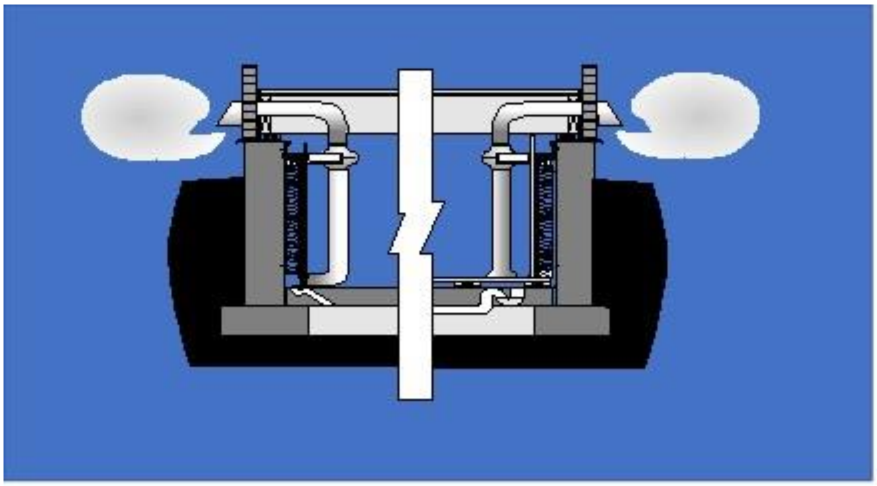
The ECHO System
Homeowner's Information Document
Release EK13.2



The ECHO SYSTEM: LS ECHO Wall System. RS: ECHO Wall and Floor System. It is the ultimate in basement finishing and winner of the 1994 Ottawa Carleton Home Builder's Association New Technology Award.

ECHO System Registration No. ……………………………………………

Address ……………………………………………………………………

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Commissioned on ……………………….

By ………………………………………………………… ECHO Air Inc.

Contractor ……………………………………………………………….

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The ECHO System was patented in Canada (Patent 1,230,461) and United States (Patent 4,843,786) and is commissioned by ECHO Air Inc. The ECHO System is approved as a foundation drainage system under the Ontario Building Code per BMEC 97-05-214.

ECHO Air Inc **www.indoorair.ca**

The ECHO System is a custom-built basement finishing system that provides important benefits unavailable from any other system.

- It saves heating costs in winter and prevents hidden mold growth in summer.

- It solves foundation leakage problems more certainly than exterior foundation sealing membranes since edge sealant that can fail as can weeping tile drainage with clogging over time.

- It prevents entry into the living space of microbial gases and spores and radon and other soil gas by covering
    - Porous foundation walls (e.g. cracked concrete, concrete block, pressure treated wood, and rubble mound).
    - Basement floors (e.g. Concrete slabs, earth).
    - Sump pits.
    - Crawl spaces.

Figure 1 ECHO basement living space is healthy living space, doubling the available quality living space in bungalows and increasing it by a third in two story residences. Its wall and floor ventilation rate is an order of magnitude more effective than that of a heat recovery ventilator in eliminating basement microbial air pollutants. Most importantly, foundation leakage problems are permanently resolved without costly exterior digging.

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SUMMARY

The ECHO System is made up of specially constructed tightly sealed, drained, and continuously ventilated and depressurized ECHO Walls, ECHO Subfloors, ECHO Sump Pits and ECHO Crawl Spaces. These spaces are continuously depressurized with air exhausting to the outdoors using natural intake and exhaust heat exchange and an energy efficient continuous duty blower operating at flows that are a fraction of those of a bathroom fan. The ECHO Control Panel controls the blower flow rate, continuously monitors the System depressurization relative to the living space and displays the System Commissioning Certificate.

Several ECHO components are available, either singly or in combination:

(I) ECHO Depressurized Walls Venting.
(II) ECHO Depressurized Subfloors Venting.
(III) ECHO Depressurized Sump Pit Venting.
(IV) ECHO Depressurized Crawl Space Floor and Wall Venting.

What makes ECHO component ventilation special is that each component (ECHO Wall, ECHO Subfloor, ECHO Sump Pit, ECHO Crawl Space) is vented and depressurized throughout relative to the adjacent living space at the lowest possible flow rate and this is continuously monitored. This makes ECHO not only the most certain solution to the typical air quality problems associated with each, but also the most energy efficient. Further ECHO Walls and Subfloors are drained as well as ventilated making them both a safe and certain solution to foundation leakage and helpful in sewer back-ups. Regarding sewer back-ups, the floor drain inside the ECHO Subfloor may have a back-flow preventer depending on local building codes.

The ECHO Subfloor prevents radon and other soil gas entry into the living space where sub-slab depressurization will not in the absence of a continuous gravel layer under the slab The ECHO Subfloor prevents radon and other soil gas entry into the living space where sub-slab depressurization will not in the absence of a continuous gravel layer under the slab which is often the case in older houses.

The ECHO System Wall-Subfloor system saves on winter-time heating costs with its low emissivity subfloor, and prevention of warm living space air circulating behind the insulation against the cold foundation wall and then re-entering and cooling the living space. With ECHO a fraction of that amount of air is circulated from upstairs into the tightly sealed ECHO walls and subfloor and then vented directly outdoors. In addition, it recovers radiant house heat as it enters the house and gives up house heat as it to ECHO floors and walls before it exits to the outdoors.

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The ECHO System ventilation dehumidifies and vents ECHO Walls and Subfloors, crawl spaces and sump pits. It seals off foundation walls of all types - poured concrete, pressure treated wood, rubble mound and block foundation walls.

The ECHO Subfloor cavity has a low emissivity upper surface which provides R4 thermal resistance. The continuous venting dries flow paths in the Wall and Subfloors and along with drainage solves foundation crack water leakage more certainly than exterior membranes and weeping tile systems since membrane edge seals can fail and weeping tile can clog.

This document contains sections on how to operate and maintain the ECHO System and what to do in case of flooding or a basement renovation that will introduce holes in the seal and affect its depressurization capability, how the system is constructed and the science behind the ECHO System.

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Figure 3 The ECHO System Control Panel with the differential pressure meter, the blower speed control, the connections to pressure sensing tubes and the commissioning certificate.

Figure 2 The ECHO System Blower

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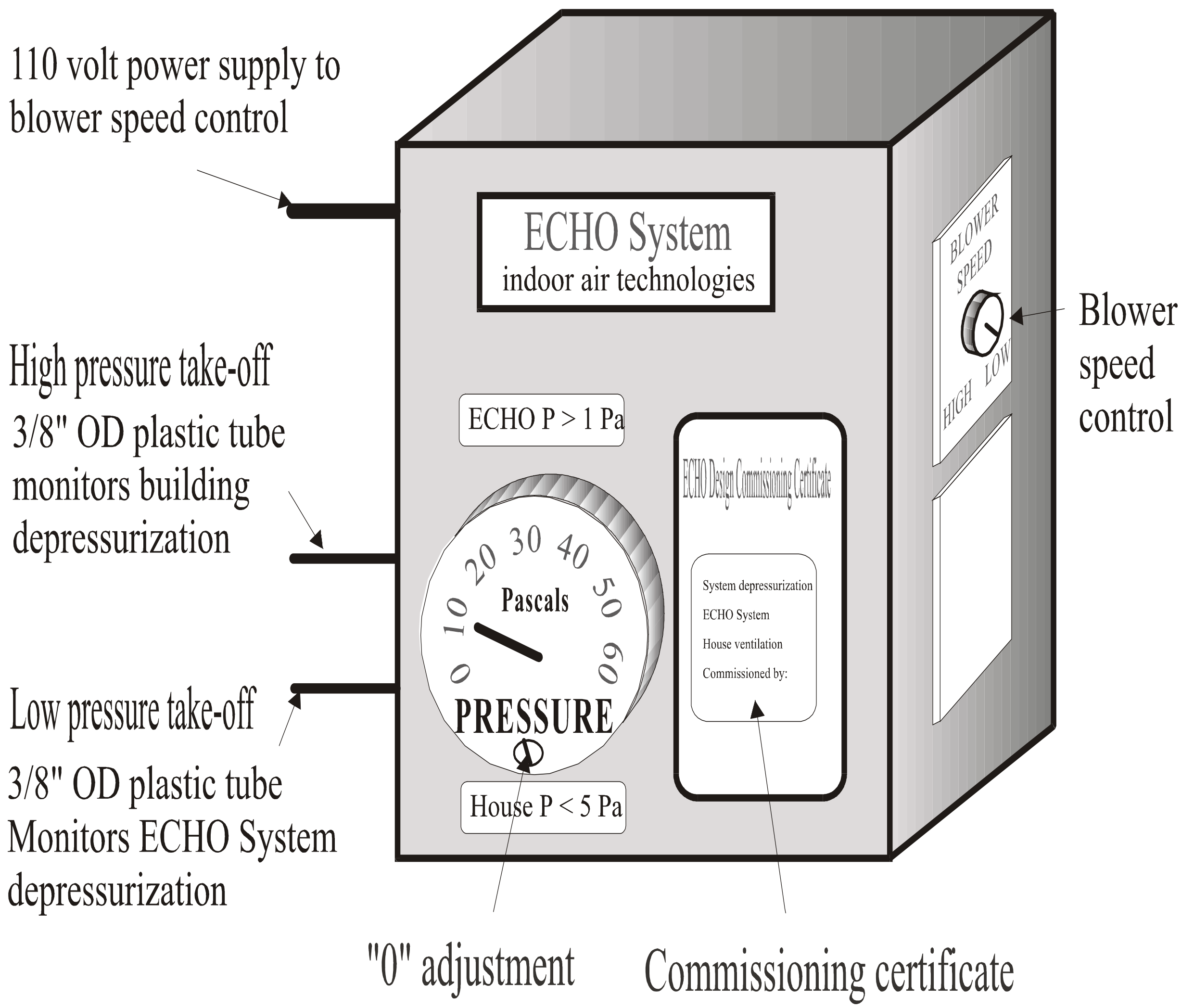

Figure 4 Schematic of the ECHO Control Panel

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ECHO SYSTEM OPERATION

Referring to Figures 3-5:

1. The ECHO System blower should always be operating at or higher than the speed set on the Commissioning certificate on the Control Panel, and the differential pressure meter should register at least 1 Pascal depressurization.

2. For most basements, operation of the blower on low will keep the ECHO Walls and Subfloor, the sub slab, or the crawl space depressurized. However, for some higher flow rates will be required, for example for block wall and rubble mound foundations.

3. ECHO ventilation creates depressurized insulation envelopes. Air is drawn through the envelope from the living space and exhausted to the outdoors. This constant insulation envelope air exchange keeps enclosure wood, drywall, and insulation dry, removes foundation leakage water through evaporation. This provides energy efficient house ventilation while preventing entry of soil and envelope gases and vapours. The 120 V, 83.4 W blower on low speed uses the power of a 20-watt light bulb. Its operation saves on house heating costs due to the envelope heat recovery and the prevention of conditioned basement air circling behind the insulation and back to the basement.

4. Periodically open the tap providing water to the drain P trap in the ECHO Subfloor. This might be set up to be done automatically, for example when you use your laundry tap.

5. Periodically check the system depressurization at the ECHO Control Panel. Listen to hear if the blower is operating and make sure the differential pressure meter reads at least 1 Pascal indicating the ECHO Subfloor and the ECHO Perimeter Walls are depressurized relative to the living space.

6. If the meter reading is lower than 1 Pa, check that the meter is 'zeroed' by disconnecting the pressure input tubing at the bottom left side of the Control Panel. 'Zero' the meter if necessary, by turning the screw at the bottom of the gauge. Reconnect the tubing and if the pressure is low but positive and the day is very cold, leave it. If the meter reading is less than 2 Pa and it is not a cold day, turn up the blower speed using the control at the right side of the ECHO Control Panel. Off is at both ends of the control turn. Most speed controls are 3 speed. Listen to the sound variation with blower speed.

7. If the blower has stopped working (many are still working after 20 years), contact us for a new one.

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8. If you are painting or doing some other odour producing activity in the basement, turn the ECHO System blower on high to help clear the air.

9. If there is a basement flood overtopping the ECHO Subfloor, turn the ECHO System blower on high and quickly dry wet materials with space heaters blowing hot air at them. If the drywall remains wet for more than two days, replace the wet portions. To be made aware if there is any water accumulation in the ECHO subfloor before it causes a problem such as from a sewer back up, install a water leak detector sensor near the floor drain inside the ECHO Subfloor. There is one sold by Honeywell, for example, that we use. It is powered by batteries and connects to your house WIFI and will let you know if there is any water present.

10. For further information, contact us via email or phone available on our web site www.indoorair.ca.

ECHO SYSTEM AIR SEAL

1. It is important to maintain the ECHO Air Seal. Penetrations of the seal by a few nails and screws to hang pictures and the like are not a problem. However, if the seal is broken in a substantial way, the system pressure will fall to zero. Then the breaks must be resealed ASAP.

2. If you are planning a renovation that involves opening an ECHO System wall or subfloor, contact us in advance so we can review the changes planned and how best to address them.

3. It is always wise to have your house insurance cover basement flooding damage as finished basement repairs, including to the ECHO System, can be costly. If your basement floods and the System will no longer depressurize, contact us.

WHAT THE ECHO SYSTEM DOES NOT DO

1. The ECHO System does not dehumidify the house air. You must keep the house relative humidity (RH), including the basement where RH is normally highest, below 60% (target 50%) to avoid visible mold growth on the drywall especially in cold corners and at the top of basement walls. So, in summer, operate an air conditioner and/or a basement dehumidifier, and ensure closets allow air circulation and furniture is away

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from walls, especially in corners. In winter to avoid hidden condensation, if you need to humidify for health reasons, do so just in the room you are using, rather than in the whole house.

2. The ECHO System is not a heating system. In spring when the furnace stops heating the house and the air conditioning system starts, basements can be uncomfortably cool. To counter this, run the furnace fan continuously, close the cold air supply vents in the basement and first floor of a two-story house, and operate ceiling fans in the stair wells drive the air downward. These measures will help even out temperature differences between upstairs and basements and save on house air conditioning costs.

3. The ECHO System is not a living space air cleaner. The ECHO System prevents ground sourced air contaminants hidden mold growth odours entering the living space. If there are odours originating in the living space, you will need to solve these separately although turning ECHO on high will help clear basement air odours.

THE SCIENCE BEHIND THE ECHO SYSTEM[1]

Most of us are aware of the water leakage, weeping tile failure, sewer back up, sump failures, mold growth, moisture problems with cracked foundation walls and interior wood stud walls and subfloors, and radon entry problems that finished basements can suffer. However, the wintertime energy loss due to envelope air circulation is not on the list of concerns, but it should be. This loss is caused by stack pressures across the insulation vapor barrier and drywall finish that draw basement air behind the insulation via leakage pathways at the insulation envelope air barrier at top of the wall and push it out into the room after it is cooled at the bottom.

The leakage pathways at the top of the wall are unintentional and the result of the difficulty in sealing of air barrier sheets to the underside of the floor above between and around the joists. Leakage pathways at the bottom of the air barrier are somewhat intentional, intending to allow wintertime house humidity condensation on the cold foundation to exit the wall via evaporation in the spring with this air circulation. Such air circulation is at least 100 cfm in a typical 1000 SF finished basement even when the insulation is kept a foot or more above the floor and the vapor barrier is not intentionally left open. The insulation bypass circulation could be several times that when the vapor barrier is

[1] Douglas S. Walkinshaw and Raymond H. Horstman. "Stack Pressure-Created Airflows in Insulation Envelopes, Part 1: Buildings." ASHRE Journal, April 2020, pp. 12-25

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intentionally left open at the bottom. This moisture accumulation is a potential major moisture problem in humidified houses and in new houses with new concrete still curing.

Building design codes with one exception[2] generally do not recognize this impact stack pressures play in finished basement energy use, and the moisture and air quality concerns and problems they are responsible for creating. Neither do they provide measures to resolve these concerns and the problems they can cause in basements. Our stack pressure and basement batt insulation envelope flow measurement experience and related calculations in quantifying and solving these problems, indicate that when counter measures are not taken, a substantial portion of thermally conditioned air circulates behind the basement insulation in winter due to these stack pressures, while in summer lower stack pressures create stagnant air pockets behind the insulation air barrier which trap ground-sourced humidity and moisture.

This section provides the science behind these stack pressures and their effects, analyses the current situation for batt-insulated basements and energy implications, and provides the ECHO System details used to create tightly sealed and insulated perimeter walls and low thermal emissivity subfloors that can be depressurized throughout with small exhaust air flows (10-30 cfm) to the outdoors which efficiently eliminate soil and envelope moisture, humidity and air contaminants without relying on less efficient whole-house ventilation and dehumidification systems. This insulation envelope sealing, and depressurization system has been successfully used in several hundred residential basements for many years. The first two systems were demonstrated in 1987 with the help of Canada Mortgage and Housing Corporation.

Foamed-in-place insulation over interior foundation walls as an alternative solution is not a practical alternative for several reasons including cost. Further, it does not solve water leakage problems.

STACK PRESSURES

Stack or buoyancy pressure differentials across perimeter insulated foundation walls and slabs are created by indoor and outdoor temperature differences. These pressures increase both with increased height of the cold air column in the insulation envelope and increased temperature difference. If the bottom of the wall is open to the room, then the stack pressure is based on the full height of the wall. However, the floor can act as a flow blocker if the attachment to the wall is sealed. If this is done, the stack pressure is reduced

[2] The Ontario Building Code allows the ECHO System interior finished basement insulated envelope ventilation system as an alternative to foundation exterior sealing and drainage systems.

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to half. Air will continue to enter and exit the envelope through other cracks and seams throughout the wall.

Stack pressures are predicted by [3,4]

$dP_r = (\rho_2 - \rho_1) * g * h$ ………………………………. (1)

Substituting

$\rho = P/RT$ ……………………………………..…. (2)

Gives

$dp = p_1 (1/T_1 - 1/T_2) * g * h/R$ ……………..…..(3)

Where

P = air pressure

ρ= air density

dP_r = reference pressure difference

ρ_1 = air density in the living space (slug/ft^3)

ρ_2 = air density behind the insulation (slug/ft^3)

h = height above the neutral plane (ft)

p_1 = living space air pressure (lb/ft^2)

T_1 = temperature in room (^{o}R)

T_2 = temperature behind the insulation (^{o}R)

R = individual gas constant for air =R_og (1716 ft^2/s^2-^{o}R)

g = acceleration due to gravity (32.2 ft/s^{-2})

dp = stack pressure (lb/ft^2) or customarily in units of Pa (47.88 Pa/ lb/ft^2)

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[3] Walkinshaw, D.S., and Preston, K.F. 2011. "Controlling Cabin and Envelope Air Flows and Pressure Differentials to Prevent Envelope Condensation, Enable Cabin Humidification, Improve Fire Safety, and Decrease Fuel Use." *SAE Int. J. of Aerosp.* 4 (2): 1243-1253.

[4] American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 2005. "Fundamentals". ASHRAE: 27.12.

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Using Equation 3, the stack pressure at the top of a basement wall with the air barrier sealed at the floor, is shown in Figure 6(a) for a range of temperatures behind the insulation and wall heights. Leaving the insulation envelope air barrier open at the floor doubles the stack pressures which are shown in Figure 6(b).

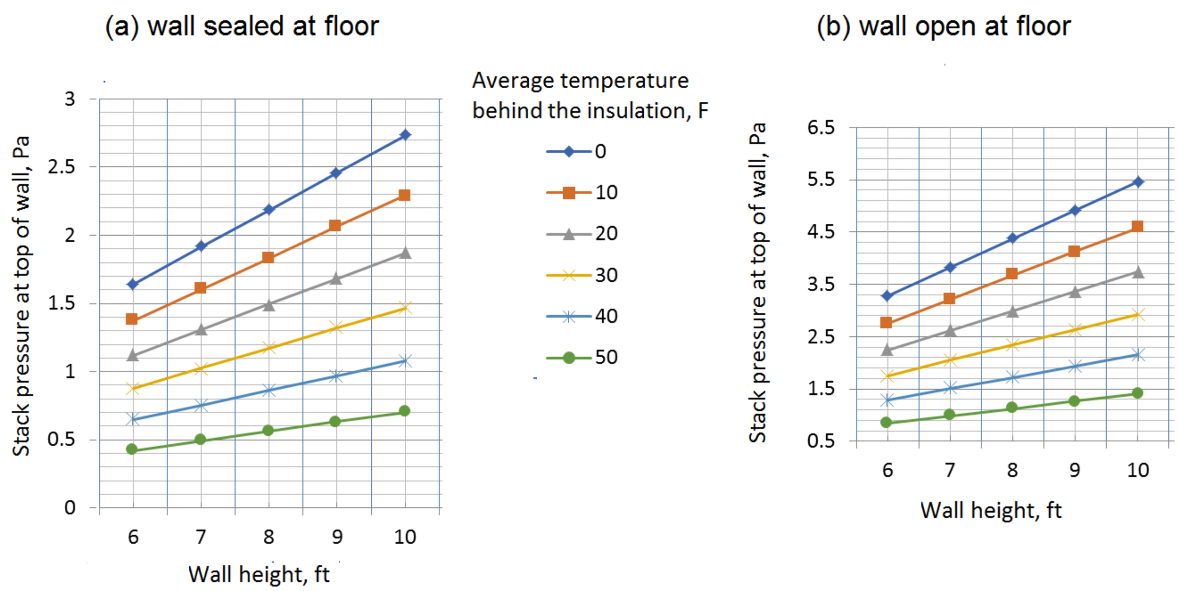

Figure 5 (a) Stack pressure at the top of insulated basement stud wall sealed at floor, (b) basement stud wall open at floor, room air temperature= 70F, air pressure = 14.694 psia.

The soil in cold climates is colder than the living space year-around (e.g. 46 to 50 ^{o}F at foundation depth; 26 to 32 ^{o}F at the ground surface in winter and near average air temperatures at the ground surface in summer). Hence temperatures between the insulation and the foundation wall inside the building are always colder than in the living space.

AIR FLOWS BEHIND THE INSULATION

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The airflow rate through the insulation envelope, Q, is governed by the following equation[5]

$$Q = (ELA)Cd\sqrt{(2dPr)/\rho} \quad \text{.. (4)}$$

Where

Q = predicted flow rate, ft^3/s (=cfm/60)

C_d = discharge coefficient (varies between

0.6 for small sharp-edged openings and 1 for large openings).

ELA = equivalent or effective leakage area, ft^2 (=in^2/144)

ρ = mass air density, 0.002379 slug/ft^3 (=0.07659 lb/ft^3/g) at sea level and 59 ^oF

dP_r = reference pressure difference (lb/ft^2) or customarily in units of Pa (=47.88*lb/ft^2)

Figure 7 shows a range of conditioned air circulation behind the insulation for a range of peak stack pressures (see Fig 6b), under winter conditions and a range of air barrier leakage areas.

We have measured flows through basement stud wall insulation envelopes that are sealed at the wall top and bottom of much greater than 100 cfm under winter-time stack pressures in homes. Air barrier seals at discontinuities such as at pipes, wall plugs, electrical breaker or around furnaces in subfloors also may be leaky. In some basement wall insulation, the air barrier has been left open at the bottom to avoid winter-time condensation and summertime mold growth problems. In these houses the stack pressure doubles with the envelope ELAs limited by the tightness of top edge seal. In fact, it is practically impossible to depressurize most standard basement walls envelopes. From Figure 7, this suggests typically insulated basement envelope ELAs of much greater than 50 in^2 and likely more than 500 in^2. These homes may have had baseboard heating or forced air heating and cooling systems in the 1000-1500 cfm range. This suggests wintertime basement insulation air barrier leakage rates approaching 50% or more of the house conditioned air circulation rate.

This circulation can cause winter time cold surface condensation, especially in humidified homes, behind the insulation on the above ground portion of the foundation, which when spring comes will melt and drain to the bottom of the wall where it creates mold growth. In the summertime, stack pressure flow decreases. The moisture wicking via foundation walls will dampen floor level cellulose materials with associated microbial growth

[5] American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 2009. Fundamentals Handbook: 16:14

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particularly in corners where temperatures behind the insulation are lowest and humidity highest.

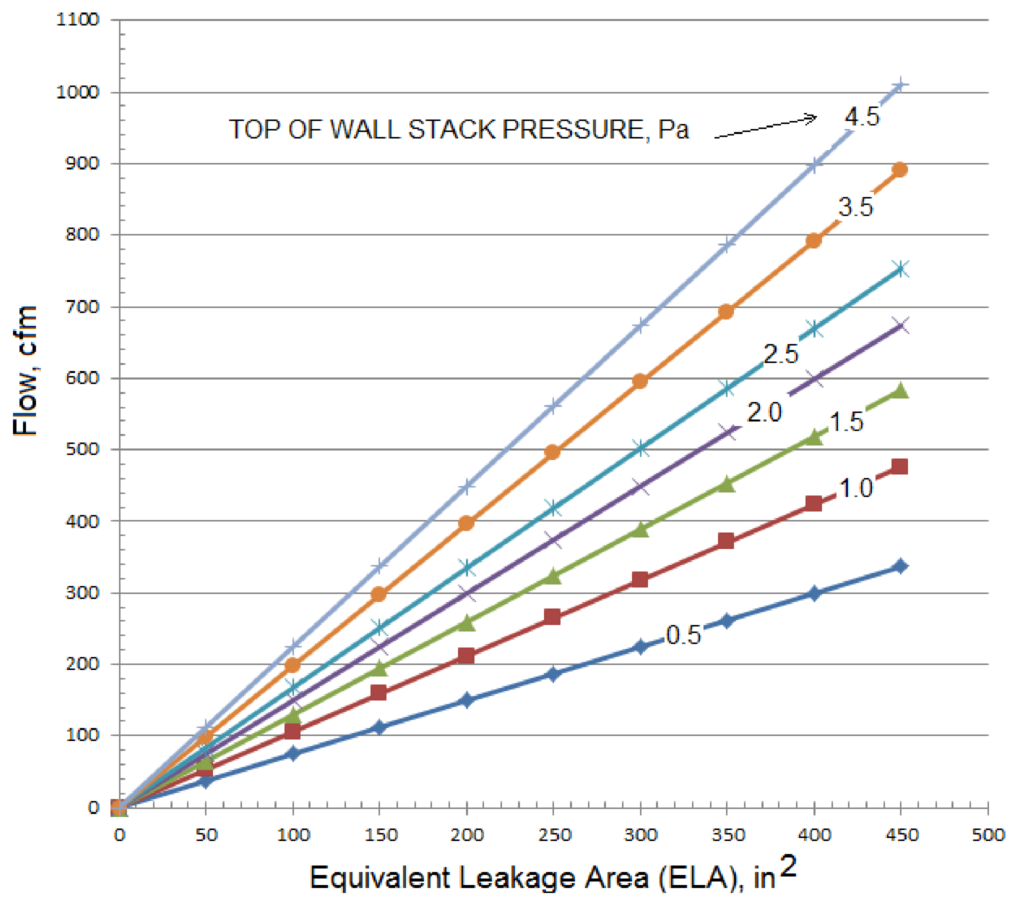

Figure 6 Conditioned airflow behind insulation versus ELA and stack pressure

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HEAT LOSS

Estimating Foundation Temperatures

A transient conduction model was made using heating degree days (HDD) weather data for Seattle with the following conditions:

Density of soil	120 lb/ft3
Thermal Conductivity of soil	0.8 Btu.ft/hr.ft2.ºF
Specific heat of soil	0.345 BTU/lb.ºF
Density of concrete	65.5 lb/ft^3
Concrete thickness	8 in.
thermal conductivity	0.439 Btu.ft/hr.ft^2.ºF
Fiberglass insulation thickness	3.5 in.
thermal conductivity/in.	0.27 Btu.in./hr.ft^2.ºF
Plywood thickness	0.5 in.
thermal conductivity	2.12 Btu/hr.ft^2.ºF
Inside air film thermal conductivity	1.5 Btu/hr.ft^2.ºF
f to inside of concrete	1/(1/1.5+3/0.27+1/2.12) =0.0816 Btu/hr.ft^2.F
Outside effective film thermal conductivity based on forced convection (15 mph wind max) and sky radiation	6.0 Btu/hr/ft2-F
Far field (ground water) temperature	52 F
Daily temperature time, theta	$(n_{day}/365)(2\pi)-0.75\pi$ (Jan 1 is n_{day}=1) radians
Daily temperature variation	T_{mean}=52+12.45.sin(theta)
Hourly variation	$T_{outside}=T_{mean}+12(\text{time of day}/24)-2\pi$
Solution time step	0.01 hours

Effect of daily variation in temperature

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The first simulation was run to determine the short-term temperature variation on cold days (20 F mean temperature). The inner concrete wall temperatures seemed to reach a (slowly ramping down) equilibrium after 72 hours. The sinusoidal variation in concrete temperature with time reduces with depth. At about 1/2 ft. depth (line B in Figure 8), the sinusoidal variation is nearly gone, and the long-term seasonal variation is more significant. This thermal behaviour justifies the use of overall daily averages in the calculation of energy loss.

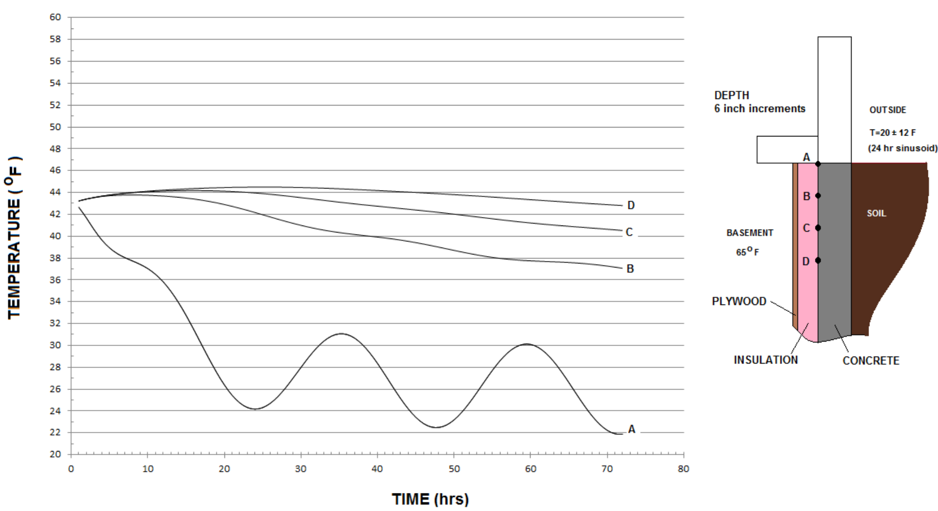

Figure 7 Effect of daily temperature variation on inside basement wall temperatures on a cold (20 F) day

An equation was fit to the average temperature from the Heating Degree Days (HDD) for the Seattle area and is compared in Table 1

$$\text{theta}=(n_{day}/365)(2\pi)-0.75\pi \quad (\text{Jan 1 is } n_{day}=1) \text{ radians}$$

Table 1 Comparison of the equation for daily ambient temperature variation to that from HDD

month	theta radians	mean temperature from equation	Heating degree days	number of days m	n_{day}	Average from heating degree days =65-HDD/m
Jan	-1	39.5483871	828	31	1	38.29032258
Feb	-0.866	41.21690323	678	28	31.33333	40.78571429
Mar	-0.5	45.77419355	657	31	61.66666	43.80645161
Apr	0	52	474	30	91.99999	49.2
May	0.5	58.22580645	295	31	122.3333	55.48387097
June	0.866	62.78309677	159	30	152.6667	59.7

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July	1	64.4516129	56	31	183	63.19354839
Aug	0.866	62.78309677	62	31	213.3333	63
Sept	0.5	58.22580645	162	30	243.6666	59.6
Oct	0	52	391	31	274	52.38709677
Nov	-0.5	45.77419355	633	30	304.3333	43.9
Dec	-0.866	41.21690323	750	31	334.6666	40.80645161

The second simulation was run for 13 months, starting with January, to have correct initial conditions for the following January. Equations shown above for seasonal mean temperature for Seattle were applied as the air temperature boundary condition.

The warmest month was August, showing an average upper soil temperature near 64 F. While the coldest month showed an average upper soil temperature near 40 F. (Figure 9)

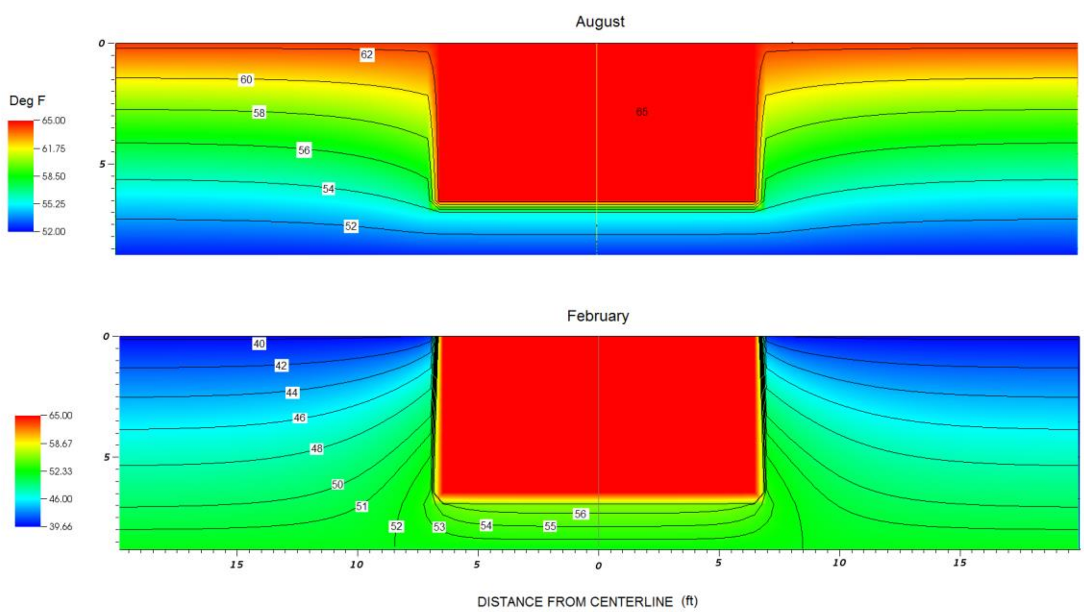

Figure 8 Temperature contours for warmest and coolest months

The average inner surface temperature contours for the insulated wall show that the upper sections are warmer than the lower sections during summer and reverse during winter (Figure 10). This raises the possibility for internal condensation on cooler wet surfaces due to evaporation from warmer wet surfaces within the envelope during any time of year especially when the envelope is tightly sealed.

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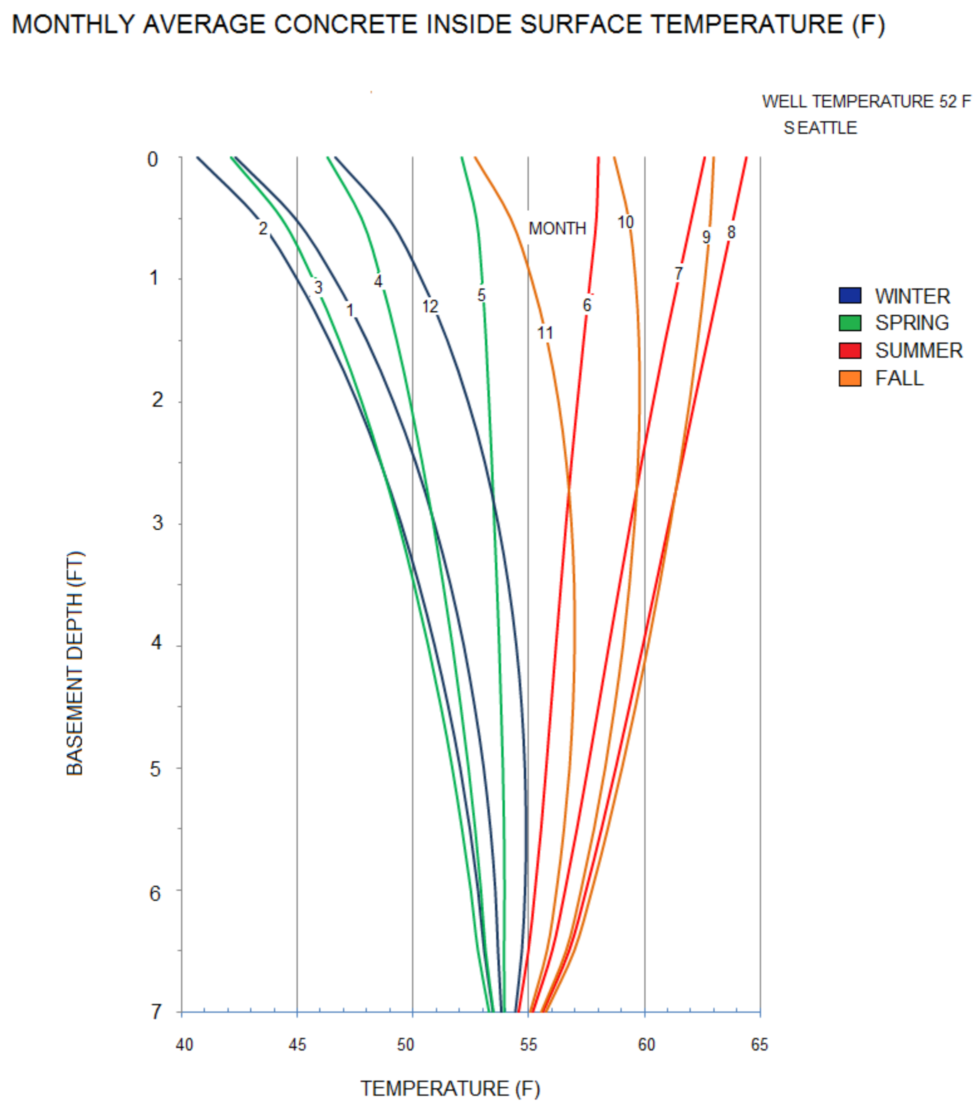

Figure 9 Inner concrete surface average monthly wall temperatures

When these surface temperatures are converted to Heating Degree Days, there is a clear distinction between the heating requirements of the house compared to the basement (Figure 11).

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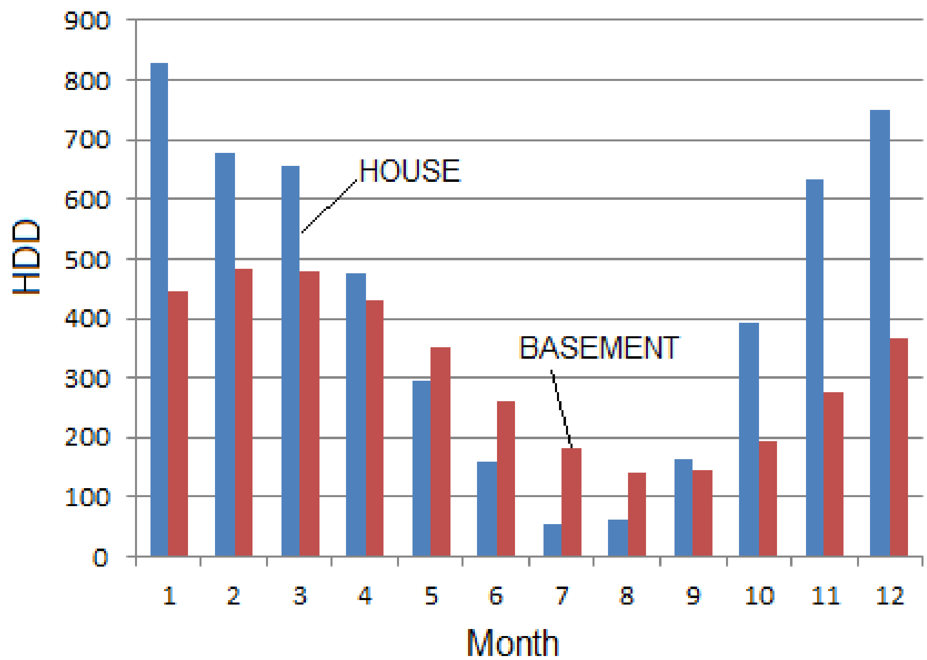

Figure 10 Heating Degree Days (HDD) environment for the above ground part of the house versus the insulated basement (Seattle)

In order to estimate the energy penalty of leakage through the envelope, some simple assumptions are made: that the stack pressure drives the flow, the stack pressure is derived from the averaged wall temperatures, the energy lost is related to leakage flow using the temperature entering and exiting the envelope.

$$E = \rho g Q c_p (T_a - T_{env\ exit})$$

$$T_{env\ exit} = T_{concrete} + 0.292(T_{wall} - T_{concrete})$$

$$Q = C(ELA)\sqrt{dp/\rho}$$

E	Energy lost due to envelope leakage BTU/s
T_a	Temperature of air in basement=65 F
T_{wall}	Average monthly temperature for inner surface of the concrete
$T_{env\ exit}$	Air temperature exiting the envelope* F
ρ	Density of air in basement, slug/ft^3

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Q	Leakage flow, ft^3/s
c_p	Specific heat of air, 0.24 BTU/lb F
dp	Stack pressure from equation, lb/ft^2 (=Pa/47.88)
g	Gravity acceleration, 32.2 ft/s^2
C	Flow coefficient, 0.3 for glass wool loosely filled envelopes
A	Physical leakage area, ft^2
ELA	Equivalent leakage area= 35.3% A (includes flow in and out- in series), ft^2

*CFD models of 7 ft. tall wall, 3,5" insulation, K=0.27 BTU-in/hr-ft2-F, permeability $3x10^6$ Darcy's, at given temperatures, show factor or 0.292 (i.e. simple average factor is 0.5)

After some unit conversions, the monthly variation in energy loss for physical leakage area is shown for the Seattle area (Figure 12):

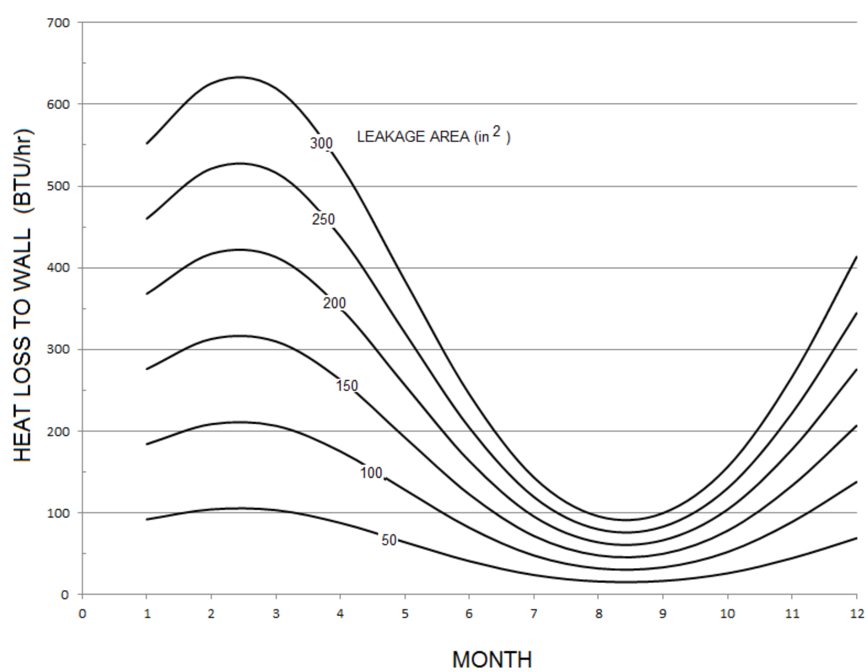

Figure 11 Heat loss due to envelope leakage for a basement in the Seattle area, C=0.3

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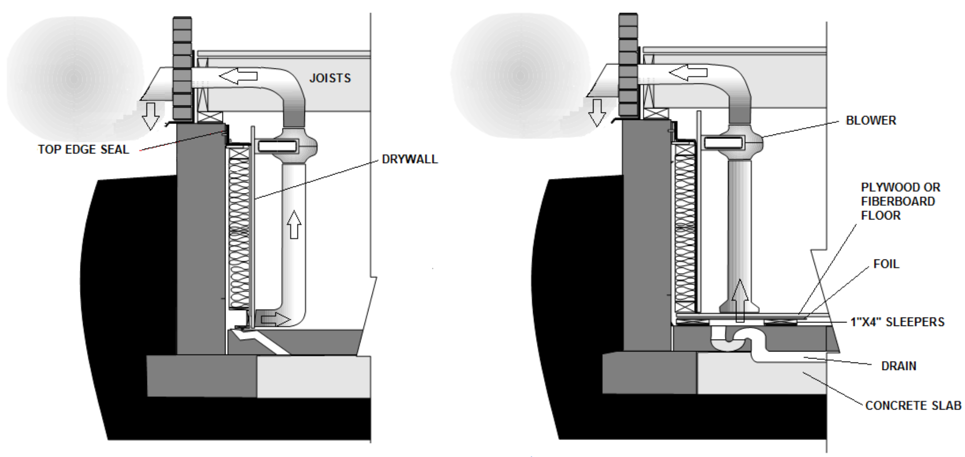
THE ECHO SYSTEM ENVELOPE SEALING and VENTILATION SOLUTION

Construction of an ECHO System is exacting, requiring sealed perimeter wall and floor insulation envelopes that can be readily depressurized by at least 2 Pascals by a small continuous duty blower, typically with envelope ventilation flows half that of a bathroom fan. These flows remove soil gases and moisture that are drawn into basements by building stack pressures before they can enter the living space or damage susceptible envelope materials. Any water leaking though foundation cracks is removed by this ventilation and as a safety measure, by drainage, without ever reaching susceptible materials.

Figure 13 illustrates typical basement foundation walls and slabs, and a tightly sealed stud wall, and a stud wall and subfloor insulation envelope system constructed over top. The basement foundation walls can be poured concrete, concrete block, and rubble mound. Typically, there is a concrete slab floor. Sometimes the basement floor is just the ground soil, bedrock, or a gravel layer and poly over the soil.



Drained & depressurized wall & sub-slab

Drained & depressurized wall & sub-floor

Figure 12 Main elements of depressurization system (a) wall only and (b) wall and floor

The top wall edge seal is above the ground level and below the joists supporting the floor above (figures 13a and 13b). This creates a flow blocker near the bottom of the coldest section of insulated wall as well as the top of the underground wall. This "L" shaped seal near the top of the wall creates a tight air seal and minimizes airflow from outdoors into the envelope system and reduces stack pressures affecting air leakage into the insulated space above.

The plywood or fibreboard floor (Figures 13b and 14b) continues the sealed wall "cavity" envelope with 4'X8' sheets that are sealed at joints which are positioned over 1"x4" sleepers on spaced sill plate gasket shims if over a concrete slab. The subfloor has aluminum foil paper (shiny side down giving an R4 insulation value) over the sleepers which themselves are supported on spaced and folded sill plate gasket 'shims' on the slab so as to allow air and water if there is foundation leakage to pass underneath. The sleepers can be replaced by dimpled plastic sheets, dimples down, in which case the R4 insulation value is lost. There is a standard water drain within the floor system as well as one on top of the subfloor system.

A continuous duty blower exhausts the envelope air to the outdoors (Figures 13a, 13b and 14a). The blower exhaust rate is controlled by a 3-speed fan control set according to the reading of a differential pressure gauge measuring the pressure differential between the basement and the sealed envelope in units as small as 2 Pascals.

The sealed envelope is pre-commissioned prior to the drywall going up and if depressurization versus exhaust rate is too low (less than 10 Pa at 85 CFM), leaks are searched using a smoke pencil, found, and sealed.

Once deemed acceptable the drywall and baseboards are installed and the floor finished as desired with hardwood, carpet, tile etc. The system is then final commissioned, and the minimum ventilation rate set for summer and winter. Emissions from basement sump pits normally connected to perimeter weeping tile are also separately exhausted by this system.

The sealed envelope system is continuously depressurized by at least 2 Pa (Figure 4b) year-round typically by a flow in the 10-30 CFM range, with air taken from the living space and exhausted outdoors. This exhausting provides continuous energy efficient low-level house ventilation and envelope air contaminant and moisture exhaust. It is energy efficient with the exhaust air drying the envelope insulation, warming the envelope while house radiant heat loss warms the replacement air entering via above-ground walls leaks. At the same time, the exhaust air with its soil gases such as radon, microbial, concrete and envelope sealant material off gases, cannot enter the living space where otherwise these can only be addressed by considerably less efficient whole house ventilation dilution and filtration. The occupants will know if the system is working properly by observing the depressurization instrumentation shown in Figure 18 and, if necessary, they can always adjust the blower exhaust rate to ensure system depressurization relative to the living space . Some wall and floor areas of the basement are not covered by this system (e.g. the electrical circuit board and the furnace and hot water tank).

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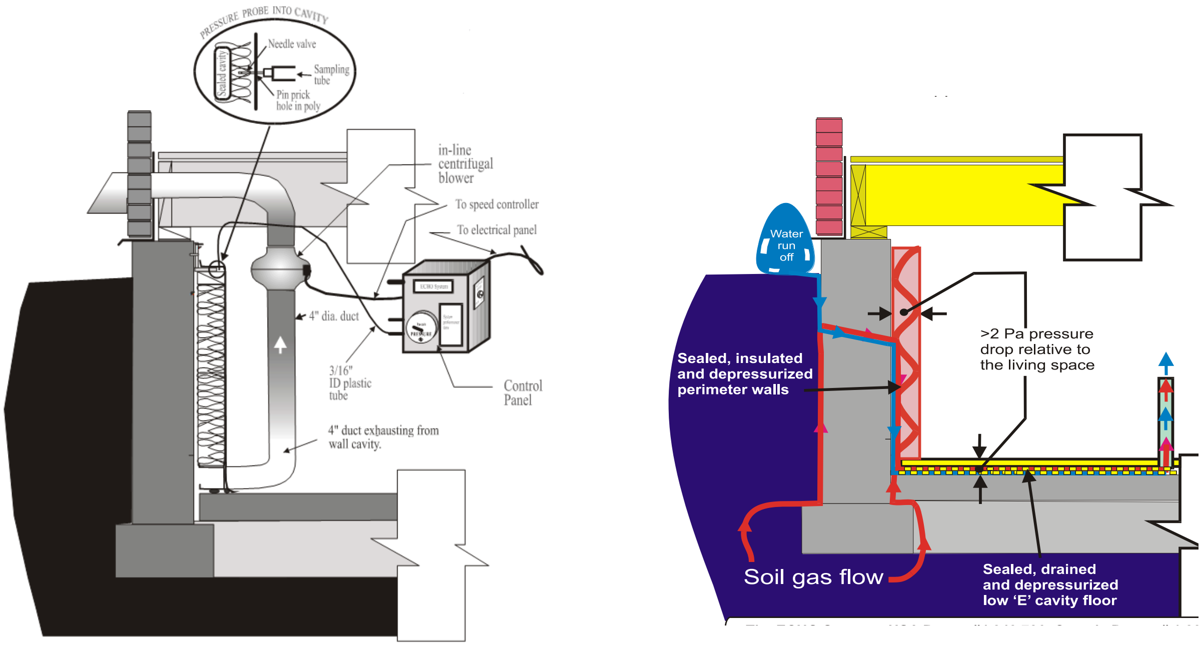

Figure 13 Depressurized (a) insulated wall with blower and control panel; (b) insulated wall and Low E floor with leaking cracked foundation wall.

The system is robust, surviving even sewer backups that raise water levels above the floor. Some are 3 decades old and have maintained their same tightness. It helps prevent living space interior condensation and high humidity by preventing the humid air in the envelope from entering the basement living space, by removing the soil moisture wicking through the concrete footings and slabs. This can be as much as 2 gallons per day in summer - moisture that would otherwise be trapped by standard basement finishing and summertime stack pressures. Note that if house living space air humidity is above 65% it can cause microbial growth inside the living space. So, while this system helps reduce house humidity, it does not replace air conditioners or dehumidifiers. These devices are required to maintain living space humidity below 65% (target 50% in an open area in the basement) in summer high humidity conditions.

This design is approved by the Ontario Building Code as an acceptable foundation water leakage protection system. Foundation water leakage is either evaporated or drained from the envelope without causing any damage to the system or the finishing materials. It has been used as a back- up to exterior foundation leakage protection systems that can or have failed. Such failures can happen when the perimeter footing weeping tile clogs up and/or there are edge sealing or other imperfections in exterior foundation surface coatings and membranes.

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Since the soil is colder than the living space year-around (e.g., 8-9 ºC at foundation depth; -3 to 0 oC at the surface in winter and near average air temperatures in summer), temperatures between the insulation and the foundation wall are always colder than in the living space. Exhausting building air through the cavity has a slight warming effect. On average the cavity air temperature behind the insulation is ~10ºC and ECHO wall stack pressures offset system depressurization by some 0.5 Pa.

Building stack effect pressures further offset (or augment during building air-conditioning in hot weather) ECHO system depressurization. The amount depends upon both building envelope leakage quantities and leakage locations. For example, an ECHO System covering a block wall will be more affected by building stack effect than one over a poured concrete foundation. A two-storey house with a tight envelope or a chimney leading from the basement will produce greater offsetting pressures on the system than a house with a leaky envelope or an open furnace make-up air duct. In theory a two-storey house might induce stack pressures up to ~4 Pa. In practice, wall cavity stack pressures to be offset range up to 2 Pa, with hight values in winter.

As a result, an ECHO System depressurization of 1 Pa will offset stack pressures during the non-heating season - a period when mold and material offgasing are generally highest. A 1 Pa depressurization will also offset heating season stack effect in many installations most of the time. However, in some houses, a 2-3 Pa depressurization will be required in cold weather. In homes with concrete block foundation walls, higher ECHO System depressurization may coincidentally depressurize the block cavities. If so, the entry of block and soil gases into the house via block >chimneys= and through small cracks in the top of the wall will also be prevented. Again, such depressurization will have to be higher in winter.

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EQUIVALENT LEAKAGE AREA (ELA)

The objective is to create a tightly sealed perimeter wall subfloor insulation envelope and to depressurize this envelope to the outdoors with a continuous duty blower with low exhaust air flow. Well-sealed, low ELA ECHO Systems covering the walls and floor of a 1000 ft^2 basement will depressurize by 10 Pa or more with an 80 CFM exhaust rate prior to dry wall installation and by 2 Pa or more at 10-30 CFM after drywall installation. From Table 2 ELA calculations indicate ELAs for typical ECHO Systems range from 7-20 in^2.

Table 2 Calculated Equivalent Leakage Area (ELA) vs Blower Exhaust Rate and System Depressurization, dP

		Exhaust, CFM										
	dP, Pa	10	20	30	40	50	60	70	80	90	100	110
ELA, in^2	2	7	13	20	27	33	40	47	53	60	67	73
	5	4	8	13	17	21	25	30	34	38	42	46
	10	3	6	9	12	15	18	21	24	27	30	33
	15	2	5	7	10	12	15	17	20	22	24	27
	20	2	4	6	8	11	13	15	17	19	21	23
	30	2	3	5	7	9	10	12	14	16	17	19
	40	1	3	4	6	7	9	10	12	13	15	16
	50	1	3	4	5	7	8	9	11	12	13	15
	60	1	2	4	5	6	7	9	10	11	12	13
	100	1	2	3	4	5	6	7	8	8	9	10

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MOLECULAR DIFFUSION

Trace amounts of contaminant gases can escape from a depressurized ECHO System into the house through a phenomenon known as molecular diffusion. The quantities of cavity gases entering the house via diffusion depends upon the system ELA, tightness of the drywall, and the system exhaust rate.

Molecular diffusion of a gas is calculated from

$M_d = D * (\rho_2 - \rho_1) *A/L$ (5)

where

M_d = mass transfer of a gas or vapour due to diffusion

D = mass diffusivity for the gas in air

$\rho_2 - \rho_1$ = partial density gradient of the gas

A = cross sectional area over which diffusion takes place

L = length over which diffusion occurs

Mass diffusivity of a gas varies inversely with the square root of its molecular weight. Thus, the mass diffusivity coefficient D for radon is 0.46 times that for ethanol. For methane, D is 1.7 times that for ethanol.

Diffusion of a gas from an ECHO wall is countered by its convective mass transfer back into the wall. Convective transfer is calculated using

$M_c = C_1 * Q$ (6)

where

M_c = mass transfer due to convection (mg/s)

C_1 = concentration of the gas (mg/m^3)

Q = flow (m^3/s)

For example, an ECHO cavity may contain mold gases entering from the soil. For a tight ECHO system (poly ELA = 42 cm^2, drywall ELA = 84 cm^2), mass transfer of ethanol (a microbial offgas, D = 11.9) due to diffusion in still air would create a concentration in the living space of ~ 0.1% of the cavity concentration with the drywall in place and a cavity exhaust rate of 5 L/s. With only the poly in place, the living space concentration would be some 6% of the cavity concentration. It should be noted that since diffusion entry from

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the ECHO cavity is not through still air, but upstream through air currents, these values are overestimates.

For a leaky ECHO System (poly ELA = 477 cm^2, drywall ELA = 954 cm^2), mass transfer of ethanol due to diffusion would create a concentration in the living space of ~ 0.2% of the cavity concentration with the drywall in place and a cavity exhaust rate of 40 L/s. With only the poly in place, the living space ethanol concentration with a leaky ECHO System would be some 16% of the cavity concentration.

From the above, diffusion of gases is likely to be unimportant for properly built, finished, and commissioned ECHO System construction.

WATER VAPOUR TRANSFER

Unperturbed soil (e.g., under foundation wall footings) generally has high water content. This soil moisture passes through concrete via capillary action. Once inside a conventionally finished basement, it is trapped inside stud wall and subfloor cavities, and under carpets. Stack effect pressures prevent circulation of house air through these cavities (except in air-conditioned houses during hot weather when it does little good), eliminating convective transport. This leaves diffusion.

For a water vapour concentration of 9600 mg/m^3 in a stud wall cavity, a drywall leakage area ELA = 1000 cm^2, and a living space concentration of 6,000 mg/m^3 , moisture transfer via diffusion into the basement living space would be at the rate of less than 0.7 mg/s.[6] Over a day this equates to 60 gm of water. Moisture entry through foundations (excluding leakage) typically ranges between 2.5 and 10 kg/day. Hence, diffusion has negligible impact on removing the soil moisture entering wall and subfloor cavities, and even >dry= finished basements can become moldy.

n the other hand, the convective removal used by an ECHO System is effective. For example, for a cavity air moisture concentration of 9,600 mg/m^3 and a living space moisture concentration of 6,000 mg/m^3, convection removes between 18 mg/s to 144 mg/s (1.6 and 12.4 kg/day) for ventilation rates of 5 and 40 L/s, respectively - rates of removal comparable to basement moisture entry rates.

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[6] A water vapour concentration of 9600 mg/m^3 equates to 100 % relative humidity in air at 10°C or 60% RH in air at 20°C. A water vapour concentration of 6000 mg/m^3 equates to 40% relative humidity in air at 20°C.

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ISN'T BASEMENT VENTILATION EQUALLY EFFECTIVE?

An important note to make: the infiltration energy loss from the basement is like the infiltration from the house above ground, *without the benefit of fresh air quality*. This air contains odours and gases emitted from wet soils and concrete or other things that might incubate in the envelope.

For example, the worst scenario would be a house and basement that does not use forced air heating. Instead it uses point sources like electric heaters or heat pump split units. Since the only connection between levels is the stairway, the stairway is the only path for dilution of "basement gases". If the recommended envelope flow of 10-30 cfm is simply circulated to the basement instead of through the envelope to the outdoors, the basement contaminant gas levels remain high.

A simple compartment model shows that basement gases for a flow of approximately 30 cfm would only drop about 12% to 88% of a closed basement (Figure 15a). A split unit CFD model with species equations added, shows worse, dropping about 8% to 92% (Figure 15b).[7]

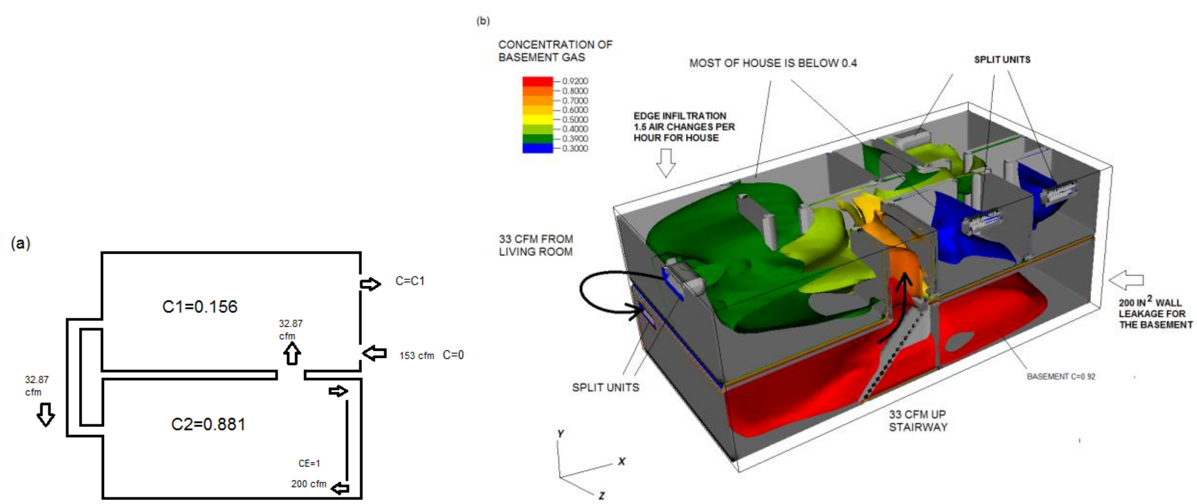

Figure 14 Compartment flow(a) and CFD(b) estimates of "basement gas" dilution

With the depressurization system properly working, these basement gas levels essentially drop 100% to a level of 0% in the basement breathing air

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[7] California State University. 2014. Center for Energy and Environmental Research and Services split unit prototype code.

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CONCLUSIONS

1. The ECHO System is an integrated method for the construction and mechanical ventilation of basements to improve air quality. It eliminates or reduces mold and similar airborne contaminants growing in basement insulation envelopes, crawl spaces and sump drainage systems, excess humidity, radon gas, and energy loss. The extra seal measures taken while requiring some extra time to make the seal tight enough, are in principle simple to implement, working with existing construction methods and materials. Careful attention is given to sealed air barriers, and continuity of the insulated wall and floor, the crawl space and sump pit cavities with low-level ventilation of these cavities to the exterior. The design is supported by a demonstration of the results of stack effect within typical existing basement wall assemblies which currently contribute to heat loss, mold growth, and poor air quality. The addition of very low-level continuous ventilation greatly improves the passive performance of the physical construction.

2. What makes this ECHO ventilation special is that each component (ECHO Wall, ECHO Subfloor, ECHO Sump Pit, ECHO Crawl Space) is vented and depressurized throughout relative to the adjacent living space at the lowest possible flow rate. This makes ECHO not only the most certain solution to the typical air quality problems associated with each, but also the most energy efficient. Further ECHO Walls and Floors are drained as well as ventilated making them both a safe and certain solution to foundation leakage and helpful in sewer back-ups.

3. At least 10% and perhaps 50% or more of the building conditioned air circulates behind the insulation in standard batt-insulated finished basements under winter-time stack pressures in Canadian and northern US houses and buildings, increasing heating costs commensurately.

4. Standard batt-insulated finished basements may not only be wasting wintertime heating energy, their insulation systems may also be hiding winter-time condensation and bringing damp envelope concrete and cellulose microbial offgasing and allergenic aerosols, and soil air contaminants into the living space where they can only be addressed by costlier and less efficient whole house ventilation and filtration systems.

5. This heat loss and potential air contamination warrants the attention of building code setting bodies and agencies promoting building energy conservation and the benefits in this regard of healthy as well as energy efficient finished basements in homes.

6. The solution described for the stack-induced air flow problem as well as for foundation leakage damage mitigation has worked for the many installations built over the last three decades. It has not only kept basements odour-free and comfortable and the envelope materials dry and performing as designed. It has conserved winter-time

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heating energy, provided an air barrier to soil gas entry both under the slab and through foundation walls, and solved foundation leakage and sewer back-up problems. The solution described is approved as a foundation drainage system and, if retrofit, solves foundation leakage problems without costly exterior excavation. The annual cost to operate the blower continuously is about $10-20 and blowers are typically lasting 20 years or more under continuous operation. This ventilation removes typical basement envelope and soil gas air pollutants with a small amount of ventilation air, something a standard heat recovery ventilator cannot do as completely with a much larger flow rate. It is energy efficient ventilation as the air exhausted from the basement gives up a portion of its heat as it passes through the insulation envelope and the basement air that replaces it comes from above ground infiltration air that has absorbed some of the house radiant heat loss. Home builders should consider developing the tools and skills necessary to seal and depressurize the envelope adequately. This solution has been used in other applications including creating common wall air barriers around smoking rooms, and between contaminated and occupied above-ground spaces.

7. Foamed-in-place insulation over interior foundation walls will prevent conditioned air from travelling behind foundation insulation. However, it is expensive, requires fire-rated drywall over it, and makes retrofitting electrical outlets and bathroom vent pipe outlets difficult. Further, unlike the solution proposed, it does not solve a foundation leakage problem without having to dig outside the foundation to seal cracks. Neither can it mitigate sewer back-ups. Finally, if there is a fire, post-fire odour clean-up is more difficult. Hence its use is mainly limited to sealing and insulating foundation walls above the sill plate, and insulating envelopes where flooding has occurred.

8. The ECHO Subfloor prevents radon and other soil gas entry into the living space where sub-slab depressurization will not in the absence of a continuous gravel layer under the slab which is often the case in older houses.

9. This ECHO System concept of controlling insulation envelope vs living space pressure differential to prevent deleterious stack pressure induced flows is being considered for passenger aircraft implementation as well. There it promises to prevent some 25% of the cabin ventilation air entering the insulation envelope and bypassing the passengers for whom it is intended. Coincidently, ECHO envelope pressurization (not depressurization for this application) will prevent cabin air humidity condensing on the cold fuselage behind the cabin insulation. Preventing this condensation will automatically raise the cabin humidity to more healthy levels. This is important, as cabin relative humidity currently is very low (~ 10% during flights after the first hour), and low humidity compromises our immune defences against viral infections such as from COVID-19 and influenza, and turns cough and sneeze droplets into aerosols which stay in the air longer travel further and penetrate deeper into the respiratory system causing more serious infections.

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