood 4 feet long requires cutting only once. Five-foot wood may be used by cutting it twice into two 2-foot pieces and a 1-foot piece. The short pieces can best be used at the top of the charge where close packing is not important. A mixture of large and small sizes is desirable but sticks more than 7 inches in diameter (or its equivalent when split) are difficult to handle. The sticks should be reasonably straight.

On the basis of air-dry volume, the denser hardwoods such as oak, ash, hickory and black birch produce the most heat per cord and for these species a cord of seasoned wood is almost equivalent in heating value to a ton of anthracite coal. Lighter hardwoods such as basswood, aspen and gray birch contain more air spaces per unit of volume and their heating value per cord is relatively low. The softwoods (conifers) such as pine and hemlock are of comparatively low density but their fuel value is increased by the presence of resins and oils. None of the latter was tried experimentally.

Unseasoned Wood

Cordwood of oak, maple, ash, hickory and gray birch, cut within 10 days, was used successfully in the unit. No difficulties were encountered, although it was found advisable to maintain a thicker charcoal bed than was necessary with seasoned wood. Very good results were obtained with freshly cut gray birch, but the efficiency was probably not as high as for the denser species. The adaptability of the unit to green as well as seasoned wood is important in view of the very limited stocks of seasoned wood on hand for the winter of 1942-43.

CONCLUSIONS

Wood cannot be burned to advantage in the average household furnace because of the limited capacity of the firebox and insufficent room for the gases to burn out. Chimney losses are high and heating surfaces and flues often become fouled with tar.

The use of the conversion unit described makes it possible to operate a furnace with wood as fuel and obtain a degree of comfort and convenience comparable to that from a hand-fired coal furnace. Wood of any moisture content can be used and a low fire can be maintained without fouling the furnace and smoke pipe.

The principle of slow combustion has much to commend it to designers and builders of heating equipment for solid fuels, particularly wood. It has been employed extensively abroad to secure better combustion from these fuels but has found only limited use in this country. It could well be used to improve the design of wood-burning equipment which is needed in rural sections where wood is plentiful.

The use of wood to replace other fuels is a conservation measure especially in the present emergency. Unlike coal and oil, wood is a renewable resource. There are some problems involved in moving it from stump to consumer, but these are strictly local and do not affect the major transportation systems which are so badly needed to carry vital war materials.

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BILL OF MATERIALS

The following bill of materials shows approximately the kind and amount of each item needed to complete a conversion unit. Some items, such as refractory cement, fire clay and asbestos, come in units of fixed size and the amount shown is the least number of units that will be needed. Material for insulating the chamber walls is not specified. The number of insulating bricks indicated should be sufficient for the average installation.

For the Chamber Walls and Combustion Tunnel

Materials	Size or unit	Number
Fire brick		
Standard	2½ x 4½ x 9 inches	303
Soaps	2¼ x 2½ x 9 inches	22
Splits	1¼ x 4½ x 9 inches	34
Long brick	2½ x 4½ x 13½ inches	8
Insulating brick	2½ x 4½ x 9 inches	25
Pipe, 1-inch	2 feet	1
Cap for 1-inch pipe		1
Fire clay	50-pound can	2
Asbestos (flake)	100-pound sack	1

For the Top

Materials	Size or unit	Number
Cast iron door assembly		1
Refractory cement	100-pound sack	3
Block insulation, 2 inches thick (optional in place of asbestos on cement slab)	square feet	5
Block insulation, 1 inch thick (for door)	square feet	2¼
Brick splits	1¼ x 4½ x 9 inches	4
Woven asbestos tape, ½-inch wide	feet	8
Lumber for forms		

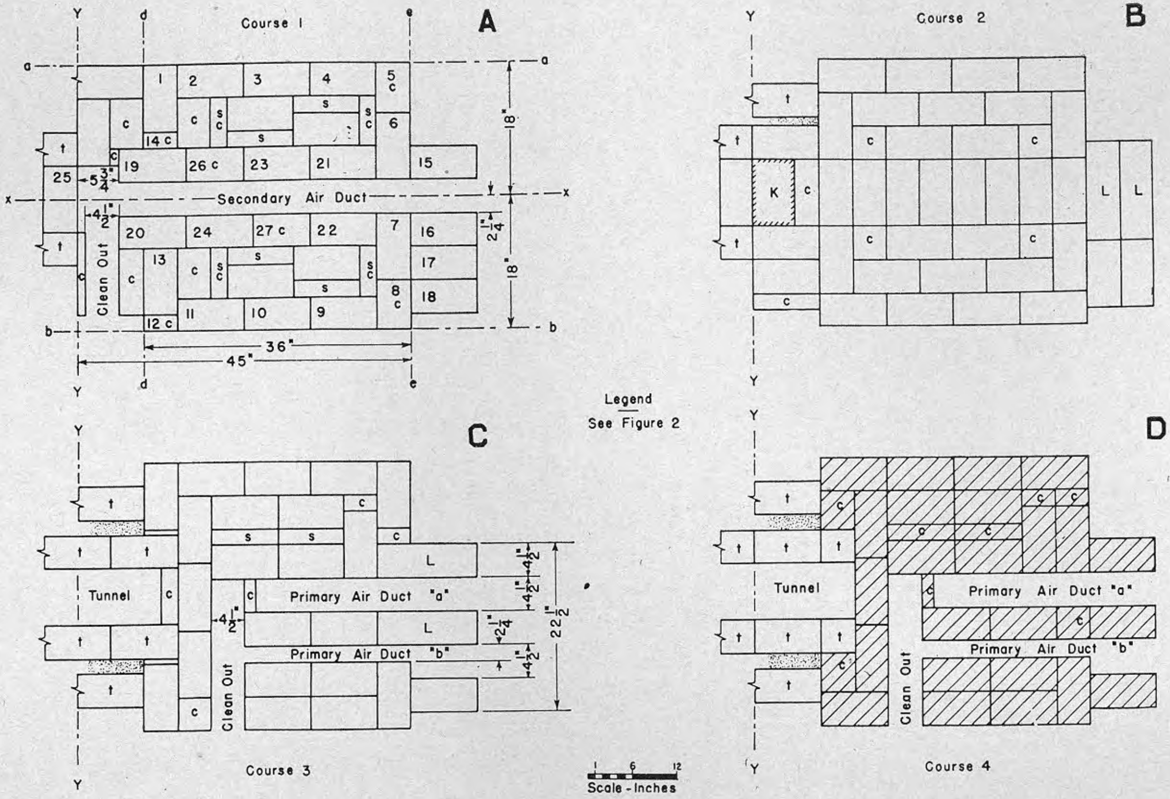

FIGURE 1.

A to D. Diagrams showing the location and kind of fire brick used in laying up the first four courses of the conversion unit. Note that course 4 is laid with brick splits instead of standard brick.

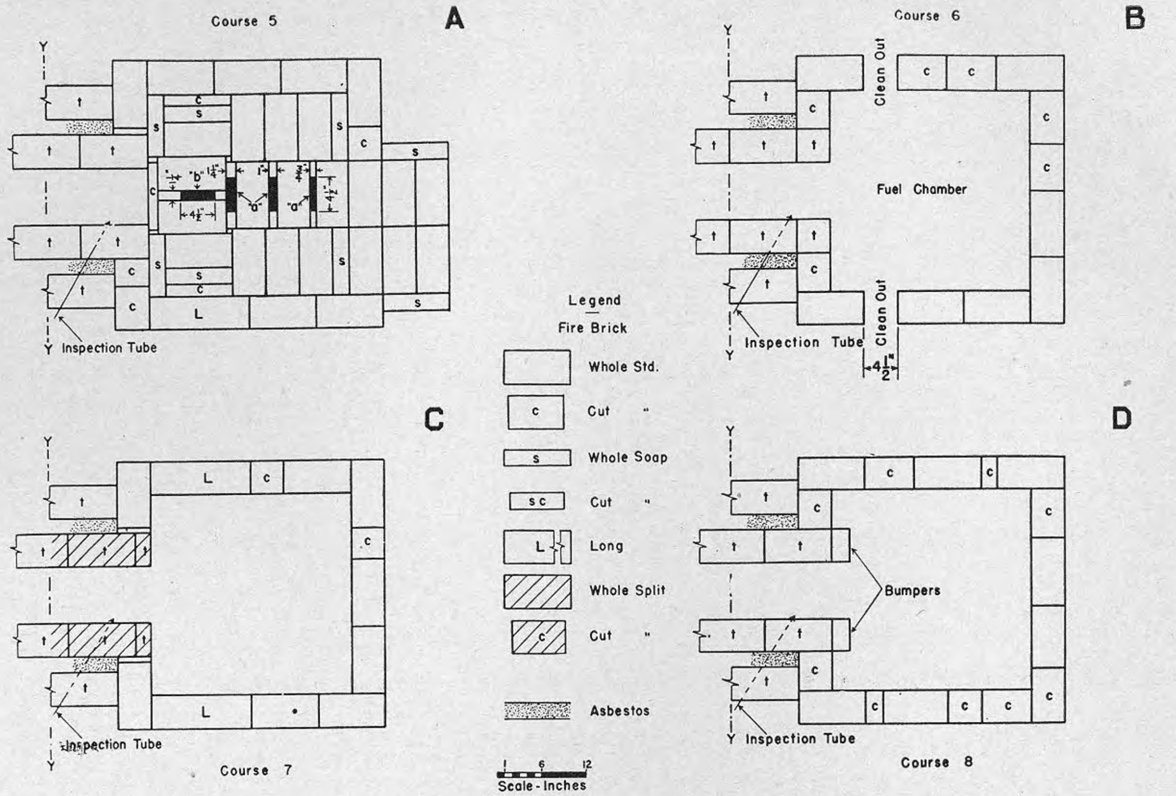

FIGURE 2.

A to D. Diagrams showing the location and kind of fire brick used in laying up courses 5 to 8, inclusive, of the conversion unit. The black rectangles shown in course 5 are openings in the chamber floor to admit air from ducts "a" and "b". All are 4½ inches long. The opening marked "b" is 1¼ inches wide. The openings marked "a" are, reading from right to left, ¾ inch, 1 inch and 1¼ inches wide, respectively.

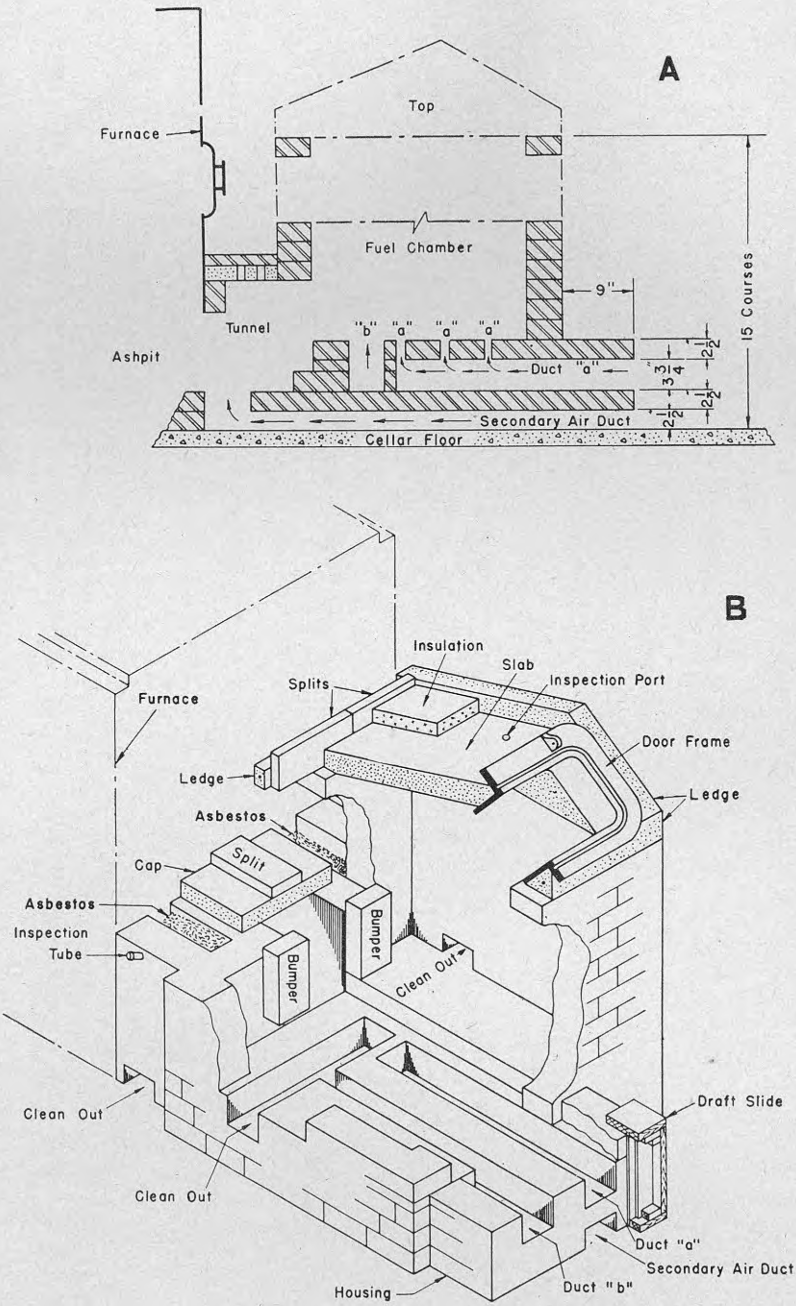

FIGURE 3.

A. Vertical cross-section of the conversion unit showing furnace, fuel chamber, combustion tunnel and a part of the air supply system.

B. Isometric drawing of the conversion unit with parts cut away to show the interior.

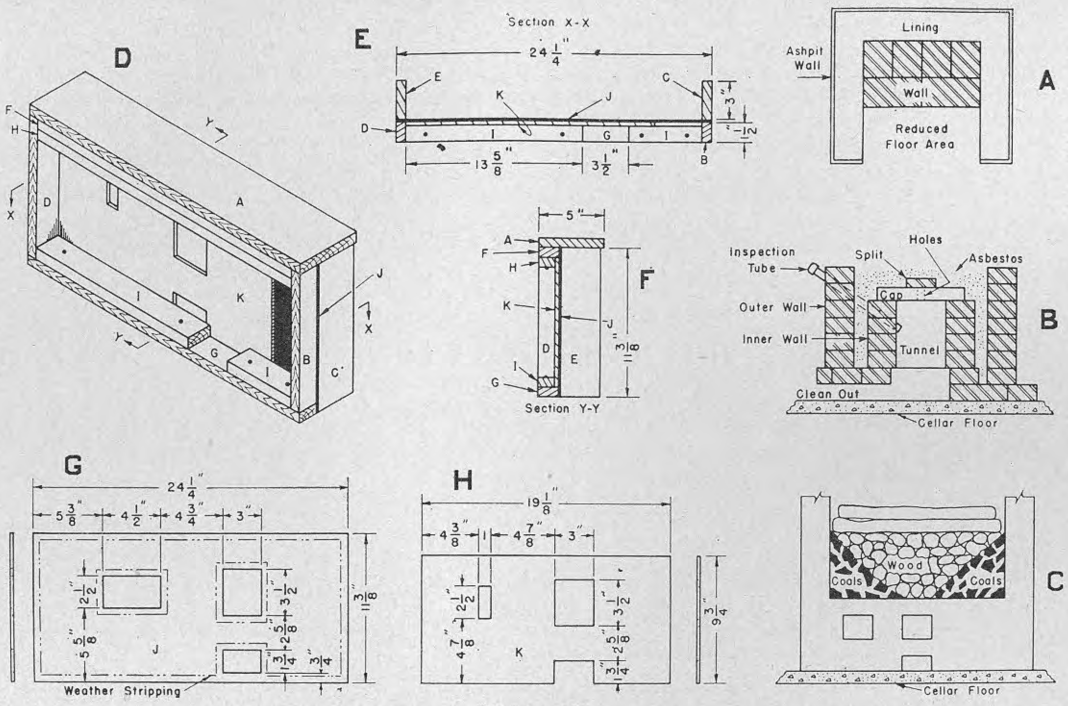

FIGURE 4.

A. Method of reducing the floor area or hearth of the ashpit by laying up a loose firebrick wall.
B. Vertical cross-section of combustion tunnel showing method of construction (diagrammatic).
C. Vertical cross-section of the fuel chamber showing method of piling wood.
D. Isometric drawing of the draft slide assembly.
E. Horizontal cross-section of the draft slide assembly.
F. Vertical cross-section of the draft slide assembly.
G. Front view of panel J showing location and size of openings and position of weatherstripping (- - —— - - ——).
H. Front view of slide K showing location and size of openings.

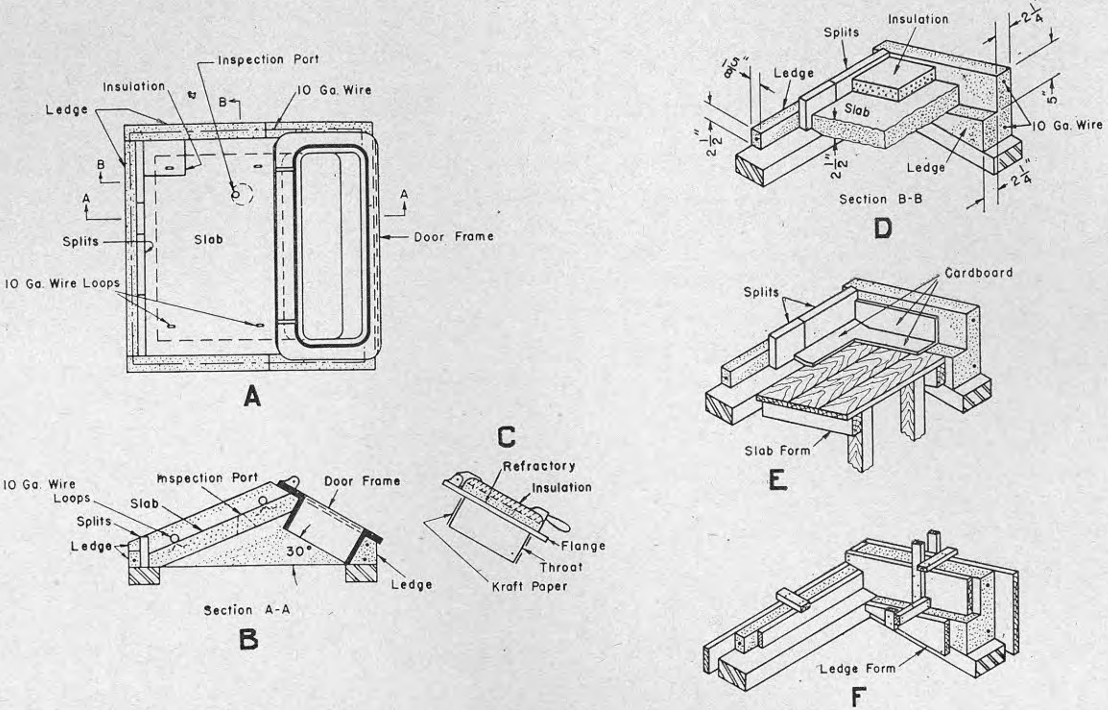

FIGURE 5.

A. Plan view of the top of the conversion unit showing cast-iron feed door frame, cement slab and supporting ledge.
B. Vertical cross-section of the top of the conversion unit. For location of the section, see A-A, Figure 5A.
C. Side view of cast-iron feed door assembly.
D. Isometric cross-section of an upper corner of conversion unit. For location of this section, see B-B, Figure 5A.
E. Isometric drawing showing construction of wood floor form for casting cement slab.
F. Isometric drawing showing construction of wood forms for casting the ledge.