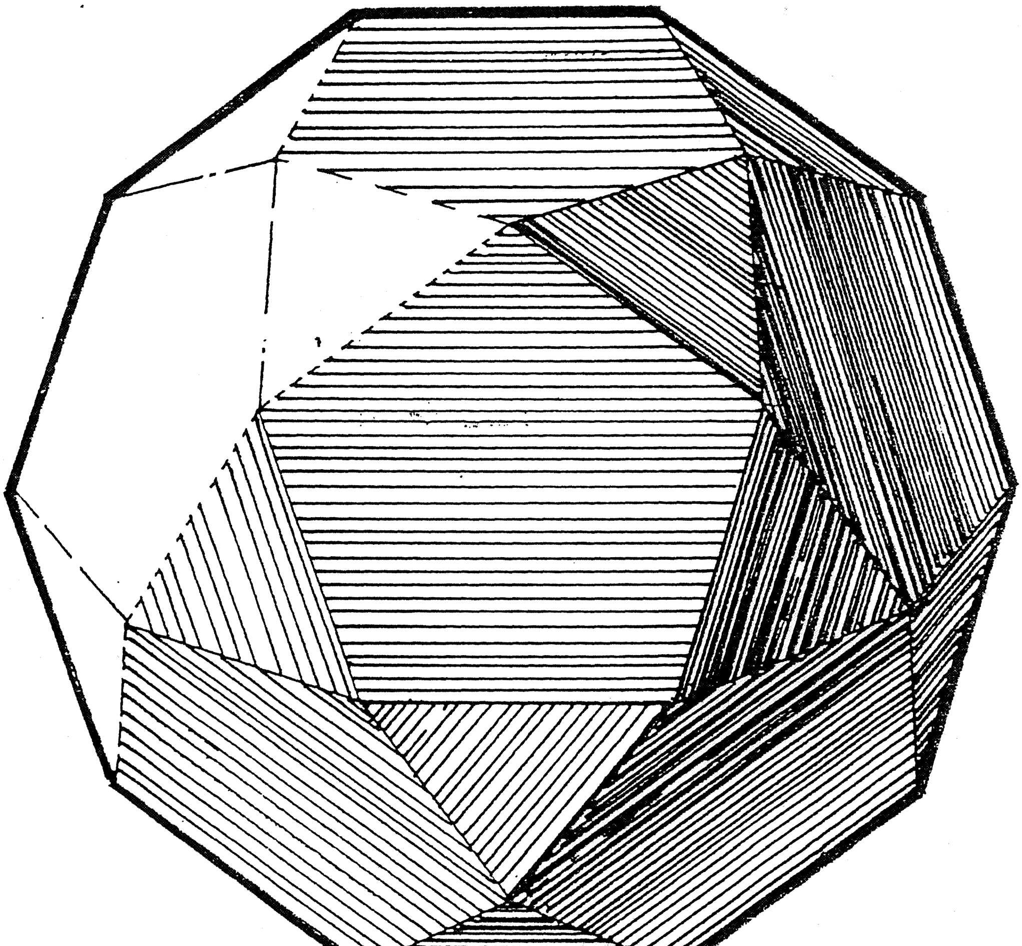
HOW TO BUILD A
SUPERINSULATED
HOUSE



COLD WEATHER EDITION
PROJECT 2020

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HOW TO BUILD A SUPERINSULATED HOUSE; Cold Weather Edition, P.O.Box 81961, College, AK, 99708

First, a Definition

A superinsulated house is one in which the temperature of the house is kept in the comfort zone mainly by the ability of the walls, ceiling, and floor to contain heat. Comfort in a conventional, minimally insulated house is provided mainly by the ability of the heating plant to produce and distribute heat to all parts of the house; superinsulation is a structural way of doing what can also be done with fuel and a heating plant.

Depending on what you know already, this booklet may contain all the information you need to design and build the superinsulated part of a superinsulated house--but only the heat containing part; we have very little to say about foundations, plumbing or wiring (except as relates to vapor barriers--often called "VB" in this booklet), finish work, etc. If you don't know how to frame a house in the conventional manner, you'll need to consult a carpentry book before the framing section will make much sense to you. Michael and I referred to Canadian Wood-Frame House Construction and Modern Carpentry .

We put this booklet together as we did on the assumption that if you understand what you're trying to do and why, you'll be able to figure out the details. We have suggested techniques to use for solving various problems; we hope that instead of locking you into ideas we'll give you the information you need to make up your own solutions to the problems that confront the housebuilder who wants to stay warm without paying for fuel.

Let me assure those readers who live in hot places that this book will still prove useful in most respects, but you must understand one thing: if you are mainly concerned with cooling your house instead of heating it, the vapor barrier needs to go on the outside of the insulation, rather than the inside. The rule is: VB goes on the warm side of the insulation, for either heating or cooling. So, if you mostly cool, the VB goes on the outside of the insulation. If you both heat and cool, put the VB on the inside.

What is R?

I constantly use the term 'R', sometimes saying 'R value', sometimes 'R factor', and sometimes just 'R' or 'R's'. R stands for 'resistance to heatflow'. R26 has twice as much resistance as R13. 3 1/2 inches of fiberglass has an R value of 11 or 13, depending on who makes it. If you stack a piece of R13 insulation on top of another R13 piece, you have insulation with an R factor of 26. With more R's, you have less heatloss; with less R's, you have more heatloss. If you divide 1 by any R value (1/R) you get a number which engineers call U. U tells how many BTU's will be lost in 1 hour through 1 square foot of an insulation of specified R value when the temperature on the warm side of the insulation is 1 degree warmer than the temperature on the cool side. 1 BTU is the amount of heat required to raise 1 pound of water 1 degree in temperature.

FRAMING/ SECTION I

The 2 Rules of Insulation

1.) Provide a continuous layer of insulation.

This rule is just common sense: if you want to contain water, make sure there are no holes in the bucket; if you want to contain heat, make sure there are no holes in the insulation. In practical terms, this rule becomes: make sure there are no holes in the insulation, and make sure there are no conductive materials-- wood, metal, ice, etc--going through it from inside to outside.

2.) Keep the insulation dry.

In more general terms, this might be stated: deal with the nature of the insulating material you're working with.

Insulation doesn't work when it's wet--you know that already: think of how you get cold when your clothes get wet. One commercial insulation, known variously as 'blue Styrofoam', 'Dow Styrofoam', 'extruded polystyrene', 'blue foam', etc., is not affected by water; all the rest must be kept dry.

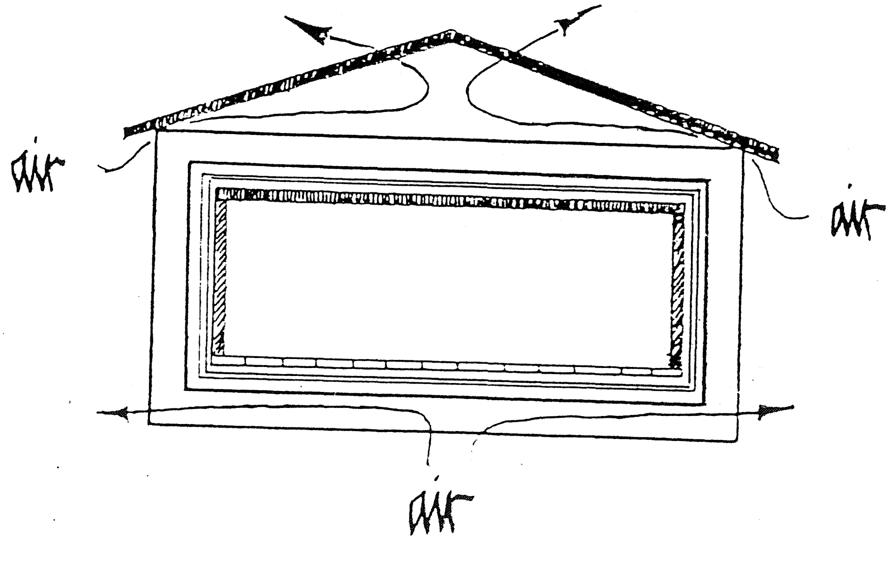
Rule 2 translates into practice as 2 techniques:

1.) On the warm side of the insulation, install a vapor barrier.

2.) On the cool side of the insulation, arrange for constant air circulation to remove any moisture which gets through the VB and into the insulation. If you made a perfect vapor barrier, you wouldn't worry about ventilation on the cool side of the insulation. In real houses, the vapor barrier is seldom perfect, so ventilation is usually necessary.

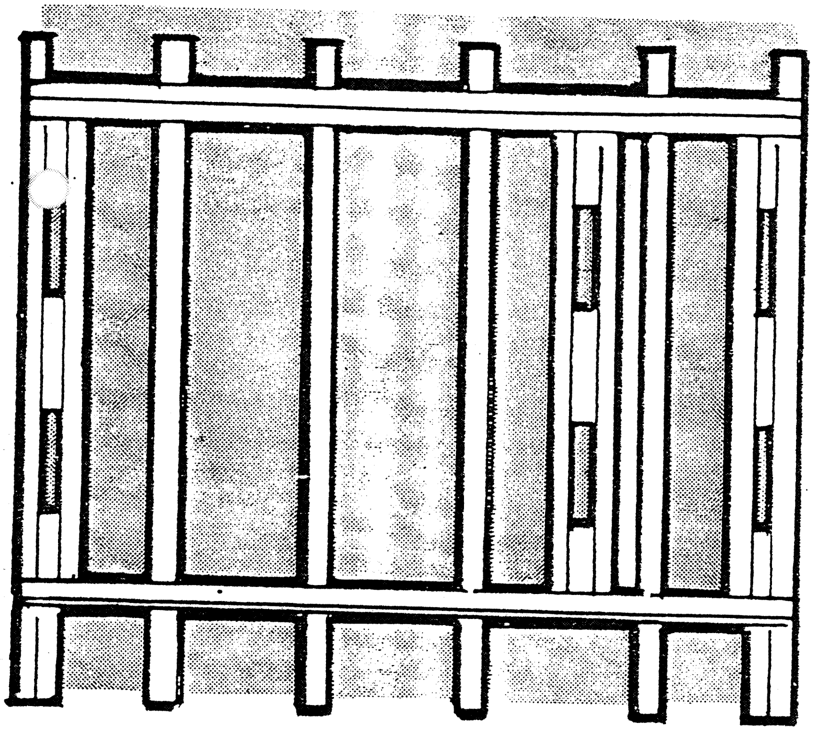
The attempt of the framing section is to show you some alternatives for a framing system which will yield a continuous layer of insulation, a hole free vapor barrier on the inside of the insulation, and constant ventilation on the outside. We don't mean at all to suggest that frame houses are the only way to build; but if you understand the problems and their possible solutions, you'll be well set to build any aboveground structure that appeals to you.

From inside to outside: interior sheathing, vapor barrier, insulation, exterior sheathing.



Problems of Conventional Structures

When insulation became a fad, people began to put more of it into framing systems that were originally designed for no insulation at all. 2X4 platform frame construction became popular because it is fast to put up, and that, along with its familiarity, remains its leading virtue. Balloon framing is better suited for superinsulation, but often has VB leaks at the junction of wall and 2nd floor. In general, conventionally framed structures have 3 kinds of problems:



Stud wall as radiator.

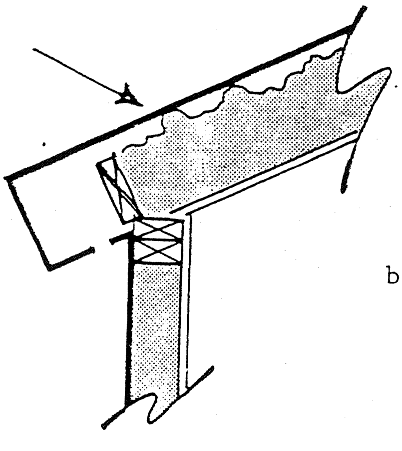
Conduction problems

If you were trying to build a wooden radiator with insulation between the fins, you'd build a 2X4 frame wall. Including the studs, bottom plate, double top plates, extra window and door framing, and sometimes firestop (you don't need firestop in a wall filled with insulation) the framing members often comprise 20% of a wall. When you figure in the R value of the wooden part of the wall (max of 1.55 per inch thickness), a so called R13 wall (3 1/2 inches of fiberglass) drops off to around R9 or R10. 'Energy conserving' houses often use 2X6 wall framing, spreading out the studs from 16" oc to 24" oc. That's a definite improvement, but has the same problem as the 2X4 wall: because of stud conductance, you don't get the R19 or R21 you paid for when you bought the fiberglass, but something more like R16 or R17.

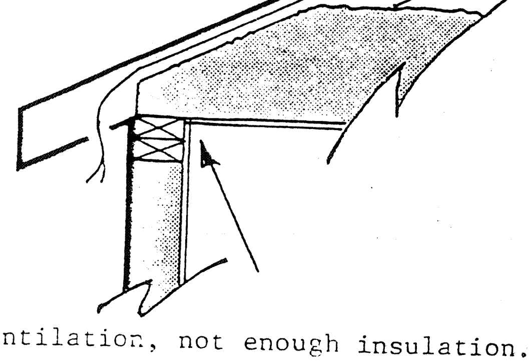
Ventilation problems

Standard roof trusses have their main problem right over the tops of the walls they sit on. There, at the shallowest part of the truss, there is simply not enough room for both adequate insulation and ventilation over the top of the insulation. Eave vents are often blocked.

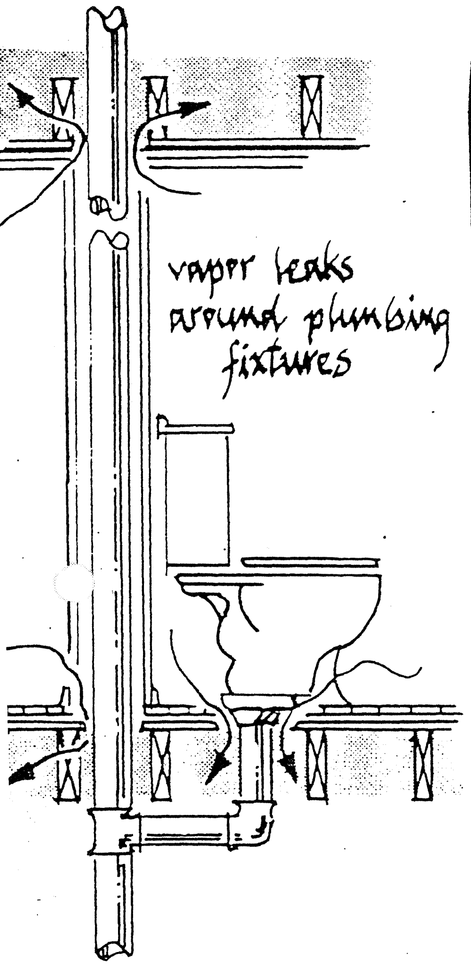
Standard flat roofs, shed roofs, and cathedral ceiling-roofs have problems as well. Unless specially designed, they are seldom deep enough for adequate insulation and adequate ventilation. There's just no way to put 16 inches of insulation and a 4 inch ventilation space into the cavities formed by 2X12's.

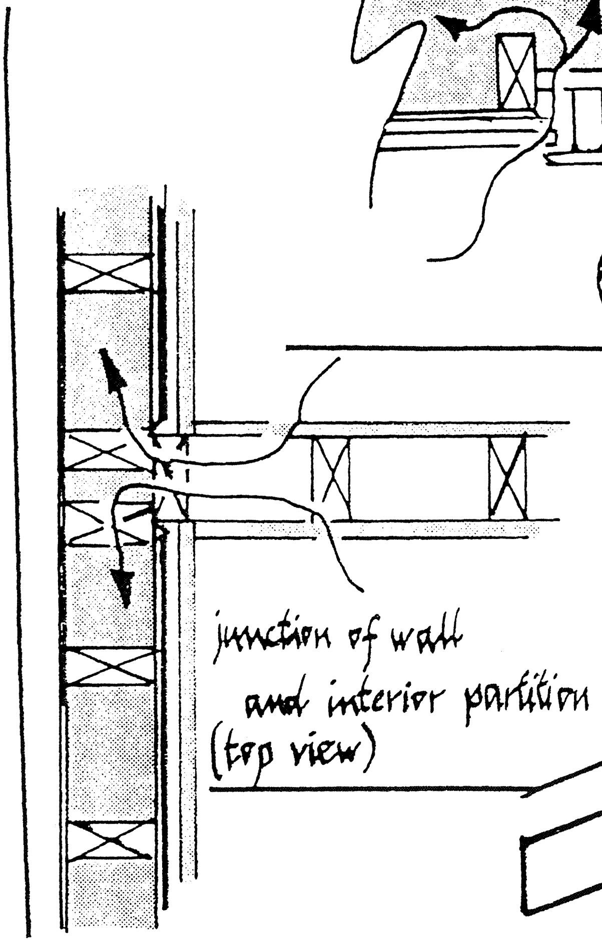


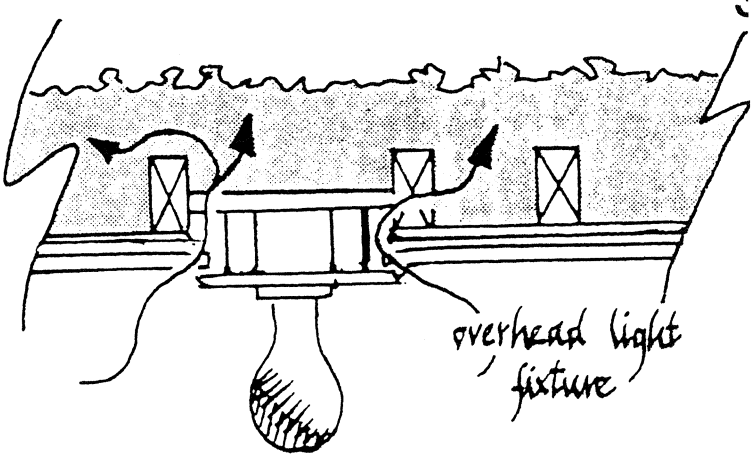
Insulation, but no ventilation.



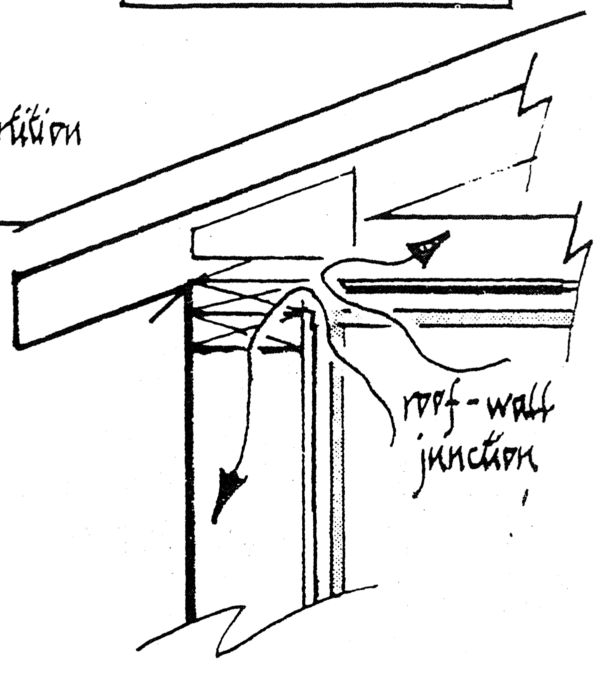
Ventilation, not enough insulation.







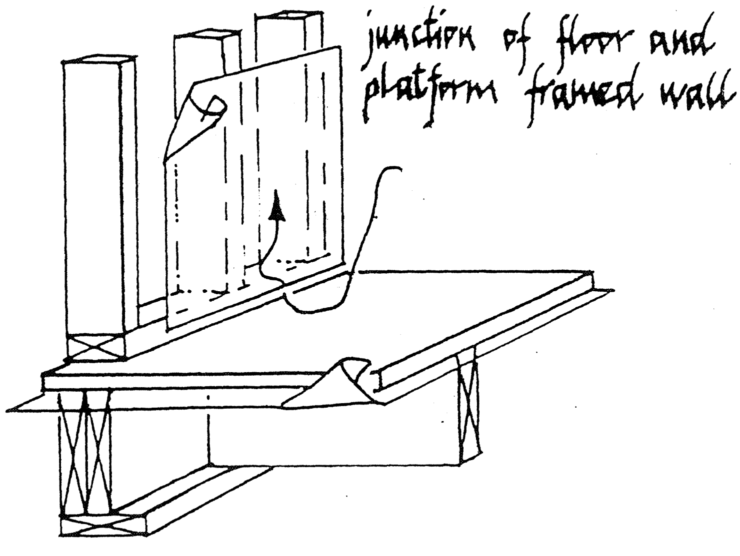
ALL THE ARROWS
show vapor leaks

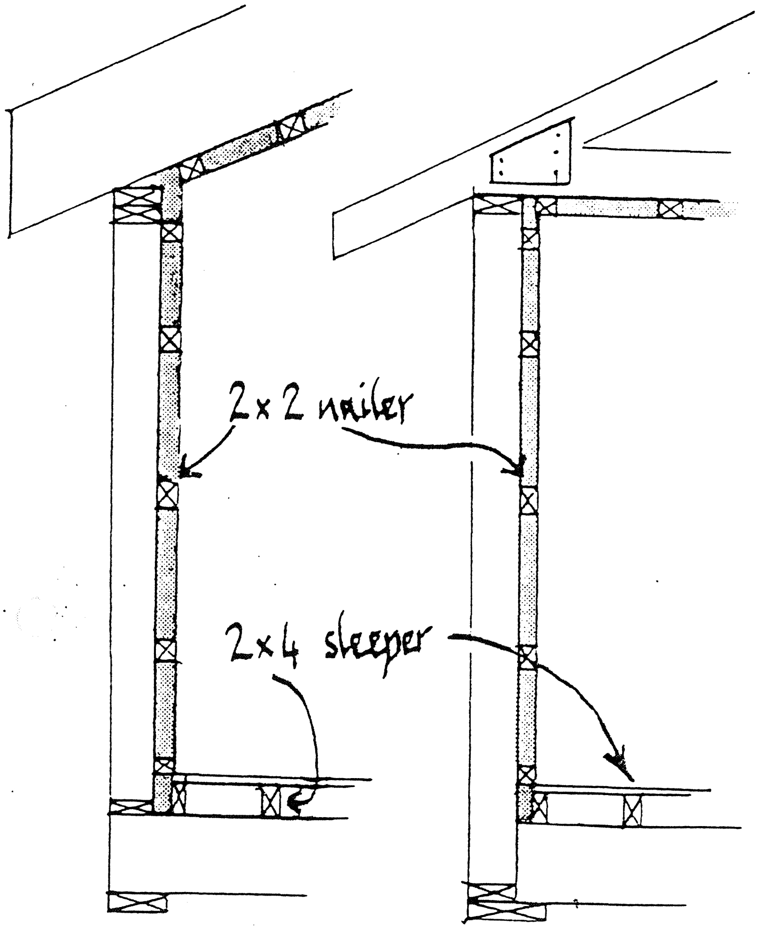


VB problems

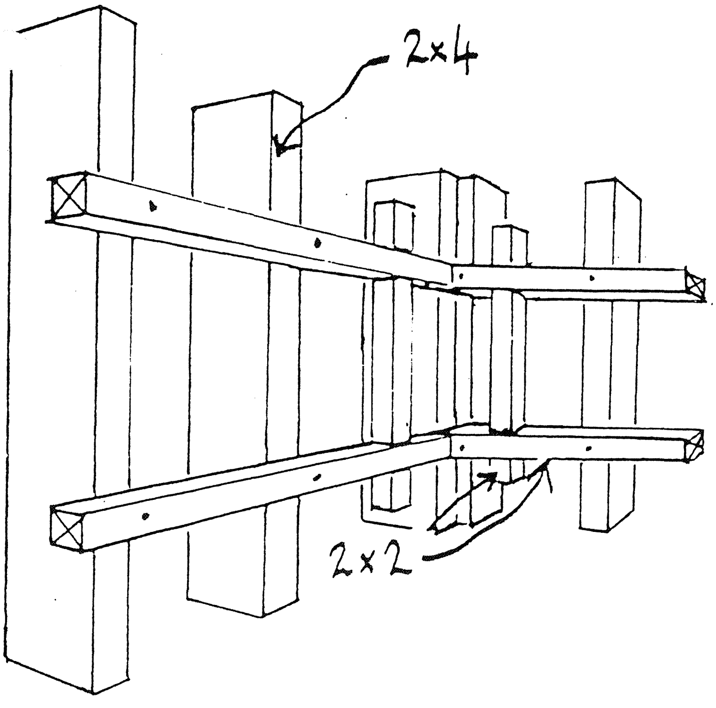
Standard frame houses have vapor barrier leaks all over them. Electrical ring continually crosses and recrosses the plane of the vapor varrier, seams are seldom sealed, the plumbing leaves gaping holes, and neither electrical boxes nor fixtures are VB's, since they have holes in them. Holes around vents, chimneys, and attic scuttle openings (best avoided completely) are seldom sealed, and there are almost always vapor leaks over the tops of interior partitions, and at junctions of walls and floors. With extraordinary care and labor, most of the holes can be patched, but very few people put that much tedious work into making a solid VB.

Enough of harping on what's wrong with the way houses are usually built: the rest of the bbook tells how to build them right. Anyone who wants to know more about the problems will find that the works of Axel Carlson and Ivan Branton (see biblio) discuss them thoroughly.. Onward!





2 applications of the crosshatch technique. Note platform frame on left, balloon frame on right.



Very little wood goes from inside to outside.

THE ALASKANDINAVIAN

What I call the Alaskandinavian cross hatch technique came originally from Sweden. Axel Carlson (see bibliography) carried the idea from there to Fairbanks, where it caught on rapidly.

To build a house using the crosshatch technique, you frame pretty much as usual, and then nail 2X2's perpendicular to the studs and joists. I have used this technique as a retrofit measure ('retrofit' is jargon for adding insulation to a house that's already built) in two houses. Here are a few tips that may not make much sense just now, but will if you start to build using this technique.

1.) 2X2's will often split if you try to nail through them close to the end; drilling a pilot hole is the surest way to keep them from splitting out.

2.) If you use platform framing, nail the bottom 2X2 to the studs above the bottom plate , and the top 2X2 below the top plates . This will stop conductance through those framing members.

3.) If you use this technique for new construction, you could make it go more smoothly by modifying the corner framing so that there's something to nail the 2X2's to. I've gotten around this by scabbing scrap pieces of 2X4 to the corner studs, and by staggering the 2X2's--neither of which is an ideal solution.

The main advantage of the crosshatch technique is that it significantly reduces heatloss through the framing members. It is reasonably easy to build, and doesn't cost a great deal more than conventional framing.

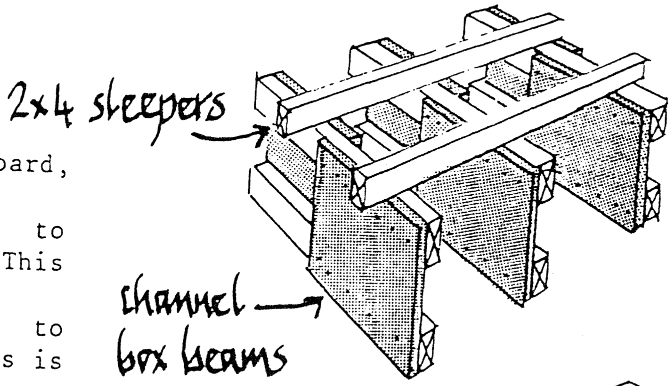
There are several problems connected with the technique:

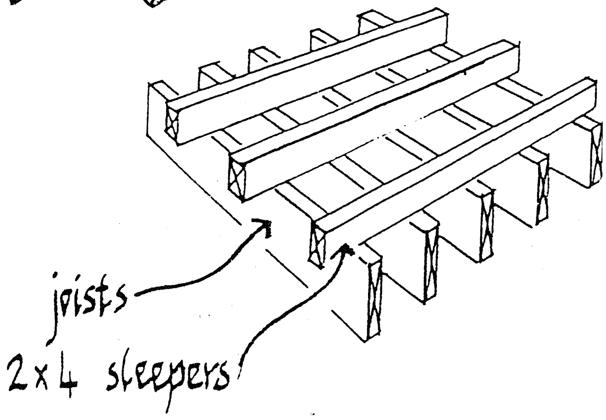
1.) The inside surfaces of crosshatched walls and ceilings will be flat and plane only if you use perfectly dimensioned lumber. Roughcut gives wavy surfaces.

2.) So far as I know, you can't buy 1

CROSSHATCH TECHNIQUE

2 crosshatch systems for roof or floor.





1/2 inch fiberglass insulation. Beadboard, however, will fit.

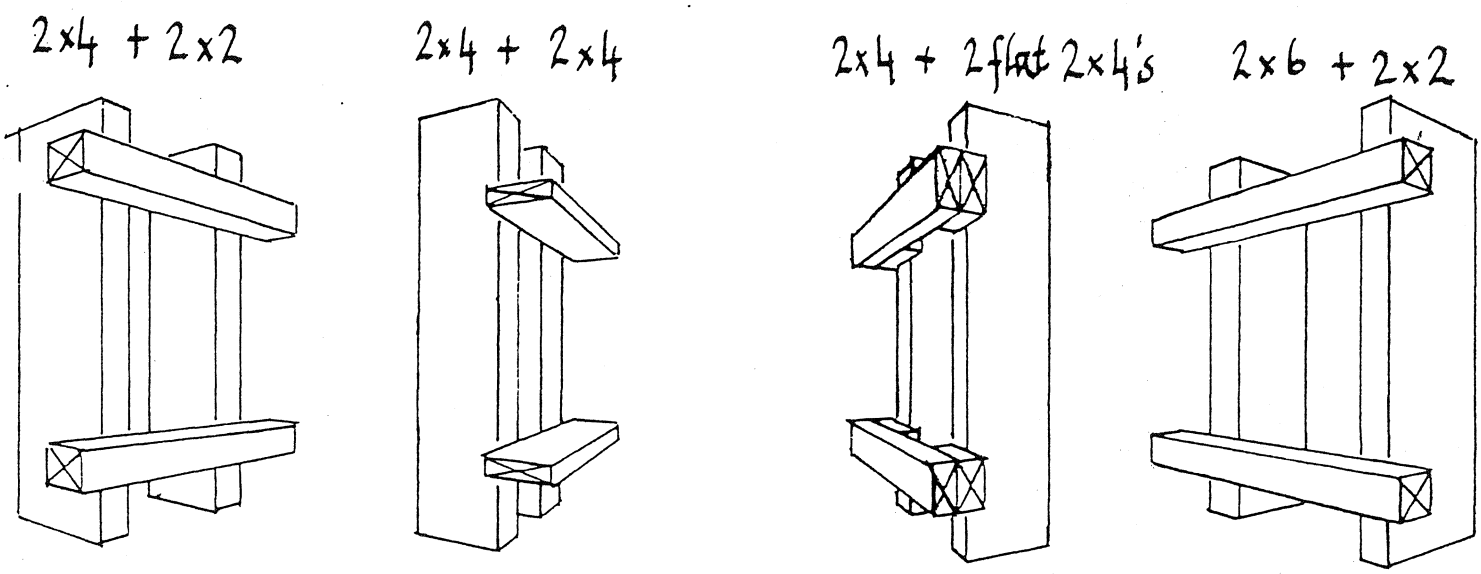
3.) The 2X2's have more bounce to them than 2X4 studs or larger joists. This makes sheetrocking more difficult.

4.) Door and window casings have to be custom made--prefab won't fit. This is a general problem with thick-wall houses.

5.) The technique doesn't make the framing around doors and windows any less conductive.

6.) If you put wiring in the walls, you have to add vertical 2X2's to attach the boxes to. If you put the wiring on the cold side of the VB, leaks are probable.

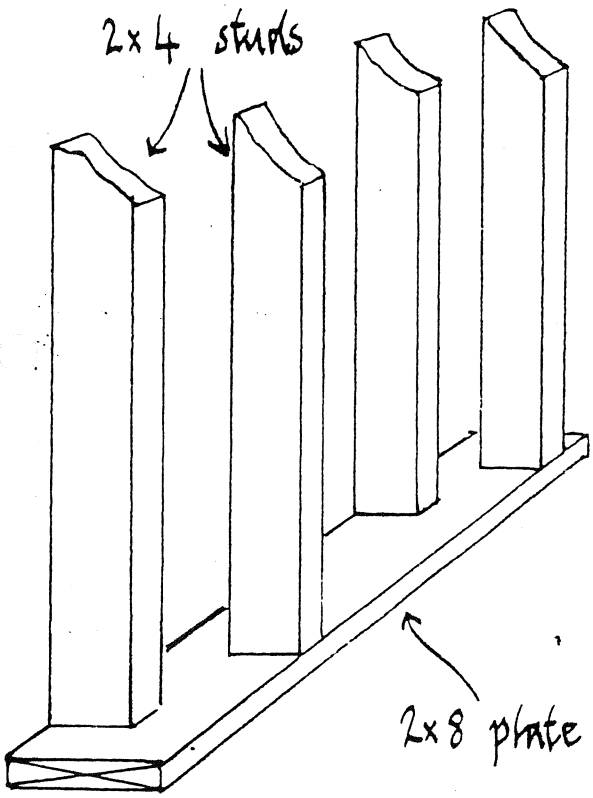
Variations



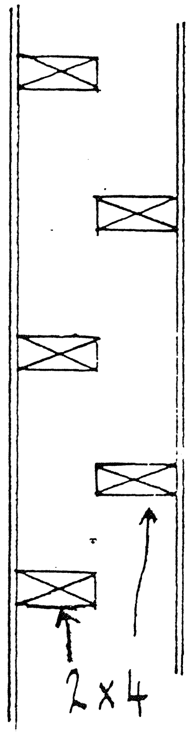
In Scandinavia, no insulation is installed in the cavity formed by the 2X2 nailers, but instead, the vapor barrier is located between the nailers and the studs or joists. The wiring and plumbing then go on the warm side of the vapor barrier, thus assuring a good VB.

In Fairbanks, everyone (to my knowledge) who's tried this technique has put insulation into the cavity formed by the nailers. Various builders have constructed walls of 2X4's plus 2X2's, 2X6's plus 2X2's, 2X8's plus 2X2's, 2X4's plus 2X4's on edge (to attach, the builder used a circular saw to cut birdsmouths in the 2X4 nailers, then nailed through the V notches with 16d nails) and 2X4's plus 2 flat 2X4's (so that the wall is 6 1/2 inches thick). The nailers can go on inside or outside. One local contractor has insulated warehouses using factory built panels of 2X4's plus 2X2's which folded so as to sit on a flatbed truck, and then were unfolded on site, filled with insulation, and set in place with a boom truck.

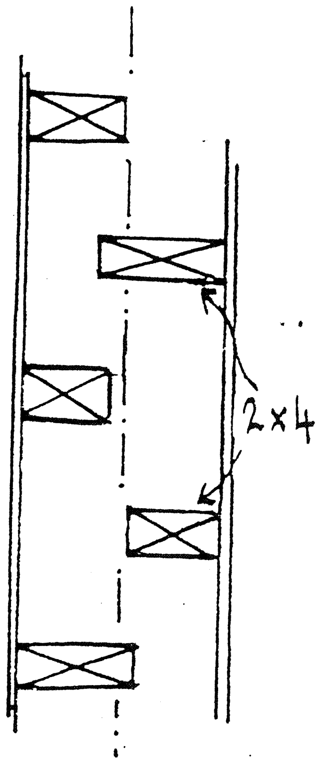
★★★★★★★★★★★★★ THE DOUBLE



Party wall



Party wall
(top view)



Roughcut

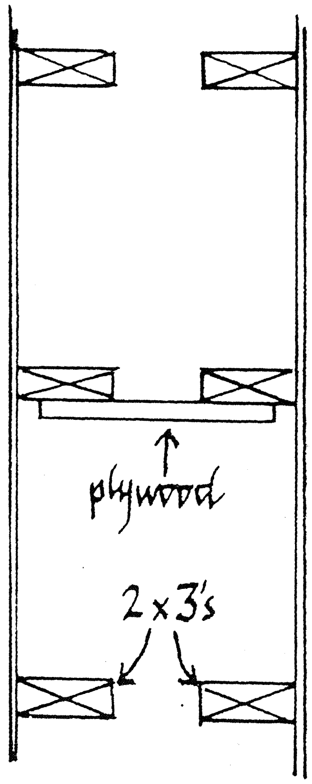
Rough dimensioned lumber causes no problems

I've never built a double walled house, but I've watched them being built and inspected the finished product.

The double wall technique is familiar to many as the party wall, often used between adjacent apartment units to keep sound from traveling through the walls. Many double walls are built as party walls--the studs are staggered and share common bottom and top plates. This still allows for conductance through the plates-- while the rest of the wall may be R30, three 1 1/2" thick bands of R12 run all the way around the house.

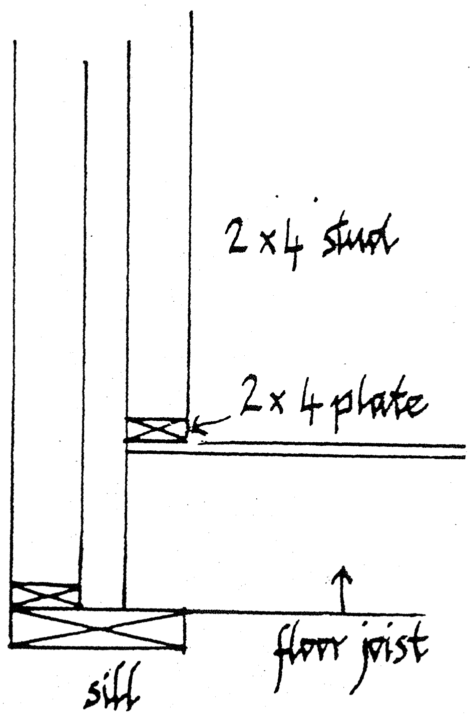
An improvement on the party wall design is the split plate wall, which essentially creates two separate walls. The studs can then be set apart to any distance you want--if you want a 24" thick wall filled with sawdust (R65, more or less), this is a good way to do it. As the pictures show, this technique lends itself to the use of roughcut lumber, since both inside and outside surfaces can come out flat and plane even tho the dimensions of the lumber aren't true. Double walled construction also lends itself to exploiting the best features of both platform construction and balloon framing. Especially in multistoried houses, it's nice to be able to install the floors one at a time and have a surface to work from; with double walls you can platform frame the inside walls, then balloon frame the outside walls to get the superior thermal performance which that method offers. It should be mentioned that with balloon framing, you can't use precut studs, which are cheaper than lumber sold by the foot--but if you go to roughcut lumber, the costs will come out about the same.

★★★★★★★★★★★★★★★★★★★



Double wall

With plywood gusset (top view)



Note platform frame on inside, balloon frame on outside

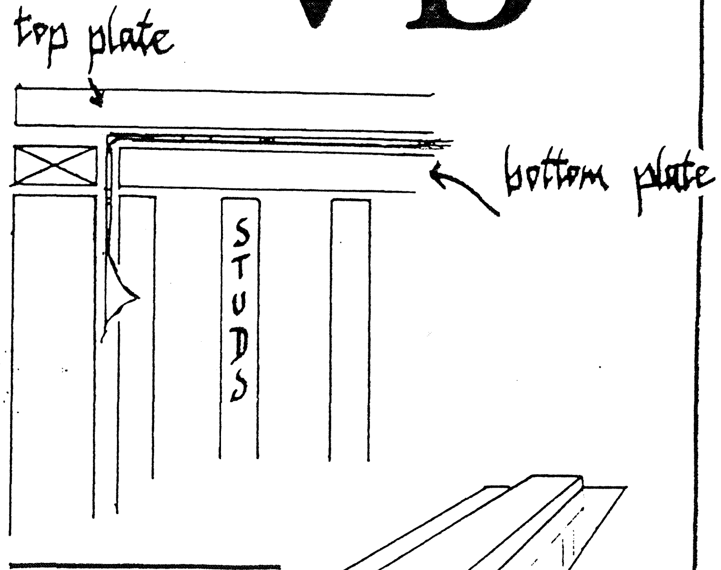
echnique is not really very well worked out; there are a large number
uild it, and if you understand what you're trying to do, it's hard to
inside nor the outside wall needs to be framed, of course--one or
of masonry, wood, or whatever. The important thing is to have a space

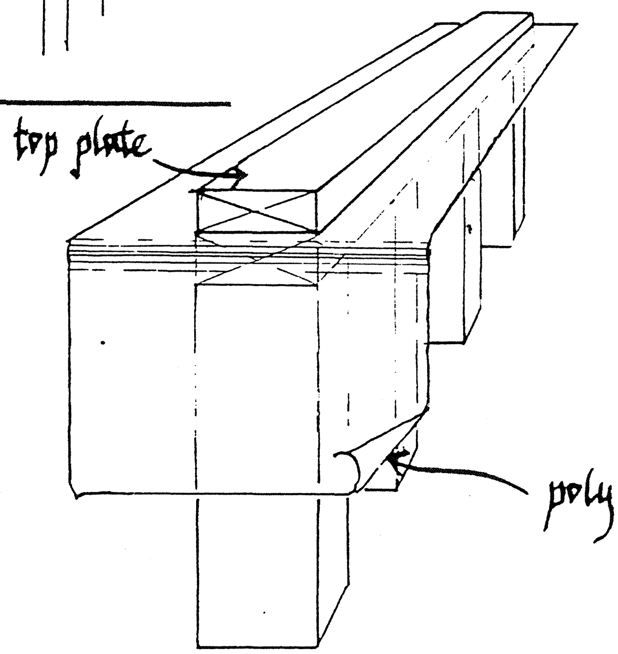
A Few Design Suggestions

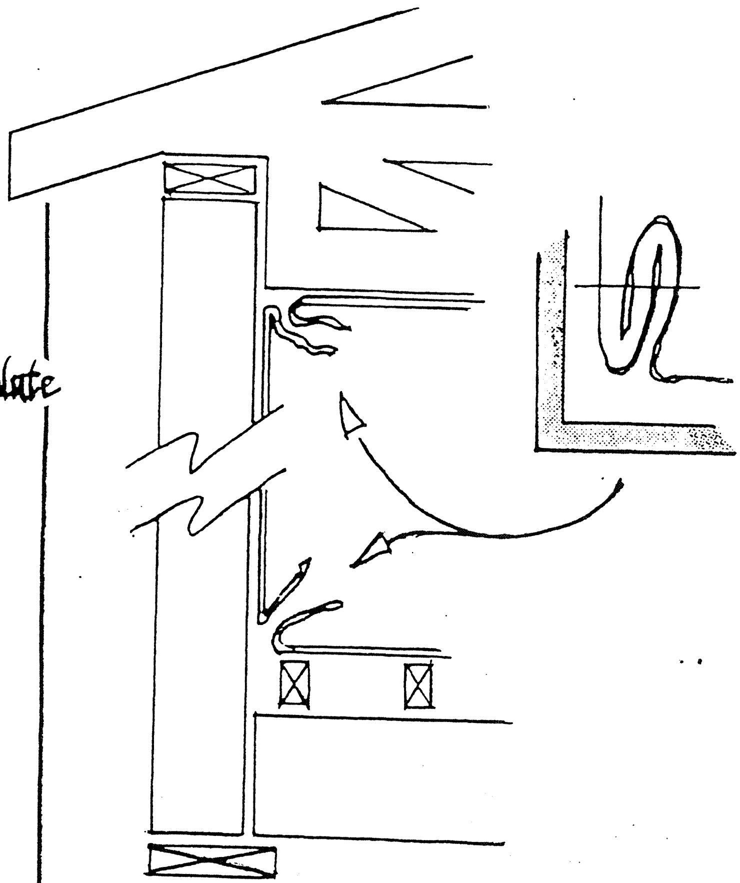
amount of materials used, you might space the studs more widely,
on the outside and 2' on the inside studs. Such an arrangement would
turally, tho the outside sheathing would need to span 4 feet.
the inside and outside studs do not need to be tied together; to
ight go to 2X3's or 2X2's and tie inside studs to outside studs with
iagonals, thus making a sort of truss. Rough 2X3's should be ade-
may have more bounce than desired; 2X2's definitely lack the neces-

ouble walled house builders have framed their windows so that the
ger than the outside opening. This puts a lot more light into the
tunnel feeling that a thick wall window can have. In both cases
the outside of the casing, leaving a large windowsill

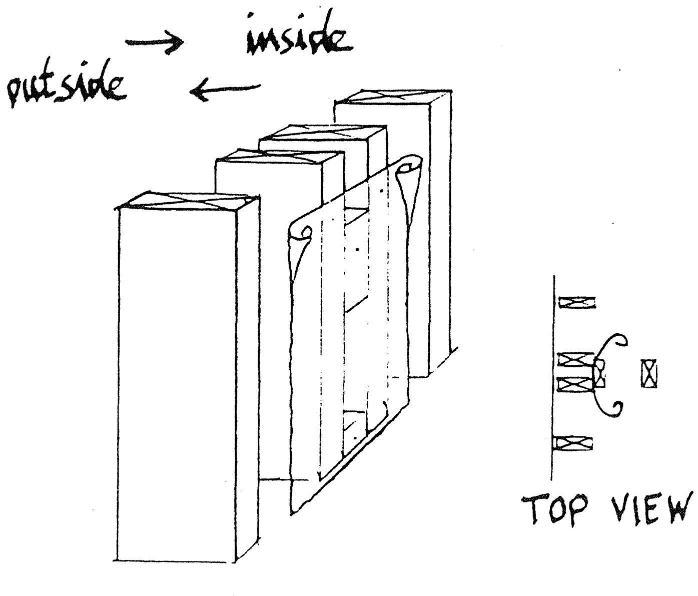
VB







The french seam: fold the poly as shown and staple thru the fold.
To the left: a solution to the problem presented by interior partitions. Install a 16" to 2' wide strip of poly between the top pl plates and down the wall, then attach edges to the large sheets.



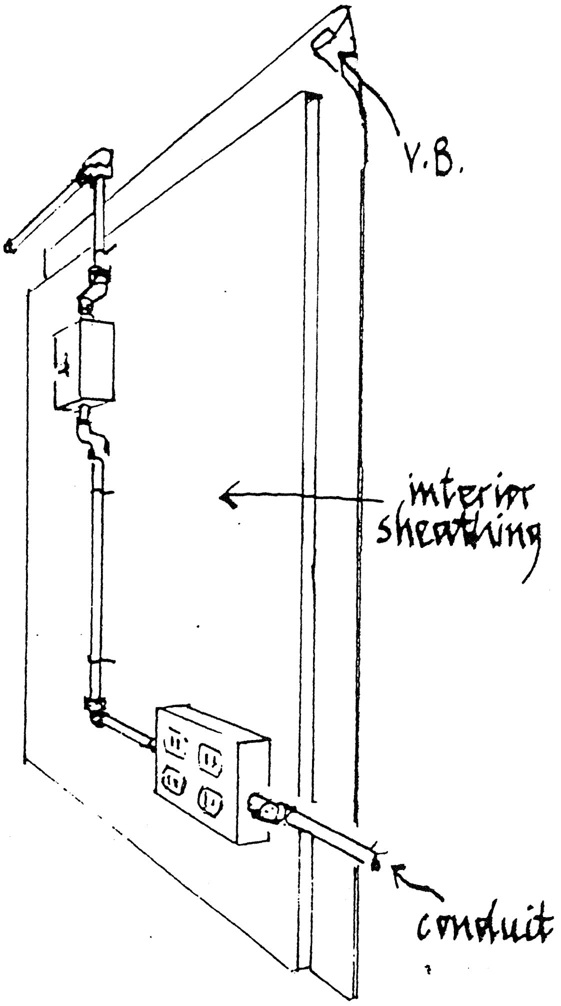
Interior partitions

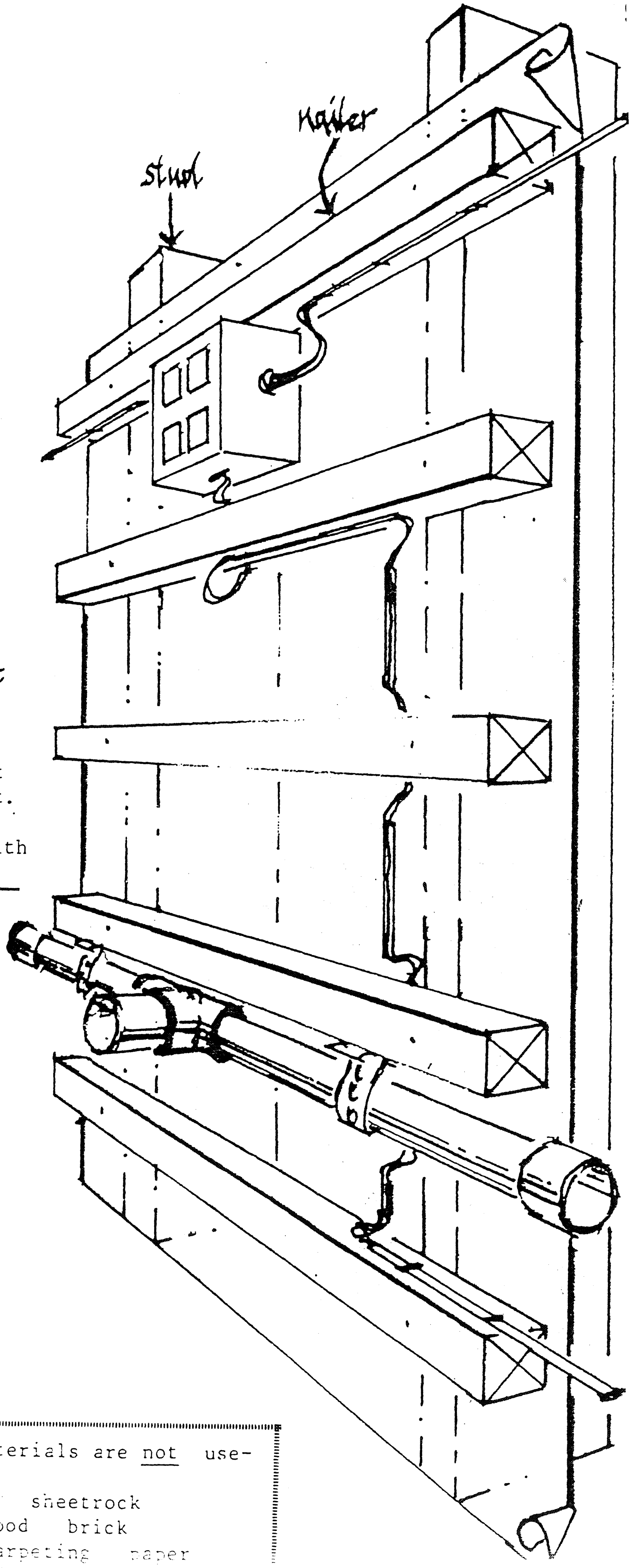
VAPOR BARRIER MATERIALS

Every material is to some extent a vapor barrier, but for housebuilding purposes, only a few materials are useful VB's. Here are the most common of them:

Polyethylene, a plastic film made of petroleum, can be bought at lumber yards and hardware stores. It's sometimes semi-transparent, sometimes black, and sometimes reinforced with nylon cord, and comes in rolls of greatly varying widths, lengths, and thicknesses. Thicker stops water vapor better than thinner, costs more, and gets torn less easily. In most cases, you want to work with sheets as large as you can handle-- pieces that will cover a whole ceiling and drop down to catch a wall or so. Sealing seams is a lot of work, and with thicker poly (6-10 mil) french seams leave bumps. Tape and spray adhesive work, but you have to pay for them.

Aluminum foil is a perfect vapor barrier, so long as it doesn't oxidize or get torn (No data on time of oxidation, sorry). It's available locally in 3' wide





2 solutions to how to wire a house without damaging the vapor barrier. Above: conduit. Decorator conduit--wiremold--is available. To the right, the crosshatch technique, with VB behind the nailers.

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rolls. Seams need to be taped with VB tape, which you'll have to locate on your o . Foil is quite cheap, especially when it can be used as vapor barrier and reflective insulation at the same time.

Butyl sheeting is what Malcolm Wells recommends for underground construction (see bibliography).

Glass is a perfect VB, or nearly so.

Dow Styrofoam is very close to being a perfect VB.

Some paints are vapor barriers (no more data presently available).

Tar and tar paper are semi-vapor barriers. They're not good enough VB's to put on the warm side of the insulation, but they're too good to put on the cold side. Even 15# building paper should probably have a few holes poked in it to allow a vapor escape path from the insulation to the outside air.

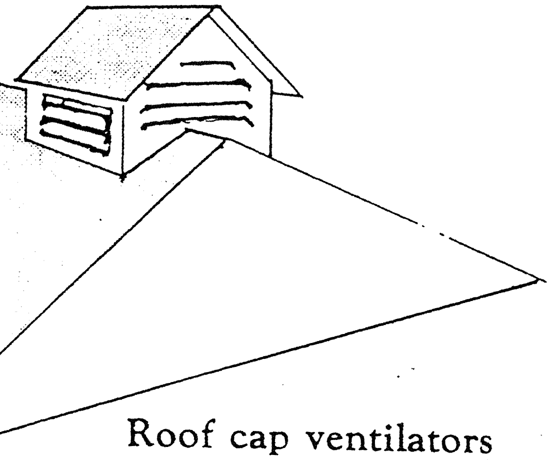
The following materials are <u>not</u> useful vapor barriers:

dirt rocks sheetrock
concrete wood brick
plaster most carpeting paper

ROOFS

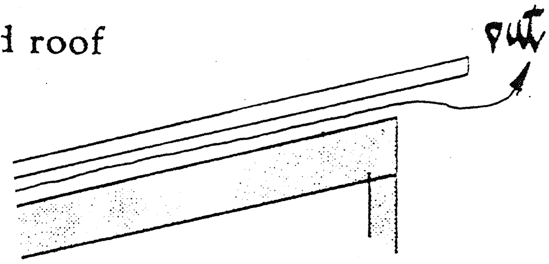
The main problem we confront in designing a roof is how to build a cavity that is deep enough to allow both enough insulation and a space for air circulation over the top of the insulation. In Fairbanks, 12 inches of cellulose or fiberglass (R45, roughly) is considered minimum insulation for a roof, and some people are going to 16 or 18 inches (R60-R70). In addition to that measurement, we want a few inches of air space on top of the insulation.

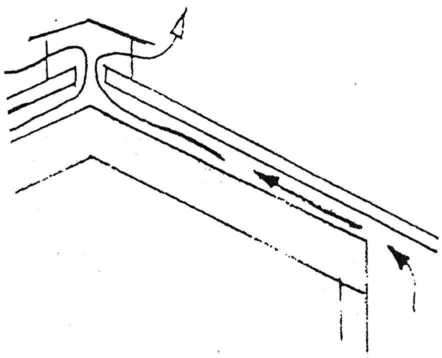
Generally, you want to bring air in at the eaves, no matter what style of roof you build. With a pitched truss and flat ceiling arrangement, the air escapes through ventilators in the gable ends. It is said that the ventilator area should be at least 1/150 of the roof area. With a pitched roof where the line of the ceiling follows the line of the roof, you need roof cap ventilators at the peak of the roof. In the case of a shed or flat roof, air can come in on one end and go out the other. To keep out insects and rodents, vents need to be screened.



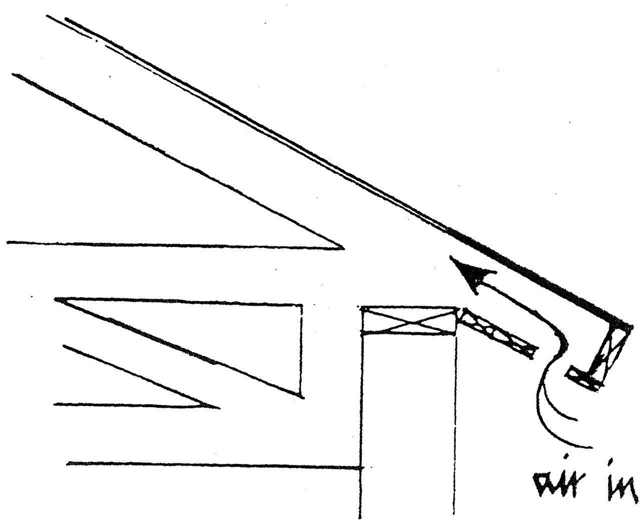
Roof cap ventilators
or cathedral style roof

d roof

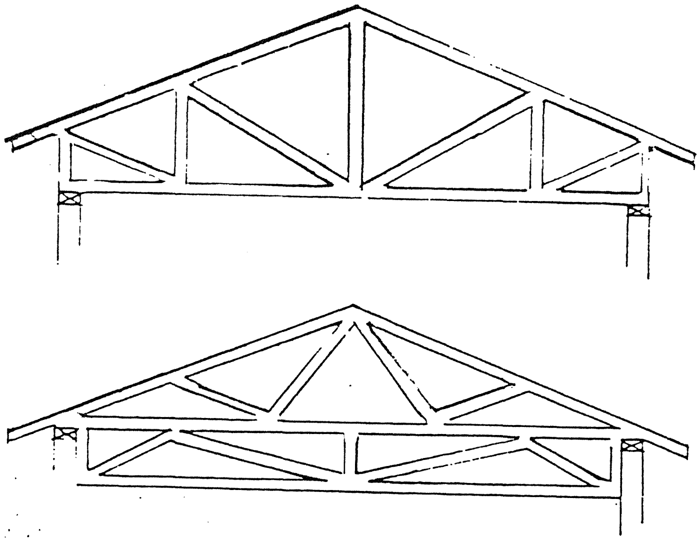




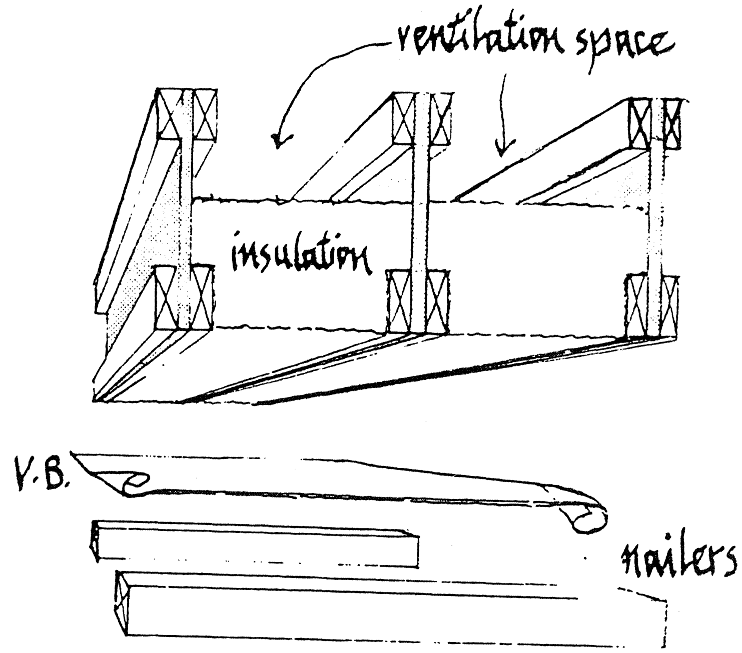
f cathedral style roof



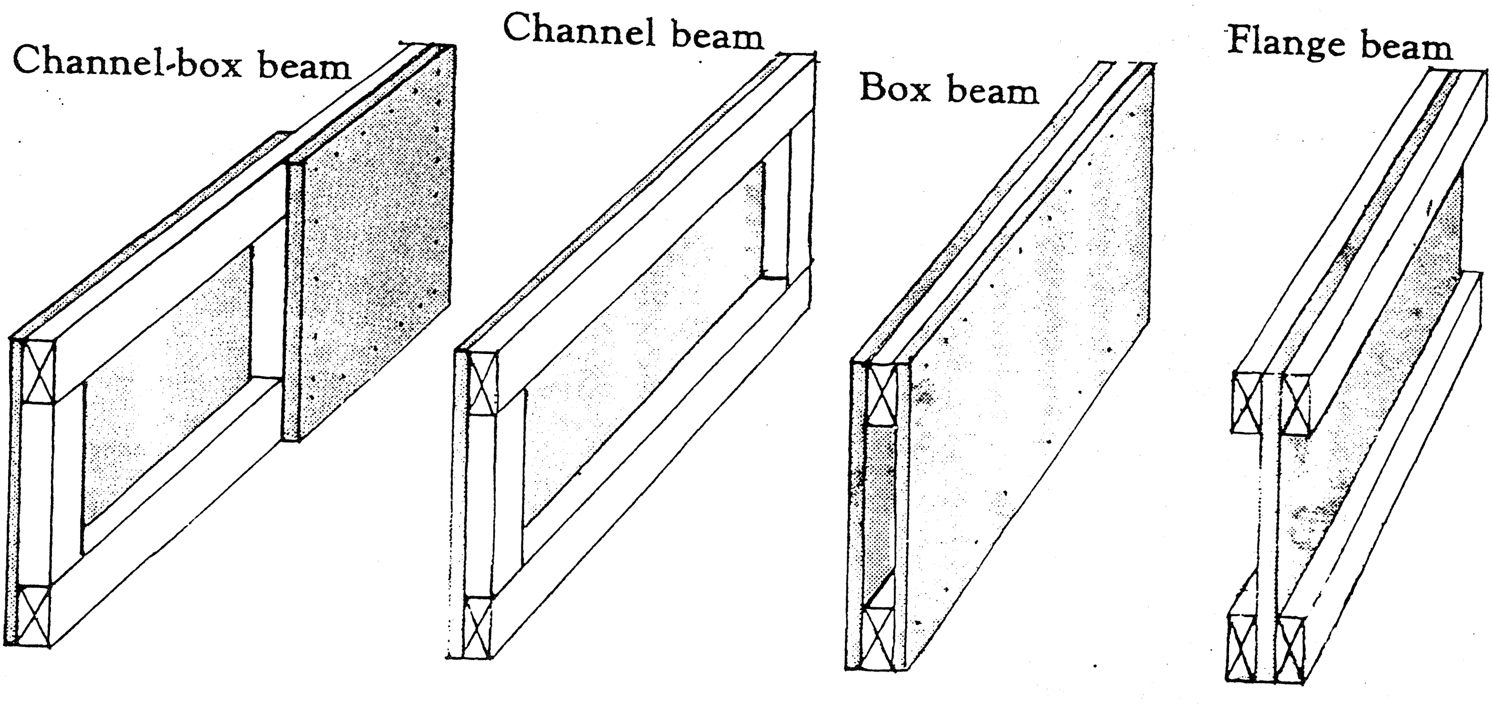
Balloon style truss, with soffit vent



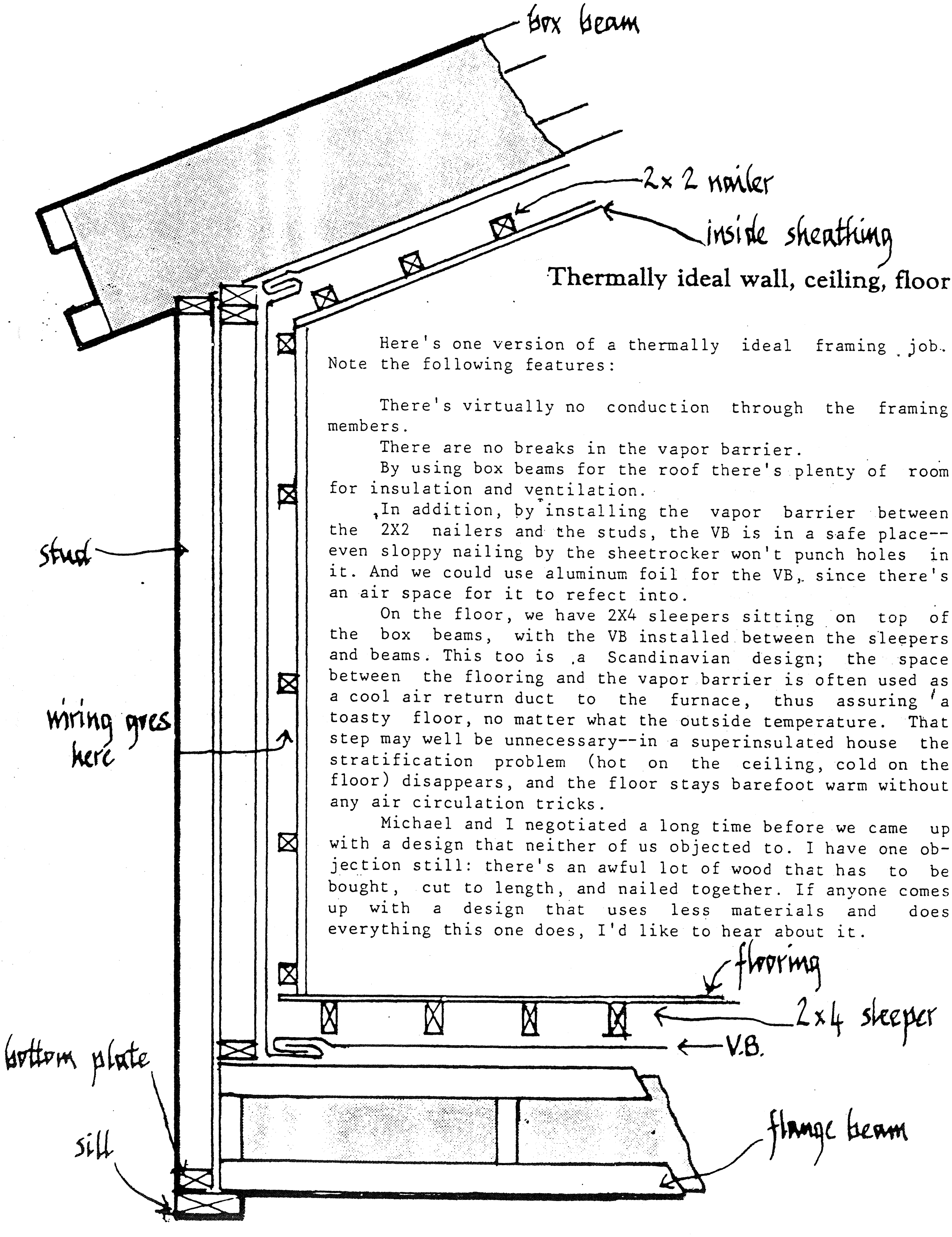
Two trusses which are specially designed for using lots of insulation. The top truss is made for sitting on top of platform framed walls; the one on the bottom is a balloon style truss. It's nothing more than a conventionl roof truss with a scabbed on extension that fits between the walls. You might consider buying a prefab truss and adding the extension yourself.



Above, an exploded drawing of a Scandinavian style roof system. The beams are set at 4' oc; the roofdeck could be 2X tongue and groove, or 1 1/4 inch plywood.



Above are 4 lumber-plywood beams that are used to make deep roofs. The beams are strongest when glue-nailed. Tho it doesn't show in the illustration, the channelbox normally has a plywood gusset on both sides of it at each end of the beam. Since the strength of a beam is proportional to the cube of its depth, when these beams are built 16" or 24" deep they'll carry large loads. According to Carlson, built-up lumber-plywood beams are in common use in Scandinavia, and are often set on 4' centers with 2X3 or 2X4 nailers installed, top and bottom, on 2' centers, so as to have something to hold the roofdeck and interior sheathing. Similar arrangements are used in floors.



Thermally ideal wall, ceiling, floor

Here's one version of a thermally ideal framing job. Note the following features:

There's virtually no conduction through the framing members.

There are no breaks in the vapor barrier.

By using box beams for the roof there's plenty of room for insulation and ventilation.

In addition, by installing the vapor barrier between the 2X2 nailers and the studs, the VB is in a safe place--even sloppy nailing by the sheetrocker won't punch holes in it. And we could use aluminum foil for the VB, since there's an air space for it to refect into.

On the floor, we have 2X4 sleepers sitting on top of the box beams, with the VB installed between the sleepers and beams. This too is a Scandinavian design; the space between the flooring and the vapor barrier is often used as a cool air return duct to the furnace, thus assuring a toasty floor, no matter what the outside temperature. That step may well be unnecessary--in a superinsulated house the stratification problem (hot on the ceiling, cold on the floor) disappears, and the floor stays barefoot warm without any air circulation tricks.

Michael and I negotiated a long time before we came up with a design that neither of us objected to. I have one objection still: there's an awful lot of wood that has to be bought, cut to length, and nailed together. If anyone comes up with a design that uses less materials and does everything this one does, I'd like to hear about it.

MATERIALS/ SECTION II

A note on R values: the rated R value of a material is always plus or minus 10%--that's the leeway that the manufacturers allow themselves.

*

Cellulose

Cellulose fiber is rated at R3.8 to R4.2 per inch of thickness. It consists of chopped up newsprint plus a chemical fire retardant, and is gray in color. A small manufacturing plant costs in the neighborhood of $100-250,000, and can be operated by 3-5 people. The Mother Earth News (#48) has printed an article about homemade cellulose; the main piece of equipment needed is a hammermill such as farmers grind grain with.

Cellulose is primarily a loosefill insulation, tho it has been produced in the form of batts and, mixed with glue, as a wet-blow, spray-in-place insulation. Cellulose can be installed by small owner/operator units, the equipment being a truck, a blowing machine, and hoses. Individuals can also rent the blow units and install their own cellulose. The work of installing is dusty and unpleasant, but so far as present knowledge goes is not dangerous to your health.

Cellulose is for practical purposes fireproof. It needs to be protected from moisture; it requires a vapor barrier. Since newsprint has starch in it, it provides sustenance for insects and rodents. Chemicals are sometimes added along with the fire retardant to discourage animals; physical barriers such as screen and chicken wire are also used.

Cellulose is used primarily as floor and ceiling insulation. If you want to use it in walls or in a sloped roof, your design must take into account the fact that the fiber will settle about 10%.

Cellulose is as close to a "people's insulation" as anything you can buy. It costs a bit more installed than fiberglass batt does at the store, has a slight edge on fiberglass in R value per inch, and the supply of raw material is practically endless.

The cellulose industry is booming right at the moment. ERDA in tests found the quality of samples to vary widely; there will soon be government intervention to assure quality control. Along with the cellulose boom have come rip-off operators who sell chopped up newsprint with no fire retardant added. The paper insulates, but burns wildly. You can run your own quality assurance test by grabbing a handful of the material and holding it next to a flame. If it shows any tendency to burn, you don't want it.

*

Fiberglass

Fiberglass is rated, in batt and roll form, at R3.1 to R3.7 per inch of thickness. Loose fill is rated at R2.2.

It is made of minerals--rock, slag, or glass--and thus there's a good supply of the raw materials.

The manufacturing process is a fairly high tech, high energy one, requiring high temperatures and a large capital investment.

Fiberglass batts and rolls come in widths of 16 and 24 inches, and (harder to find) 4 feet. Available thicknesses are 2 1/2, 3 1/2, 6 and 9 inches. As loosefill, fiberglass can be applied to any thickness. Batts and rolls can be had unbacked (friction fit), or backed with aluminum foil or kraft paper. The aluminum foil functions as a vapor barrier only if all seams are sealed and all tears patched; the foil functions as reflective insulation only when it has an airspace of at least 3/4 inch to reflect into, and is free of dust.

Blowing loosefill fiberglass is essentially the same procedure as blowing cellulose. Installing batts and rolls is a job that can be done by almost anyone. Fiberglass is a hazard both to the skin and the lungs of the people who install it. The hazard can be lessened by wearing full body clothing, such as coveralls, hat, gloves and a paper-gauze respirator. No matter what precautions you use when handling it, fiberglass usually makes you itch, due to tiny fibers becoming embedded in your skin.

For practical purposes, fiberglass doesn't burn. Insects seem not to be attracted by it, but rodents like to build nests out of it, or move in, if possible. Screening and chicken wire will usually keep them out.

Fiberglass is "America's favorite insulation" for use in roofs, walls, and floors of frame buildings.

It needs a vapor barrier, and loses R value rapidly with the addition of moisture. It also loses R value when compressed.

Beadboard

Beadboard is rated at R4.5 per inch of thickness.

It is a petroleum product, and is made by fusing beads of polystyrene into sheets, using heat and pressure. The manufacturing process might be described as intermediate tech.

Beadboard is white, has a stippled surface, and comes in 4' X 8' sheets, 1" and 2" in thickness.

It is easy to install; you can cut it with a handsaw, or run a hot wire through it. The fumes are dangerous. Beadboard will burn, and needs the fire protection of sheetrock or equivalent. It degrades in ılight, and must be protected from UV. It will take on moisture, and needs a vapor barrier. Animals will chew on it if they get the chance.

Beadboard is used for insulating on the outside of basement walls in dry soil, for shutters, for insulating solar collectors, for doors, and for walls, roofs, and floors of frame houses. As house insulation, it costs more than fiberglass or cellulose, but because of its higher R value per thickness, yields a building with more compact walls and a lower profile.

Styrofoam beads are useful as insulation without being formed into sheets. You can use them to fill a cavity to any thickness you want; beads have been used for insulating doors, and tanks (build a box around the tank and fill with beads). Steve Baer's patented Beadwall shutter system uses a vacuum cleaner type arrangement to blow beads between 2 panes of glass; he sells an "anti-static agent" which keeps the beads from clinging to the glass.

Styrofoam

Styrofoam is rated at R5.5 per inch.

It is a petroleum product. It is made by Dow Chemical in a high tech, high energy process. It is not fused, like beadboard, but is extruded and is often referred to as extruded styrofoam, or closed cell styrofoam. It is easy to work with, and may be cut with a handsaw or hotwire.

Styrofoam is available in 2' X 8' sheets, flat edge or tongue and groove, 1" or 2" thick.

Styrofoam will burn, and produces thick black smoke. In a horizontal position, it is self extinguishing, but it burns readily in a vertical position. It needs to be isolated from living spaces by sheetrock or equivalent. It is not generally attractive to insects or other animals. It degrades in sunlight, and needs to be protectd from UV. Styrofoam is in itself a vapor barrier, though vapor will move through cracks beetween sheets. It does not take on moisture.

Styrofoam is used to insulate underneath concrete slabs and footings, underneath highways, underneath garden beds, and anywhere else where the insulation needs to take heavy loads and/or get wet. It is also used to insulate doors, shutters, collectors, etc. Like beadboard, it can be used where you'd usually use fiberglass or cellulose--it just costs more per R value attained.

Urethane

Polyurethane foam is rated at R4 to R9 per inch of thickness. Urethane is a petroleum product. Unlike all the other mass insulations, which insulate by entrapping tiny pockets of air within internal voids, urethane entraps tiny pockets of Freon. Freon conducts heat less well than air, and this is what gives urethane its edge over the other insulators in R value per inch. However, there are two problems with the product: 1. As urethane ages, the Freon tends to escape to the atmosphere and is replaced by air. This phenomenon can be largely prevented by spraying a high density skin on both sides of the insulation, or encasing it in metal or plastic; the latter technique is used in the insulation of spacecraft. 2. At about -20 degrees, Freon condenses (changes from a gas to a liquid). Liquid Freon conducts heat more readily than air.

These two phenomena yield the varying R values that urethane may have. Under carefully controlled conditions, NASA produced urethane with an R per inch of 9 and above; the urethane which you have sprayed may have an R value of 6 or 7 when new, and dip down to R4 after aging a few years or in cold weather.

Urethane comes from a petrochemical plant to applicators as drums of two different chemicals. Application is a matter of combining the two and spraying the result on a surface. The equipment needed to spray urethane (truck with covered van, compressor, hoses, nozzles) costs in the range of $10-20,000. Quality varies with the applicator. Spraying urethane is rather unpleasant work: there are fumes and spatter. Some operators coat unclothed portions of their body with Vaseline, to which urethane will not adhere.

Urethane is available as preformed 4' X 8' boards and as preformed pipe insulation. It can also be bought in the form of small portable units (Frothpak is one brand name) which allow you to spray it, on site, without equipment. These units are quite expensive, and often troublesome. People who use them do so because 1. they have a specialized job to do, and nothing else will work, or 2. they don't know any better.

Urethane is flammable, and must be isolated from living spaces by sheetrock or equivalent. It burns rapidly, with thick black smoke, and releases a gas which is toxic to humans. It does not seem to be attractive to animals, tho some will gnaw at it. Urethane degrades in sunlight, and needs to be protected from UV. Urethane will take on moisture; it requires a vapor barrier on the warm side, and protection from moisture on the cold side.

Urethane is used as residential insulation. It is much more expensive than most other house insulations, but can be applied very quickly. It is best applied to a warm surface; some applicators will not guarantee foam sprayed on a cold surface. For insulating underground water and sewer pipes, urethane is not quite ideal, since it will take on moisture, and tends to crack and deform under compression, but it is the best insulation currently available for that purpose, and does work to some extent. It is also handy for insulating pipes, tanks, and other non-square surfaces. It is sometimes used to seal cracks between sheets of beadboard or Styrofoam. In the recent past, urethane was often sprayed on burlap which had been stretched over a geodesic dome frame. Foamdomes were semi-instant buildings; the urethane acted as inside surface, outside surface, and insulation all at once, and so it seemed economic. However, unless fitted out with VB and fire retardant covering inside, and weatherproofing plus UV filter outside, they deteriorated within 2-5 years.

Urea-Formaldahyde

UF foam is rated at R4.4 to R4.8 per inch of thickness. It is an organic insulation, and resembles shaving lather. It requires a mixing and spraying machine to apply. The insulation is poured into cavities, and has no structural rigidity.

UF seems to have no burn problems; it will take on moisture. A major problem with UF is that it shrinks as it dries in the wall cavity. When dried slowly it is reported to shrink 1.8%; when dried quickly it will shrink 3% or more. Unless you can come up with a design that will make the shrinkage problem non-significant, UF is virtually eliminated from consideration as an insulator for new construction. It would seem to have a use in retrofitting--even with gaps all around the edges, it's better than no insulation at all.

Wood

Soft woods are rated at R1 to R1.5 per inch of thickness, depending on density and moisture content, and whether heat is being conducted across the grain or along the grain. This R factor is for cross grain--it's lower along the grain.

Looked at only as insulation, wood is extremely expensive; however, the cost goes down when it functions as structure too. Wood has a high heat holding capacity when compared to other insulators; for this reason a log cabin, tho minimally insulated, is more comfortable than a minimally insulated frame building. A log house cools down slowly when the fire goes out; by the same token, when you start a fire in a cold cabin, it takes a long time to warm it up.

Experience and engineering theory seem to say that if you're going to add insulation to a log structure, you'd do best to add it on the outside, not the inside. Many people object to this notion on aesthetic grounds: what's the point of living in a log cabin if the neighbors can't see the logs?

Wood houses have been built by tacking short logs like firewood. In Siberia, animals other than human are sometimes housed in domelike structures make by stacking short log sections with the big end out, and mortaring it all together. Calculations (mine) indicate that if you took a several year supply of firewood and built a house out of it instead of burning it, you'd end up cutting a lot less firewood.

Reflective Foil

RF, when facing an airspace of 3/4" or more, is rated at R4.4 when reflecting down (in a ceiling), R2.4 when reflecting up (in a floor), and about R3 when reflecting horizontally (in a wall).

RF may be in the form of aluminum foil, aluminum coated plastic or paper, or gold or silver applied to some backing. Aluminum foil for building construction comes in 3' wide rolls, 500' long. Aluminum is a virtually perfect vapor barrier, but all seams and holes have to be patched with a vapor barier tape in order for it to function as VB.

RF does not work when coated with dust; this is a special problem in floors, and less so in walls and ceilings.

The main value of RF is that it stops reflective heat loss, which accounts for 10% of heat loss from a building, and cannot be stopped in any other way. 1 layer of RF, when facing an airspace, will stop about 90% of the reflective heat hitting it; a 2nd layer will stop 90% of the 10% that gets through the first one. The contribution of reflective heat loss to total heat loss varies with the cube of the temperature differential between inside and outside, and so in space, where delta T may be several hundred degrees, multilayers of RF with evacuated spaces between them were used successfully.

Sawdust

Sawdust is rated at R2.6 per inch of thickness. That number will vary with density and moisture content.

Since it is a by product of lumber mills, it can often be gotten for the hauling, or cheaply.

Sawdust is extremely flammable, and needs to be isolated from living spaces by sheetrock or equivalent. It would seem that it could be mixed with fire retardant and made less hazardous. Sawdust is attractive to animals and insects. That problem may be solved with physical barriers, or seemingly could be solved with chemicals. Sawdust will rot if it gets wet; it requires a vapor barrier on the warm side and a weather barrier on the outside. It settles, which presents a problem for use in walls. Some people tamp it as they pour it into place.

Sawdust is used presently, and has a long history of use, as residential insulation. Double walled houses with sawdust filled cavities were once common in the North, and are now seeing a revival. Generally, sawdust can be used in place of any other loosefill insulation. It has been used in the ground, where it rots after a few years and must be replaced. Because of its low cost, it deserves consideration as a temporary insulation. When it begins to rot, it can go into the compost pile. Spruce sawdust is acidic, and needs to have lime added before putting on the garden.

Shavings

Wood shavings are a useful insulation, and have most of the general properties of sawdust. The R value is a bit lower. Shavings are best compacted a bit when poured into a wall cavity.

Moss

Dry sphagnum moss is rated at R3.8 per inch of thickness. It is subject to rot, and needs VB on the warm side and weather barrier on the cold side. Moss burns; normal precautions are in order. 15 years ago Joe Balch fireproofed some moss by sprinkling in Borax, and it remains fireproof to this date. Animals like moss, and need to be kept out of it.

Moss is widely used as residential insulation, and also as chinking material between logs and poles. Peatmoss bricks have been produced in Alaska and used as structural and insulative building material. As I understand it, you put the moss in a mold and add heat and pressure.

'Recycled', etc.

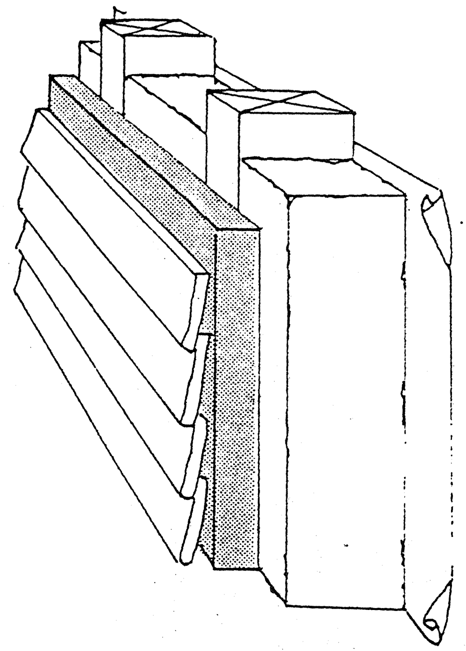
Scrap urethane, ground in a garden mulcher and tamped into the cavity formed by a double wall, has been measured at R5 per inch of thickness.

Companies which manufacture urethane pipe insulation and rigid urethane board typically haul their scrap to the dump, and will sometimes let you have it for hauling or a small price. The same companies will often turn loose of skin sheets and irregular sheets for a fraction of their value.

Other plastic insulations are lying all over the place; styrofoam cups and packing material have been used as house insulation, tho there is a large amount of work involved in gathering them.

Desperate and /or ingenious people have used a wide variety of other materials for insulation: popcorn (popped), old army parkas, hay, wool .ankets and other fabrics, old mattresses, etc.

Dow Total Wall



From inside to outside: VB, studs with fiberglass, Styrofoam, siding.

The following chart compares insulation costs on a unit basis: price per square foot of R1. This unit is analagous to the board foot, by which lumber is priced.

These prices were average prices in Fairbanks, AK, in the spring of 1978. Except in remote Northern locations, costs should be lower almost anywhere.

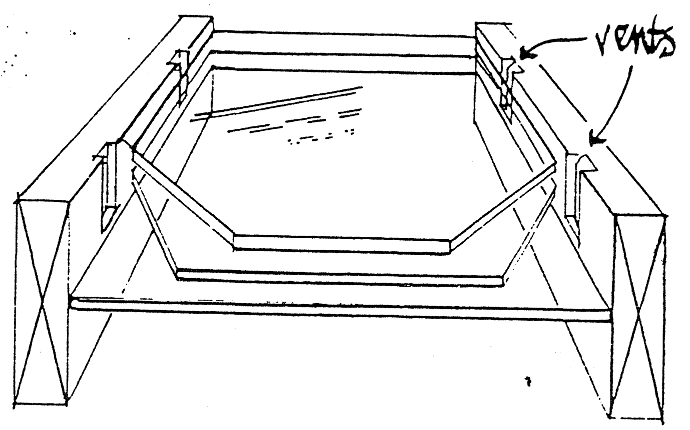
Using these unit prices, we can quickly estimate the cost of insulating a building. The formula is: square feet X intended R value X multiplier.

Thus, to figure out the cost for an 800 square foot house (roughly 2800 sq ft of surface area) insulated to R40 with fiberglass, 2800X40X.023=$2576 . A house insulated to the same R value in urethane would cost $8960.

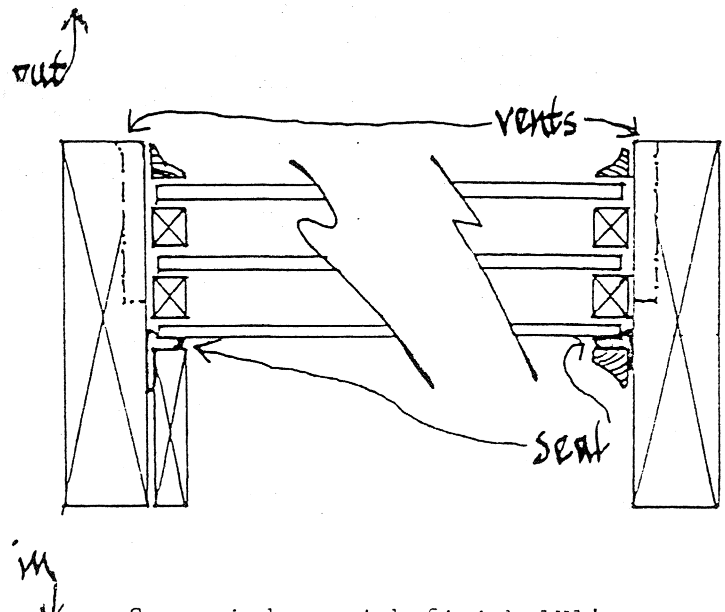
REFLECTIVE FOIL (material only)	$.0054
CELLULOSE (you rent a machine and blow it yourself.)	$.0094
FIBERGLASS BATT (material only)	$.018
CELLULOSE (contractor installed)	$.022
LOOSEFILL FIBERGLASS (contractor installed)	$.023
BEADBOARD (material only)	$.050
STYROFOAM (material only)	$.058
URETHANE (sprayed in place)	$.082
WOOD (material only)	$.24

HOLES/ SECTION III

A frostfree triplepane window



Seal the inside pane, but allow any moisture which gets between pane 1 and pane 2 to escape to outside air.



Same window, with finish 1X1's as pane spacers.

Once you've built superinsulated walls, ceilings and floors, the job of building a superinsulated house is nearly half done. In this section I discuss techniques involved in slowing down heat loss through a house's necessary entrances and exits: windows, doors, vents, and chimneys.

Windows

Here are 3 window building rules:

1. Vapor seal the inside pane with silicon caulking or something similar.
2. Allow outside pane(s) to leak vapor: don't seal them.
3. For maximum insulation value, seperate the panes of glass by about 3/4 inch.

Thermopane windows are often put together with a dessicant (silica gel) between the panes to absorb any moisture which becomes trapped there. You can sometimes talk a window building shop into selling you some dessicant.

The chart on the next page compares heat lost thru 100 square feet of various windows during an average December in Fairbanks. I assume that for 4 hours a day, the windows won't be losing any heat at all; because of the sun shining thru them, they'll be gaining heat or breaking even. I assume further that in the case of the shuttered windows, the shutters will be open an average of 6 hours a day--the rest of the time it'll be dark outside, so they'll be closed. My assumptions about the number of hours the shutters will be open and closed may not correspond exactly to reality, but they're close enough for demonstration purposes.

		1 pane R.89	2 pane R1.8	3 pane R2.8	1 pane +R15 shutter	2 pane +R15 shutter	3 pane +R15 shutter
	at R.89	620	**	**	62	**	**
Hours	at R1.8	**	620	**	**	62	**
of	at R2.8	**	**	620	**	**	62
Loss	at R15.89	**	**	**	558	**	**
	at R16.8	**	**	**	**	558	**
	at R17.8	**	**	**	**	**	558
BTU'S	thru glass	54.3	26.9	17.3	5.4	2.7	1.7
100000	thru shutters	***	***	***	2.7	2.6	2.4
Lost	total	54.3	26.9	17.3	8.1	5.3	4.1

Here's the formula with which the heat loss numbers are derived:

Heat Loss=Q=A/RxTxdelta T.

Q is expressed in BTU'S/100000, which translates roughly into gallons of fuel oil. That's handy, but the real reason I use BTU'S/100000 is that it removes a lot of zeroes from the equation.

A=Area; in this case, 100 square feet of windows.

R=the R value, as given.

T=Time, in hours. There are 744 hours in December.

Delta T=Temperature difference between inside and outside. Since December in Fairbanks averages -8 degrees, Delta T here is 70-(-8)=78 degrees.

As you look at the chart, note these relationships:

in the case of the windows with a single pane of glass plus shutter, the glass loses twice as much heat as the shutter, tho I assume the glass to be losing heat only 2 hours a day.

The double glazed window plus shutter loses about 1/10 the heat of the double glazed window without shutter.

The triple glazed window with shutter loses only half of what the single glazed window with shutter does. The difference is attributable to the extra 2 panes of glass.

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Doors

For insulation purposes, a door may be thought of as a wall section on hinges. General principles apply: we want

1. as little conduction as possible
2. VB on the inside
3. a moisture escape path on the outside.

2 popular 'alternative' cold weather doors are

1. the refrigerator style door, in which the door is larger than the hole it covers, and sits off the surface. The seal is gasket-to-gasket. The refrigerator door, if large enough, eliminates heat loss through the door casing and all the extra framing members which normally go around the casing.

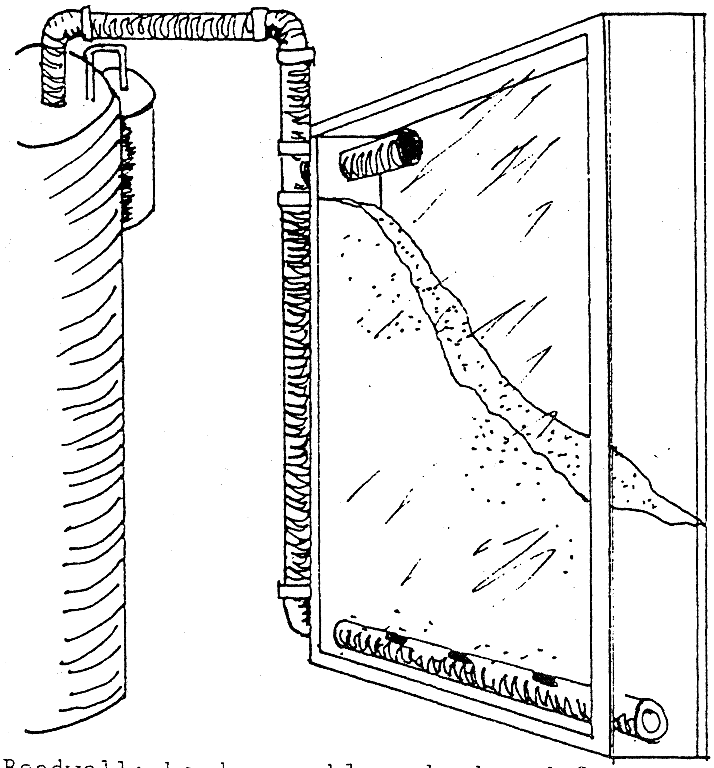
2. The friction fit door. Here the door sits inside a casing, as conventional, but the edges push up against a little puff of fabric filled with fiberglass, wool, or some other spongy material. Friction fit doors have the advantage that they don't have to fit the casing very closely, yet they'll still seal. With this technique, the usual problems of woodframe doors--warpage, shrinkage, swelling--disappear. The friction fit obviates the need for a door latch, as well.

Shutters

If there were a transparent insulation, we'd probably all prefer it to shutters. Day Chahroudi and the people at Suntrek (see CoEvolution Quarterly #16, "Buildings as Organisms") have for a number of years been trying to produce see thru insulation; their product (Heat Mirror) is still pretty much at the R&D stage.

The simplest and most immediate way to achieve the shutter effect is to hang curtains, drapes, a wool blanket, or some other insulating fabric over a window. ich measures make a house more comfortable by cutting down on cold weather window chill, and can easily cut heat loss in half.

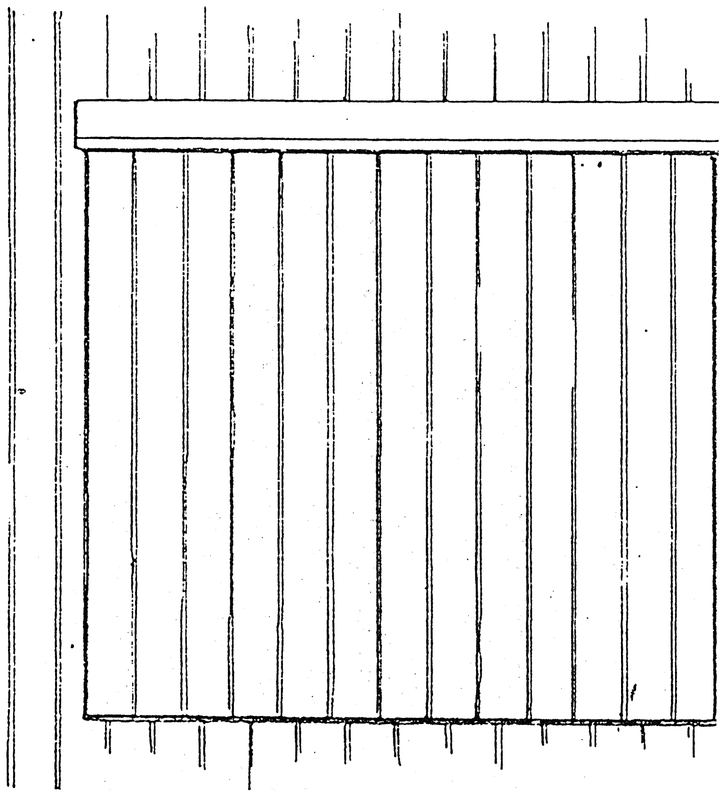
The next most immediate measure is to make removeable insulated panels that go on the inside of the window--at night they're in place, in the daytime you store them. From a thermal point of view, this is a measure worth taking, but there's a fair bit of daily care involved in it:



Beadwall: beads are blown back and forth from window to storage bin.

such systems tend not to get used on a regular basis.

A general problem of inside shutters is that unless the shutter vapor barrier seals with the wall VB, the windows tend to fog or frost, depending on how cold it is outside. Since the glass is on the cold side of the insulation, and is a VB, the cold surface will condense the moisture out of any room air that comes in contact with it. In a house with low humidity, this can be a very small problem, or none at all; in a high humidity house you may collect more water than you'd like. It's been suggested locally that perhaps you should just design for it-- put a drain



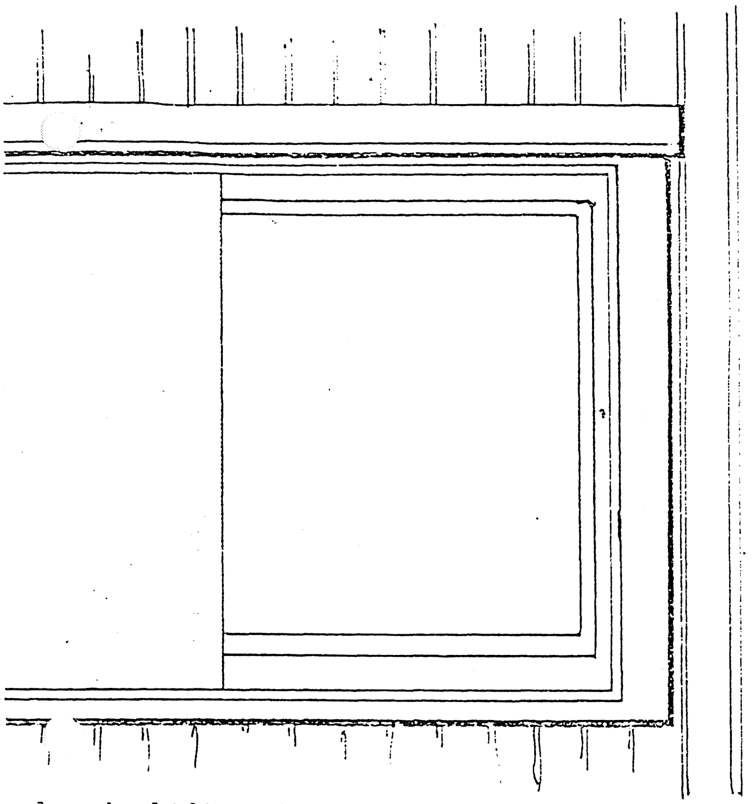
Window, with partiall

channel at the bottom of each window, so that the water running off the glass doesn't rot the window sill.

One way to build a shutter is to think of it as a door: put it on hinges, let it swing up, down, or sideways. 1 major design difference: an outside door is generally closed most of the time; a shutter is open more than half the time. So the inside surface of the shutter must be able to handle exterior weather conditions, and the shutter casing (as opposed to a door casing) is going to be out in the weather as well. Snow, rain, and ice have to be prevented from getting into the system, or you end up with shutters that freeze shut. While it's open, the shutter has to be able to handle wind loads, as well.

One approach to controlling the movement of a hinged outside shutter is to use a hand crank connected by a shaft through the wall to a worm gear which connects to a shaft on the shutter. Any metal used in this design must be considered a thermal liability, since it will conduct heat out of the house, and will frost in cold weather. For inside to outside connections, plastic, rope, nylon cord or wood are to be preferred.

There are problems (soluble, no



closed sliding shutter.

doubt) involved with using a pull string to close a swinging shutter--you start with an over-center problem, as you'll see if you draw it out.

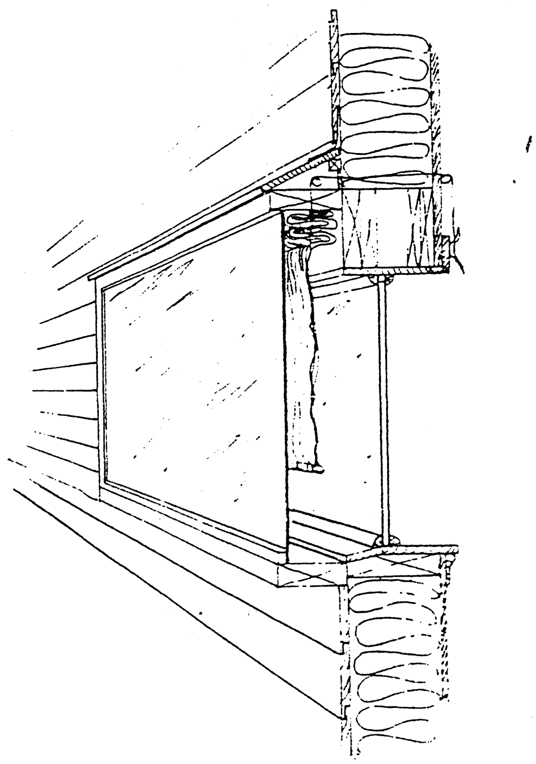
A shutter that swings up can be useful as a window shading device. Shading can cut down solar gain up to 60%: you still get diffuse radiation, but no direct. A shutter that swings down seems meant for gathering rain and snow--that's not bad, but plan on it happening.

As I mentioned last section there's a shutter which uses polystyrene beads in raw form(!), blowing them from window to storage bins and back again. According to all reports the system works well. So far as I know it's never been tested in extreme cold; I can see no problems provided you arrange to keep moisture out of it. Equipment required: 2 halfhorse blower motors ($70 or so new), storage bins, and hosing. Maintenance costs are for the anti-static agent, which keeps the beads from clinging to the glass, and the small amount of electricity used to transport the beads.

Plans for Beadwall are available for $15 from Zomeworks Corp, P.O. Box 712, Albequerque, NM 87103. By asking, you can get their advertising and order form, and from that you might figure out how to build it, provided you have some basic knowledge of caprentry, plumbing, wiring, and vacuuum cleaner motors.

Zomeworks also sells prefab systems. For a 46" by 76" finished window you'll pay a minimum of $335 plus local cost of 3/8" patio door glass. R value when closed is 8.5. If total system costs were a conservative $400, the cost of 1 square foot of R1 would be roughly $2.00.

The design of the sliding shutter shown in the middle picture is discussed at greater length on the inside back cover. Remember: it's a design: I've never built it.



From inside to outside: double pane window, fold up (or roll up) insulating blanket, storm window. The blanket is weighted so as to seal at bottom.

Shutter Controls

Manual

a.) As noted before, you can lift panels in and out of the window, or use some pull string or hand crank arrangement. To simplify the mechanical end of it, the shutter may be spring loaded or counterweighted, so that you operate the crank or pull the string to open it, but to close the shutter, you merely release the action. The open and close procedure can be reversed to suit your needs.

b.) You can use an electric motor to open and close. For control, the most basic arrangement would be a switch that you flip to activate the motor. To power the shutter in both directions (open, close) you'd need a reversible motor plus 3 way switch, or you could use a counterweight or springload technique, and get away with a 1 way motor plus switch and release.

2.) Automatic

When you go to the electric motor, you remove your muscle power from the system; if you use electronic controls, you can revove your attention as well. 4 possibilities:

a.) You could tie the switch to a timer, so that the shutters open and close at preappointed times. To achieve photoperiods that match those outside, you'd have to change the setting on the timer at least once a week in far north latitudes, less often as you get nearer the equator.

b.) You could tie the switch to a photosensor, so that the shutters open at one preset light level, and close at another.

c.) If you were more concerned with loss and gain of heat than of light, you could tie the switch to a thermosensor, so that the shutters will be open only when solar gain can occur.

d.) You could tie everything into a microprocessor, and program it so that the shutters open and close under whatever conditions you feel appropriate.

You can probably buy off-the-shelf components to make as fancy an electronic system as you want. Check magazines such as Popular Science, Popular Mechanics, Mother Earth News, and Harrowsmith for ads and articles.

Infiltration

In a conventional house, especially one built more than 10 or 20 years ago, fresh air usually comes in through cracks around windows and doors, and sometimes between the walls and the floor. Standard texts on heating and cooling generally lay out a method for determining infiltration heat loss by "crack estimation".

In a superinsulated house, however, there are no cracks: there'll be no exchange between inside and outside air unless we arrange for it (except of course when the door is open). Properly speaking, "infiltration" will not occur at all, or only minimally.

But humans can't live in a hermetically sealed enclosure; we and our living processes in time will make the air dangerous and unpleasant.

ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers) recommends that the air in a house be changed at a rate of .2 volumes per hour. Bring outside air in, send inside air out. This, they say, will assure that you're breathing clean air. If your house is 1000 square feet, with 8 foot ceilings, each hour you bring in 1600 cubic feet of air(=27CFM).

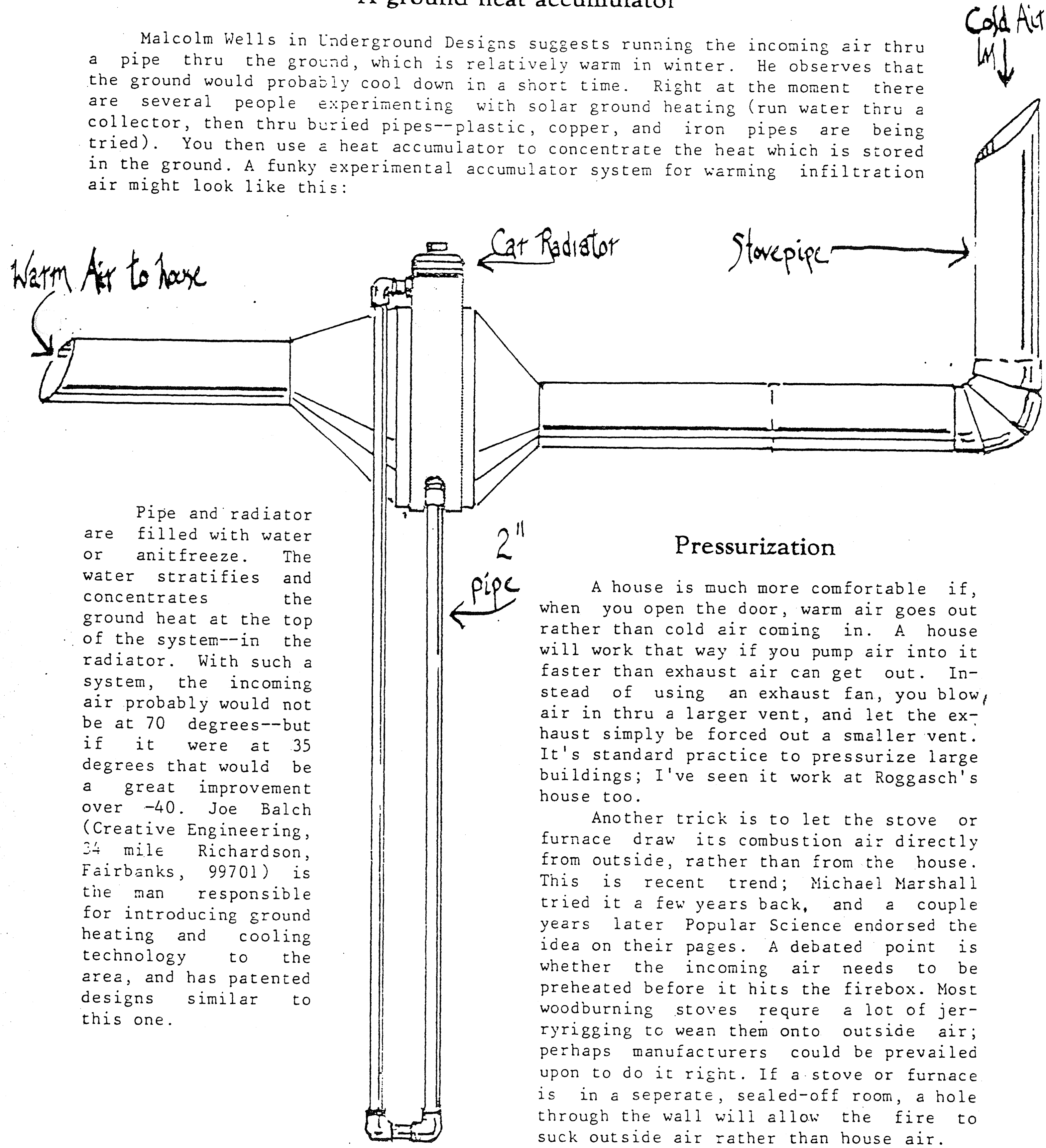
If you look at the chart in Section V, Economics, you'll see that for the example houses, a large part of total heat loss is attributable to infiltration.

1 possible solution to this problem is to find a cheap heat source with which to warm up the incoming cold air. An obvious possibility is the outgoing warm air. To make the trade, we need a heat exchanger.(see page 26)

Another approach, and one mechanically less demanding than the heat exchanger, is to pull the incoming air in through a solar collector or greenhouse. That's not a wholly adequate solution in the North (no sunshine when you need it most) but in a place with moderate climate and lots of sun, it could be a quick, cheap, adequate solution. Or instead of bringing the air through a collector, you might dump collected heat into a storage system, and pull the incoming air through that, to heat the air all night long.

A ground heat accumulator

Malcolm Wells in Underground Designs suggests running the incoming air thru a pipe thru the ground, which is relatively warm in winter. He observes that the ground would probably cool down in a short time. Right at the moment there are several people experimenting with solar ground heating (run water thru a collector, then thru buried pipes--plastic, copper, and iron pipes are being tried). You then use a heat accumulator to concentrate the heat which is stored in the ground. A funky experimental accumulator system for warming infiltration air might look like this:



Pipe and radiator are filled with water or anitfreeze. The water stratifies and concentrates the ground heat at the top of the system--in the radiator. With such a system, the incoming air probably would not be at 70 degrees--but if it were at 35 degrees that would be a great improvement over -40. Joe Balch (Creative Engineering, 34 mile Richardson, Fairbanks, 99701) is the man responsible for introducing ground heating and cooling technology to the area, and has patented designs similar to this one.

Pressurization

A house is much more comfortable if, when you open the door, warm air goes out rather than cold air coming in. A house will work that way if you pump air into it faster than exhaust air can get out. Instead of using an exhaust fan, you blow air in thru a larger vent, and let the exhaust simply be forced out a smaller vent. It's standard practice to pressurize large buildings; I've seen it work at Roggasch's house too.

Another trick is to let the stove or furnace draw its combustion air directly from outside, rather than from the house. This is recent trend; Michael Marshall tried it a few years back, and a couple years later Popular Science endorsed the idea on their pages. A debated point is whether the incoming air needs to be preheated before it hits the firebox. Most woodburning stoves requre a lot of jerryrigging to wean them onto outside air; perhaps manufacturers could be prevailed upon to do it right. If a stove or furnace is in a seperate, sealed-off room, a hole through the wall will allow the fire to suck outside air rather than house air.

Air Cleaning

Another approach to infiltration is to clean and recycle a house's air. A closed loop air system has its attractions: in a polluted city you could escape to a house with pure air, rather than breathing the public air. It appears to me, and I make no claim to know a great deal about it, that a total air cleaning system would be extremely expensive, rather high tech, and more or less experimental. Current trends seem to be in the directon of biological technology for air purification systems: plants remove carbon dioxide and replace oxygen, hemoglobin filters pick off the carbon monoxide--I don't know much about it.

Carbon Monoxide

If it's available, our bodies prefer carbon monoxide to oxygen in a ratio of 200 to 1. So if CO's around, it'll end up in your blood. I've located in the literature no strong evidence that CO levels up to 50 ppm are really bad for you, so long as you're healthy to begin with. Such high levels are bad for people with angina or emphysema, or similar. In test situations, even slightly increased levels seem to give subtle effects--fatigue, lack of awareness, headaches--but the causes and quantities of such symptoms are hard to determine. At the far end of the spectrum, high percentage concentrations of CO will swiftly kill you. Whether the human body adapts to low, but increased-from-wilderness CO levels seems to be a part of what isn't known.

Inside houses, there are 3 main sources of carbon monoxide, whose source is incomplete combustion.

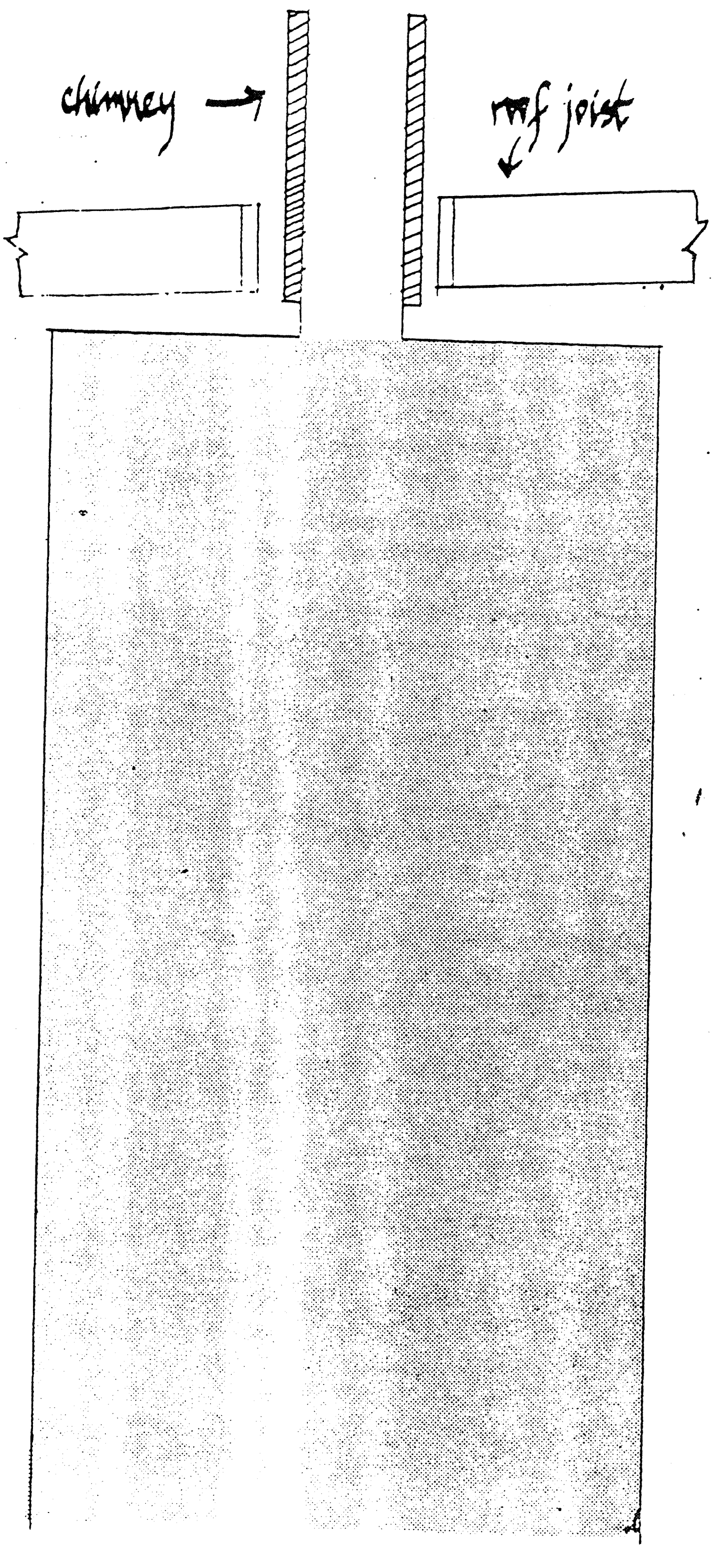
1.) Leaky stoves and stacks

This problem is not terribly widespread; most heat systems don't leak or back up to a serious degree. For total assurance you go to a tall (20 ft. minimum, 30 is nice) insulated stack, preferably of masonry or other construction incorporating thermal mass.

2.) Cooking with gas or propane produces both CO and Nitrogen Oxide. A proper air to gas mixture helps prevent, and a vented range hood helps remove. It doesn't look like a serious problem, in any event.

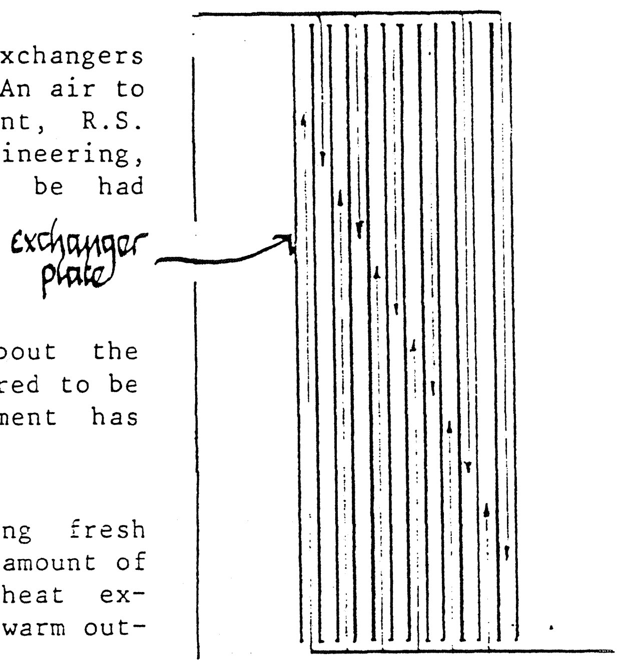
3.) Smokers of tobacco and marijuana are responsible for the largest contributions of CO to houses. Houses (and bodies, naturally) of smokers often have far higher CO levels than the air of the most polluted cities.

Fireplace design



All the masonry is inside the house; metalbestos chimney goes through the roof.

Air to Air Heat Exchangers



Most of my information on air to air heat exchangers comes from a 12 page engineering bulletin called 'An air to air heat exchanger for residences', by R.W. Besant, R.S. Dumont, and D. Van Ee, Department of mechanical engineering, University of Saskatchewan in Saskatoon. A copy can be had by writing

Department of Mineral Resources
1404 Toronto Dominion Building
Regina, Saskatchewan
S4P 3P5

You might ask at the same time for a brochure about the Prairie Sunshine Trap, an experimental, engineered to be 100% solar heated house that the provincial government has built in Regina.

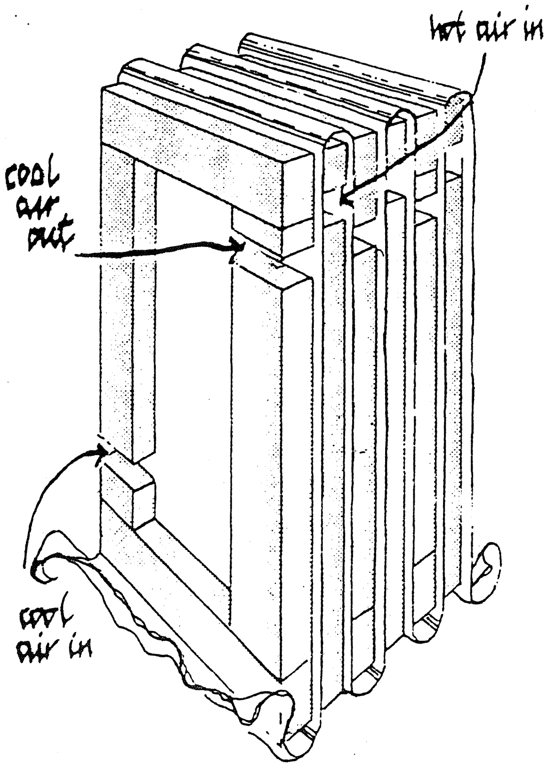
OVERVIEW

To take care of your oxygen needs etc, you bring fresh air into the house. At the same time an equal amount of house air is being dumped outside. An air to air heat exchanger is a device for removing the heat from the warm outgoing air and putting it into the cool incoming air.

One way to arrange for the heat transfer to take place is to pass warm air along one side of a conductive plate, and on the other side of the plate, going in the opposite direction (counterflow) you pass cool air. The warm air heats up the exchanger plate and it, in turn, gives up the heat to the cool air. A few possible exchanger plate materials: polyethylene, glass, aluminum, copper, steel.

AIR FLOW REQUIREMENTS

Each hour, you need to pass around these plates a volume of air approximately equal to 20 % of the volume of the house. 20 is a safe number--you might vary it to 15 or 25% depending on your needs and tastes. Volumes of flowing air are measured in cubic feet per minute (CFM from here on). In an 800 square foot house with 8 foot ceiling, the hourly volume at .2 air changes will be 1280 cubic feet, and that equals 21.3 CFM. To move 20 cubic feet of air per minute thru a boxful of heat exchanger plates you need a fan--ask plumbing and heating people what size. You only have to pump the air one way. In a tightly sealed house--and these exchangers will be much less effective in an unsealed house--you can pump air in and the exhaust air will make its own way out. The Saskatchewan design pumps air out and lets the fresh air be sucked in by negative house pressure.



The Saskatchewan design uses 1/2" plywood for spacers, and folds polyethylene around them to form 30 exchanger plates.

A DESIGN PROBLEM

The house air is warm and moist. As it goes thru the exchanger, it cools down and the water vapor in it condenses. Water droplets then cling to the exchanger plates, and will freeze if it's cold enough outside. The Saskatchewan design uses three dampers with which the exchanger can be put into defrost mode. When set to defrost, warm house air recirculates thru the exchanger; a drain pan catches the dripping water. In very cold weather you might need to defrost every few days. Better solutions remain to be built.

If your windows tend to ice up, the Saskatchewan design will solve that problem. Its engineers calculate that in a house with an air flow rate of 70 CFM and an indoor relative humidity of 30%, the exchanger will collect about 5 gallons of water per day.

MASS / SECTION IV

The identifying property of thermal mass is its ability to take on and release heat. Any physical material--liquid, solid, or gas-- may be thought of as thermal mass; we are interested in materials which can accept and release relatively large amounts of heat. Thus, we are looking for materials with a combination of high heat capacity and high density.

The following chart first gives densities, and then heat capacities, for various materials.

MATERIAL	DENSITY	HEAT CAPACITY	STORAGE
IRON, STEEL	440-500	.11	50
WATER	62.4	1	62.4
GLASS	160	.2	32
BRICK	100-130	.22	25
WHITE SPRUCE	28	.65	18
OAK	48	.57	27
PARAFFIN	56	.69	38.5
CONCRETE	100-150	.156	15.6-23.4
DIRT	75-100	.44	33-44
FIR	32	.65	20
ICE	56	.46	26
SHEETROCK	50	.26	13
CORK	15	.485	7

[Th]e numbers in the 3rd column are obtained by multiplying density times heat capacity, and tell how many BTU's 1 cubic foot of that material will take on or release as it rises or drops 1 degree in temperature. As you can see, some of the densities are given as a range, rather than a single number. Densities vary with temperature, moisture content, and exact composition--if you need an exact density, measure out a cubic foot of the material in question and weigh it.

Numbers

In order to become familiar with calculations involving thermal mass, let's put together an example house, add some mass to it, and see how the system performs.

We'll supose that the house is 20'x40' (800 square feet), and has 80 square feet of windows plus a 20 square foot door. We'll pretend that the construction is slab-on-grade, with 2 inches of blue (extruded) Styrofoam (R11) under the slab, and that the rest of the house has an integrated R factor (IR) of 40. To get IR, you add up the heat loss from the various differently insulated parts of the house, then divide the total outside surface area by the total heat loss. IR does not mean average R value--if you play around with it, you'll see that average R value is a meaningless number, since it doesn't predict actual heatloss.

Now we get around to thermal mass.

We already have a 20'x40' concrete slab, 4" thick. Let's add half inch sheetrock to walls and ceiling, and build in a planter that runs across the south wall of the house (40' long, 2'8" wide) and say that it's constructed of 4" thick concrete walls, 3' high, and filled with dirt. We want to find out how many BTU's are stored in that thermal mass.

The formula is:

VOLUME x DENSITY x HEAT CAPACITY = STORAGE.

VOLUME is given in cubic feet.

DENSITY is given in pounds per cubic foot.

HEAT CAPACITY tells us how many BTU's must be added to raise 1 pound of the material 1 degree--and on the flip side, how many BTU's 1 pound of the material will release as its temperature drops 1 degree.

The product of those 3 numbers is STORAGE. This tells us how many BTU's the whole thermal mass will take on or release as it rises or drops 1 degree.

To find the volume, we multiply length x width x thickness. To get V for the sheetrock, for instance, we find the area of the walls and ceiling, subtract area of windows and door, and multiply by 1/2 inch, or 1/24 feet, rather, to keep all the terms in feet.

To get DENSITY we look at the chart, or to be certain, weigh a known volume of the actual material.

HEAT CAPACITY comes from the chart too.

THERMAL STORAGE IN EXAMPLE HOUSE:

MATERIAL	VOLUME	X DENSITY	X HEAT CAPACITY	= STORAGE
SHEETROCK	69	50	.26	900
CONCRETE- SLAB	264	125	.156	5180
PLANTER	79	125	.156	1540
DIRT	240	80	.44	8450
TOTAL				16000

So, to raise the temperature of the whole mass by 1 degree, we have to add roughly 16000 BTU's. And as the house temperature drops off 1 degree, the mass will give up 16000 BTU's. What does that do for us?

Let's pretend it's zero outside, and that the temperature of the ground underneath the slab is 45 degrees.

The heatloss formula is: Q=A/R x delta T, where Q=heatloss, A= the surface area through which heat is lost, in square feet, R= the R value of the surface, and delta T=inside temperature - outside temperature.

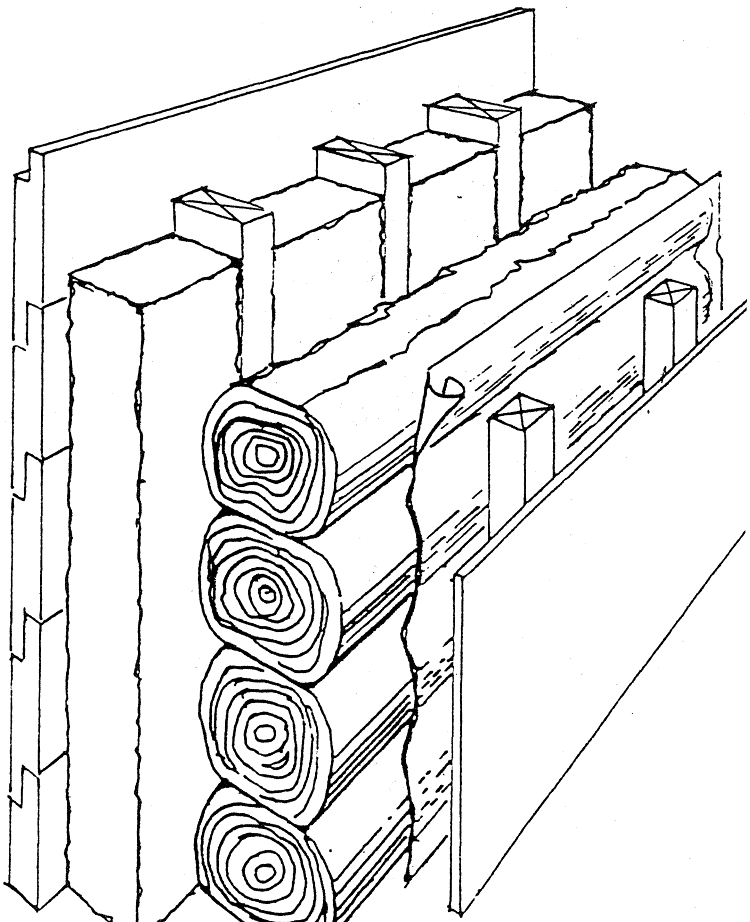
For the aboveground section of the house, A is roughly 2000 square feet, R=40, delta T=70-0, and 2000/40 x 70=3500.

For the slab, A=800, R=11, delta t=70-45=25, and 800/11 x 25=1800. Add the products together (3500+1800) and we see that the house will lose (structurally) about 5300 BTU's per hour. Let's simplify things by assuming that we've found a technical fix for infiltration heatloss.

Let's imagine that this is a solar heated house, and the sun has just set; or that this is a woodheated house, and the fire just went out; or that this is a gas heated house, and the electricity just went off, so the furnace is down. What happens?

If we divide STORAGE (16000 BTU/degree) by heat loss (5300 BTU/hr) we know approximately how long it'll take the house to drop off 1 degree--provided the mass can release its heat fast enough to keep up with heatloss. So, 16000/5300=3: in 3 hours, the inside of the house will be 69 degrees, assuming it was 70 before. That's approximate: it will actually take a bit longer to drop 1 degree, because the formula for heatloss (1 more time!) is : Q=A/R x delta T, and as the inside temperature drops off, delta T becomes less and less, and so heatloss slows down proportionally. Thus, in 3 hours, the temperature will be 69, and in slightly over 3 hours more, it'll be 68, and in a little more than slightly over 3 hours more, T will equal 67. And of course if this were a real house there'd be other mass inside it as well, so the cooldown rate would be even slower. I did a computer run on the example house (you can do the same thing with pencil or calculator, it just takes

Log wall, insulated on outside



From inside to outside: sheetrock, 2X2 furring, VB, logs, air space, studs and insulation, shiplap siding. If you want to see the logs, build it: logs, VB, air space, insulation, siding. Caution: the latter arrangement <u>might</u> cause moisture problems.

longer) and found it would take about a week for the inside temperature to drop off to 32 degrees, assuming a steady outside temperature of 0 degrees.

Conductivity

One other factor to consider is the rate at which a material can take on and release heat. Mass trades heat with air by being in contact with it, so if we increase the surface to volume ratio of the mass, we increase the rate of heat transfer. In passive solar houses, designers try to arrange it so that the sun shines through the windows directly onto the mass--it picks up heat faster this way than if it were merely in contact with heated air.

So far as various massive materials are concerned, I give here a sort of qualitative description of their conductive properties. The discussion doesn't really do justice to the phenomenon of conductivity (I'm running out of time and space, and I know just enough about it to lead you astray), so if you need to make exacting calculations, I suggest you go bother the Cooperative Extension Engineer at your local university.

Metals in general have high conductivities--heat transfer happens quickly. Copper has the fastest heat transfer rate of any material a housebuilder might have occasion to use. Insulating materials have very low conductivities--that in large part defines an insulator. Water, as usual, is a special case. It has a fairly low conductivity, but because of its convection (it moves within a container, carrying heat with it) it acts as if it were highly conductive. Think about bathtubs: add some hot water and pretty soon the whole bath is at a higher temperature. Imagine next a bathtub full of dirt: add hot dirt at one end and it'll take hours before you'd notice a temperature change at the other end, if at all.

As you add water to dirt, it transfers heat more quickly--in the case of our planter, the dirt will be more or less wet, and so we'll be able to get BTU's into and out of it faster than if it were dry. Rocks will have more surface area exposed to the air than dirt, and so they'll transfer heat more quickly.

Thermal mass generally costs very little. In the case of water, the container can get expensive, but for solid materials, the main cost is for the space that they occupy within the building. Looked at from this perspective, we become interested in the highest possible BTU storage per cubic foot.

Integration

Many passive solar house builders achieve their high mass requirements by putting a concrete wall (the Trombe wall) or water-filled 55 gallon drums (the water Trombe) in front of south facing windows. This works, unquestionably, but architecturally it lacks finesse. 1 good solution is to follow the Frank Lloyd Wright rule: never allow a material to perform only 1 function if you can allow it to perform 2: integrate the thermal mass with the structure, so that the heat storage system is a part of the house.

Here are a few suggestions as to how to make a high mass house that doesn't look artificial:

I'm obviously a fan of planters--they not only store BTU's, but they look nice and you can grow food and other things in them.

Everybody likes fireplaces, and it's part of their nature to incorporate large amounts of thermal mass. Caution: unless a fireplace is properly designed (airtight damper system, and <u>all</u> the mass <u>inside</u> the house) it can be a thermal liability rather than an asset.

A floor slab can be 2' thick instead of 4". It doesn't have to be all concrete; build it (from the bottom up), outside dirt, then blue styrofoam, then compacted dirt or gravel, then concrete slab. This is only an idea: I wonder: will the Styrofoam handle the pressure of compaction? How many psi does a compactor exert? Check it out before you try it.

Dirt can go on a roofdeck, and a greenhouse can go over that. You might get away without buying any roof insulation at all this way: you won't need it in summer, and when it gets cold, you can mulch the garden with a couple feet of sawdust. While we're on the topic, I'll pass on Michael Marshall's quippish formula for how to build an underground house: 1.) build a basement. 2.) set a bridge deck on top of it. That took the mystery out of underground houses for me.

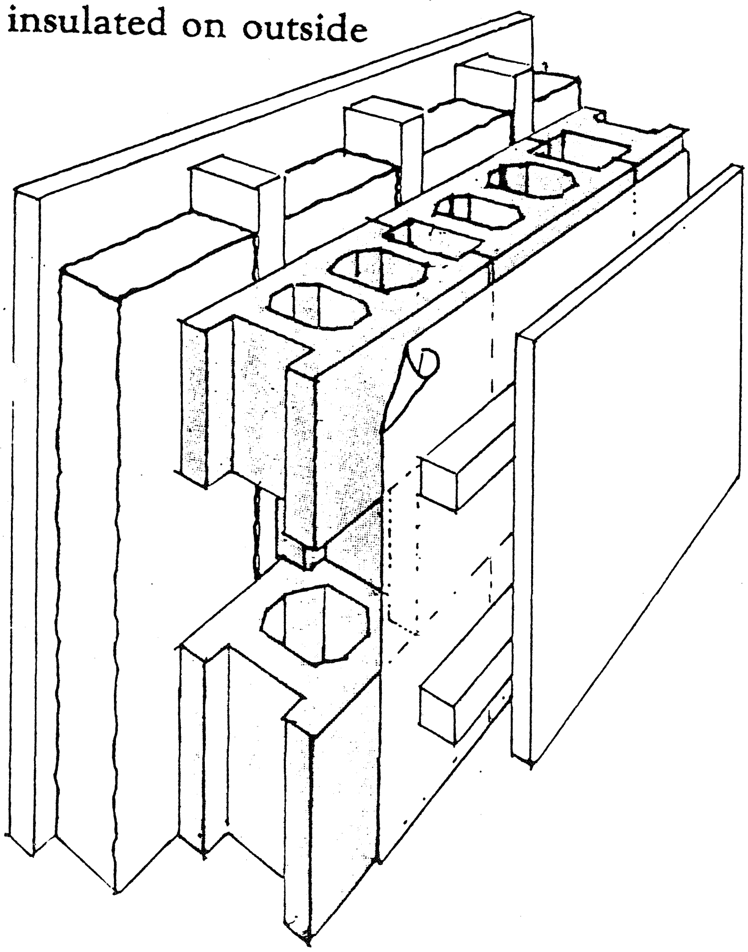
Metal and glass sculptures fit nicely into houses.

Some people might get off on making house furnishings out of broken engine blocks, worn out Caterpillar parts, etc.

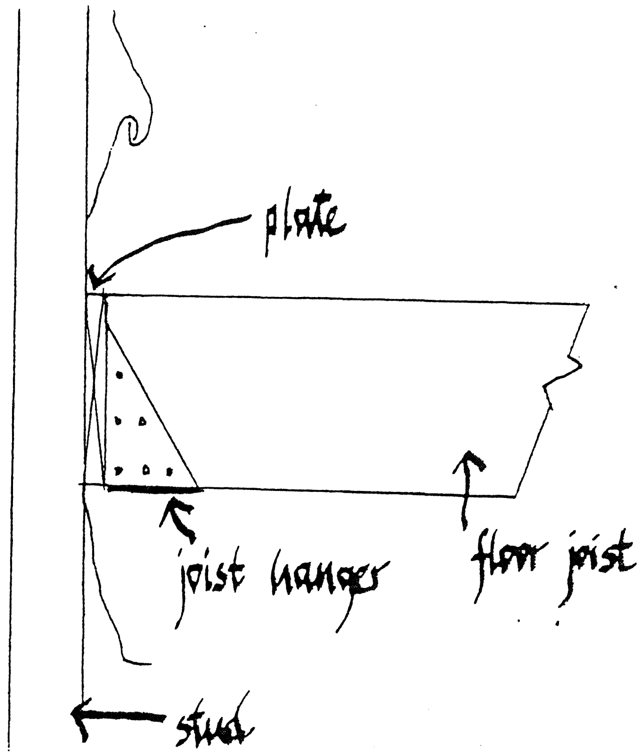
And of course if you've got local stone, brick, or adobe, you've got it made.

I suspect that over the next few years thousands of people will find thousands of amazing ways to put mass inside houses. It should be interesting.

Concrete block wall, insulated on outside



From inside to outside: sheetrock, 2X2 furring, VB, blockwork, insulation, plywood sheathing. Another way is to adhere beadboard or blue Styrofoam to the masonry. Beadboard needs a VB.



2nd floors and balloon frames

The conventional method for putting a 2nd floor into a balloon framed house is to let a 1X4 ribbon into the studs, then set the joists on the ribbon and nail through the joist ends into the studs. This guarantees a vapor leak. A technique which takes VB needs into account is shown in the illustration above. You nail a plate to the studs, either after the VB is in place, or using a strip which can later be patched to. The floor joists are then attached to the plate with joist hangers.

Infiltration calculations

The formula for figuring infiltration heatloss:

volume of house X air changes per hour X heat capacity of air X density of air X delta T = BTU loss per hour

Volume of house equals width times length times heighth.
Let's assume that we change .2 of the house air per hour.
Heat capacity of air is .24
Density of air equals approximately 39.6/(460 + outside temperature), based on a barometric pressure of 29.92
Delta T is the difference between inside and outside temperatures.

For an 800 square foot house at -20, then:

6400 X .2 X .24 X 39.6/(460 + -20) X 90

ECONOMICS/SECTION V

The whole point of economic analysis is to determine a "correct" amount of insulation to use. While working on this section, I became convinced that the traditional method of economic analysis is unable to make that determination, and at the end of the chapter I suggest an alternative method for figuring out how much insulation a house needs. But since there's so much to be learned from looking at the situation in the traditional way, I'll get on with it.

I use a few jargony terms in the discussion, not because I want to confuse, but because they say what I mean more precisely than any colloquial terms I'm aware of.

DEFINITIONS

A 'thermal enclosure', or 'thermal enclosure system', or 'insulated shell' is that part of a house which contains heat. It includes the framing, insulation, and VB for the exterior walls, roof, and floor; the windows and doors, and casings for same; shutters and their control system, and all the miscellaneous nails, staples, caulking and hardware that it takes to put the thermal enclosure together. A thermal enclosure does not include flooring, carpets, plumbing, wiring, interior or exterior sheathing, a front lawn, or anything else which doesn't contribute to containing heat.

A 'heat production and distribution system' or 'heating system' is the whole system required for turning fuel into heat and scattering the BTU's around to all the parts of the house. A heating system might consist of windows plus thermal mass, or a wood or oil burning stove, or it might be a hot water system--a buried fueloil tank, boiler, baseboard piping system, thermostatic zone controls, and circulating pumps.

A 'thermal system' includes both the thermal enclosure and whatever heating system it will require to keep the house at 70 degrees (or as wished) for the life of the building.

ANALYSIS

According to traditional economic analysis, there are 2 factors to consider when trying it come up with the cheapest way to put together a thermal system:
1.) the cost of the thermal enclosure and,
2.) the cost of adding heat for the life of the building. Normally the life of a building is calculated at 30 years, because banks customarily sell 30 year mortgages. Well built houses can last hundreds of years; poorly built houses often last less than 30 years, and frequently burn down.

There is an inverse relationship between the cost of the thermal enclosure and the cost of adding heat to it: spend more on the enclosure, and you'll spend less on adding heat; spend more on heating and you can spend less on the insulated shell. Economic analysis asserts that there will be some lowest total system cost: at some point you could put more money into insulation, but the system cost would be higher because you'd achieve only an insignificant decrease in the cost of adding heat, and vice versa. We're looking for the balance point: the lowest total cost of building a thermal enclosure and keeping its interior at a comfortable temperature for the life of the building. Here are most of the variables you need to consider:

1.) Cost of thermal enclosure

A.) Capital investment, materials and labor

There are more materials in the thermal enclosure system of a superinsulated house than in that of a conventional house, and it takes proportionally more labor to assemble the system. Insulated shells, however, are relatively inexpensive. Superinsulated or not, they represent only a very small part of the cost of buying property and building a house on it. Additional costs of a superinsulated thermal enclosure (as compared to conventional) lie in the following areas:

1.) If we start with a given floor area and ceiling height, and start to insulate around them, the outside dimensions of the superinsulated shell will be bigger than those of conventional. The house gets taller, the roof has to be bigger, the foundation must increase in size. As a tradeoff, of course, you could slightly decrease your useable floor area, and so keep the outside dimensions the same.

2.) You can't buy prefab window and door casings for walls that are a foot to 2 feet thick--they'll have to be custom made.

3.) The shutter system is extra.

In order to encourage housebuilders to buy insulation rather than fuel, many states offer a tax credit equal to 10 % (up to $200) of the capital investment for the thermal improvements. A similar credit is now being considered at the federal level; if bills pass with present language, both the percentage and the upper limit will be considerably higher than that of the states.

B.) Interest on capital investment.

If you borrow money to buy a thermal enclosure, you'll probably have to pay interest. The more the shell costs, the more interest you'll have to pay.

C.) Maintenance for life of system

Windows break, and moving parts--hinges, wheel-track arrangements, etc.--may require maintenance. Any electronic shutter control devices will probably require maintenance. If well built, the non-moving parts of a thermal enclosure should give no trouble for a long long time.

2.) Cost of adding heat.

A.) Capital investment for heat production and distribution system.

In a superinsulated house, the heating system can be minimal--in many locations you might get away with nothing more than thermal mass to store the BTU's coming through the windows; at the next step up you might spend $200-$1000 for a wood or oil or gas burning stove. Convection and radiation (both free) will take care of distributing the heat, even in a big house (that's not theory, I've seen it). The lower the insulation value of a house, the higher the capital investment for a heating system. A large, zoned hot water or hot air system can run to several thousand dollars.

B.) Interest on capital investment.

The more the heating system costs, the more interest you'll have to pay, if you've borrowed money to buy it.

C.) Cost of maintenance on system.

The more mechanical and electronic parts a heating system has, the more likely it is to break down, and the more likely it is that you'll have to pay a technician $20-$35 an hour plus parts to fix it. On the flip side, the less moving parts a heating system has, the less likely to break, and the more likely that you'll fix it yourself when it does. Heating systems sometimes disintegrate partially or completely during the life of a building--whatever part of the system you have to replace, you pay once again the (inflated) initial cost.

D.) Cost of system failure.

In a minimally insulated house, if for some reason the heating system fails when it's cold outside, you can expect small catastrophes such as broken pipes, frozen plants, perhaps damage to a piano or a piece of electronic equipment. If you build a superinsulated house, you are entitled to a reasonable expectation, given minimal care on your part, that the inside of the building will never reach 32 degrees.

E.) Cost of fuel for life of building

It is impossible to predict what fuel will cost in the future. If you burn fossil fuel, it's likely that it will cost more next year than it does this year, tho how much is open to question. As to fuels of the future, there's always a chance that the high tech boys will come through with incredibly cheap hydrogen, or fusion generated electricity, or something yet unthought of. And there are "alternative" fuels which may remain cheap for our lifetimes-- lumber mill by-products, crankcase oil, waste paper, etc.

Tho we can't say or do much about the future price of fuel, the quantity of fuel a house will require has an inverse relationship to the integrated R value of the thermal enclosure: more insulation, less fuel. To find life cycle fuel costs for heating a thermal enclosure of specified IR, you first of all figure out the total number of BTU's needed (A/R x 24 hours x average annual degree days x years) and then calculate the cost of that many BTU's, taking into account the unit cost of the fuel you use and the efficiency of the heat production and distribution system.

There are 2 sources of BTU's which decrease the heating load in a building. The first is solar gain, and the second is what I call "living process heat gain". LP heat gain is what you get from body heat, lights, refrigerators, TV's, computers, cooking, heating water, drying clothes, ironing, etc. You can up your LP gain significantly by retrieving heat from gray water (baths, showers, dishwater, etc.) before you dump it. In an "average household" LP gain will amount to several thousand BTU's per hour; depending on IR of thermal enclosure and lifestyle factors--how much do you bake? how many electrical appliances do you use?--LP heat gain may be all the heat you need down to 0 degrees (with high IR), or it may be just a drop in the bucket at 50 degrees (with low IR, that is, in a minimally insulated building).

It should be noted also that heatloss from a building is determined not only by its IR, but by its outside surface area, and the outside environmental conditions. A big house will necessarily lose more heat than a small house, given equal IR's in the 2 buildings. The environmental conditons are a large variable. The Degree Day concept (formula for degree days: DD=delta T x days. In 1 day at -60 degrees, there are 130 degree days (70-(-60)=130); to find DD for 1 year you subract average annual temperature from 70 degrees, then multiply by 365) assumes that the whole surface area of the building is in contact with the air, and doesn't take into account the effects of wind, or the effect of the sun shining on the outside of the building and warming it up. If a house sits on grade, or is wholly or partially buried in the earth, air temperature DD won't predict heatloss. It is true that ground DD are approximately equal to air DD--average annual soil temperature approximately equals average annual air temperature--but this doen't take into account the fact that 6 or 8 feet into the earth, the highest temperatures in the annual cycle occur just before the air temperatures are lowest, and the lowest ground temperatures occur in late winter and spring, when in most locations there are vast quantities of BTU's (sunshine) to be had for the grabbing.

VB vs Ventilation

The colder your outside design temperature, the more important a leakfree vapor barrier becomes, and the less you can rely on ventilation. If the temperature stays under 32 degrees for an extended period of time, any moisture which gets into the insulation will freeze there, melting only when the temperature warms up.

In milder climates you can get away with a less than perfect vapor barrier, provided you have plenty of ventilation.

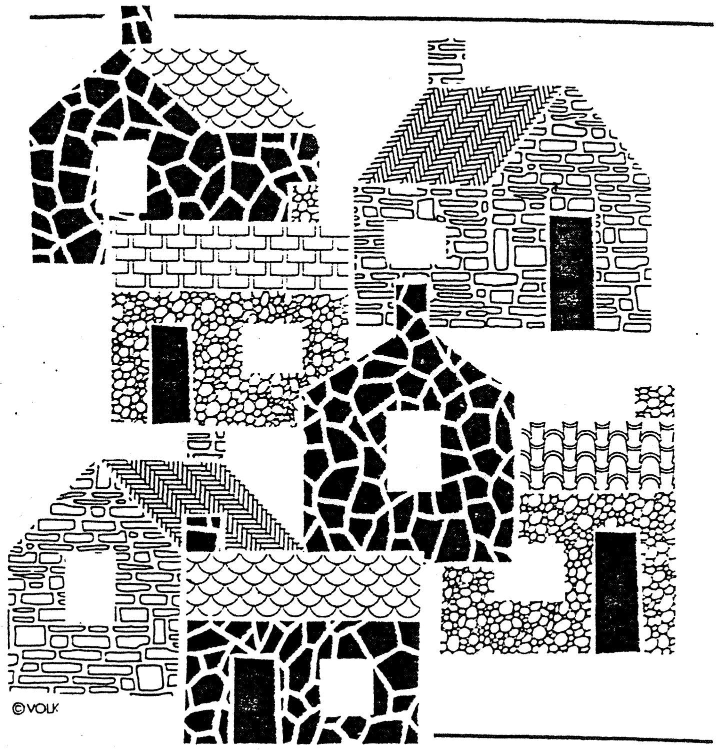
But any moisture in the insulation makes it much less effective (R19 fiberglass performs as R9.5 when 3% of the weight of the insulation is water), so if you can arrange it, a good VB is desirable, even in comparatively mild climates.

★★★★★★★★★★★★★★★

There is a debate about how well roof cap ventilators work, and if they work at all. They definitely won't provide escape for moisture laden air if the vents are covered with show. And caps which have vents only at the ends seem to need wind to insure sufficient air circulation. There's also a question whether air will move through flat or low pitched roofs: no chinmey effect. Perhaps some draft action could be added with solar heated stacks. Research remains.

One other factor: if you enclose any portion of a building in a greenhouse you effectively reduce the number of degree days, because the temperature outside the enclosed section of the house will generally be higher than outside air temperature. In far north latitudes, however, at the coldest part of the year, the temperature inside a greenhouse is generally just about the same as the outside air temperature.

In general, using the degree day concept on an annual basis does not accurately predict thermal performance of a building. The accuracy increases proportioanally as you cut the time span; plotting performance on an hourly basis gives a fairly realistic indication of what actual performance will be.



INSIDE DESIGN TEMPERATURES

For calculation purposes, I assume throughout this booklet that the temperature inside a house will be 70 degrees. ASHRAE uses 65 degrees, because you don't need to heat an uninsulated house when the temperature is above 65--solar and living process heat gain will take care of it.

However, a superinsulated house may not need any additional heat till 0 degrees, so the ASHRAE distinction doesn't apply. And when it's -40 outside, you 'll be heating the house up to 70-- maybe even 72 or 77.

* * * * * * * * * * ALTERNATIVE * * * * * * * * * * *

'He searched that menu thru and thru
To see what fifteen cents would do.
One meatball...'

There follows an outline of an alternative method for figuring out how much insulation any house of a particular size needs to have. If you're familiar with the Depression era song called 'One Meatball', you'll understand why I call this the Meatball Method. Here we go:

1.) Figure out how big your house is going to be.

2.) Decide, on an hourly basis, how many BTU's you'll have available to heat the house with. The 3 sources of BTU's will be :

A.) Solar gain through windows, which will vary with window area, orientation, latitude, time of year, percentage of total possible sunshine you actually get, and amount of thermal mass inside house.

B.) Living process heat gain. This will vary not only with your lifestyle, but with the time of year, in many cases. For instance, in winter, you might do more baking, or you might use a bunch of growlights to keep plants growing. For calculating LP heat gain, you can get data from Energy Primer or numerous other publications.

C.) Fuel. You can get virtually any number of BTU's you want from fuel, provided you're willing to buy it or otherwise put energy into acquiring it.

3.) Sit down with all the local weather records you can get your hands on. Be aware of any differences between the weather at the weather station and that at the spot on (in) which you intend to build. For instance, in Fairbanks, it's common knowledge that during the wintertime, the temperature in the hills is generally 10 or 20 or so degrees warmer than in the flats, where the weather station is located. Try to get a feel for the environmental conditions your house will have to live in at any given time of the year. Note average high and low temperatures, record highs and lows, cloud cover, wind velocities, etc. I feel that when you can tell yourself a fairly lengthy story about what the weather will probably be like for the 1st and 15th of each month, you pretty well know what your house is going to be up against.

4.) Decide what, if anything, you're going to do about infiltration heatloss.

5.) Start looking at the heatloss chart. Find the column that applies to the size of house you'll be building. Run down the column headed "Q,hr" till you see a number that's close to the number of BTU's you've decided you can afford. If the number in the column immediately to the left (headed "T,o", meaning outside temperature) is close to your mean annual temperature, then insulating to the value in the next column to the left (headed "IR", meaning integrated R value) will allow you, on an annual basis, to use roughly the number of BTU's you've decided you can afford.

6.) Look at the chart further. See what IR you'd have to go to to use up your allotted BTU's only at your outside design temperature (which means "the coldest it ever gets for any length of time in your area"). The design T for Fairbanks is -60. If you went that route you'd be paying for BTU's only in the very coldest weather--the rest of the year it would be free, except that you'd have to arrange to get rid of excess solar and LP BTU's.

7.) Keep looking. Try to imagine all the possibilities. I'm sorry that the chart doesn't have smaller gradations, but all the relationships are linear, so it's fairly easy to extrapolate or interpolate.

8.) If you want to work with it, here's the computer program that generated the numbers on the chart. The system is BASIC:

```
10 Let R=5
20 Let A=1440+(R/65*306)
30 Let T=60
40 Let D=70-T
50 Let Q=A/R*D
60 Print R,T,Q
70 Let T=T-20
80 If T>-61 then 40
90 If T<-61 then 100
100 Let R=R+5
110 If R<61 then 20
120 If R>61 then 990
990 END
```

In the program, R means IR, A means outside surface area of building (1440 is for 400 square feet, and the part in parentheses is a jerryrigged way of tying increasing outside dimensions to increasing R; 306 is the difference between the outside square footage of the house with no insulation and with 18 inches of fiberglass (R65, more or less) all around) . T means outside temperature, D means delta T, and Q means heatloss in BTU's per hour. You can make the gradations as fine as you like by specifying smaller ones; if you wanted to see all R values between 1 and 60 for instance, you would change line 10 to 'Let R=1', and line 100 to 'Let R=R+1'.

9.) Before you start building, remember: IR describes total heatloss from a thermal enclosure. If you're looking for an IR of 40, say, you'll probably insulate roof, walls, and floor to R60 or so, and go light on the shutters and doors, since moveable R40 insulation would be problematic, owing to its bulk. There's (hopefully) enough information in this booklet that you can figure out how to insulate to any IR you decide is appropriate for your particular case.

In conclusion I'd like to say that to do the thermal engineering on your own house, you don't need to be either a computer programmer or an architect, you merely need to have a basic knowledge of insulation and arithmetic, and have a very intimate knowledge of the weather for the spot on which you intend to build. I'd like to comment further that I consider all these numbers to be interim technology: we need them now because superinsulated housebuilding is a baby art; but in a few years the quantities and techniques will have filtered into local folk knowledge: instead of busting your head on numbers, you'll ask your friends and the people who live on the next lot over, and they'll tell you how they made a house that doesn't burn any fuel.

400 sq.ft

IR	T.D	Q/hr	INF
5	60	2927	117
5	40	8781	365
5	20	14635	634
5	0	20490	926
5	-20	26344	1244
5	-40	32198	1593
5	-60	38052	1977
10	60	1487	
10	40	4461	in-
10	20	7435	fil-
10	0	10410	tra-
10	-20	13384	tion
10	-40	16358	
10	-60	19332	loss
15	60	1007	
15	40	3021	will
15	20	5035	
15	0	7050	stay
15	-20	9064	
15	-40	11078	the
15	-60	13092	
20	60	767	same
20	40	2301	..
20	20	3835	
20	0	5370	more
20	-20	6904	
20	-40	8438	R's
20	-60	9972	
30	60	527	will
30	40	1581	
30	20	2635	not
30	0	3690	
30	-20	4744	help
30	-40	5798	..
30	-60	6852	
40	60	407	
40	40	1221	
40	20	2035	
40	0	2850	
40	-20	3664	
40	-40	4478	
40	-60	5292	
50	60	335	
50	40	1005	
50	20	1675	
50	0	2346	
50	-20	3016	
50	-40	3686	
50	-60	4356	
60	60	287	
60	40	861	
60	20	1435	
60	0	2010	
60	-20	2584	
60	-40	3158	
60	-60	3732	

800 sq.ft

IR	T.D	Q/hr	INF
5	60	5186	234
5	40	15557	730
5	20	25928	1268
5	0	36299	1852
5	-20	46670	2488
5	-40	57041	3186
5	-60	67412	3954
10	60	2626	
10	40	7877	
10	20	13128	
10	0	18379	
10	-20	23630	
10	-40	28881	
10	-60	34132	
15	60	1772	
15	40	5317	
15	20	8861	
15	0	12405	
15	-20	15950	
15	-40	19494	
15	-60	23039	
20	60	1346	
20	40	4037	
20	20	6728	
20	0	9419	
20	-20	12110	
20	-40	14801	
20	-60	17492	
30	60	919	
30	40	2757	
30	20	4594	
30	0	6432	
30	-20	8270	
30	-40	10108	
30	-60	11945	
40	60	706	
40	40	2117	
40	20	3528	
40	0	4939	
40	-20	6350	
40	-40	7761	
40	-60	9172	
50	60	578	
50	40	1733	
50	20	2888	
50	0	4043	
50	-20	5198	
50	-40	6353	
50	-60	7508	
60	60	492	
60	40	1477	
60	20	2461	
60	0	3445	
60	-20	4430	
60	-40	5414	
60	-60	6399	

1200 sq.ft

IR	T.D	Q/hr	INF
5	60	7115	351
5	40	21344	1095
5	20	35574	1902
5	0	49803	2778
5	-20	64033	3732
5	-40	78262	4779
5	-60	92492	5931
10	60	3595	
10	40	10784	
10	20	17974	
10	0	25163	
10	-20	32353	
10	-40	39542	
10	-60	46732	
15	60	2421	
15	40	7264	
15	20	12107	
15	0	16950	
15	-20	21793	
15	-40	26636	
15	-60	31479	
20	60	1835	
20	40	5504	
20	20	9174	
20	0	12843	
20	-20	16513	
20	-40	20182	
20	-60	23852	
30	60	1248	
30	40	3744	
30	20	6241	
30	0	8737	
30	-20	11233	
30	-40	13729	
30	-60	16225	
40	60	955	
40	40	2864	
40	20	4774	
40	0	6683	
40	-20	8593	
40	-40	10502	
40	-60	12412	
50	60	779	
50	40	2336	
50	20	3894	
50	0	5451	
50	-20	7009	
50	-40	8566	
50	-60	10124	
60	60	661	
60	40	1984	
60	20	3307	
60	0	4630	
60	-20	5953	
60	-40	7276	
60	-60	8599	

1600 sq.ft

IR	T.D	Q/hr	INF
5	60	9044	468
5	40	27132	1460
5	20	45220	2536
5	0	63308	3704
5	-20	81396	4977
5	-40	99484	6372
5	-60	117572	7907
10	60	4564	
10	40	13692	
10	20	22820	
10	0	31948	
10	-20	41076	
10	-40	50204	
10	-60	59332	
15	60	3071	
15	40	9212	
15	20	15353	
15	0	21495	
15	-20	27636	
15	-40	33777	
15	-60	39919	
20	60	2324	
20	40	6972	
20	20	11620	
20	0	16268	
20	-20	20916	
20	-40	25564	
20	-60	30212	
30	60	1577	
30	40	4732	
30	20	7887	
30	0	11041	
30	-20	14196	
30	-40	17351	
30	-60	20505	
40	60	1204	
40	40	3612	
40	20	6020	
40	0	8428	
40	-20	10836	
40	-40	13244	
40	-60	15652	
50	60	980	
50	40	2940	
50	20	4900	
50	0	6860	
50	-20	8820	
50	-40	10780	
50	-60	12740	
60	60	831	
60	40	2492	
60	20	4153	
60	0	5815	
60	-20	7476	
60	-40	9137	
60	-60	10799	

2000 sq.ft

IR	T.D	Q/hr	INF
5	60	10973	585
5	40	32920	1825
5	20	54866	3168
5	0	76813	4628
5	-20	98759	6221
5	-40	120705	7965
5	-60	142652	9884
10	60	5533	
10	40	16600	
10	20	27666	
10	0	38733	
10	-20	49799	
10	-40	60866	
10	-60	71932	
15	60	3720	
15	40	11160	
15	20	18599	
15	0	26039	
15	-20	33479	
15	-40	40919	
15	-60	48359	
20	60	2813	
20	40	8440	
20	20	14066	
20	0	19693	
20	-20	25319	
20	-40	30946	
20	-60	36572	
30	60	1907	
30	40	5720	
30	20	9533	
30	0	13346	
30	-20	17159	
30	-40	20972	
30	-60	24785	
40	60	1453	
40	40	4360	
40	20	7266	
40	0	10173	
40	-20	13079	
40	-40	15986	
40	-60	18892	
50	60	1181	
50	40	3544	
50	20	5906	
50	0	8269	
50	-20	10631	
50	-40	12994	
50	-60	15356	
60	60	1000	
60	40	3000	
60	20	4999	
60	0	6999	
60	-20	8999	
60	-40	10999	
60	-60	12999	

THE LAST WALTZ

This booklet was put together in the following way:

MICHAEL MARSHALL came up with the original idea, convinced me it was worth doing, and greatly influenced the contents. He did all the illustrations, except those by JANE GALBLUM, who drew up the shutter designs. KATHY FLETCHER added the calligraphy. EVA BEE did the layout, bookkeeping, and some clerical work. TOM MCGRATH fronted some much needed money. I, ED MCGRATH, was the project director, and so did everything that anyone else didn't do.

I got my information mainly from the following books, articles, bulletins, etc.

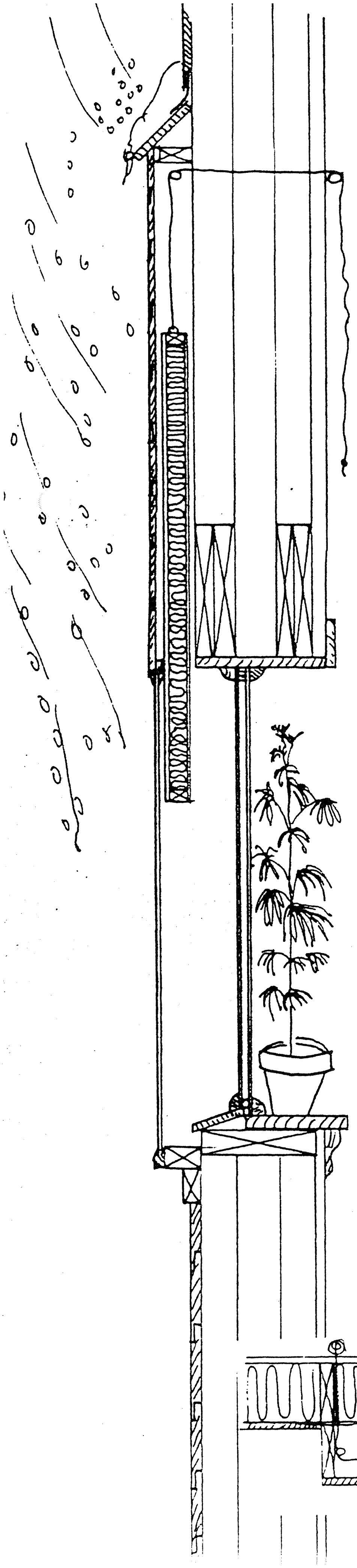
P559 Design of Roofs for Northern Construction
HSC33 Design of Floors for Arctic Shelters
HSC30 Effects of 2X4 Studs on Heat Loss
HSC16 Effect of Wall Framing on Heat Loss
P-4-756 Thermal Properties of Walls
HSC7 Temperature Gradients of Walls
P558 Heat Loss and Condensation in Northern Residential Construction
P1155 Temperature Gradients of 2X4 Stud Walls
ES2 Temperature Gradients of Windows
HSC9 Temperature Gradients of Floors
HSC8 Temperature Gradients of Roofs
P560 Tips on Insulating an Existing House
P1151 Checksheet of Common Condensation Problems in Alaskan Homes
P457 Windows Regulate Relative Humidity
HSC31 Insulation Value of Windows and Drapes

Copies of these bullitens, all by Axel Carlson, may be obtained from the Cooperative Extension Service, University of Alaska, Fairbanks, AK, 99701. They are free to Alaskans, $.25 each to anyone else.

Design of Insulated Buildings for Various Climates, T.S.Rogers
Thermal Design of Buildings, T.S. Rogers
Thermal Resistance of Building Insulation, C.J. Shirtliffe, from Canadian Building Digest (Read before using urethane)
Introduction to Heat Transfer, Brown and Marco
The Internal Environment of Dwellings, R.M.E. Diamant
The Energy Miser's Manual, W.H. Morrell
Mechanical Engineer's Handbook, Lionel S. Marks, Editor
Condensation Control for Alaskan Homes, I.C. Branton
The Use of South Facing Windows for Solar Heating in a Northern Climate, R.R. Gilpin, U of A, Edmonton, Alta, Canada
Thermal Insulation Systems, A Survey, NASA, SP5027
ASHRAE Handbook of Fundamentals
Underground Designs, Malcolm Wells
The Use of Earth Covered Buildings, NSF-RA-76006, USGPO, Washington DC, 20402 $3.25
Building in the North, Eb Rice
Thermal Insulation, John Malloy (standard text, engineering for engineers)
Energy Primer, Portala Institute
Making the Most of your Energy Dollars in Home Heating and Cooling, U.S. Dept. of Commerce, Nat'l Bureau of Standards
Harnessing the Sun to Heat your Home, John Keyes

In addition to the publications, I got a tremendous amount of information, ideas, and help from the following people:
Axel Carlson, Cooperative Extension Engineer, U of A * Ralph Mathews, Insulation Engineering, Inc. * Rich Seifert, Dept of Water Resources, U of A * George Winford, Journalism Dept, U of A * Luke and Larry, computer node superintendents, U of A * Tom Moyer, DEC * Jack Coutts, EPA * John Zarling, Mechanical Engineering, U of A Helen Meyers, WAMI, U of A * Bob Roggasch, Gypsy Sawyers * Tony Silva, Johns Manville Earl Ziegler, Dow Chemical

And besides that, the project was speeded along by my friends, who gave me things like a bicycle, free typing, CB equipment, food and shelter, rides, trips, free labor, information, ideas, advice, good deals, paint brushes, and literally thousands of questions about insulation. They taught me how to write the book.



A sliding shutter

This shutter design consists of an insulated panel which slides inside a box. The box is a little bigger than twice the size of the window opening, and is nailed or lag bolted to the outside of the house, right over the framing. Looking at it from the outside, you see a surface which is half storm window, and half finished out in the same sheathing as the rest of the house. The storm window is used so that you can pop it off and wash windows from time to time. The box is only 6 or so inches thick; looking at it head on, you might not even notice it.

From inside to outside, the shutter panel is constructed:

inside sheathing, then a 3/4 inch airspace, then a layer of refelective foil, then rigid plastic insulation to desired thickness, then outside sheathing. For inside sheathing material, I suggest something like a printed fabric or canvas; the outside sheathing might be pressboard-- something that won't warp is what we're looking for.

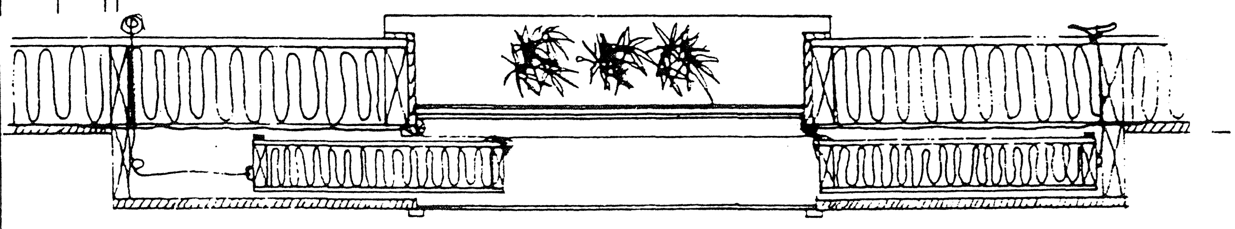
The panel sits inside the box (the edges might be made of 1X4, 1X6, or 1X8 lumber, depending on how thick you make the shutter panel) and slides in wooden tracks. It can slide up, down, sideways, or split in the middle and slide two ways at once. It's quite flexible as to shape, and thus will fit most windows, be they old or new. Jane says the design won't work on bay windows.

You open and close the shutter by pulling or releasing a nylon cord that runs through the wall. I suggest the cord be threaded through a piece of 1/2" plastic pipe with a scrap of innertube hoseclamped to both ends, the tube being packed with wool for insulation purposes. This arrangement will allow an easy fix when the cord breaks. If you counter-weight the shutter, you'll need to pull the cord in only one direction, and it'll slide the other way when you release the cord.

As shown in the drawings, there's a friction fit seal all the way around the window frame. For materials I suggest ripstop nylon covering (minimum of friction is the idea) and wool or fiberglass or whatever's handy for the insulation.

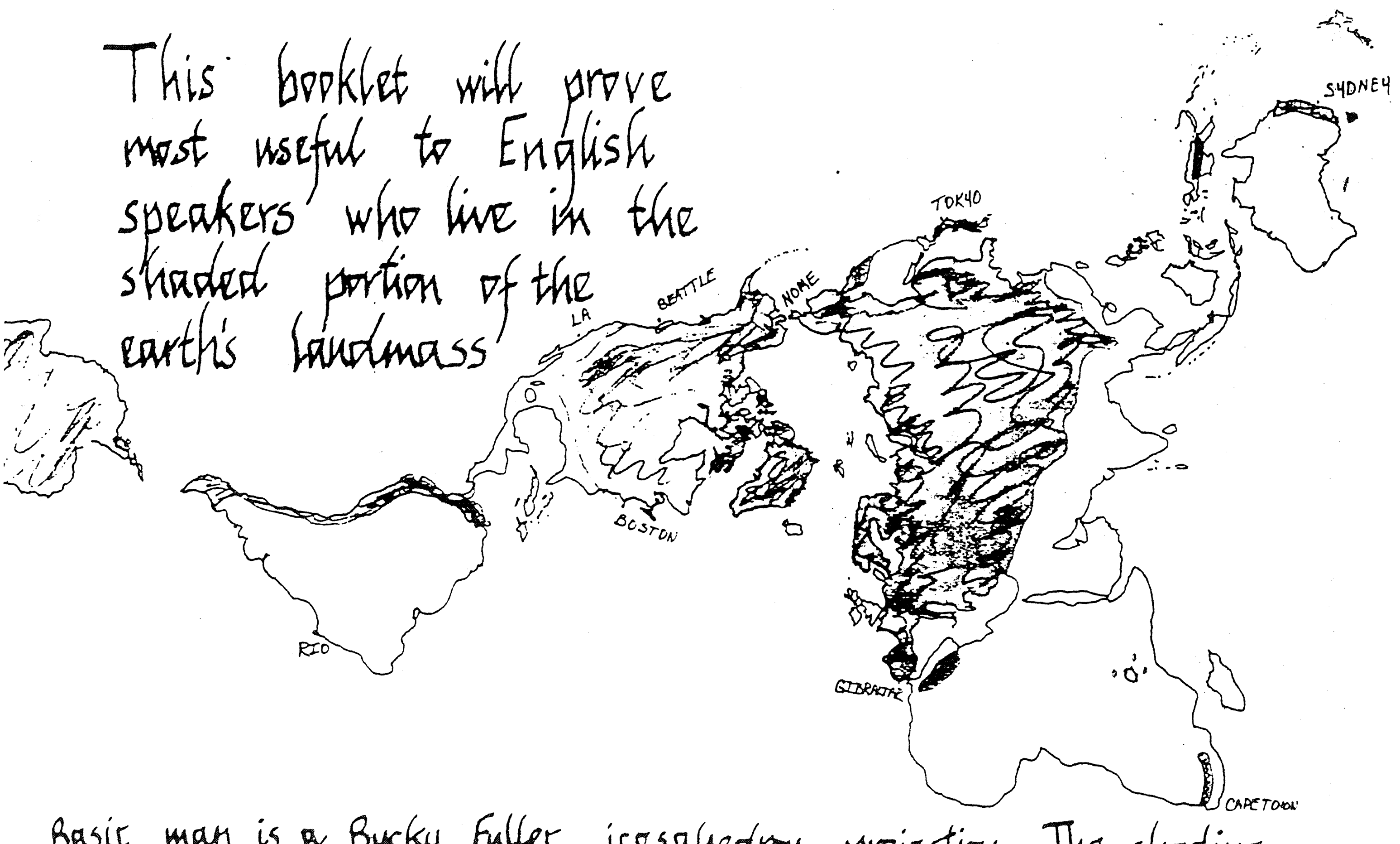
You could build the shutter box only slightly larger than the window; I suggest building it big enough that the shutter when closed covers the window casing and any conductive framing.

Top view of shutter which splits in the middle and slides both ways.



INSIDE THE COLD WEATHER EDITION

This booklet will prove most useful to English speakers who live in the shaded portion of the earth's landmass



Basic map is a Bucky Fuller icosahedron projection. The shading was interpreted from a map of World Snow Cover by Environment Canada