Thermal Assessments

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Credit: 1 PDH

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THERMAL ASSESSMENTS

Before applying any energy efficient or renewable energy measure, you should always analyze the building envelope first. One of the most crucial aspects of energy efficiency is the building envelope, and an envelope upgrade is often the most recommended energy reduction measure (ERM). An envelope upgrade can refer to anything regarding improvements to the shell of the building, which include but are not limited to, window upgrades, air sealing, insulation upgrades, improved vapor barriers, and thermal short reductions. More often than not, envelope upgrades are overlooked because of poor returns on investment or high initial costs; however, there are many techniques you can apply to drastically improve the performance of your envelope which are both simple and inexpensive. Not to mention, many of these simple strategies and measures are funded through state and federal incentives. One such method – air sealing – can be done very quickly and economically, and the same is true for partial envelope renovations. Usually it's only parts of walls that are the problem, not the entire façade.

One difficulty with these upgrades is finding the problems. Beyond the everyday eyesore – leak in a ceiling, mold growth, strong draft – how do we discover these areas? Tear down every wall and examine its interior? Have hydroscopic and indoor air quality evaluations done? See your local psychic? The best solution is usually a **thermal imaging evaluation** or any form of an **infrared assessment.**

Thermal Resistance

Infrared technology allows users to see and capture changes in temperature of a surface; changes that often cannot be seen or felt. Even the most subtle changes in temperature can be a red flag. Think about it – why would a solid surface constructed of the same materials and under the same conditions have different thermal characteristics? The answer is: it wouldn't. There is likely an unseen variable either behind the surface or within it. For example, water infiltration can be an unforeseen problem. As it is absorbed and spread within your building envelope, water will lower the thermal resistance, also known as "R-Value," of the materials in contact. Thermal resistance is the property of a material which quantifies its ability to resist heat, and it is the inverse of a material's thermal conductivity. Under an infrared camera, water infiltration will appear as a random discoloration within materials usually appearing in the shape of spilled milk. Although the area might not be as random as you might imagine. Water issues are usually found below a pipe, around a window frame, near a wall penetration, or under an air-conditioner; areas where condensation or infiltration is most common but often disregarded. Usually, these kinds of issues can be the result of poor workmanship; however, they can also be associated with poor design, poor materials, traffic, age, and/or weathering.

Resistance Equation

Thermal Resistance, $R = L/K$ (Eq. 1)

where,

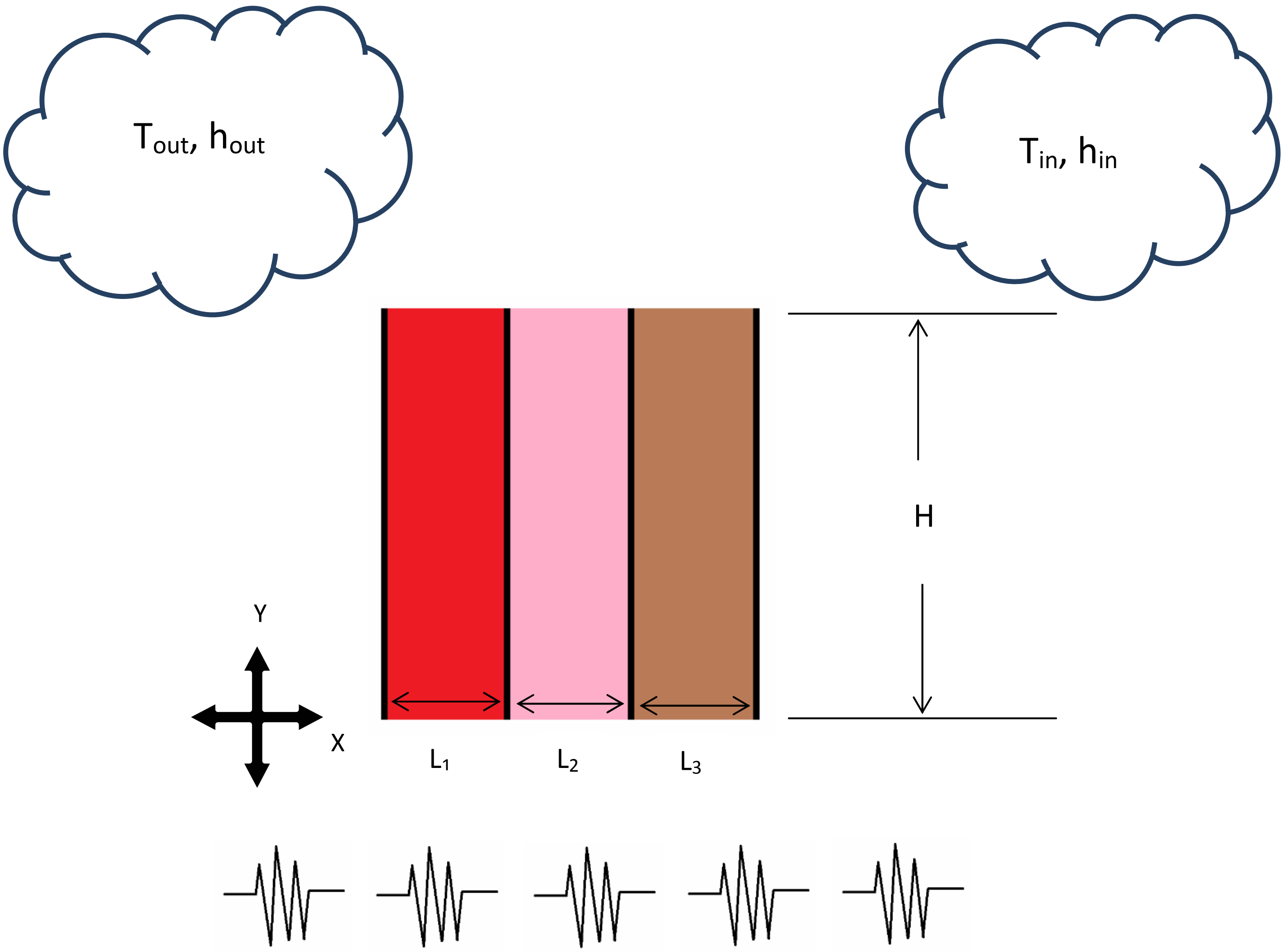
L = thickness of a material

K = Thermal Conductivity

Note: Many national standards, such as ASHRAE, the American Society of Heating, Refrigeration, and Air-Conditioning Engineers, publish R-Values for different materials based upon thickness, or R/in.

Example: Finding the total resistance of a wall

The example below will demonstrate a practical application of determining the R-value of a wall. Materials of the wall consist of Brick, Fiber glass insulation, and Gypsum board from (left to right) and for this example will be identified with subscripts 1, 2, and 3 respectively.



The resistance of this wall is a combination of three materials in series and can simply be added up for a total R-Value. If there was a window or some other fenestration, then the R-value of that would be in parallel with the materials making up the wall and will be calculated by:

$$\frac{1}{R_{TOT}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots$$

Check to be sure that all units are the same, either in metric or empirical, and the conversion if necessary.

Temperature	**Thermal Conductivity**	**Cross sectional Length**
T_{out} = 95F = 35C	h_{out} = 10 w/mk	L_1 = 3.5in = 0.889m
T_{in} = 70F = 21.11 C	h_{in} = 15 w/mk	L_2 = 18" = 0.4572m
	K_1 = 1.4 w/mk	L_3 = ½" = .0127m
	K_2 = 0.035 w/mk	
	K_3 = 0.17 w/mk	

$$R_{TOT} = \frac{1}{10} + \frac{0.889}{1.4} + \frac{0.4572}{.035} + \frac{.0127}{0.17} + \frac{1}{15} = 13.94$$

To find the heat transfer through the wall it is simply the change in temperature divided by the resistance multiplied by the surface area of the wall. In this example the area of the wall is unknown; therefore, the heat transfer through the wall will be in Watts/meter^2. The surface area would be found by multiplying the height of the wall, labeled as 'H' from the diagram, by the depth of the wall.

$$q = \frac{35 - 21.11}{13.94} = 1\,\frac{w}{m^2}$$

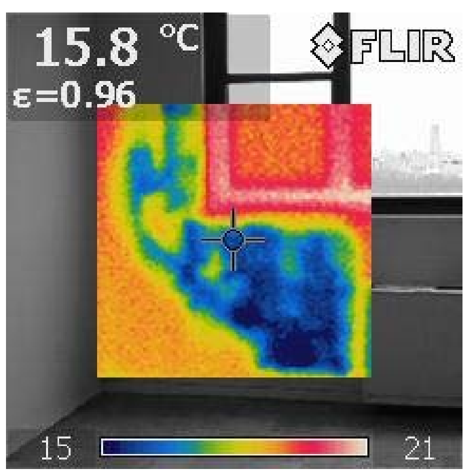


Fig. 1 – Water Infiltration from Poor Window Sealing and Lack of Vapor Barrier

IR Assessment Abilities

IR Assessments provide the ability to:

- Improve energy efficiency and operating costs
- Identify sources of water and air infiltration
- Prevent mold and structural damage
- Pinpoint missing, damaged, wet, or fallen insulation
- Identify caused for frozen pipes and ice dams
- Correct cold spots, drafts, and thermal comfort
- Verify construction workmanship and materials
- Resolve post construction disputes

It is important to keep in mind while evaluating these images that thermal resistance does change through the construction of a wall. Walls are never consistent throughout a surface; there are frames, screws, nails, seams, and other thermal shorts that will alter surface temperature. You can usually locate these materials within the infrared imaging because of their symmetry and geometry.

Thermal Bridges

When Figures 2 and 3 are evaluated, we find there are bands that have more thermal transmission than the rest of the wall. These bands represent thermal bridges that are caused by the studs or framing that transmit more thermal energy than the rest of the wall.

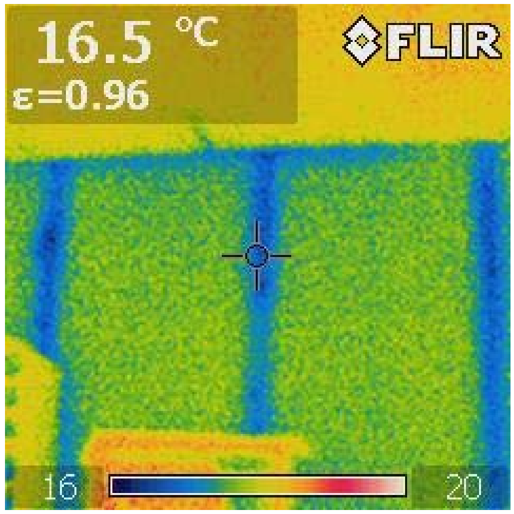
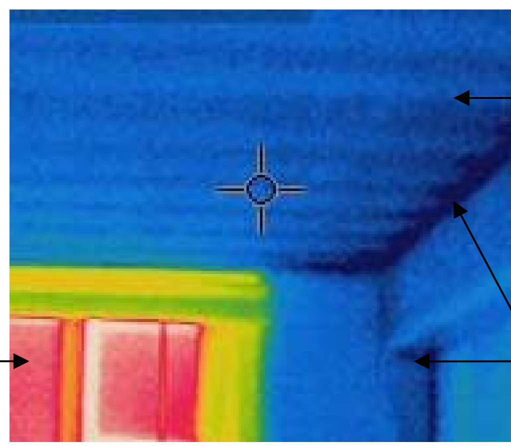


Fig. 2 – Lower Resistance of a Frame Wall Visible through IR Photography

Windows have very low thermal resistances. Evidently, temperatures outside were much higher than inside the living space. Windows create a large part of the cooling and heating load within a building. IR Evaluation can also be affected by solar radiation. Be sure to take into account environmental conditions.



Dark blues lines represent the reduced thermal resistance of the ceiling frame construction.

Joints of walls and ceilings are typically subject to infiltration and poor insulation.

Fig. 3 – Thermal Image of a Residential Living Room

U-Value

The most common misconception of wall construction is their assumed overall heat transfer coefficient, or U-Value. The U-Value of the wall is the inverse of an assembly's effective thermal resistance. Walls usually have more than one type of cross sectional construction. At one point it could be just concrete block and at another point it could brick facade, vapor barrier, stud frame, batt insulation, and dry wall. When the various types of wall construction are placed side by side to create a surface, they are said to be in parallel. The U-Value of walls with parallel thermal resistances can be calculated in two different ways:

Overall Heat Transfer Coefficient

In most steady-state heat transfer problems, more than one heat transfer mode is involved. The various heat transfer coefficients may be combined into an overall heat transfer coefficient so that the total heat transfer rate can be calculated from the terminal temperatures. The solution to this problem is achieved using thermal circuits.

Introduction to Theoretical Heat Transfer Coefficient

Consider the steady-state heat transfer from one fluid to another separated by a solid wall: from the warmer fluid at t_1, to the solid wall, through the wall, then to the colder fluid at t_2. The wall surface temperatures are t_{s1} and t_{s2}. An **overall heat transfer coefficient U** based on the difference between bulk temperatures $t_1 - t_2$ of the two fluids is defined as:

$$Q = UA(t_1 - t_2) \qquad \text{(Eq. 2)}$$

where *A* is the surface area.

Because Equation (3) is a definition of *U*, the surface area *A* on which *U* is based is arbitrary and should always be specified in referring to *U*. In steady state, heat transfer rates are equal from the warmer fluid to the solid surface, from one solid surface to the next, and then to the cool fluid. Temperature drops across each part of the heat flow path are related to the resistances as:

$$t_1 - t_{s1} = qR_1 \qquad t_{s1} - t_{s2} = qR_2 \qquad t_{s2} - t_2 = qR_3$$

Adding the three equations gives:

$$\frac{t_1 - t_2}{q} = (R_1 + R_2 + R_3) \qquad \text{(Eq. 3)}$$

The equations are analogous to those for electrical circuits. For thermal current flowing through *n* resistances in series, the resistances are additive. [1]

Effects of Thermal Shorts

Often, construction proposals say one thing but actual construction says another. Moreover, installers and designers often forget to incorporate thermal shorts into their calculations. Although the surface they are installing has an overall U-Value of 0.083 Btu/hr·ft^2·°F (equivalent to R-12, effectively), it may have to be mechanically fastened with screws, nails, washers, bolts, and/or several other different types of metals and thermally conductive materials. These thermal shorts can drastically affect the performance of your envelope. Many metals have a nearly negligible thermal resistance due to their high conductivity. In short, although you're paying for an R-20 roof, you may be getting an R-5.

[1] 2005 ASHRAE Handbook - Fundamentals (2005, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA), 3.19.

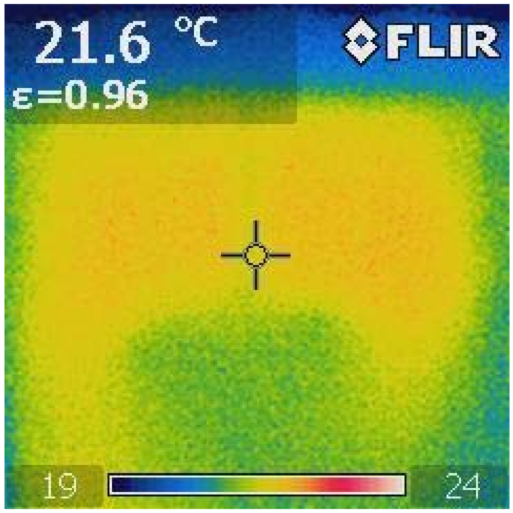


Fig. 4 – Fallen Insulation within the Top Half of a Frame Wall

One method of verifying thermal resistance, workmanship, and construction is to utilize thermal imaging. Over the past decade, infrared technologies have made leaps and bounds to become more practical. Although they still may be expensive, they are more readily available than ever and could be a great investment for a realty company, maintenance contractor, building owner, and especially, an energy auditor, engineer, or architect. Of course, there are thermal assessment professionals available all over the world that can perform this function for you. Thermal assessment operators must be extremely familiar with their equipment and the environment of the object of interest, as well as possess the skills necessary to plan and execute a proper thermal survey of the object. Before purchasing thermal assessment equipment, it is paramount that operators have the necessary training and understanding. Be sure to read all equipment catalogs and user manuals as well.

Factors that Affect Data Results from an IR Camera

Several factors can affect the data resulting from a thermal assessment, which is precisely why people emphasize proper training before conducting surveys. Wind, sunlight, object emittance, object surface orientation, thermal conditions of surroundings, humidity, cloud cover, and perspective can all affect the outcomes of infrared sensing. It is crucial for people to understand the effects of certain variables, and more importantly, understand best practices of thermal assessments to avoid inaccurate data. Where, when, and how you perform your survey can determine whether you are getting reliable information. For example, what type of survey is best for a thermal assessment: interior survey or exterior survey? Although the choice should depend on the variables previously mentioned, usual circumstances would lead to the conclusion of an interior survey. Because warm or cool air does not always escape from a building in a straight line, assessing the exterior of a construction can be misleading. Heat loss in an area of an exterior surface could be originating from an entirely different area. Furthermore, it is always more difficult to obtain accurate results on exterior walls due to wind and solar radiation effects.

Another part of a proper evaluation is being prepared. Make sure to move all furniture and drapes, as well as obstructive materials from the object being evaluated. Lamps, mirrors, artwork, and furniture can produce errors in the evaluation and cover up issues lying behind their position. Thermal evaluations should also be planned on days with optimal weather conditions which produce at least a 20°F difference between ambient and inside conditions (also recommended: days with little to no chance of rain). For northern states, thermographic evaluations are recommended in the winter time, and for southern states, it is recommended during hot weather with the air-conditioning running.

Frequently major problems such as water infiltration can go unseen because of the lack of heat. Large temperature differences increase heat through materials and allow evaluators to discover issues. Occasionally a problem will need to be located immediately when temperature differences are not large enough. Based upon the laws of heat transfer, as temperature gradients are minimized, so is heat transfer. Even though temperature gradients may not change, by increasing the amount of air flow and infiltration, heat transfer can be increased. By producing an increase in heat transfer, temperature differences of the construction surface are exaggerated and more easily discovered. The equation below illustrates how heat transfer is increased with this technique.

$$Q = mc_p\Delta T \qquad \text{(Eq. 4)}$$

where, m = mass flow rate of air

C_p = specific heat of air

ΔT = temperature change of air

Assuming c_p and ΔT remain constant, any increase in the flow of air (m) will increase the amount of heat transfer (Q). In effect, areas of leakages will begin to change temperature and will be more noticeable within the thermal evaluation.

In order to increase infiltration, a negative pressure must exist within the building. This can be accomplished by closing all windows, doors, and ventilation ducts while running kitchen and/or bathroom exhaust fans within a space. Another method is conducting a thermal assessment during a blower door test, which can create even larger pressure differences. FLIR®, a manufacturer of IR imaging technology, recommends conducting inspections with a pressure differential of at least 10-50 Pa.

More Applications for IR Cameras

Thermal assessments can do much more than just identify existing envelope issues. They can be an effective preventative measure as well. As we examined earlier, temperature differences create heat, and heat can be responsible for a myriad amount of problems. One by-product of too much heat is fire. By using infrared imaging, fires can be prevented by discovering large temperature differences between materials.

One classic example is electrical fires. Often, electrical fires are caused by improper or oxidized socket contacts. Poor socket connections reduce contact areas while the oxidation of socket connections increases resistance. As a result, both can produce large amounts of heat which can result in an electrical fire. Evaluators should consult electrical professionals with certain discoveries as temperature increases can sometimes be deceiving. Often, temperature differences can occur because of increased loads or difference in the manufacture of a socket. Although a socket may not be hot enough to produce electrical fires, increased temperature usually denote electrical waste in the form of heat. By identifying and repairing poor socket contacts, electrical efficiencies can be increased which can save on utility costs.

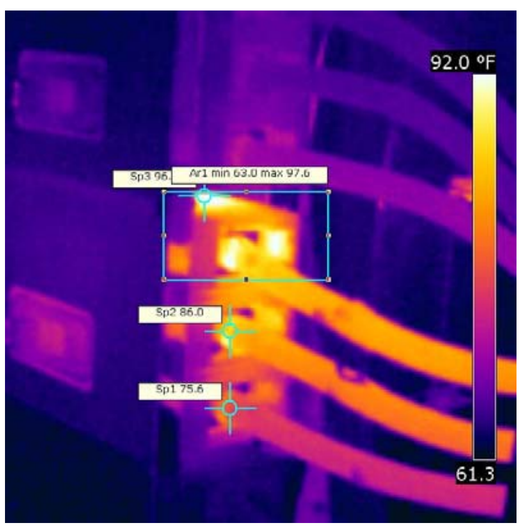


Fig 5 – Temperature Differences between Three Sockets

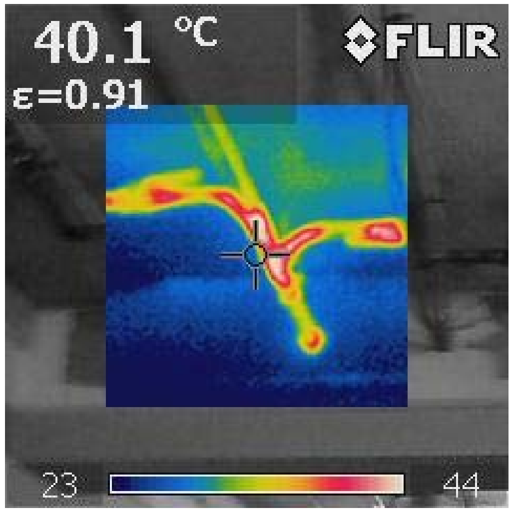


Fig. 6 - Image of a Domestic Hot Water Pipe

Ventilation Needs

As you make these improvements to your building, infiltration and natural ventilation may be reduced, thereby lowering the existing ventilation rates. In these circumstances, mechanical ventilation must be increased to provide the required amount of fresh air. This is one reason why energy recovery ventilation is so important in every building. Of course, most buildings do not increase mechanical ventilation after envelope upgrades, and they usually fall victim to the "sick building syndrome," a condition of poor air circulation, air quality, and occupant health. Studies have shown employee absences will increase and productivity will decrease as a direct result from poor indoor air quality. This is a negative effect of which no building owner, manager, or tenant should suffer.

In order to properly estimate thermal resistance of a wall or roof construction, a temperature gradient of the construction must be determined. It's also important to record the temperature of either the indoor or ambient conditions during the evaluation. For this calculation the assumption must be that at the instant a measurement is taken, the object in question was in a steady operation; i.e. heat transfer between the interior and exterior is constant, and there is no other heat generation present. In order to make this assumption, surveyors and auditors must ensure effects of environmental variables are at a minimum. During steady operation, the rate of heat transfer into the wall is equivalent to the rate of heat transfer out of the wall:

$$Q_{in} = Q_{out} \text{ or } Q_{in} - Q_{out} = 0 \qquad \text{(Eq. 5)}$$

When expanded, the two equations become:

$$Q_{out} = \frac{T_{es} - T_{is}}{R_{const} + R_{air\ film}} xA \qquad \text{(Eq. 6)}$$

$$Q_{in} = \dot{m}c_p(T_{is} - T_{space}) \qquad \text{(Eq. 7)}$$

Where,

T_{is} = Temperature of the interior surface of the wall or roof construction

T_{es}= Temperature of the exterior surface of the wall or roof construction

R_{const} = Thermal Resistance of the construction being evaluated

T_{space} = Temperature of air

T_{is} and T_{es} can be discovered using IR Photography, and T_{space} can be discovered by using the room thermometer or a recording temperature sensor. $R_{air\ film}$ is a constant property of still air within a building (typically is valued at 0.68 hr·ft^2·°F/Btu and is actually a form of convection, rather than conduction). That leaves only one variable left to solve for: R_{const}. You can plug in all your numbers and solve the equation for the unknown variable. Figure 7 uses the theoretical equations of heat transfer to develop a fast and easy way to roughly estimate the R-Values for all construction within the given parameters.

Calculating R- Values

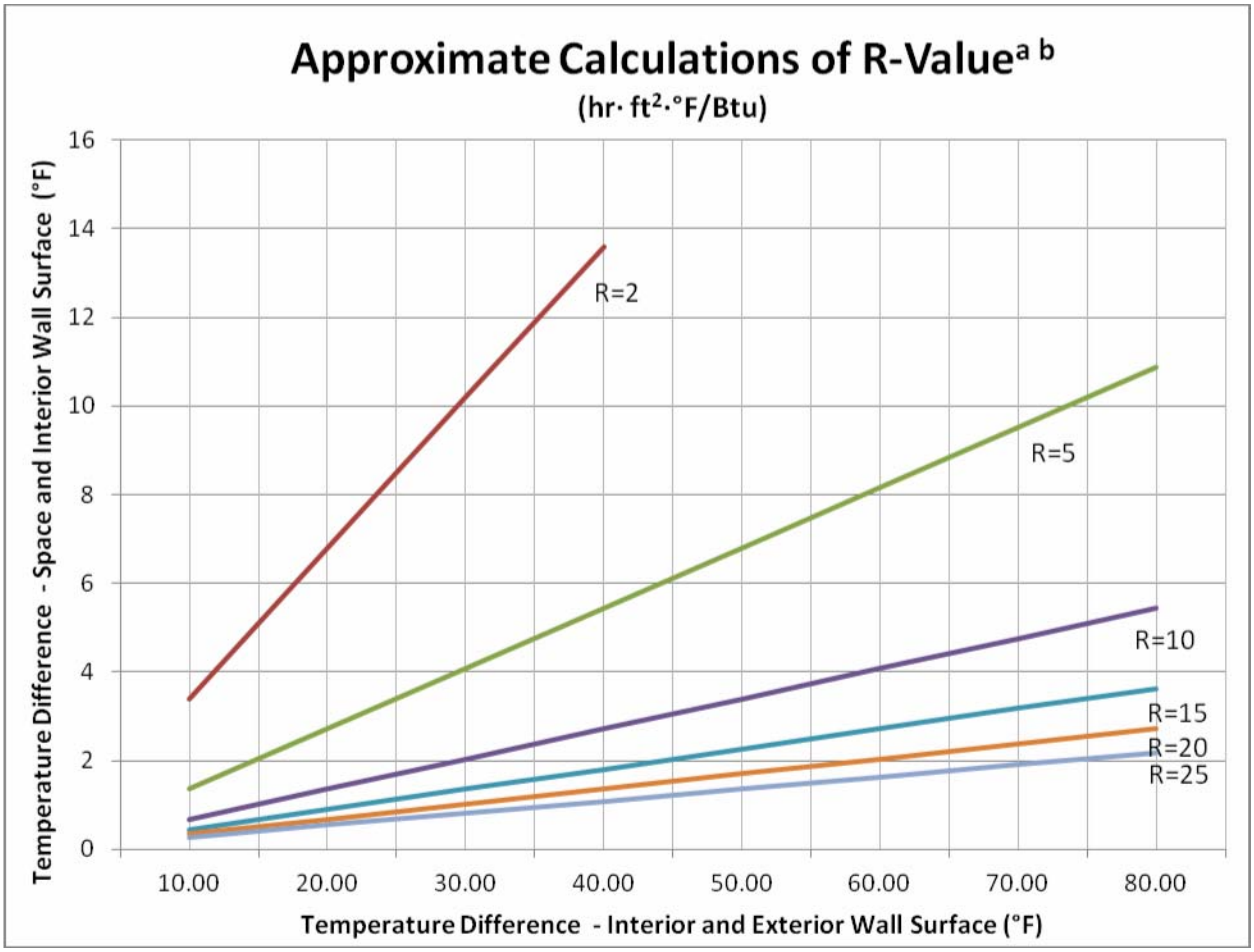


Fig. 7 – Theoretical R-Values of Walls based upon Temperature Gradients

<u>Note</u>:

a. Air film R-Value between interior wall surface and ambient air is assumed to be 0.68.

b. This calculation is based upon assumption of steady heat conduction in plane walls.

Envelope Investment Tip: As you can see from the graphic above, as thermal resistance increases, the lines begin to converge. With every increase in R-Value, there will be a smaller effect than the previous increase on energy savings. This is important to understand when investing in an envelope upgrade. Often, project costs will increase faster with the R-Value than savings, or in other words, returns on investment will begin to reduce at a certain point when comparing different envelope upgrades.

After analyzing the different thermal resistances within a construction, R_{eff} and U-Value calculations must be made to discover the true nature of the wall.

To evaluate the best financial impact for several ERM's it is very effective to use IRR (Internal Rate of Return) for the different envelope upgrades, high performance lighting, HVAC upgrades, energy recovery, and other possible ERM's. Different wall thicknesses of resulting R-Values can be compared as different ERM's and a combination or optimized final list of ERM's can be found. With computer analysis and careful energy engineering, you can model and optimize balance between HVAC equipment efficiency and higher thermal envelope R-Values. Refer to ASHRAE 2011 Handbook, under Owning & Operating, Chapter 37 – Financial Calculations & IRR.