Project: DFCM Infiltration Study
Date: August 15, 2013

Summary:

By requiring building infiltration rates to be reduced from an average construction value of 0.5 cubic feet per minute per square foot (CFM/FT^2) of envelope area to 0.1 CFM/FT^2 of envelope area, utility costs can be reduced by $0.06-$0.19 per square foot of envelope area.

Synopsis:

Infiltration is defined as uncontrolled outside airflow into a building. Infiltration typically occurs through cracks in the building envelope, joints between building envelope types, such as walls and windows, and openings to the building, such as doors and windows. Variations in building design, construction industry personnel, as well as the means and methods by which buildings are constructed, cause tested building infiltration rates to vary by as much as 0.1 CFM/FT^2 to 2.25 CFM/FT^2 of envelope area.[1] Building infiltration is tested per ASTM STP719, which requires the building be negatively pressurized to 75 Pascal, at which the infiltration rate is measured in CFM/FT^2 of envelope area. Actual building infiltration varies considerably, and is affected by a wide variety of factors including, building construction, stack effect, wind speed, outside and inside temperature, different HVAC systems, and occupant behavior.

Utah Division of Facilities Construction & Management (DFCM) contracted with Colvin Engineering Associates Inc. (CEA) and Architectural Testing Inc. (ATI) to determine the feasibility and energy cost savings of including an infiltration requirement in the State of Utah's High Performance Building Standard (HPBS). Through a series of meetings with DFCM, ATI, and CEA it was determined that an infiltration rate of 0.1 CFM/FT^2 of envelope area was readily achievable without unnecessary burden on the design or construction team and would be used as the Baseline measurement for the study.

CEA analyzed nine DFCM projects and three private development projects that were in various stages of development, from early design to completed construction and occupied. To analyze these projects CEA used the energy modeling software Trane Trace™. Trane Trace is based off the Energy Plus[2] engine developed by the US Department of Energy, and is considered the most advanced energy modeling engine available at the time. When performing an energy model for a building, the building is created virtually, within the software, including all building components, such as the envelope areas, (walls, windows, and roof) construction and insulation types, internal loads, (ie. people, lights, and equipment) HVAC systems, and HVAC plant equipment. A schedule of each building component is applied, and the building is simulated for an entire year of operation using a typical weather data file from the National Renewable Energy Laboratory (NREL). Results from the energy model are useful to determine the relative difference and impact changes to the building will make, before constructing the building.

Each project was simulated using minimally code compliant envelope construction, lighting, and HVAC equipment, (Baseline) as well as actual or designed envelope construction, lighting, and HVAC equipment (Proposed). The projects were simulated using ASHRAE 90.1-2007 Appendix G protocol. ASHRAE 90.1-2007 Appendix G protocol is accepted as the most accurate to determine relative impacts of building changes be many organizations, including the IRS, US Green Building

[1] ASHRAE 2009 Fundamentals ISBN 978-1-933742-54-0
[2] www.trane.com

Council, and Designed for Energy Star. DFCM, ATI, and CEA analyzed three different infiltration rates, as defined by the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE), tight construction 0.1 CFM/FT^2 of envelope area, average construction 0.5 CFM/FT^2 of envelope area, and leaky construction 0.8 CFM/FT^2 of envelope area. Due to the complexity of infiltration, the wide variety of factors that can affect the infiltration rate, and the relatively new development of energy modeling software, the infiltration modules within all energy modeling software is not fully developed. Infiltration rates can only be entered into the energy modeling software as CFM/FT^2 of above grade exterior wall area. The energy modeling software then varies the infiltration volume by the outdoor wind speed, from the typical year weather file[3]. In addition to the simulations of 0.1 CFM/FT^2 of wall area, 0.5 CFM/FT^2 of wall area, and 0.8 CFM/FT^2 of wall area, two projects were simulated at additional infiltration rates, to determine if the results could be appropriately extrapolated from CFM/FT^2 of wall area to CFM/FT^2 of envelope area. This analysis showed that the results could be appropriately.

Infiltration can have a significant impact on not only the annual energy consumption, but also the size of the HVAC equipment required to condition the uncontrolled air introduced to the building. In addition to annual energy cost savings, the study also focused on the reduced HVAC conditioning capacity and the saving associated with reducing the equipment size.

Infiltration not only affects annual utility costs but also thermal comfort of the occupants. Drafts of more than 50 feet per minute across the occupants head can negatively affect occupant comfort and task performance[4]. The quantifiable savings from decreased thermal comfort due to infiltration is beyond the scope of this study. However, the importance should not be overlooked with developing a proposed infiltration rate for the HPBS.

Summary of results table:

A description of each column in the results table is offered below.

Project Name - Name of the project. Note that to protect the clients interest, private development projects have not been named explicitly.

Climate Zone - ASHRAE 90.1-2007 defined climate zone for each building location. Generally the lower the number the hotter the climate. The B represents a dry climate.

Gross Floor Area - Gross floor area of the entire building.

Floors - Number of floors on the project.

Gross Above Grade Wall area - Area of above grade walls adjacent to conditioned spaces.

Gross Wall Area (Above and Below Grade) - Area of above and below grade walls adjacent to conditioned spaces.

Roof Area - Area of all roofs.

Glazing Area - Percentage of above grade walls that is glazing. Glazing is defined by ASHRAE 90.1-2007.

Proposed or Baseline - If the results presented are from the Baseline model or Proposed model as defined by ASHRAE 90.1-2007 Appendix G.

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[3] Typical Year Weather files are obtained in TMY3 format from NREL.gov
[4] ASHRAE 2009 Fundamentals ISBN 978-1-933742-54-0

Primary HVAC System - The predominate HVAC system installed on the building. Other smaller systems may be present on the project for specific individual rooms.

Infiltration Rate per Wall area - Simulated infiltration rate per unit of above grade exterior vertical wall area.

Electric Cost - Results of annual electricity costs.

NG Cost - Results of annual natural gas costs.

Purchased CHW - Results of annual purchased chilled water costs.

Purchased HTW/Steam - Results of annual purchased High Temperature Water or Steam costs.

Total Utility Cost - Total of all annual utility costs for the project.

Gross CLG Plant Size - Total required peak cooling capacity of the HVAC source equipment.

Gross Heating Plant Size - Total required peak heating capacity of the HVAC source equipment.

Comments: - Additional information about the project that may affect the results from what is expected.

Results Interpretation: - A short summary of the results, as well as an explanation of any abnormalities in the results.

Total Envelope Area - Total area of the building envelope within the air barrier. This information was not available for some projects, and therefore, it was assumed to be:

$$Total\ Envelope\ Area = 2x\ roof\ area + Gross\ Wall\ Area$$

Ratio of Wall area to Envelope Area - Ratio of wall area to Envelope Area:

$$\text{Ratio of Wall area to Envelope Area} = Total\ Envelope\ Area/Gross\ Wall\ Area$$

Infiltration rate per Envelope Area - Infiltration rate per unit of whole building (all exterior surfaces within the air barrier) envelope area.

Leakage per wall area - Equivalent leakage rate of infiltration per unit of wall area, given infiltration rate per unit of envelope area.

Extrapolated utility costs per envelope area - Extrapolated costs from simulations using infiltration rates in units of wall area to units of envelope area.

Additional Utility Costs per Envelope Area (0.1 CFM/FT^2 Baseline) - Additional annual energy cost with different rates of infiltration per unit of envelope area. 0.1 CFM/FT^2 was the Baseline comparison.

UT DFCM Infiltration Study Results CEA 1/28/2013	Building Data									Modeling Results										Extrapolated Energy Cost Savings Results					
Project Name	Climate Zone	Gross Floor Area	Floors	Gross Above Grade **Wall** Area	Gross **Wall** Area (Above and Below Grade)	Roof Area	Glazing Area	Proposed or Baseline	Primary HVAC System	Infiltration Rate per W**all** area	Electric Cost	NG Cost	Purchased CHW	Purchased HTW/Steam	Total Utility Cost	Gross CLG Plant Size	Gross Heating Plant Size	Comments:	Results Interpretation:	Total **Envelope** Area	Ratio of **Wall** area to **Envelope** Area	Infiltration rate per **Envelope** Area	Leakage per **wall** area	Extrapolated Utility Costs per envelope area	Additional Utility Costs per Envelope Area (0.1 CFM/FT2 Baseline)
(-)	(-)	(ft^2)	(#)	(ft^2)	(ft^2)	(ft^2)	(%)	(P/B)	(-)	(CFM/ft^2 of Wall)	(Annual $)	(Annual $)	(Annual $)	(Annual $)	(Annual $)	(Tons)	(Mbh)	(-)	(-)	(ft^2)		(CFM/ft^2 of Envelope)	(CFM/ft^2 of Wall)	($)	($/ft2)
UU Dee Glen Smith Athletic Center Expansion	5B	117,622	2 + Partial Basement	43,324	53,091	60,706	18.9%	B	Packaged VAV w/ reheat (90.1-2007 App. G System #5)	0.1	$184,551	$95,769	N/A	N/A	$280,320	447.5	8894.5	Unusually large process loads, extensive food service, and rather large exhaust volume.	For this size of building, the effects of infiltration appear less significant than actual, in terms of percentages, due to the unusually large utility cost, and plant sizing, which is a function of such high process loads and exhaust requirements.	174,503	4.03	0.1	0.403	$285,004	-
										0.5	$187,952	$98,957	N/A	N/A	$286,909	473.1	9609.3					0.5	2.014	$309,928	$0.14
										0.8	$190,323	$100,826	N/A	N/A	$291,149	489.7	10090.7					0.8	3.222	$328,622	$0.25
								P	IDEC VAV w/ reheat (condensing boilers)	0.1	$154,196	$87,474	N/A	N/A	$241,670	440.1	8640.6					0.1	0.403	$243,596	-
										0.5	$154,523	$89,655	N/A	N/A	$244,178	452.3	8736.8					0.5	2.014	$253,843	$0.06
										0.8	$155,019	$91,103	N/A	N/A	$246,122	457.8	8775.2					0.8	3.222	$261,528	$0.10
SLCC Instructional & Administration Building	5B	151,133	4 + Partial Basement	73,843	92,753	42,898	33.5%	B	VAV w/ reheat (90.1-2007 App. G System #7)	0.1	$116,568	N/A	$19,160	$19,355	$155,083	501.9	10543.5	Model is based on LEED Treatment of District Thermal Energy Option 1.	Due to the unusually high ratio of wall to floor area, it was expected that more impact would be realized as a function of infiltration. However, a large number of perimeter zones have high occupant densities, and therefore, large internal thermal gains, which offset the effects of winter infiltration (and reduce winter cooling loads, in these spaces.) Additionally, there is a reduced occupancy, in summer months which also reduces the effects of infiltration, for occupied hours.	178,549	2.42	0.1	0.242	$157,013	-
										0.5	$117,434	N/A	$19,256	$23,973	$160,663	544.7	10967					0.5	1.209	$170,181	$0.07
										0.8	$118,214	N/A	$19,317	$27,082	$164,613	592.8	11642					0.8	1.934	$180,057	$0.13
								P	IDEC VAV w/ perimeter radiant heating	0.1	$104,504	N/A	$4,522	$26,042	$135,068	496.1	9752.2					0.1	0.242	$136,729	-
										0.5	$106,148	N/A	$4,993	$28,518	$139,659	516.5	10530.6					0.5	1.209	$148,056	$0.06
										0.8	$107,670	N/A	$5,339	$30,257	$143,266	533.5	11915.5					0.8	1.934	$156,551	$0.11
UVU Classroom Building	5B	223,949	5	81,550	81,550	67,380	40.0%	B	VAV w/ reheat (90.1-2007 App. G System #7)	0.1	$182,423	N/A	$34,174	$31,247	$247,844	821.2	16201.4	Model is based on LEED Treatment of District Thermal Energy Option 1. Iterations performed using Design Assist hypothetical Proposed model that does not necessarily represent final Construction Documents.	Because the models' definition for infiltration is based on a CFM/ft^2 of exterior wall, and the exterior wall is reduced, due to the large quantities of curtain wall glass/spandrel, the effects of infiltration are somewhat diminished. The same building with a lower glass/spandrel percentage would demonstrate greater effects due to varying infiltration rates, as performed in this study.	216,310	2.65	0.1	0.265	$249,799	-
										0.5	$183,167	N/A	$34,457	$35,040	$252,664	898	17238.4					0.5	1.326	$262,350	$0.06
										0.8	$183,881	N/A	$34,662	$37,582	$256,125	958.9	18195.6					0.8	2.122	$271,764	$0.10
								P	IDEC VAV w/ reheat	0.1	$174,130	N/A	$4,097	$26,359	$204,586	644.5	11033.3					0.1	0.265	$206,559	-
										0.5	$174,816	N/A	$4,117	$30,189	$209,122	686.4	11175.3					0.5	1.326	$219,224	$0.06
										0.8	$176,117	N/A	$4,136	$32,689	$212,942	730.6	11257.3					0.8	2.122	$228,723	$0.10
Provo Office Building (Private Development)	5B	158,401	6	84,490	84,490	50,913	40.0%	B	VAV w/ reheat (90.1-2007 App. G System #7)	0.1	$156,525	$39,413	N/A	N/A	$195,938	706.1	13714.6	Includes a significant sky-lit 4-story atrium that is served by radiant floor, in conjunction with displacement ventilation diffusers. Also includes a data center and some minor retail sales.	Due to the use of chilled beams, the heating plant size for the Proposed model iterations is relatively small, compared to more common primary HVAC system types.	186,316	2.21	0.1	0.221	$198,570	-
										0.5	$158,818	$45,492	N/A	N/A	$204,310	730.1	16324					0.5	1.103	$217,835	$0.10
										0.8	$160,711	$50,515	N/A	N/A	$211,226	758.3	18325.4					0.8	1.764	$232,283	$0.18
							46.5%	P	Active Chilled Beams	0.1	$151,049	$8,690	N/A	N/A	$159,739	683.2	7249.8					0.1	0.221	$161,724	-
										0.5	$151,717	$15,033	N/A	N/A	$166,750	708.4	10028.6					0.5	1.103	$176,253	$0.08
										0.8	$151,861	$19,408	N/A	N/A	$171,269	727.9	12012.3					0.8	1.764	$187,150	$0.14
Salt Lake City Office Building (Private Development)	5B	178,000	6	75,419	75,419	39,462	25.8%	B	VAV w/ reheat (90.1-2007 App. G System #7)	0.1	$167,440	$14,814	N/A	N/A	$182,254	394.5	6076.8	Models are based on LEED Core & Shell program protocol, not full build-out.	Zoning protocol for core & shell projects (4 perimeter & 1 core zoning per floor) is not necessarily an accurate representation of the effects of infiltration, for the full tenant-finished condition.	154,343	2.05	0.1	0.205	$184,292	-
										0.5	$168,352	$21,328	N/A	N/A	$189,680	427.5	7967.9					0.5	1.023	$200,233	$0.10
										0.8	$169,404	$26,482	N/A	N/A	$195,886	454.1	9961.4					0.8	1.637	$212,189	$0.18
								P	IDEC VAV w/ reheat	0.1	$137,702	$13,282	N/A	N/A	$150,984	347.3	7154.4					0.1	0.205	$152,259	-
										0.5	$137,734	$17,902	N/A	N/A	$155,636	377.7	9336.2					0.5	1.023	$162,234	$0.06
										0.8	$137,783	$21,731	N/A	N/A	$159,514	398.1	11001.9					0.8	1.637	$169,716	$0.11
Utah County Office Building (Private Development)	5B	278,144	5 + Partial Basement	130,980	138,826	80,085	40.0%	B	VAV w/ reheat (90.1-2007 App. G System #7)	0.1	$419,767	$55,571	N/A	N/A	$475,338	851.8	15,069.5	Project includes amenities building with cafeteria and gym.	The Proposed building includes a huge amount of glazing, and the perimeter zones are corridors. Both of which are not typical for office building construction.	298,996	2.28	0.1	0.228	$477,811	-
										0.5	$421,016	$62,422	N/A	N/A	$483,438	893.2	15,498.6					0.5	1.141	$495,416	$0.06
										0.8	$422,113	$66,721	N/A	N/A	$488,834	927.9	15,864.1					0.8	1.826	$508,619	$0.10
							64.3%	P	Parallel Fan Powered VAV Boxes w/ reheat and IDEC	0.1	$347,280	$19,386	N/A	N/A	$366,666	834.1	12,145.7					0.1	0.228	$369,107	-
										0.5	$348,704	$25,433	N/A	N/A	$374,137	981	14,986.9					0.5	1.141	$386,480	$0.06
										0.8	$348,818	$31,167	N/A	N/A	$379,985	1132.1	16,843.7					0.8	1.826	$399,511	$0.10
Dixie State Holland Centennial Commons	3B	170,070	5	66,158	68,918	36,300	40.0%	B	VAV w/ reheat (90.1-2007 App. G System #7)	0.1	$126,511	$24,314	N/A	N/A	$150,825	643.7	4,163.7	Project is located in St. George, Utah, which is ASHRAE climate zone 3B.	The climate in St. George allows re-heating energy to be offset by bringing in outside air directly, through infiltration. This would not be a good design because the space would be drafty and uncomfortable, the majority of the year.	141,518	2.14	0.1	0.214	$152,824	-
										0.5	$133,166	$24,717	N/A	N/A	$157,883	791.7	5,342.0					0.5	1.070	$167,841	$0.11
										0.8	$138,471	$24,639	N/A	N/A	$163,110	904.8	6,283.8					0.8	1.711	$179,103	$0.19
							40.6%	P	IDEC VAV w/ Hot Water Reheat	0.1	$78,435	$16,247	N/A	N/A	$94,682	730.1	11,114.4					0.1	0.214	$98,186	-
										0.5	$89,791	$17,049	N/A	N/A	$106,840	735.1	11,120.2					0.5	1.070	$124,502	$0.19
										0.8	$92,342	$23,870	N/A	N/A	$116,212	803.7	10,907.0					0.8	1.711	$144,240	$0.33
Ogden Juvenile Courts	5B	88,201	5	66,033	66,033	22,892	39.2%	B	VAV w/ reheat (90.1-2007 App. G System #7)	0.1	$82,095	$14,623	N/A	N/A	$96,718	329	4,902.9	Project is still under design and information presented is subject to change.	Because the building is tall and narrow, there is a high ratio of exterior wall to floor area. The potential savings for reduced infiltration, on equipment sizes, is higher than average.	111,817	1.69	0.1	0.169	$97,703	-
										0.5	$84,524	$17,975	N/A	N/A	$102,499	367.4	5,267.2					0.5	0.847	$107,325	$0.09
										0.8	$86,438	$20,224	N/A	N/A	$106,662	398.8	5,573.6					0.8	1.355	$114,542	$0.15
								P	IDEC VAV w/ Hot Water Reheat	0.1	$50,201	$16,082	N/A	N/A	$66,283	248.7	4,020.6					0.1	0.169	$66,691	-
										0.5	$49,157	$19,797	N/A	N/A	$68,954	287.1	4,396.8					0.5	0.847	$70,682	$0.04
										0.8	$48,429	$21,978	N/A	N/A	$70,407	320.2	4,745.1					0.8	1.355	$73,675	$0.06
SJ Quinney Law Building	5B	163,600	6	73,978	73,978	35,181	40.0%	B	VAV w/ reheat (90.1-2007 App. G System #7)	0.1	$149,615	$35,694	N/A	N/A	$185,309	540.5	10,466.9	Project is still under design and information presented is subject to change.	Due to the use of chilled beams, the heating plant size for the Proposed model iterations is relatively small, compared to more common primary HVAC system types.	144,340	1.95	0.1	0.195	$186,926	-
										0.5	$150,528	$42,129	N/A	N/A	$192,657	579.7	10,930.9					0.5	0.976	$200,192	$0.09
										0.8	$150,641	$46,567	N/A	N/A	$197,208	612.4	11,400.6					0.8	1.561	$210,142	$0.16
							48.1%	P	Chilled Beams	0.1	$82,788	$14,630	N/A	N/A	$97,418	289.2	3,097.8					0.1	0.195	$99,401	-
										0.5	$83,435	$21,218	N/A	N/A	$104,653	291.7	4,891.0					0.5	0.976	$115,670	$0.11
										0.8	$85,268	$26,742	N/A	N/A	$112,010	308.5	6,251.0					0.8	1.561	$127,871	$0.20
Utah National Guard TASS Building A	5B	60,311	2	32,817	32,817	23,404	12.3%	B	Packaged VAV w/ reheat (90.1-2007 App. G System #5)	0.1	$41,776	$33,201	N/A	N/A	$74,977	171.3	3,361.4	Project contains an unusually low percentage of glazing, and lots of densely occupied classrooms and meeting rooms.	Potential savings is due to the low amount of exterior glazing, which creates a lot of exterior wall area. Since the analysis is based on CFM/FT2 of wall area, the potential savings is higher than average.	79,625	2.43	0.1	0.243	$75,689	-
										0.5	$42,164	$34,768	N/A	N/A	$76,932	181.7	3,458.1					0.5	1.213	$80,533	$0.06
										0.8	$42,540	$35,931	N/A	N/A	$78,471	191.1	3,565.8					0.8	1.941	$84,167	$0.11
								P	IDEC VAV w/ Hot Water Reheat	0.1	$26,049	$24,033	N/A	N/A	$50,082	159.6	3,348.6					0.1	0.243	$50,517	-
										0.5	$25,972	$25,171	N/A	N/A	$51,143	160	4,145.0					0.5	1.213	$53,479	$0.04
										0.8	$25,709	$26,509	N/A	N/A	$52,218	163.4	4,726.2					0.8	1.941	$55,700	$0.07
Utah National Guard TASS Building B	5B	45,144	2	28,129	28,129	17,003	20.6%	B	Packaged VAV w/ reheat (90.1-2007 App. G System #5)	0.1	$56,303	$3,312	N/A	N/A	$59,615	86.2	1,612.6	Project is a billitings building which schedules are more typical of a residential building rather than a commercial building.	The cooling and heating load in the Proposed design caps out during 0.5 and 0.8 CFM/FT2 of wall area infiltration. The ground source heat pump well, in the Proposed design, has not been designed to handle the additional infiltration load, and therefore, the 0.5 scenario is using extreme pump and fan energy to try and offset the difference. A larger well would need to be designed to accommodate the additional load.	62,135	2.21	0.1	0.221	$65,705	-
										0.5	$74,134	$3,312	N/A	N/A	$77,446	131.2	2,120.7					0.5	1.104	$110,217	$0.72
										0.8	$91,567	$3,312	N/A	N/A	$94,879	175	2,621.6					0.8	1.767	$143,601	$1.25
								P	Ground Source Heat Pumps	0.1	$20,872	$2,451	N/A	N/A	$23,323	67.3	1,249.7					0.1	0.221	$25,626	-
										0.5	$67,372	$2,451	N/A	N/A	$69,823	94.3	2,428.3					0.5	1.104	$42,457	$0.27
										0.8	$34,206	$2,451	N/A	N/A	$36,657	94.3	2,428.3					0.8	1.767	$55,080	$0.47
SUU Gibson Science Center Addition	5B	44,891	4	25,684	45,547	14,412	25.5%	B	Packaged VAV w/ reheat (90.1-2007 App. G System #5)	0.1	$59,403	$40,616	N/A	N/A	$100,019	176.5	3,452.8	Project includes a large amount of lab and vivarium space. The labs and vivariums have a high requirement of air changes per hour, which make up the majority of the energy costs.	Due to the very high ventilation airflow requirements, the potential savings for infiltration is not realized, because the infiltration is an insignificant portion of the actual load to the space.	74,371	2.90	0.1	0.290	$101,172	-
										0.5	$59,811	$44,586	N/A	N/A	$104,397	183	4,154.0					0.5	1.448	$108,219	$0.09
										0.8	$60,034	$44,244	N/A	N/A	$104,278	189.2	4,686.0					0.8	2.316	$113,505	$0.17
								P	Direct Evaporative VAV w/ Hot Water Reheat	0.1	$54,080	$26,251	N/A	N/A	$80,331	161	2,705.8					0.1	0.290	$80,654	-
										0.5	$53,784	$27,025	N/A	N/A	$80,809	159.8	3,383.9					0.5	1.448	$82,628	$0.03
										0.8	$53,738	$27,786	N/A	N/A	$81,524	161.2	3,901.0					0.8	2.316	$84,109	$0.05

COLVIN ENGINEERING ASSOCIATES