CORBOND®

# Air Barrier Systems for Buildings Utilizing Spray-In Place Closed Cell Polyurethane Foam

Neal E. Ganser
Corbond Corporation

As Presented To:

Air Barriers Solutions for Buildings in North American Climates
A BETEC Symposium

June 5, 2001
Washington D.C.

Walls That Work

No Matter What

# CORBOND®

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**Don't Just Insulate... ISOLATE!**


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No Matter What

## Executive Summary

Neal E Ganser, Corbond Corporation, BETEC Air Barriers III,
Washington DC  June 5, 2001

The effort to control the building envelope and to manage its' interior climate for comfort and efficiency has gone through years of mutations as various climatic effects were dealt with using a variety of products and schemes. Today the concept of exterior air barriers is being experimented with and even being adopted by code agencies as the latest answer in this challenge. As we do these experiments on real buildings we can measure the energy efficiency change almost immediately. Unfortunately we cannot measure the building longevity and human health impacts until years later. Some climates do help us along however. In Wisconsin, air/moisture retarders were placed on both sides of glass fiber insulation in walls, a situation known as Tri-State Homes. The houses rotted - fast. Recent reports from Seattle and Vancouver report more moisture problems than ever in new construction since the 1984 energy code was passed, while most older buildings somehow escape moisture damage.

We continually believe that we can correct a given problem without considering secondary effects which may flow from that correction. I have identified six mechanisms of heat loss or gain that must be considered all at once with each material change in building practice. They are Conduction, Radiant, Air Convection, Air Infiltration, Air Intrusion, and Moisture Movement and Accumulation. These are recognizable by their various marketing remedies: R-value, radiant barriers and window coverings, air/vapor retarders, house wrap (air barrier), venting, drainage plane, etc. All of this and all the other variations is attempting to effectively separate two antagonistic climates yet may have contradictory purposes such as venting vs R-value.

The problem has been solved for years in the agricultural, refrigeration and roofing industries using spray-in-place and pour-in-place polyurethane foams and polyiso board. It is likely that the potato, carrot or apple you eat in the wintertime has been stored in polyurethane spray foamed storages. These are so well air barriered by the closed cell spray foam that in the case of apples, the air is replaced with nitrogen. Refrigerator manufacturers moved from glass fiber to closed cell polyurethane pour foams in the 1960s. Then consider roofs. The differences between an unvented commercial flat roof – and a residential cathedral roof are two: 1) one is flat and the other sloped, and 2) the one is commonly insulated with closed cell polyiso or spray polyurethane and the other typically insulated with glass fiber. The first has successfully isolated the climates apart in all of the six mechanisms through the roof systems entire thickness, a condition I call "climate isolation" when used in the context of our installed Corbond system. The glass fiber system has failed to isolate the climates apart in all of the six mechanisms excepting conductive losses to varying degrees, depending on moisture load and air movement.

There are other differences that follow on the insulating system choice in the cathedral roof. The air/moisture retarder behind the interior wallboard is the dividing line between interior and exterior and divides the climates by just 6 mils. This becomes the condensation plane in the air conditioning season. We intentionally breach the air barrier created by the roofing venting to carry off moisture but regrettably this becomes the conduit for moisture in summer. Slope, rafter length, heat loss, ambient temperatures, dew point, sunshine and snow cover affect roof system performance in infinite variations. We put fiber in cathedral roofs and attics and vent like crazy. We put fiber in walls and are now promoting sealing them up. Is a wall so different than a cathedral roof? Would anyone promote air barriers for stopping up soffit and roof vents and claim there would be no negative consequences? There would be severe negative consequences in winter and positive consequences in summer. This raises an important question. Which do we build for in what climate zones?

The Climate Isolation System is Thermal Control (R-Value), Air Control, Moisture Control and Reversibility all-in-one. An air barrier system that performs all four of these functions will work. An air barrier that does not perform all four functions will work to control air, but cause building damage and health problems resulting from moisture accumulation or entrapment. Seasonal climate change and the advent of air conditioning require that the system be viable in both directions. A system with a 'breather' on one side doesn't qualify because of seasonal vapor drive reversals. A system with a vapor retarder on either side does not qualify for the same reason. A system with air in its' insulated core doesn't qualify because where there is air there is moisture which will move to the dew point. To control all the six mechanisms all the time, the system must do all four – thermal, air and moisture control, in both directions – all the way through – displacing air and moisture while developing significant R-Value.

The necessity for an air barrier cannot be overemphasized. However, unless thermal, air and moisture isolation, as well as reversibility are integrated within and throughout the air barrier, failure of one nature or another will occur in time. Spray-in-place, closed cell polyurethane answers all these criteria in all types of buildings in every climate in North America. The indoor climate is controllable mechanically without a negative impact on the building envelope. The insignificant costs of this high efficiency product are more than offset by construction simplicity, high R-value in very thin spaces which eliminates oversized framing and venting, human comfort and health, building longevity without continuous reconstruction, and of course, super energy efficiency.

Neal Ganser, CORBOND Corporation - Bozeman, MT

# Air Barrier Systems for Buildings Utilizing Spray-In-Place Closed Cell Polyurethane Foam


Considering the natural interactive impacts of antagonistic climates (interior/exterior) on any building envelope seems to be adequate when designing or selecting an air barrier. It is my experience, however, that we must also consider the climate **within** the wall or roof as we consider an insulation/air barrier system.

**Six Mechanisms of Heat Loss and Gain**

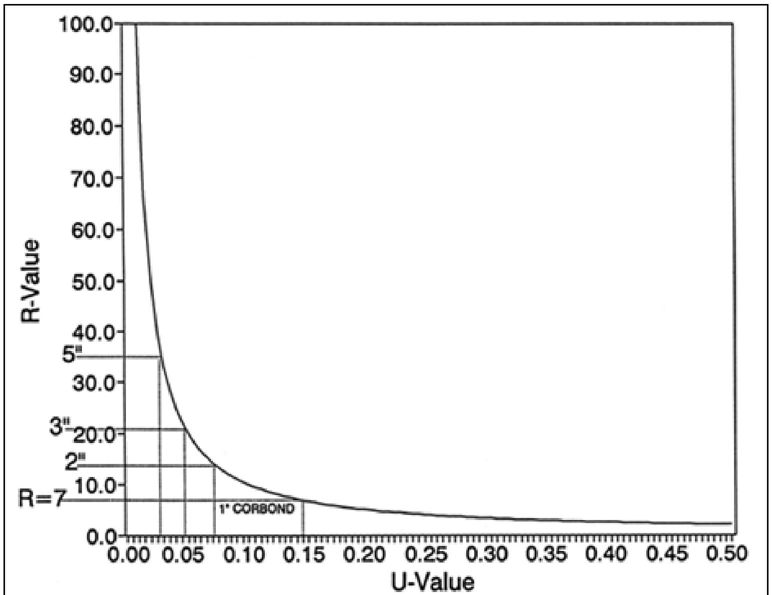
I have identified six interactive and dynamic climate impacts and called them the "Six Mechanisms of Heat Loss and Gain" in a building. These concepts are not new. They are however, seldom considered all at once, although they occur all at once.

- Conduction
- Radiant Heat Loss/Gain
- Air Convection
- Air Infiltration/Exfiltration
- Air Intrusion
- Moisture Movement and Accumulation

**Conduction**

Conduction is reported in R = I/ U. R reported this way has to do only with the Conductive Mechanism, yet is today the definitive design factor for insulation in the marketplace.

Graphing the R/U relationship from 0-100R reveals the classic diminishing returns of ever higher R-Values; that is if there are no other impacts on R-Value performance.



The R/U Relationship

Corbond Corporation has developed an alternative method of reporting the effectiveness of insulation, which is *Efficiency* (similar to furnaces and boilers). Beginning with heat flow through bare plywood - 0% efficient – and adding thickness. Therefore, % Efficiency = 1 – (End heat flow/ Beginning heat flow)

| CORBOND® 68°F/18°F 50°F ΔTemp | Btu/Hour 24.5 sq. Ft. test area | % Efficiency (Reduction in Heat Loss) |
|---|---|---|
| 0" (plywood only) | 558 | 0 |
| 1" (2.54 cm) | 156 | 72% |
| 1 1/2" (3.80 cm) | 104* | 81% |
| 2" (5.08 cm) | 79* | 86% |
| 2 1/2" (6.35 cm) | 65* | 88% |
| 3" (7.62 cm) | 59 | 90% |
| 4" (10.16 cm) | 48* | 92% |
| 5" (12.70 cm) | 38 | 93% |
| 6" (15.24 cm) | 33* | 94% |
| 7" (17.78 cm) | 30 | 95% |

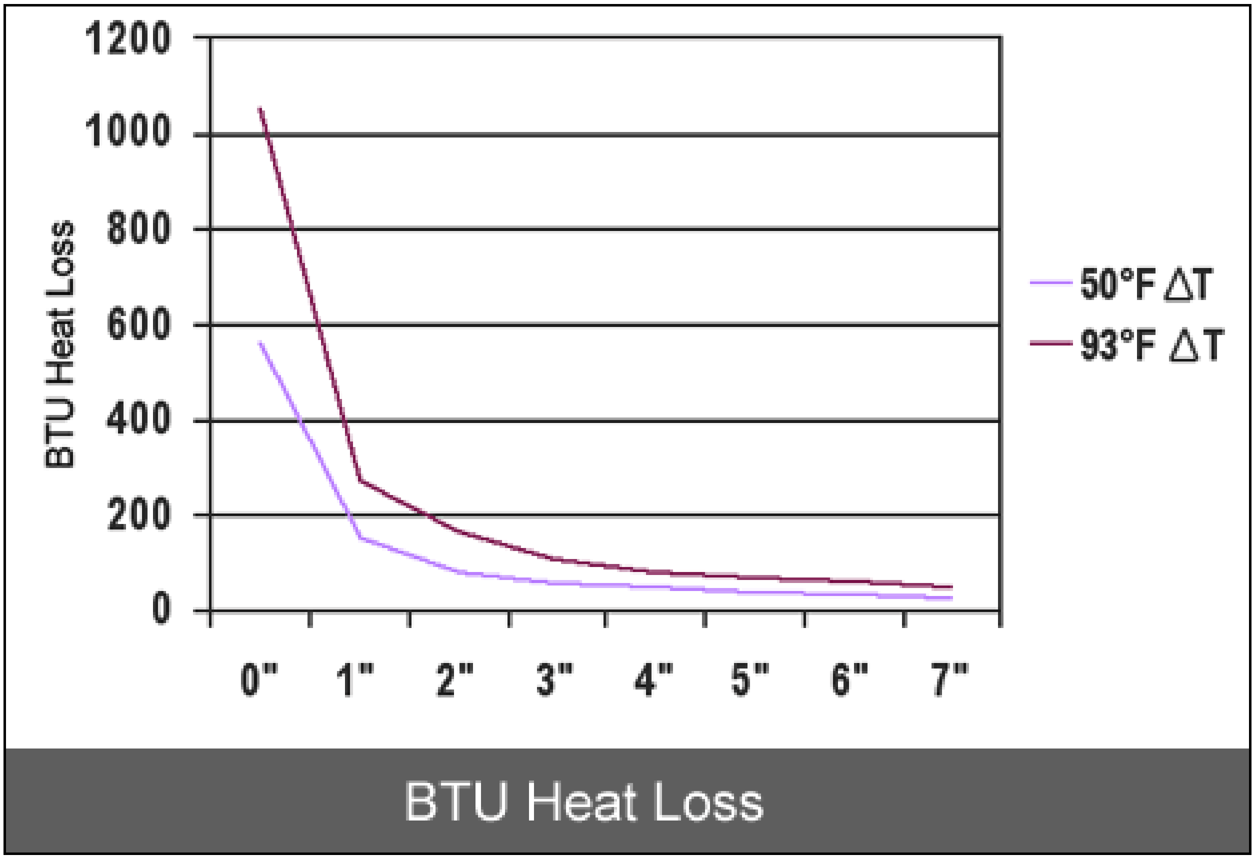
**Efficiency testing with a 50° F difference in temperature**

| CORBOND® 68°F/-25°F 93°F ΔTemp | Btu/Hour 24.5 sq. Ft. test area | % Efficiency (Reduction in Heat Loss) |
|---|---|---|
| 0" (plywood only) | 1050 | 0 |
| 1" (2.54 cm) | 277 | 74% |
| 1 1/2" (3.80 cm) | 202* | 81% |
| 2" (5.08 cm) | 165* | 84% |
| 2 1/2" (6.35 cm) | 135* | 87% |
| 3" (7.62 cm) | 109 | 90% |
| 4" (10.16 cm) | 78* | 92.6% |
| 5" (12.70 cm) | 69 | 93.4% |
| 6" (15.24 cm) | 60* | 94.3% |
| 7" (17.78 cm) | 53 | 95% |

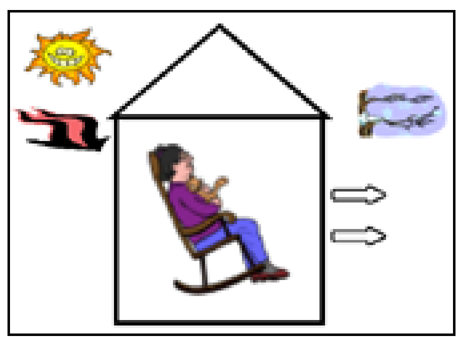
**Efficiency testing with a 93° F difference in temperature**

This is not a closed cavity test but simply an application of a given thickness of our insulation product to plywood without additional air barriers.

Graphing product efficiency illustrates the diminishing value of greater thickness & R-value. You will note that optimum efficiencies of the spray in place polyurethane can be achieved with a very small thickness.



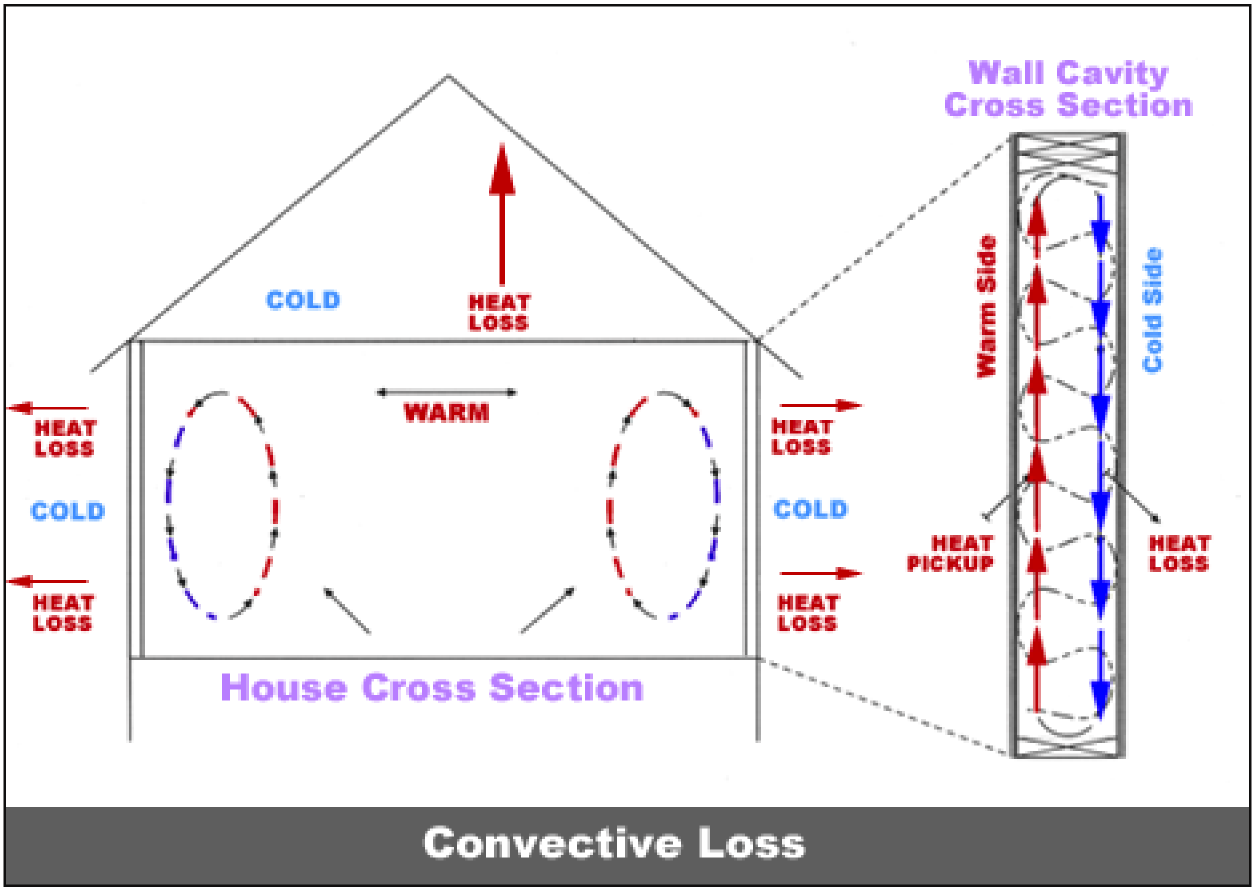

**Radiant**



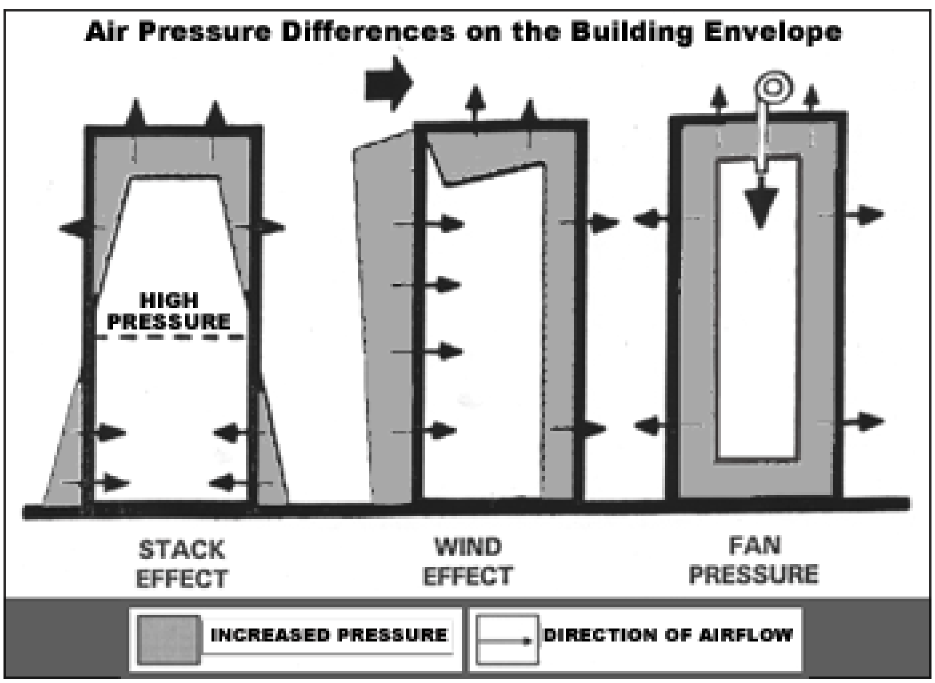
The Radiant Mechanism has a large impact on comfort in both hot and cold climates. It is difficult to measure but common belief is that any radiant energy impact on a persons skin outside their comfort zone causes them to change a thermostat setting despite the surrounding ambient air temperature or how tightly the building envelope may be air-sealed. Radiant heat from the sun turns to the conductive mechanism when it strikes the surface of a building, is conducted through that material – fast or slowly depending on the materials conductivity – and reradiated to the next cavity in the construction.

**Convection**

Convective loops – like radiant, effects comfort because of "drafts" which prompt changes in thermostat setting despite ambient indoor air temperatures. These "drafts" tend to make the




feet feel cool. This violates a pricipal of comfort in a heated environment which is to keep the feet warm and the face cool. Convection within insulated building cavities reduces R-Value, which can be called "Thermal Drift", and moves moisture to the dew point.



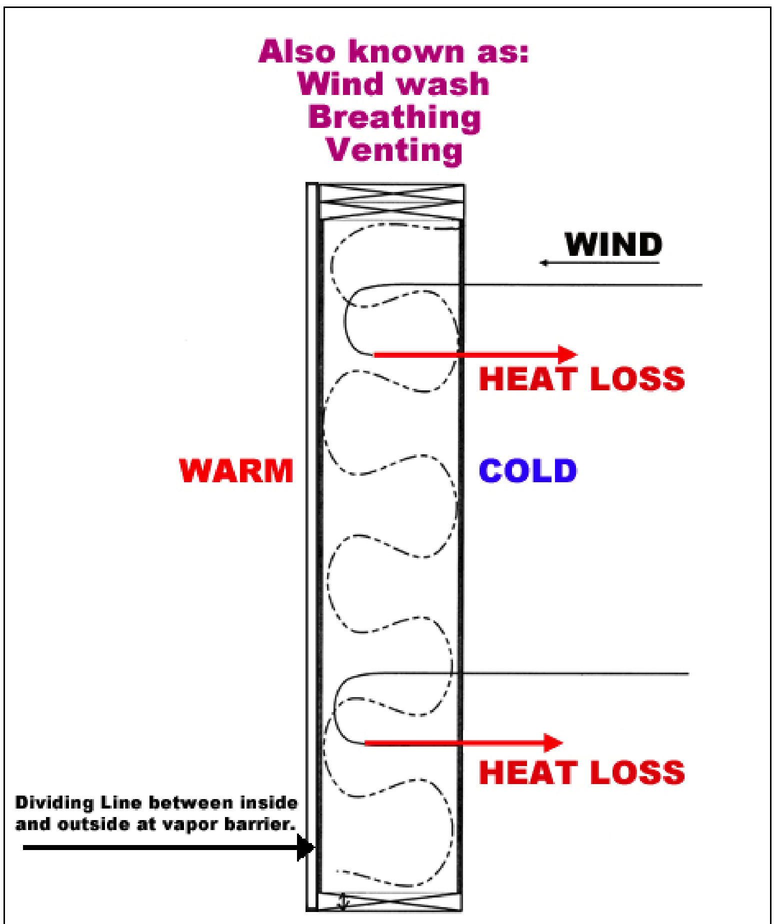

**Air Infiltration/ Exfiltration**

The largest of the three air infiltration/ exfiltration impacts is stack effect – and the taller the building the more severe they can be. All three cause "thermal drift" which is deterioration of R-Value efficiency of conventional insulations. These air movements also move moisture to the dew point or conversely can promote drying within building cavities. This Air Barriers Symposium addresses only this mechanism, an illustration that we tend to approach our problem one mechanism at a time rather than comprehensively. For instance "wind driven rain" – are we getting water intrusion into the building cavity because of positive pressure against the siding or because the negative pressure (x4) on the inside of the wall is pulling it through. An effective exterior air barrier may then manage this better than a drainage plain but would create a vapor trap in a fiber insulated wall. We could try to dry the wall cavity to the interior in which case no interior vapor barrier should be used. In that case are we adequately venting to the interior? What is really needed to begin with is the management of pressure effects through the core of the insulated cavity and over the entire building envelope. In the heating season, infiltrating cold air and air cooling at a cold building envelope surface and convecting downward are the cause of air temperature stratification. Again, the resulting cold feet violates the comfort principal and the thermostat setting goes up. In leaky multi-story buildings, the first story occupant is never warm and the upper story occupant has to open windows or run the air conditioner.

**Air Intrusion**

Air Intrusion is often called:

- Wind Wash
- Breathing
- Venting

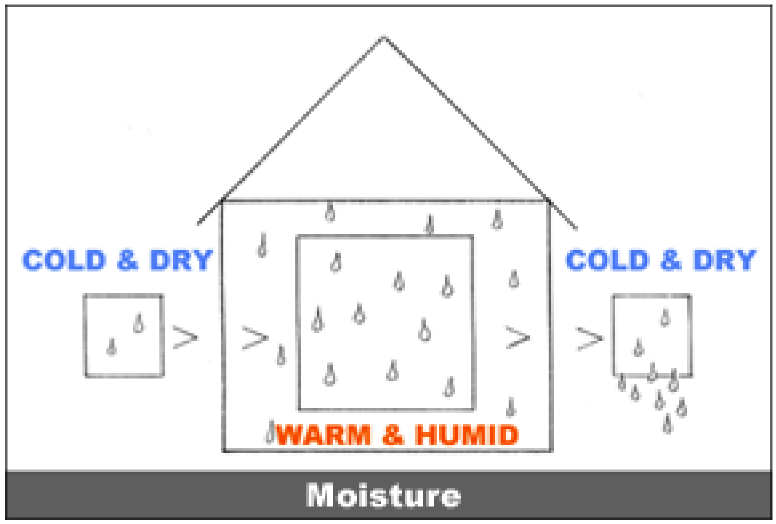



Air Intrusion

Since the advent of air/vapor barrier use on the warm side in winter, the dividing line between inside and out has been just behind the building interior finish. Building efficiency has been measured at this point using a blower door – leaving all the R-Value, moisture accumulation, air intrusion and drying on the outside at the whims of nature. We like this in insulated cathedral roofs and call it venting. We try to stop it in walls and call it Air Barriers. We now propose adding an air barrier to the exterior or moving it to the exterior. If we do either without dealing with our concept of insulation within we will create vapor traps and building problems in all climates unprecedented in U.S. building history. Randy Voss, a Wisconsin building inspector states in April 2001, Energy Design Update, that: *"In this climate we are seeing serious moisture and rot problems inside 2 x 6 walls, because we have basically moved the dew point right inside the cavity. The lawsuits are already starting to make news, and I think it's going to be 10 or 15 years before we can reeducate builders, solve existing or developing moisture problems, and put this bad chapter behind us."*

**Moisture Movement & Accumulation**

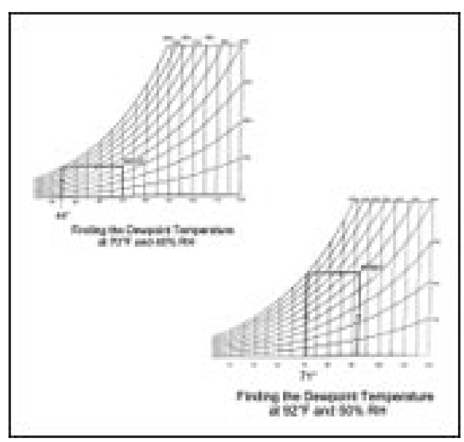
In addition to moisture diffusion we must consider air transport of moisture, the dew point, frost, water and evaporation, heating and air conditioning vapor drive reversals, air infiltration/exfiltration vapor drive reversals and moisture related "bugs mold and rot".




A simple illustration of how 'breathing' or venting moves moisture. Heat recovery ventilators are designed to do this mechanically in a 'tight' house. Unfortunately they do not condition the air within the insulation blanket because the dividing line of interior and exterior is behind the sheet rock at the vapor barrier. This could change if we adopt exterior air barriers and abandon the traditional interior vapor barriers. Of course we would then need to vent each cavity to the interior to dry them in summer. We now vent our cathedral roofs (*and walls if we're smart*) to the exterior in winter. Of course, this is all backwards in summer. We can dream about putting super air/vapor barriers on both sides and claim the moisture just won't get in – but a simple change in building cavity temperature or barometric pressure forces a pumping action of the air in each cavity that looks a lot like the illustration above.

**Dew Point (DP) Temperature differs with Temperature and Relative Humidity (RH):**

•At 70° F & 40% RH, DP occurs @ 44 degrees F
•At 92° F & 50% RH, DP occurs @ 71 degrees F
•At 95° F & 95% RH, DP occurs @ 88 degrees F



*Note: For full size graphs, see Appendix*

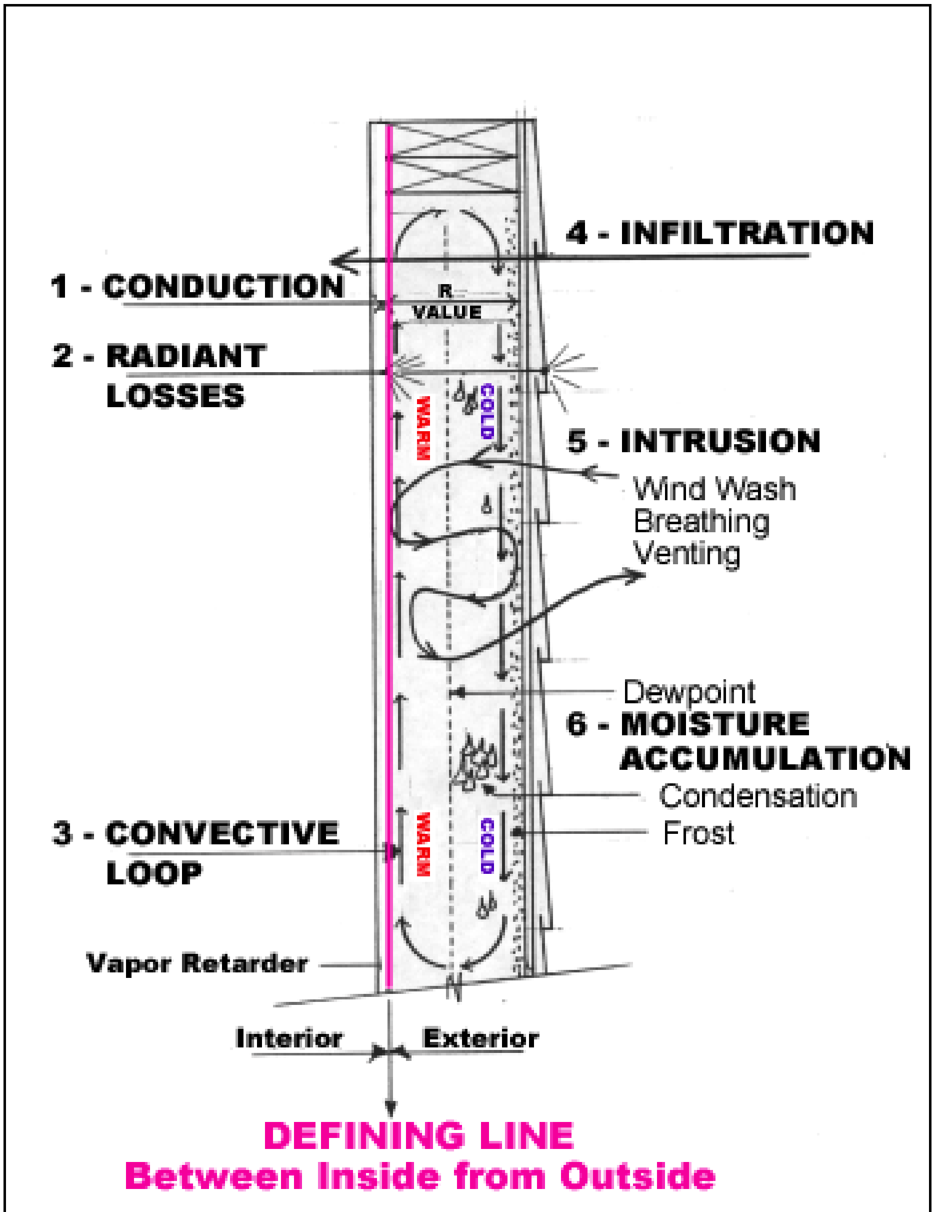
This illustrates that any surface in the insulated cavity that is below these temperatures during any season is subject to wetting of surfaces and the insulation. The more R-Value in fiber you put in the cavity the more severe the condition because the temperature difference in the cavity goes up and the cold side surface is closer to ambient cold – whether exterior in winter or interior in the air conditioning season.

**The Six Mechanisms Taken Together**

Controlling each mechanism individually is confused and produces contradictory results. In the air conditioning season results are reversed; for example, air intrusion, which dries fiber and sheathing in the winter and wets fiber and sheetrock in the summer. Which season and in which climate or which mechanisms do we build for, and which do we ignore?

How is the insulated cathedral roof different from an insulated wall? The difference between a cathedral roof and a wall is that one slants and the other is vertical. Adding snow to the roof, all the antagonistic climate impacts are the same.

This common construction contradicts the current theory that sheet air barriers – interior or exterior or both – will solve more problems than they'll cause. Considering the roofing and its' underlayment as a reasonably good air

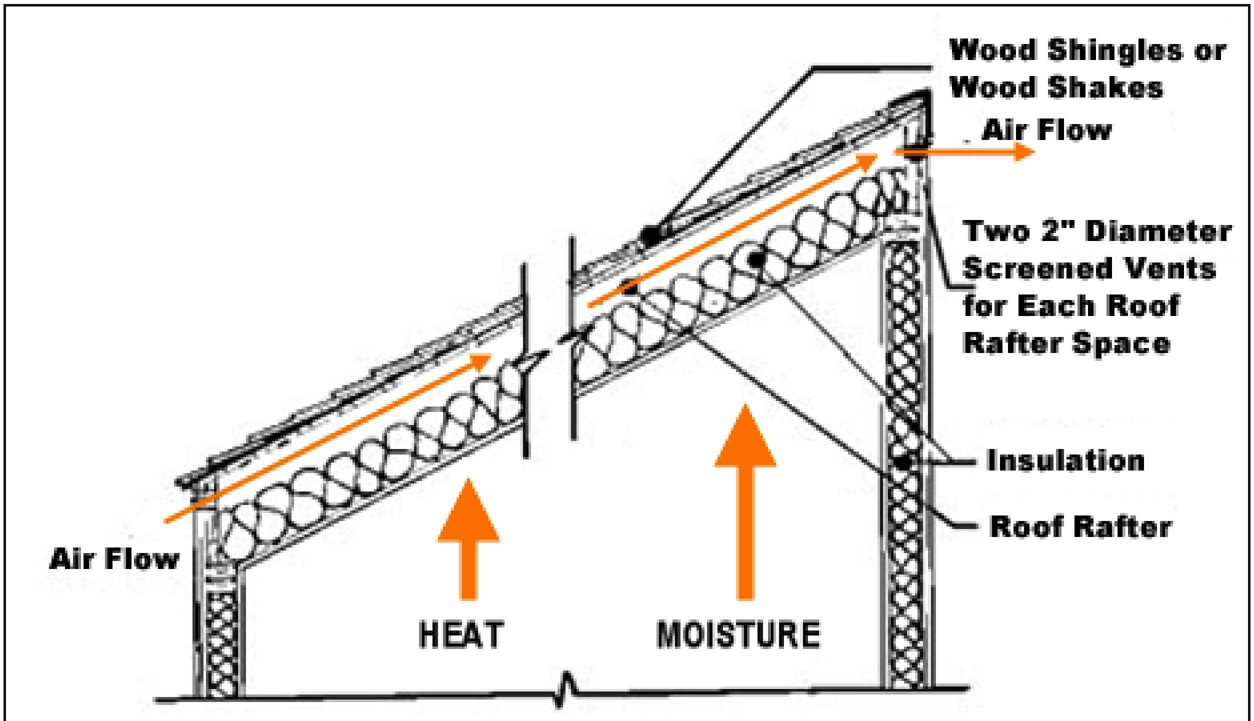


Six Mechanisms of Heat Loss (or Gain)

barrier, we had to bypass this in order to dry the cavity to keep the whole ceiling and insulation from falling on our heads.   A two-dimensional air barrier such as house wrap on the wall is equivalent to the stopping up of the vents of a cathedral construction.

In the roof situation we put holes top and bottom and 'vent'.  The reasons we vent are to carry off interior moisture that has entered the fiber filled cavity and to dry condensation from the underside of roof sheathing.  This attempts to prevent mold growth, sheathing deterioration and to minimize moisture related sheathing movement that can cause premature failure of roofing materials.

Successful venting requires:
• Continuous and complete air flow across the underside of roof deck.
• Heat loss sufficient to continuously heat venting air to increase its moisture carrying

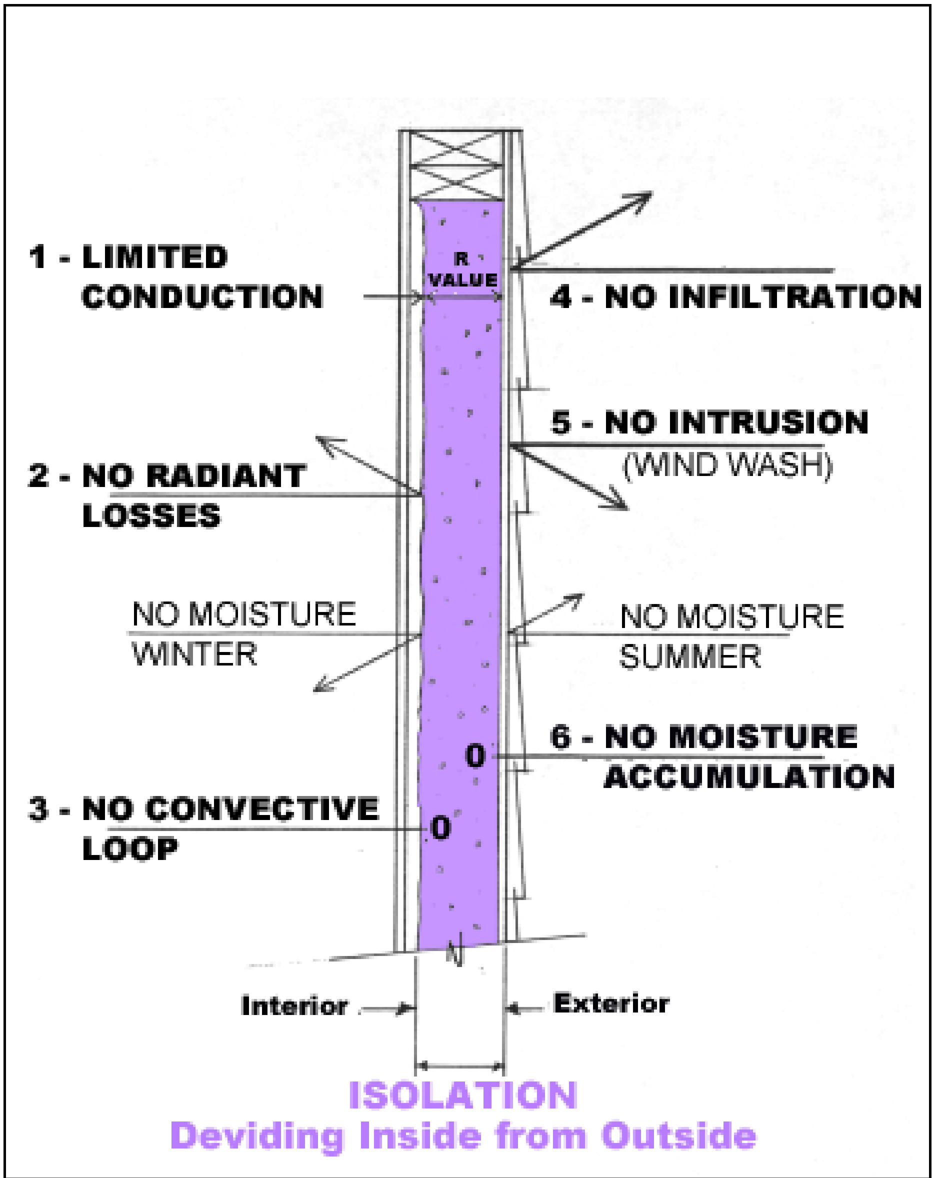


Cathedral Roof - Source: NRCA Manual

capacity as it rises through the cavity.  The higher the R-Value the less effective the venting.
• Calculating accurately the above in conjunction with maximum rafter length, roof pitch and configuration, orientation, prevailing winds and snow depths.  No one has yet mastered this complex equation on a universal basis. Like the cathefral roof without venting, and the two dimensional air barriers may solve an energy problem to cause building and health problems.

Spray in place closed cell polyurethane solves this by functioning in multiple dimensions. By its nature it is impervious to air going through it, being fully adhered air can't go around it, by having thickness it develops high R-Value in 1/2 the space of the next best thing and being closed cell, low permeance it controls moisture in all directions. The complex thermal, air, and moisture control equation is simplified to a single product that is multifunctional. At Corbond Corporation we call this multi-functionality "**Climate Isolation®**", which requires four characteristics:

- **Thermal Isolation** – satisfying the insulating function.
- **Air Isolation** – satisfying the interior and exterior Air Barrier function.
- **Moisture Isolation** – satisfying the moisture retarder function and elimination of the dew point in the construction.
- **Reversibility** – satisfying the above functions in any direction, any season, any climate.




Six Mechanisms Under Control
"Climate Isolation"

Climate Isolation at work in relation to the six mechanisms of heat loss and gain. The product must be closed cell – *low permeance* – and fully adhered so the hostile climates neither go through or around it from either direction. The two environments (indoor & outdoor) are not allowed to interact. They are isolated from one another.

No third “mixed climate” exists in the building cavity.

Spray-in-place, closed cell polyurethane – CORBOND – perfectly fulfills the requisite characteristics of Thermal, Air and Moisture Isolation with Reversibility. The illustration shows how this separation of environments is achieved. The dividing line between inside and outside is now three dimensional and includes the entire thickness of the CORBOND insulation and attached sheathing.

The concept of unvented, closed cell foam, full air barrier systems is not new. We have built them for years in commercial flat roofs using combinations of foam boards and roof membranes or with spray in place closed cell polyurethane foam and coatings. There are no fasteners in a fully adheared, seamless spray-applied roofing system.

The concept behind Climate Isolation has been proven for decades in both roofs and walls. There really is little difference when they are properly understood.

This is not new information – the refrigerator industry has used closed cell polyurethane for 40 years – commercial coolers and freezers from behind the local hamburger stand to giant cold storage have used closed cell polyurethane Structural Insulated Panels (SIP’s) and spray in place for that long as well.

Agriculture has used spray in place closed cell polyurethane for 35 years for potatoes, apples, carrots, and other consumables. All of these have the goal of no air leakage, thermal and moisture control. All of these are ‘controlled atmosphere storages’ that cannot afford food contamination from bugs mold or rot or short-term building or performance failure. We have finally gotten to the point of understanding that <u>all</u> buildings are ‘controlled atmosphere’. We cannot afford contamination of people’s lives from the same sources and we require sustainable construction. A spray in place climate isolating air barrier system makes it possible in any construction.

**Conclusion**

If an Air Barrier System does not meet the definition of climate isolation the construction will – sooner or later – develop problems.

If a vapor retarder system doesn’t meet the definition of climate isolation, the construction will eventually develop problems.

If an insulation system in a closed cavity doesn’t meet the definition of insulation – that is to isolate – the construction will eventually develop problems.

Attempting to develop three different systems for heating/mixed/and air conditioned climates is trouble already because since nearly all structures in the U.S. and southern Canada are both heated and air conditioned, they are all "mixed climates" with multi directional thermal, air and moisture drives.

Closed cell, spray in place polyurethane as an exterior or interior air barrier does all three – in all the climates – in any direction.

This system **works**, in any construction, no matter what.

**Don't Just Insulate... ISOLATE!**

Image courtesy of Lei Meng [meng@physics.montana.edu]

The following photographs are examples of closed cell spray-in-place polyurethane used as an insulating Air Barrier system – uncomplicated by recipes made up of a myriad of products with contradictory design purposes and results.

**Rim Joists – above foundations and between floors are vapor retarded, insulated and air barriered with complete moisture control in a single application of the closed cell spray polyurethane.**

**A wall ready for interior finish – no thin air/vapor retarder to sustain damage or be poorly installed.**

**Spray in place polyurethane naturally adapts to any shape – no cutting or fitting or seams to be compromised.**

**Spray foam adheres tenaciously to all construction surfaces including all board insulations.  This develops high R-Value air barriered walls at minimum wall thickness and insulates framing.  An excellent approach in Steel Stud Constructions.**

**Friday Harbor, San Juan Islands**
**Exterior applied at cathedral roof over tongue and groove deck.**

**Boulder School, Boulder Montana**
**54,000 sq. feet of unvented cathedral roof installed in rafter lengths up to 48 ft. Application direct to underside of cathedral roof deck.**

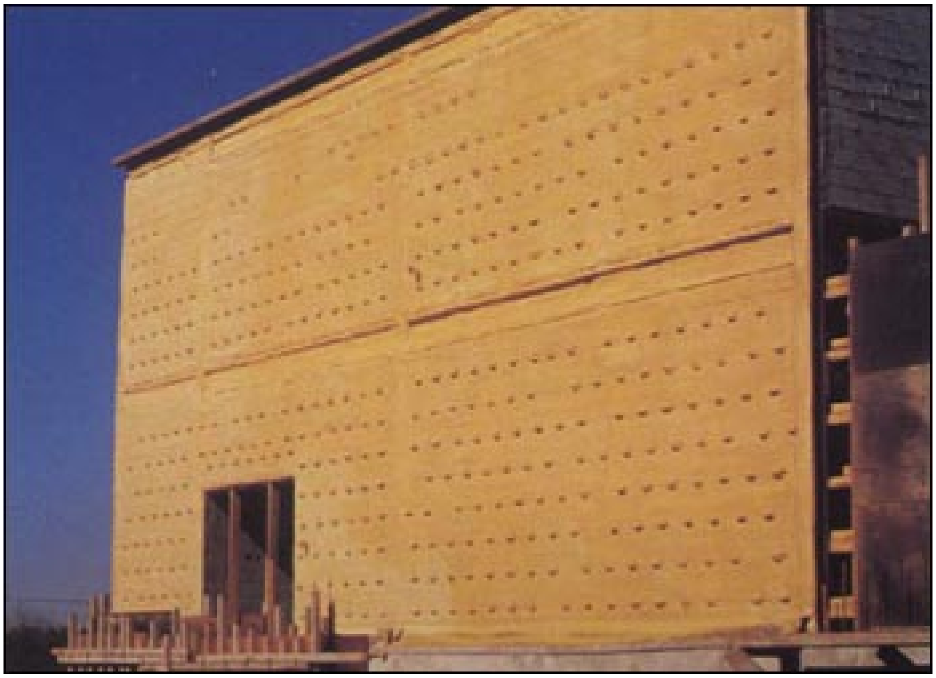
**Closed cell spray polyurethane as air/moisture barrier, thermal insulation and stucco base over adobe.**

**Timber frame application before siding.**

**Residential/Commercial/Institutional swimming pool enclosure system where climate isolation requires no compromise.**

**Commercial roof and wall – complete indoor climate control.**

**Details that are difficult with sheets and caulks are little challenge for Spray Foam.**



**Courtesy: CHEM-THANE, Concord Ontario, CA**
**Application to cement block with masonry ties protruding to accept brick veneer. This constitutes the entire thermal, air and moisture barrier system in both directions.**

**Courtesy: CHEM-THANE, Concord Ontario, CA**
**Ease of sustaining air-barrier continuity in complex situations.**

**Tahama Golf Club,  Monterey, CA**
**Application over concrete parking garage.**

**Harvard Law School Library Reconstruction**
**Application up to cast in place concrete roof deck.**

**Monona Terrace Convention Center – Madison, WI**
**Complex pre cast arch shapes require thoughtful attention to thermal, air and moisture impacts.**

**Monona Terrace Convention Center, Madison WI.**
**Complex arch shapes using CORBOND and Thermal Barrier.**

**Junior High Gymnasium Bozeman, MT**
**Accoustical thermal barrier finish applied direct to spray foam under roof deck.**

**RSI 4-01**
**The concept of unvented, closed cell foam, full air barrier systems is not new. We have built them for years in commercial flat roofs using combinations of foam boards and roof membranes or…**

**IBM – Courtesy SPFA**
**…with spray in place closed cell polyurethane foam and coatings.**


**This is not new information – the refrigerator industry has used closed cell polyurethane for 40 years – commercial coolers and freezers from behind the local hamburger stand to…**


**…giant cold storage have used closed cell polyurethane SIP's and spray in place for that long as well.**

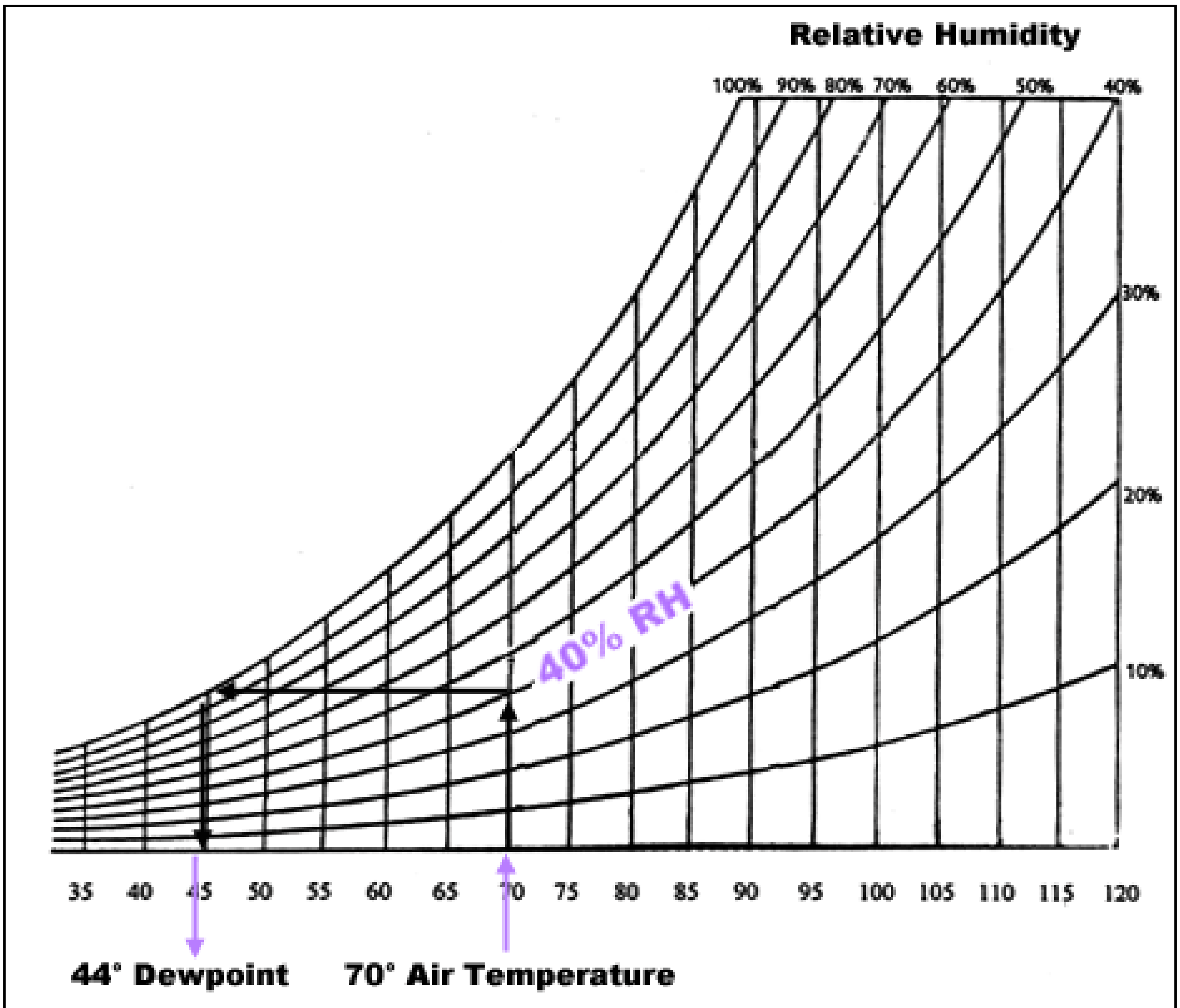
**Potato Storage**

**Agriculture has used spray in place closed cell polyurethane for 35 years for potatoes, apples, carrots, and other consumables. All of these have the goal of no air leakage, thermal and moisture control. All of these are 'controlled atmosphere storages' that cannot afford food contamination from bugs mold or rot or short-term building or performance failure. We have finally gotten to the point of understanding that <u>all</u> buildings are 'controlled atmosphere'. We cannot afford contamination of people's lives from the same sources and we require sustainable construction. A spray in place climate isolating air barrier system makes it possible in any construction.**

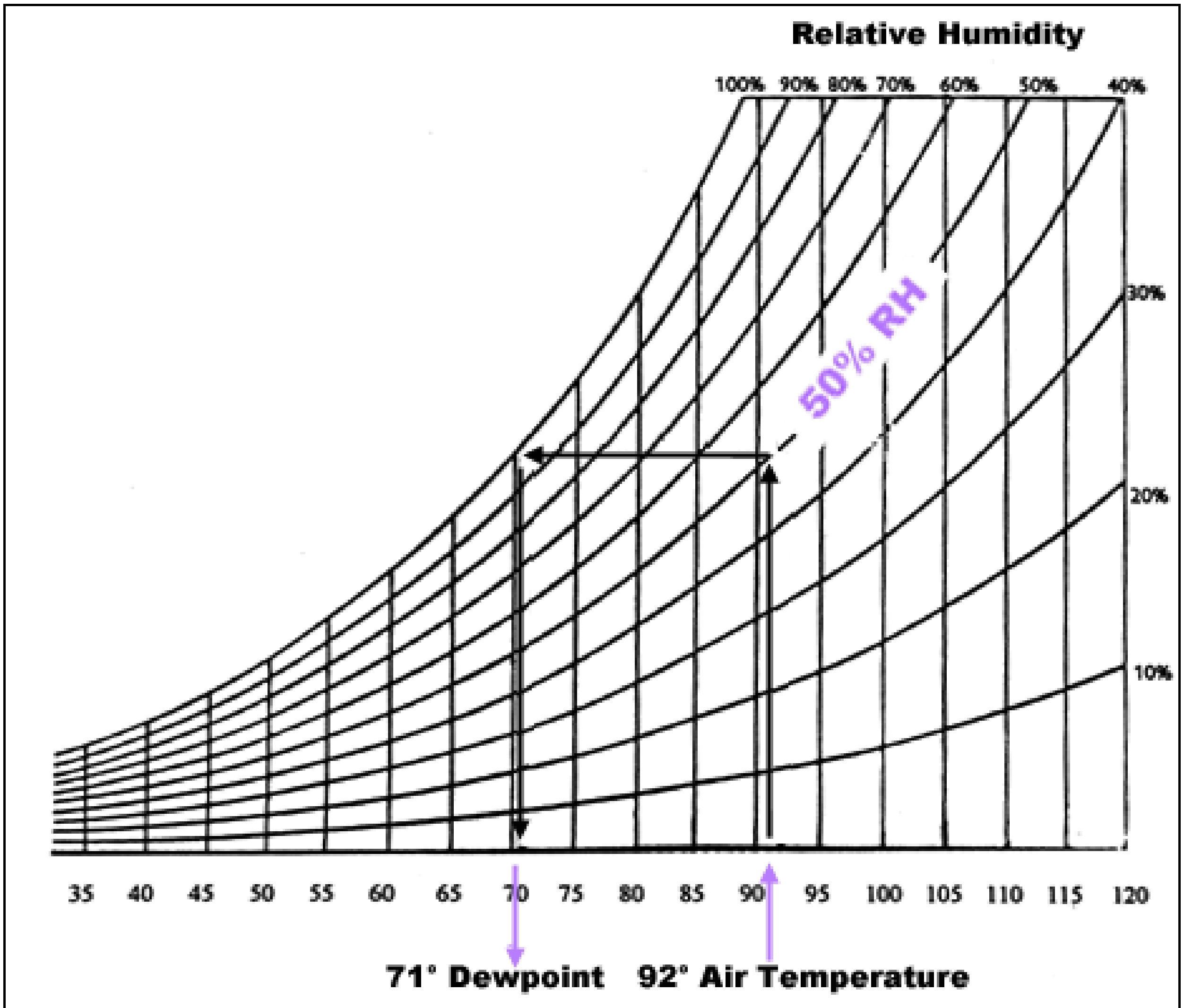
Walls That Work

No Matter What

## APPENDIX




**Finding the Dewpoint Temperature of Air at 70°F & 40% Relative Humidity**




**Finding the Dewpoint Temperature of Air at 92°F & 50% Relative Humidity**

## GLOSSARY

**Absolute humidity**
(1) The ratio of the mass of water vapor to the volume occupied by a mixture of water vapor and dry air. (2) Mass of water contained in a unit volume of moist air.

**Advection**
The horizontal transfer of air mass properties by the velocity field of the atmosphere.

**Atmospheric pressure**
Pressure (force per unit area) exerted by the atmosphere on any surface by virtue of its weight; it is equivalent to the weight of a vertical column of air extending above a surface of unit area to the outer limit of the atmosphere.

**Condensation**
The physical process by which a vapor becomes a liquid or solid; the opposite to evaporation. In meteorological usage, this term is applied only to transformation from vapor to liquid; any process in which a solid forms directly from its vapor is termed sublimation, as is the reverse process.

**Convection**
Atmospheric motions that are predominantly vertical, resulting in vertical transport and mixing of atmospheric properties; distinguished from advection.

**Dew point**
(dew-point temperature) The temperature to which a given parcel of air must be cooled at constant pressure and constant water-vapor content in order for saturation to occur. When this temperature is below 0 °C, it is called the frost point

**Evaporation**
The physical process by which a liquid or solid substance is transformed to the gaseous state; the opposite of condensation. In meteorology, evaporation usually is restricted in use to the change of water from liquid to gas, while sublimation is used to the change from solid to gas as well as from gas to solid.

**Frost point**
The highest temperature at which atmospheric moisture will sublimate in the form of hoar-frost on a cooled surface. It is analogous to the dew point.

**Heat balance**
Equilibrium between the gain and loss of heat at a specific place or for a specific system.

**Heat budget**
Relation between fluxes of heat into and out of a given region or body and the heat stored by the system. In general, this budget includes advective, evaporative, and other terms as well as a radiation term.

**Humidity**
1) Water vapor content of the air. 2) Some measure of the water-content of air. See absolute h., relative h., specific h., dew point.

**Isotherm**
A line of equal or constant temperature.

**Radiation**
1) Emission or transfer of energy in the form of electromagnetic waves. 2) The process by which electromagnetic radiation is propagated through free space by virtue of joint undulatory variations in the electric and magnetic fields in space. This concept is to be distinguished from conduction and convection.

**Relative humidity**
The (dimensionless) ratio of the actual vapor pressure of the air to the saturation vapor pressure. The relative humidity is usually expressed in per cent, and can be computed from psychrometric data. See humidity.

**Saturation**
The condition in which the partial pressure of any fluid constituent (water in the atmospheric air) is equal to its maximum possible partial pressure under the existing environmental conditions, such that any increase in the amount of that constituent will initiate within it a change to a more condensed state. Evaporation ceases under such conditions.

**Sensible heat**
Same as enthalpy; the heat absorbed or transmitted by a substance during a change of temperature which is not accompanied by a change of state. Used in meteorology in contrast to latent heat.

**Specific humidity**
The mass of water vapor per unit mass of air, including the water vapor (usually expressed as grams of water vapor per kilogram of air).

**Stable air mass**
Air mass having static stability in its lower layers; it is free from convection, has a low degree

of turbulence and may have stratiform clouds or fog, or no clouds.

**Sublimation**
The transition of a substance from the solid phase directly to the vapor phase, or vice versa, without passing through an intermediate liquid phase.

**Temperature**
A physical quantity characterizing the mean random motion of molecules in a physical body. In other words, it is a measure of the degree of hotness or coldness of a substance.

**Unstable air**
Air in which static instability prevails. This condition is determined by the vertical gradients of air temperature and humidity.

**Water vapor**
Water substance in vapor (gaseous) form; one of the most important of all constituents of the atmosphere.

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