Super Good Cents Heat Loss Reference

Volume III:

MANUFACTURED HOMES:

Heat Loss Assumptions and Calculations
Heat Loss Coefficient Tables

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1 Introduction

This manual is intended to assist builders of manufactured homes in assessing the thermal performance of structural components (floors, ceilings, walls, and windows) used in the Super Good Cents Program. U-factors for these components are calculated using the ASHRAE (1989) parallel heat loss method adapted to the construction practices found in the Pacific Northwest manufactured home industry. Ecotope staff visited several Northwest manufactured home plants in 1990 to determine current construction practices.

A detailed description of the heat loss methodology (used for site-built homes) can be found in Volume 1 of this series (Baylon & Heller 1988a). Volume 2 of the series (Baylon & Heller 1988b) presents tables of U-factors found during the site-built analysis and drawings of construction details.

This volume is organized component-by-component, with explanations of how different components are put together and which methods were used to find thermal conductivities (U-factors) for components. The appendices to this report contain representative component drawings and U-factors for the many possible insulation strategies.

This volume does not discuss two manufactured home components: skylights and doors. For information on the thermal performance of these components, the reader should refer to Section 7 of Volume 2 of this series.

2 Component Construction and Analysis

2.1 Floor Systems

2.1.1 Construction Techniques

Manufactured home floor systems differ from site-built home floors in two important respects. First, the floor is framed on top of a steel undercarriage made of steel I-beams (which run the length of the home) and outriggers (placed several feet apart, which run from the outer I-beam to the perimeter of the home). This undercarriage is the means by which the home is towed from the factory to the home site. In the most commonly found construction techniques, the crushing of insulation batts between the floor joists and the undercarriage reduces the thermal performance of insulation. Second, heating system ducts run in the floor system. In most insulation strategies currently used, the ducts compromise the thermal performance of the floor system.

Three floor system construction techniques are described here. The "transverse" floor, in which the floor is framed perpendicular to the steel undercarriage, is the most common technique found in the Northwest. The framing scheme of the "cut-in" floor, used in Zone 3, is the same as the transverse floor, but the floor is insulated in a manner which minimizes the batt compression found in the transverse floor. The "longitudinal" floor is framed so that the floor joists run parallel to the steel I-beams. Duct losses are confined to a smaller region in this strategy and hence the thermal performance of the floor system is improved relative to the transverse floor.

Transverse Floor

The transverse floor is the floor built by most Northwest manufacturers. In this configuration, 2x6 floor joists are placed at right angles to the steel I-beams and parallel to steel outriggers (which extend from the I-beams to the perimeter joists) that make up the undercarriage of the home. The floor is assembled upside down, with the heating ducts, plumbing lines, and electrical service located in the center ("belly") portion of the floor system. A "belly blanket" (one or more layers of insulation) is placed over the floor framing and the various utility conduits, then covered with a reinforced plastic sheet called the "belly (or "bottom") board." The steel undercarriage is placed on top of this layer and strapped and bolted to the joist assembly. The entire system is then flipped back over and the flooring and heating registers installed.

Each half of a double-wide home's floor is thus constructed. The two halves are joined, and an insulated flexible crossover duct, which runs below the belly board, connects the two supply ducts in each half.

Depending on the manufacturer, various levels of insulation are used in the floor assembly. There is always a belly blanket, of varying thickness. The main difference between current practice and Super Good Cents floor systems is that joist insulation is added in the Super Good Cents home.

The belly blanket is crushed at the edges of the home and between the steel I-beams and the floor joists. Joist insulation is compressed if it is R-19 or more, since the cavity space is only 5 1/2" and the R-19 batt is 6" thick. Compression reduces the performance of the insulation and is taken into account when computing the overall floor U-factor.

Duct conductive losses and the infiltration/exfiltration they induce affect the performance of floor insulation. The effect of duct leakage on the floor U-factor is taken into account in the U-factor calculation (see Section 2.1.3).

Duct insulation improves the floor system's thermal performance for almost all nominal values of belly and/or joist insulation. This is particularly true if belly blanket insulation is minimal (R-7 or R-11). In this report, two different types of duct insulation are discussed: "sound" insulation, where the top side of the duct is insulated with an R-5 batt so that vibrations between the metal duct and the adjacent floor joists are damped (and, coincidentally, conductive duct losses are reduced); and a full R-5 wrap around the duct.

Cut-in Floor

The cut-in floor system is used by many manufactured housing builders. It is discussed here because it offers a significant improvement in the thermal performance and requires only minor adjustments to the commonly found transverse floor.

The thermal performance of the floor is improved with this techniques because duct losses to the crawlspace are reduced and much less heated air is trapped in the duct region of the belly. Trapping heated air below joist insulation in common practice floors increases losses to the crawlspace and effectively renders the joist insulation useless, since the performance of insulation is directly proportional to the difference in temperature between the conditioned and unconditioned space. With the cut-in floor, the amount of heated air leakage that occurs between the duct region and the outrigger area (especially for higher belly blanket R-values) is also reduced.

The basic structural approach for the cut-in floor is the same as for the transverse floor. The difference is in how the insulation is installed. The belly blanket insulation is brought up into the joist cavity in the outrigger region (the outer 3 feet of each side of the double-wide) by cutting the batts where they come up against the joists and pulling the batts into the joist cavity. This strategy prevents the compression which normally occurs when the belly blanket is crushed between the steel undercarriage and the joists.

Depending on the thickness of the belly blanket, it may still be compressed somewhat in the regions around the perimeter joists and between the bottom of the duct and the belly sheathing (R-33 and R-44 cases). This compression reduces the performance of the insulation and was taken into account when computing the overall U-factor for the floor.

Longitudinal Floor

In the longitudinal configuration, the floor is constructed in a way that is similar to the transverse floor; however, the 2x6 floor joists are placed parallel to the steel undercarriage I-beams. The heating ducts, plumbing lines, and electrical service are located inside (uninsulated) joist cavities in the center portion of the floor.

The longitudinal floor is currently somewhat rare in the Northwest. This is unfortunate, for this configuration offers significantly improved thermal performance -- for the same nominal R-value of floor insulation -- over the more common transverse floor.

Because of its positioning, the ductwork (whether insulated or not) contributes less to the heat loss of the longitudinal floor than the transverse floor. There is always some belly blanket insulation below the ducts, but never any above, since the duct takes up almost all of the space in the joist cavity where it is located. Conductive and other duct losses are confined in a relatively small space and a significant portion of the losses leak back into the house. Increasing belly blanket insulation beyond the minimum enhances this effect. Adding joist cavity insulation (in areas other than the duct runs) and insulating the duct further improve floor performance.

2.1.2 Insulation Options

The location of the furnace ducts in the floor system and the need to provide adequate connection between the wooden floor joists structure and the steel undercarriage complicate the task of insulating floors in manufactured homes. The standard procedure is to use a belly blanket. This insulation is compressed between the joists and undercarriage in areas where the joists cross the carriage. Figure 2.1 shows the most common ("transverse") floor system configuration.

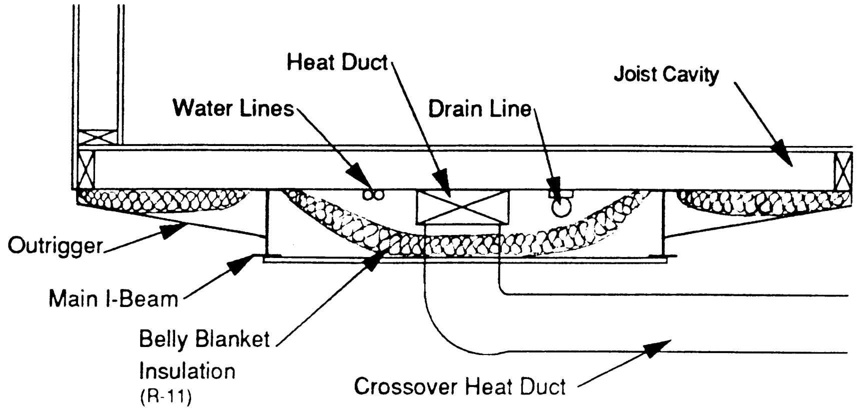


Figure 2.1 Transverse Floor System Cross-Section

Insulation amounts vary with manufacturer and with the specific home. Generally, the belly blankets are nominally R-11 or R-22. Insulation is also added to the joist cavities by some manufacturers, with up to a nominal value of R-22 compressed into the 5-1/2" space.

Insulating the heating ducts improves the thermal performance of the floor system regardless of the nominal value of the insulation used in the floor. Two levels of duct insulation are considered: 1) sound insulation (one layer of R-5 insulation placed between the top of the duct and the floor joist, used primarily to muffle duct-joist vibration); and 2) a layer of R-5 insulation wrapped completely around the duct and taped securely together.

To improve floor system performance over that achieved by the common practice of using only an R-7 or R-11 belly blanket, several alternatives can be considered.

1) Joist cavity insulation: Placing insulation of an R-value up to 22 in this cavity increases the total insulation value of the floor by a factor of almost 3. However, since the heating ducts are below the joists, this strategy isolates the duct from the home. All conductive losses and duct leakage occur in the area below the joist cavity insulation but above the belly insulation. This results in an effective reduction by a factor of 2 between the nominal value and the actual performance value of the insulation. (This issue is discussed in depth in Section 2.1.3, below.)

A variation on this approach is to increase the belly insulation while adding insulation to the joist cavity. This improves the insulation associated with the floor system since the duct is now better insulated from the outside.

2) Longitudinal floor: Use of this option with more than minimal joist and belly insulation is a good approach, since duct losses are confined to a much smaller region than in the transverse floor system. The ducts are placed in between floor joists rather than strapped below them, thus reducing considerably the amount of duct conductive loss into the belly region.

3) Cut-in floor: This variation of the transverse floor uses the same framing technique but a more effective insulation method. Insulation is placed under the duct in the center part of the steel carriage and then cut in to fit into the joist cavity in the outrigger area. This technique provides joist insulation in approximately 50% of the overall floor area but does not place insulation above the duct. In this configuration, duct insulation does not improve the thermal performance of the floor as dramatically as for the other floor strategies. This approach gives U-factors comparable to those found for longitudinal floors for the same nominal R-value.

2.1.3 Thermal Analysis

To analyze thermal performance of floor systems in manufactured homes, we used a one-dimensional heat loss analysis, adjusted to account for two important factors. The first of these is the compression (and subsequent reduction in performance) of belly blanket and joist insulation. The second is the interaction between the heating system ducts and the floor system insulation.

The first step in finding a U-factor for a given insulation value is to calculate a "steady-state" conductance of the floor system. This calculation takes into account the compression of insulation in the belly blanket and (if applicable) in the joist cavities. The framing correction is made in this step. The next step is to adjust the U-factor so that the effect of duct losses are included. The buffering effect of the crawlspace is taken into account in this step.

Insulation Compression and Conductance

The belly blanket conductance varies due to compression of the insulation. There are several distinct compression regions for the belly blanket, each corresponding to an area of the floor, and each with a different conductance. The compression for different floors was determined from site visits and some simplifications were made (for example, assuming a uniform slope of the insulation in compression zones). Figure 2.2 shows the compression regions with corrected R-values for a floor with an R-22 blanket. This figure extends from the band joist (at left) to the other side of one half of a double-wide home.

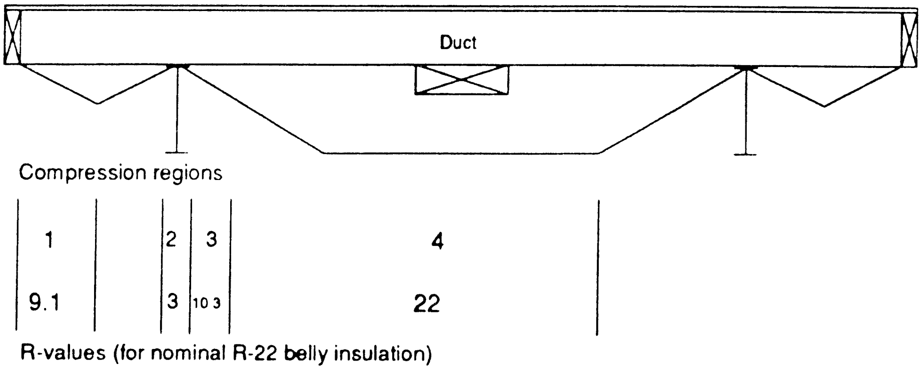


Figure 2.2 Insulation Compression Regions in Floor System

In cases where the compression in the region was less than or equal to 50% of the nominal thickness of the batt or batts, numerical integration was used to find an average R-value for the region. This integral was based on the following equation (Volume 1, Equation 1):

$$R_{Nom} = \left(4.53 + (K_N - 4.53)\frac{T_F}{T_I}\right)T_F$$

Where:

K_N = R-Value per inch $\left(K_N = \frac{R_{Man}}{T_I}\right)$

R_{Man} = Manufacturer's Specified R-Value

T_I = Initial Batt Thickness

T_F = Final Batt Thickness

R_{Nom} = Final Batt R-Value

In cases where compression exceeded 50% (where the insulation was crushed between joist and I-beam, for example), information from manufacturers (Manville 1988) was used to estimate the R-value.

R-values were calculated for the joist and belly regions in each compression zone. These values were weighted by the zone's square footage and summed. The reciprocals of the values for joist and belly regions, the so-called "steady-state" U-factors, were input into the duct model (described below) to calculate an overall floor system U-factor.

Effect of Forced Air Furnace and Ducts on Floor Performance

System supply ducts located in the belly cavity (between the floor joists and the belly blanket) complicate the calculation of the floor U-factor. The ducts conduct heat and leak conditioned air into this cavity. If there is insulation between the duct region and the living space, a great deal of this insulation is rendered useless, since there is little difference in temperature between the belly cavity and the inside of the home when the furnace is operating. The degree to which the joist insulation is bypassed is dictated by the insulation configuration and the amount of heat the ducts lose to the belly cavity.

The belly cavity behaves like a buffer space and the total floor-to-buffer and buffer-to-ambient conductivities must be added in series (after correction for insulation compression, described above) to get the overall floor system U-factor.

This process is complicated by the definition of the buffer space. We define the buffer as the space where air moves freely between the lower edge of the joists and the belly blanket. At a minimum, air circulates freely in the zone between the two floor I-beams. Typically, though, some air moves beyond the I-beams, particularly when there is no joist insulation or if there are perimeter air leaks where the blanket sheathing is attached to the band joists.

In calculating the overall floor conductivity, we looked at two buffer space scenarios. In scenario one, the buffer was considered to be restricted to the area between the I-beams. In scenario two, the buffer was considered to extend all the way to the perimeter joists.

For cases with no joist insulation, air flow was assumed to go throughout the floor. For the "longitudinal" floor and for "cut-in" floors with nominal R-values above R-22, we assumed no air flow beyond the duct region (between the I-beams). For all other cases with joist insulation, we assumed an air flow rate equal to the average of the two scenarios.

We calculated an adjusted overall floor conductivity (U-factor) for every combination of joist and belly insulation. Since the amount of insulation bypass depends on the duct heat flow (which is affected by duct insulation, if it is used), adjusted U-factors for the different duct insulation levels were also calculated.

To determine the amount of insulation bypass and the effective floor conductivity from the belly cavity region to the outside, we used a special version of the SUNDAY simulation program. The program combines SUNDAY with an equipment model developed for use in WATTSUN 5.0. The full model explanation can be found in Kennedy (1991).

SUNDAY is used to calculate the building load for a typical year. The equipment model then calculates the duct load and equipment energy needed to meet the building load. The model estimates a duct space temperature (in this case, the belly cavity temperature) and duct temperature, which are then used to calculate duct conduction loss and to adjust the floor loss. The effective conductivity of the belly region is this adjusted floor loss, normalized by the house-to-ambient temperature difference and the belly cavity area (square footage).

Inputs necessary for the duct model are the conductivity of the supply duct, the conductivity of the house-to-belly cavity interface (the "steady-state" joist U-factor, from above) and the belly cavity-to-ambient interface (the "steady-state" belly U-factor, from above), the belly cavity area, and the leakage fraction of the supply ducts. The furnace on-time is also needed. It is found in an earlier part of the model through an iterative solution.

The supply duct conductivity is calculated based upon the duct area and the presence of insulation. Heat loss from the bottom of the duct is ignored in this calculation since it presses directly into the belly insulation and does not contribute heat into the belly cavity. The conductivity used for bare metal duct is 1 Btu/hr-ft^2-°F; the conductivity for a metal duct with R-5 insulation is 0.25 Btu/hr-ft^2-°F; and the top surface conductivity for a metal duct with R-5 sound insulation on the top surface is 0.25 Btu/hr-ft^2-°F.

The duct insulation conductivity is an estimate and is considered roughly the same for duct insulation between R-4 and R-7. For the higher R-values, insulation compression will reduce the actual R-value of the insulation. We chose R-5 as the most likely average value of duct insulation and used a U-factor which is a bit more conservative than the value obtained from the reciprocal of 5 (0.20).

We use a supply duct leakage fraction of 3.5 percent of the air handler flow. This value was derived from detailed constant-injection tracer gas measurements of a single manufactured home (Palmiter & Bond 1990). Using this single measurement is necessary and acceptable since duct system construction is nearly identical in all manufactured housing.

Table 2.1 shows the extent to which the performance of selected floor systems is reduced by the effects of a forced air furnace and ducts. The numbers listed (called "furnace efficiency factors") are the ratio between the yearly building load without heating system effects and the load with induced infiltration and conduction losses from the heating system and ducts included.

The table can be used to compare homes with forced air furnaces to those without. A home's steady-state UA can be divided by the appropriate furnace efficiency factor to calculate a corrected UA which includes heating system and duct effects.

The performance of the floor varies dramatically, depending on the amount of insulation used and the way it is installed. The cut-in and longitudinal floor systems offer the smallest reduction in performance, since losses to the outside are reduced and there is much less joist insulation bypass. Duct insulation, especially a full R-5 wrap, also improves floor system performance.

Table 2.1
Furnace Efficiency Factors

Floor Type	Nominal Belly Insulation (R-value)	Nominal Joist Ins. (R-value)	Uninsulated Ducts	Duct Sound Ins.	R-5 Duct Wrap
Current Practice Transverse	7	0	0.86	0.89	0.93
	11	0	0.88	0.91	0.94
SGC Transverse	11	19	0.76	0.82	0.89
	22	22	0.80	0.90	0.94
Longitudinal	11	19	0.91	--	0.94
	22	22	0.93	--	0.95
Cut-in	22	--	0.92	0.94	0.95
	33	--	0.94	0.95	0.96

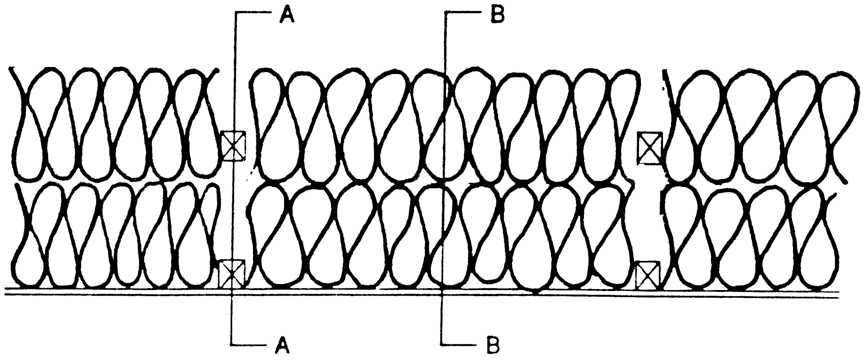
2.2 Ceilings

2.2.1 Construction Techniques

In general, ceiling systems in manufactured homes are similar to site-built ceilings. Pre-manufactured trusses are shipped to the manufactured home plant or are made in the plant. Batt or blown insulation is used to insulate the attic or vault cavity. Because of the sequence of building in manufactured home plants, access to the attic and vault area is more convenient and therefore one can, in general, expect a consistently better job of ceiling insulation than found in site-built homes.

There are some significant differences between site-built and manufactured housing roof assemblies which must be taken into account when estimating the thermal performance of manufactured home ceilings.

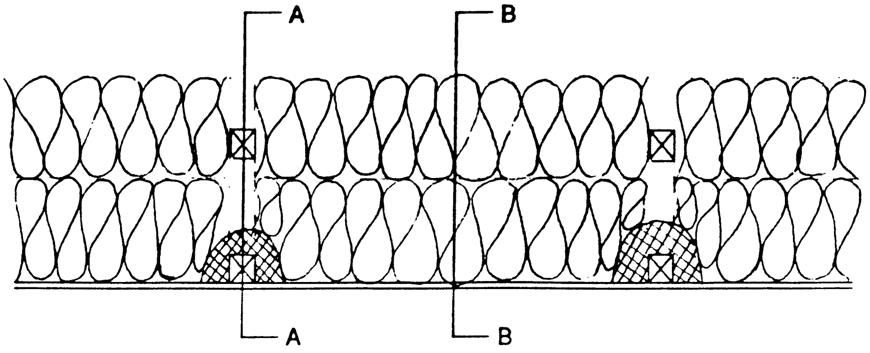
- Trusses are made of 2x2s (rather than 2x4s), so the framing factor for the ceiling must be reduced from that used for site-built ceilings.
- Based on field observations, batts were placed between the truss members rather than over them (shown in Figure 2.3). This procedure undercuts significantly the thermal performance of the ceiling because the space over the truss members is uninsulated. Note the dramatic difference in R-value between the two paths shown in Figure 2.3 The insulating quality of the roof assembly in this "uninsulated slot" region comes solely from two 2x2s, the ceiling wallboard, the roof decking, and the interior and exterior air films.



Path A-A: R-4.80   Path B-B: R-39.17

Figure 2.3 Uninsulated Slots Over Truss Members

- Some manufacturers use a polyurethane-based mastic foam to attach trusses to the ceiling gypboard. The analysis considered a scenario where enough extra mastic was sprayed on to get an average of one inch (R-6 per inch) of foam over the top of the bottom truss cord. This approach (Figure 2.4) is a dramatic improvement over current practice and should be a SGC option.



Path A-A: R-10.80 Path B-B: R-39.17

Figure 2.4 Ceiling System With Foam Insulation

- For ceilings insulated with batts, U-factors are calculated for three different batt placement methods for each nominal R-value. The first method (Figure 2.5) places the full nominal R-value of insulation all the way to the edge of the truss. A cardboard baffle is used to ensure at least a 1" airspace above the insulation. Continuous soffit vents are also used to ventilate the attic. In some cases, this means the batts are crushed considerably to fit into the available space. The second method (not shown) uses gable vents and induced ventilation and stuffs the full nominal R-value of insulation into the truss heel. The third method (Figure 2.6) stacks the batts in staggered "cake" fashion so there is no crushing of the insulation. This method results in reduced performance relative to the crush method because of the voids that result over the first layer of insulation for higher nominal R-values.
- For blown-in insulation with continuous soffit venting, a 1" airspace is maintained above the insulation. For gable vents, the truss heel cavity is blown full.

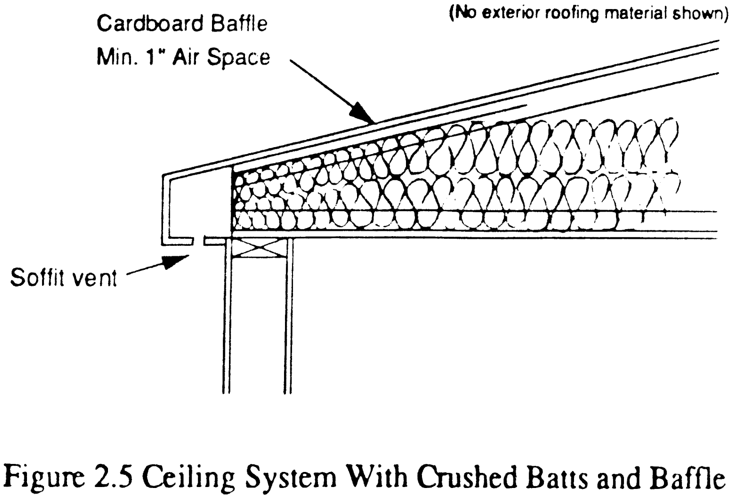


Figure 2.5 Ceiling System With Crushed Batts and Baffle

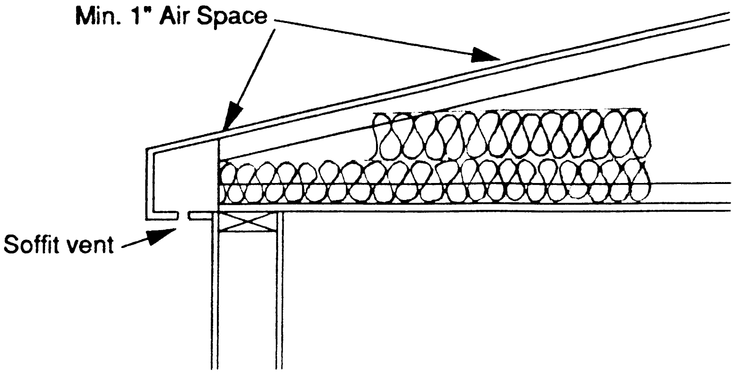


Figure 2.6 Ceiling System With Stepped Batts

2.2.2 Thermal Analysis

For the most part, the same methods were used to determine ceiling U-factors as found in Sections 3.2, 3.3 and 4 in Volume 1 of this series. A parallel heat loss calculation, corrected for the effects of the attic or vault buffer space, was done for different ceiling insulation nominal R-values.

The spreadsheet that was used to calculate the tables of U-factors found in Volume 2 (for site-built homes) was modified to account for differences in construction practice between site-built and manufactured homes and then used to calculate U-factors.

Based on field observations, a number of different heel cavity widths, ranging from 3 1/2" to 9 1/8," were used in calculating the U-factors. The wider heel widths were found in houses built for Climate Zone 3. The most common heel width was 5-1/8". (Actually, the heel width was 6 1/8" with a 1" airspace above the insulation.)

For flat ceilings, the maximum insulation cavity width (found at the marriage line of the two halves of the house) is 40" for all cases except the 8 and 9 inch heel widths, where the maximum cavity width is 42". For vaults, the maximum width is 16" for all but the two widest heels; their center width is 18". Roof pitch (outside surface) for both cases is 0.21; the vaulted ceiling pitch (inside surface) is 0.10.

A 1" airspace above the insulation for ventilation was assumed in cases with soffit vents. In other cases, venting was assumed to come from gable-end vents.

Mineral wool (2.9 hr-ft-°F/Btu-inch) was the assumed material for blow-in cases.

A numerical (integral) solution for the U-factor of the insulated space was attempted at first but was unsuccessful. Instead, the R-value was calculated at 1 inch increments along the horizontal dimension of the truss. This was done using the size of the cavity (found geometrically), the insulation's adjusted R-value, if crushed (see Volume 1, Section 3.1.2), and the R-values of inside and outside air films and gypsum wallboard. An area-weighted R-value for the insulation cavity was calculated and its reciprocal (U-factor) then found. A framing and buffer correction were applied to the cavity U-factor to find the overall ceiling U-factor.

2.3 Walls

2.3.1 Construction Techniques

Wall system design in manufactured homes is significantly different from site-built design. Up to 70% of the design stress load on the wall occurs during transportation to the building site. The walls are therefore designed to handle the stresses of transportation as well as to support the roof.

Wall systems are designed in two ways. The first is to use conventional site-built structural methods. These methods rely on a post-and-beam design strategy in which the studs and plates in the wall structure are designed as simple load-bearing spans. The alternative is to design the entire wall as a diaphragm or stress-skin panel. Using this design strategy, the wall sheathing and members work together to provide greater wall structural stability. This method uses significantly less lumber to frame the walls but requires more design and quality control in the assembly of the wall.

In both construction approaches, the wall design is the product of detailed engineering calculations and/or rigorous field testing. Field tests employ standard methods to demonstrate that the home can withstand the forces associated with transportation to the building site. These tests are reviewed by H.U.D. or their representative and must be repeated for a new home design. Acceptable engineering practice can substitute for often lengthy and costly field testing; often, however, relying on calculations alone results in the use of more structural material than necessary.

Post-and-Beam Walls

Two main advantages of manufactured housing are its more efficient use of material and consistent quality control. This is especially true for walls. Relatively few manufacturers use a wall-detailing system similar to site-built homes. Some manufacturers, largely for marketing reasons, use standard site-built construction and argue that the additional lumber required gives a wall equivalent in strength to the stress-skin wall.

Post-and-beam walls contain a greater percentage of wood (more framing) than stress-skin walls. This decreases the thermal performance and hence increases the U-factor of the wall.

Various combinations of header and corner framing strategies are used in these walls. The "solid header" is composed of three 2x6's or one 4x6 over each window and door opening. This increases the total percentage of the wall in solid wood by about 25%. The second header type is a "box beam," which is usually assembled from 2X6's and which allows a 2 1/2" space for insulation. The corner framing technique most often used is the "3 stud" corner. A "2.5 stud" corner, with two 2x6's and an extra piece of blocking, is also used. Although this amount of wood is probably unnecessary, it is in keeping with the manufacturer's intent to build a wall that is very similar or identical to a site-built wall.

Stress-Skin Walls

Stress-skin design has distinct advantages to manufacturers. This design allows the engineered wall to include the structural characteristics of the interior and exterior sheathing in order to make a full diaphragm. The sheathing, which is glued and nailed to each structural member, assists the structural member in carrying the load by reducing buckling and transmitting the load laterally away from window and door openings. This approach allows less wood to be used in headers and increases the structural strength of the individual framing members and the sheathing. This method also allows the use of fewer studs, permitting more room for insulation than is typical of site-built homes or of homes built by manufacturers who use the simple-span method to determine structural requirements.

The net result of using stress-skin wall construction is about a 30% reduction in the wall framing correction. This means the wall conserves resources at the start and more energy in the long run than the post-and-beam wall for a given wall R-value.

There are two variations of the stress-skin framing method. In one, the corner is framed with only two studs, the remainder of the area being given over to insulation cavity. In the other, the corner is framed with two and a half studs, where an additional framing member is placed at the corner. With this framing approach, no special header detail is required, although the insulated box beam is sometimes used.

2.3.2 Thermal Analysis

We adapted a spreadsheet, based on methods described in Volume 1, Section 5.1, to find wall U-factors for manufactured homes. Framing factors (Table 2.1) were modified in the spreadsheet to reflect the different combinations of corner framing and header construction found in manufactured homes.

For walls with R-11 batts, 2x4 framing at 16" on center is assumed. For R-19 and R-22 walls, 2x6 framing at 16" on center is assumed. For R-19 and R-22 walls, some compression of the batts occurs; this compression reduces the performance of the insulation and is figured in to the calculation of the U-factor. A detailed discussion of the U-factor calculation can be found in Section 5.1 of Volume 1 of this series.

Table 2.2
Wall Framing Factors

Type*	Frame	Cavity	Header
SS1	.133	.867	--
SS2	.138	.862	--
SS3	.136	.824	.040
PB1	.170	.790	.040
PB2	.179	.781	.040

* Explanation of Types:
SS1: 2 stud corner, no header
SS2: 2.5 stud corner, no header
SS3: 2.5 stud corner, box beam header
PB1: 3 stud corner, box beam header
PB2: 3 stud corner, solid header

2.4 Windows

Windows used to meet the SGC specifications for manufactured homes are a critical component of an energy-efficient conservation package. Windows are also subject to the most variation and uncertainty in actual performance.

The SGC window standards require a Class 40 window. This means that the entire frame and glass assembly should have an average conductivity (U-factor) of 0.40 or less. If the U-factor of the window exceeds this, then window areas are reduced or the conductivity of other components are decreased to compensate.

2.4.1 Testing and Simulation

The most common method for estimating window performance is to use a tested value provided by each manufacturer for each window type. One reference which summarizes these values is the biyearly publication of the Seattle Department of Construction and Land Use (1990). These values are based on tests conducted by the American Architectural Manufacturers' Association (AAMA) (test procedure #1503.1-1980), or on results from the American Society of Testing Materials (ASTM) test C-236.

The testing procedures used by AAMA include details of testing conditions which are essential in interpreting the test results. These include the presence or absence of window shades and drapes, the degree to which the window is protected from air flow (wind) by being recessed in the frame, the possibility that on-site wind speeds may average substantially less than the tested assumption of 15 mph, the window's orientation and solar flux, the outdoor relative humidity and temperature, and the shading and obstructions around the building. In addition, test values can be influenced by the size of the window and the performance of the window seals. With test values, the window makers and particular windows may vary from 5 to 10% around a particular value; and for specific windows, variations even larger than that may be present even though the windows might perform equivalently when installed in the home.

Since test values are conducted using an assumed air flow to simulate a 15 mph wind, it should be pointed out that wind speeds substantially lower than that can result in a 5 to 10% reduction in U-factors and thus higher performance. Tests conducted on homes in the Northwest typically find average wind speeds between 1/2 and 2 mph, suggesting that the use of 15 mph winds imposes a large conservative bias on estimates of window performance.

The second method is to use a detailed calculation procedure to infer the window conductivity by simulating the interaction of glazing type, air space, frame type, etc., to arrive at a standardized conductivity for each window type. The advantage of the latter is that all windows of one type will have the same U-factor, given the same specifications and assumptions. This report (see appendix) lists simulated values, in order to provide default values in the event that tested values are not available.

These U-factors are generated by the *Window 3.1* simulation program (Lawrence Berkeley Laboratory 1989). This program is used by ASHRAE (1989) to determine window conductivity. The values found in the 1989 Handbook were supplemented to cover the range of window frame types and gas fills found in Northwest manufactured homes. In the supplemental runs, we preserved the ASHRAE assumptions of window size, frame U-factor, wind speed, and frame size.

2.4.2 Window Types

Windows distributed in the Northwest region for purposes of residential construction vary widely. For purposes of this report, we limited the number of frame types to those frames likely to produce a conductivity of 0.60 or better. These are:

1) a vinyl frame window,

2) a wood frame window,

3) an aluminum frame window with a thermal break,

4) a double-glazed aluminum framed window with or without thermal break with one or two additional glazings (storm windows).

Vinyl Frame Window

The vinyl frame window currently on the market is a common energy-efficient window used in residential construction and has become increasingly important to the manufactured home industry over the last two years. The frame is made with a procedure that allows a standardized extrusion to be used by the manufacturer and improves the performance of the windows over aluminum windows by about 40%. Windows built with vinyl frames perform better than any windows with metal frames, even aluminum frame windows with a thermal break.

Metal reinforcers are sometimes added to vinyl frame windows. This practice is generally limited to larger windows used in commercial buildings; however, it is sometimes used in residential windows. The metal increases the thermal conductivity of the frame and hence decreases the U-factor of the window. The table of window U-factors includes entries for vinyl (and wood) frame windows which have metal reinforcers.

Wood Frame Window

Wood frame windows, although rarely used by manufactured home builders, offer significant improvements in the thermal performance over metal frame windows. U-factors for wood frame windows (including those with metal frame reinforcers) are included in the table found in the appendix.

Aluminium Frame Window With Thermal Break

In recent years, in an attempt to improve on the performance of metal windows, manufacturers have added a thermal break between the interior and exterior of the metal window frame. This break is typically an insert of plastic or other low conductivity material. Use of the thermal break cuts the conductivity of the frame itself approximately in half. While this type of window does not typically outperform vinyl frame windows, it does provide an alternative to conventional metal frames, which is especially important when higher grade glazings are used.

Aluminum Frame Window With Storm Window(s)

An alternative method of reducing the thermal conductivity of aluminium windows is to add a single- or double-pane storm window to the prime aluminum window. This can be done with or without a thermal break in the prime window. The storm window serves as a thermal break, as it is typically positioned in an independent frame away from the prime window. The double-pane storm window is an additional prime window which is mounted in the window opening.

The advantage of this system is that no additional manufacturing changes are required to bring the overall window system to a higher thermal standard. The disadvantage is that the occupant must ensure that the storm window is securely in position, especially during the heating season. If the storm window is removed during the summer, it must properly re-installed at the beginning of the heating season to deliver the expected thermal performance of the entire window system. This requirement of occupant involvement almost certainly reduces the effectiveness of a storm window.

2.4.3 Glazing Products

In the last decade, the availability and the thermal performance of glazing products have improved markedly. We analyzed three strategies used to reduce the thermal conductivity of a single clear pane of glass.

Multiple Glazings

The first and most common glazing improvement is the use of multiple layers of clear glass, particularly double-glazing, which is available in practically every product line made by every window maker in the country. This consists of two layers of clear glass sealed at their edges, with dry air or inert gas inserted between the two panes. Some manufacturers use three or even four layers of glazing to provide additional benefits.

The space between the glazing layers accounts for most of the improved thermal performance. For double-glazed windows, a half-inch of air space is usually the minimum width needed to meet Super Good Cents specifications. Additional thermal benefits accrue to air spaces up to three-quarters of an inch. With triple glazing, the air space can be up to a half-inch. However, the limits of overall glazing thickness in most frame types often prevent this much air space (common air spaces are three-eights or five-sixteenths of an inch) and reduce the performance of triple glazing from what might be expected in the ideal situation.

Argon Fill

One method of improving the performance of double-glazed windows is to fill the sealed air space between the glass panes with a low-conductivity gas such as argon or krypton. The presence of this gas improves the performance of double glazing by 5 to 10%. The principal problem with this method is ensuring that the argon is properly installed and that replacement windows are also argon-filled so that the window performance remains the same over the life of the home. There are unresolved questions about gas diffusion through the window seals, which could reduce window performance.

Low-E Coatings

One of the most important advances in window performance was the development of "low-emissivity" (Low-E) coatings which can be applied to the glass surface. Since one of the principal modes of heat transfer through glass is absorption and reradiation, the emissivity of the glass surface is a principal determinant of the amount of heat that is able to pass through the glass from the living space to outside. Use of a low-emissivity coating reduces the amount of heat absorbed by the glass, thus reducing glass conductivity.

There are numerous types of Low-E coatings on the market and the performance of these coatings, for the most part, is determined by the coefficient of emissivity (ε). In general, there are two types of Low-E coating: soft coat and hard coat. The soft coat, or sputter coat, has a emissivity of between 0.05 and 0.15 and results in a U-factor improvement of 30-35% over a typical double-glazed window. The hard coat has emissivities of 0.20 to 0.40 and results in less improvement than the soft coat. Typically, fabricating windows with the soft coat is more complicated and therefore more expensive.

A related product, called Heat Mirror®, is distributed to a limited extent. With this product, the Low-E coating is applied on a plastic sheet which is suspended between the two layers of glass. This results in an effective triple-glazing with low-E coating, giving an overall conductivity reduced to almost half of conventional double-glazed windows.

Low-E coatings can be combined with low-conductivity gas (e.g. argon) to further improve performance. For most windows currently available, this configuration is limited to low-E soft and hard coats and results in a 5 to 10% gain over the performance of the low-E coating alone.

3 References

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APPENDICES -- TABLES OF U-FACTORS

Current Practice Transverse Floor System

The transverse floor is the floor built by most Northwest manufacturers. In this configuration, 2x6 floor joists are placed at right angles to the steel I-beams and parallel to steel outriggers (which extend from the I-beams to the perimeter joists) that make up the undercarriage of the home. The floor is assembled upside down, with the heating ducts, plumbing lines, and electrical service located in the center ("belly") portion of the floor system. A "belly blanket" (one or more layers of insulation) is placed over the floor framing and the various utility conduits, then covered with a reinforced plastic sheet called the "belly (or "bottom") board." The steel undercarriage is placed on top of this layer and strapped and bolted to the joist assembly. The entire system is then flipped back over and the flooring and heating registers installed.

Each half of a double-wide home's floor is thus constructed. The two halves are joined, and an insulated flexible crossover duct, which runs below the belly board, connects the two supply ducts in each half.

Depending on the manufacturer, various levels of insulation are used in the floor assembly. There is always a belly blanket, of varying thickness. The main difference between current practice and Super Good Cents floor systems is that joist insulation is added in the Super Good Cents home.

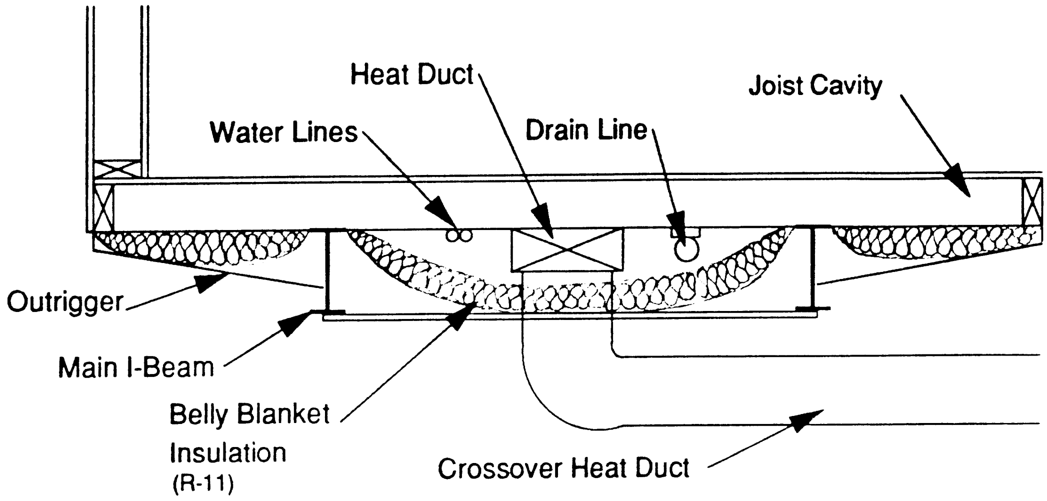
The belly blanket is compressed somewhat in the region between the outermost I-beam and the perimeter joists and crushed dramatically where the I-beams and floor joists cross. Joist cavity insulation is compressed if it is R-19 or more, since the cavity space is only 5 1/2" and the R-19 batt is 6" thick. This compression reduces the performance of the insulation and was taken into account when computing the overall floor U-factor.

Duct conductive losses and the infiltration/exfiltration they induce affect the performance of floor insulation. The effect of duct leakage on the floor U-factor is taken into account in the U-factor tables found in this section. (See Section 2.1.3.)

Duct insulation improves the floor system's thermal performance for almost all nominal values of belly and/or joist insulation. This is particularly true if belly blanket insulation is minimal (R-7 or R-11). In this report, two different types of duct insulation are discussed: "sound" insulation, where the top side of the duct is insulated with an R-5 batt so that vibrations between the metal duct and the adjacent floor joists are damped (and, coincidentally, conductive duct losses are reduced); and a full R-5 wrap around the duct.

In current practice homes (not built to SGC specifications), the floor joist cavity is uninsulated, and in most cases, so are the ducts; consequently, conductive and other duct losses add significantly to the overall heat loss of the house.

The following table shows floor U-factors for three current practice belly blanket insulation options. It is clear that increasing the belly blanket from R-7 to R-22 improves the thermal performance significantly, as does insulating the ducts.



Cross-Section of Current Practice Transverse Floor System

U-Factors for Current Practice Transverse Floor Systems (Btu/hr•ft2•°F)			
Nominal Belly Ins. (R-value)	No Duct Ins.	Duct Sound Ins.	R-5 Duct Wrap
7	0.124	0.115	0.107
11	0.101	0.094	0.088
22	0.073	0.070	0.065

Super Good Cents Transverse Floor System

The transverse floor is the floor built by most Northwest manufacturers. In this configuration, 2x6 floor joists are placed at right angles to the steel I-beams and parallel to steel outriggers (which extend from the I-beams to the perimeter joists) that make up the undercarriage of the home. The floor is assembled upside down, with the heating ducts, plumbing lines, and electrical service located in the center ("belly") portion of the floor system. A "belly blanket" (one or more layers of insulation) is placed over the floor framing and the various utility conduits, then covered with a reinforced plastic sheet called the "belly (or "bottom") board." The steel undercarriage is placed on top of this layer and strapped and bolted to the joist assembly. The entire system is then flipped back over and the flooring and heating registers installed.

Each half of a double-wide home's floor is thus constructed. The two halves are joined, and an insulated flexible crossover duct, which runs below the belly board, connects the two supply ducts in each half.

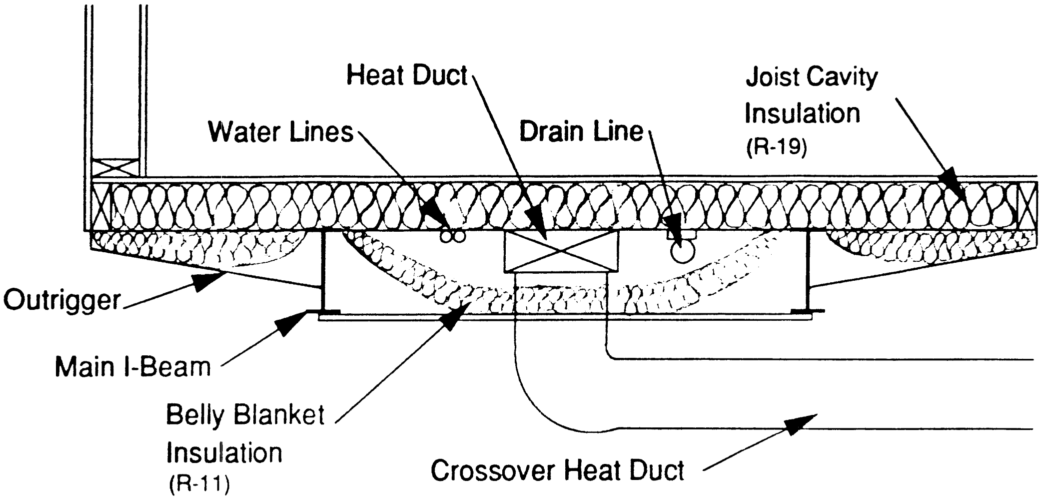
Depending on the manufacturer, various levels of insulation are used in the floor assembly. There is always a belly blanket, of varying thickness. The main difference between current practice and Super Good Cents floor systems is that joist insulation is added in the Super Good Cents home.

The belly blanket is compressed somewhat in the region between the outermost I-beam and the perimeter joists and crushed dramatically where the I-beams and floor joists cross. Joist cavity insulation is compressed if it is R-19 or more, since the cavity space is only 5 1/2" and the R-19 batt is 6" thick. This compression reduces the performance of the insulation and was taken into account when computing the overall floor U-factor.

Duct conductive losses and the infiltration/exfiltration they induce affect the performance of floor insulation. The effect of duct leakage on the floor U-factor is taken into account in the U-factor tables found in this section. (See Section 2.1.3.)

Duct insulation improves the floor system's thermal performance for all nominal values of belly and/or joist insulation. This is particularly true if belly blanket insulation is minimal (R-7 or R-11). In this report, two different types of duct insulation are discussed: "sound" insulation, where the top side of the duct is insulated with an R-5 batt so that vibrations between the metal duct and the adjacent floor joists are damped (and, coincidentally, conductive duct losses are reduced); and a full R-5 wrap around the duct.

The following table shows U-factors for floor systems built to SGC specifications. It is clear that increasing the belly blanket from R-7 to R-22 improves the thermal performance significantly, as does insulating the ducts.



Cross-Section of SGC Transverse Floor System

U-Factors for SGC Transverse Floor Systems (Btu/hr•ft2•°F)				
Nominal Belly Ins. (R-value)	Nominal Joist Ins. (R-value)	No Duct Ins.	Duct Sound Ins.	R-5 Duct Wrap
7	11	0.079	0.069	0.059
11	11	0.068	0.060	0.053
22	11	0.055	0.049	0.044
7	19	0.072	0.060	0.050
11	19	0.062	0.053	0.045
22	19	0.051	0.044	0.039
7	22	0.071	0.059	0.049
11	22	0.062	0.052	0.044
22	22	0.050	0.044	0.038

Cut-in Floor System

The "cut-in" floor system is not found in many manufactured home factories. It is discussed here because it offers a significant improvement in the thermal performance and requires only minor adjustments in the commonly found transverse floor construction detail described in the previous two sections.

In this configuration, 2x6 floor joists are placed at right angles to the steel I-beams and parallel to steel outriggers (which extend from the I-beams to the perimeter joists) that make up the undercarriage of the home. The floor is assembled upside down, with the heating ducts, plumbing lines, and electrical service located in the center ("belly") portion of the floor system. A "belly blanket" (one or more layers of insulation) is placed over the floor framing and the various utility conduits, then covered with a reinforced plastic sheet called the "belly (or "bottom") board." The steel undercarriage is placed on top of this layer and strapped and bolted to the joist assembly. The entire system is then flipped back over and the flooring and heating registers installed.

Each half of a double-wide home's floor is thus constructed. The two halves are joined, and an insulated flexible crossover duct, which runs below the belly board, connects the two supply ducts in each half.

The belly blanket is brought up into the joist cavity in the outrigger region (the outer three feet of each side of the home) by cutting the batts where they come up against the joists and pulling the batts into the joist cavity. This strategy eliminates the "sandwich" effect in the transverse floor, where the batts are crushed between the I-beams and floor joists.

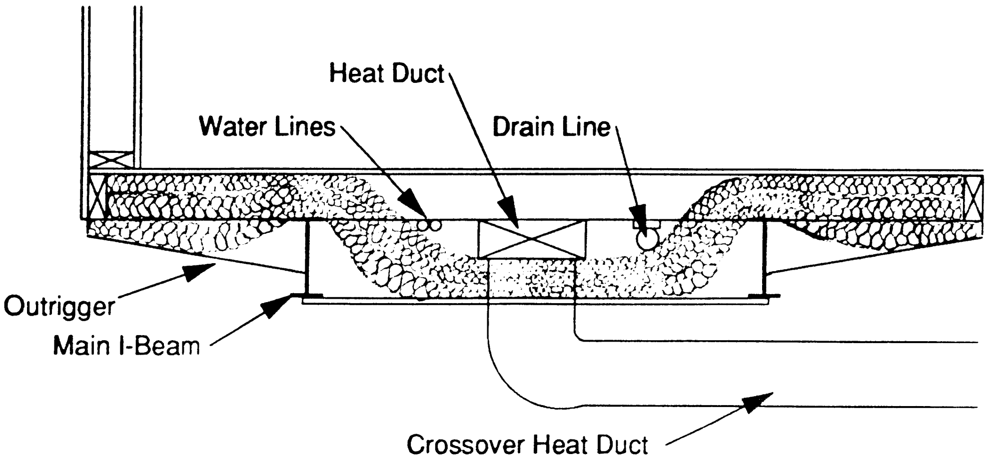
The belly blanket is still compressed somewhat in the outrigger region, and, depending on its thickness, compressed where the I-beams and floor joists attach. (See the depiction of the R-33 floor on the next page).

Duct conductive losses and the infiltration/exfiltration they induce affect the performance of floor insulation. The effect of duct leakage on the floor U-factor is taken into account in the U-factor tables found in this section. (See Section 2.1.3.)

Duct insulation improves the floor system's thermal performance for almost all nominal values of belly and/or joist insulation. This is particularly true if belly blanket insulation is minimal (R-7 or R-11). In this report, two different types of duct insulation are discussed: "sound" insulation, where the top side of the duct is insulated with an R-5 batt so that vibrations between the metal duct and the adjacent floor joists are damped (and, coincidentally, conductive duct losses are reduced); and a full R-5 wrap around the duct.

In current practice homes (not built to SGC specifications), the floor joist cavity is uninsulated, and in most cases, so are the ducts; consequently, conductive and other duct losses add significantly to the overall heat loss of the house.

The following table shows floor U-factors for three current practice belly blanket insulation options. It is clear that increasing the belly blanket from R-7 to R-22 improves the thermal performance significantly, as does insulating the ducts.



Cross-Section of Cut-in Floor System (R-33)

U-Factors for Cut-in Floor Systems (Btu/hr•ft2•°F)			
Nominal Belly Ins. (R-value)	No Duct Ins.	Duct Sound Ins.	R-5 Duct Wrap
11	0.075	0.072	0.070
19	0.054	0.052	0.050
22	0.049	0.047	0.046
33	0.035	0.034	0.033
44	0.032	0.031	0.031

Longitudinal Floor System

In the longitudinal floor configuration, the floor is constructed in a way that is similar to the transverse floor; however, the 2x6 floor joists are placed parallel to the steel undercarriage I-beams. The heating ducts, plumbing lines, and electrical service are located inside (uninsulated) joist cavities in the center portion of the floor.

The floor is assembled upside down. First, the wooden floor frame is nailed together. The utility conduits (electrical and plumbing lines, heating ducts) are installed, then a "belly blanket" (one or more layers of insulation) is rolled over the assembly and covered with a reinforced plastic sheet called the "belly (or "bottom") board." The steel undercarriage is placed on top of all of this and strapped and bolted to the joist assembly. The entire system is then flipped back over and the flooring and heating registers installed.

Each half of a double-wide home's floor is thus constructed. The two halves are joined, and an insulated flexible crossover duct, which runs below the belly board, connects the two supply ducts in each half.

Depending on the manufacturer, various levels of insulation are used in the belly blanket and joist cavities. The belly blanket is compressed somewhat in the region between the outermost I-beam and the perimeter joists and crushed dramatically where the I-beams and floor joists cross. Joist cavity insulation is compressed if it is R-19 or more, since the cavity space is only 5 1/2" and the R-19 batt is 6" thick. This compression reduces the performance of the insulation and was taken into account when computing the overall floor U-factor.

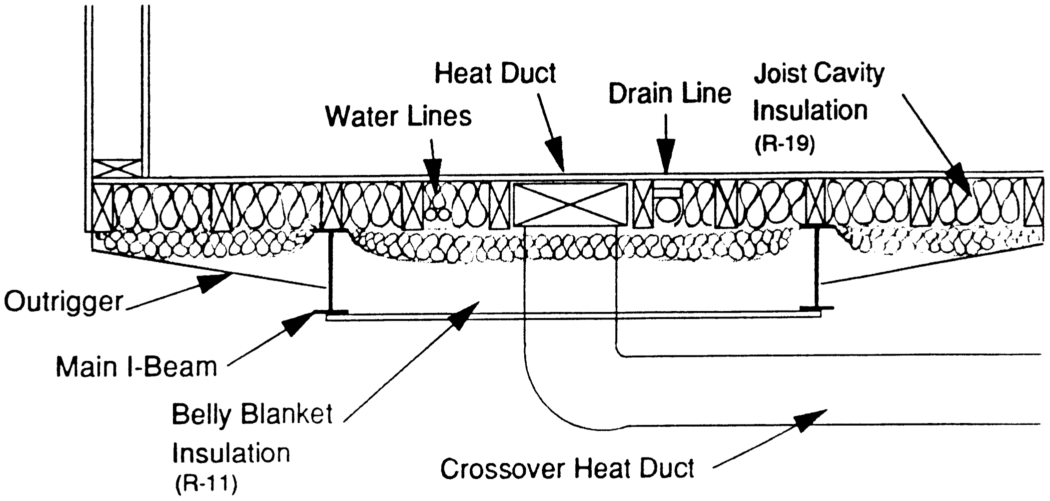
Duct insulation improves the floor system's thermal performance for all nominal values of belly and/or joist insulation. This is particularly true if belly blanket insulation is minimal (R-7 or R-11). The U-factor calculations for longitudinal floors include a scenario where the duct is completely wrapped in a R-5 batt.

Duct conductive losses and the infiltration/exfiltration they induce affect the performance of floor insulation. The effect of duct leakage on the floor U-factor is taken into account in the U-factor tables found in this section. (See Section 2.1.3.)

The "longitudinal" floor is currently somewhat rare in the Northwest. This is unfortunate, for this configuration offers significantly improved thermal performance -- for the same nominal R-value of floor insulation -- over the more common transverse floor (described in preceding sections).

Because of its positioning, the ductwork (whether insulated or not) contributes less to the heat loss of the longitudinal floor than the transverse floor. There is always some belly blanket insulation below the ducts, but never any above, since the duct takes up almost all of the space in the joist cavity where it is located. Conductive and other duct losses are confined in a relatively small space and a significant portion of the losses leak back into the house. Increasing belly blanket insulation beyond the minimum enhances this effect. Adding joist cavity insulation (in areas other than the duct runs) and insulating the duct further improve floor performance.

U-factors for various combinations of belly blanket, joist, and duct insulation are shown on the next page.



Cross-Section of Longitudinal Floor System

U-Factors for Longitudinal Floor Systems (Btu/hr•ft2•°F)			
Nominal Belly Ins. (R-value)	Nominal Joist Ins. (R-value)	No Duct Ins.	R-5 Duct Wrap
7	0	0.107	0.099
11	0	0.087	0.081
22	0	0.064	0.062
7	19	0.050	0.046
11	19	0.043	0.040
22	19	0.034	0.033
7	22	0.049	0.045
11	22	0.042	0.039
22	22	0.033	0.032

Flat and Vaulted Ceilings With Crushed Batt Insulation and Gable Vents

For the most part, the same methods were used to determine ceiling U-factors as found in Sections 3.2, 3.3 and 4 in Volume 1 of this series. A parallel heat loss calculation, corrected for the effects of the attic or vault buffer space, was done for different ceiling insulation nominal R-values. A detailed description of the analysis is found in Section 2.2.2.

In general, ceiling systems in manufactured homes are similar to site-built ceilings. Pre-manufactured trusses form the ceiling structure, and insulation batts are placed between the truss members. Because of the sequence of building in manufactured home plants, a complete and consistent job of insulation can be expected.

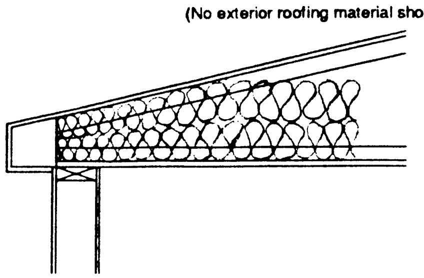
There are some significant differences between site-built and manufactured housing roof assemblies which must be taken into account when estimating the thermal performance of manufactured home ceilings.

- Trusses are made of 2x2s (rather than 2x4s), so the framing factor for the ceiling must be reduced from that used for site-built ceilings.
- Based on field observations, batts were placed between the truss members rather than over them. This procedure undercuts significantly the thermal performance of the ceiling because the space over the truss members is uninsulated.
- Some manufacturers use a polyurethane-based mastic foam to attach trusses to the ceiling gypboard. The analysis looked at a scenario where enough extra mastic was sprayed on to get an average of one inch (R-6 per inch) of foam over the top of the bottom truss cord. This approach gives dramatic improvement over current practice and should be considered as a SGC option.
- In most manufactured homes, the truss heel has a 6" to 6 1/2" cavity, allowing a batt of up to R-19 to be placed all the way to the edge without being crushed.
- Attic venting is accomplished with gable-end vents and some sort of mechanical ventilation.

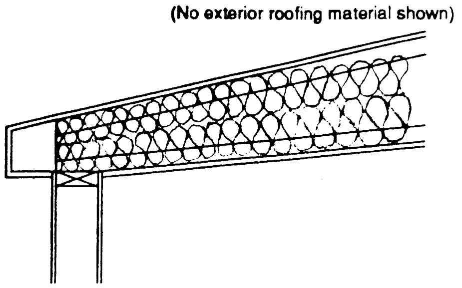
Because of the gable-end venting, batts can be placed at full depth (or crushed, depending on their nominal R-value) into the truss heel without leaving an air space above. Depending on the initial thickness of the batt and the extent to which it is crushed, the ceiling's thermal performance can be reduced considerably by crushing. This reduction is accounted for the in the calculation of the overall ceiling U-factor.

Depending on manufacturer (and climate zone), the size of the cavity at the truss heel varies. The most common width found in field visits was 6 1/8." In all cases, a 0.21 roof pitch was assumed. Vaulted (inside) ceiling pitch was assumed to be 0.10.

Following are drawings of the flat and vaulted ceilings with gable vents and a table of U-factors.



Flat Ceiling With Gable Vents



Vaulted Ceiling With Gable Vents

U-Factors for Flat and Vaulted Ceilings (With Gable Vents)

Flat Ceiling U-Factors (Btu/hr•ft^2•°F)				Vaulted Ceiling U-Factors (Btu/hr•ft^2•°F)			
Nominal R-Value	Heel Width (Inches)	Crush Batts	w/1" foam (R-6)	Nominal R-Value	Heel Width (Inches)	Crush Batts	w/1" foam (R-6)
19	4.5 6.125 9.	.056 .056 .056	.048 .048 .048				
22	4.5 6.125 9.	.052 .052 .052	.044 .043 .043	22	4.5 6.125 9.	.052 .052 .052	.044 .043 .043
25	4.5 6.125 9.	.049 .048 .048	.040 .040 .040	25	4.5 6.125 9.	.049 .048 .048	.041 .040 .040
30	4.5 6.125 9.	.045 .044 .044	.036 .035 .035	30	4.5 6.125 9.	.048 .046 .044	.038 .036 .035
33	4.5 6.125 9.	.043 .042 .042	.034 .033 .033	33	4.5 6.125 9.	.046 .044 .042	.036 .034 .033
38	4.5 6.125 9.	.040 .039 .039	.031 .031 .030	38	4.5 6.125 9.	.043 .041 .039	.034 .032 .030
49	4.5 6.125 9.	.037 .036 .035	.028 .027 .026				

Flat and Vaulted Ceilings With Crushed Batt Insulation, Baffle, and Soffit Vents

For the most part, the same methods were used to determine ceiling U-factors as found in Sections 3.2, 3.3 and 4 in Volume 1 of this series. A parallel heat loss calculation, corrected for the effects of the attic or vault buffer space, was done for different ceiling insulation nominal R-values. A detailed description of the analysis is found in Section 2.2.2.

In general, ceiling systems in manufactured homes are similar to site-built ceilings. Pre-manufactured trusses form the ceiling structure, and insulation batts are placed between the truss members. Because of the sequence of building in manufactured home plants, a complete and consistent job of insulation can be expected.

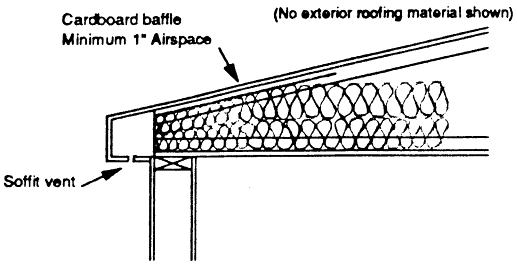
There are some significant differences between site-built and manufactured housing roof assemblies which must be taken into account when estimating the thermal performance of manufactured home ceilings.

- Trusses are made of 2x2s (rather than 2x4s), so the framing factor for the ceiling must be reduced from that used for site-built ceilings.
- Based on field observations, batts were placed between the truss members rather than over them. This procedure undercuts significantly the thermal performance of the ceiling because the space over the truss members is uninsulated.
- Some manufacturers use a polyurethane-based mastic foam to attach trusses to the ceiling gypboard. The analysis looked at a scenario where enough extra mastic was sprayed on to get an average of one inch (R-6 per inch) of foam over the top of the bottom truss cord. This approach gives dramatic improvement over current practice and should be considered as a SGC option.

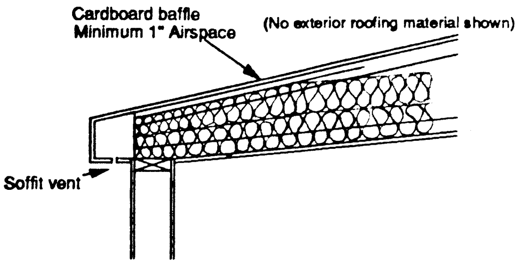
Soffit vents and cardboard baffles are used in this approach. The baffle is stapled to the top of the trusses and maintains an air space of at least 1" between the insulation and the roof sheathing. The full nominal value of insulation is placed all the way to the edge of the truss heel, even if it must be crushed into the small space. Depending on the initial thickness of the batt and the extent to which it is crushed, the ceiling's thermal performance can be reduced considerably by crushing. This reduction is accounted for the in the calculation of the overall ceiling U-factor.

Depending on manufacturer (and climate zone), the size of the available cavity at the truss heel varies. The most common width found in field visits was 5 1/8" (actually 6 1/8" with a 1" air-space). In all cases, a 0.21 roof pitch was assumed. Vaulted (inside) ceiling pitch was assumed to be 0.10.

Following are drawings of the flat and vaulted ceilings with soffit vents and stepped batts and a table of U-factors.



Baffled Flat Ceiling With Crushed Batts & Soffit Vents



Baffled Vaulted Ceiling With Crushed Batts & Soffit Vents

U-Factors for Flat and Vaulted Ceilings (With Soffit Vents & Carboard Baffle)							
Flat Ceiling U-Factors (Btu/hr•ft^2•°F)				Vaulted Ceiling U-Factors (Btu/hr•ft^2•°F)			
Nominal R-Value	Heel Width (Inches)	Crushed Batts	w/1" foam (R-6)	Nominal R-Value	Heel Width (Inches)	Crushed Batts	w/1" foam (R-6)
19	3.5	.056	.048				
	5.125	.056	.048				
	8.	.056	.048				
22	3.5	.052	.044	22	3.5	.053	.045
	5.125	.052	.044		5.125	.052	.044
	8.	.052	.044		8.	.052	.043
25	3.5	.049	.041	25	3.5	.050	.042
	5.125	.049	.040		5.125	.049	.041
	8.	.048	.040		8	.048	.040
30	3.5	.045	.036	30	3.5	.047	.039
	5.125	.044	.036		5.125	.045	.037
	8.	.044	.035		8.	.044	.035
33	3.5	.043	.034	33	3.5	.046	.038
	5.125	.042	.034		5.125	.044	.035
	8.	.042	.033		8.	.042	.033
38	3.5	.041	.032	38	3.5	.044	.036
	5.125	.040	.031		5.125	.042	.034
	8.	.039	.030		8.	.039	.031
49	3.5	.037	.028				
	5.125	.036	.027				
	8.	.035	.026				

Flat and Vaulted Ceilings With Stepped Batt Insulation and Soffit Vents

For the most part, the same methods were used to determine ceiling U-factors as found in Sections 3.2, 3.3 and 4 in Volume 1 of this series. A parallel heat loss calculation, corrected for the effects of the attic or vault buffer space, was done for different ceiling insulation nominal R-values. A detailed description of the analysis is found in Section 2.2.2.

In general, ceiling systems in manufactured homes are similar to site-built ceilings. Premanufactured trusses form the ceiling structure, and insulation batts are placed between the truss members. Because of the sequence of building in manufactured home plants, a complete and consistent job of insulation can be expected.

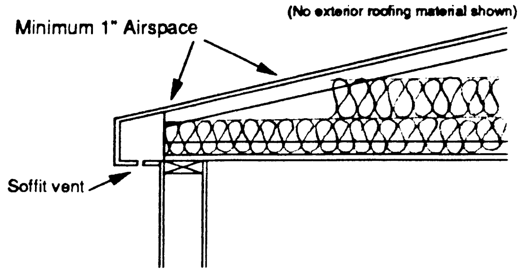
There are some significant differences between site-built and manufactured housing roof assemblies which must be taken into account when estimating the thermal performance of manufactured home ceilings.

- Trusses are made of 2x2s (rather than 2x4s), so the framing factor for the ceiling must be reduced from that used for site-built ceilings.
- Based on field observations, batts were placed between the truss members rather than over them. This procedure undercuts significantly the thermal performance of the ceiling because the space over the truss members is uninsulated.
- Some manufacturers use a polyurethane-based mastic foam to attach trusses to the ceiling gypboard. The analysis looked at a scenario where enough extra mastic was sprayed on to get an average of one inch (R-6 per inch) of foam over the top of the bottom truss cord. This approach gives dramatic improvement over current practice and should be considered as a SGC option.

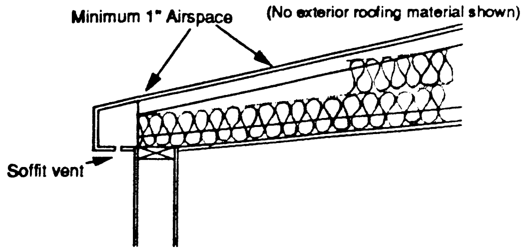
Soffit vents are used in this approach. Air is expected to flow between the insulation and the roof sheathing; therefore, a 1" air space is maintained above the batts. In this ceiling type, the batts are placed so that there is no crushing or only minimal crushing: the first batt is placed all the way to the edge of the truss heel and additional batts are stacked in staggered "cake" fashion down the length of the truss, added sequentially at a point where there is enough space to accommodate their full thickness and also maintain a 1" airspace. This technique all but eliminates batt compression, but it leaves spaces in the attic where the full nominal thickness of the insulation has not been installed.

Depending on manufacturer (and climate zone), the size of the cavity at the truss heel varies. The most common width found in field visits was 5 1/8." In all cases, a 0.21 roof pitch was assumed. Vaulted (inside) ceiling pitch was assumed to be 0.10.

Following are drawings of the flat and vaulted ceilings with soffit vents and stepped batts and a table of U-factors.



Flat Ceiling With Stepped Batts & Soffit Vents



Vaulted Ceiling With Stepped Batts & Soffit Vents

U-Factors for Flat and Vaulted Ceilings (With Soffit Vents & Stepped Batts)							
Flat Ceiling U-Factors (Btu/hr•ft²•°F)				Vaulted Ceiling U-Factors (Btu/hr•ft²•°F)			
Nominal R-Value	Heel Width (Inches)	Stepped Batts	w/1" foam (R-6)	Nominal R-Value	Heel Width (Inches)	Stepped Batts	w/1" foam (R-6)
22	3.5 5.125 8.	.054 .053 .052	.046 .045 .043	22	3.5 5.125 8.	.059 .056 .052	.051 .048 .043
30	3.5 5.125 8.	.046 .045 .044	.038 .037 .035	30	3.5 5.125 8.	.051 .048 .045	.042 .040 .037
33*	3.5 5.125 8.	.046 .045 .044	.038 .036 .034	33	3.5 5.125 8.	.049 .047 .044	.041 .038 .035
38	3.5 5.125 8.	.043 .042 .041	.035 .033 .032	38	3.5 5.125 8.	.052 .050 .046	.043 .041 .037
49	3.5 5.125 8.	.040 .039 .037	.032 .030 .029				

* In R-33 "step", first 2 R-11s are compressed together at truss heel.

Flat and Vaulted Ceilings With Blown-In Insulation and Gable Vents

For the most part, the same methods were used to determine ceiling U-factors as found in Sections 3.2, 3.3 and 4 in Volume 1 of this series. A parallel heat loss calculation, corrected for the effects of the attic or vault buffer space, was done for different ceiling insulation nominal R-values. A detailed description of the analysis is found in Section 2.2.2, above.

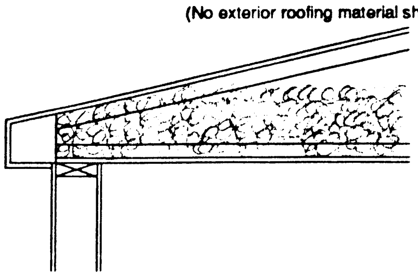
In general, ceiling systems in manufactured homes are similar to site-built ceilings. Premanufactured trusses form the ceiling structure, and insulation is blown into the ceiling cavity, completely covering at the lower truss cord for the amounts of insulation discussed here. Because of the sequence of building in manufactured home plants, a complete and consistent job of insulation can be expected.

For this section, the material used for insulation is assumed to be blown-in mineral wool, R-2.9 per inch. In the factory, compressed insulation is fed into a machine which blows it through a large tube for application to the ceiling cavity. For a given nominal R-value of the ceiling, the manufacturer determines how many bags of insulation are required and the cavity is blown to more or less uniform thickness (save some "piling" to compensate for the region at the truss heel where there is a much smaller cavity).

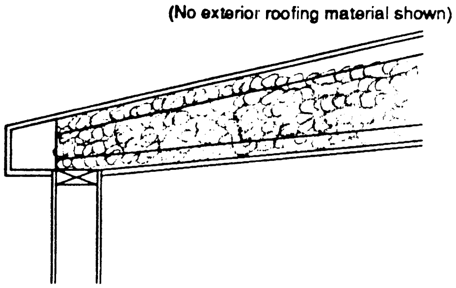
Depending on manufacturer, the size of the cavity at the truss heel varies. The most common width found in field visits was 6 1/8." The trusses are assumed to be made of 2x2s at 24" o.c.. In all cases, a 0.21 roof pitch was assumed. Vaulted (inside) ceiling pitch was assumed to be 0.10.

The venting strategy in this case is a gable-end vent with an induced attic ventilation system. The insulation is blown in at the edge all the way to the roof sheathing to achieve higher insulation values than could be obtained if a uniform airspace were needed above the insulation (This is what occurs in the next section, where soffit vents are used.) This gives better thermal performance, especially for vaulted ceilings.

The following page presents drawings of the ceiling systems and a table of U-factors.



Blown Attic With Gable Vents



Blown Vaulted Ceiling With Gable Vents

U-Factors for Blown Flat and Vaulted Ceiling (With Gable Vents)

Flat Ceiling U-Factors (Btu/hr•ft²•°F)			Vaulted Ceiling U-Factors (Btu/hr•ft²•°F)		
Nominal R-Value	Heel Width (Inches)	U-factor	Nominal R-Value	Heel Width (Inches)	U-factor
19	4.5 6.125 9.	.046 .044 .044			
22	4.5 6.125 9.	.041 .039 .038	22	4.5 6.125 9.	.041 .039 .038
25	4.5 6.125 9.	.037 .035 .033	25	4.5 6.125 9.	.037 .035 .033
30	4.5 6.125 9.	.033 .030 .028	30	4.5 6.125 9.	.033 .030 .028
33	4.5 6.125 9.	.031 .028 .026	33	4.5 6.125 9.	.031 .028 .026
38	4.5 6.125 9.	.029 .026 .023	38	4.5 6.125 9.	.029 .026 .023
49	4.5 6.125 9.	.026 .023 .020			

Flat and Vaulted Ceilings With Blown-In Insulation and Soffit Vents

For the most part, the same methods were used to determine ceiling U-factors as found in Sections 3.2, 3.3 and 4 in Volume 1 of this series. A parallel heat loss calculation, corrected for the effects of the attic or vault buffer space, was done for different ceiling insulation nominal R-values. A detailed description of the analysis is found in Section 2.2.2, above.

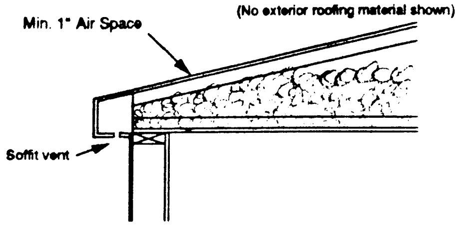
In general, ceiling systems in manufactured homes are similar to site-built ceilings. Premanufactured trusses form the ceiling structure, and insulation is blown into the ceiling cavity, completely covering at the lower truss cord for the amounts of insulation discussed here. Because of the sequence of building in manufactured home plants, a complete and consistent job of insulation can be expected.

For this section, the material used for insulation is assumed to be blown-in mineral wool, R-2.9 per inch. In the factory, compressed insulation is fed into a machine which blows it through a large tube for application to the ceiling cavity. For a given nominal R-value of the ceiling, the manufacturer determines how many bags of insulation are required and the cavity is blown to more or less uniform thickness (save some "piling" to compensate for the region at the truss heel where there is a much smaller cavity).

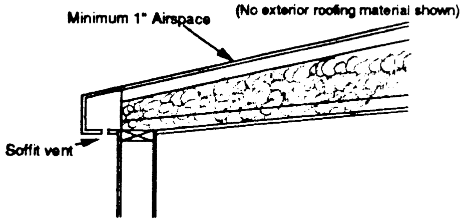
Depending on manufacturer, the size of the cavity at the truss heel varies. The most common width found in field visits was 6 1/8." The trusses are assumed to be made of 2x2s at 24" o.c.. In all cases, a 0.21 roof pitch was assumed. Vaulted (inside) ceiling pitch was assumed to be 0.10.

The venting strategy in this case is a continuous soffit vent at the eaves. The insulation is blown in to allow 1" clearance below the roof sheathing. This results in reduced depth at the truss heel and over much of the truss area, particularly for vaulted ceilings.

The following page presents drawings of these ceiling systems and a table of U-factors.



Blown Flat Ceiling With Soffit Vents



Blown Vaulted Ceiling With Soffit Vents

U-Factors for Blown Attic and Vaulted Ceiling (With Soffit Vents)					
Flat Ceiling U-Factors ($\text{Btu/hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}$)			**Vaulted Ceiling U-Factors ($\text{Btu/hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}$)**		
Nominal R-Value	Heel Width (Inches)	U-factor	Nominal R-Value	Heel Width (Inches)	U-factor
19	3.5	.047			
	5.125	.045			
	8.	.044			
22	3.5	.043	22	3.5	.043
	5.125	.040		5.125	.040
	8.	.038		8.	.038
25	3.5	.039	25	3.5	.040
	5.125	.036		5.125	.036
	8.	.033		8.	.033
30	3.5	.035	30	3.5	.035
	5.125	.032		5.125	.032
	8.	.028		8.	.029
33	3.5	.033	33	3.5	.033
	5.125	.030		5.125	.030
	8.	.026		8.	.027
38	3.5	.031	38	3.5	.031
	5.125	.028		5.125	.028
	8.	.024		8.	.024
49	3.5	.029			
	5.125	.025			
	8.	.021			

Post-and-Beam Walls

The calculation of U-factors for manufactured home walls must address the variety of wall construction techniques found in the industry. Wall design can be done in one of two ways. The first is to use conventional post and beam (simple span) construction. The alternative is to design the entire wall as a diaphragm or stress-skin panel.

The wall framing strategy used by some manufacturers is similar to that used in site-built homes. The structural engineering is based on a post-and-beam, (simple span) design which assumes, for the most part, that each structural element in the wall operates independently. As a consequence of this, a larger portion of the wall is given over to studs, headers, and other structural members than in the second type of wall (stress-skin) used in the industry.

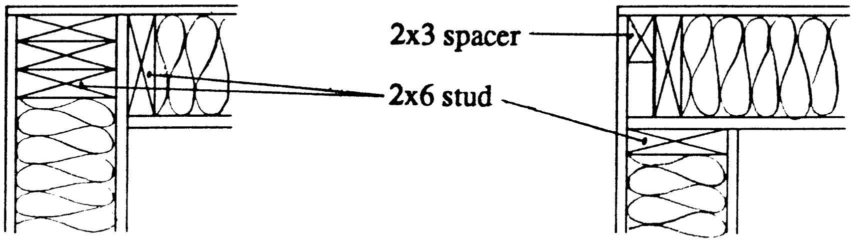
Two building methods for this type of wall were observed in the field. The first uses solid wood headers (usually three 2x6s) and solid wood corners (three 2x6 studs or a 4x6). The second method uses a box beam header, with insulation stuffed into the 2 1/2 space between two 2X6s, and a two stud corner with an extra piece of blocking (the "2.5" stud corner) which creates an additional uninsulated cavity. When framing is done with 2x4 studs, these methods are identical, since there are no cavities available for extra insulation.

The assumptions used to generate U-factors for this wall framing strategy are:

- The wall studs are framed at 16" on center, with extra studs for headers.
- For R-19 and R-22 walls, the insulation is crushed into the 5 1/2" cavity, reducing its performance somewhat. This crushing is factored into the wall U-factor calculation. The R-21 insulation is a high-density batt which is 5 1/2" thick and therefore does not have to be crushed into wall cavity.
- Single layer exterior sheathing and siding is used, a single layer of interior gypsum wall board is used.
- A 1x6 single bottom plate and a 2x6 single top plate are continuous across the wall length.

Some manufacturers add 1/4" of foam (R-1) to the wall exterior during framing. This adds a continuous layer of R-1 to the wall. Others use 1/2" of extruded polystyrene (R-2.5). Separate columns for these augmentations are included in the U-factor tables which follow.

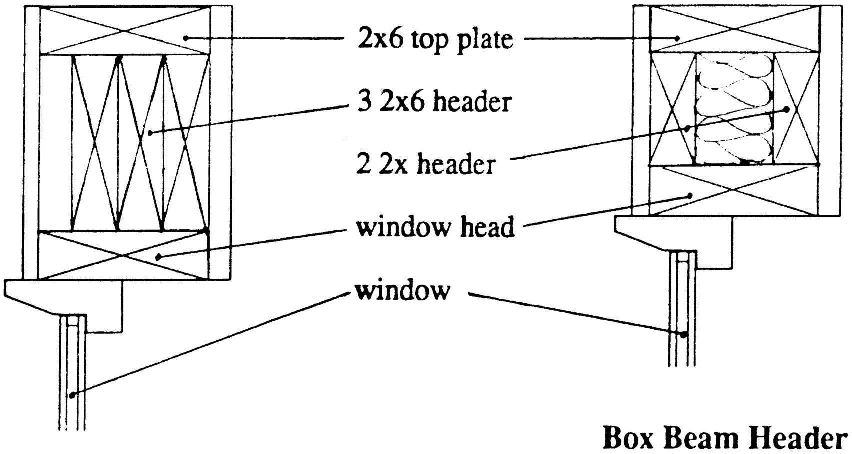
Wall Corner Types



3 Stud Corner

"2.5" Stud Corner

Header Types



Box Beam Header

Solid Header

Post & Beam Wall U-Factors (Btu/hr•ft^2•°F)

	Insulation Nominal R-value	3 Stud Corner	w/ R-1 Foam	w/R-2.5 Rigid Ins.	"2.5" Stud Corner	w/R-1 Foam	w/R-2.5 Rigid Ins
Box Beam Header	19	.058	.054	.050	.056	.053	.049
	21	.053	.050	.046	.051	.048	.045
	22	.056	.053	.049	.055	.051	.047
Solid Header	11	.088	.080	.071	--	--	--
	19	.060	.056	.051	--	--	--
	21	.056	.052	.048	--	--	--
	22	.059	.054	.050	--	--	--

Stress-Skin Walls

The calculation of U-factors for manufactured home walls must address the variety of wall construction techniques found in the industry. Wall design can be done in one of two ways. The first is to use conventional post-and-beam (simple span) construction. The alternative is to design the entire wall as a diaphragm or stress-skin panel. This design strategy allows the wall sheathing and framing to work together to provide more sufficient structural stability while using less wood than in the post and beam wall.

A primary reason the stress-skin method is used by manufacturers is because of their ability to enforce strict quality control in the factory. Another reason is the combination of reduced framing and improve thermal performance this technique offers. The stress-skin design depends on an integrated, whole-wall structural system. The wall finish and exterior sheathing combine with the wall studs to give the wall its strength. As a result, most of the ceiling load is borne without needs for true headers; window and door openings require little additional framing. The amount of wood needed for wall framing is reduced by about 25% and the U-factor of the wall is correspondingly better, since this wood is replaced by fiberglass insulation.

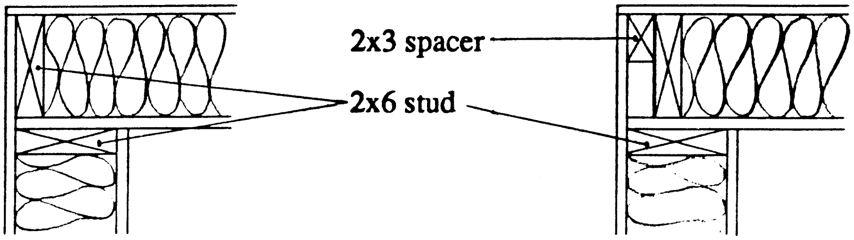
The stress-skin approach uses a single-stud "header" (actually, the cross-section looks like the rest of the wall) and a two stud corner. Some manufacturers use a box beam header, especially for large openings, and a two stud corner with an extra piece of blocking (the "2.5" stud corner) which creates an additional uninsulated cavity.

The assumptions used to generate U-factors for this wall framing strategy are:

- The wall studs are framed at 16" on center, with single studs at large openings.
- For R-19 and R-22 walls, the insulation is crushed into the 5 1/2" cavity, reducing its performance somewhat. This crushing is factored into the wall U-factor calculation. The R-21 insulation is a high-density batt which is 5 1/2" thick and therefore does not have to be crushed into wall cavity.
- Single layer exterior sheathing and siding is used, a single layer of interior gypsum wall board is used.
- A 1x6 single bottom plate and a 2x6 single top plate are continuous across the wall length.

Some manufacturers add 1/4" of foam (R-1) to the wall exterior during framing. This adds a continuous layer of R-1 to the wall. Others use 1/2" of extruded polystyrene (R-2.5). Separate columns for these augmentations are included in the U-factor tables which follow.

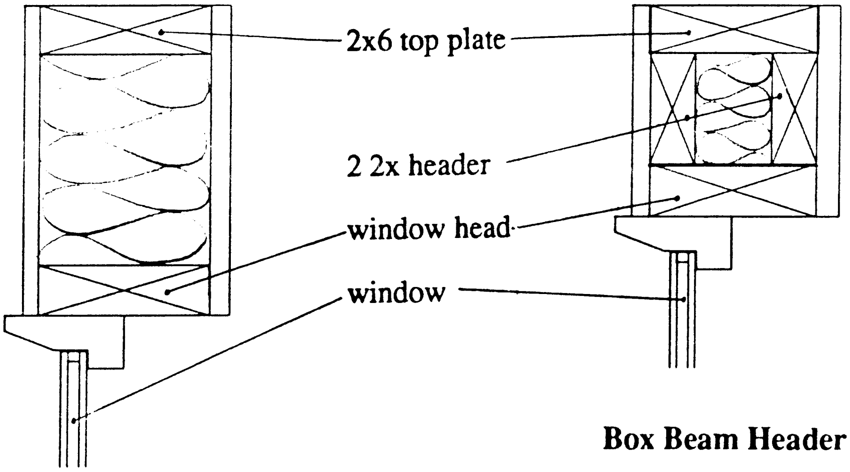
Wall Corner Types



2 Stud Corner

"2.5" Stud Corner

Header Types



Box Beam Header

Single Stud Header

Stress-Skin Wall U-Factors (Btu/hr•ft²•°F)

	Insulation Nominal R-value	2 Stud Corner	w/ R-1 Foam	w/R-2.5 Rigid Ins.	"2.5" Stud Corner	w/R-1 Foam	w/R-2.5 Rigid Ins
Single Stud Header	11	.081	.075	.067	.082	.075	.067
	19	.055	.052	.048	.056	.052	.048
	21	.050	.047	.044	.050	.048	.044
	22	.054	.051	.047	.054	.051	.047
Box Beam Header	19	--	--	--	.056	.053	.049
	21	--	--	--	.051	.048	.045
	22	--	--	--	.055	.051	.047

Windows

The U-factors in the attached table were generated using the *Window 3.1* simulation program, which was developed by Lawrence Berkeley Laboratory. This program uses the same thermal conductivity values found in the 1989 ASHRAE Handbook of Fundamentals. In most cases, the U-factors in the table match those in the ASHRAE tables. We ran additional simulations for several combinations of window frame and low-emissivity (Low-E) coatings not covered in the ASHRAE tables, including vinyl window frames, Low-E hard coats (0.20 emissivity), Low-E soft coats (0.10 emissivity). We also ran a simulation for a single- and double-pane aluminum frame storm window added to a prime aluminum frame window.

Most Low-E manufacturers use windows with coatings in the middle emissivity range (ε=0.20).

We calculated the values in the table by averaging the simulation results for two window types: a large fixed window and a smaller operable window. Because we used averages, the values differ slightly from those contained in the 1989 ASHRAE Handbook of Fundamentals. Since manufactured homes typically contain a variety of window sizes and frame types, the average is probably a good representation of actual window packages installed in manufactured homes.

The values derived from the simulation runs agree well with the test values for these windows provided by the window makers, except for windows with an argon fill. In this case, the test values are somewhat lower than the simulation results.

The values in this table can be used for reference when assessing conservation options. However, once the actual window selection is made, the Super Good Cents specifications require use of the tested values of the actual windows to prove compliance.

Simulated
Window U-factors (Btu/hr•ft2•°F)

	Glazing Type											
	Double Clear		Hard Coat Low-E (ε=0.4)		Hard Coat Low-E (ε=0.2)		Soft Coat Low-E (ε=0.1)		Heat Mirror		Triple Glaze	
Frame Type	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon
Vinyl/Wood	0.47	0.45	0.40	0.37	0.36	0.33	0.34	0.30	0.30	0.27	0.36	0.33
Vinyl/Wood*	0.49	0.46	0.42	0.39	0.38	0.34	0.36	0.32	0.33	0.30	0.38	0.36
Alum. w/TB	0.62	0.59	0.55	0.52	0.51	0.48	0.49	0.44	0.44	0.41	0.50	0.48
Alum. w/storm	0.45	0.43	0.42	0.40	0.40	0.38	0.39	0.36	--	--	--	--
Alum. w/double storm	0.35	--	--	--	--	--	--	--	--	--	--	--

* Use of metal cladding or reinforcement on wood or vinyl frames results in an increase in frame conductivity and thus an increase in window U-factor.