HEAT FLOW BASICS

Heat flows from hot to cold.

Always. Within air conditioners and heat pumps this process is manipulated to make it appear that the opposite occurs.

Temperature – a measure of thermal energy, units of Kelvin (K) or Celsius (C)

Conductivity – a material property, heat flow per unit area per unit thickness per unit temperature, symbol k (W/m K)

Conductance – a property of a material layer, heat flow per unit area and temperature, symbol C (W/m^2 K) = conductivity k / thickness l (in meters)

Resistance – a property of a material layer or wall measured from surface to surface, equals 1/C , symbol RSI (m^2 K /W) Imperial value R (ft^2•F•r/Btu) = 5.678 RSI

Overall heat transfer coefficient – a property of an enclosure assembly, basically the thermal conductance of an assembly, heat flow per unit area and temperature, symbol U, U = $1/R_{total}$, units W/m^2 K.

Example: Given that the thermal conductivity of Type 4 extruded polystyrene (for example, Styrofoam SM) is 0.029 W/mK, find the conductance and resistance of a layer 50 mm thick in both imperial and metric units.

Answer:

Conductance = conductivity k / thickness l (in meters). 50 mm = 0.050 m so …

$C = 0.029 / 0.050 = 0.58 \ W / m^2•K$

this means, for example, that a one square meter panel of 50 mm thick Styrofoam SM will allow 0.58 watts of energy to pass through it under a one degree Kelvin (or Celsius) temperature change.

Resistance, RSI = 1 / conductance, so

$C = 1 / 0.58 = 1.724 \ m^2•K / W$

Hence, a layer of SM would have a thermal resistance of RSI 1.724. If one were to look in a building supply store, a sheet of 2" SM would be stamped with RSI1.76, since 2" sheets are slightly thicker than 50 mm. By the way, a layer of 100 mm would have a thermal resistance of RSI3.45, eg twice the thickness, twice the resistance (this does not work with conductance).

The thermal resistance in imperial R-value would be:
Imperial value R (ft^2•F•r/Btu) = 5.678 RSI
R_{imp} = 5.678 * 1.724 = R_{imp}9.8

Again, a full 2" thick sheet would have a slightly higher R-value of R10. Thus, one often speaks of an "insulation value" of R5 per inch. Four inches, R20 for this layer, 1.5", R7.5 for the layer.

Most building enclosures include more than just materials – they also include air spaces, which are insulating. The heat transfer from the air next to the enclosure to the surface of the enclosure is also not perfect. Hence, one needs to calculate the impact of this effect. These complications are discussed next.

SURFACE FILMS

To account for both the radiative and convective heat transfer modes at the exterior and interior surfaces of building components, the radiative and convective heat transfer coefficients are used in the form of an *equivalent conductance* or, alternatively, equivalent resistances. These equivalent coefficients are termed *surface film coefficients.* It is important to recognize that a surface film does not exist in reality. The term film is used simply so that a layer (of indefinite thickness) can be added to a typical conductive heat flow analysis.

The resistance to heat flow at a surface is small relative to the heat flow resistance of most modern wall assemblies and therefore need not be accurately estimated for most purposes. Poorly insulated walls and windows have a lower overall thermal resistance and thus surface effects are more important. Hence, a more precise calculation of surface films is justified for these types of enclosures.

The overall equivalent surface conductances, h_o, or resistance in Table 1 can be used in to find heat flow without further modification. Again, note that surface films are fictitious: they do not physically exist, or have thickness.

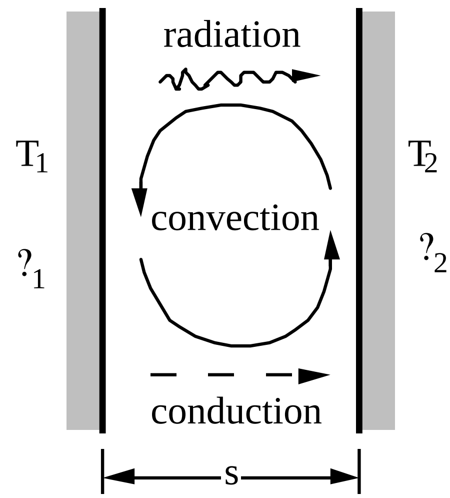
Surface Position	**Flow Direction**	**Resistance**	**Conductance**
Still Air (e.g. indoors)		RSI [m^2K/W]?	[W/m^2K]?
Horizontal (i.e. ceilings	Upward	0.11	9.3
and floors)	Downward	0.16	6.1
Vertical (i.e. walls)	Horizontal	0.12	8.3
Moving Air (e.g. outdoors)			
Stormy 6.7 m/s (winter)	any	0.03	34
Breeze 3.4 m/s (summer)	any	0.04	23
Average conditions	any	0.06	17

Table 1: Equivelant Total Surface Film Conductances (h_o)

PLANE AIR SPACES

Plane air spaces are commonly used in building assemblies. Heat is transferred across air spaces by a combination of conduction through still air, convection flows, and by net radiation from the warm side to the cold. The modes of heat transfer vary in importance depending on: the emissivities of the surfaces, the thickness of the air space, and the absolute and relative temperatures of the two surfaces.

The heat flow across a plane air space can be found with a reasonable degree of accuracy by using detailed correlations of convection and radiation. However, a high degree of accuracy is rarely necessary or justified in light of the many poorly known variables (e.g. variable cavity widths, blocked cavities, etc.) and the relatively small influence that the airspace has on the thermal resistance of modern enclosure assemblies. Simplified values for most practically encountered situations are presented in Table 2. The values in Table 2 are also given in terms of resistances so that they can be directly used in the heat flow equation.



Heat Transfer Across Plane Airspaces

Situation (non reflective surfaces)	RSI Value	Conductance
Heat Flow Down (20-100 mm)	0.18	5.5
Heat Flow Across (20-100 mm)	0.17	5.9
Heat Flow Up (20-100 mm)	0.15	6.5

Table 2: Thermal Resistance for non-reflective Enclosed Airspaces ($W/m^2 \cdot K$)

In many practical situations an air space is either intentionally or accidentally vented. Air flow through an air space can change the heat flow characteristics, although significant flows are required to modify the equivalent conductances listed above. In most cases, the effect of vented can be ignored, and only in extreme cases does in need to be accounted for. Extreme cases includes highly ventilated attics (at least 1% venting area) and wall panels with at least 2% vent area and cavities over 50 mm in size.

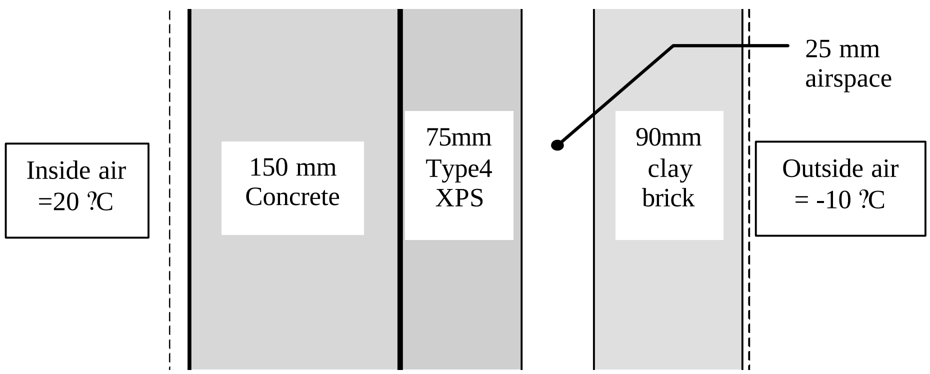
HOW TO CALCULATE THE "R VALUE" OF AN ENCLOSURE ASSEMBLY

Remember: one cannot add conductances, you must add resistances

1. List each material in the wall or roof, its conductivity (k) and its thickness (l) in m
2. Calculate the conductance of each layer (C) using C = k / l .
3. Calculate the thermal resistance of each layer using RSI = 1 / C
4. Sum the individual thermal resistances to get the answer.

Usually the thermal resistance of the air films that exist on both the interior and exterior surfaces of an assembly are added to the wall as virtual layers. This makes our calculations more accurate.

Example: Calculate the total thermal resistance (R) and overall heat transfer coefficient (U) of the wall shown below. Use conductivity values from tabulated values.



Answer:

Layer Material	Conductivity	Thickness	Conductance	Resistance
Interior film [note 1]	N.A.	N.A.	8.3	0.120
Concrete	1.8	0.150	12	0.083
Type 4 XPS	0.029	0.075	0.39	2.56
Air space [note 2]	N.A.	25	N.A.	0.17
Brick	1.3	0.090	14.4	0.069
Exterior film [note 1]	N.A.	N.A.	34	0.029
		RSI total		**3.04**
		Overall Heat Transfer, U		**0.33**

Note 1: Table 1. Since the interior and exterior films are fictitious, they do not have a thickness, and so no conductivity. Hence, tables typically contain only conductances or resistances for the layer. These values can be quite variable, but as can be seen, the effect of the value of the film resistance on the total resistance of a wall is small if the wall is a modern insulated assembly.

Note 2: Table 2. The flow of heat through an air space is complicated by convection (air flows) and radiation and so tabulated values of conductance are used instead. Like surface films, the values are variable but not important to accuracy in the calculation in most modern walls.

The total resistance is RSI3.04 (or imperial R 17.2), 84%of it provided by the insulation, and heat flow will be 0.33 W/m^2 K.

HOW TO CALCULATE THE STEADY-STATE HEAT FLOW THROUGH AN ENCLOSURE SYSTEM

Heat flow across an assembly is simply the temperature difference divided by the R-value times the overall heat transfer coefficient. The temperature difference is usually just (t_{inside} – $t_{outside}$).

1. Find the total thermal resistance of the enclosure as described earlier
2. Find the overall heat transfer coefficient U, using $U = 1/R_{total}$
3. Multiply the temperature difference across the assembly by U, i.e., $U*(t_{inside} - t_{outside})$

Of course if the sun is shining on the wall, the outdoor *air* temperature is not the correct one to use, (the actual solar heated surface temperature is more accurate, but difficult to find sometimes – use the table provided for guidance).

The effect of heat storage, or thermal mass, is very important for the wall since heavy mineral-based materials can store a lot of heat.

Example: Calculate the amount of heat flow through the wall of the previous example when it -10 C outside with no sun and 20 C inside.

$$\text{Heat flow} = U*(t_{inside} - t_{outside}) = 0.33\ (20\ -10) = 0.33\ (30) = 10\ W/m^2$$

Ans. Heat flow outward would be 10 W/m^2.

If the wall were exposed to bright sun, the temperature of a very dark surface would be expected to be as much as 48*1 = 48 C above the air temperature (see Table 3 later in this document). For this example, we will assume dark red brick (absorptance =0.85) and thus estimate a surface temperature of about 48 * 0.85 = 40 C above the air temperature. This means:

$$\text{Heat flow} = U*(t_{inside} - t_{outside}) = 0.33\ [20\ -(-10+40)] = 0.33\ (-10) = -3.33\ W/m^2$$

Ans. If the wall were dark red and exposed to bright sunshine, the heat flow would be inward and about 3.33 W/m^2.

ASSESSING THE ENERGY LOSS DUE TO AIR LEAKAGE

If cold air leaks out of the building in winter, it is of course replaced with cold/hot air. This cold/hot air must be heated up to make it comfortable. The energy impact of air leakage is significant and must be considered since it is often an important heat loss/gain component of modern buildings. It can be included by calculating an *equivalent heat loss coefficient* for air leakage. This can be found from:

$$U_{air} = 0.3 * n * V$$

Where U_{air} is the heat loss coefficient due to air leakage (W/ C)
N is the number of complete air changes per hour (ACH)
V is the total air volume of the building (in m^3)

U_{air} can be included in calculations just like U_{wall} or U_{window}.

HOW TO CALCULATE THE STEADY-STATE HEAT FLOW THROUGH A BUILDING SYSTEM

The easiest means of estimating heat flow through an entire building is to

1. Calculate and then list the U-value for each element (wall, roof, window, door) along with the area of that element
2. The product of each elements' area and its U-value is the heat loss coefficient for that enclosure element per unit temperature difference (SI units: W/C)
4. The sum of these products is the overall heat loss coefficient for the building.
5. To find the overall heat loss (or gain) multiply the overall heat loss coefficient for the building by the temperature difference across the assembly.

Example: An industrial "big box" store is 8 m high, 32 m long and 64 m wide.
The enclosure has a lightweight roof (U=0.36 W/m^2/C and) and precast concrete walls (U=0.4 W/m^2/C). The front of the store (which faces west) has a 6 m high by 24 m long glass curtainwall with a U-value of 2.0 W/m^2/C. Six loading doors are at the back, each 5 m high and 3.5 m wide with a U-value of 1.0. The building is estimated to leak at 0.5 ACH under normal conditions.
Ignoring the effect of the floors, sun, and any other doors, find the heating requirements when it is -10 C.

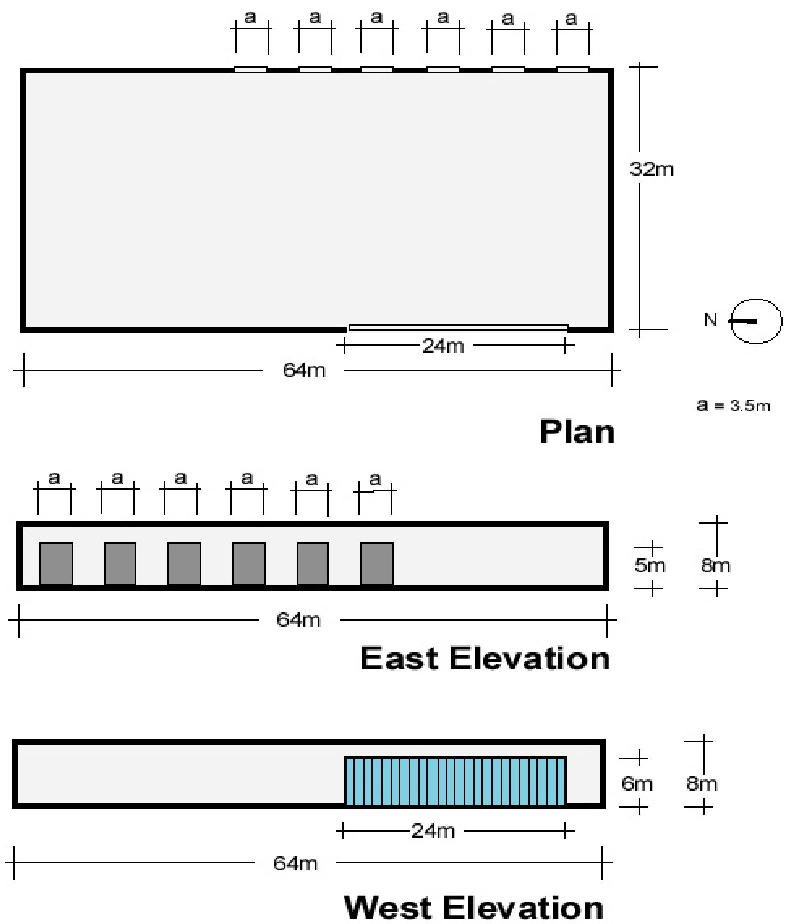
Answer:

See the sketch of the building for details of the areas.

Air leakage Heat loss: 0.3 n V = 0.3 (0.50) (16384) = 2458 W/C.

Enclosure Component	Area (m2)	U Value (W/m2/C)	Q Heat Loss (W/C)	% Total Heat Loss
Walls	1287	0.40	515	**13%**
Roof	2048	0.36	737	**18%**
Doors	105	1.0	105	**3%**
Curtain Wall	144	2.0	288	**7%**
Air Leakage		*from above*	2458	**60%**
Overall Building Heat Loss Coefficient			**4103 W/C**	

Therefore, the total heat loss can be seen to be 4103 W per degree Celsius difference. For an outdoor temperature of -10 C, indoors of 20 C, the difference is 30 C, and total heat loss is 123 kW.



Building Volume
=32x64x8
=16384

Roof Surface Area
=32x64
=2048 m2

Curtain Wall Surface Area
=24x6
=144 m2

Door Surface Area
=6(3.5x5)
=105 m2

Wall Surface Area
=(64x8)2+(32x8)2-(105+144)
=1024+512-105-144
=1287 m2

Building Surface Area
=2048+144+105+1287
=3584m2

The relative impact of each building component can also be seen. For this building type, the U-value of the enclosure is unimportant relative to the impact of air leakage. It should also be noted that the amount of lights and equipment and people in the store will typically consume 30 to 50 W/m^2 of electricity, all of which is converted to heat. Hence, if we assume an average energy use of 40 W/m^2, the interior gains would be:

$$2048 \text{ m}^2 \times 40 \text{ W/m}^2 = 81920 \text{ W}$$

This energy will offset the losses of 123 kW, but a heating system of some type would be needed to make up the remaining (123-82) = 41 kW.

SOLAR RADIATION THROUGH WINDOWS

Solar gain through windows exposed to either the direct sun, or reflected sun (reflected off the particles in the sky, creating diffuse radiation or reflected off terrestrial surface, creating beam radiation) can dramatically affect the energy balance of a building. Hence, the energy flows calculated in the previous section must be adjusted by adding the solar gain through windows. This amount of energy can completely dominate the performance of a modern building.

The Solar Heat Gain Coefficient (SHGC) is the window property used to rate the amount of energy allowed through windows. The SHGC is the fraction of incident solar radiation that passes through a window and becomes heat inside the building. For example, if the SHGC of a glazing unit is 0.50, and the sun is shining on the window with an intensity of 500 W/m^2, 250 W/m^2 will enter the building.

The lower the SHGC, the less solar heat that the window transmits through and the greater its shading ability. In general, South facing windows in houses designed for passive solar heating (with a roof overhang to shade them in the summer) should have windows with a high SHGC to allow in beneficial solar heat gain in the winter. East or West facing windows that receive large amounts of undesirable sun in mornings and afternoons, and windows in houses in hot climates, should have a low SHGC. Most large commercial buildings should have few losses or gains through the building enclosure (this can be calculated) but windows can dramatically alter this.

To calculate the impact of windows on cooling:

1. estimate the solar radiation (from charts and tables) that will be striking each building orientation during the cooling period (it is often the hottest outside when it is sunny)
2. multiply the clear area (not including mullions) of each window system on each orientation by the SHGC of that window.
3. add this energy to the energy calculated for conduction and air leakage gains.

To calculate the impact of windows on heating is not as straight forward. The balance can be found for any given situation, but the coldest periods are almost always during the night, when there is no sun. Cold days, however, tend to be sunny. Therefore, simple calculations can not be used to estimate how much a furnace can be reduced in size because of solar gain. What can be calculated easily is the impact of overheating. Many solar buildings have overheating problems because of excessive areas of unshaded glass. To investigate this overheating problem, the outdoor temperature should be assumed to be the average temperature in a cool month (e.g. November or March). The maximum solar energy (usually noon with south facing glass for a solar building) should then be calculated. If the energy gain is much more than the energy loss calculated, the building will over heat. Operable shade and large amounts of ventilation will therefore be required, or the window area should be reduced.

The most direct and powerful method of controlling solar gain through windows is through the use of shading and orientation. Good control requires a designer to understand the location of the sun over the day and over different orientations. Shading should be on the EXTERIOR of the glazing unit or it will trap heat in the building. With modern glazings, interior shading should primarily be used to control glare. Exterior operable shades are used through out Europe, and work remarkably well. The SHGC for good exterior shades is in the order of 0.05 to 0.10. The same blinds on the interior will reduce the SHGC by about a third.

Material	Density (kg/m3)			Conductivity Range (W/m K)			Conductance Range (W/m2 K)		
Board / sheet products									
Plywood	400	-	600	0.08	-	0.11			
OSB	575	-	725	0.09	-	0.12			
Waferboard				0.1					
Hardboard				0.105					
Vegetable Fiberboard	270	-	300	0.045	-	0.07			
Particleboard	590			0.102					
Particleboard	1000			0.17					
Strawslab	260	-	350	0.085	-	0.11			
Corrugated Metal Deck							negligible		
Finishes									
Ceramic Tiles				1					
Acoustic Tiles - fibreboard				0.065					
Acoustic Tiles - glassfibre				0.036					
Gypsum Board	800	-	900	0.16					
Sand Plaster / Lath				0.71					
Gypsum plaster / Lath				0.16	-	0.35			
Sand :Cement plaster	1570			0.53					
Gypsum plaster w/perlite	720			0.22					
Gypsum plaster w/sand	1680			0.8					
Carpet Fibrous Underlay							2.73		
Carpet Rubber Underlay							4.42		
Terrazzo				1.8					
Hardwood Flooring				0.16					
Siding / Cladding									
Hardboard siding	640			0.094					
Wood Siding - lap				0.1	-	0.12			
Plywood Siding				0.09					
Face Brick - clay	2000			1.3					
Face Brick - concrete	2200			1.9					
Metamorphic Stone	2600	-	3000	2	-	2.8			
Sedimentary Stone	2200	-	2600	2.1	-	2.3			
Metal vinyl clapboard/V-groove							8		
Metal - flush installed				40	-	80	0	negligible	
Cement Stucco	1800			0.7	-	1.4			
Structural Materials									
Softwood lumber	510			0.1	-	0.14			
Hardwood Lumber	720			0.15	-	0.18			
Cedar Logs and Lumber				0.098	-	0.12			
Concrete	2400			1.4	-	2.6			
Concrete (limestone)	1920			1.1	-	1.3			
Concrete (light)	1300			0.5	-	0.7			
Aerated Concrete	400			0.12	-	0.15			
Aerated Concrete	600			0.18	-	0.2			
Carbon Steel	7680			40	-	80			
Aluminum	2800			160	-	200			
Cement Mortar	1800			0.8					
Concrete Block 200 mm							5.1		
Lt. Wt. Concrete Block, 200 mm							2.84		
Concrete Block, 100 mm							8		
Hollow tile, 100 mm							5.5		

Durisol	400	-	500	0.072	-	0.085			
Adobe	1400	-	1800	0.4	-	0.8			
Clay Straw (function of density)	600	-	1400	0.15	-	0.5			
Cement-bonded rice husk	720			0.15					
Wood fibre and cement	1550			0.32					
Insulations									
EPS Type 1	16			0.039					
EPS Type 2	24	-	32	0.034					
EXPS Type 3 and 4				0.029					
Batt Insulation				0.036	-	0.048			
Rigid Mineral Fiber				0.03	-	0.04			
Rigid Fibrous Roof Insulation				0.036					
Rigid Polyurethane				0.024					
Rigid Polyisocyanurate				0.02	-	0.024			
Phenolic Foam (closed cell)				0.017	-	0.02			
Urea Formaldehyde				0.031	-	0.032			
Fibreboard	270			0.052					
Cellulose Fibre	37	-	51	0.039	-	0.046			
Sawdust	145	-	160	0.05	-	0.08			
Strawbale	120	-	200	0.06	-	0.075			
Corkboard	145			0.042					
Sprayed Asbestos				0.05					
Vermiculite, exfoliated	64		130	0.06	-	0.07			
Perlite, expanded	800			0.2	-	0.26			
Perlite, expanded	320			0.07	-	0.08			
Perlite, bonded/expanded	16			0.052					
Eel Grass batt	145	-	215	0.043	-	0.049			
Jute Resin bonded	420			0.065					
Peat slab	240	-	480	0.058	-	0.101			
Sheeps Wool, fluffy	50			0.045					
Roof Materials									
Built-up Bitumen Roofing				0.17					
Asphalt Shingles							12.9		
Wood Shingles							6		
Crushed Stone				1.60					
Thatch-Straw	240			0.07					
Thatch-Reed	270			0.09					
Other Materials									
Fresh Snow	190			0.19					
Compacted Snow	400			0.43					
Ice at -1 and -20 C	920			2.24	-	2.45			
Water at 20 C	1000			0.60					
Earth, dry to damp	1400	-	2000	0.80	-	2.00			
Sand dry	1400			0.30	-	0.80			
Air, still (conduction only)	1.2			0.03					
Glass, soda lime	2500			0.80	-	1.00			
Copper				380					
Lead				35					
Brass				120					
Nickel				60					
Rubber				0.2					

THERMAL BRIDGES AND OTHER COMPLICATIONS

One-dimensional steady-state heat flow assumptions may not allow for the accurate prediction of space-conditioning energy consumption for three main reasons:

1. **Thermal Bridging**: structural members (e.g., wood or steel members in light-frame construction and concrete and steel columns/walls in commercial construction) can act as a thermal bridge causing heat flow to short-circuit. Only two- or three-dimensional analysis can predict and quantify this type of heat flow. The use of insulation to break thermal bridges will effectively reduce this type of heat transfer.

2. **Thermal Mass**: heat flow through building enclosures is not steady-state. Heat stored in the thermal mass of buildings and then released can reduce both heating and cooling requirements. Thermal mass also makes it possible to make more effective use of internal and solar gains. Simple steady-state methods of analysis cannot model these effects. Hour-by-hour computer programs are widely available to aid in the assessment of dynamic effects.

3. **Air Leakage**: Air leakage through the building enclosure can be a major source of energy loss. Airtight buildings use far less energy. Again, the simple, commonly used, analysis techniques cannot assess the influence of air leakage on the thermal performance of a building system. The loss of energy by air leakage (convection) must be calculated in addition to the loss by conduction through the enclosure.

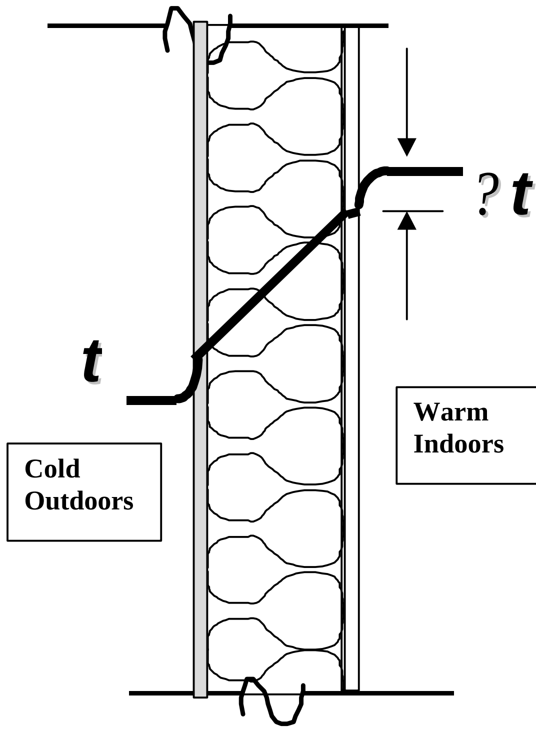
Heat flow deviates from one-dimensional at corners, parapets, intersections between different assemblies, etc. When heat flows at a much higher rate through one part of an assembly than another, the term *thermal bridge* is used to reflect the fact that the heat has bridged over / around the thermal insulation. Thermal bridges become important when:

? they cause cold spots within an assembly that might cause performance (e.g., surface condensation), durability or comfort problems

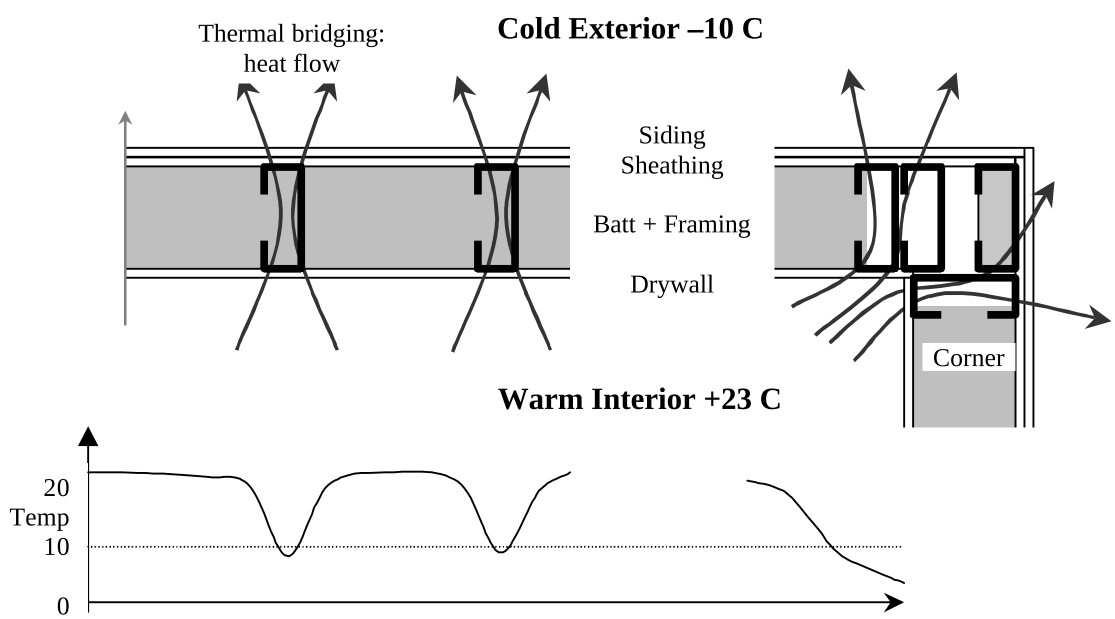
? they are either large enough or intense enough (highly conductive) that they affect the total heat loss through the enclosure

Thermal bridging, especially by steel framing, or at the intersection of wall corners with roofs and floors, projecting structural elements like balconies and perimeter slabs often causes cold interior surface temperatures and thus condensation. Attached figures provide a schematic of how temperatures at studs and near corners can cause low surface temperatures. In the case of the steel framing shown, an exterior temperature of –10 C can result in interior surface temperatures of 5 to 10 C at studs, and below freezing at floor to wall corners.

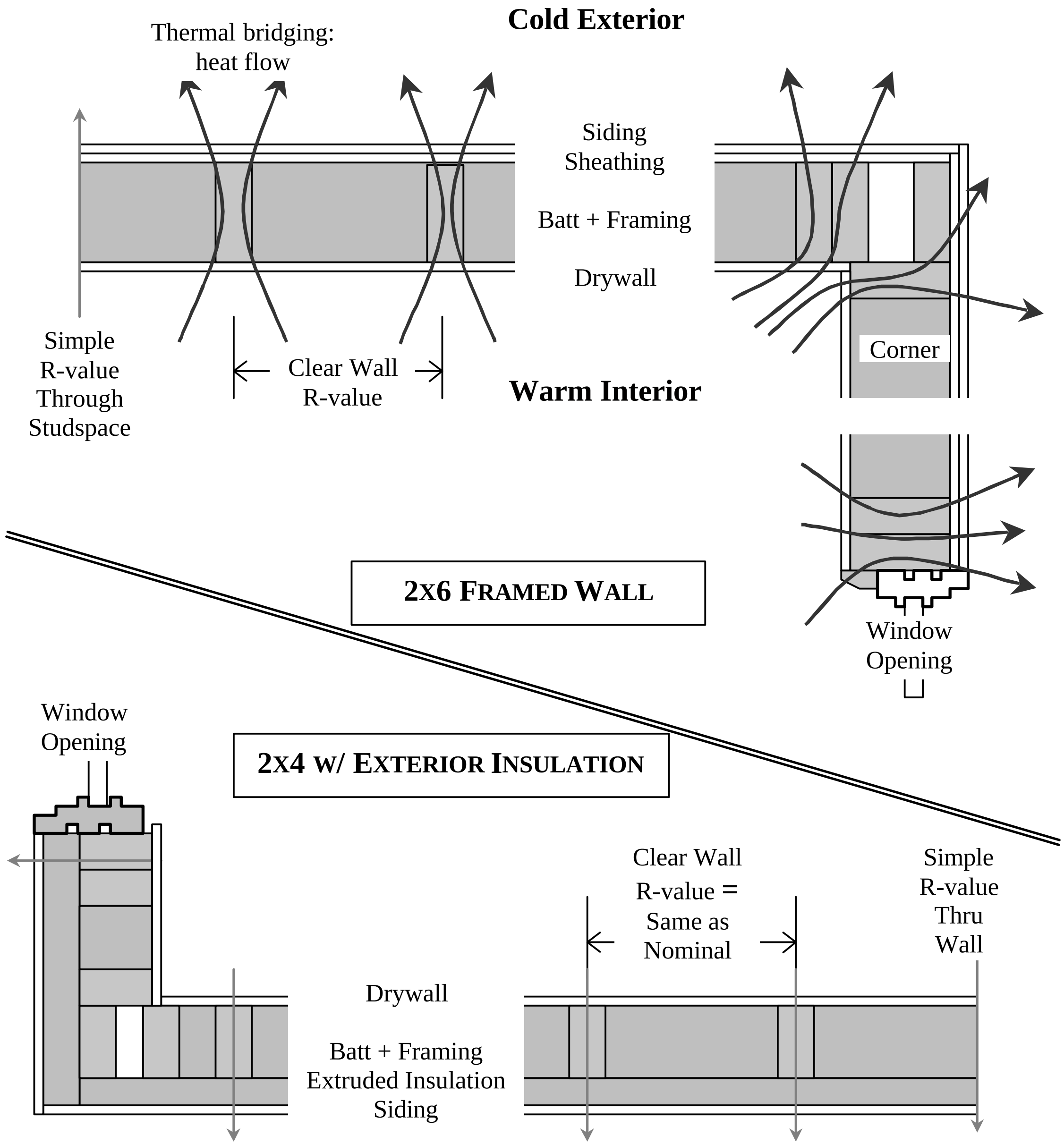
All enclosures should be designed to avoid a large number and extreme thermal bridges. The most effective solution, insulating wall sheathings (e.g., rigid foam), are quite useful for "blunting" thermal bridges and also offer energy saving benefits, wind washing resistance, and improved resistance to exfiltration condensation. Convective cooling, or wind-washing, should also be controlled, especially at corners).



Plot of Temperature Through Wall Showing Drop At Surface



Plot of Temperature Along wall Mid-height



Cold Exterior
Thermal bridging: heat flow
Siding
Sheathing
Batt + Framing
Drywall
Corner
Simple R-value Through Studspace
Clear Wall R-value
Warm Interior
2X6 FRAMED WALL
Window Opening
2X4 W/ EXTERIOR INSULATION
Window Opening
Clear Wall R-value = Same as Nominal
Simple R-value Thru Wall
Drywall
Batt + Framing
Extruded Insulation
Siding

RADIATION-INDUCED EXTERIOR SURFACE TEMPERTAURES

Radiation, either solar heating by the sun or cooling by radiation to the night-sky, can have a very significant influence on the thermal exposure of the building enclosure. Although rarely warranted, detailed procedures can be used to relatively accurately calculate, in terms of energy transfer rates (e.g. W/m^2), the effect of solar heating and night-sky cooling on enclosure surface temperatures.

It is often convenient to have simple equivalent temperatures that can be entered directly into a standard conductive heat flow analysis. When an equivalent air temperature is used, the temperature is termed the *sol-air temperature*. This procedure has the drawback that air temperature is no longer realistic and the advantage that surface films play a role in the definition of the temperature. The value for the overall surface film coefficient is often assumed to be 17 $W/m^2{\cdot}{}^oC$ although this coefficient is quite variable, especially if the surface becomes hot. In fact, under solar-heating, the coefficient is likely to be as much as two times larger.

A simple and equally realistic approach is to use *approximate surface temperatures*. Table 3 is a compilation of the most useful approximate surface temperatures based on calculation (using refined surface heat transfer coefficients) and supported by several years of field measurements.

Situation	**Thermally Massive**	**Thermally Lightweight**
Roofs: direct sun	t_a + 42 ?	t_a + 55 ?
roof: sun plus reflected / emitted radiation	t_a + 55 ?	t_a + 72 ?
roof exposed to night-sky	t_a - 5 ?	t_a - 10 ?
walls: winter sun	t_a + 35 ?	t_a + 48 ?
walls: summer sun	t_a + 28 ?	t_a + 40 ?
walls exposed to night sky	t_a - 2 ?	t_a - 4 ?

Notes: t_a refers to the ambient air temperature, ? is the surface emmittance, and ? is the solar absorptance. The emmittance is about 0.90 for most materials. The absorptance varies with colour from about 0.3 for white/beige objects to 0.65 for forest green to 0.95 for flat black. Thermally massive refers to walls with a significant amount of thermal storage capacity (e.g. brick veneer or equivelant) outside of a low conductance material (e.g. insulation). Walls with significantly more mass (e.g. multi-wythe brick, rubble) or less insulation (U > 1 $W/m^2/{}^oC$) will be less affected. Vinyl, metal and EIFS are lightweight walls; other walls can be interpolated based on heat capacity. All values are for approximately 45º North. The values for walls are likely clear night or sunny day maximums and apply to east/west orientations in summer and south orientations in the winter.

Table 3: Approximate Radiation-Induced Surface Temperatures (ºC)