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Building Barriers: Air Barrier Systems in Predominantly Cooling Climates

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Introduction

Energy codes now require air barriers that contribute significantly to improve the building energy efficiency, durability, and occupant comfort, health and safety. A continuous air barrier functions by enclosing the building blocking, energy loss (air flow, convective heat loss), moisture (vapor via air flow), pollutants and insects.

Up to 40% energy savings has been achieved in northern climates, with a 9-14% energy savings[1] in air conditioned climate zones 1 and 2. For the University of Hawaii at Manoa air barrier installations on existing buildings would have saved the campus millions in annual cooling costs.

Background

The Building Enclosure

The most basic function of a building enclosure is an environmental separator for the interior and exterior building environments. The enclosure's functions are to provide physical support, control or regulate the heat, air and moisture flows between the interior - exterior environments and provide the support and finish for both interior and exterior surfaces. Though both the physical support and finish functions of the enclosure are important, the influences of heat, air and moisture transport are the primary considerations interacting with each other as well as influenced by the materials used within the building enclosure system.

The three phases of water are vapor, liquid and solid. Due to the differing mechanisms of moisture movement between the vapor or liquid phases we separate the two, adding both to the controlling factors of the building's enclosure. Thus we define the controlling factors necessary for the building's enclosure as: Heat, Air, Moisture (liquid) and Moisture (vapor) or HAMM. **Table 1** summarizes the Functions, Mechanisms and Strategies required for the building enclosure for these factors.

Current building performance requirements separate the controlling functions into multiple layers, each providing a component for various degrees of control of heat, air and moisture flows. Typically the enclosure's protecting functions, HAMM, in order of importance are Moisture (liquid), Air, Moisture (vapor) and Heat.[2, 3] Controlling bulk moisture can be as simple as providing an adequate roof assembly with large overhangs and a sufficient wall design that incorporates a moisture barrier adequate to control bulk moisture sources such as wind driven rain.

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[1] Emmerich, S. J. Impacts of Airtightness on Energy Use, JBED, Winter 2007

[2] Latta, J. K., CBD-30 Water and Building Materials 1992.

[3] Garden, G. K. CBD-40 Rain Penetration and its Control April 1963.

Controlling Function	Physical Mechanism	Controlling Strategy
Heat Transfer	Radiation Conduction Convection	Radiation Barrier (opaque assembly) Thermal Insulation Air Barrier System
Air Leakage	Stack (Natural Convection) Wind &Mechanical (Forced Convection	Air Barrier System
Moisture (liquid)	Bulk Water	Deflection Conveyance Drainage Storage & Drying Rain-Screen Dynamic Buffer Zone Perfect Barrier
	Capillary Water	Capillary Barrier Capillary Break
Moisture (vapor)	Vapor Diffusion	Vapor Retarder Thermal Insulation
	Air Leakage	Air Barrier System Thermal Insulation

Table 1: *Controlling functions and their controlling strategies for Heat, Air, Moisture (liquid) and Moisture (vapor)*[4].

Vapor Diffusion Control

Vapor control is often confused with air control. Diffusion functions independently from air movement in retards to the migration of water vapor through materials of the building assembly. Unlike air movement, which is a must faster process, vapor diffusion is the transfer of moisture in its gaseous state through the building materials and is typically 100 fold slower than air movement that easily passes through gaps and openings in the enclosure. A vapor control layer located within the enclosure and its level of permeability is a combination of climate and the interior conditions. F.L. Browne, L V. Teesdale, T. S. Rogers and Frank Rowley in the early 1950s advanced the misperception that vapor diffusion and vapor barriers were key in preventing condensation problems.[5] It has since been proven that uncontrolled air flow is the culprit for energy loss and condensation issues.

Low-permeance vapor retarders do not typically improve the hygrothermal performance and may in fact increase the possibility of condensation or trapping moisture within the enclosure's system.[6], [7] When moisture is trapped due to vapor barrier installation, drying of building materials can only proceed in one direction or not at all. Laboratory results have shown that the drying potential of OSB sheathing, for

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[4] From Whole Building Design Guide as adapted from M.T. Bomberg and W.C. Brown, 1993. Building Envelope and Environmental Control: Part 1 – Heat, Air and Moisture Interactions. Construction Canada, 35 (1) p. 15-18.

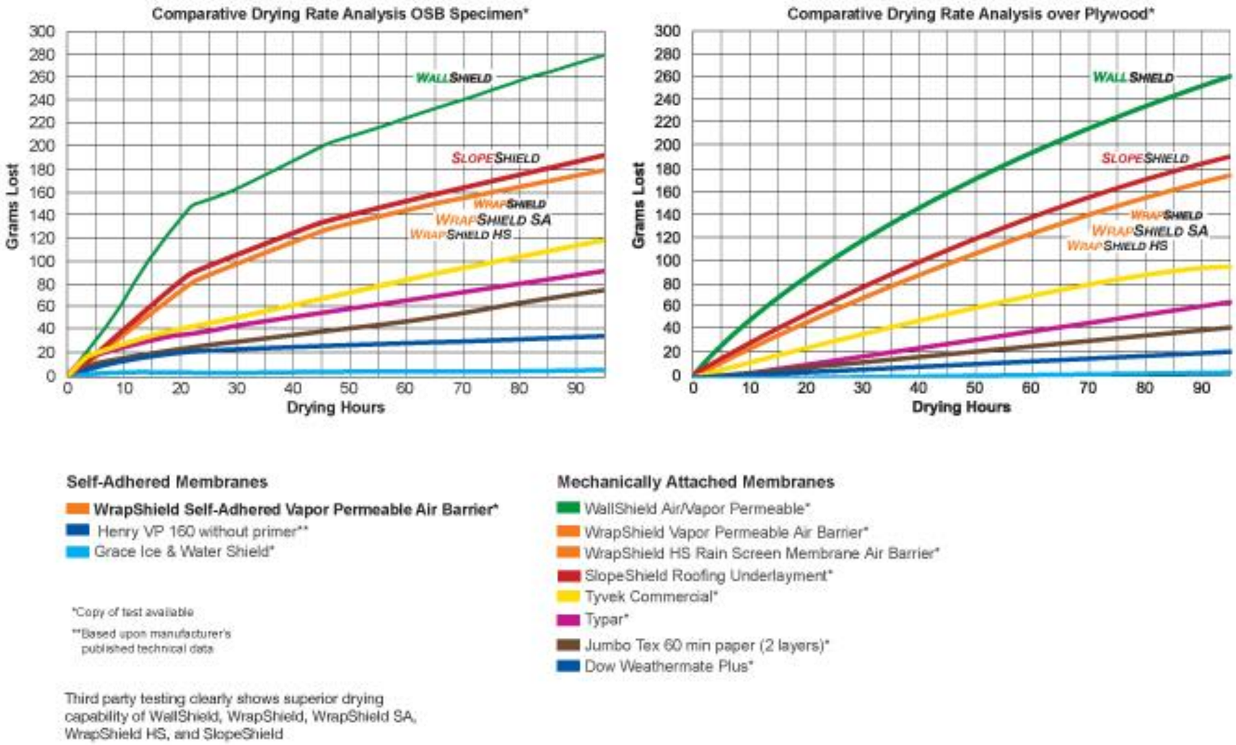
[5] Rose, W.; Moisture Control in the Modern Building Envelope: The History of the Vapor Barrier in the US – 1923 to 1952, APT, Volume XXVIII, Number 4, 1997.

[6] Straube, J. F., The Influence of Low-Permeance Vapor Barriers on Roof and Wall Performance, Proc. Of Thermal Performance of Building Envelopes VII, Clearwater Beach Florida, December 2-7, 2001

[7] Morse, R. G., Air Barriers vs. Vapor Barriers, BEST 1 Conference June 10-12, 2008

example, is severely limited when reduced or low vapor permeable moisture resistive barriers are used.[8] To limit the possibility of trapping moisture within the envelope system, in most cases, a vapor open system is preferred to a vapor closed. **Figure 1** shows what can happen if condensation is trapped and vapor retarders such as paints limit the drying potential. When vapor open materials are used as a weather-resistive barrier to stop bulk moisture the drying potential is increased dramatically (See **Figure 2**).

Figure 1: *Damage due to limited drying potential.*



Third party testing clearly shows superior drying capability of WallShield, WrapShield, WrapShield SA, WrapShield HS, and SlopeShield

Figure 2: *Third party testing clearly shows superior drying of vapor open water resistant barrier (WRB)and air barrier materials.*

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[8] Boone, K., et al. 2004. Wall drying in hot and humid climates. Proceedings, Symposium on Hot and Humid Climates, Richardson, TX, May 2004.

Air Transported Vapor Control

In 1953, Neil Hutcheon, followed by Wilson in 1961 and Garden 1965, correctly identified air leakage as being primarily responsible for serious condensation problems.[9, 10]. In 1985, Rick Quirouette developed the design criteria for air barriers in the building enclosure, clearly delineating the differences between the air and vapor controls.[11] Research finds that air leakage accounts for anywhere from six to 100 times as much moisture transfer as vapor diffusion.[12] When we realize that air transported moisture typically far exceeds that of vapor diffusion, as well as transports heat through the enclosure system by convection, then can we appreciate the importance of air leakage and its required control[13].

Air control is used to mitigate infiltration and exfiltration of air through the building's enclosure, separating the conditioned areas from the unconditioned areas of the building. The infiltration and exfiltration movement are provided primarily by: temperature differences (stack effect), wind pressure, and mechanical pressure generated by the HVAC system.

This air flow through the enclosure often has serious and sometimes catastrophic consequences. Unintentional air leakage can bring unfiltered, unconditioned outdoor air through any discontinuities in the air barrier. This leakage can occur in a building to the inside (infiltration) or the uncontrolled leakage of indoor air through any envelope penetrations to the outside (exfiltration). Often critical and costly are the decreases in health, safety, indoor comfort and building material durability, due to poor indoor air quality and lack of building moisture control. This lowers worker productivity and business revenue in problem buildings when air flow is not addressed.

To control air flow a continuous air barrier on all six sides is required. Interfaces, such as windows to wall, wall to roof, and wall to foundation are especially important to design and construct properly in order to maintain continuity. The air barrier location is less important than its ability to be continuous, though positioning is critical if a vapor closed material is used. Typically an air barrier is easiest to install on the exterior of the enclosure, usually doubling as the moisture barrier. Since most of the North American climate zones do not require a vapor retarder of more than the paint on a wall, an air barrier should be vapor open to maximize drying potential and preventing trapped moisture within the enclosure.

Air Barrier Materials

Materials designated as an air barrier must have an air permeance rating equal to or less than 0.02 $L/(s{\cdot}m^2)$ [0.004 cfm/ft^2] measured at an air pressure difference of 75 Pa [1.57 psf] as tested using ASTM E2178 Standard Test method for Air Permeance of Building Materials. The material must be able to maintain this air permeance rating, be easily installed and facilitate ease of transition around roof/wall, wall/window junctions and control joints where movement is expected. Since the final assembly's ability to stop air permeance is clearly the goal when incorporated in a building's enclosure it must have an air permeance rating to less or less than 0.2 $L/(s{\cdot}m^2)$ [0.04 cfm/ft^2] measured at an air pressure difference of 75 Pa [1.57 psf] as tested using ASTM E2357 Standard Test method for Determining Air Leakage of Air Barrier Assemblies (See **Figure 3**) or ASTM E1677 Standard Specification for Air Barrier (AB) Material or System for Low-Rise Framed Building Walls.

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[9] Wilson, A. G. CBD-23 Air Leakage in Buildings, November 1961.

[10] Garden, G. K. CBD-72 Control of Air Leakage IS Important December 1965.

[11] Quirouette, R.L., The Difference Between a Vapor Barrier and an Air Barrier, Building Practice Note No. 54, National Research Council of Canada, Division of Building Research, ISSN 0701-5216, July 1985

[12] Thermal and Moisture Protection Manual, Christine Beall, 1999. pp.154-159

[13] Hutcheon, N.B. Fundamental Considerations in the Design of Exterior Walls for Buildings. Engineering Journal, Vol. 36, No. 1, pp. 687-698, June 1953.

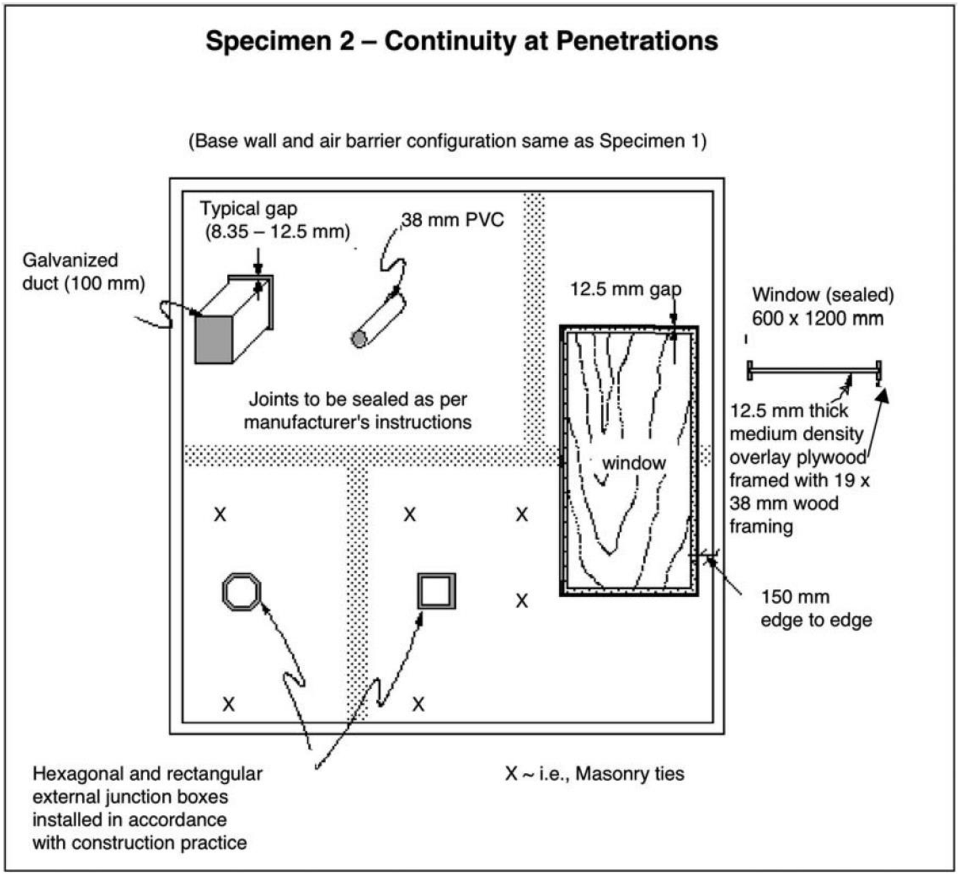

Figure 3: *Diagram of specimen wall for testing air-barrier assembly performance from the ASTM Standard E2357.*[14]

For North America, in 1995 the National Building Code of Canada was revised in order to help reduce air leakage in buildings. In 2001, Massachusetts became the first state to incorporate air barrier material requirements into the state building code.[15] The 2012 International Energy Conservation Code (IECC), 2012 International Green Construction Code (IgCC), ASHRAE 189.1-11 and ASHRAE 90.1-2010 all now have requirements for air barrier systems. Currently many states have implemented air barrier requirements, some requiring whole building testing to confirm the expected lower air leakage rates.

The material used for air barrier systems vary in composition including materials mechanically fastened, self-adhered, and fluid applied air/moisture/vapor barrier materials. Combining the air and moisture barrier offers the advantage of a single barrier system capable of both water and air hold out. When designing for and selecting air barriers (especially when providing multiple functions such as moisture and vapor control) several factors should be considered. These should include: worst-case levels of moisture exposure, vapor permeability requirements, constructability and installation costs.

Mechanically attached materials usually appear less costly, though once labor, sealant, and tape are factored in, the cost is similar to self-adhered membranes. Fastener failure and billowing can result in both moisture and air movement through the mechanically attached air barrier system. Some self-adhered membranes require primers to aid adhesion to substrates. These primers increase both material

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[14] ASTM E2357-11 Standard Test method for Determining Air Leakage of Air Barrier Assemblies.

[15] Massachusetts Energy Code. 2001. Section 1304.3.1 Air Barriers.

and installation costs, reduce the overall drying potential and typically contain hazardous and toxic components, posing increased risk to worker health and building fire safety.

The fluid applied membranes vary in vapor permeance from vapor closed to vapor open and usually require a complex and integrated array of materials for an effective air barrier system which must be continuous. As with most liquid applications, they are affected by inclement weather including wind rain and cold temperatures, and often required primers as well.

Air Barrier Testing

The material and system testing methods described above are useful in evaluating the products used for the air barriers, though they fail to show actual performance in the field. Field testing the building's air barrier establishes the air leakage rate of the building, providing a performance measure of the installed air barrier system. Strict performance testing is required for all US Army Corp of Engineers projects (See **Figure 4**) with air barrier leakage to not exceed 0.25 cfm/ft^2 @ 75 Pa when tested in accordance to ASTM E 779 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization.[16] A less stringent leakage rate is 2 L/(s·m^2) [0.4 cfm/ft^2] such as Washington State's air barrier testing specification (See **Table 1**).

Figure 4: *A "blower door" installation fitted to the exterior doorway for a USACE air barrier pressure test.*

Standard	Specification	cfm/ ft^2 @75Pa [m^3/hr at 50Pa]
ATTMA TSL2 Small Building	15 m^2/h/m^2 @ 50Pa	**0.82 [15]**
ASHRAE 90.1 Leaky	0.60 cfm/ ft^2 @ 75Pa	**0.60 [8.4]**
WA State Energy Code	0.40 cfm/ ft^2 @ 75Pa	**0.40 [5.6]**
IECC	5.6 m^3/h/m^2 @ 50 Pa	**0.40 [5.6]**
ATTMA TSL2 Large Building	5 m^2/h/m^2 @ 50Pa	**0.36 [5]**
LEED Multifamily	0.23 cfm/ ft^2 @ 50Pa	**0.17 [2.4]**
ASHRAE 90.1 Average	0.30 cfm/ ft^2 @ 75Pa	**0.30 [1.52]**
Army Corps	0.25 cfm/ ft^2 @ 75Pa	**0.25 [3.5]**
NBCC (Canada)	0.02L/(sm^2) @ 75Pa	**0.13 [0.66]**
ASHRAE 90.1 Tight	0.10 cfm/ ft^2 @ 75Pa	**0.10 [0.51]**
Passivhaus	0.05 cfm/ ft^2 at 75Pa	**0.05 [0.64]**

Table 1: *Performance verification specifications.*

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[16] U.S Army Corps of Engineers: Air Leakage Test Protocol for Measuring Air Leakage in Buildings.

Air leakage rate testing and thermography testing in combination can provide illustrative results showing the areas where air leaks occur. For example, **Figure 5** shows air leakage at the concrete masonry unit (CMU) and insulated metal-panel wall junction as wispy, dark colored bands where the cold exterior air has cooled the interior wall surface. In **Figure 6**, the air leakage at the CMU and insulated metal panel junction is visible on the exterior as wispy warm colored bands.

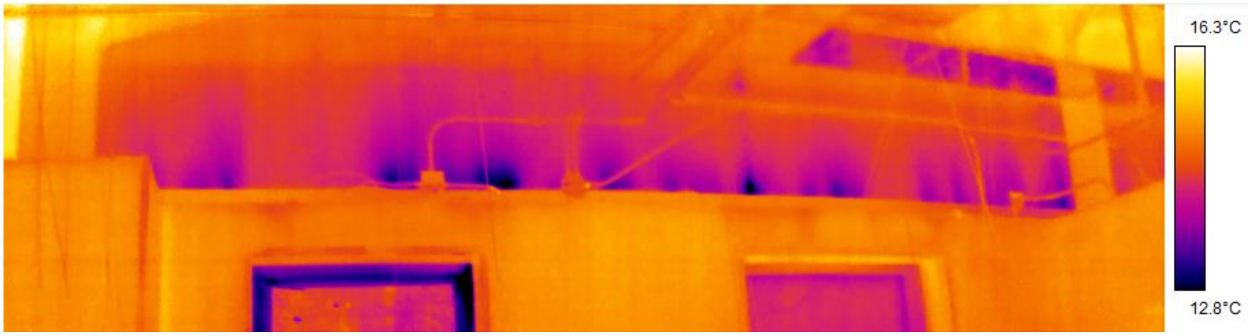

Figure 5: Air leakage observed using infrared thermography of a CMU to insulated metal panel junction.

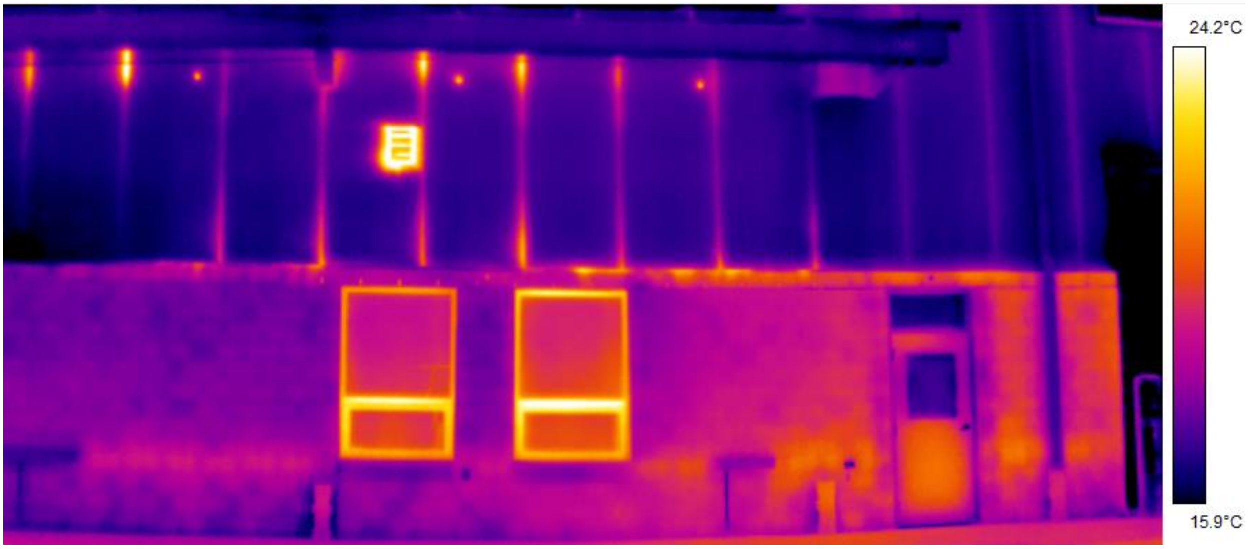

Figure 6: Air leakage observed using infrared thermography of a CMU insulated metal panel cladding.

Energy Savings

Continuous air barriers greatly reduce convective heat transfer, lowering the energy loss through the building enclosure. Studies conducted on high-rise residential and commercial buildings in cold climates have shown that anywhere from 20 to 50 percent of heat loss can be attributed to air leakage.[17, 18, 19] Estimates for the heating load due to air infiltration for two U.K. office buildings of approximately equal

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[17] Hill, D., "Valuing Air Barriers," *Home Energy*, September/October 2001, pp.29-32.

[18] Woods, T., "Reducing Air Leakage Through the Building Envelope Cuts Energy Demand and Consumption," *Air Barriers III: Air Barrier Solutions for Buildings in North American Climates*, Washington, DC, 2001.

[19] Scanada Consultants Ltd. and CanAm Building Envelope Specialists Inc., "Development of Design Procedures and Guidelines for Reducing Electric Demand by Air Leakage Control in High-Rise Residential Buildings," Ontario Hydro/Canada Mortgage and Housing Corporation, Ottawa, ON, 1991.

size show a reduction in air leakage by 63 percent could result in a reduction in annual heating energy loss of about 300 MW/m^2 (26416 BTU/sft^2).[20]

Air barrier systems are beneficial in every climate. Payback analysis varies depending on climate and region. In simulations, this shows reducing air leakage can result in up to 36% heating energy cost savings in northern climates such as Minneapolis and Bismarck. When air leakage rates were reduced in the simulations for hot climates, such as Phoenix, an energy savings of 10% in cooling costs was achieved.[21] Neither of these examples account for the latent loads or effects on humidity levels.

Based on energy savings simulations, different climates have different paybacks for air barrier incorporation. This is due to the temperature differences between the indoor and outdoor air. In heating climates the outdoor and indoor air differences can be 38°C (70°F). For a cooling climate, the outdoor-indoor air temperature difference may be 8°C (15°F). It takes a great deal of energy to condition the air per temperature difference, not only considering the dehumidification demands for the outdoor air. Cooling humid air requires more energy than dry air due to the increased latent load of the former.

For retail buildings, the electrical savings in the hot climates are about as large as the gas savings in the cold climates in absolute terms.[22] The installation of an air barrier system would save the University of Hawaii Manoa Campus cooling costs of 25 – 38 cents per year per square feet of occupied space based on 2004 building energy consumption data.[23] The 5 million square feet of the University's occupied space would provide the university a $1.25 – 190 million annual savings[24].

Residential Energy costs in Hawaii are greater than three times those for the mainland cooling climates costs.[25] Based on average electrical consumption of 615kw per hour per month, the average Hawaii residence would save 19 – 29 kw per hour per month with the installation of an air barrier system.

Air leakage through the building enclosure negatively impacts the building system by; causing damage to the envelope components (condensation), increased heating and cooling costs (convection), and occupant health and safety (stimulated mold growth and dust and pollution entry). All of these issues have driven the implementation of more stringent regulations for air barriers systems in buildings, making quality material, design and installation critical to their success.

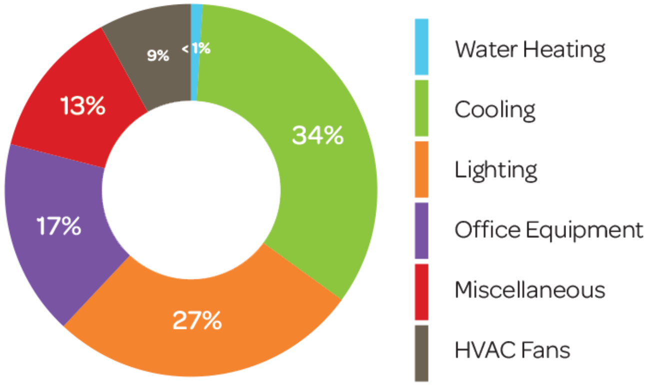

Figure 7: Typical Electrical Use for Office Buildings in Hawaii.[26] .

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[20] Potter, I., Jones, T., and W. Booth. 1995. *TechNote 8/95 Air Leakage of Office Buildings. Building Services* Research and Information Association

[21] NISTIR 7238 Emmerich, McDowell, Anis. Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use. June2005

[22] Emmerich, S. J. Impacts of Airtightness on Energy Use, JBED, Winter 2007

[23] Cedric D.O. Chong & Associates, Benchmarking Study for University of Hawaii at Manoa Campus, March 2004

[24] Based on 34% total energy for cooling and 35.69 cents per kilowatt.

[25] DBEDT's Monthly Energy Trends, hawaii.gov/dbedt/info/economic/data_reports/energy-trends. 2014

[26] Information from Hawaii Energy based on 23 kilowatt hour/square-foot-year usage. 2014