

Rocket Mass Heater As-Built Drawings

Greenhouse 8" Heater

duct-heated raised bed

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DRAFT 3: For residential heaters, we publish as-built drawings for our favorite designs only after the project has proved itself by 1 full year of operation to its owners' satisfaction. Most of our greenhouse beta-testing sites had construction delays and/or did not report back after getting up and running. The current draft is based on successful heaters for other outbuildings, prototype tests, and preliminary reports.

If you use these plans for a greenhouse, the authors offer in-kind compensation for accurate reports of performance, including finished dimensions and good-quality photos and details. (Compensation may include project consulting, photo/contributor credits, access to future editions, or possible purchase of professional-quality photos). We are interested in both successes and failures, as long as they are built to plan.

If interested, please contact us at questions@ErnieAndErica.info



Materials Used:

- Firebrick - 48 full, 34 split (2 for air control)
- floor pad - 22 full
- burn tunnel - 26 full-size
- heat riser - 32 splits (skinny half-bricks)

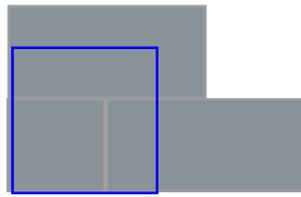
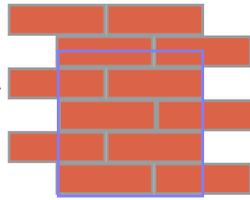
Insulation:

- Perlite - 1 bag (4 cu ft)
- Rock wool - 2 ft by 10 ft ("Durablanket" or Roxul)

Box casing: Choose masonry or wood:

Masonry bench:

- Brick: Figure about 7 bricks per square foot of box sides. For a 12' by 18" by 30" bench, 300 bricks for the sides, plus 140 to 200 bricks for top.
- Concrete masonry units (CMU's, or "cinderblock"): 8" by 16" faces give 0.8 sf per unit, so the sides of our 12' by 18" by 30" box could be built with about 50 CMU's. For a paver top, get another 30 square feet of brick, 2" pavers, or stones (30 12" by 12" units with tile saw, or 140 bricks).
- Lime or cement mortars: as needed to set bricks (about 1 cubic foot of mortar per 100 bricks, varies with brick and joint sizes, and experience/waste). To set and fill CMU's, about the same lbs of cement as CMUs.



Wood box: Lumber and/or plywood to frame and side the box, with at least 4" space between pipes and wood.

Example: a 12' x 18" x 30" (interior space) bench:
10 pcs 2"x6" x 12 ft for sides,
or 3 4x8' 3/8" plywood,
80 board feet 2"x4" (10pcs 8ft boards) for bracing

Fill and mortars:

- Mineral soil: approximately 2 yards fill dirt (50 cubic feet); more for longer designs.
- Clay - for sealing bricks and stabilizing perlite:
3 buckets (15 gal) clay slip, or 1 to 2 50-lb bags powdered clay (e.g. fire clay, mortar clay)

Metals:

- Barrels - 2 55-gal drums, 1 or 2 band-clamps, and 1 removable lid, cleaned of paint & debris
- Fiberglass woodstove gasket - 2 pieces, 72" length, flat woven style preferred: 1/4" to 3/8" size. (Optional metal heat shield: 7 ft by 3 ft)
- Wire mesh to support insulation - 3 ft by 4 ft

Ducting, stovepipe, or clay chimney liner:

- 8" interior diameter stovepipe / galv. ducting:
 - 20 ft of straight sections (in bench*)
 - 3* T's with 3 caps
 - 1 90 elbow
- *To fit building (not shown):
 - Through-roof kit suitable for roof (8" ID)
 - Straight sections from final cleanout to thru-roof
 - Insulated sections for roof/wall penetrations,
 - Screened chimney cap

Tools:

Layout and Prep:

- Tape measure
- Level (2' to 4' length)
- (Plumbline, square)
- (Cardboard, markers, masking tape)
- (pocket knife)

Carpentry tools

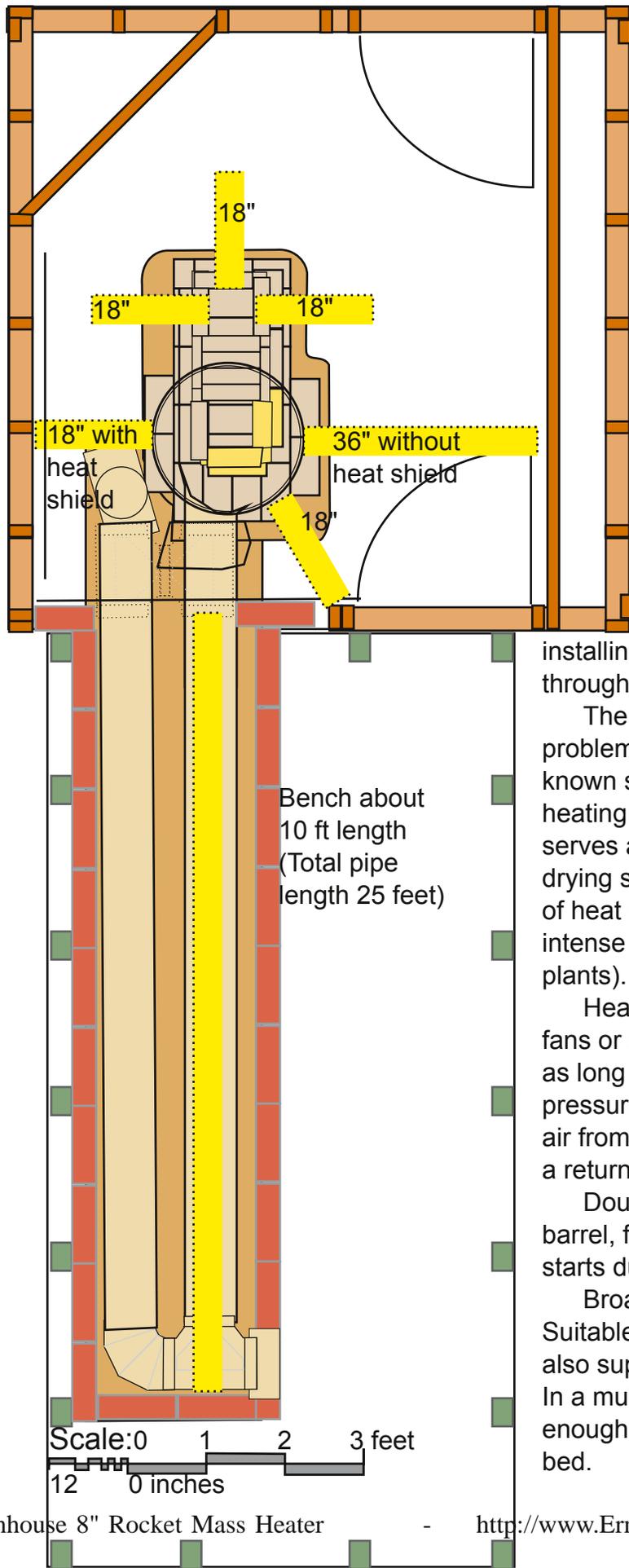
- saw(s), hammer,
- screws & screwdriver

Ducting tools:

- Tinsnips,
- crimpers or pliers,
- screws and/or foil tape to secure joints

Masonry tools:

- Wheelbarrow (mixing pan + hand truck)
- Buckets - 5 to 10
- Mason's trowel and/or float
- Bricksets, masonry saw, or tile saw,
- Mallet / handle of trowel
- (gloves, boots, dust masks / respirators)



Concept A:

- Combustion unit in dedicated space
- Doubled duct in bench
- Bench length 10-12 feet
- Total duct length 25-28 feet

The combustion part of the heater may be easiest to manage by building a wood or masonry fire-house or sauna as an addition to an existing greenhouse. This process can sidestep many common problems.

Many greenhouse membrane materials are highly flammable, and prone to melting and offgassing noxious chemicals as they burn. Calculating safe clearances for a temporary greenhouse structure can be a matter of trial and error, as can

installing conventional chimney options through a membrane roof.

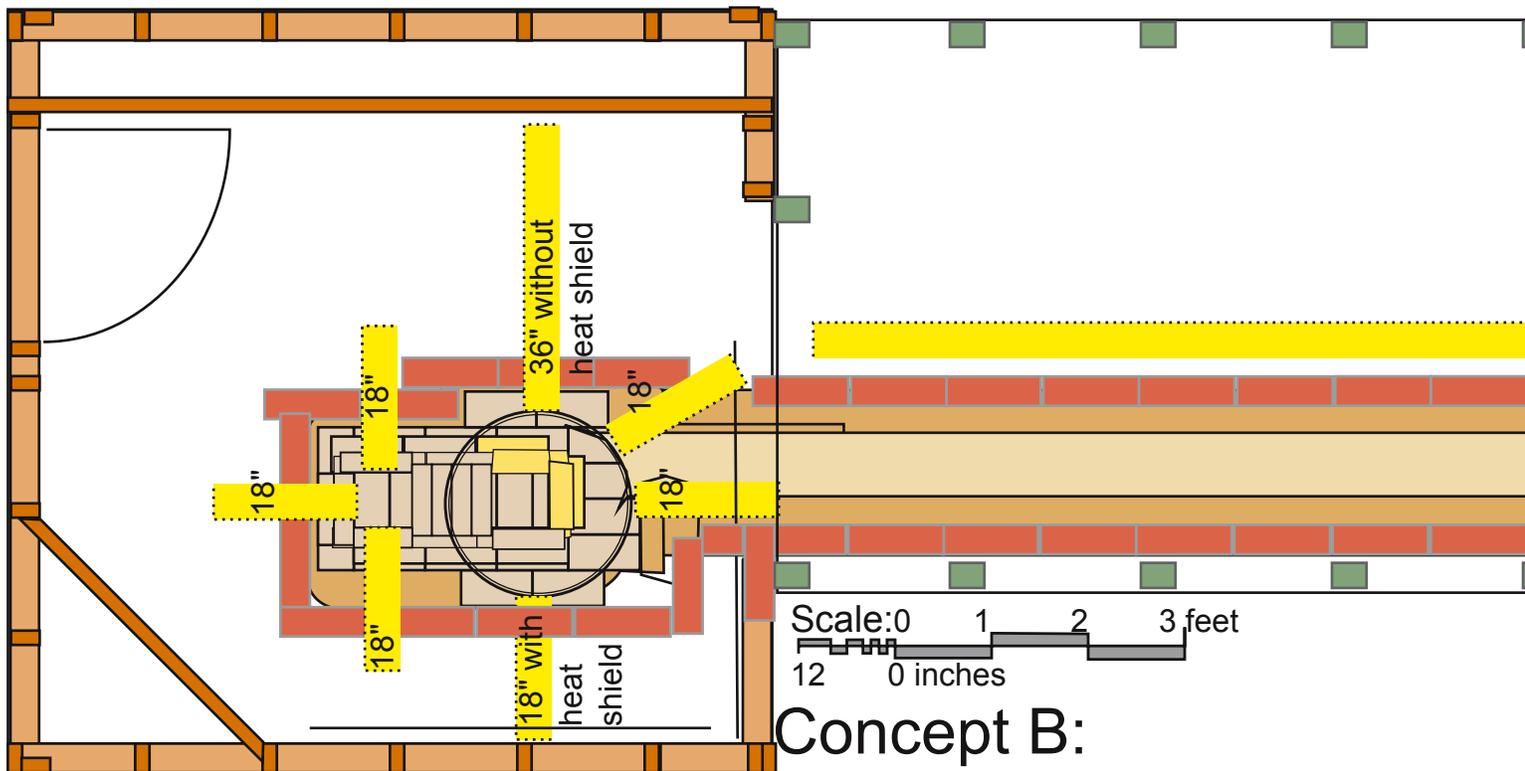
The separate combustion room puts these problems back in a more familiar context, with known solutions. The separation can reduce heating to the greenhouse proper, but it also serves as a potential wood-drying or herb-drying shed, and avoids the possible problem of heat spikes during extended firing (too-intense radiant heat can damage nearby plants).

Heat can be blown into greenhouse using fans or dedicated room-air ducting (not shown) as long as this does not create negative pressure in the fire room. A fan directing cold air from the greenhouse into the fire room, with a return vent up high, might work well.

Doubled duct brings exhaust back close to barrel, for self-priming draft (helps with cold starts due to damp soil).

Broad heated bench (at least 32" wide). Suitable for large trays or pots of plants; can also support shelving or a raised bed. In a multi-use space, this bench is also wide enough to be used as a table, cot, or guest bed.

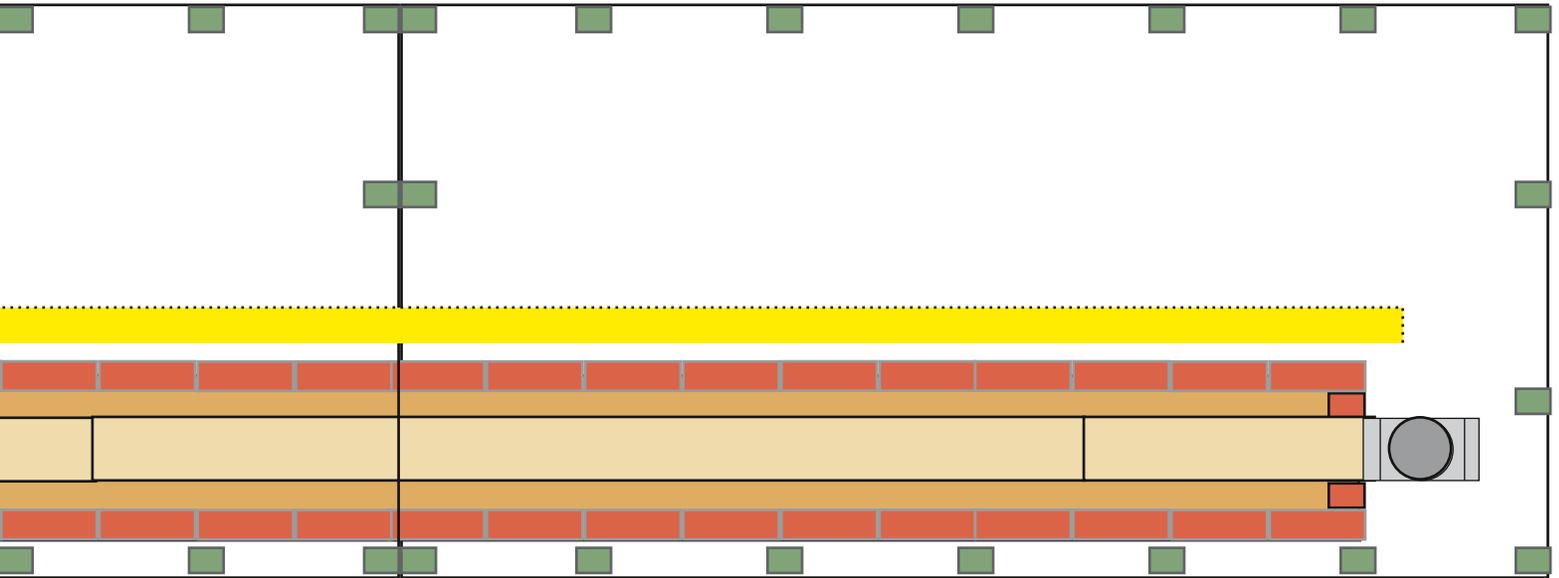




Linear bench: Single run of pipe in a 24" by 24" box.
 Bench length shown: 22 feet.
 (Shown with dedicated fire-house to illustrate clearances)

Differences in performance compared with version A:

- Heat gradient: the bench is hotter near the fire, cooler near the exit pipe.
 This can be an advantage for smaller operations that grow a variety of plants with different soil temperature needs, but a disadvantage for heating a large space evenly.
- Cooler exit chimney: Less wasted heat, but greater chance of chimney stalls during cold starts.
 The exit chimney should be inside the greenhouse, and painted black, to induce the best draft and overcome any cold-lock of moist air in the pipes. Priming the chimney with heat or a small fan may be necessary at times for cold starts (times when the mass of the heater is cooler than outside air).
- Thinner bench: This layout creates a skinnier bench, which may fit better in small greenhouses.
 For a large greenhouse with a central aisle, two heaters with this general layout could be installed head-to-tail for even heating.
- Cleanout detail: Where pipe exits bed and connects to chimney, a cleanout opening allows both maintenance and the option of priming (pre heating) the exit chimney. If it is not practical to create a cleanout opening below the bench level, a cleanout T can be located anywhere near the bottom of the chimney.



Concept C (below):

Entire system built into one box. Exit near barrel (see A for advantages of this option).
 Shown at 12 to 15 feet bench length; may use up to 20 ft length (40 feet of duct) in colder climates.

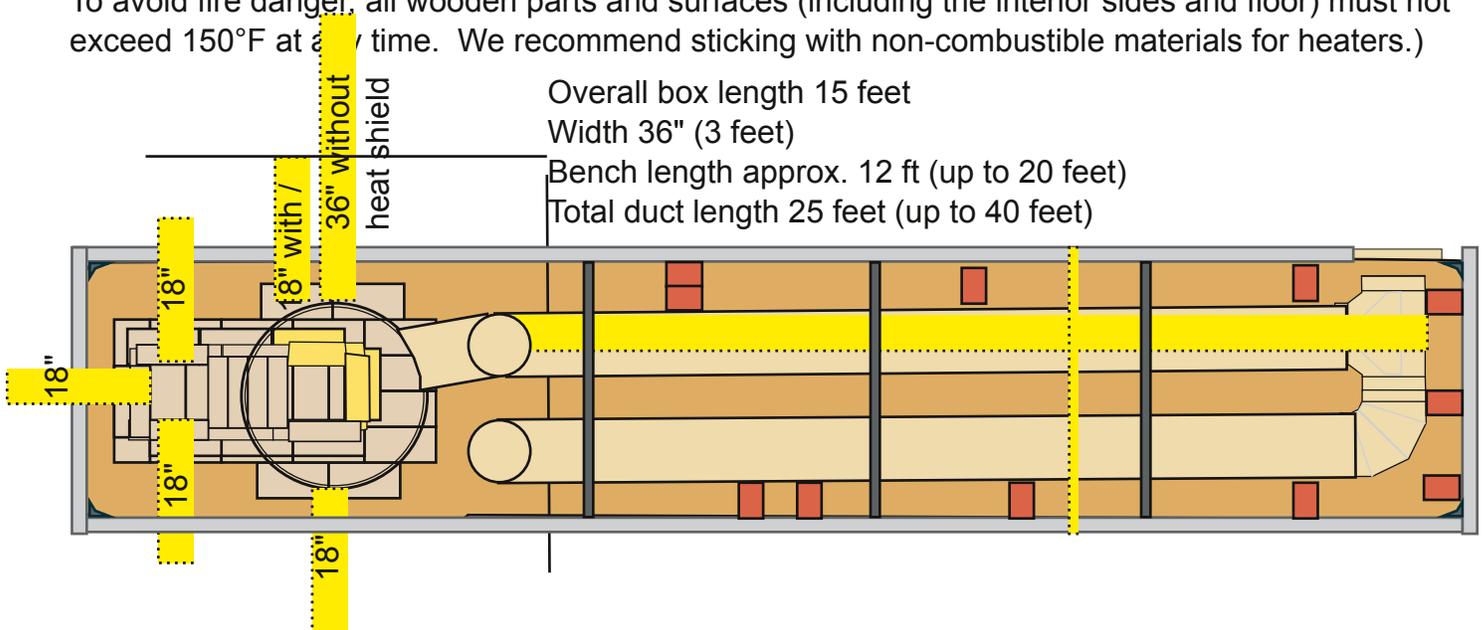
This heater is much like configuration A, but packed into a box which can be located within the greenhouse almost anywhere a chimney can be installed.

This sketch shows a damp-tolerant cement-board, such as is typically used for backing board in tiled shower stalls. Angle-iron supports the corners, with metal strapping around the middle to prevent sagging due to wet soil weight. (See Matt Walker's half-barrel-bell-bench designs on permies.com to reduce the soil weight further, or if you have more barrels than pipe available.)

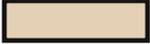
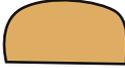
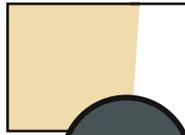
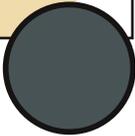
To make a narrower bench in a box, some people have prototyped using a super-insulated refractory firebox and smaller barrel. With super-insulated fireboxes you may experience hotter downstream temperatures than are typical for brick fireboxes, so plan for a high-temperature exhaust and/or some adjustment time to tweak the bench volume and planting depth to suit the actual heat output.

(Wood Box: Not recommended.)

We have seen and played with wooden box designs much like this. Some of them catch on fire. Many people are not aware that wood becomes more flammable at temperatures as low as 200°F. To avoid fire danger, all wooden parts and surfaces (including the interior sides and floor) must not exceed 150°F at any time. We recommend sticking with non-combustible materials for heaters.)



Rocket Mass Heater - Firebox Layout for 8" diameter exhaust channels

-  Brick (firebrick)
-  Insulation (2" perlite or 1" refractory wool)
-  Ordinary combustible walls (stick-frame e.g.)
-  Masonry - non-combustible (brick, stone, etc)
-  Earthen fill / adobe or cob in fire shed.
-  Wood framing - cedar or redwood preferred
-  Topsoil or planting trays
-  Stovepipe (inside bench may be galv. duct)
-  Cleanouts (barrel is also removable for cleaning)

Using an Architectural Scale:

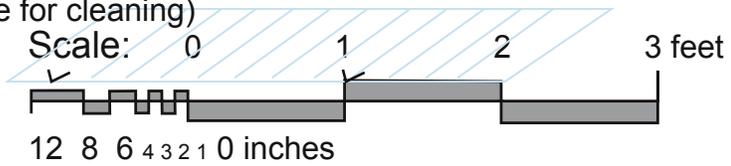
Dimensions and clearances are drawn to scale.

To find a measurement, take a dimension from the drawing and hold it next to the scale. A compass is particularly handy for taking quick measurements, or you can use a piece of paper, string, etc.

Say you want to know the barrel's width. Lay your scrap paper across the barrel. Mark a little line where the barrel starts and stops.

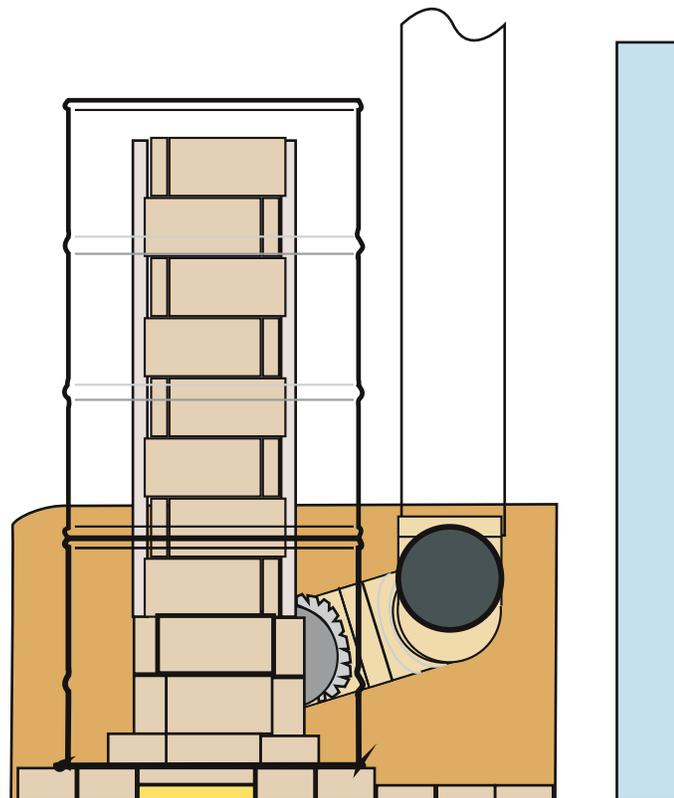
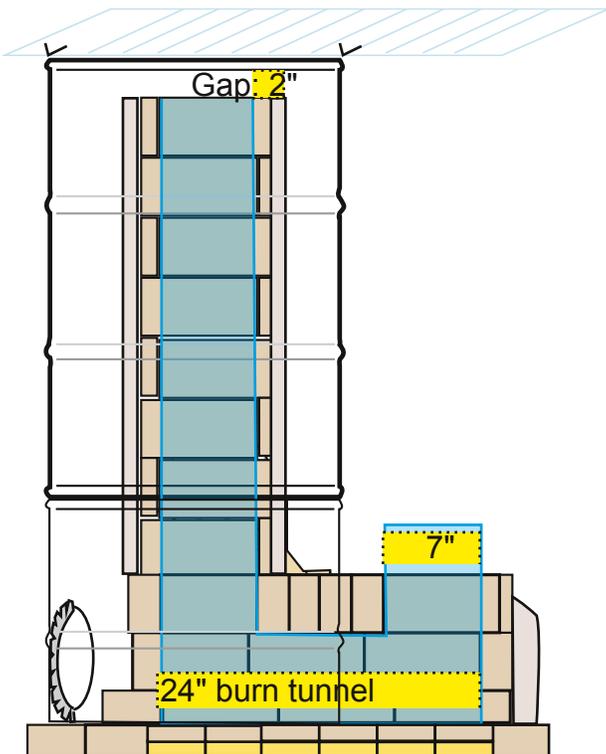
Now hold that mark against the scale. It's almost 2 feet, but not quite. So line it up with the 1 foot mark, and let it hang off past the zero to read feet plus inches.

It's about 2'10" or 2'11" - 22 or 23".

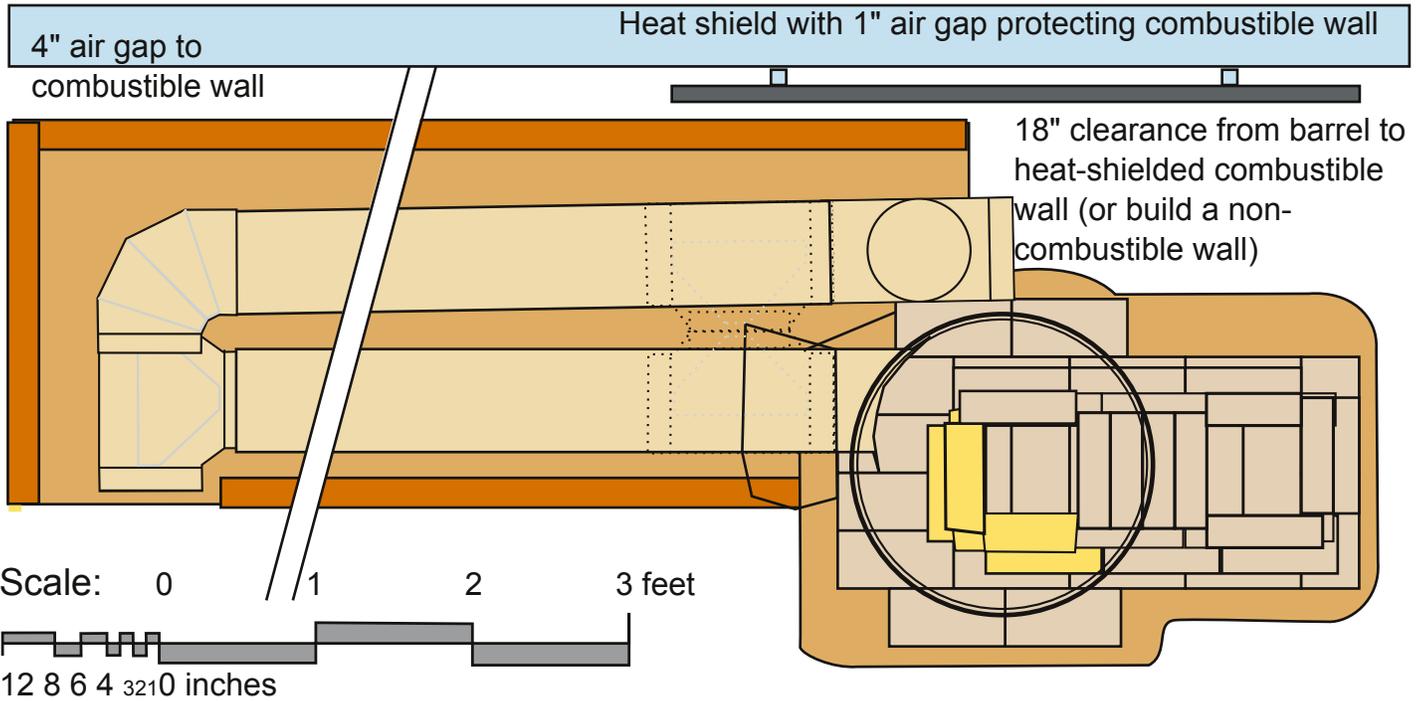
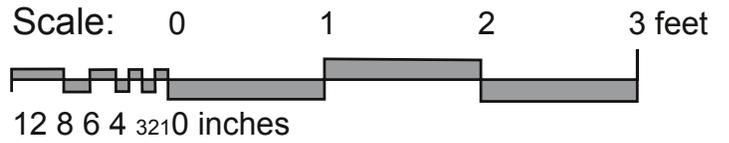


Front View - Combustion Unit

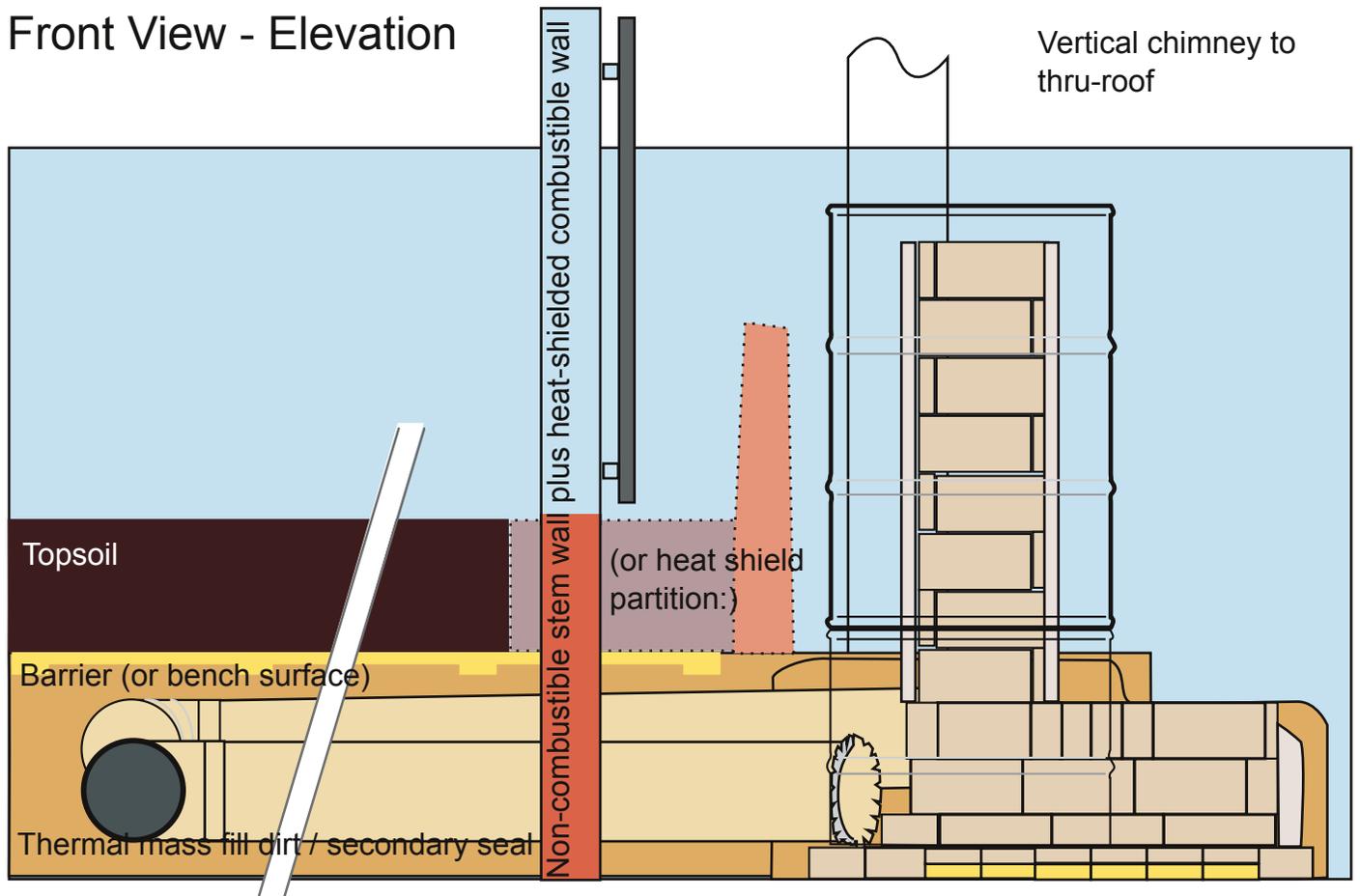
Side View - End Elevation



Top View (Plan)

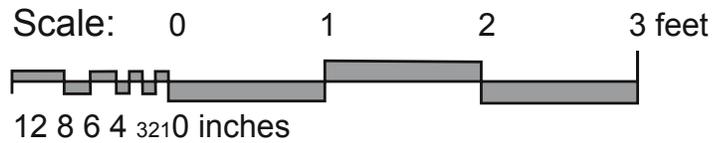
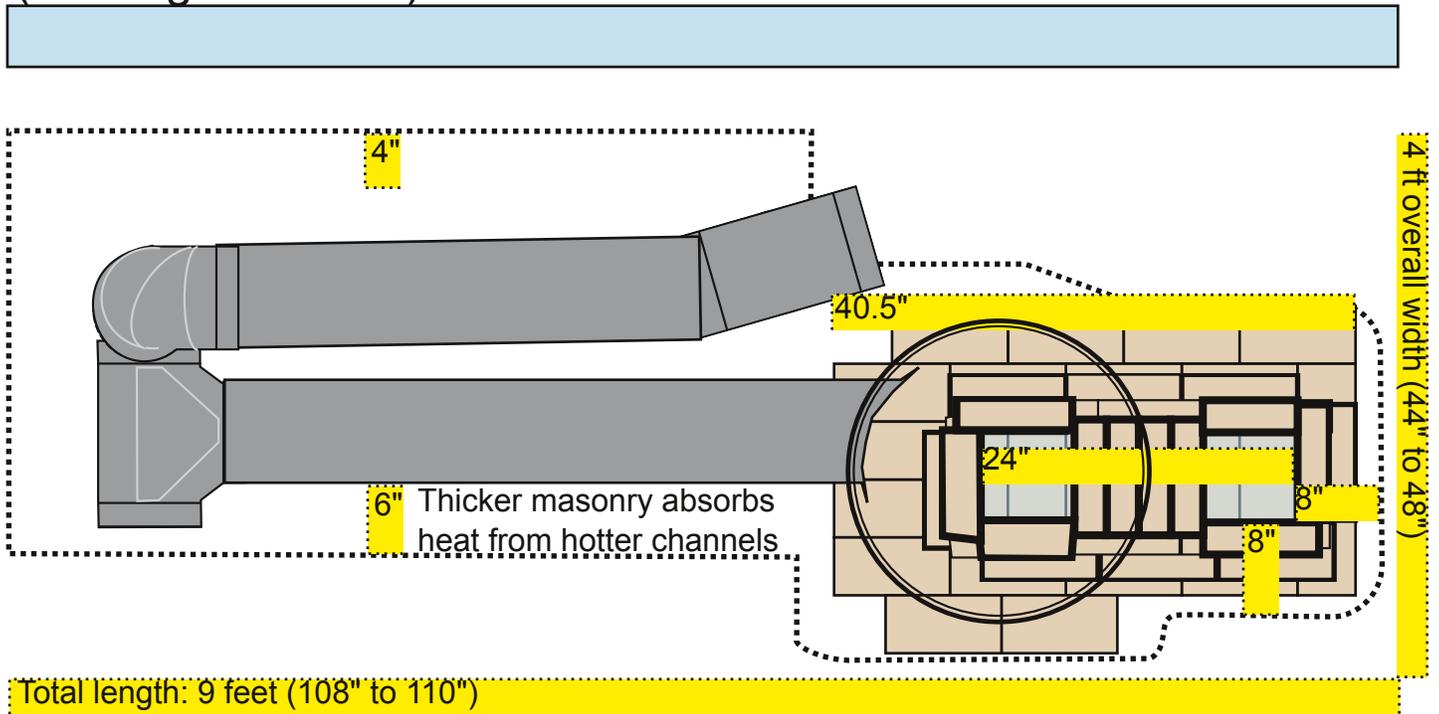


Front View - Elevation

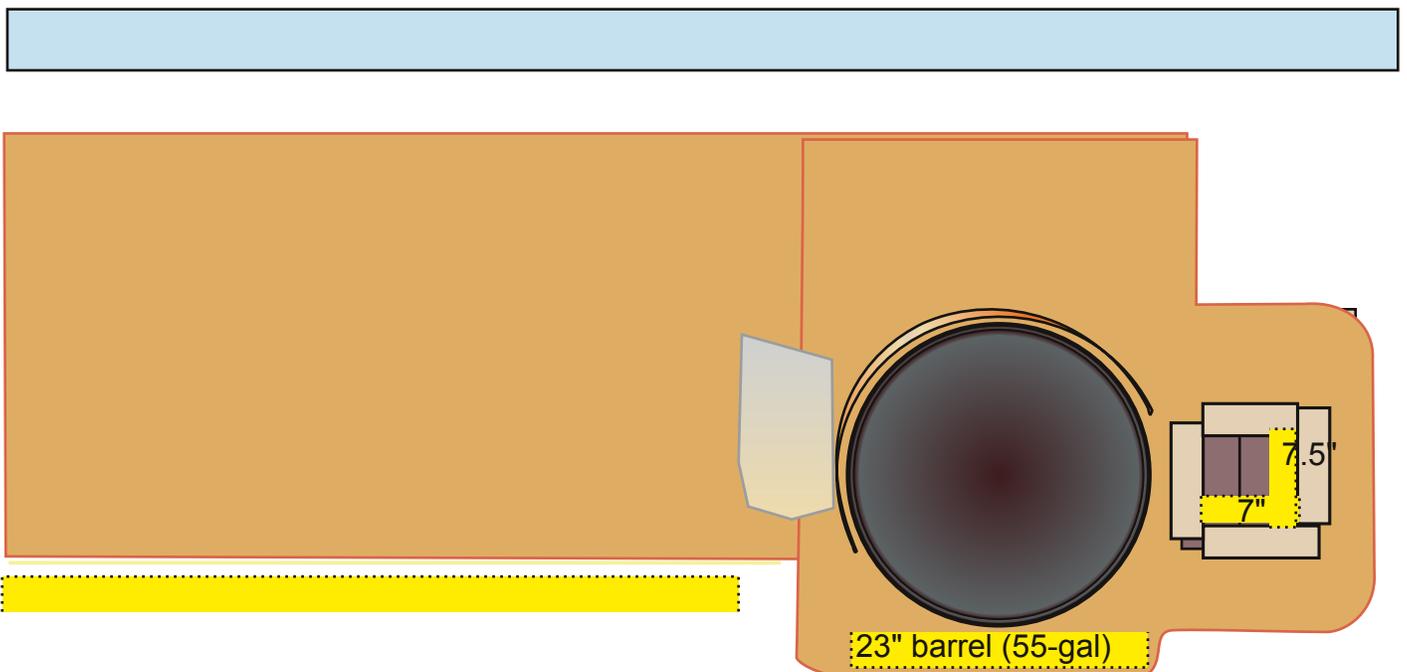


Top View (Plan)

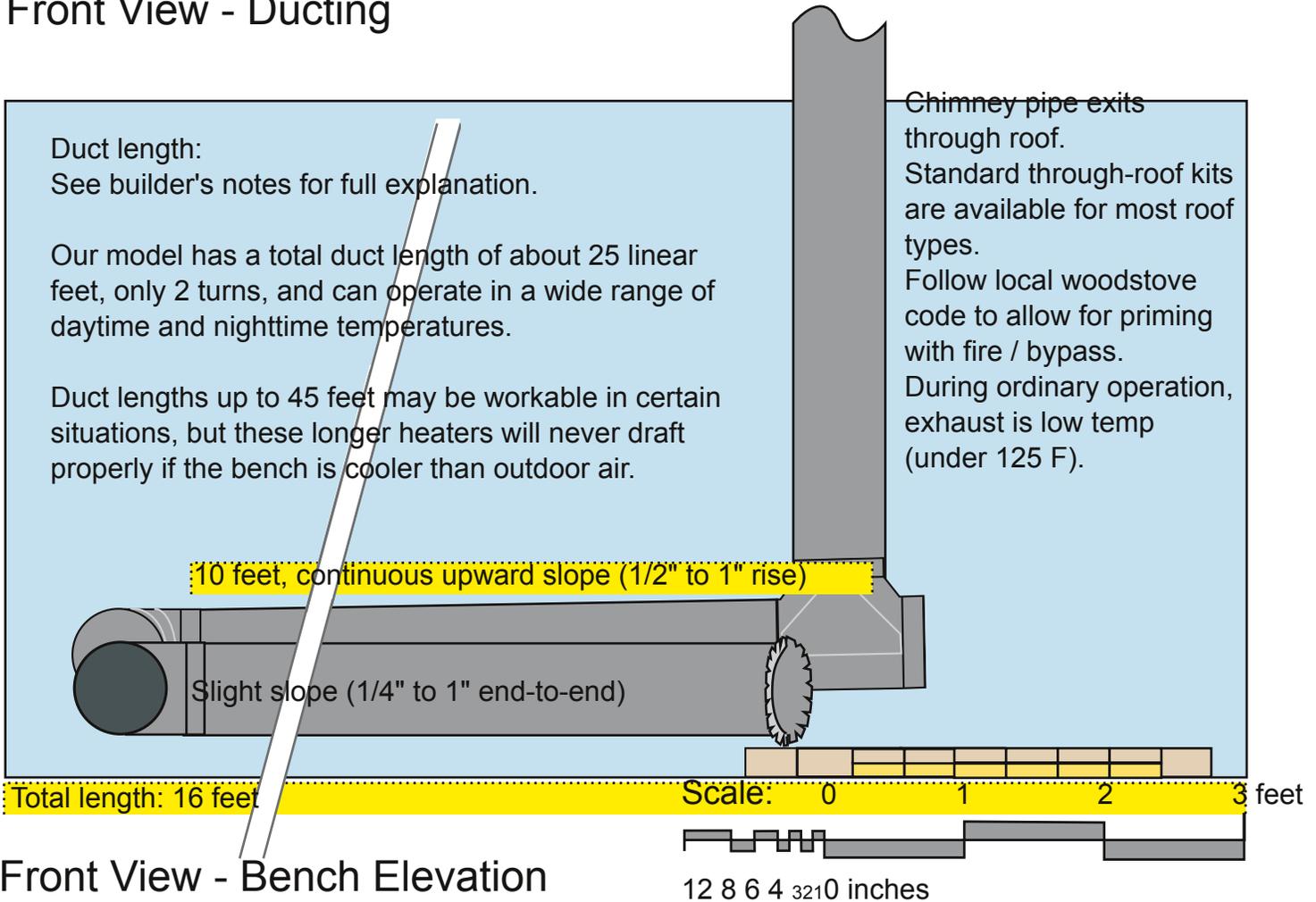
Internal Channels (Ducting and Brick)



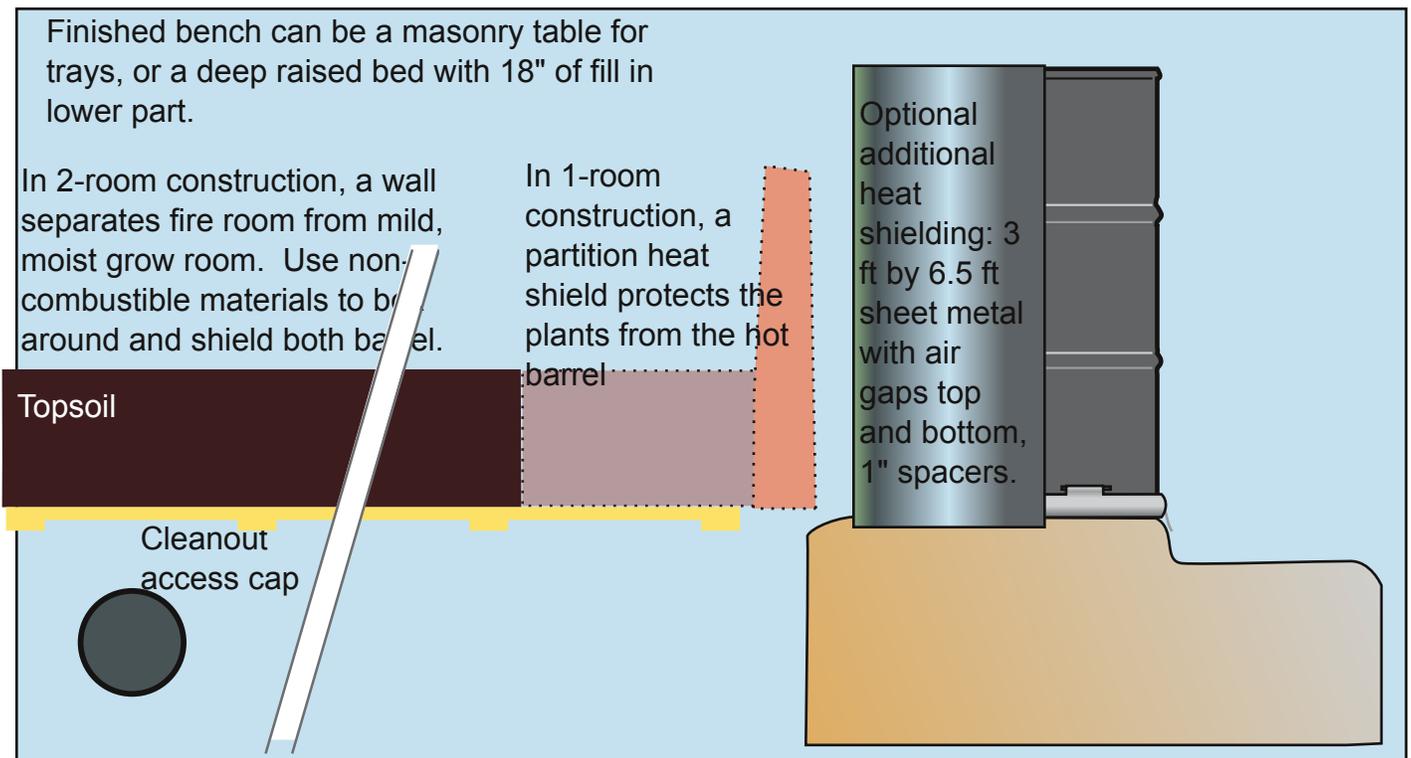
External Appearance



Front View - Ducting



Front View - Bench Elevation



Floor is existing mineral soil, compacted gravel, or 4" concrete pad. Insulate below if possible.

Brick coursework:

Interior dimensions:

The burn tunnel is 24 inches long.

All brick channels are 7" x 7.5 inches:

- 7.5 inches wide, by
- 7 inches tall (2.5" plus 4.5"),
- 7" long openings at fuel feed and heat riser.

If your brick courses are not exactly 2.5" by 4.5" tall, find the closest height you can get with your bricks, then adjust width to give the same area (50 sq. inches).

*The length of openings will stay the same as the burn tunnel height (7" in our case), and the same as the length of the two cut-off bricks beside the bridge.

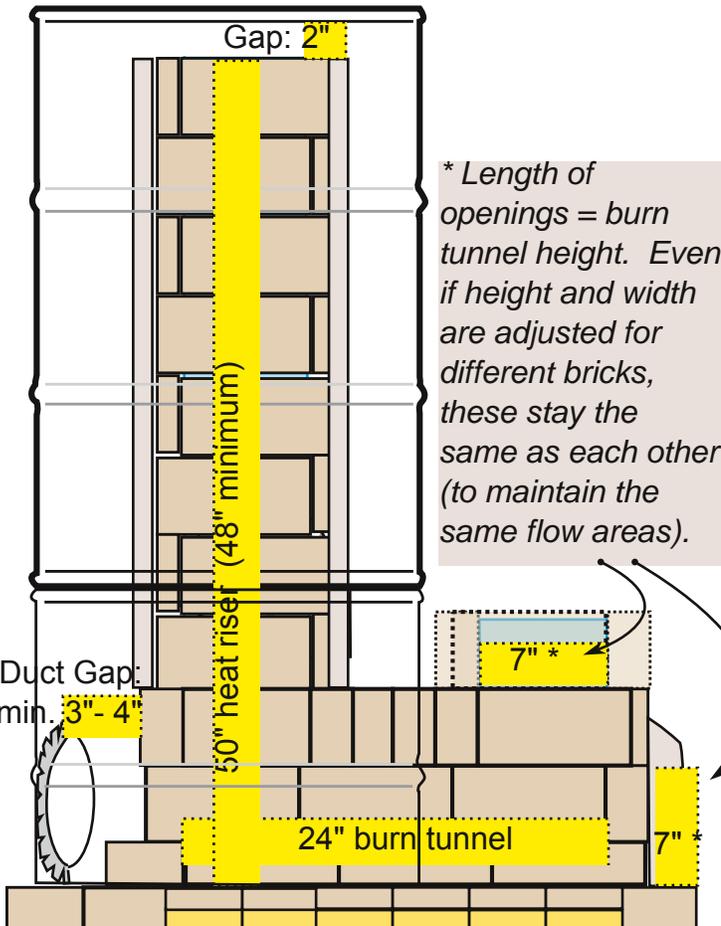
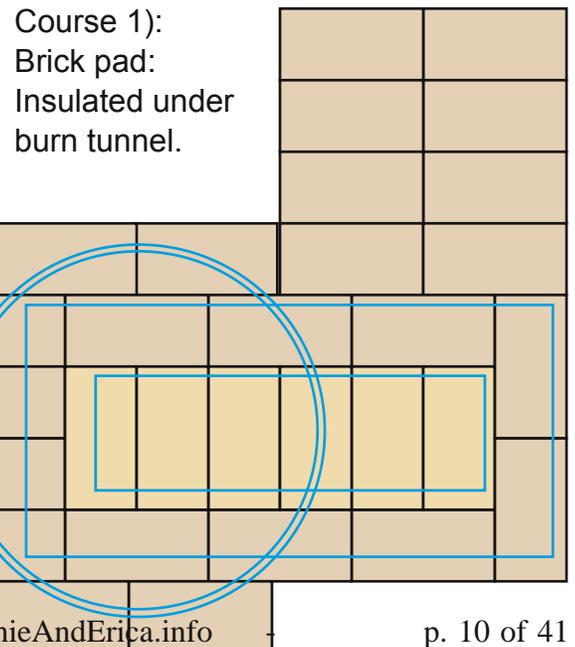
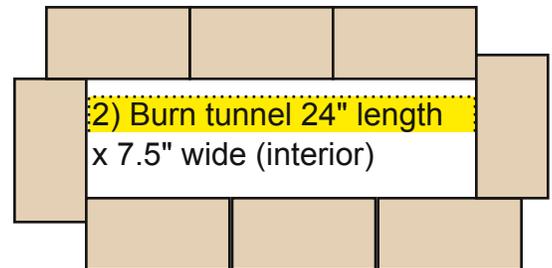
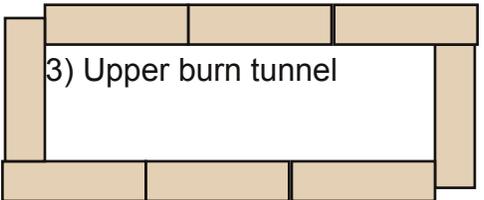
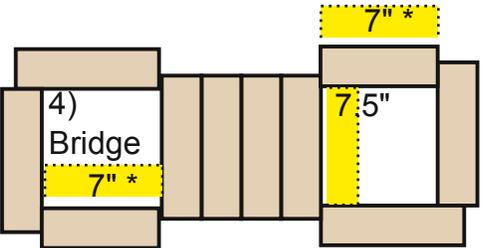
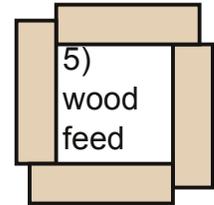
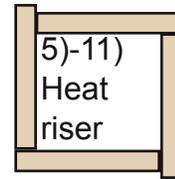
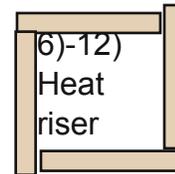
The alternating spiral layout allows any dimension of brick to make any interior dimension, with minimal running joints.

We set the bricks with clay slip (refractory clay). Level the pad or use mortar to level the first course. Check each course for flush interior walls.

We used a handful of light, foamy kiln brick.

If kiln brick is not available, then we use firebrick plus refractory insulation blanket, board, or clay-stabilized perlite. (Level entire pad on stabilized perlite if needed.)

Metric Users: Please see Ontario project (p. 29) for civilized dimensional units.

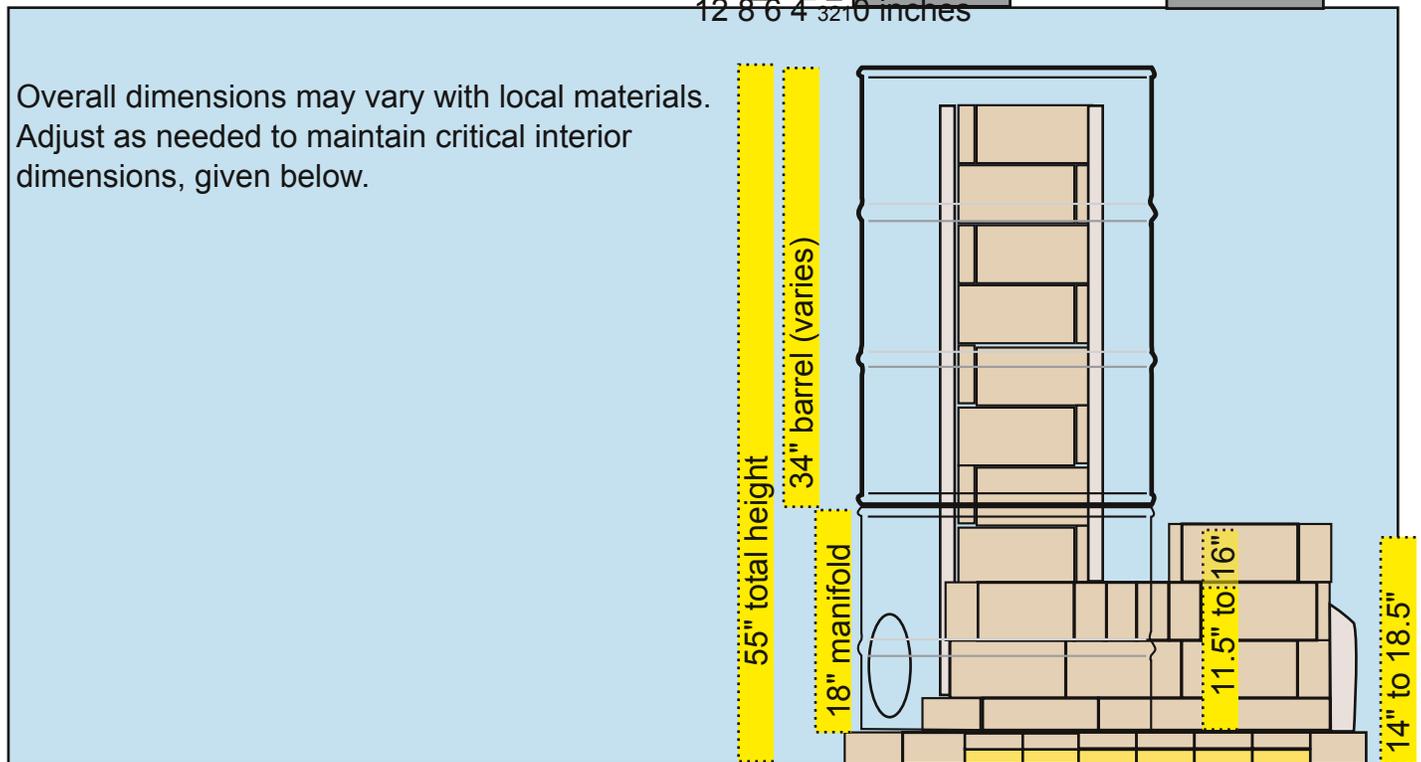


** Length of openings = burn tunnel height. Even if height and width are adjusted for different bricks, these stay the same as each other (to maintain the same flow areas).*

Front View - Combustion Unit



Overall dimensions may vary with local materials. Adjust as needed to maintain critical interior dimensions, given below.



Two Barrel Bell:

40.5" level brick pad

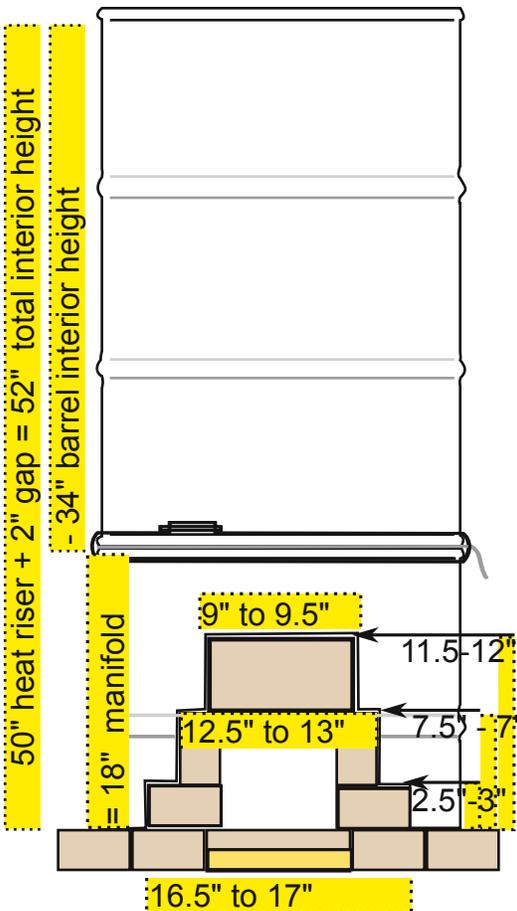
Two barrels, joined with a band clamp and woodstove gasket, offer maintenance access to the ash cleanout area. A lid with a second gasket gives access at the top. If lifting the barrel sounds awkward, include a capped T cleanout in the ducting.

The height of the lower barrel sets the placement on the upper barrel. Leave a 2" gap between the heat riser and upper barrel's inside top. Set the barrel temporarily on 2" spacers to determine cut length, or use measurements of actual heat riser in place and actual barrel (inside height). If later adjustment is needed, add a bead of mortar under the barrels, or atop the heat riser.

Index the lower barrel to fit over the bricks; cut with grinder and/or tinsnips. Cutting 1/4" to 1/2" oversize allows for adjustment, mortar, and heat expansion. Blanket insulation crushed under the metal edge serves as an expansion joint. Trace & cut the hole for the duct on the other side.

When ducting and heat riser are laid and sealed, we set the lower barrel in 4" earthen masonry around all seams. We set the upper barrel on top and seal well (foil tape helps eliminate any air leaks at the lower joint). Test-firing the system while the earthen material is still damp helps set the expansion tolerance.

Steel drums, steel or stainless steel cylinders, and water heater tanks have all been used as barrel/bell. The metal bell may be heat-shielded, but should not be insulated, nor covered over more than 1/3 of the surface (to preserve downdraft).





Photos showing a very similar combustion unit from an outdoor demonstration workshop.

Left: Ceramic wool insulation blanket, with wire mesh to protect it during cleaning.

Below: Clay slip painted on bricks helps bond, seal, and level them during assembly.

For permanence, the bricks must be supported from the outside against fuel handling impacts. Fiber-reinforced earthen masonry can work if it's test-fired early in the drying process; or include an expansion gap stuffed with insulation between inner bricks and outer masonry.



Duct length:

Cold, damp beds plus warm daytime weather during firing will cause the system draft to lock unless the beds are relatively short, and the chimney quite warm.

This short, reliable heater has total duct length 20-25 feet, with only 2 turns. Working bench length about 10-12 feet depending on wall and heat shield construction. A straight run of 25 feet can also work, provided that the vertical chimney is sheltered.

If the bench is relatively dry and warm at all times, and the heater fired only during sub-freezing weather, lengths up to 45 feet might be workable.

Optional Bypass for Rocket Mass Heaters:

For cold-start priming, or extra control of heating and cooling, you may want to include a bypass damper. This allows you to 'bypass' the heated bench, shunting the draft to the exit chimney along a shorter path.

Pre-heating the chimney gives better draft for cold starts (whenever the greenhouse or thermal mass of the heater is colder than outside air, a frequent situation with damp raised beds.)

A bypass can also help prevent over-heating if you discover your planting bed temperature is rising too quickly during the firing cycle.

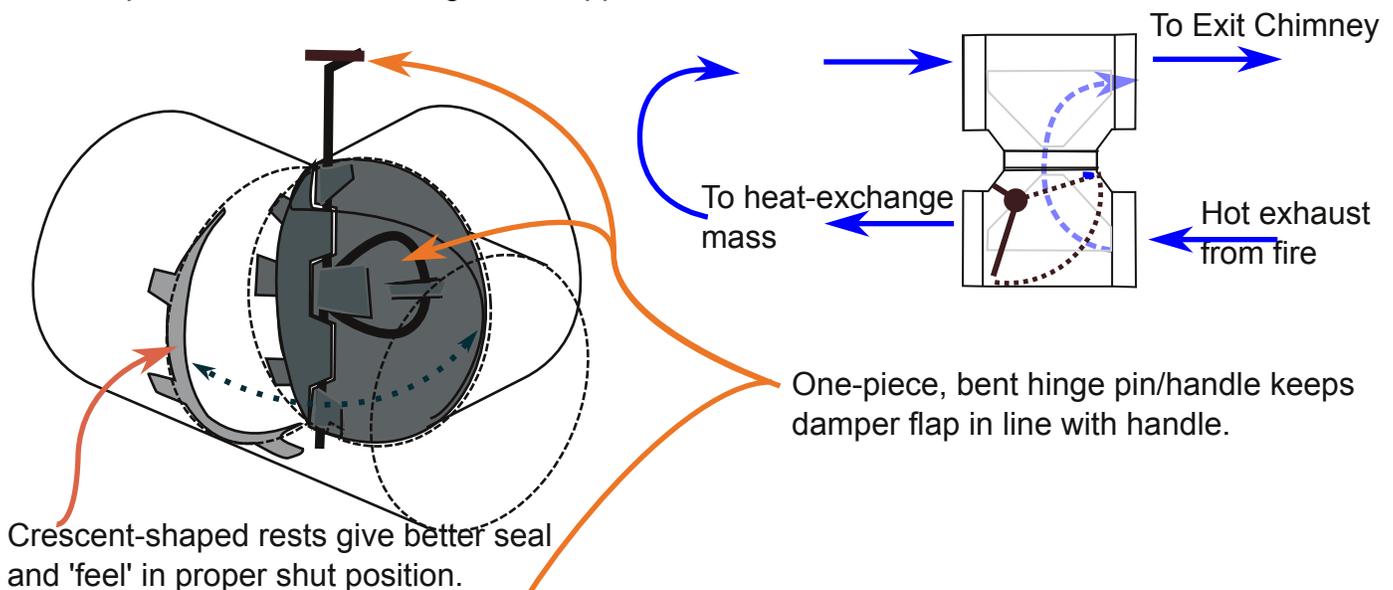
The tradeoffs include some wasted heat due to slow leaks and higher exhaust temperatures giving slightly lower efficiency. There is also slightly more complexity to operation: dampers left open during firing resulting in no heat storage; dampers closed too suddenly giving smoke-back. Dampers should be adjusted slowly to full open to gradually flush out cold exhaust in bench.

A bypass should never block the exhaust at any setting, only divert it. Always allow 100% flow volume.

The goal is to create a bypass valve that is very simple to operate, durable, and effective.

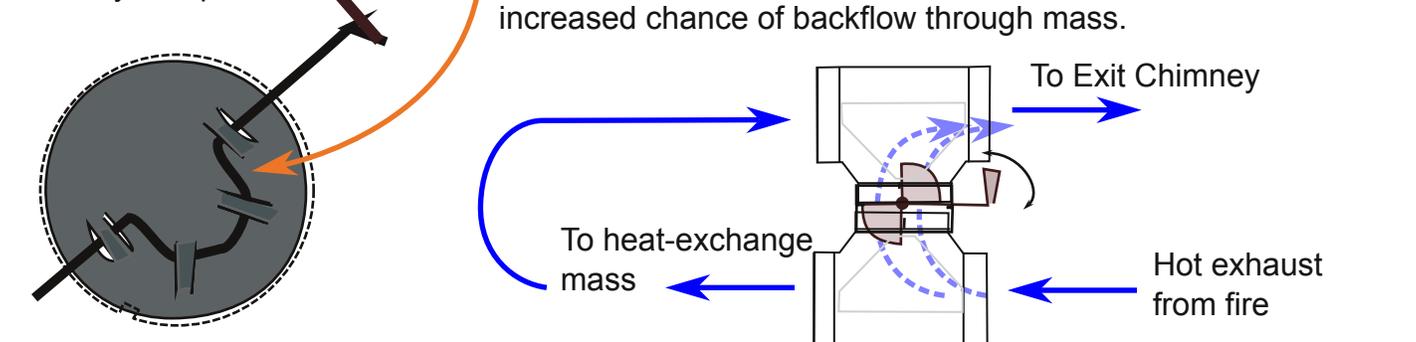
Bypass option 1:

Custom part for best control: a good scrapper can make one from a T on site.



Bypass option 2:

Ordinary damper:



Greenhouse Exit Chimneys

Greenhouses and membrane roof general pointers:

Through-roof openings are easiest to install and maintain near the roof peak, where there is no runoff or snow load from the roof above. This is also the best location for good draft.

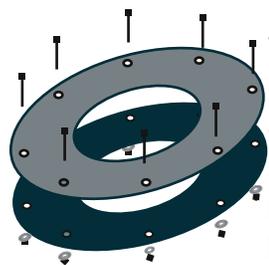
Research and follow local conventions for chimney height. Chimneys should generally open

- at least 2 feet above anything within 10 feet;
- 3 feet above the ridge or expected snow level; and
- well above any other roof vents.

Manufactured chimneys typically come with recommended clearance instructions: 2" from triple-wall insulated, 6" from double-wall, 9" from single-wall. These are for woodstove exhaust (typically 350F-800F).

The heater's exhaust is typically below 125 F during normal operation. However, people may 'prime' cold chimneys with burning newspaper or a hot exhaust bypass, or re-use the chimney for a fireplace or woodstove. We recommend up-to-code woodstove chimney materials and clearances for safety.

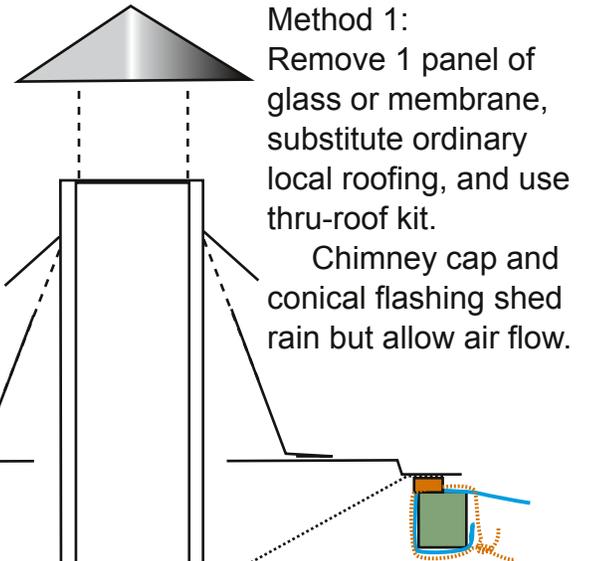
Method 2: Membrane roof stovepipe kit
(As sold for yurts and tents).



There are many models available. Most designs include at least two flashing pieces designed to bolt or glue tightly to the membrane, and spacers or collars to support the chimney. Look for rounded corners to reduce wear on membranes, and a reasonable air gap between membrane edges and the stovepipe itself.

Membranes are generally more heat-sensitive than other roof and wall structures, so insulated or multi-walled pipe is highly recommended. Look for kits that do not require patching or sewing waterproof seams (can be done for nylon or canvas but not for typical greenhouse membranes), and that allow several inches of air space to protect the cut edges of membrane from heat.

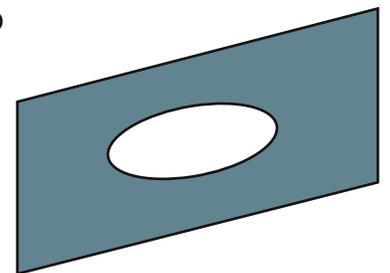
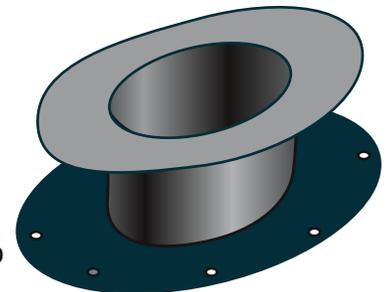
The chimney should be fundamentally self-supporting in this setup, and strong enough to resist wind forces from billowing membranes. Metal bracing, brackets, or guy wires from nearby structural members can help support the chimney without transferring too much heat. A collar that fits around a solid section of pipe (as opposed to right at the joint between two pieces) may be helpful to prevent wind chafe from pulling the outer chimney loose.



Method 1:
Remove 1 panel of glass or membrane, substitute ordinary local roofing, and use thru-roof kit.
Chimney cap and conical flashing shed rain but allow air flow.

Weight supports - ceiling box or wire collar

Lash or staple membrane to framing. Secure all combustibles at least 9" back from exposed stovepipe (more if possible for plastic membranes).



Method 3: Self-flashing hatch for flexible membrane:

This method raises a rim from the flexible membrane itself to divert water around the chimney. It can be particularly useful in situations where it is inconvenient to puncture the membrane (for example, living roofs lined with EPDM). Do not cut the membrane until all the framing is in place.

Round method: Use a section of oversized triple-wall ducting or insulated triple-wall stovepipe, with a suitable collar. (Single- or double-wall stovepipe could melt membrane and waste all your efforts, not to mention light the whole place on fire some night.)

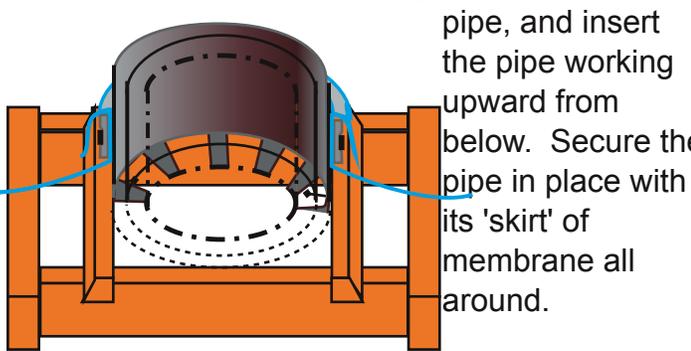
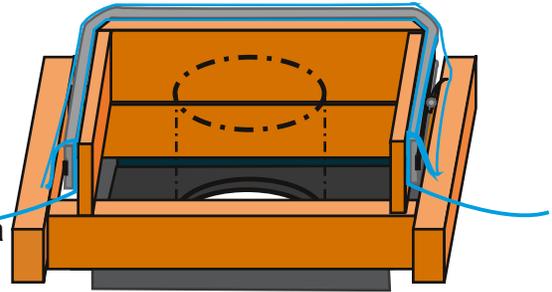
Working from below, frame in supports for the pipe. Cut a hole in the membrane about 2-3" smaller than the outside diameter of the pipe. Stretch the membrane to fit tightly around the

Rectangular box method:

Support the chimney with ordinary framing and collar (aka a 'ceiling box').

Working from below, frame in from the existing structure with cross-braces to set the proper clearance (fit to flanges on chimney box). Above this, the hatch rim will need to stretch the membrane up at least 2-3" above roof level on the high side (higher in snow country) so that roof drainage flows around box on all sides, in all weather.

Build the hatch rim to fit, and round off the corners (use carpet, cardboard, or rubber for extra padding). Carefully lift the membrane up without puncturing it, and install the rim under the membrane.



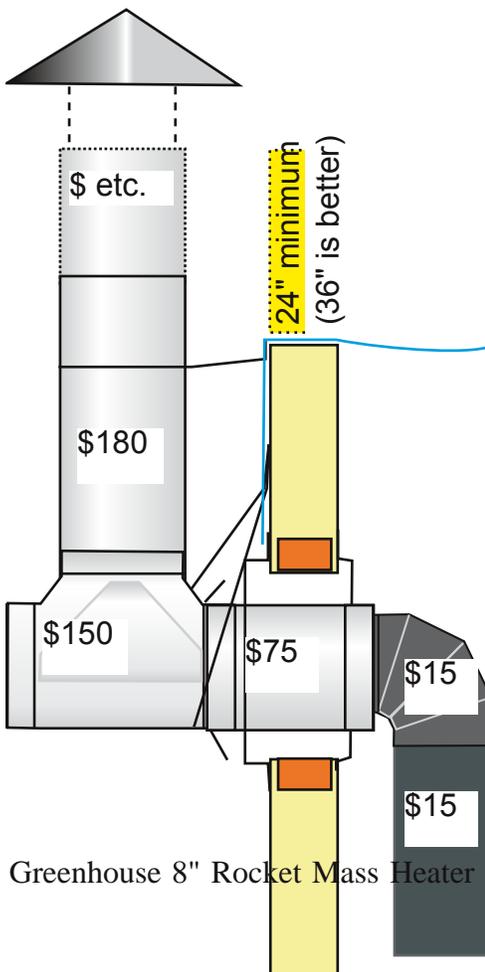
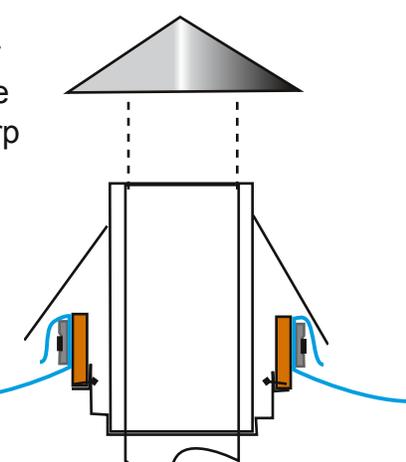
pipe, and insert the pipe working upward from below. Secure the pipe in place with its 'skirt' of membrane all around.

Hatch methods continued:

From above, wrap a wide strip of rubber around the membrane to draw it against the hatch frame, and to protect it from any sharp edges of the clamp.

Clamp the rubber in place using a metal band-clamp, or battens and screws. If membrane is stretchy enough, fold the excess over at the top if you like.

Attach a flashing collar to the stovepipe itself, to shed rain outside the hatch rim.



Method 4: Gable-end wall exit (left).

Wall exits may seem easier, but usually aren't. They require more insulation, priming (pre-heating), supports, leak-proofing (water runs down chimney), etc.

Historic, inflated-roof-membrane, or removable-membrane greenhouses may call for a wall exit. We exit as high as possible on the gable (end) wall. Insulate any exposed pipe, finish the chimney as high and vertical as for other methods, and use flashing collars to exclude rain running down the sides.

Greenhouses bring some specific considerations that are not usually present in a residential rocket mass heater.

There are two basic heater shapes:

- bury underfloor in the greenhouse, to raise the overall temperature
- build into a raised bed, to raise the temperature of specific seed beds.

There are a few more complex variations, like trying to heat tanks or ponds within a greenhouse, but these require additional design considerations.

We like raised-bed construction for several reasons.

Less Digging/Insulation: Under-floor installations involve a fair amount work to dig a perimeter all the way around, and underneath, to insulate the installation from the surrounding ground below frost level. If uninsulated, a lot of the heat is lost to the ground as a whole – no small consideration when the ground may be damp or frozen right up to the greenhouse perimeter. Thawing the frost line can absorb a HUGE amount of energy.

Easier to Remember: Floor installations can be harder to map and protect from damage when digging or installing other amenities. Damaged pipes in turn raise the chances of exhaust gas leaks into the greenhouse, or draft problems that cause the stove to choke and smoke back at the firebox.

More Heat Exposure: Raised bed construction allows much greater use of heat: the exposed sides offer radiant warmth to adjacent beds. Insulation is much easier to install, and less is needed to do the job. It's also much easier to create effective cleanouts; inspect and maintain the piping; and to keep it dry for greater longevity.

Within the raised bed, we still locate the pipes as low as possible, to give a good buffer between tender roots and excess heat. We

tend to include a protective barrier above the pipes: This can take the form of a finished tile counter with planter boxes on top; or just a layer of tile or brick within the loose soil of a rough box-like raised bed.

Some General Planting-Bed Goals:

Optimal soil temperatures for rapid germination and growth may be 65-95°F, depending on your crop. Most seeds germinate faster when warmer, so long as they don't get cooked. Our mentor Ianto Evans used to keep beans and other seeds in his front pocket during germination, sharing body heat like a mama kangaroo.

You will see a gradation in temperature throughout the beds. with higher soil temperatures closest to the combustion area, dropping with distance. You can start with the pipe deeper, bringing it at an upward slope to distribute heat more evenly at the growing level.

You will also see gradients in soil temperature with dampness, proximity to the pipe, and sometimes with air movement within the soil. With damp soil, heat transmission may be extremely rapid, as water conducts heat. Evaporation moderates the heat toward the surface, but deeper temps can get quite hot.

Be sure to test the temperatures with damp as well as dry soil before starting to run a heater under actual plants: the wrong combination of heat and water could inadvertently steam-cook plants. We sometimes use a plastic or airtight masonry barrier to suppress conductive heat transfer upward within the bed, reducing the risk of runaway steam heat transfer.

The radiant heat coming out the sides of the bed can also help warm up gardeners' toes, or break up pockets of frosty air that sometimes gather in low spots. Very frost-tender plants that require warm air as well as warm roots can be grown up against the side of the heater, with a cold-frame over them for

extra protection.

Most greenhouses are primarily used as season extenders, not year-round growing environments, due to the difficulty of preventing overheating in summer, and the expense of maintaining all-night heat in winter. The usual controls (vents, artificial light, etc) should still be included; the rocket mass heater will only affect heat delivery and storage.

The rocket stove will keep soil temperatures up, and help keep the greenhouse warm; but in most greenhouses it will not maintain air temperatures at unseasonable warmth all night. Row covers, cloches, double glazing, night-time insulation curtains, or other barriers may be needed if trying to grow cold-sensitive plants in the depth of a Northern winter.

Plants also respond to daily cycles of warmth, light, and climate. Some care may be needed to adjust the timing of firing cycles to produce the healthiest effect on the plants.

Some plants are extremely susceptible to smoke damage, and all plants require oxygen at night. So it may be beneficial to locate the firebox itself in an attached work area rather than the main growing area of the greenhouse. We have shown our heater located in a gable-end drying room, or mud room, with less flammable walls and ventilated with outside air.

Death Traps:

We occasionally get inquiries about using rocket mass heater exhaust inside the greenhouse, to boost carbon dioxide (CO₂) levels in intensive cultivation. **Please do not do this.**

Rocket mass heaters are not designed to produce breathable exhaust, though they do burn cleaner than most other wood heaters. Wood is a natural fuel with natural variability, and burning it releases highly volatile plasma and smoke chemicals, which may not always be fully finished reacting before the escape the

heater. Though rocket mass heaters smoke less, they do not produce breathable air.

Running any fire within a closed environment depletes the oxygen and eventually smothers the flame. Invisible CO (carbon monoxide) is often present in the exhaust, especially when re-loading or restricting air to the fire. CO is a slow poison that accumulates in the bloodstream, preventing oxygen from reaching the body, which causes headaches, fatigue, drowsiness, fainting, and death.

We don't know if CO has the same effect on plants, but it might. We do know that plants require oxygen after dark, the time that the heater would most likely be operated to control growing temperatures, and thus CO₂ levels would be highest at times when the plants do not need it.

So if the possibility of lethal asphyxiation of human and animal occupants isn't enough, there are some technical reasons it might be counterproductive for plants too. We definitely recommend against this whole concept.

There are safe, controllable CO₂ sources such as cannisters or purpose-designed gas burners if you really want to play with boosting the concentration by the tiny amounts some growers have found beneficial, and there are also natural processes such as fermentation that might better fit the daily growth cycle of plants.

Horizontal Exhaust:

Some builders in the past have successfully used a variety of tricks to avoid building a chimney. **We do not recommend this for most situations.** These tricks work best in places where there is a consistent wind direction, sheltered aspect, and few or no vents above the level of the horizontal exhaust exit in a well-sealed, low building. Even there, they work only intermittently, and great care may be required in the timing and tending of heating fires.

However, in most situations we have seen, this type of extreme design leads consistently to problems with draft during certain wind or seasonal weather conditions. The last thing you want is a heater that won't work during an unusual storm! So we prefer to design conservatively, making a heater that will always draft. The most reliable solution for consistent draft is a conventional chimney.

Fans are a common suggestion, which you are welcome to explore, but most electric fans are not as reliable in the damp, corrosive, hot conditions inside a chimney.

If the exhaust is not adequate to maintain draft under all weather and greenhouse-venting conditions, you risk creating a smoky death trap that can poison plants and gardeners alike. (Tomato seedlings really don't like smoke, among other plants.)

Construction materials and methods:

Damp conditions:

Earthen masonry is not a structural material in damp conditions. Clay-based masonry hardens by drying alone, and will re-soften with watering. We have seen several examples of badly crushed pipes because people stepped up onto a damp earthen bench to water plants or work overhead. For greenhouse designs, we recommend working with damp-resistant, non-combustible, non-rot-prone materials, and building structural supports around earthen infill for heaters.

Damp conditions also mean that condensation, mold, rot, and fungal blights are major issues in many greenhouses. If you are just starting to work with greenhouses, know that all your current versions may be subject to change. A permanent masonry bed may become a curious relic if the greenhouse needs to be relocated or redesigned due to bad mold problems.

If you have enough experience (or experienced advice) to be planning a totally permanent installation, we might suggest using smooth, ceramic pipe (drain pipe or

chimney liner) in place of the metal ducting for heat-exchange channels. Make sure to use the specified internal (not external) diameters. Ceramic materials will tolerate damp better than any metal, and tolerate careful disassembly for cleaning and remodeling. Clay will even survive root incursions, though this is less of a problem with hot pipes than with water drainage pipes.

Around the heat-exchange channels, a sturdy box supports the gardeners' weight and soil mass. Even if your plan involves only growing salad or herbs, anticipate that you may need to climb atop this mass at some point, either to fiddle with the overhead structures, or to hang supporting twine or hanging plants. A stout box will tolerate a wide variety of uses.

Brick, clay tiles, retaining-wall pavers, fieldstone or dressed stone could all be used for the main box walls around the heating pipes. Be aware that concrete and some other masonry materials may be alkaline, which can affect your plant and soil choices.

Anticipate that the box will be constantly moist, and water and minerals may seep through the surface, leaving evaporation deposits. Some provision for drainage collection both at the base of the planting layer, and at the bottom of the box itself, is wise.

For the most neutral chemical composition, reasonably easy DIY skill factor, and good heat storage properties, we like clay brick set with very thin layers of clay-sand mortar. Dry-stacked block or retaining-wall masonry are also easy, though more alkaline.

If you want to use a wooden box, please consider what you would do if it caught fire, or if the wood rotted out or sagged around the heater. Pressure-treated (rot resistant) wood often contains toxic minerals or chemicals that can contaminate soils and food plants. Naturally rot-resistant wood (black locust, cedar, redwood) may be preferable, though some types are also mildly toxic to certain plants.

If you have lead paint in your soils, or other heavy metals in your structure or box-building materials, root crops are the most likely to pick up heavy metal contamination, followed by stems, leaves, and fruits. All produce will pick up a certain amount of surface contamination if such minerals are present. A quick rinse in a very weak detergent solution is highly effective at reducing the levels when present.

We have a preference for using as much natural material as possible to limit contamination of these intensively grown plants. After all, greenhouse produce is already a premium product. If you are going to invest this much energy and effort to grow food out of season, why spoil the results?

Bench or Trough?

Do you want to simply fill the box with mineral soil, planting directly in the raised bed? Or do you want to create a heated bench for portable plant containers (trays, pots, tanks, etc)?

A bench lets you move plants along the temperature gradient as their needs change. Drainage and temperatures may be easier to control, but need more attention. The surface can also be cleanable, reducing some mold or mildew problems. Some growers rely on portable containers for most of their production.

A raised bed may work better with permanent plantings, deeper roots, and polycrop methods, or for a more natural-looking pleasure garden. A heated raised bed can be built within one container by dumping mineral soil around the heating pipes, laying down some protective tiles, and then filling with at least 12" of your choice of topsoil. (8" plus plant rooting depth; deeper for the bigger and longer-rooted plants).

Layout:

The heater itself works best in certain configurations. Our basic, recommended model is a 10- to 15-foot bed, with a down-and-back pipe. The side-by-side pipes will

serve to even out the temperature gradients. Bringing the exit chimney back past the barrel boosts exit temperatures for better draft.

Damp soil draws an immense amount of heat out of the exhaust, making cold starts more likely. This problem can be severe if a long single-pipe bed happens to also point in the wrong direction with respect to local wind.

Locating Heat within the Greenhouse:

North (shady) side, or coldest side: good for counteracting overnight chill, may also help save space in small greenhouses, and may be a good location for passive solar gain.

Center of a N-S axis, with paths on both sides: helps create even heat and light for two aisles, and possibly also hanging plants.

Multiple beds (larger greenhouses): you may want the heat located either centrally, or on the cooler side. Consider using the heater and other beds to create sunken cold frames for very tender plants.

Off-center or short-end placement: good for creating hotter and cooler sections for a wide range of exotic plants. (Higher and lower racks can also separate plants into hotter and cooler strata of air, if the greenhouse is protected against daytime overheating.) If you really want separate environments, a separate (dry) combustion room could house mold-sensitive plants, desert plants, and drying racks for produce.

Designing the greenhouse itself:

Greenhouses must be built in a sunny location: a place the sun reaches for many hours each day during the time of year the greenhouse will be used (winter, spring and fall, or year-round). If the greenhouse location does not receive sun, you may as well grow plants indoors with a grow-light, because the heating costs will be much easier in an insulated building.

The primary heat source for a greenhouse is always the sun. Wood and other fuels serve as reserves of recent solar energy. Since it's much more work to grow, cut, dry, stack, and burn wood, we highly recommend tapping the direct solar energy first.

Plants also need almost full-spectrum light to grow. Some plants will not be happy with shorter winter sun hours, no matter how warm they are, so it's wise to learn the plants' needs before designing the greenhouse.

The thermal mass of soil and water stores energy from sunlight all day. Protecting this warmth with insulation will help store that energy all night. Sometimes adding some water barrels and insulation, or a second layer of glazing, does more for your temperature stability than the best heater system.

Glass or Plastic?

Finding greenhouse glass or plastic that admits full-spectrum natural light (including the infrared or heat-type light that plants use), yet blocks heat loss, is a design challenge. First, think hard about where the sunlight actually comes from - many walls of a greenhouse won't receive sun, and don't need to be made of transparent materials. We'll go into more depth on solar orientation shortly.

Second, seek out dedicated greenhouse materials, rather than just looking for the cheapest generic plastic. A small amount of the right glazing or plastic can produce better results than a large expanse of cheap material, especially if the cheap material

blocks some of the light plants need to grow.

Reflectors and insulation:

Some operations (small-scale enough for personal attention, or large enough for mechanization) can even have insulative covers that go over the clear panels at night, effectively stopping radiant heat loss, and are removed during the day to allow natural light. The extreme version of this for Arctic or illicit crops is an indoor 'greenhouse,' a grow room with reflective, insulated walls and artificial light.

Even in a fully solar-powered greenhouse, insulating the north wall and adding reflective materials can nearly double the sunlight delivered, and also helps protect against the inevitable heat lost both night and day on this shady side.

For all-year greenhouses, and attached growing sheds beside a house or barn, it may be worth considering a 'passive solar' sun-angle design. Opaque or reflective roofing set at the minimum sun angle can block unwanted summer sun while admitting low-angled winter rays. East and west sides can be clear, with racks for shade-cloth if needed. Vertical glass, or near-vertical angles for slanted glass, will admit more light in winter while reflecting more in summer. It is possible to design passive-solar based on pure geometry for a given latitude: summer and winter solstice sun-angles are simple to figure. But personal observation of the short winter days and long summer evenings is likely to give much better clues as to what angles of light are likely to be most useful, or most unwelcome, for maintaining comfortable temperatures.

We've heard from many greenhouse owners who sing unstinting praises of automatic vents. It's very easy for daytime sun to spike temperatures in the greenhouse well into the roasting range, and large vents may be needed to shed excess heat. Unless you intend to dote with constant attention on your greenhouse during the entire growing cycle within, having vents that are controlled by a

thermostat or bimetal spring will likely save your crops multiple times per season while allowing you freedom to pursue other activities (like selling those same crops off-site).

We've heard praise for Mike Oehler's semi-sunken greenhouse designs. These designs use earth-sheltering, sunken paths that serve as drainage channels for cold air, and raised beds at several levels to stabilize interior temperatures and make the most of available solar heat.

Solar Orientation:

Catching the sun is arguably the single most important function of a greenhouse.

You need sunlight to grow plants (the "green" part of "greenhouse,"), and sunlight also offers free thermal energy to capture and store for overnight heating.

However, too much sun in a glass house can cause serious overheating, crisping or boiling your plants.

Your first goal is to observe the local climate, and consider your specific growing goals, so that your greenhouse can offset rather than exaggerate the undesirable extremes.

If you don't know your plans yet, talk with other gardeners in the area. Look for designs, plant varieties, and general approaches that have proven successful, easy, or rewarding. Also look for realistic time, labor, and other costs, and methods that could fit your lifestyle.

Climate Observations:

Sun comes in at different angles during the day and year. We also need different amounts of heat at different times of year, depending on what the greenhouse is doing. There is a thermal lag time (the day and year are hotter *after* the maximum sun, and colder after the minimum). There are local effects, like moisture, "lake effect" or maritime effects, and inland, dry-lands, or alpine extremes. Reflected heat, shade, hot or cold winds may

come from local landscape features.

The best way to determine your situation is by direct observation.

You can set up a sundial or shadow-stick (or observe the shadow of any convenient object such as a flagpole or small tree). Record the position of its shadow at various times and seasons. Take particular note of the position of the shadow during critical times: the seasons you would want to start plants, any weeks when you are uncomfortably cool or hot, any times of day that you might want to block or gather more sun. Note any positions that occur with both too-hot and too-cold temperatures. Also watch for plants that seem to prefer certain conditions (shade, damp, full sun, dry or wet parts of slopes).

Temperature extremes, moisture, drought, and other climate problems can be exaggerated in a greenhouse.

If you are in a hurry and can't wait for a full year of sun-watching, the full moon casts a shadow roughly comparable to the sun at the opposite time of year (so a June full moon, on its fullest day, runs a track similar to the December sun).

Watching the actual sun (or moon) helps you anticipate site factors like the shadows of mountains, trees, or nearby buildings. Solar energy specialists may also have shadow-box, lens, or photo methods to capture information about local shadows and sun potential.

Some climates' weather patterns bring more clouds or rain at certain times of year. Where clouds coincide with cold weather, and sunny skies with summer (Mediterranean climate), solar heating may be tricky since the sun is most available when it's least needed. Longer-term energy storage, seasonal or automated controls for extreme conditions, and/or realistic goals will be the keys to success.

In monsoon climates (summer rains, winter sun), solar energy can more readily offset

seasonal differences. Passive solar systems, using basic solar orientation and seasonal shade, may be very successful in these climates.

Climate-Adjustment Goals:

Think about what seasonal uses the greenhouse might serve.

All greenhouses provide a certain amount of frost protection, just by interposing a layer of warmer material between your plants and the cold night sky. One rule of thumb says that every 2 layers of glass moves you roughly 1 USDA zone toward the equator.

The greenhouse effect can also contribute to daytime overheating, or partially shade plants from specific types of light (such as UV) that they may need. Instead of more layers of permanent glass or membrane, consider flexible options like cloches, cold-frames, shade-cloth, insulation or awnings, indoor-outdoor structures, and thermal mass.

Winter or Year-Round Production:

For a winter-food greenhouse or orangerie, start by planning your greenhouse to receive ample winter sun. Low-angled winter sun comes from specific angles, usually south-east to south-west, where it can be blocked by buildings or evergreen trees.

For heating efficiency, consider building the greenhouse partially underground (Oehler has one good design), or attached to other heated building(s) to share warmth. Attached greenhouses and sunrooms may get more use in all weather, but watch for damp problems - the connecting wall(s) should be detailed to avoid or shed any condensing moisture. Also consider vertical windows and reflecting ponds for capturing low-angled winter light.

Tropical greenhouses and orangeries, in non-tropical climates, need extensive artificial climate controls. Artificial climates are expensive to maintain, and vulnerable to

power outages and equipment failures.

Tropical days are nearly identical in length, with similar climate year-round. Temperate climates have longer summer days with potential overheating, followed by shorter days and low sun angles in winter. Supplemental light, humidity, ventilation, climate controls, and more insulation and glazing may be needed to maintain the artificial climate. It may be cheaper to move operations to the tropics, or switch species to climate-tolerant cousins or indoor plants that tolerate lower humidity.

Seasonal Extension / Targeted Heat Collection

Some greenhouses are used mainly as potting sheds for starting transplants. If the greenhouse is intended to offset a specific seasonal vulnerability, such as the first or last frost dates, you could just go for maximum heat capture through those specific sun angles. However, in most situations, a maximum-capture greenhouse will also tend to overheat in summer.

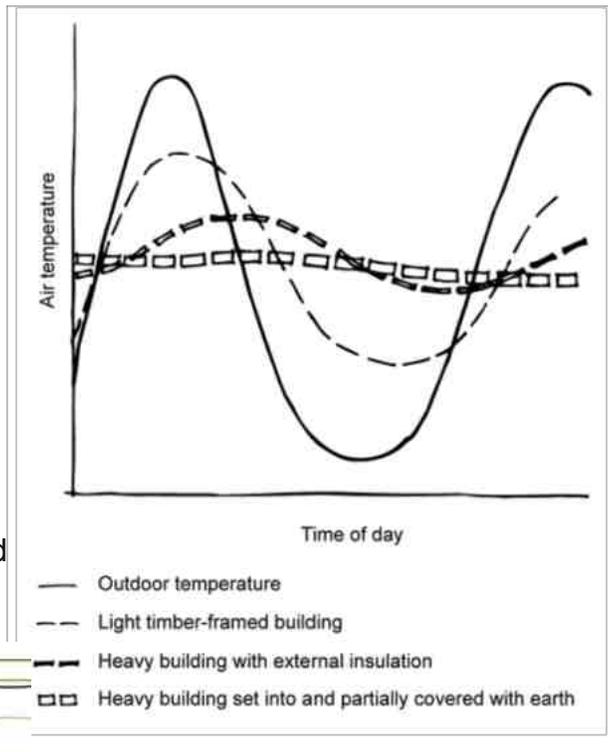
Thermal Lag

Both sun and greenhouses have a thermal lag. The day is hottest a few hours after noon, and the year is hottest for a month or two after summer solstice. While the sun is highest in late June, and roughly similar in late April or late August, the heat is very different. This is mainly due to the thermal mass of the earth itself. Areas with more thermal mass in the earth and air (moist coastal climates, humid rock and lake shores) tend to have more stable temperatures from day to night, while arid climates (with pale, dry soils and clear skies) endure more extremes of heat and cold. Water in the environment can also hold temperatures in the life-friendly zone by state-change processes such as freezing and evaporation, which can release or absorb large amounts of heat.

Thermal mass stretches out thermal lag times, soaking up excess heat and then releasing it

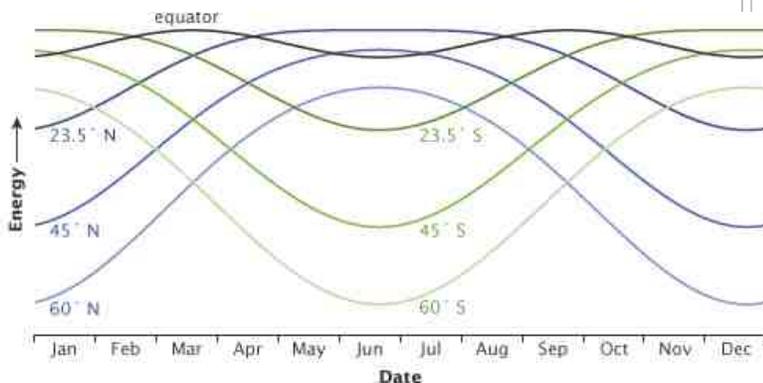
slowly. Water tanks, thick masonry walls, earth, or concrete can all serve as thermal mass. The larger and denser the mass, the more energy it can store. Consider aiming for an 8- to 12-hour lag to offset daily extremes, or a huge mass (such as the entire soil bank of the greenhouse floor, insulated from outdoors) to bank summer heat or overhead daytime heat for frost protection through the short fall days and longer nights.

Thermal mass and thermal lag:
the earth is slow, but the oxen are patient.



A) Insolation: incoming sun energy.

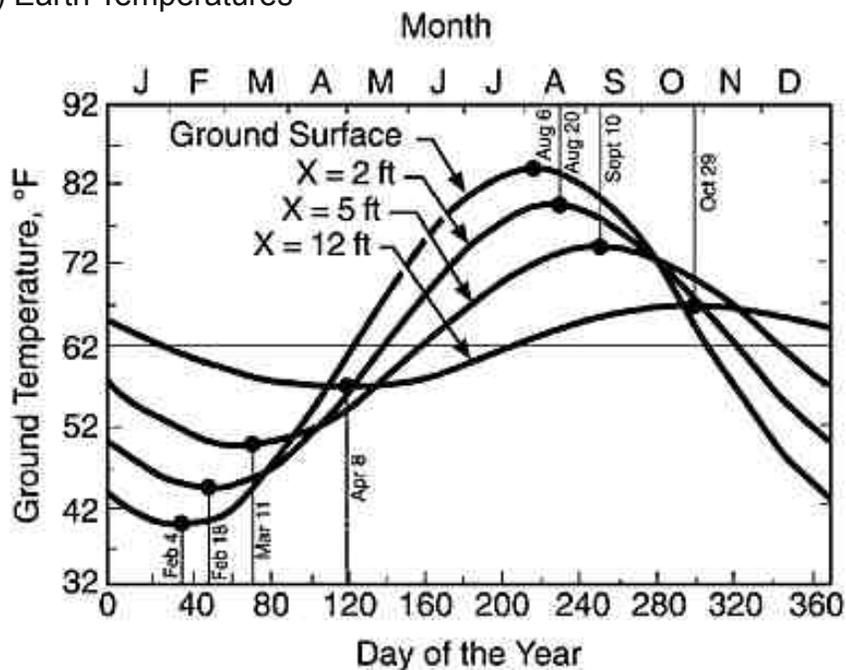
Source: "Energy Balance of Earth," March 2013, site visited Aug 2014: <http://www.eoearth.org/view/article/152458/>



C) Indoor thermal lag for building types

Source: <http://www.yourhome.gov.au/passive-design/thermal-mass>, 2014

B) Earth Temperatures



Compare (A) the peak availability of sun (June 20-22 throughout the Northern Hemisphere), with (B) the peak ground temperatures at various depths for a sample climate.

The more thermal mass is involved, the slower the temperature change and the greater lag times. At 12 feet underground, the average soil temperature peaks in late October, more than four months after the peak solar energy input.

Thermal mass in buildings rarely is large enough to offer months of offset like 12 feet of earth, but it can still offset daily temperature extremes (C), turning scorching days and frosty nights into stable, average temperatures.

Geo temperature gradient

terratek.ca/services/thermal/category/geothermal/#

State-change materials: water, wax, or other materials that can melt and freeze near our target temperatures can absorb and release energy at a near-constant temperature. Once frozen, however, it takes a lot of energy to re-melt them.

Ground effect: Underground temperatures are more stable than air temperatures, averaging 50 to 60 degrees in many climates. Orchard growers sometimes use liquid water (pumped from underground storage at about 55 F) to protect blooming crops from frost on cold spring nights.

Preventing Summer Overheating:

All greenhouses are susceptible to overheating during peaks of summer and sunny days. Upper areas of a greenhouse may be 10 to 20 F hotter than the ground level.

Venting is the most common way to mitigate overheating, using fans or high vents to get rid of excess hot air. Adequate greenhouse vents vary by climate, but are often 1/10 or more of the total end-wall surface area. Automatic vent controls are available to open vents at a pre-determined temperature to prevent overheating.

Venting a greenhouse can produce pressure differences that may affect any combustion heaters or vented appliances.

Shade and insulation can block sun as well as cold and frost. Summer's excess sun comes from a few special angles: higher overhead and farther around the sundial. Summer sunset and sunrise angles extend beyond true east and west, while winter sun angles fall short. A tall shade tree planted due west could block unwanted late-afternoon sun in summer, while admitting most or all the afternoon sun on short winter days.

Some passive-solar building systems use sliding, rolling, or hinged insulation panels to stop heat loss at night, then open these shades again for solar gain in the daytime. Adjustable awnings, panels, and shade cloth can also be employed for a few hours a day or from higher angles to block summer heat, especially if they are outside the greenhouse membrane itself.

For "automatic" shade to offset seasonal differences - particularly the greater heat of late summer compared with early spring, despite their identical sun angles - consider plants. Grape or hops trellises, vines, deciduous trees, or other plants that leaf out late in spring can block summer sun, while allowing more exposure to spring sun.

Note carefully the actual sun and shade requirements of target plants. Many plants requiring "full sun" only need 4 to 8 hours per day; a temperate summer day can offer 12 to 15 hours of daylight, more than double what most plants need. Tropical rainforest or river-bottom plants may be adapted to very low light conditions, and many heat-loving plants (tomatoes, peppers, squashes and melons among them) are susceptible to sunburn if their leaves are damaged.

Strips of shade cloth or reflectors can block up to half the overhead sun in summer, reducing overheating while still giving plants what they need. If sensitive plants become leggy or pale, remove the shade panels in their area to increase their light allowance.

Companion planting can also mitigate excess sun, using a sun-loving canopy of sunflowers, shrubs, or vines to shade tender plants below.

Dry and alpine climates are more extreme: daytime overheating and night-time frost may be possible throughout the growing season. Some desert growers will swap hoop house plastic for shade cloth in summer, providing

both shade and frost protection.

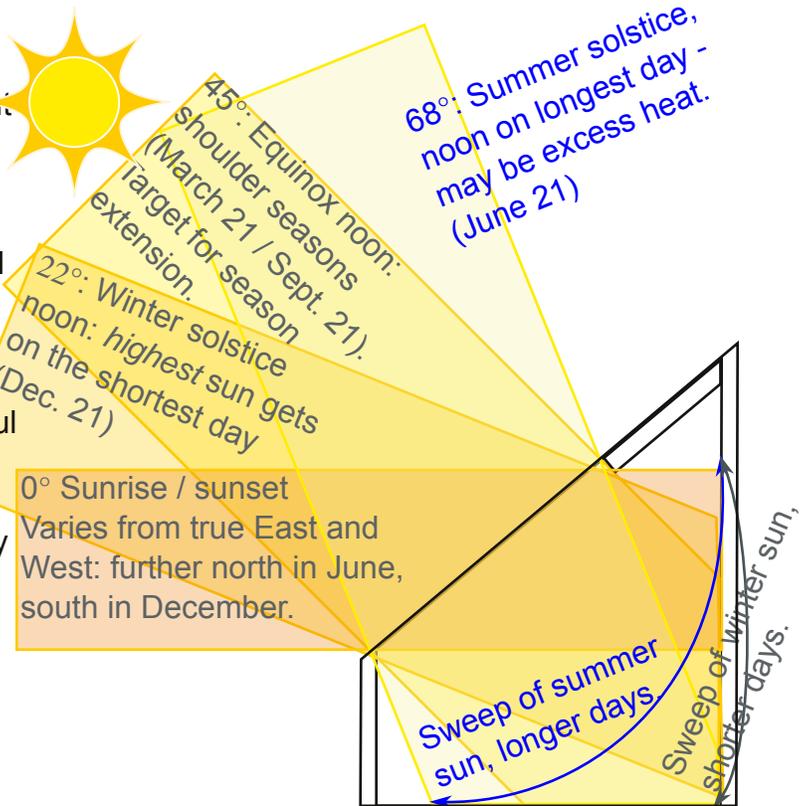
Thermal mass heat-storage banks can also reduce extremes. One thermal-mass storage method involves insulating the ground perimeter of the greenhouse up to 4 to 6 feet below the walls, and burying pipes about 4 feet underground with their ends raised into the upper third of the greenhouse space. A small fan can draw hot air from the greenhouse 'attic' area down underground, reducing summer overheating while storing warmth for nights and potentially well into fall. This 'climate bank' may not store heat through the entire year, but it can capture daily excess heat and extend the frost-free season with minimal power input. The stored heat also remains available in power outages, though it may not be possible to continue banking additional heat without supplemental power.

Skylight Sunroom:

The angled glazing maximizes equinox light (good for spring planting), but note where the sunbeams are broadest. This design captures the most sun during the hottest parts of the day and year. Massive thermal batteries may be needed to even out this unfortunate concentration of heat energy.

Note that back wall receives the most useful heat (during winter / cooler hours). The floor receives mainly unwanted summer heat. Plants on the floor may become leggy in winter yet bake in the summer.

This design resembles solar ovens. It targets a maximum rather than moderating the extremes.

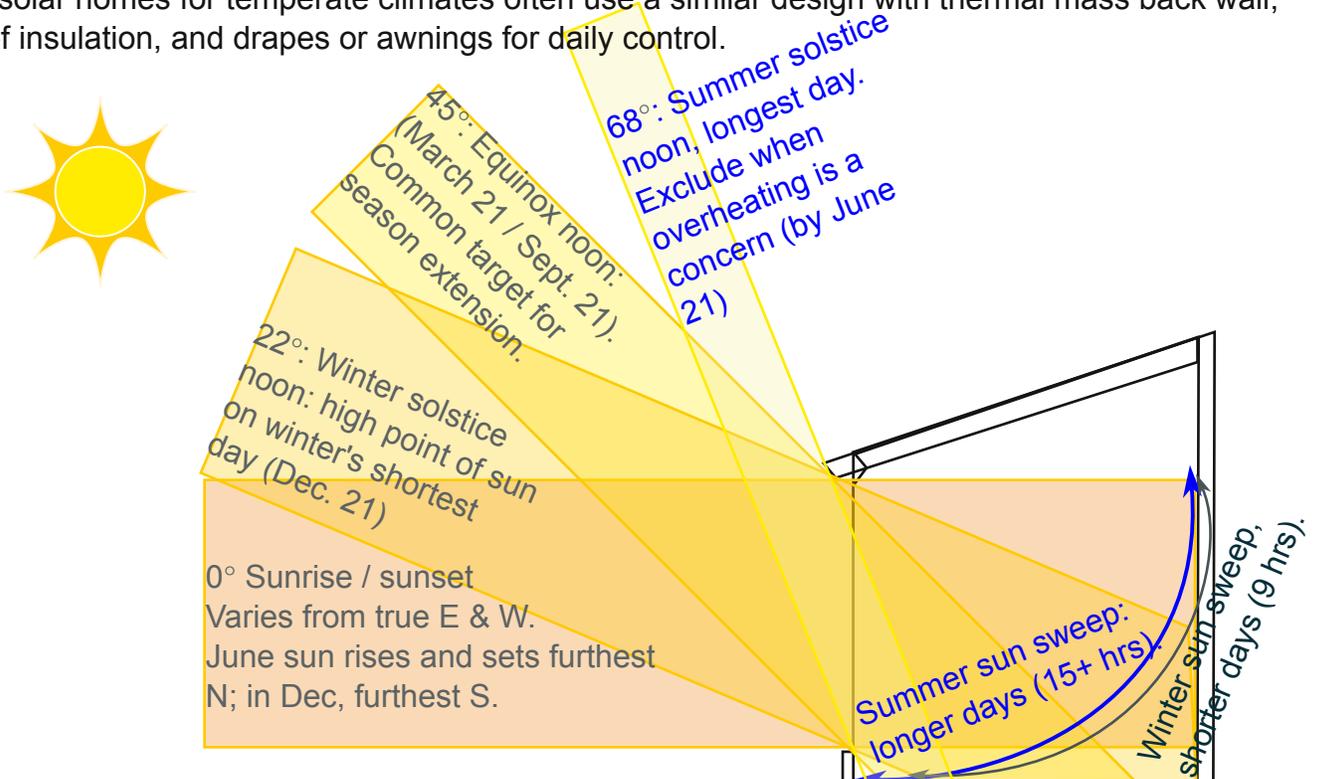


Window-Walled Sunroom:

Vertical or steep glazing excludes more sun in summer, while admitting more in winter. When you consider glare (more sun enters if the beam is pointed more directly at the glass), this is big difference.

A small change in eave length can exclude a lot of summer sun without limiting winter light. A pond or other reflector outside the windows can boost light, while mitigating summer heat.

Passive-solar homes for temperate climates often use a similar design with thermal mass back wall, good roof insulation, and drapes or awnings for daily control.

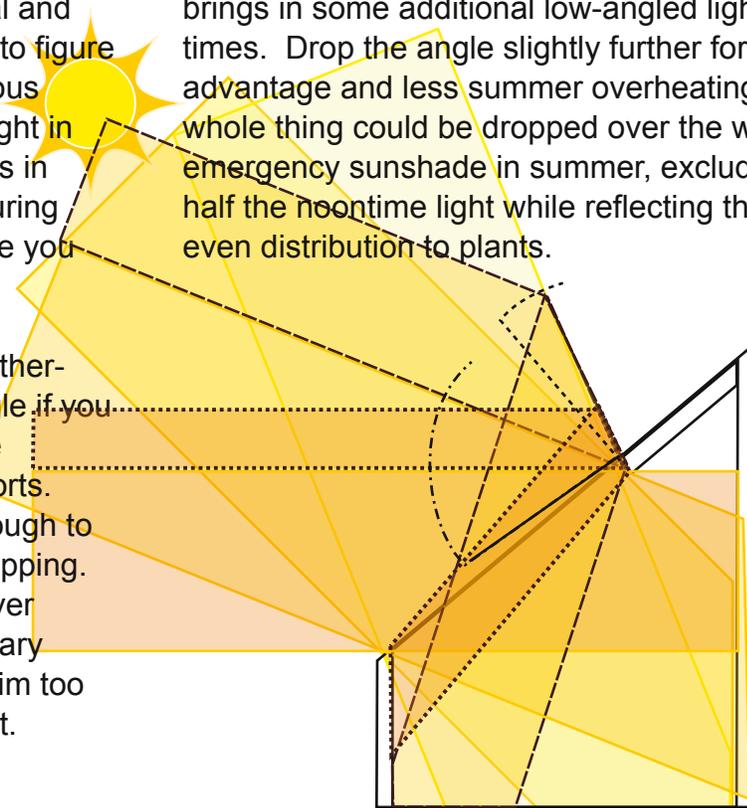


Reflector / Awning:

Although it takes a little more ladder work than putting in a pond (below), trial and error is as effective as calculation to figure out a good reflector angle for various purposes. You can collect more light in winter, exclude some of the excess in summer, or use it as an awning during heat waves. An adjustment handle you can reach easily is a big plus.

Set parallel with the highest summer sun angle, this reflector blocks no summer noon-time light, but brings in some additional low-angled light at other times. Drop the angle slightly further for more winter advantage and less summer overheating. The whole thing could be dropped over the window as an emergency sunshade in summer, excluding about half the noontime light while reflecting the rest for even distribution to plants.

While it's possible to mount a weather-proof reflector at a permanent angle if you like, it may be simpler to hinge the reflector and use adjustable supports. The support should be secure enough to prevent wind-driven banging or flapping. Foil-backed bubble wrap, or foil over cardboard, make a decent temporary reflector that doesn't tear up the trim too much while you're trying things out.



Reflector Pond:

Dotted beams show additional sunlight that can be reflected in through the window: a well-placed pond almost doubles the light source, although not all available light is reflected (some is absorbed or transmitted down into the pond).

The glare-angles and vertical windows continue to favor the low-angled winter light (more bounces off the pond, and then enters the window more directly with less scattering). And summer's hottest sun is partly absorbed by the pond, reflected away by the shallow angle that it hits the window, or excluded by the window openings / sills.

Ceiling reflectors of metal, foil, or glass; or even just bright white paint (with mica if you like natural glitter), can bounce light further back into the space and augment growing conditions for winter.



Adjusting for your latitude:

Sun angles change throughout the day because of Earth's rotation, and throughout the seasons of the year because the earth is tilted by 23 degrees. As we go around the sun, first the north pole tilts toward the sun, then the south pole. The tilt doesn't change much because we're spinning fast: like a gyroscope, but way bigger and steadier.

For math folks:

To find local sun angles for these key points,

- Find your latitude on a map or GPS. It is given in degrees N or S of the equator.
- For equinox sun angles, subtract your latitude from 90 degrees (gives sun angle at equinox noon, with 90 being directly overhead).
- For solstice sun angles, add 23 degrees to the equinox angle for mid summer noon (maximum local sun angle, shortest shadow). Subtract 23 degrees from the equinox angle for winter solstice (tilted away from sun).
- Sunrise / sunset is always 0 degrees (horizon) unless obstructed. This means that at higher latitudes, there will be a smaller angle of available sun overall. This is compensated for in summer by longer days (the tropics generally have a sudden sunrise and sunset around 6:00, am and pm, all year round). However, in winter the shorter days and lower angles add up, and we lose energy fast.

Climate observation is more important than precise angles. If you are within a few degrees of 45, you can use these general notes without re-calculating. It's more important to learn local patterns: when to expect excessive heat, cold, wind, or encroaching shade from the surroundings. If the only time you get frost is with an east wind, it may be more important to provide shelter on that side than to catch the eastern sun.

Maximum heat is not always best. Temperate climates are anything but - they can have extreme heat as well as extreme cold, and much variation between days and seasons. Consider when and how to exclude heat or light, and how

you plan to control overheating. Look for ways to offset extremes.

Consider climate-tolerant plants or animals to minimize the artificial controls you need to manage. The difference between tilapia and catfish, or yams and sunchokes, can be the difference between a full-time job and a nice winter vacation.

For non-math folks:

Look again at the sunroom drawings.

The sun angle change from summer to winter is always the same: 23 degrees each way from the middle angle. If you're at the equator, the goes back and forth almost directly overhead (and why do you need a greenhouse, anyway?). There is little change of seasons in the tropics. If you are higher up the curve, you are more diagonal to the sun, or even side-on at the poles.

The equator is called 0 degrees latitude, and the poles are 90 degrees. 45 is halfway in between. So if your number is smaller, you are closer to the equator, with overhead sun. Bigger latitudes are up toward the poles, with long shadows and longer sunsets.

Imagine tilting the building in the picture. For higher latitudes, tilt it farther away from the sun. Day length is a bigger deal farther from the equator, with short growing seasons but lots of summer daylight.

If your latitude is lower than 45, you are closer to the equator. Imagine tilting the building more toward the sun. In the tropics your angles and seasons are not as dramatic - so you might be trying to control day to day extremes more than seasonal variances.

Sunset and sunrise are still horizontal, so line them up parallel with the floor of the building.

Watch out for low-angled winter shadows from buildings or trees that can take a big bite out of your short winter sun exposure.

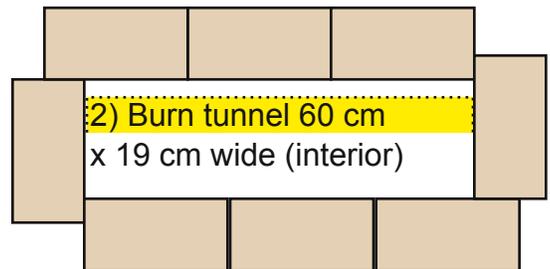
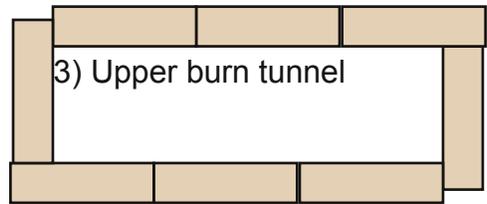
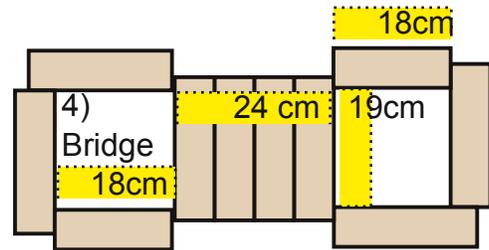
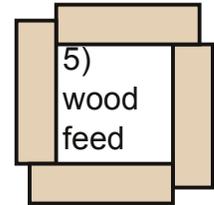
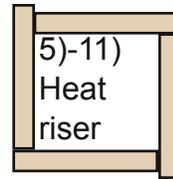
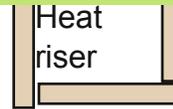
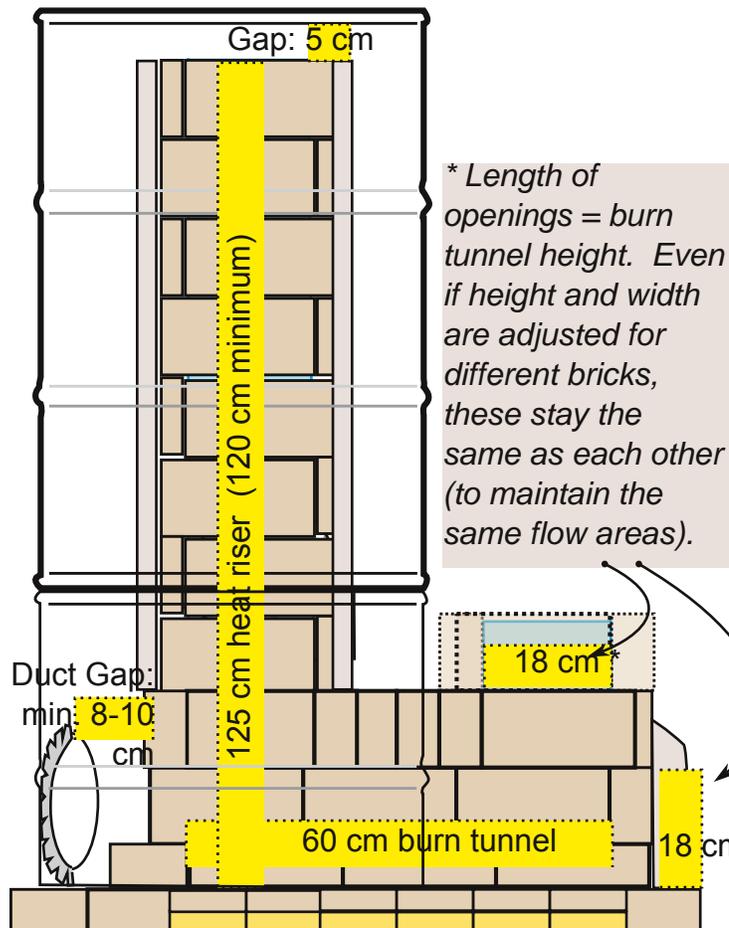
Sample Project A: 8" Rocket Mass Heater - Ontario

For our rational metric-using readers, the firebox dimensions are re-presented here in civilized format.

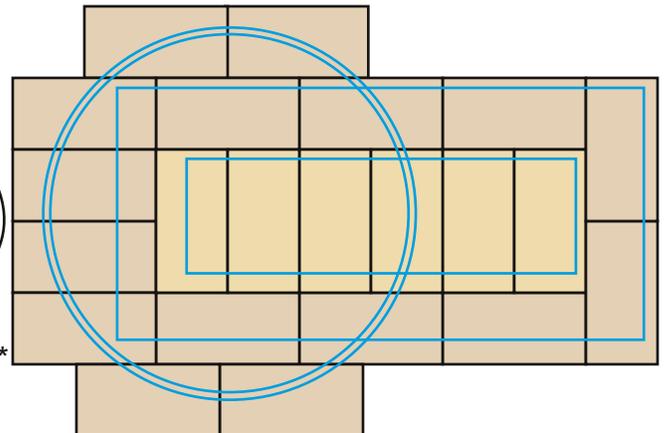
This heater was built as a demonstration project near Guelph, Ontario (Canada). Because of the site's shallow bedrock and poor drainage, the heater was built on a 24" (60 cm) fieldstone / gravel infill foundation.

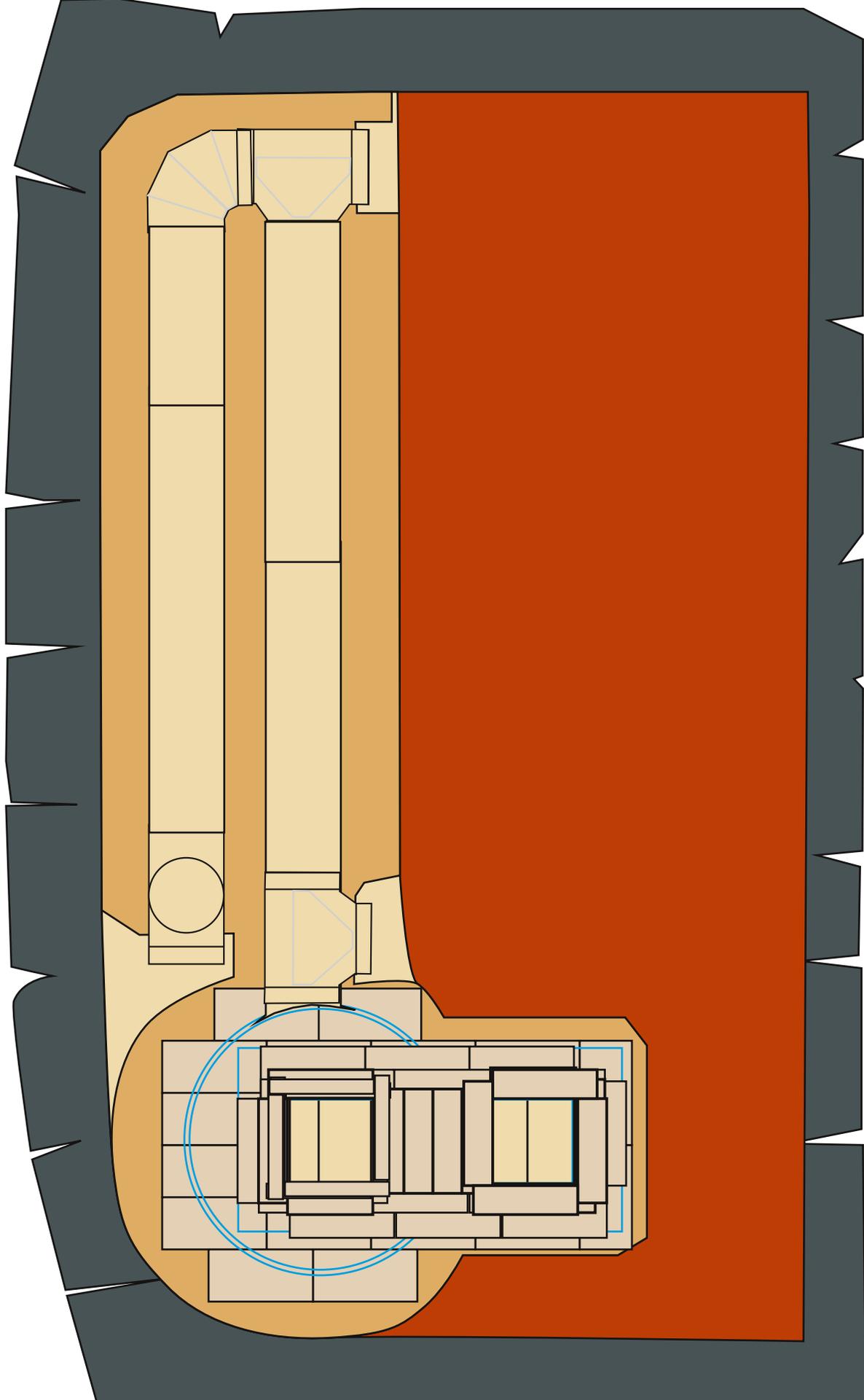
The project was built before the greenhouse walls. The entire heater is at the north end of the planned greenhouse; it will serve as a drying shed and sitting room, with 20 cm masonry (non-combustible) walls on all three sides of the heater, and a removable front wall across the front of the heater enclosure to share heat with the larger greenhouse.

Because the heater is intended to serve more as a dry space, and not a starting bench, earthen masonry was used for the bulk of the thermal mass. A tile or slate cap could be added to protect the heater from damp conditions if usage changes.



Course 1):
Brick pad over perlite insulation





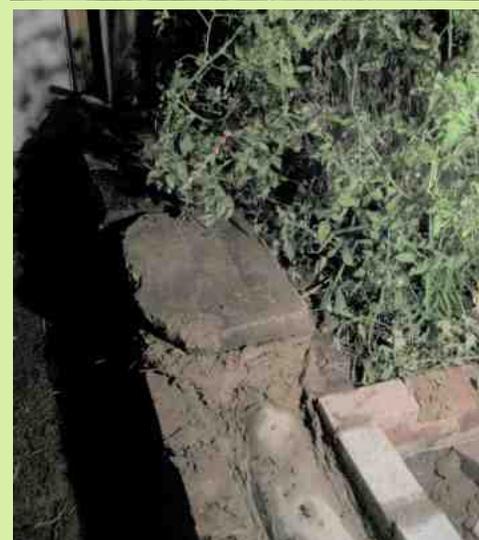
Sample Project #2: Greenhouse heater for north end of a combined hothouse / guest cabin.

Dark grey outline shows rock foundation for cob north walls and a flexible dividing wall between heated room and greenhouse area.

Brown and ochre areas show heater bench and earthen floor.

Barrel does not require clearances to masonry walls except for maintenance (don't bury it in a wall). Here we've allowed a 4" to 8" air gap around the barrel, ample room for easy cleaning or retrieval of dropped items.

Sample Project B: GREENHOUSE 8" Rocket Mass Heater



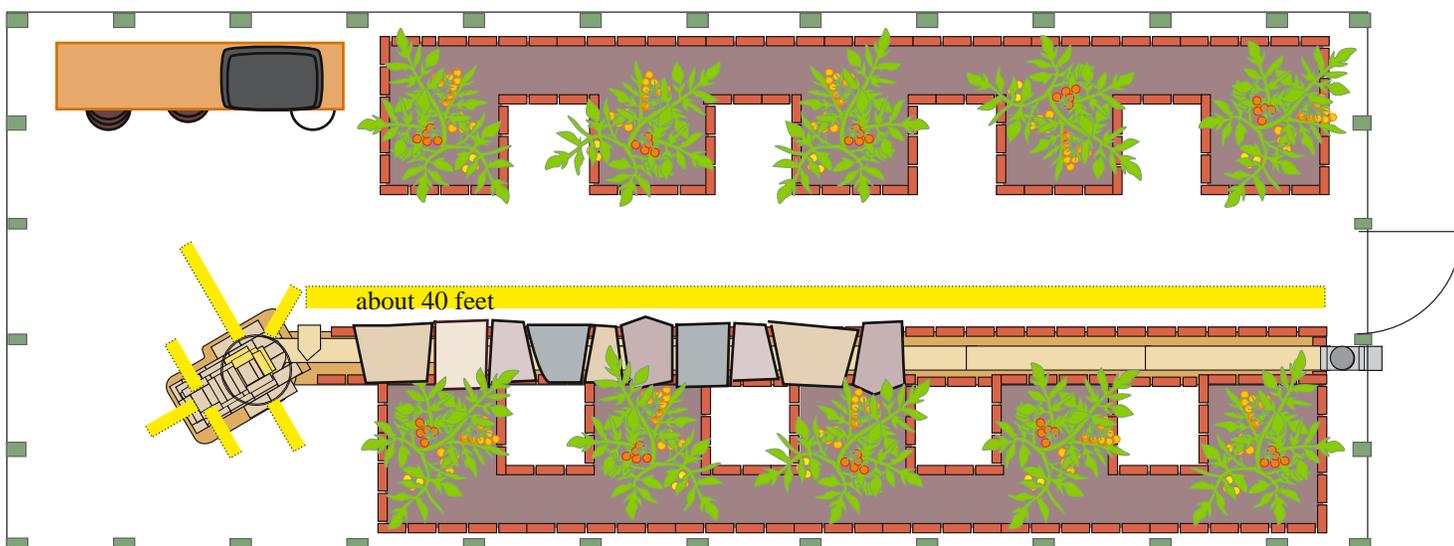
This heater was a 'rescue' project, repairing a few problems left by the original builders and maintenance volunteers.

Above: Cob (earthen masonry) softens when exposed to constant damp. This bench was used as a step to water plants hanging overhead, resulting in completely crushed ducting.

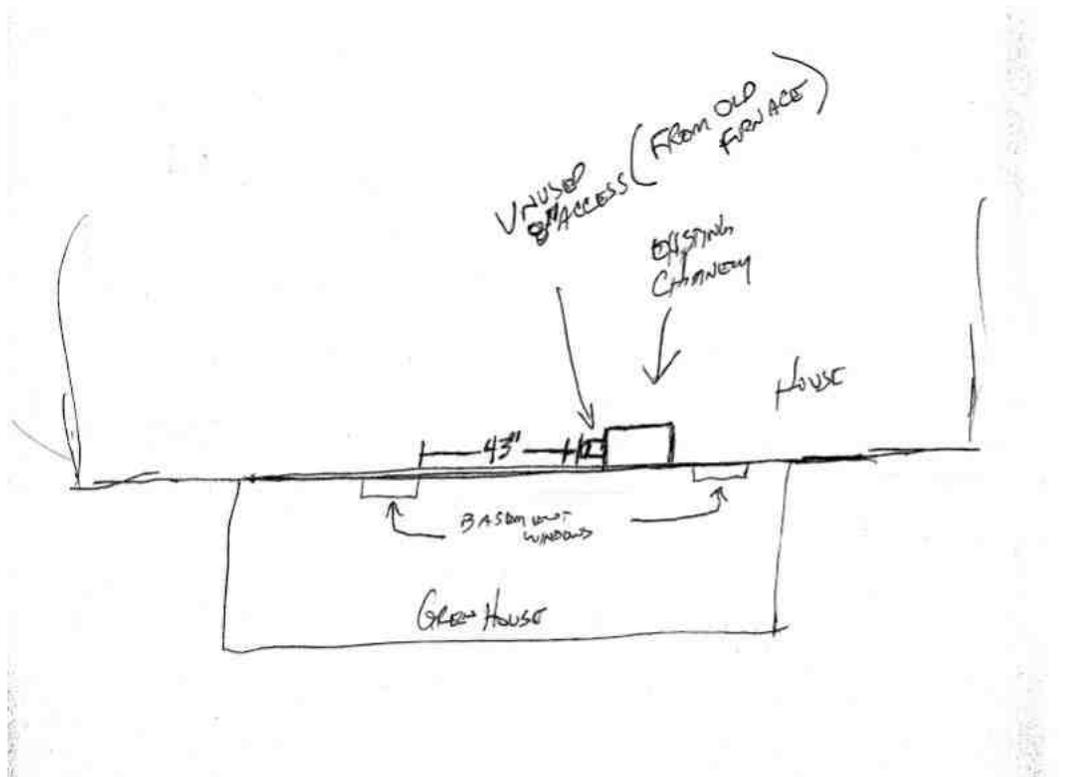
We replaced the crushed pipe, and re-set the channel within a load-bearing masonry box of bricks and sandstone (right).

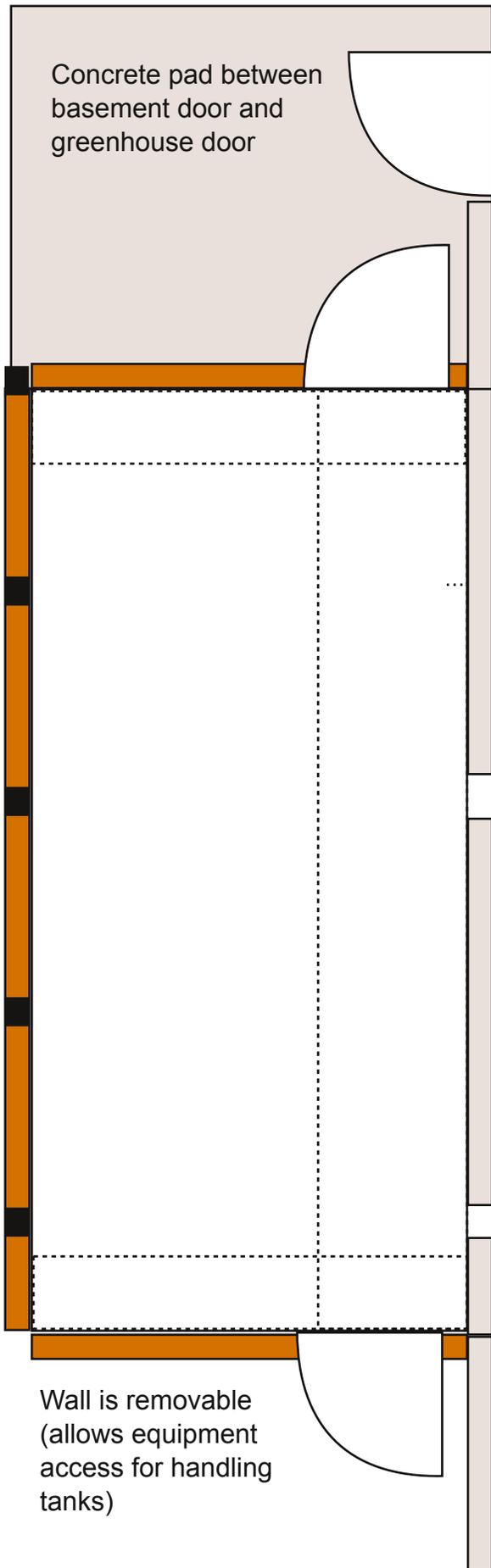
We also re-worked both the heat riser and exit chimney for better draft. We sealed leaks, enlarged flow volume in the manifold, and improved insulation around the original heat riser.

The exit chimney was originally horizontal, and tended to catch wind gusts spinning off a large building nearby. We rebuilt the chimney as vertical as possible: up inside the greenhouse for warmth, exit out the end wall, then vertical to above the roof.



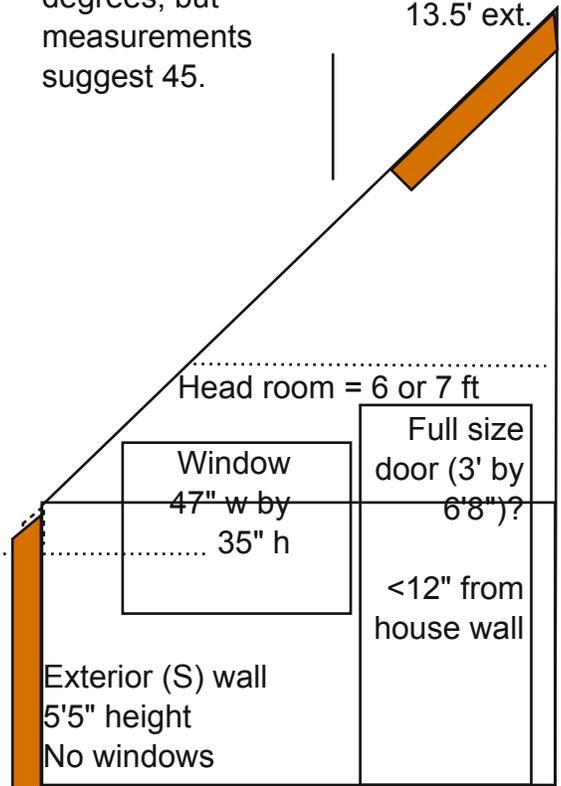
Mid-Atlantic Aquaponic Greenhouse Rocket Mass Heater, designed August - September 2014





Roof described as 50 degrees, but measurements suggest 45.

Height at tallest point: 13' interior, 13.5' ext.



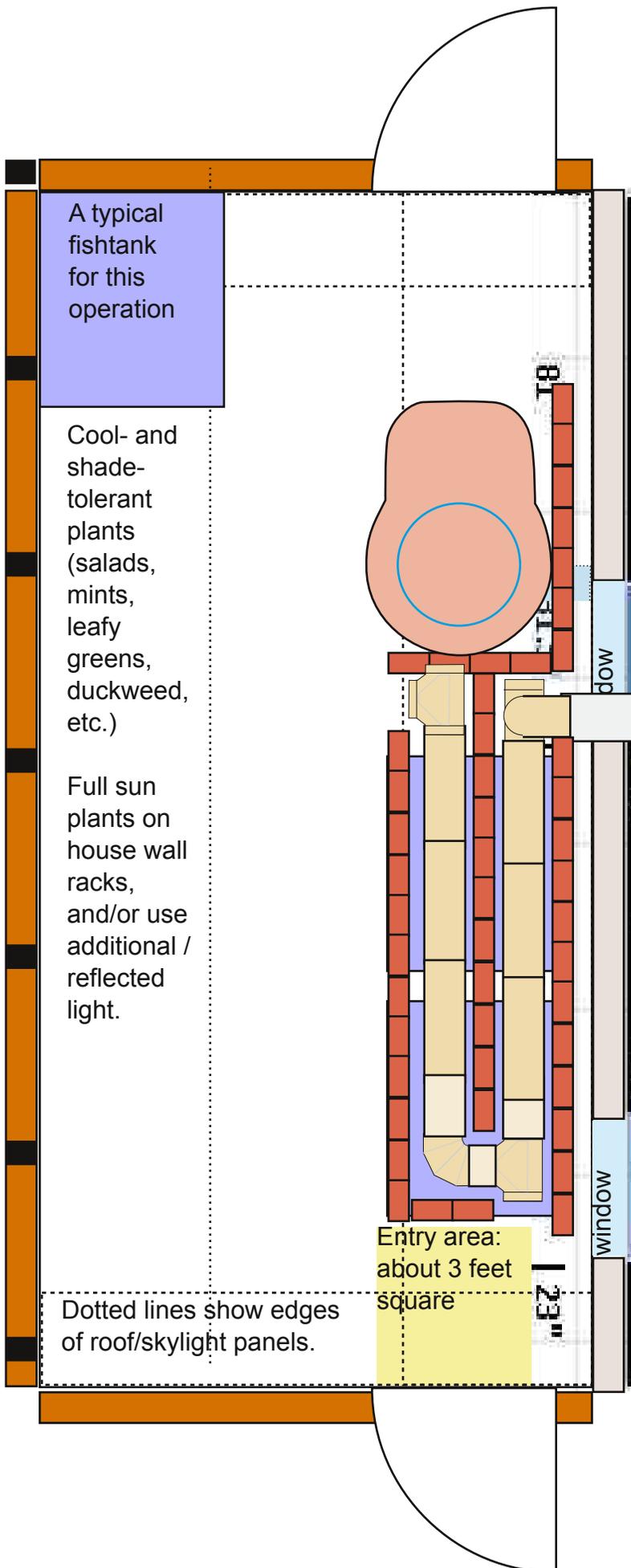
Goals include: Keeping tilapia at 70 to 80 F, year-round, in 2 to 4 300-g tanks (tanks also have electric heaters).

Growing staple foods year-round
Combination of soil, various hydro grow systems.

Diverting solar heat to main house when appropriate; venting to outdoors if excess.

Observations:

Note that cross-ventilation with house may not be appropriate while supplementing greenhouse heat with wood heat - the necessity of bringing in cold air somewhere to feed the ventilation cycle may result in a net heat loss, and/or negative pressure.



Clearances:

- Barrel: 4" masonry half-wall heat shield, with 4" air gap both sides, allows minimum 12" clearance from barrel to combustible walls.
- Hearth / fuel feed: 12" hearth, 36" clearance / walkway.
- Other masonry: 5" masonry thickness around channels, 4" air gap to combustibles (wall).

36" clearance if no heat shields. 18" with metal shields with 1" air gap.

Heat-exchange channels:
 Shown with 8" ID stovepipe, brick support walls, and earth infill for thermal mass.

Pale sections of stovepipe are

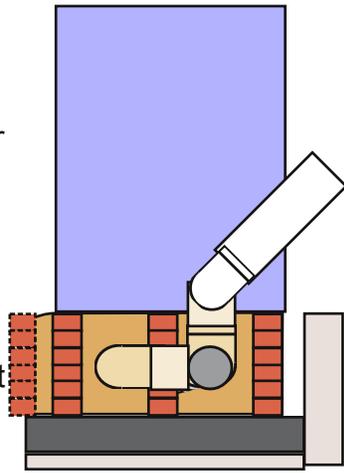
- 1) Silver: Class A chimney for wall penetration (may also use inside house for reduced wall clearances),
- 2) Buff: Other sections that may need to be adjusted to actual.

Dotted lines show edges of roof/skylight panels.

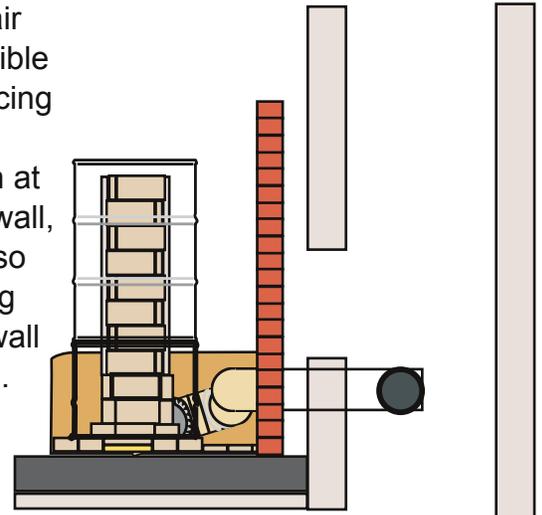
Fish tank footprint (3' x 3.5')

This top view shows 2 tanks oriented parallel to house wall

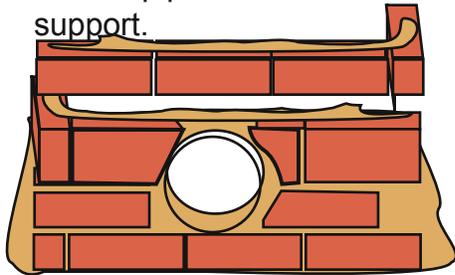
Bench: 16" tall brick walls support tank weight, protect pipes or channels under about 6" of dirt and/or pavers. May cap brick walls with 18" pavers if desired. Width: 30" minimum; must be wide enough to adequately support tanks. Dotted bricks show optional, unheated width (up to 48" wide).



Brick wall has 4" air gap from combustible house wall. If bracing is needed, avoid blocking air flow in at bottom, up along wall, and out at top. Also avoid heat-bridging where the shield wall is closest to barrel.



Detail: Work brick and mortar around pipes for best seal and support.



Dark circles show connection to an existing chimney. Depending on height of existing chimney inlet, the exhaust can be horizontal or angled upward (upward angles offer better draft).

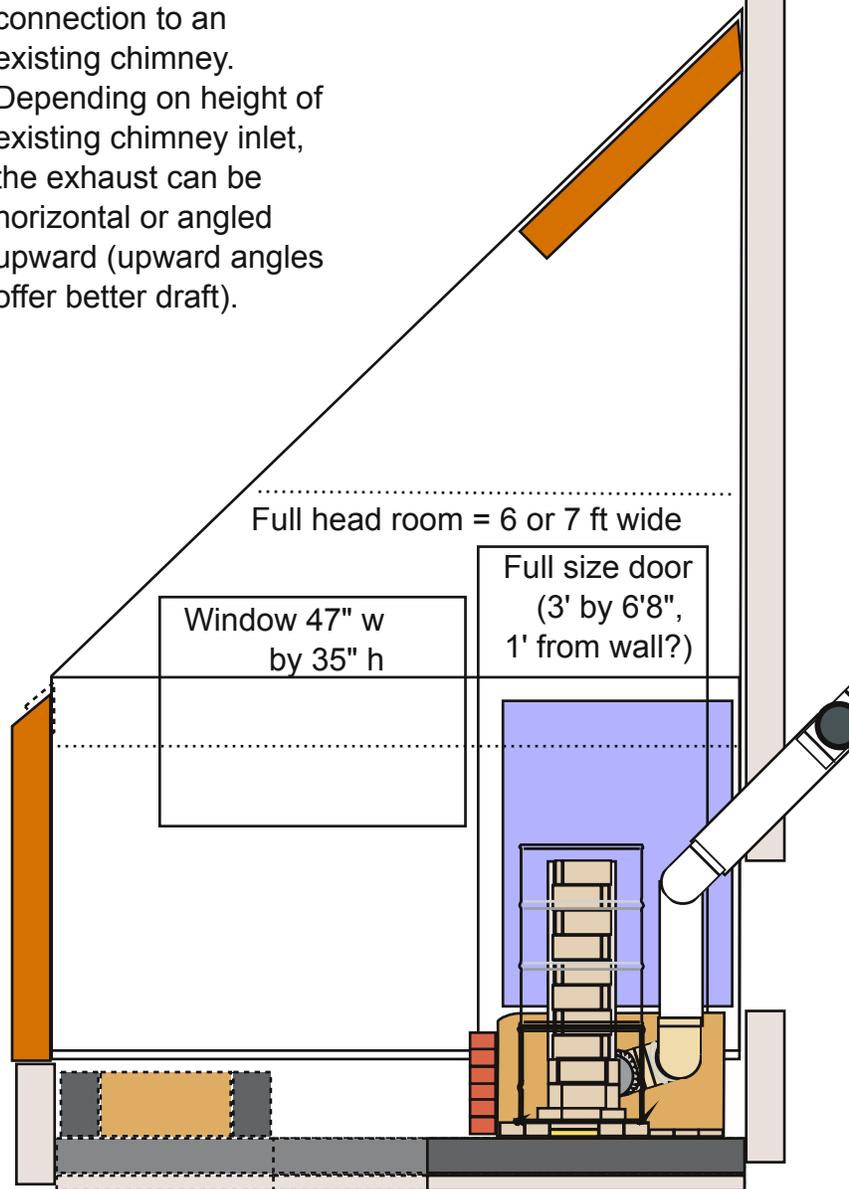
Footings:

- extend 6" beyond heater on all sides.
- Insulate below footings, or along perimeter.

- If desired, dig down to locate bench below door height (Shown at right). Make steps from door to lower walkway (shown; can collect some of the coldest air at night to protect plants and tanks), or back-fill with dirt around heater for level footing.

Point loads on footings are 133 lbs/sf for masonry bench, 240 lbs/sf for tanks, total 375 lbs/sf. Up to 500 lbs/sf for masonry up to 5 feet tall (e.g. heat shield wall).

We believe a slab about 6" thick will do the job, but we are not structural engineers. If you have any concerns about weight support, point or live loads, on this size of project it's cheaper to add extra inches of thickness than to hire an engineer.



Slab can extend for the entire floor (dotted), or just 6" beyond the edge of bench (solid).



For this project, the owners decided to dig out the dirt, so the heater would be near floor level.



They poured a concrete base pad (6" to 8" thick) and built a brick heat shield and support walls.





The firebox was laid using firebrick (similar color, but different dimensions and heat tolerance.)



A carefully-spaced gap allowed the lower barrel (manifold) to connect to pipe through the wall).

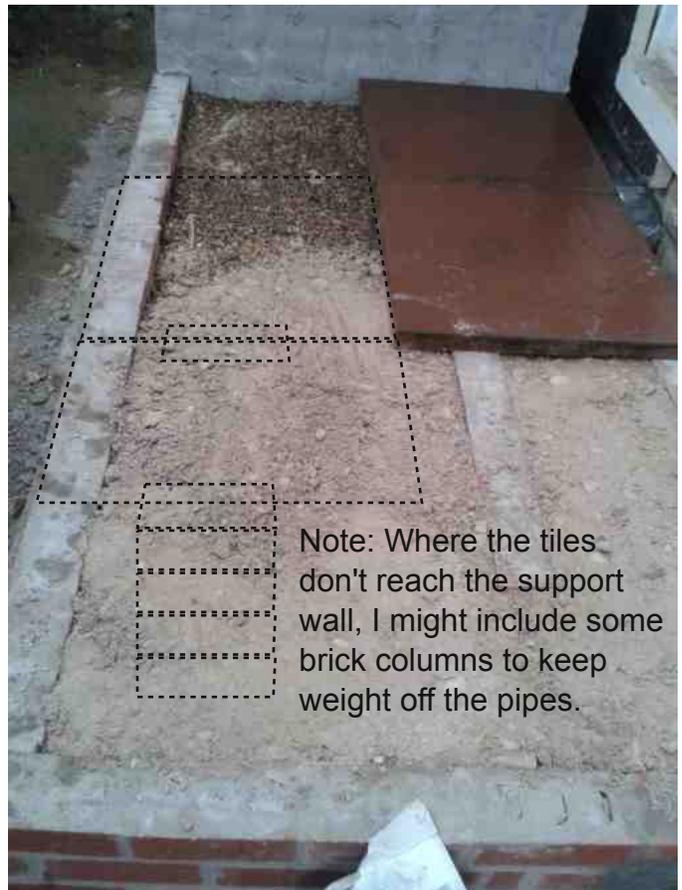




Here we see the pipes being laid within the brick box, including cleanout ports. Then it's filled in.



The dirt and rock fill are tamped down damp for dense heat storage. Big tiles protect the pipes.



Note: Where the tiles don't reach the support wall, I might include some brick columns to keep weight off the pipes.

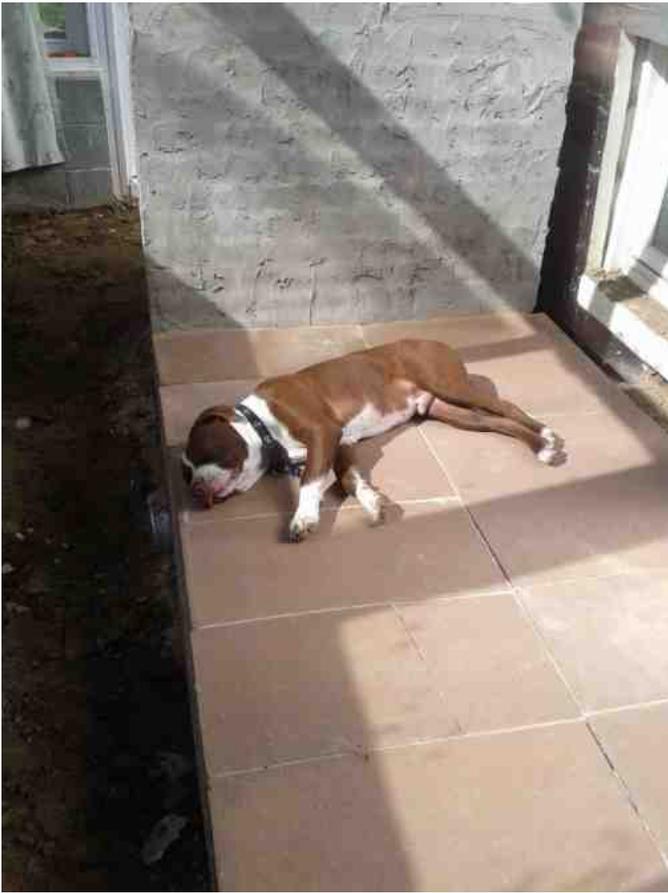


Not shown: a barrel is clamped onto the rim of the manifold, sealing the heater. After a successful test-fire, the area around the heater is insulated and backfilled with dirt. (Note: A utility box around those cleanout ports might help with seasonal maintenance.)



Above: The whole capped heater bed.
Below: Infilling dirt outside and inside the heater.





The heater has official approval. Note excellent placement to capture solar gain as well.



and now we see why this heater needed so much attention to weight support: fishtanks!



The brick wall around the barrel serves as a heat shield to keep the plastic fishtanks accident-free, and also as additional heat storage, turning that hot barrel output into steady warmth.

Water and masonry both serve as thermal mass, so these tanks will soak up sunlight and heat from the heater. The tanks are provided with thermostat-controlled electric heaters, but the sun and fire should reduce the heating costs substantially and provide a backup in case of power failures.

This heater was finished in October of 2014. In exchange for extra consulting time, the owners agreed to share these pictures. The first report after building up the heat reserve with 3 consecutive days of intermittent test-firing, the owner measured the mass temperature at about 130°F. We look forward to further reports about the heater's performance through the mid-Atlantic winters.

Greenhouse 8" Heater general parameters:
Footprint: Combustion unit 3 by 4 feet,
within a 7' diameter clearance to
combustible walls.
Bench 30" by 12 feet,
or 18" by up to 40 ft.

Ducting: 8" inside diameter
Duct length: 20 to 40 ft, with up to 2 90-
degree bends, effective drag length 30 to
50 ft.
Fuel feed: 7" by 7.5" wide, 16" tall

Bench volume: 2 to 5 cubic yards
Approx. weight: varies with length; dead
load at 18" height = 120 to 250 lbs/sf

Working temperatures:
Flame path: 1200-2800 F
Barrel surface: 200-800F (hottest at top)
Masonry surfaces: 60-100 F

This heater design has not yet been fully
tested, but is based on systems that have
proven reliable in the past. Please check
for updates as our test sites report back
from their first full year of use.

Yours,
Erica and Ernie Wisner
www.ErnieAndErica.info

Resources and Further Reading:

For wood heat in general, we suggest:

- www.chimneysweeponline.com
- www.woodheat.org

For masonry heaters in general, we suggest

- the Masonry Heater Association, www.mha-net.org
- ASTM standard E-1602 for masonry heaters

For rocket mass heater resources and free online technical discussion, we suggest

- the wood burning stoves and alternative energy forums at www.Permies.com
- the book Rocket Mass Heaters, by Ianto Evans and Leslie Jackson, www.rocketstoves.com
- and our own website's rocket stove pages (including discussions of site planning, permitting, and a free downloadable owner/operator/maintenance manual) at www.ErnieAndErica.info