MINNESOTA DEPARTMENT OF COMMERCE
DIVISION OF ENERGY RESOURCES

The Energy Conservation Potential of Displacement Ventilation Technology in Minnesota Climate Conditions

Conservation Applied Research & Development (CARD)
FINAL REPORT

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Executive Summary

Displacement ventilation (DV) is a technology that provides ventilation air directly to occupant breathing zones using low fan speeds and cool delivery temperatures. Simulations of this technology predict significant energy savings resulting from its use in commercial buildings (Bourassa et al. 2002; Holland and Livchak, 2002; Chen and Glicksman, 1999). Though it is widely utilized in some parts of the world (Cho, Im, & Haberl, 2005), displacement ventilation has not yet fully penetrated the U.S. market.

The primary goals of this project were to: 1) evaluate the energy conservation potential of displacement ventilation as applied to Minnesota buildings, and 2) identify possible barriers to its market adoption. Fifty-seven building candidates were identified for inclusion in the study. Of these, four were found to be served by underfloor air distribution (UFAD) rather than displacement ventilation. Among the remaining candidate buildings, twenty-six chose to participate. Surveys were distributed and collected from this group.

One immediate finding was that the technology exhibited significant variability in the amount of energy savings achieved. The bulk of this variability could be traced to a particular subset of the sample that was designed and operated by the same entities. This suggests that design and/or operation play a major role in achievement of savings with this technology. The remainder of the sample exhibited whole building energy use intensity (EUI) savings of 16 ± 4%. Monthly analysis indicates that the greatest savings are achieved during summer months, likely due to cooling benefits associated with DV's low supply air temperatures.

Estimated utility cost savings resulting from the use of displacement ventilation are \$0.32 ± \$0.08/ft^2/yr. Added first costs associated with this technology range from \$0-2/ft^2. Using the median added cost (\$1/ft^2) results in payback timescales of 2-4 years. This estimate is generally consistent with existing predictions in the literature (e.g., Hicks et al. 2014; Hamilton et al. 2004; Roth et al. 2002).

Overall, owners tend to be pleased with displacement ventilation technology, and a majority (86%) would choose the technology again. The most frequently cited reason for choosing DV is improved air quality, followed by energy savings and occupant comfort. Maintenance concerns were the main source of any negative perceptions toward the technology among owners; however, these concerns were voiced by only 28% of participants.

Minnesota building professionals (architects, engineers, etc.) were surveyed to evaluate the market position of displacement ventilation and identify barriers to its acceptance. Although most professionals had minimal exposure to the technology, they tended to exhibit positive attitudes toward it. A lack of market penetration and general unfamiliarity with the technology are viewed as its greatest barriers. Lack of owner exposure to DV is a particularly important challenge to its market success, and persists despite the fact that current owners tend to be very pleased with the technology's performance in their buildings.

Introduction/Background

Commercial HVAC systems have traditionally fallen into a few categories of tried and tested technologies. In recent years, however, there have been numerous advances in HVAC technology that have gained significant traction. In large part this is due to growing trends toward green buildings and energy efficient systems, and claims by manufacturers and designers that significant energy savings can be achieved by using these alternative technologies. The only way to truly vet these technologies is through in situ studies which evaluate the technology as operated in the field.

Displacement Ventilation

Our Conservation Applied Research and Development (CARD) study is a detailed, field-based assessment of the actual energy benefits of displacement ventilation technology in Minnesota. Displacement ventilation provides air distribution via floor level diffusers. When cool, low-velocity air enters an occupied zone, it flows horizontally until a warm object causes a natural upward air flow. As the warmed air rises it carries pollutants with it through a ceiling level outlet (Figure 1).

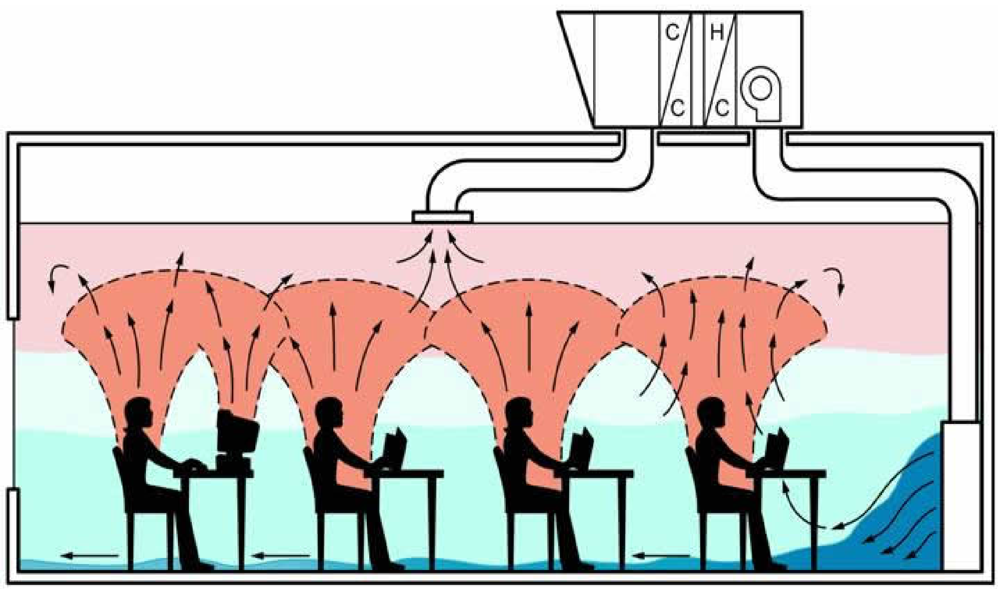

Figure 1: Diagrammatic Representation of Displacement Ventilation (Source: Energy Design Resources, 2010).

Displacement ventilation is, as the name implies, primarily a ventilation system. It is not designed to heat or cool spaces. In regions that exhibit mild summers such as the upper Midwest, displacement ventilation can offset a significant portion of the cooling load by virtue of its comparatively low supply air temperatures. The intended benefits of DV, however, are direct, efficient delivery of clean air to occupants, and reductions in fan energy due to low discharge velocities.

Prior Studies

Displacement ventilation has been purported to not only reduce energy use in buildings, but also significantly improve air quality for occupants (e.g., Holland and Livchak, 2002; Chen and Glicksman, 1999). In their 2002 study, Bourassa et al. find impressive whole building energy savings of 30-60% from utilizing displacement ventilation. The majority of domestic studies of this technology are based on computer simulations however, and therefore our knowledge of the true energy benefits of displacement ventilation suffers from a striking lack of field-based research on actual buildings.

If computer-predicted estimates of utility savings from displacement ventilation are correct, it is a technology that could have far-reaching impacts on both power and energy savings in Minnesota. New, non-residential construction in the Twin Cities adds 10-15 million square feet of building area per year (Twin Cities Metropolitan Council). Assuming average utility bills of $2.00/ft^2/yr., a 60% savings could quickly add up, theoretically reaching $18 million/year in energy savings in the Twin Cities alone.

With significant interest in displacement ventilation and numerous indications of its potential energy savings, it is a wonder that the technology has been so slow to penetrate building markets. Countries in Europe, particularly in Scandinavia, have embraced displacement ventilation much more rapidly, with estimates that 25% of Nordic offices are outfitted with displacement ventilation (Cho, Im, & Haberl, 2005). Why then has this technology seen such a slow rise in the Midwest?

Research Objectives

The aim of this investigation is to conduct a field study evaluating the energy savings potential of displacement ventilation technology in Minnesota climate conditions, and determine significant impediments to its acceptance in the marketplace. We have constructed a sample of Minnesota buildings which utilize displacement ventilation technology and benchmarked their actual energy use as compared to typical buildings of similar function. To determine the barriers to implementation of this technology in the region, we distributed detailed and pointed surveys to members of the Minnesota buildings industry including owners, architects, and engineers.

This combination of scientific and behavioral investigation is the most effective way to drive progress toward widespread adoption of energy saving technologies in the buildings market. The first step is to ascertain the actual savings available by studying systems that are already in operation. The second step is to uncover potential cognitive biases or misinformation in the subset of people who have the most influence over whether these technologies are included in building design.

This type of applied approach is crucial for developing an accurate understanding of the practical (i.e., achievable) benefits of a technology. While academic studies are invaluable for discovering or optimizing new technologies, they have limited bearing on the real-time adoption of those technologies in the current marketplace, and therefore little immediate influence on helping Minnesota reach its 1.5 percent energy savings goal.

Deliverables of our proposed work include: a database of Minnesota buildings which utilize displacement ventilation; estimates of the energy performance of those buildings compared to typical buildings of similar function (e.g., schools, offices); statistical benchmarking of displacement ventilation energy performance in Minnesota climate conditions including a cost/benefit analysis; and evaluation of market attitudes and cognitive impediments to the adoption of this technology in the field.

Methodology

Building Identification

Our search methodology consisted of pointedly reaching out to a diverse network of architects, engineers, building owners, municipalities, and sustainability communities to help us locate buildings that utilize displacement ventilation technology. Individual communications and detailed searches resulted in a preliminary list of 57 candidate buildings, listed in Appendix A. Displacement Ventilation Candidate Buildings.

Displacement ventilation technology is relatively uncommon in Minnesota. A handful of the buildings that were suggested to us turned out to actually utilize underfloor air distribution (UFAD). Of the buildings that do use displacement ventilation, most are being served by the technology in 100% of building spaces. Approximately 20% of the final sample, however, only includes the technology in a fraction of the building (generally in large still spaces such as classrooms, etc.)

Owner Survey Distribution

All building owners were approached for study participation, and owner surveys were distributed to approximately 44 buildings (an example survey is shown in Appendix B. Example Survey). Owner surveys were completed and returned for 26 total buildings. Our final participants are listed in Table 1.

Table 1: Participating Buildings

ID	SPACE TYPE	CITY	TECHNOLOGY USAGE[a] [%]
DV-1	Library	Elk River	100%
DV-2	K-12 School	Crystal	97%
DV-3	Office	Maple Grove	100%
DV-4	K-12 School	Wadena	99%
DV-5	K-12 School	Watertown	90%
DV-6	Office Space/Community Center	St. Paul	95%
DV-7	K-12 School	Silver Bay	100%

ID	SPACE TYPE	CITY	TECHNOLOGY USAGE[a] [%]
DV-8	K-12 School	Coon Rapids	10%
DV-9	K-12 School	Brooklyn Center	63%
DV-10	K-12 School	Coon Rapids	55%
DV-11	K-12 School	Blaine	40%
DV-12	K-12 School	New Brighton	100%
DV-13	K-12 School	St. Paul	100%
DV-14	K-12 School	Mounds View	100%
DV-15	K-12 School	New Brighton	100%
DV-16	K-12 School	New Brighton	100%
DV-17	K-12 School	Shoreview	100%
DV-18	K-12 School	Brainerd	100%
DV-19	K-12 School	New Brighton	100%
DV-20	K-12 School	Mounds View	100%
DV-21	K-12 School	Shoreview	100%
DV-22	K-12 School	New Brighton	100%
DV-23	K-12 School	Shoreview	100%
DV-24	K-12 School	Arden Hills	100%
DV-25	Community College Building	White Bear Lake	-
DV-26	Higher Education	St. Paul	8%

Notes: a – Percentage of building area served by the technology, as reported on owner surveys.

Market Survey

A market survey was designed to evaluate current attitudes in the building community toward displacement ventilation as well as probe a range of variables that may affect and/or explain the source of those attitudes. The Minnesota Department of Energy Resources was consulted for feedback and approval prior to market survey distribution. Google Docs was used to construct and deliver the survey.

The market survey contained four major information gathering sections: 1) Demographics, 2) Displacement Ventilation, 3) Innovative Building Technologies, and 4) Motivations. Attitudes toward modern technologies in general were investigated as a baseline for interpreting attitudes toward displacement ventilation. Multiple question types were incorporated, including open ended, multiple choice, ordinal ranking, Likert scale, and ratio scale. A copy of the survey is shown in Appendix C. Professional Survey

The primary goal of survey distribution was to obtain input from a broad subset of the Minnesota buildings community, ideally as near to a representative subset as possible. Respondents were recruited from a variety of Minnesota locations, representing a wide range of age, experience, job function, and familiarity with the investigated technology.

In total, over 130 Minnesota building professionals were contacted via phone and/or email and asked to participate. Of these, 31 completed the anonymous survey, a participation rate of approximately 24%.

Data Analysis and Limitations

Owner Survey

Surveys were collected and raw data was converted to CSV format for further processing. Data was broken into two categories, energy use (objective) and owner satisfaction (subjective).

Though every attempt was made to verify survey responses where possible, limitations to their accuracy do exist. Overall, building area and total energy use were the most reliable response categories, so our analysis remains as close to this raw data as possible.

Quantitative conclusions drawn by this work are subject to the uncertainties associated with small number statistics. The magnitudes of these uncertainties are difficult to estimate when coupled with reporting errors, weather variations, and the inherent complexities of interacting building systems. As a rough approximation, it is estimated that uncertainties on energy benchmarking results are of order 20%.

Energy Conservation Measure Corrections

The first page of the owner survey was designed to gather physical building information such as size, location, fraction utilizing displacement ventilation technology, supplementary energy saving measures, and utility use data. Completed energy use analysis was possible for 24 of the 26 participating buildings. The two excluded buildings were unable to provide energy use data because they were connected to campus-wide systems without available sub-metering.

Additional energy conservation measures (ECMs) such as envelope upgrades were found to be present in all buildings. These ECMs are responsible for some fraction of the overall savings identified for each building. To more accurately evaluate the benefits of displacement ventilation technology, ECM contributions were estimated via a simple modeling analysis.

Only well constrained measures were addressed in this phase. Modeling more complex measures (such as additional HVAC upgrades) involves a significant number of additional assumptions, and would ultimately not improve the accuracy of study conclusions. Measures accounted for in modeling corrections include: high efficiency windows, increased wall and/or roof insulation, improved lighting power density, lighting occupancy sensors, and automatic daylight sensors.

Basic calibrated school and office EnergyPlus models were used in the analysis (Appendix D. Baseline Energy Plus Models). Models were calibrated to expected total energy consumption and end use energy distribution for Minnesota buildings using the Commercial Buildings Energy Consumption Survey (CBECS; EIA 2003). ASHRAE 90.1-2007 code was adopted for baseline models, and ASHRAE 90.1-2010 code was used to represent envelope upgrades (ASHRAE, 2007, 2010). LPD improvements were modeled as a reduction to 80% of code allowances. Lighting occupancy sensors were represented by a 10% LPD reduction in applicable spaces, and automatic daylight sensors were modeled as stepped 3-level systems.

Each building's ECMs were modeled together to account for interactions between measures. Changes in energy use intensity (or EUI, in units of kBTU/ft^2/year) between baseline building models and ECM inclusive models were recorded. The resulting EUI savings percentages were later used to adjust overall energy saving estimates for each building. Modeled ECMs and energy savings corrections are reported in the results section.

Weather Variance

Weather and temperatures can vary significantly from year-to-year, and may have a measurable effect on building energy use. In most cases, a single year of utility data was reported on each survey. To evaluate how representative this annual data was of "typical" energy use, a brief analysis was conducted using a participating building for which monthly energy data were available. The analysis performed is consistent with the EnergyStar treatment of weather normalization (EIA, 2013).

Twenty years' worth of daily temperature data was collected from a Minneapolis weather station (NCDC Quality Controlled Local Climatological Data[1]). 30-year average monthly temperatures were obtained for the same region via NOAA's 1991-2010 Climate Normals[2]. Therms and kWh were individually plotted versus monthly temperature over the duration of the reporting period. These data were then fitted with relationships (Figure 2).

[1] Data available at NOAA website. (http://cdo.ncdc.noaa.gov/qclcd/QCLCD?prior=N)

[2] Data available at NOAA website. (http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html)

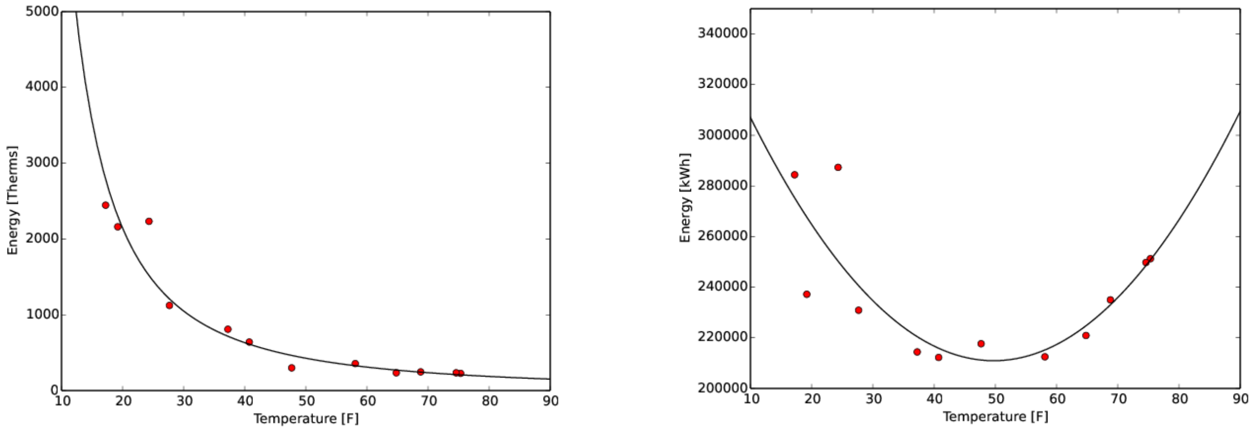

Figure 2: Energy/Temperature Relationships

Energy/Temperature relationships were then used to correct reported energy use to 30-year average monthly temperatures. Projected monthly energy use was summed and compared to the total energy used during the reported date range. Differences between reported and projected (average temperature) energy use were <1% in kWh and <2% in Therms, indicating that weather variance has a minor effect on the results of this study.

Baseline Energy Estimation

Survey questions were tailored to provide enough information to obtain Energy Star Target Finder[3] median energy use estimates for each building (based on CBECS; EIA 2003). The Target Finder tool operates by using entered building data to obtain median source energy consumption for buildings of similar type and location (an example of Target Finder output is given in Appendix E. Sample Energy Star Target Finder Output). Site energy use is backed out by matching the site fuel mix ratio of the specific building in question. Therefore if a building uses 100% electricity and is entered into Energy Star Target Finder, site energy comparisons (and subsequent cost and CO_2 comparisons) also assume 100% electricity.

The paradigm for estimation of energy savings in the buildings industry (adopted by LEED and ASHRAE 90.1 Appendix G, among others) is to match primary fuel types in baseline and design modeled energy use. While this may be the most straightforward and/or logical practice, it can have a tendency to overestimate predicted energy savings. This typically occurs when the baseline system is egregiously inefficient, since a system of this type would not likely be put in place in lieu of the advanced system being considered.

To investigate technology savings with respect to the median energy use of buildings using typical Minnesota fuel mixes, we re-entered building data into Energy Star while leaving measured utility use inputs blank. This produces median site energy use, cost, and CO_2 values based on the average fuel mix for that building type in the given location.

[3] Data available at Energy Star Portfolio Manager (https://portfoliomanager.energystar.gov/pm/targetFinder?execution=e1s1)

Median building energy use (matched fuel mix) was used to determine the total energy savings percentage achieved by each building. These were then corrected for ECM contributions. Simple as well as weighted (by the percentage of each building utilizing displacement ventilation) average savings were calculated, and are presented in the energy use benchmarking results section.

Differential First Cost Estimation

Average additional first costs for installing DV systems (compared to traditional VAV systems) are estimated at $1-2/ft^2 by the California Public Utilities Commission (Energy Design Resources, 2005, 2014). This estimate contains the caveat, however, that DV may not incur an additional cost for designs that include a central plant (due to opportunities for corresponding chiller downsizing). In a hypothetical example of an 8-classroom building in Southern California, EDR finds a cost difference of approximately $1/ft^2 when compared to overhead mixing systems.

A summary on displacement ventilation composed by the Washington State University Extension Energy Program calculates additional first costs at $0.69/ft^2, based on an incremental cost increase of 11% (Washington State University, 2016). This percent cost increase assumption stems originally from an ASHRAE Journal article on displacement ventilation (Hamilton, Roth, & Broderick, 2004).

A 2002 EERE study on the energy consumption of commercial HVAC technologies references Hu et al (1999) and reports a cost increase of approximately $0.15/ft^2 in the Midwest, taking reduced chiller sizing into account (Roth et al. 2002). In general there seems to be a lack of more recent references in the literature; most contemporary studies reference earlier work for cost estimates.

Taken together, the existing references suggest a range of first cost increase for displacement ventilation systems, extending from no increase in cost to $2/ft^2. This range is maintained throughout the cost benefit analysis, with primary focus placed on the mean value of $1/ft^2.

Monthly Savings Analysis

Displacement ventilation is expected to primarily produce electric savings, stemming from reductions in fan and cooling energy use. To investigate monthly and/or seasonal variations in savings potential, Buildings, Benchmarks, and Beyond (B3) Benchmarking[4] data was utilized.

School District 1 operates four elementary schools that utilize displacement ventilation, and 24 elementary schools that do not. Monthly gas and electric use was averaged separately for DV-served and non-DV-served elementary schools over a period of one to eight years (all available data was utilized, duration of reliable monthly data varied from building to building). Monthly data was not corrected for added ECM as this data was not available for non-DV buildings. Percent electricity, gas, and total EUI savings by month along with 1σ (68%) confidence levels were extracted from the results and are reported in the monthly savings results section below.

Owner Satisfaction Feedback

The second page of the owner survey was used to obtain feedback regarding owner satisfaction and motivation for usage of displacement ventilation technology. These data were treated similarly to the energy data, calculating averages and weighted averages. The answers to A through E

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[4] Data available at [Minnesota B3 Benchmarking](https://mn.b3benchmarking.com/). (https://mn.b3benchmarking.com/)

questions were assigned values of 1 through 5, and yes/no questions were assigned the numerical values of 1 and 0, respectively.

Market Survey

Market survey data were exported from Google Docs in CSV format for processing. Numerical values were assigned to Likert scale responses to facilitate data analysis and interpretation. Resulting quantitative survey results are subject to the uncertainties associated with small number statistics. As a rough approximation, uncertainties are expected to be on the order of 20%. Accurate 1-σ errors are calculated when possible, based on the standard deviation of an assumed Gaussian (i.e., “normal”) distribution.

Results

Energy Use Benchmarking

Annual Energy Savings

Twenty-four buildings were initially eligible for inclusion in energy use benchmarking analysis. Energy savings for this sample are reported in Table 2

Table 2: Energy Savings Estimates

OPERATIONAL GROUP	ID	PERCENT DV [%]	SITE EUI [kBTU/ft²/yr]	MEDIAN SITE EUI	CO_2 SAVINGS [%]	SITE ENERGY SAVINGS[a] [%]
Individual Buildings	DV-1	100%	50.6	76	34.1%	33.4%
	DV-2	97%	66.3	87	24.0%	23.8%
	DV-3	100%	69.2	87	21.1%	20.4%
	DV-4	99%	38.5	43	12.4%	10.6%
	DV-5	90%	72.4	70	-2.9%	-3.5%
	DV-6	95%	97.4	124	21.5%	21.4%
	DV-7	100%	86.2	90	4.8%	4.2%
School District 1	DV-8	10%	95.0	103	8.1%	7.7%
	DV-9	62.7%	61.4	83	26.3%	26.0%

OPERATIONAL GROUP	ID	PERCENT DV [%]	SITE EUI [kBTU/ft²/yr]	MEDIAN SITE EUI	CO_2 SAVINGS [%]	SITE ENERGY SAVINGS[a] [%]
	DV-10	54.5%	73.2	96	23.8%	23.7%
	DV-11	40.3%	46.1	69	34.4%	33.2%
School District 2	DV-12	100%	81.3	81	3.1%	-0.3%
	DV-13	100%	143.7	74	-93.8%	-94.1%
	DV-14	100%	130.7	87	-48.7%	-50.2%
	DV-15	100%	141.6	83	-70.4%	-70.6%
	DV-16	100%	122.8	85	-44.2%	-44.5%
	DV-17	100%	140.7	83	-67.9%	-69.5%
	DV-18	100%	195.1	82	-136.2%	-137.9%
	DV-19	100%	126.5	87	-44.2%	-45.4%
	DV-20	100%	113.6	85	-32.8%	-33.6%
	DV-21	100%	135.1	82	-63.7%	-64.8%
	DV-22	100%	126.4	85	-47.9%	-48.7%
	DV-23	100%	87.2	76	-13.3%	-14.7%
	DV-24	100%	113.0	82	-37.4%	-37.8%

Notes: a – Calculated as $(EUI_{Median} – EUI_{Site})/EUI_{Median}$

A sizeable discrepancy in energy savings can be seen between School District 2 and all other buildings in the sample, with School District 2 buildings exhibiting significantly higher energy use than median buildings. This suggests that a strong operational component is present for these participants. The statistical significance of operational discrepancies is explored in the following section.

Energy savings for the total sample are shown in Figure 3, with School District 2 buildings shown in red and all other buildings in blue. It is clear from this illustration that buildings in School District 2 perform very poorly, even compared to typical buildings.

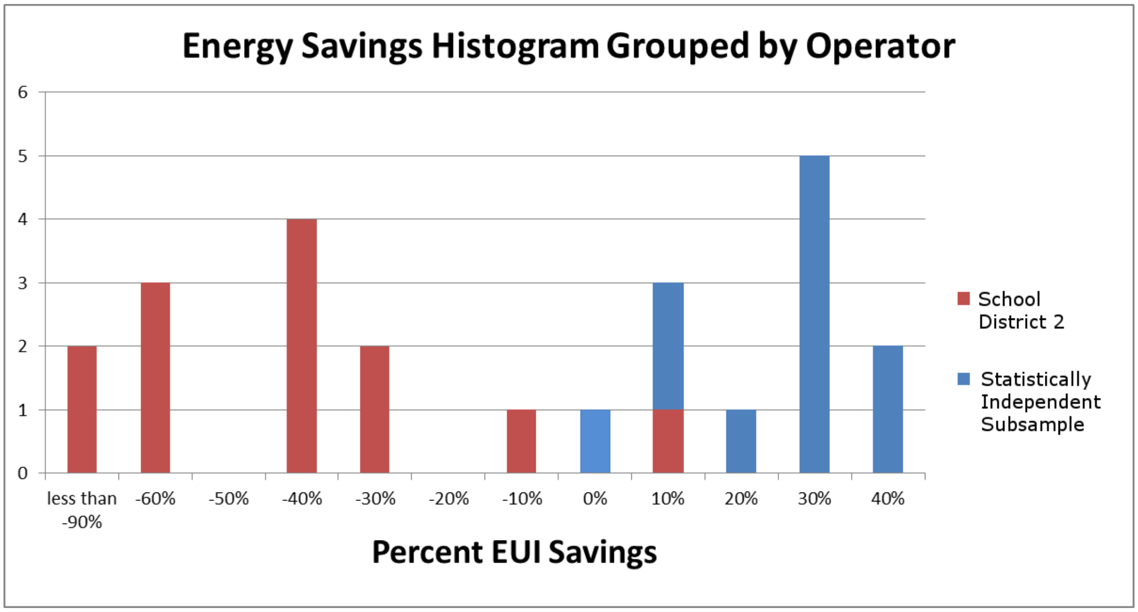

Figure 3: Energy Savings Histogram Grouped by Operator

Sample Distribution

One of the main purposes of this study is to ascertain the energy savings potential of displacement ventilation technology. The potential of this technology can effectively be evaluated only by using buildings that are operating the technology correctly (or nearly correctly). Determination of the risk or frequency of poor operation can also provide useful information about the technology; however this is difficult to probe without performing site visits to participating buildings. Some aspects of technology operation are explored via subjective owner feedback in later sections of the report.

Confirming that the sample is statistically consistent (i.e., represents a single distribution of savings) will ensure that the study is focused on a building sample that is capable of constraining energy savings potential. The values in Table 2 suggest that a discrepancy exists between the School District 2 subsample and the rest of the buildings in the study. This discrepancy can be statistically evaluated through a Kolmogorov-Smirnov test (or K-S test).

A K-S test evaluates the null hypothesis that the two groups of data being compared are sampled from the same parent distribution, or population. The result of a K-S test (the P-value) is the probability that this null hypothesis holds for the groups under investigation.

Savings estimates from Table 2 were broken into four subsamples:

- School District 1
- School District 2
- Independently operated buildings
- All buildings NOT in School District 2

K-S tests were performed on three pairs of subsamples, with results listed in Table 3.

Table 3: K-S Test Results

SAMPLES COMPARED	P-VALUE	NULL HYPOTHESIS LIKLIHOOD [%]
School District 2 / All Remaining Buildings	1.9×10^{-5}	<1%
School District 2 / Independent Buildings	2.3×10^{-4}	<1%
School District 1 / Independent Buildings	0.5	Consistent with Null Hypothesis

These results indicate that there is less than a 1% chance that School District 2 performance is statistically related to (i.e., representative of) either the entire remaining sample of DV-served buildings, or the subsample of independently operated buildings. In contrast, the distribution of School District 1 energy savings is wholly consistent with the subsample of independently operated buildings. Based on the results of this statistical testing, School District 2 buildings were excluded from further analysis.

Monthly Savings

School District 1 operates four elementary schools that utilize displacement ventilation, and 24 schools that do not. Table 4 and Table 5 show average monthly energy use data with 1-σ errors for DV-served and non-DV-served elementary schools. The value of N indicates the number of data points available for that month. Percent savings and corresponding 1-σ errors were derived from these results, using simple propagation of errors. Table 6 lists estimated energy savings by month for the DV-served sample, and Figure 4 and Figure 5 illustrate these savings.

Table 4: DV-Served Monthly Energy Use

MONTH	ELECTRIC EUI [kBTU/ft²/yr]	GAS EUI [kBTU/ft²/yr]	TOTAL EUI [kBTU/ft²/yr]	N
Jan	1.62 ± 0.07	9.0 ± 0.5	10.6 ± 0.5	141
Feb	1.49 ± 0.07	7.0 ± 0.3	8.5 ± 0.4	141
Mar	1.50 ± 0.06	5.6 ± 0.3	7.1 ± 0.3	141
Apr	1.43 ± 0.05	3.1 ± 0.1	4.5 ± 0.2	141
May	1.35 ± 0.04	1.19 ± 0.04	2.54 ± 0.08	147
Jun	0.86 ± 0.04	0.35 ± 0.01	1.21 ± 0.05	149
Jul	0.80 ± 0.05	0.171 ± 0.006	0.97 ± 0.06	149
Aug	1.02 ± 0.05	0.31 ± 0.02	1.34 ± 0.07	150
Sep	1.36 ± 0.04	1.18 ± 0.05	2.54 ± 0.09	154
Oct	1.50 ± 0.05	3.6 ± 0.1	5.1 ± 0.2	141
Nov	1.56 ± 0.07	6.0 ± 0.3	7.6 ± 0.4	132
Dec	1.59 ± 0.08	8.0 ± 0.4	9.6 ± 0.4	131
TOTAL	**16.08 ± 0.08**	**45.5 ± 0.9**	**62 ± 1**	**285**

Table 5: Non-DV-Served Monthly Energy Use

MONTH	ELECTRIC EUI [kBTU/ft²/yr]	GAS EUI [kBTU/ft²/yr]	TOTAL EUI [kBTU/ft²/yr]	N
Jan	1.59 ± 0.04	11.9 ± 0.4	13.5 ± 0.5	141
Feb	1.43 ± 0.03	8.6 ± 0.2	10.1 ± 0.2	141
Mar	1.49 ± 0.03	6.8 ± 0.1	8.3 ± 0.2	141
Apr	1.44 ± 0.04	3.86 ± 0.08	5.3 ± 0.1	141
May	1.44 ± 0.04	1.53 ± 0.04	2.97 ± 0.09	147
Jun	1.11 ± 0.05	0.54 ± 0.03	1.65 ± 0.08	149

MONTH	ELECTRIC EUI [kBTU/ft²/yr]	GAS EUI [kBTU/ft²/yr]	TOTAL EUI [kBTU/ft²/yr]	N
Jul	1.05 ± 0.06	0.35 ± 0.04	1.41 ± 0.10	149
Aug	1.25 ± 0.05	0.46 ± 0.04	1.71 ± 0.09	150
Sep	1.48 ± 0.04	1.28 ± 0.06	2.8 ± 0.1	154
Oct	1.52 ± 0.04	3.76 ± 0.08	5.3 ± 0.1	141
Nov	1.48 ± 0.03	6.7 ± 0.2	8.2 ± 0.2	132
Dec	1.52 ± 0.04	10.0 ± 0.2	11.5 ± 0.2	131
TOTAL	**16.80 ± 0.05**	**56 ± 1**	**73 ± 1**	**1717**

Table 6: Estimated Monthly Savings for DV-Served Buildings in School District 1

MONTH	SAVINGS [%]		
	Electric	Gas	Total EUI
Jan	-1.5 ± 5.2%	24.4 ± 4.9%	21.4 ± 5.0%
Feb	-3.7 ± 5.5%	19.2 ± 4.2%	16.0 ± 4.4%
Mar	-0.4 ± 4.6%	18.4 ± 4.0%	15.1 ± 4.1%
Apr	0.4 ± 4.2%	20.2 ± 3.5%	14.9 ± 3.6%
May	6.1 ± 4.2%	22.2 ± 3.3%	14.4 ± 3.7%
Jun	22.2 ± 4.9%	34.9 ± 4.6%	26.4 ± 4.8%
Jul	24.4 ± 6.4%	51.7 ± 6.0%	31.3 ± 6.3%
Aug	17.8 ± 5.0%	32.1 ± 7.3%	21.7 ± 5.7%
Sep	7.6 ± 3.7%	7.9 ± 6.0%	7.8 ± 4.8%
Oct	1.2 ± 4.1%	4.1 ± 4.1%	3.3 ± 4.1%
Nov	-5.4 ± 5.2%	10.1 ± 5.3%	7.3 ± 5.3%
Dec	-5.0 ± 5.9%	19.3 ± 4.0%	16.1 ± 4.2%
AVERAGE	**5.3 ± 4.3%**	**22.1 ± 6.0%**	**16.3 ± 3.5%**

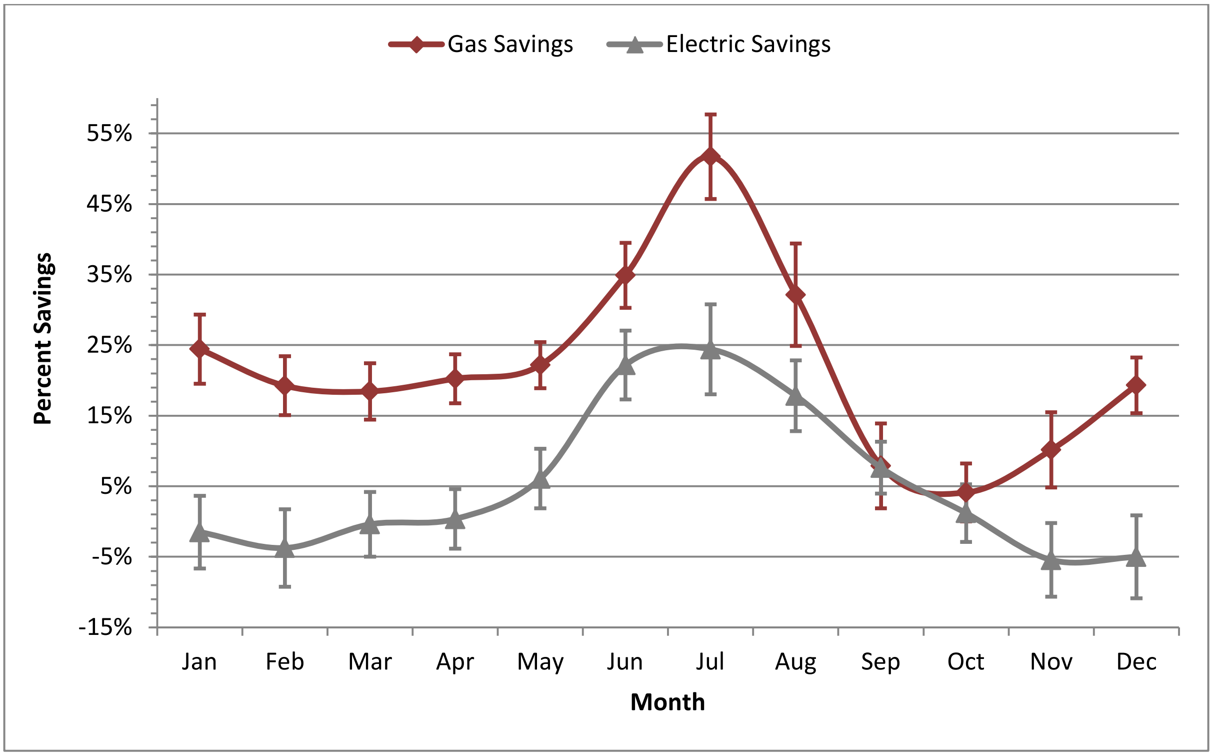

Figure 4: Monthly Electric and Gas Savings Estimates for DV-served Buildings in School District 1

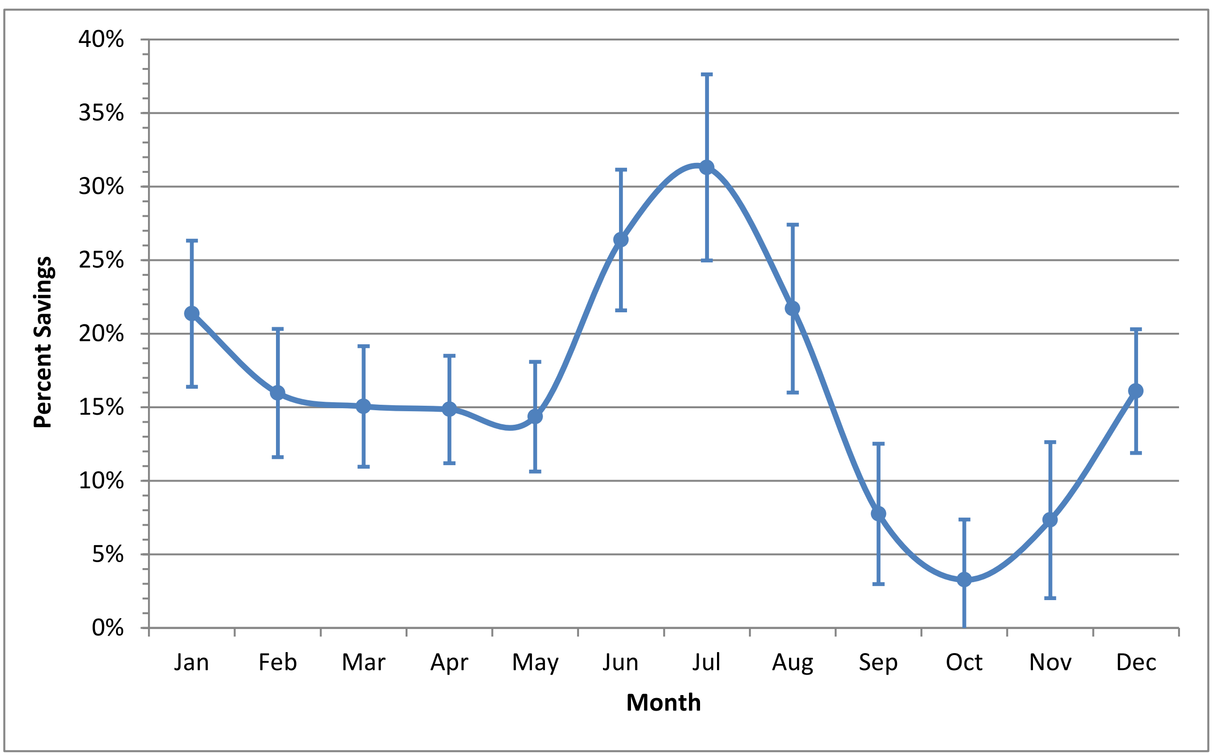

Figure 5: Monthly EUI Savings Estimates for DV-served Buildings in School District 1

Electric data shows that displacement ventilation produces significant electric savings during the summer months, but that it may use slightly more electricity during the winter, possibly due to increased fan energy consumption. Gas savings are evident throughout the year, with the most impact during summer and winter, likely due to savings on reheat. Shoulder seasons produce the least amount of energy savings.

Combined data (Table 6 and Figure 5) indicates that savings from displacement ventilation technology are greatest during summer months (20-30%), with DV-served buildings performing 16 ± 3% better than non-DV buildings on average throughout the year. Greater efficiency during the summer is expected, given that cooling savings can be most effectively achieved during summer months. Based on the possibility that some of these schools were not in full operation over the summer; these savings estimates likely represent a lower limit.

Energy Benchmarking Results

Energy conservation measures for each building in the statistically consistent subsample were modeled together to obtain estimates of their contributions to overall energy savings. Changes in energy use intensity between baseline building models and ECM inclusive models were recorded, and are listed in Table 7. The resulting EUI savings percentages were used to adjust overall energy saving estimates for each building.

Table 7: Energy Conservation Measure Corrections

ID	Daylight Sensors[a]	High Efficiency Windows[b]	Lighting Upgrades[c]	Wall/Roof Insulation Upgrades[d]	Lighting Occupancy Sensors[e]	Modeled EUI Savings
DV-1			✓	✓	✓	1.9%
DV-2	✓		✓	✓	✓	2.4%
DV-3	✓		✓	✓	✓	2.4%
DV-4			✓	✓	✓	1.9%
DV-5	✓	✓				0.9%
DV-6	✓	✓	✓		✓	1.7%
DV-7	✓	✓			✓	1.0%
DV-8	✓	✓	✓	✓	✓	2.4%
DV-9	✓	✓	✓	✓	✓	2.4%
DV-10	✓	✓	✓	✓	✓	2.7%
DV-11		✓	✓		✓	1.3%

Notes: Modeling assumptions described by **a** – stepped lighting controls (IECC 2012); **b** - ASHRAE 2010, IECC 2012 fenestration requirements; **c** - 80% of lighting allowance (ASHRAE 2013, IECC 2015); **d** – Wall/roof insulation as required by ASHRAE 2012, IECC 2015; **e** - Reduce LPD 10% (IECC 2015).

Table 8 lists the numerical results of energy use benchmarking for this sample, corrected for additional energy conservation measures. Buildings utilizing displacement ventilation achieve weighted average energy savings of 16 ± 4% over median buildings. It should be noted that this result has been corrected for energy savings measures such as envelope and lighting upgrades, but not additional HVAC-related ECMs. Overall savings estimates are highly consistent with the results of the monthly analysis completed in the previous section.

The average fuel mix of participating buildings was approximately 51% electric, whereas a more typical Minnesota fuel mix for existing buildings of similar type averaged at about 36% electric. This would have the effect of somewhat diminishing average cost savings, due to current discrepancies between electric and gas cost per kBTU.

Table 8: Energy Use Benchmarking

ID	Percent DV [%]	Site EUI [kBtu/ft²/y]	Median Site EUI[a] [kBtu/ft²/y]	Site Fuel Mix[b] [% Electric]	Average Fuel Mix[c] [% Electric]	Cost Savings [$/ft²/yr]	CO_2 Savings[e] [%]	Measured Site Energy Savings [%]	Modeled ECM Savings Correction [%]	Corrected Site Energy Savings[f] [%]
DV-1	100%	50.6	76	96.7%	36.3%	$0.77	34.1%	33.4%	1.9%	32.5%
DV-2	88.7%	66.3	87	51.0%	31.5%	$0.40	24.0%	23.8%	2.4%	22.1%
DV-3	100%	69.2	87	91.2%	56.1%	$0.41	21.1%	20.4%	2.4%	19.4%
DV-4	99%	38.5	43	86.3%	31.2%	$0.10	12.4%	10.6%	1.9%	8.2%
DV-5	90%	72.4	70	53.5%	31.3%	-$0.05	-2.9%	-3.5%	0.9%	-5.9%
DV-6	95%	97.4	124	64.1%	55.7%	$0.57	21.5%	21.4%	1.7%	18.7%
DV-7	100%	86.2	90	19.1%	31.3%	$0.04	4.8%	4.2%	1.0%	2.9%
DV-8	10%	95.0	103	15.8%	31.4%	$0.10	8.1%	7.7%	2.4%	5.8%
DV-9	62.7%	61.4	83	31.6%	31.4%	$0.33	26.3%	26.0%	2.4%	23.6%
DV-10	54.5%	73.2	96	20.2%	31.8%	$0.29	23.8%	23.7%	2.7%	21.3%
DV-11	40.3%	46.1	69	29.4%	31.6%	$0.30	34.4%	33.2%	1.3%	31.3%
AVG	**76.4%**	**68.8**	**84.4**	**50.8%**	**36.3%**	**$0.30 ± $0.07**	**18.9 ± 3.6%**	**18.3 ± 3.6%**	**1.9%**	**16.4 ± 3.6%**
WAVG	**-**	**67.5**	**82.8**	**58.4%**	**37.7%**	**$0.32 ± $0.08**	**18.5 ± 3.6%**	**17.9 ± 3.6%**	**-**	**16.0 ± 3.7%**

Notes: a – Using CBECS Database, assumes same fuel mix as participant building. **b**– Percentage of total site energy use by kBTU. **c**– Typical fuel mix based on building type, location, etc. (CBECS; EIA 2003). **d** – Operating cost savings, assuming participant building fuel mix. **e**– CO_2 emissions savings, assuming participant building fuel mix. **f** – Adjusted downward to correct for additional ECMs

Cost/Benefit Analysis

As shown in Table 8, Minnesota buildings that utilize displacement ventilation achieve weighted average cost savings of $0.32 ± $0.08/ft^2/yr. Assuming a first cost increase of $1.00/ft^2, average payback is estimated at 3 ± 1 years. Using the maximum expected cost increase ($2.00/ft^2) results in a payback range of 4-8 years. Errors on payback timescales are carried over proportionately from estimated cost savings errors (Table 8), and should be viewed as coarse approximations.

These results are wholly consistent with other estimates found in the literature. The Washington State University Extension Energy Program reports a payback of 2.9 years[5]. The Office of Energy Efficiency and Renewable Energy (EERE) estimates general payback timescales of 3.5-20 years, with a payback of 5.6 years in the Midwest (Roth et al. 2002). A study conducted by ASHRAE (Hamilton et al. 2004) gives a rather broad range of 3-20 years, also noting a strong dependence on climate. Previous work in Wisconsin (Hicks et al. 2014) estimates a payback range of 5-8 years, using the maximum expected first cost increase of $2/ft^2.

Owner Satisfaction Results

Overall, displacement ventilation is viewed as above average in the categories of energy performance, air quality, occupant comfort, and ease of operation, but average regarding ease of maintenance (Figure 6). Roughly two-thirds of owners (64.3%) feel that the technology exhibits above-average energy performance.

[5] Data available at Energy Efficiency Emerging Technologies. (http://e3tnw.org/ItemDetail.aspx?id=18)

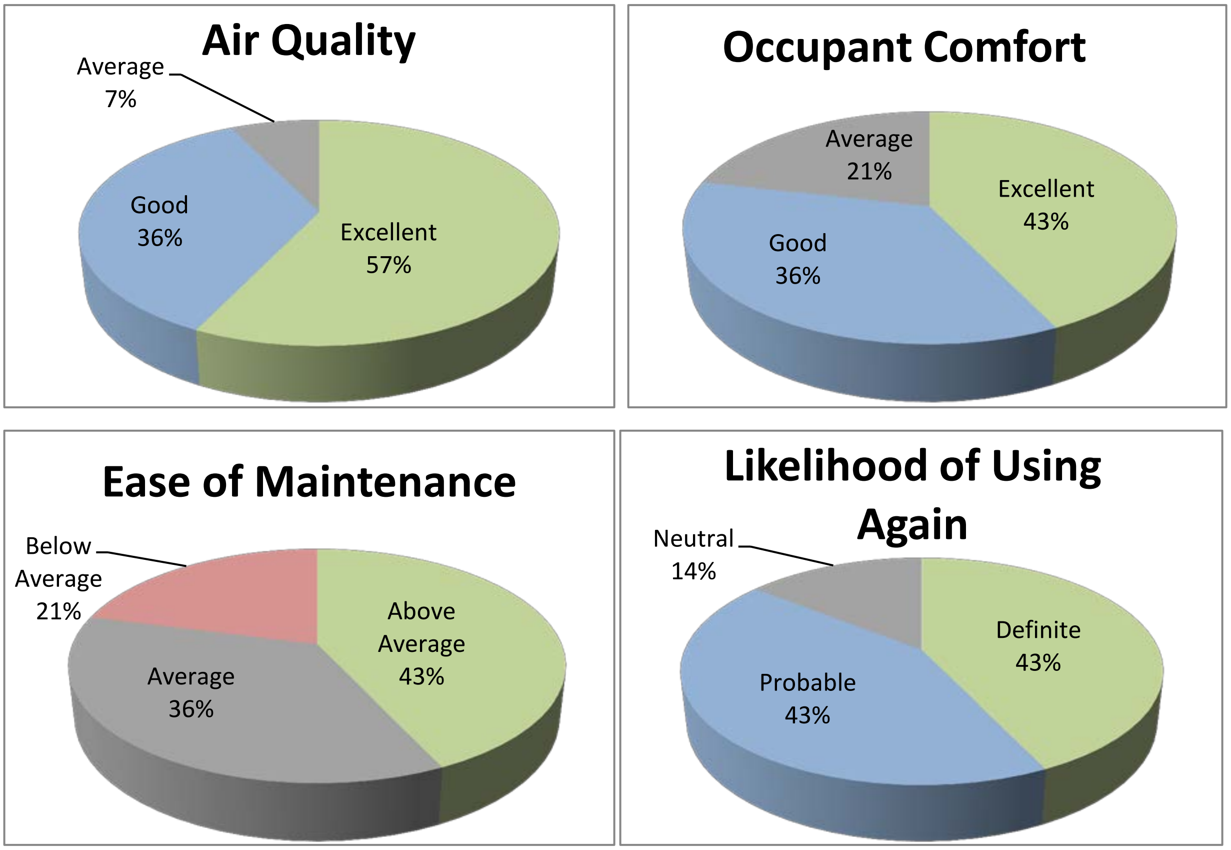

Figure 6: Displacement Ventilation Owner Feedback

Twelve out of fourteen building operators (85.8%) report that they would use the technology again, with the remaining two expressing neutrality. The above figure shows that owners have generally positive feedback about this technology. Although DV is perceived to produce only moderate energy savings, occupants are viewed as more comfortable and most owners would use the technology again.

Displacement ventilation received the highest marks in the category of air quality. Although numerical differences between seasonal comfort categories are not statistically significant, the general trend is that greater comfort is observed in the summer. This can be a consequence of inadequately sized parallel heating systems and/or attempts to use the displacement ventilation system to heat the building rather than simply ventilate.

Table 9 lists numerical results from the owner satisfaction portion of the survey. Maintenance and winter comfort are the only categories for which owners exhibited any dissatisfaction. The most frequently cited motivation for using the technology was Air Quality (78.6%), followed by a tie between Energy Savings and Occupant Comfort (both 64.3%, Figure 6).

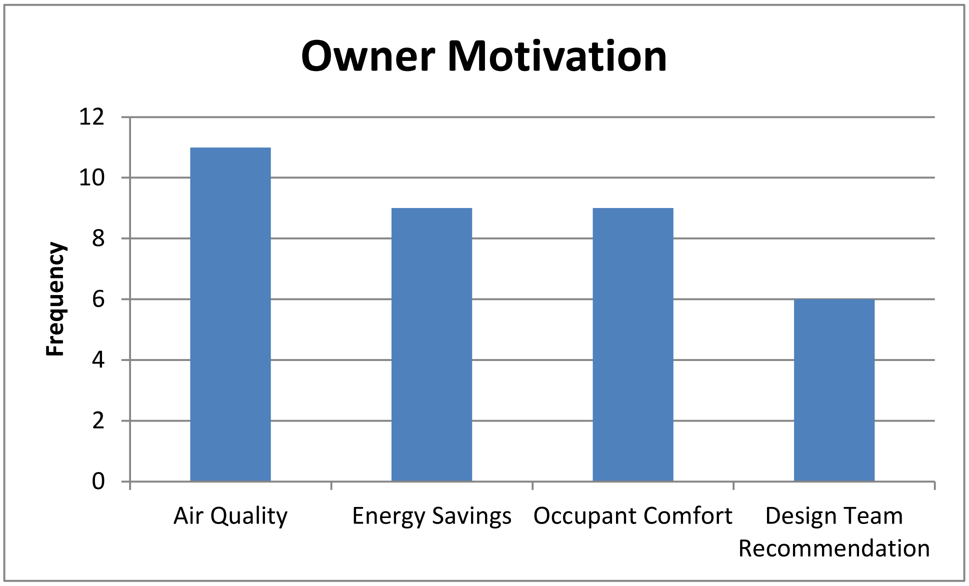

Figure 7: Owner Motivations for Using Displacement Ventilation

Table 9: Owner Satisfaction Results for Displacement Ventilation

ID	Energy Perform	Air Quality	Overall Occupant Comfort	Summer Comfort	Shoulder Comfort	Winter Comfort	Use Again	Maintenance	Ease of Operation	Motivation for Use[b]
DV-1	2	1	3	1	2	3	2	3	2	1,3
DV-2	3	2	2	2	2	2	1	5	3	1,2,3,4
DV-3	3	1	3	2	3	4	3	4	3	1,2,3
DV-4	2	2	2	2	2	2	2	3	2	3,4
DV-5	2	1	1	1	2	1	1	4	2	1,2,3,4
DV-6	2	1	2	3	3	3	2	3	2	1,2,3,4,5[c]
DV-7	2	2	2	3	2	2	2	3	2	1,2,3
DV-8	2	1	1	1	1	1	1	2	2	1
DV-9	2	1	1	1	1	1	1	1	2	1,2
DV-10	2	1	1	1	1	1	1	2	2	1,2
DV-11	3	2	1	1	1	1	1	2	3	1,2
DV-12[d]	3	2	2	2	2	2	2	2	3	1,2,3
DV-25	3	3	3	2	2	2	3	3	3	4
DV-26	2	1	1	1	1	1	2	2	2	3,4
AVG	**2.4**	**1.5**	**1.8**	**1.6**	**1.8**	**1.9**	**1.7**	**2.8**	**2.2**	**-**
WEIGHT AVG	**2.4**	**1.6**	**2.0**	**1.8**	**2.0**	**2.1**	**1.8**	**3.0**	**2.3**	

Notes: **a** - Scale of 1=Excellent/Definitely, 2=Good/Probably, 3=Average/Neutral, 4=Fair/Somewhat Unlikely, 5=Poor/Unlikely. **b** – 1=Air Quality, 2=Occupant Comfort, 3=Energy Savings, 4=Design Team Recommendation, 5=Other (described in additional footnotes). **c**– Extensive research. **d** – Single response given for buildings 12-24. **e** - Numerical values assigned to yes/no answers are 1/0 respectively.

To examine potential connections between perceived performance and likelihood of using the technology again, Spearman's Rank Correlation tests were performed on the data (Table 10). Despite Air Quality being the most cited reason for using the technology, Occupant Comfort was the most closely tied to whether the owner would be likely to use the technology again. Air Quality was very weakly if at all related.

Although Air Quality is related to Occupant Comfort, they were approached as two separate categories due to the technology-specific air quality benefits of displacement ventilation. Owner discernment between the two categories is assumed to be divided between overall (perhaps mostly thermal) occupant comfort, and perceived improvements in the freshness and/or quality of circulated air.

Table 10: Correlation of Owner Satisfaction Parameters with the Likelihood of Repeated Technology Use

	USE TECHNOLOGY AGAIN		
	Spearman's Rho [r_s]	p-value	Correlation Strength[a]
OCCUPANT COMFORT	0.79	6.8×10^{-4}	Very Strong, highly significant
MAINTENANCE	0.30	0.30	Moderate, less significant
ENERGY PERFORMANCE	0.24	0.41	Weak, barely significant
EASE OF OPERATION	0.24	0.41	Weak, barely significant
AIR QUALITY	0.23	0.41	Weak, barely significant

Notes: a – Using a 5-point scale of "very weak" to "very strong" for correlational strength, with p-value<0.05 indicating correlational significance.

Market Survey Results

Demographics

The 31 collected surveys capture the opinions of a broad cross-section of Minnesota building professionals. Architects, commissioning agents, energy efficiency consultants, mechanical engineers, and manufacturing representatives are represented. Respondents spanned an age range of 30 to 69 year olds, with the average age being close to 50. Professionals that completed the survey have an average of 24 years of experience in their fields, with the least being 5 years, and the most 45 years. Average project size is approximately 200,000 ft^2, but ranges from 3,000 to 2,500,000 ft^2. Table 11 lists the professional roles, ages, years of experience, and typical project sizes of the professionals surveyed.

Table 11: Participating Professionals

Respondent ID	Professional Role	Age	Years in Current Profession	Typical Project Size Range [ft^2]
1	Architect	41	15	3,000
2	Architect	69	37	5,000 - 20,000
3	Architect	63	40	5,000 - 150,000
4	Commissioning Agent	52	10	100,000
5	Energy Consultant/Engineer	30	6	100,000
6	Energy Efficiency Advisor	35	5	100,000
7	Energy Engineer	59	18	15,000
8	Energy Engineer	59	28	6,000
9	Mech. Engineer	33	10	100,000
10	Mech. Engineer	50	26	75,000
11	Mech. Engineer	56	32	50,000 - 250,000
12	Mech. Engineer	59	25	25,000
13	Mech. Engineer	40	13	20,000
14	Mech. Engineer	67	42	150,000
15	Mech. Engineer	35	13	10,000 - 1,000,000
16	Mech. Engineer	61	35	15,000
17	Mech. Engineer	51	28	50,000
18	Mech. Engineer	60	38	2,500,000
19	Mech. Engineer	34	5	100,000+
20	Mech. Engineer	62	40	100,000
21	Mech. Engineer	45	21	100,000+
22	Mech. Engineer	67	45	350,000

Respondent ID	Professional Role	Age	Years in Current Profession	Typical Project Size Range [ft^2]
23	Mech. Engineer	58	31	10,000 - 100,000
24	Mech. Engineer	61	36	50,000
25	Mech. Engineer	33	10	15,000 - 500,000
26	Mech. Engineer	43	15	500,000
27	Mech. Engineer	51	24	75,000
28	Mech. Engineer	34	11	450,000
29	Mech. Engineer	58	38	100,000
30	Mech. Engineer	56	28	100,000
31	Mfg. Representative	45	22	50 - 100,000
MIN	--	30	5	3,000
MAX	--	69	45	2,500,000
AVERAGE	**--**	**51**	**24**	**204,758**[a]

Notes: a – Answers which designate a range are included in this average via midpoints.

Typical geographical regions addressed by surveyed professionals' projects range from Duluth only to worldwide. All professionals surveyed had an office in Minnesota, and some or all of their projects were located in Minnesota. The distribution of project locations is shown in Table 12.

Table 12: Represented Geographical Markets

PROJECT AREA	FREQUENCY
Duluth	2
Twin Cities	3
Minnesota	13
Other Midwest	7
Other National	5
Worldwide	1

The types of projects represented are equally varied. While a few professionals specialized in a single type of building (office, higher education, and residential), most had experience with multiple building types. The distribution of building types is given in Figure 8.

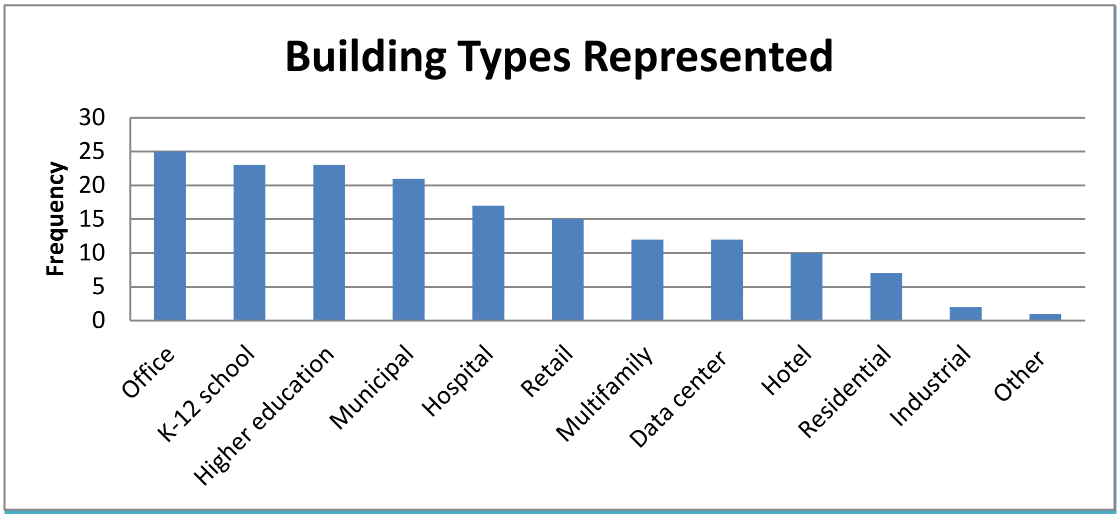

Figure 8: Distribution of Represented Building Types

Displacement Ventilation

Understanding

On average, participants indicated that they were somewhat familiar with displacement ventilation technology. Four respondents reported that they were not at all familiar, and 13 claimed that they were very familiar with the technology. After reporting on their level of familiarity, respondents were asked how they would describe displacement ventilation.

Participants mentioned "fresh air," "outside air," or "ventilation" in 52% of the responses, indicating a fair level of recognition of the main functions/benefits of the technology. Only five responses were entirely correct (16%), 15 were partially correct (48%), three answered that they did not know how to describe the technology (10%), and eight responses were found to be technically incorrect (26%). A pie graph showing the accuracy of DV descriptions is given in Figure 9.

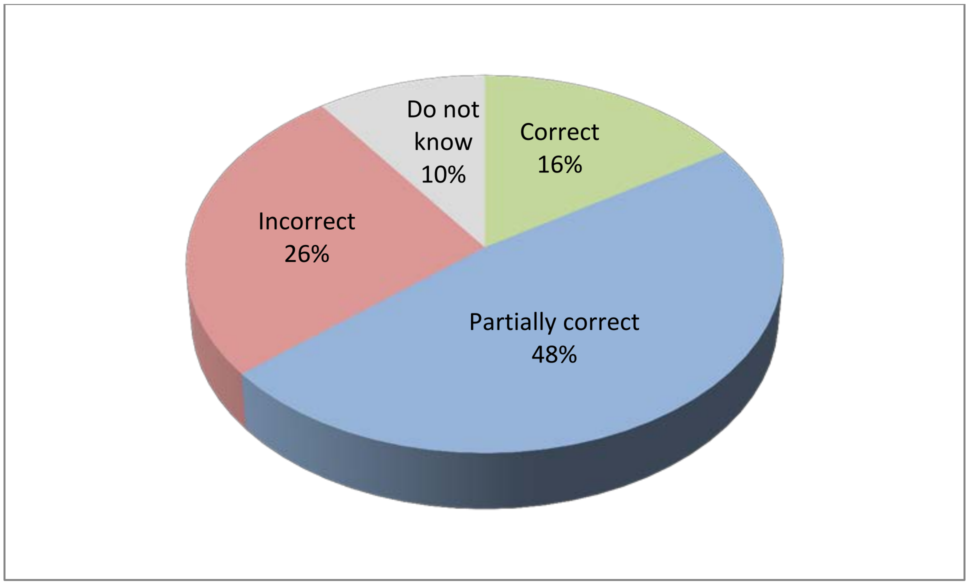

Figure 9: Accuracy of respondent descriptions of displacement ventilation.

Of the eight incorrect responses, five were put forward by professionals that claimed to be very familiar with the technology. Only one respondent directly indicated that the technology was primarily a ventilation method. Conversely, three professionals incorrectly associated the technology with heating/cooling, and one described under floor air distribution (UFAD) instead of DV.

Technology Use

Approximately two thirds of respondents indicated that they had used displacement ventilation in their projects, with 32% having never used the technology. Figure 10 shows the breakdown of usage frequency among professionals surveyed. Numerically, respondents had been involved with an average of six projects utilizing displacement ventilation, with a range that spanned never having used the technology to using it in upwards of 25 projects. One professional answered the question with a percentage rather than an integer, indicating that DV was installed in 75% of the projects that they worked on.

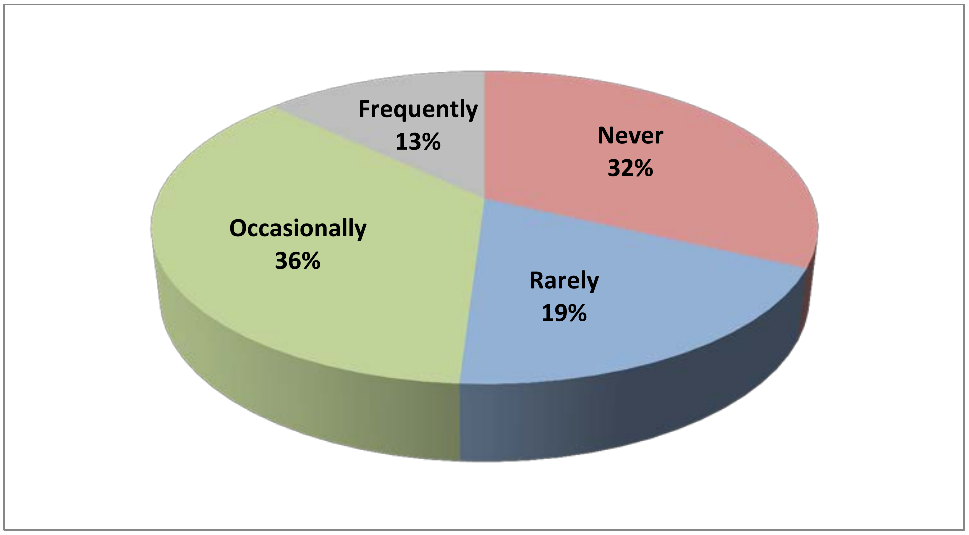

Figure 10: Displacement ventilation usage frequency.

Of those that had used the technology (and one respondent that had not yet used it), the motivations for including displacement ventilation in projects weighed heavily toward energy savings and air quality improvements. Two respondents listed owner request as their only reason for using the technology, and one cited air quality as their sole motivation. Figure 11 shows the frequency of reasons cited for using the technology.

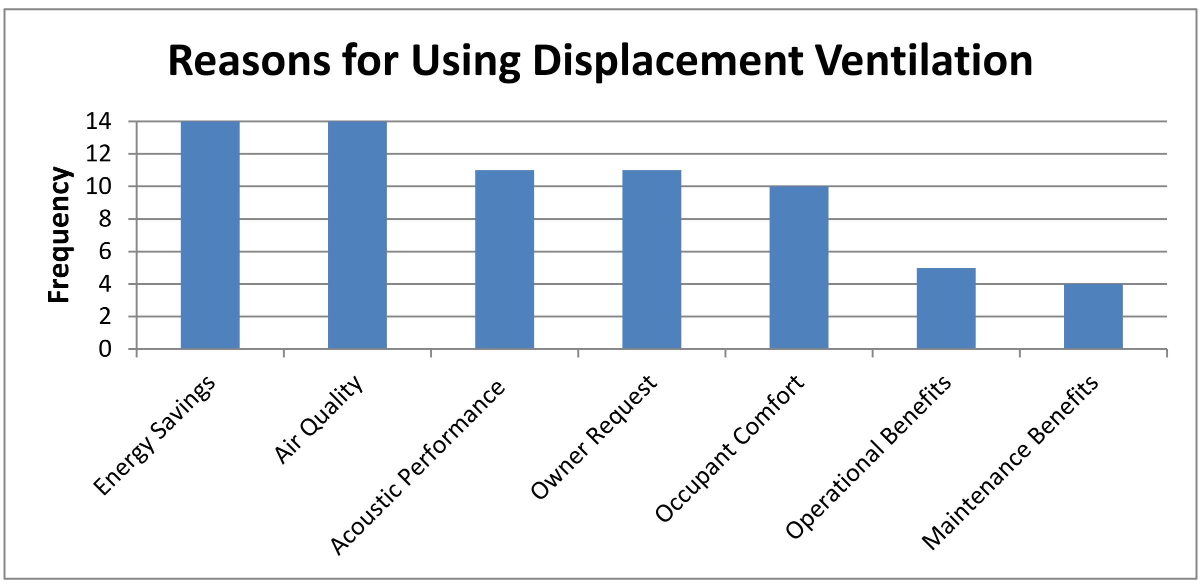

Figure 11: Reasons for Using Displacement Ventilation.

Participants were also asked to explain, in cases where displacement ventilation was actively not chosen for use in a project, why it was not used. Of the 31 respondents, 15 had participated in project that had chosen not to use DV. Cost was cited the most frequently as a barrier to choosing the technology, in four of 15 cases (27%). Lack of familiarity was next at 20% (cited three times). These were followed by the belief that DV could not provide thermal comfort for occupants (13%), and assertions that DV was a poor choice for heating (13%).

Some reasons for not using the technology which were cited only once included that DV was not appropriate for residential applications, and controls/maintenance can be difficult. One respondent stated that they were happy with traditional mixing, and another had confused DV with UFAD.

Attitudes toward Displacement Ventilation

Despite comparatively rare usage of the technology, professionals indicated, on average, that they were positively inclined toward displacement ventilation. A majority (54%) had positive attitudes toward DV, as opposed to only 9% that felt negatively toward it. A full third of respondents claimed neutrality toward the technology. Figure 5 shows the distribution of attitudes toward displacement ventilation.

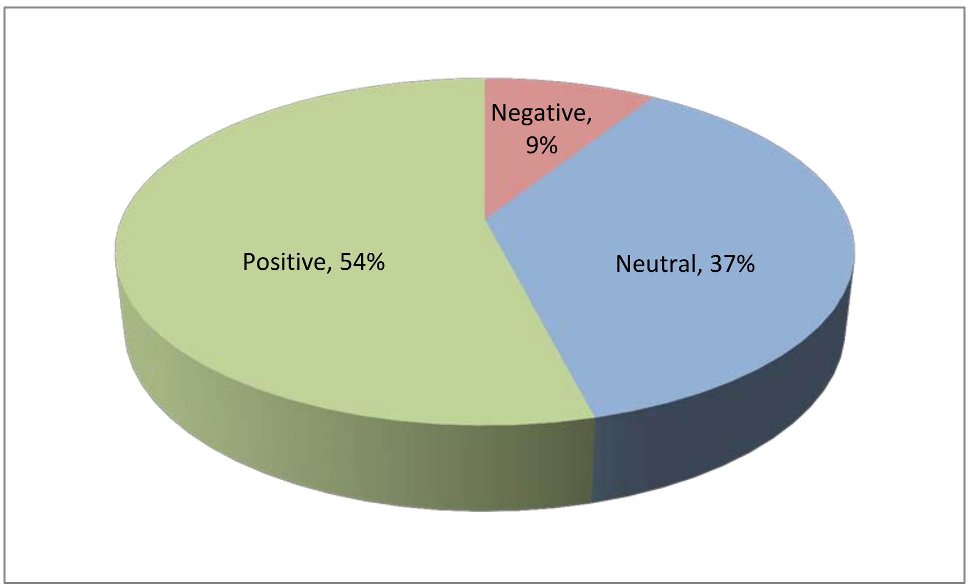

Figure 12: General attitudes toward displacement ventilation technology.

Reasons cited for being positively inclined toward DV touched on a few common themes such as energy efficiency, air quality, and acoustic performance. The most frequent explanation for a negative attitude toward the technology invoked its current lack of industry acceptance/market adoption. Other negative descriptors included the assertion that DV was not appropriate for all situations, and concerns about cost.

Perceived Technology Characteristics

When asked how they felt the cost of displacement ventilation compared to more common HVAC systems (such as variable air volume), respondents indicated that DV appeared to be somewhat more expensive, on average. Figure 13 shows the overall distribution of opinions regarding technology cost.

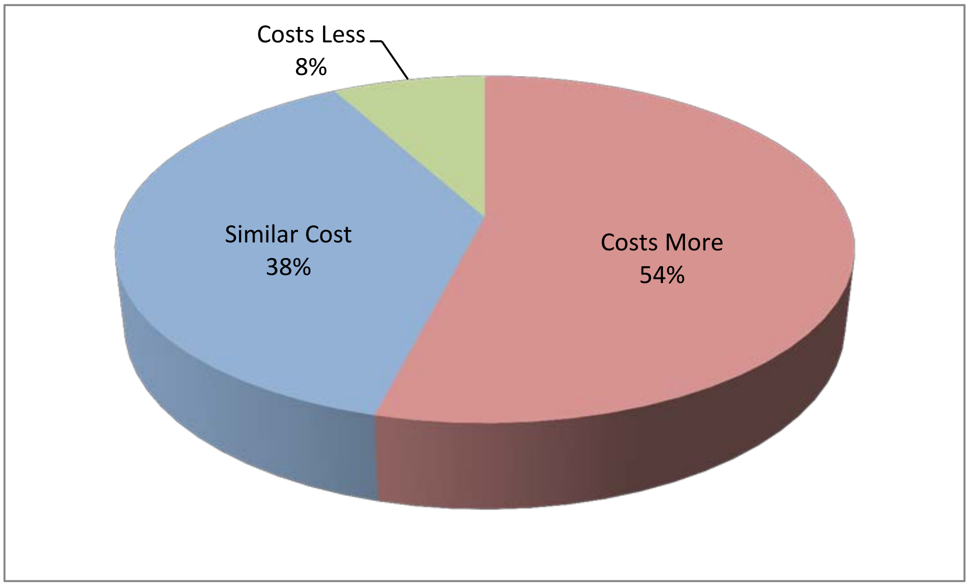

Figure 13: Perceived cost of displacement ventilation compared to more common systems (e.g., VAV).

Energy use was perceived very positively by participants, with 84% reporting that the technology used less energy than more traditional systems. Payback timescales were estimated at 10 years or less by 74% of respondents.

Displacement ventilation systems were perceived to be more difficult to operate than traditional systems by 56% of respondents, while 36% found their operation similarly difficult. Most participants found the maintenance of DV systems to be similar (44%) or more difficult (40%) as well. Despite the suggestion that both operations and maintenance were more difficult, the cost of maintaining DV systems was perceived to be the same as that of more common HVAC systems in 72% of responses.

Although 31 professionals were surveyed, six of them responded “Don’t know” to the questions in this section. The six professionals that did not respond were three architects (out of the three taking the survey) and three energy engineers (out of four). While it may not be uncommon for architects to be unfamiliar with HVAC energy use and payback timescales, it is somewhat striking to find that energy engineers are unfamiliar with this technology. As professionals who are in a position to recommend energy efficient technologies, their lack of familiarity with displacement ventilation may provide one reason that its usage remains comparably rare.

Perceived technology characteristics were statistically tested against overall attitude toward displacement ventilation to identify potential correlations. Energy use and ease of operation were the most strongly correlated with overall attitudes toward the technology. This finding suggests some ambivalence as energy savings were viewed very positively, but operation viewed as a weakness of the technology.

Payback timescale and ease of maintenance were mildly correlated with overall attitudes toward displacement ventilation. The two cost variables (overall cost and maintenance cost) were found to be uncorrelated with general opinions of the technology. Table 10 shows the results of this Spearman Rank-Order Correlation analysis.

Table 13: Correlation of Perceived Technology Characteristics with Overall Inclination toward Technology

	OVERALL INCLINATION TOWARD DISPLACEMENT VENTILATION		
	Spearman's Rho [r_s]	p-value	Correlation Strength[a]
ENERGY USE	0.52	7.6×10^{-3}	Strong, significant
OPERATION	0.48	1.6×10^{-2}	Strong, significant
PAYBACK TIMESCALE	0.36	8.1×10^{-2}	Moderate, barely significant
MAINTENANCE	0.35	8.4×10^{-2}	Moderate, barely significant
COST	0.12	0.57	Very weak, insignificant
MAINTENANCE COST	0.06	0.77	Very weak, insignificant

Notes: a – Using a 5-point scale of "very weak" to "very strong" for correlational strength, with p-value<0.05 indicating correlational significance.

Innovative Building Technologies

Opinions toward innovative building technologies (i.e., demand controlled ventilation, radiant systems, geothermal) were assessed by the survey to provide a baseline to help identify and interpret variations in attitude toward displacement ventilation technology. For this reason, many of the same questions were asked, allowing for direct comparisons between responses.

Technology Use

Every respondent indicated that they had used innovative technologies in their projects, with two thirds of respondents (65%) reporting that they used such technologies frequently. Figure 14 shows the breakdown of usage frequency among professionals surveyed. Numerically, respondents had been involved with an average of 39 projects utilizing innovative technologies, with a range that spanned using such technologies in three projects to hundreds of projects. Six professionals answering in percentages indicated that 75-100% of their projects included some type of innovative technology.

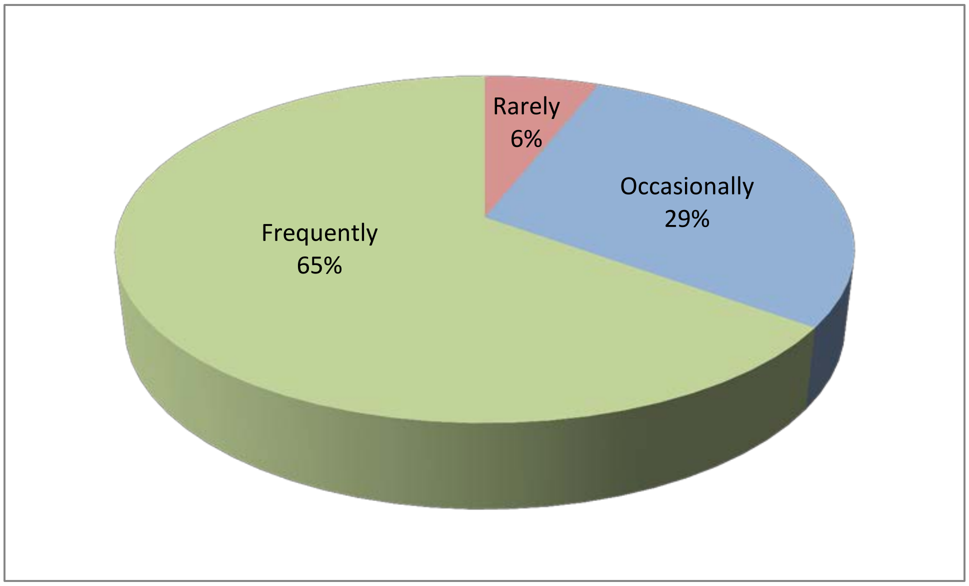

Figure 14: Innovative technology usage frequency.

The types of technologies used by respondents are shown in Figure 15. This figure illustrates the choices provided on the survey. Nine participants indicated that they had used all seven of these technologies in their work. Additional technologies written in by respondents included envelope sealing (1 response), passive solar (2), window frames (1), glazing (1), auto shading (1), passive geothermal preheat (1), ice storage (1), and DOAS (1).

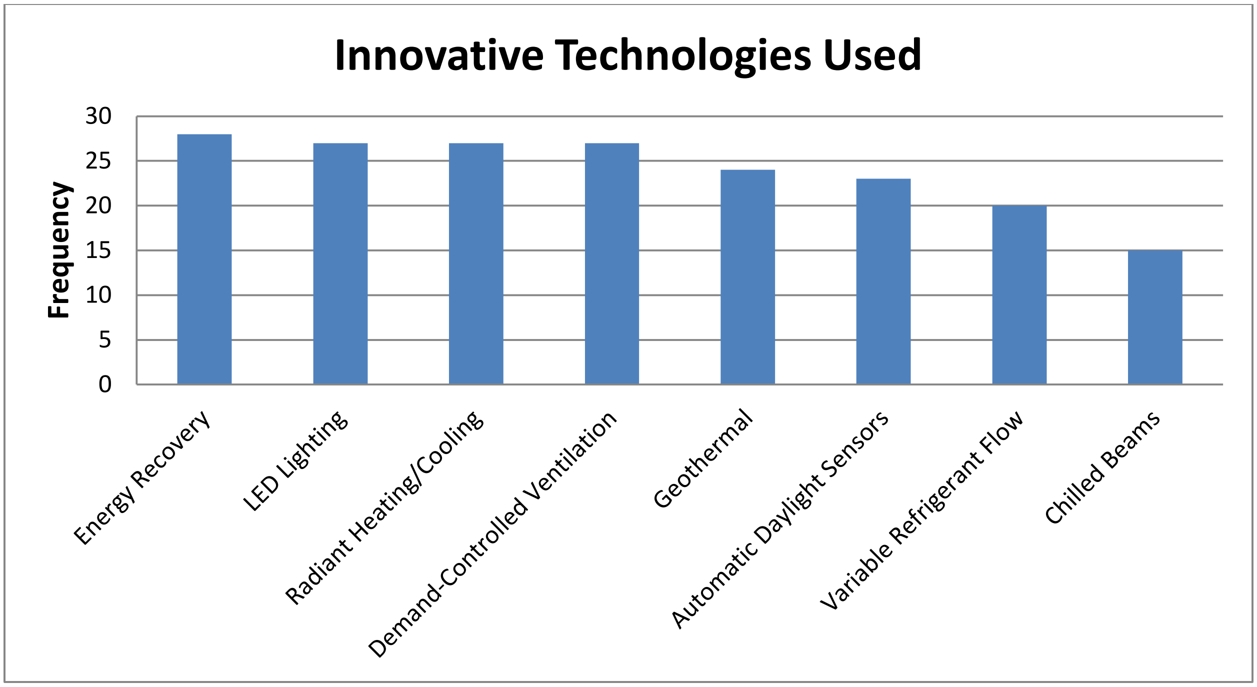

Figure 15: Types of innovative technologies used in projects by participants.

The motivations for using innovative technologies weighed heavily toward energy savings, with three participants citing energy savings as their only motivating factor. Figure 16 shows the frequency of reasons cited for using these technologies. A write-in answer by a respondent cited mandates as a motivation for using innovative technologies as well.

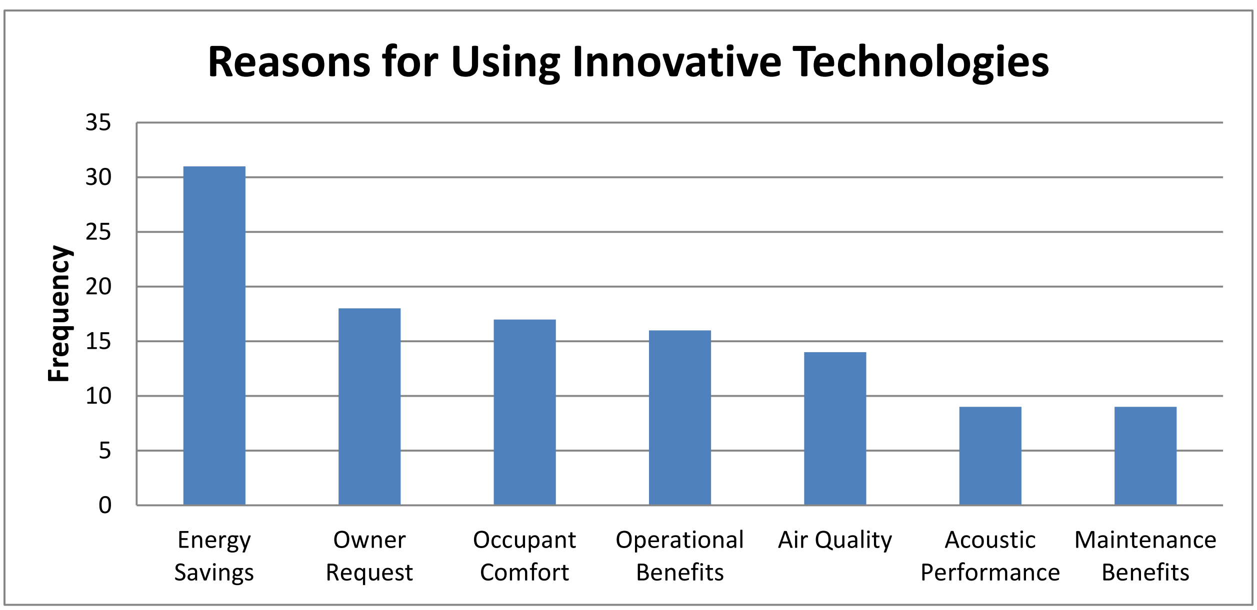

Figure 16: Reasons for Using Innovative Technologies.

Participants were also asked to explain, in cases where innovative technologies were actively not chosen for use in a project, why they were not used. Participation in projects that had chosen not to use an innovative technology was indicated by eleven of 31 respondents. Cost was cited the most frequently as a barrier, in seven of the eleven cases (64%). Owner request, operations and maintenance drawbacks, and lack of owner familiarity were tied at 18% (cited twice each). One respondent indicated a desire to use passive rather than active technologies.

Attitudes toward Innovative Technologies

Survey respondents indicated positive attitudes toward innovative technologies in 100% of cases. A very positive inclination was selected by 71% of participants, with a somewhat positive attitude chosen by the remaining 29%. The primary reason given for these positive responses was energy efficiency (or sustainability), cited by 55% of survey takers. Client request and performance were next, conveyed by 13% of participants, followed by occupant comfort (10%) and cost effectiveness (6%). This was a write-in question and respondents were able to cite multiple reasons.

Some explanations for overall attitude which were cited only once included that using innovative technologies improves indoor air quality, has operations and maintenance benefits, improves the industry, benefits business, or is simply the right thing to do. A negative response in this category referenced risks if the technology didn't "work."

A Spearman Rank-Order Correlation analysis was run to compare attitudes toward displacement ventilation with attitudes toward innovative technologies. Test results (Spearman's Rho = 0.03, p-value=0.87) showed that there is no correlation between the two. This suggests that participants' inclinations toward displacement ventilation are not greatly influenced by their attitudes toward innovative technologies in general.

Perceived Innovative Technology Characteristics

Although attitudes toward innovative technologies were overwhelmingly positive, surveyed professionals tended to view the energy savings and cost payback claims about those technologies with some skepticism. While the majority of respondents felt that energy savings resulting from the use of innovative technologies were as claimed (54%), more of the remaining participants felt that energy savings were less than claimed (32%) than those that felt more energy had been saved than was originally claimed (14%). Figure 17 shows the breakdown of responses to this question.

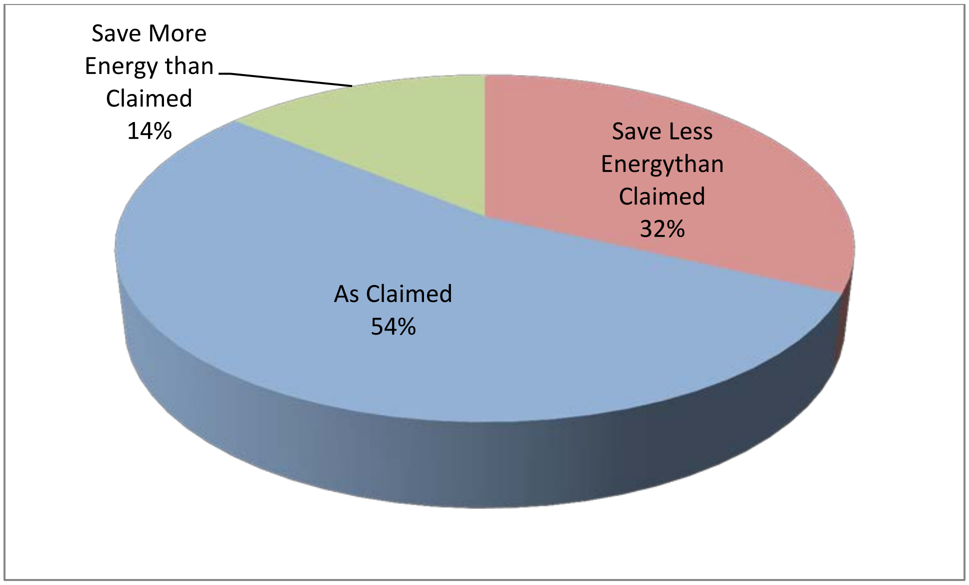

Figure 17: Perceived energy savings attained by innovative technologies.

Participants were evenly split between the perception that innovative technologies have longer paybacks than claimed (43%) and that their paybacks are as expected (43%). Only 14% of respondents felt that paybacks tended to be shorter than claimed. The distribution of responses regarding perceived payback timescales is shown in Figure 18.

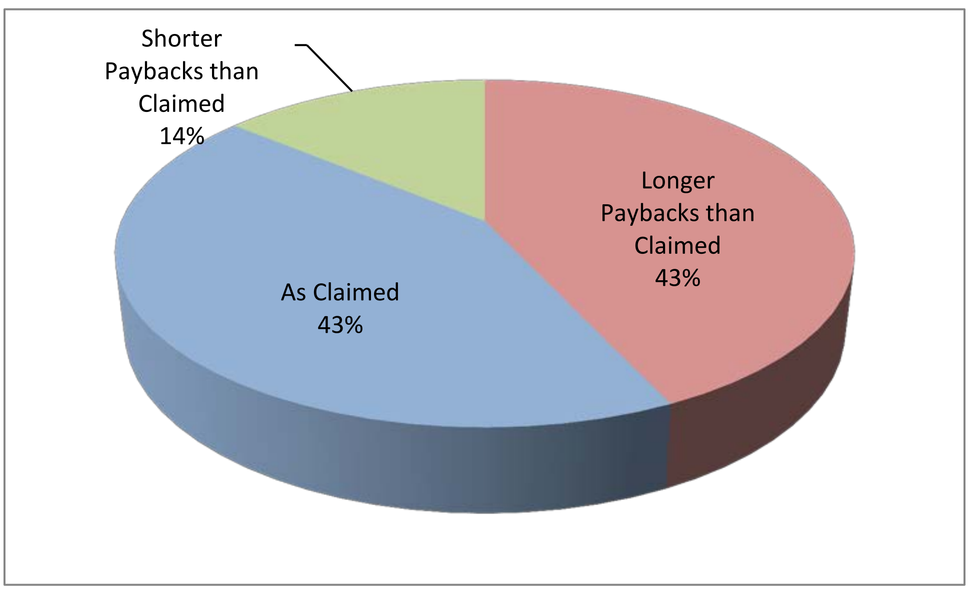

Figure 18: Perceived payback timescales of innovative technologies.

Motivations

A careful analysis of the factors underlying market opinions is necessary for accurately interpreting market feedback. To unearth these factors, participants were asked to rank a set of 10 potential project influences in order of importance. Rankings were averaged for each of the influencing factors, and 1-σ confidence intervals were calculated (assuming a normal distribution).

Figure 19 illustrates the results of this exercise. This analysis shows that owner preferences are the single most influential factor reported by the professionals surveyed. Project cost and energy efficiency are nearly tied for second place, followed by occupant comfort.

Integrating these factors with the results of previous sections can assist in the interpretation of market opinions regarding displacement ventilation. The existing lack of market exposure to displacement ventilation results in owners that are not familiar with the technology. This makes it more difficult to integrate the technology into new projects. However, the energy savings associated with displacement ventilation result in a generally positive attitude toward the technology among building professionals.

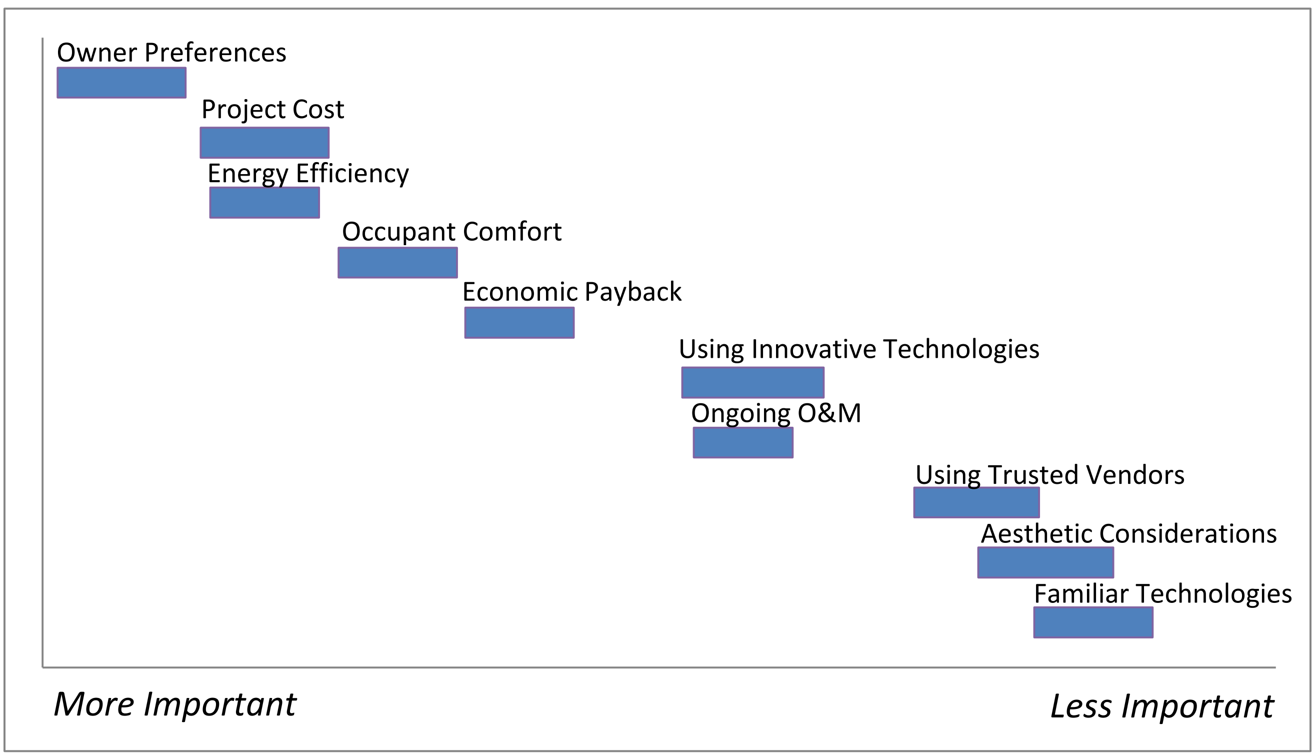

Figure 19: Relative importance of project factors. The length of each bar indicates a 1-σ error range.

Discussion of Results

The results of this study indicate that displacement ventilation can yield significant savings in cold weather climates such as Minnesota. In general, displacement ventilation is found to be an energy efficient technology, due to decreased fan and cooling energy use in the buildings it serves, with typical annual measured EUI savings of $16 \pm 4\%$ in Minnesota buildings. Associated payback timescales range from 2-8 years, depending on first cost assumptions.

Savings from DV are primarily achieved during summer months, or periods when a building is in cooling mode. Displacement ventilation also has the capability of providing superior air quality to occupants by effectively routing fresh air to head height and removing contaminants more efficiently than other HVAC systems, potentially resulting in less school or work absence due to illness. Improved air quality is the most common motivation cited by respondents for choosing to install DV systems. Most Minnesota building owners surveyed are satisfied with displacement ventilation, and would use the technology again.

DV systems are expected to have similar life expectancy as other HVAC systems, but this could be impacted by incorrect operation. Achievement of savings requires the ventilation and envelope heating components of the building load to have separate dedicated systems. Study results suggest that there are DV systems in Minnesota that have either been incorrectly designed or are being poorly operated. Follow up studies investigating specific aspects of system design and operation is necessary to fully understand the identified performance variations.

Building professionals spanning a range of job titles, ages, and primary project locations across Minnesota were surveyed to determine their acceptance and understanding of displacement ventilation technology. Most of the professionals surveyed had a basic, if imperfect, grasp of the technology and were able to identify its main benefits. Nearly one third of respondents, however, were either completely unfamiliar with the technology or held errant beliefs regarding its operation.

Although two-thirds of professionals surveyed had used displacement ventilation in projects, only 13% claimed to utilize the technology frequently. Despite this general lack of exposure, attitudes toward the technology are largely positive, due to associated energy savings and air quality improvements. Most professionals estimated the economic payback timescale for DV at 10 years or less, consistent with field results.

The most frequent explanation for a negative attitude toward the technology, as reported by building professionals, involved its current lack of market penetration. A lack of owner exposure to DV is a particularly important challenge to its market success, and persists despite the fact that current owners tend to be very pleased with the technology's performance in their buildings.

Conclusions and Recommendations

Taken together, the results of this study provide a thorough characterization of the performance potential and market status of displacement ventilation technology in Minnesota. Multiple, independent estimates of available energy savings converge at approximately 15% total energy saved. Similarly, both data-driven and professionally estimated payback timescales are consistent at less than 10 years. Significant variability in measured savings indicates that design and/or operational parameters are critical to the optimization of this technology's potential.

Professionals and building owners alike report positive attitudes toward the technology, however, lack of market exposure and familiarity with the technology in all stakeholder groups are viewed as its greatest barrier. Increasing owner exposure to the technology is particularly critical to its success, since owner preferences are shown to drive project choices. If owner exposure could be increased, market penetration should follow, since existing owners tend to be pleased with displacement ventilation, and would choose the technology again.

Displacement ventilation technology has been shown to have the potential to produce cost-effective energy savings in Minnesota commercial buildings, and should therefore be considered for inclusion in utility incentive programs. To maximize program impact, however, the authors recommend follow-up field studies identifying design and/or operational contributions to variations in the achievement of energy savings. Such studies could be used to develop design and operational guides that would aid Minnesota engineers and building operators in maximizing the energy savings achieved through use of the technology.

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Appendix A. Displacement Ventilation Candidate Buildings

Table 14: Candidate Buildings

SPACE TYPE	CITY
Office	Maple Grove
Office Space/Community Center	St. Paul
K-12 School	Two Harbors
Office Space	Roseville
University Building	Minneapolis
Library	Elk River
K-12 School	Watertown
Community College Building	White Bear Lake
K-12 School	Brooklyn Center
K-12 School	Coon Rapids
K-12 School	Blaine
K-12 School	Coon Rapids
K-12 School	Champlin
K-12 School	Coon Rapids
K-12 School	Champlin
K-12 School	Blaine
K-12 School	Coon Rapids
K-12 School	Blaine
K-12 School	Crystal
Higher Education	St. Paul
K-12 School	New Brighton
K-12 School	New Brighton
K-12 School	New Brighton
K-12 School	Shoreview
K-12 School	Brainerd
K-12 School	Moundsview
K-12 School	New Brighton

SPACE TYPE	CITY
K-12 School	Silver Bay
K-12 School	Wadena
University Building	Duluth
K-12 School	Faribault
K-12 School	Cloquet
Higher Education	Duluth
Higher Education	Duluth
K-12 School	St. Paul
K-12 School	Elk River
K-12 School	Rogers
K-12 School	Rogers
K-12 School	Zimmerman
K-12 School	Minnetonka
K-12 School	Alexandria
K-12 School	St. Joseph
Office	Milwaukee
Municipal	St. Cloud
K-12 School	North Branch School District
Casino	Morton
K-12 School	Richfield
K-12 School	Coon Rapids
K-12 School	Brooklyn Park
K-12 School	Brainerd
K-12 School	Chaska
Municipal	Hibbing (St. Louis County)
Municipal	Duluth
Higher Education[a]	Duluth
Library[a]	Minneapolis
Library[a]	Maple Grove
Library[a]	Plymouth

Notes: a – Not displacement ventilation, likely UFAD.

Appendix B. Example Survey

Minnesota CARD Buildings Research – Owner/Operator Survey

Part I: Building Data

1. Building function [School, Office, House of Worship, Senior Care, etc.]
2. City, Zip Code
3. Total square footage Cooled [and Heated, if different]
4. Year of building completion [and year of Displacement Ventilation install, if different]
5. Percentage (or area) of building served by Displacement Ventilation [% or sqft]
6. Location of Disp. Vent. diffusers [In-Floor, Vertical/Wall, or Describe Other]
7. Approximate discharge air velocity [feet per minute, or specify units]
8. Range of discharge air temperatures [°F]
9. Additional Heating and/or Cooling systems [Radiant Heat/Cool, Fin Tube, etc.]
10. Additional energy conservation measures included in building [please check all that apply]

☐ Daylight Sensors	☐ Spray Foam Insulation	☐ Solar Panels [indicate kW]
☐ Solar Hot Water	☐ Geothermal Bore Field	☐ Wind Energy [indicate kW]
☐ High Efficiency Windows	☐ Exhaust Heat Recovery	☐ Ventilation Occ. or CO_2 Sensors
☐ T5, T8, LED (etc.) Lighting	☐ Lighting Occ. Sensors	☐ 100% Outside Air (DOAS)
☐ Thick Wall/Roof Insulation	☐ Condensing Boiler	☐ Other [please indicate]

11. Additional energy uses [please provide quantity]

Cooking Facilities	Walk-in refrigerators	Computers	Parking lot [area]
Pool(s)	MRI Machines	Other [please indicate]	

12. Operating schedule [days of week and hours of day]
13. Number of occupants / workers / students
14. Please provide total annual (12-month) utility use and cost below or attach utility bills [preferred]

Electric		Gas	
Date Range [mm/yy] From	To	Date Range [mm/yy] From	To
Annual Electric Usage [kWh/yr]		Annual Gas Usage [Therms/yr]	
Annual Electric Cost [$/yr]		Annual Gas Cost [$/yr]	

Part II: Performance Feedback

RATING SYSTEM: A – Excellent / Very Likely B – Good / Somewhat Likely
C - Average / Neutral D – Below Average / Somewhat Unlikely F – Poor / Unlikely

1. What were the main reason(s) for implementing Displacement Ventilation technology
   - ☐ Air Quality ☐ Occupant Comfort ☐ Energy Savings
   - ☐ Design Team Recommendation ☐ Other (please explain)
2. How would you rate the **energy performance** of this system? ◯A ◯B ◯C ◯D ◯F
3. How would you rate **occupant satisfaction** compared to a typical building? ◯A ◯B ◯C ◯D ◯F
4. How would you rate **air quality** compared to a typical building? ◯A ◯B ◯C ◯D ◯F
5. Please evaluate **occupant comfort** during the following times of year:
   - SUMMER Occupant Comfort ◯A ◯B ◯C ◯D ◯F
   - SPRING/AUTUMN Occupant Comfort ◯A ◯B ◯C ◯D ◯F
   - WINTER Occupant Comfort ◯A ◯B ◯C ◯D ◯F
6. What percentage of energy savings (if any) were anticipated from using this technology?
7. How likely are you to use this technology again in a future building? ◯A ◯B ◯C ◯D ◯F
8. How would you rate the **ease of operation** with respect to this technology? ◯A ◯B ◯C ◯D ◯F
9. How would you rate level of **maintenance** compared to a typical system? ◯A ◯B ◯C ◯D ◯F
10. In your own words, please indicate the main benefit(s) and drawback(s) of this system
11. Would you be willing to provide more information as necessary? ◯YES ◯NO
12. Additional comments / feedback

Research Director: Amalia Hicks, Ph.D., LEED GA • Phone: 608-836-4488 x22 • Email: AHicks@sustaineng.com

Appendix C. Professional Survey

Minnesota Department of Commerce Buildings Research - Professional Survey I

* Required

Part I: Demographics

1. **Age** *

___

2. **Professional Role** *
Mark only one oval.
   - ◯ Architect
   - ◯ Mechanical Engineer
   - ◯ Electrical Engineer
   - ◯ Civil Engineer
   - ◯ Engineering Consultant
   - ◯ Other: ___

3. **Years in Current Profession** *

___

4. **Typical Project Size Range** *
[square feet]

___

5. **Typical Project Location(s)** *
[cities, states, counties, etc.]

___

6. **Typical Project Building Types** *
Check all that apply.

- [ ] Office
- [ ] K-12 School
- [ ] Higher Education
- [ ] Municipal (city hall, library, fire station, etc.)
- [ ] Hospital
- [ ] Retail
- [ ] Hotel
- [ ] Multifamily
- [ ] Residential
- [ ] Data Center
- [ ] Other: ______________________

Part II: Displacement Ventilation (DV)

7. **How familiar are you with Displacement Ventilation technology** *
Mark only one oval.

- ( ) Very
- ( ) Some
- ( ) A little
- ( ) Not at all

8. **How would you describe Displacement Ventilation to a client?** *

____

9. **Have you used Displacement Ventilation in your projects?** *
Mark only one oval.

- ( ) Frequently
- ( ) Occasionally
- ( ) Rarely
- ( ) Never

10. **Approximately how many of your projects have used Displacement Ventilation technology?** *

____

11. **If used, what were your reasons for choosing Displacement Ventilation?**
Check all that apply.
   - [ ] Owner Request
   - [ ] Air Quality
   - [ ] Acoustic Performance
   - [ ] Occupant Comfort
   - [ ] Energy Savings
   - [ ] Operational Benefits
   - [ ] Maintenance Benefits
   - [ ] Other: ______________________________

12. **If you have actively chosen NOT to use Displacement Ventilation, what were your main reasons for not using it?**

____

13. **Would you say you are positively, negatively, or neutrally inclined toward Displacement Ventilation?** *
Mark only one oval.
   - ( ) Very positively inclined
   - ( ) Somewhat positively inclined
   - ( ) Neutral
   - ( ) Somewhat negatively inclined
   - ( ) Very negatively inclined
   - ( ) Other: ______________________________

14. **Why?** *

____

15. **What is your impression of the COST (per sqft) of Displacement Ventilation as compared to more common systems (ex. VAV)?** *

Mark only one oval.

- DV costs MUCH MORE (over $5/sqft more)
- DV costs a LITTLE MORE ($1-$5/sqft more)
- DV has a SIMILAR cost
- DV costs a LITTLE LESS ($1-$5/sqft less)
- DV costs MUCH LESS (over $5/sqft less)
- Don't know

16. **What is your impression of the ENERGY USE of Displacement Ventilation as compared to more common systems (ex. VAV)?** *

Mark only one oval.

- DV uses MUCH LESS energy (over 10% saved)
- DV uses a LITTLE LESS energy (5%-10% saved)
- DV has SIMILAR energy use
- DV uses a LITTLE MORE energy (5%-10% more)
- DV uses MUCH MORE energy (over 10% more)
- Don't know

17. **How would you estimate the PAYBACK TIMESCALE of Displacement Ventilation technology?** *

Mark only one oval.

- Immediate
- less than 5 years
- 5-10 years
- 10-20 years
- more than 20 years
- Never
- Don't know

18. **How would you rate the OPERATION of Displacement Ventilation technology compared to more common systems?** *

Mark only one oval.

- Much more difficult
- Somewhat more difficult
- Same
- Somewhat easier
- Much easier
- Don't know

19. **How would you rate the EASE OF MAINTENANCE of DV systems compared to more common systems? ***
Mark only one oval.

- Much more difficult
- Somewhat more difficult
- Same
- Somewhat easier
- Much easier
- Don't know

20. **How would you rate the COST OF MAINTENANCE of DV systems compared to more common systems? ***
Mark only one oval.

- Much more expensive
- Somewhat more expensive
- Same
- Somewhat less expensive
- Much less expensive
- Don't know

Part III: Innovative Building Technologies

Examples of innovative technologies include: variable refrigerant flow (VRF); geothermal; radiant systems; automatic daylight sensors; demand controlled ventilation (DCV); energy recovery ventilators (ERV); chilled beams; LED lighting.

Unless stated, the following questions apply to these types of technologies IN GENERAL, not any one in particular.

21. **Have you used Innovative Technologies in your projects? ***
Mark only one oval.

- Frequently
- Occasionally
- Rarely
- Never

22. **Approximately how many of your projects have used Innovative Technologies? ***

23. **If used, which technologies?**
Check all that apply.

- [ ] Variable refrigerant flow (VRF)
- [ ] Geothermal
- [ ] Radiant heating / cooling
- [ ] Automatic Daylight Sensors
- [ ] Demand controlled ventilation (DCV)
- [ ] Energy Recovery Ventilators (ERV)
- [ ] Chilled beams
- [ ] LED lighting
- [ ] Other: ____________________

24. **If used, what were your reasons for choosing those technologies?**
Check all that apply.

- [ ] Owner Request
- [ ] Air Quality
- [ ] Acoustic Performance
- [ ] Occupant Comfort
- [ ] Energy Savings
- [ ] Operational Benefits
- [ ] Maintenance Benefits
- [ ] Other: ____________________

25. **If you have actively chosen NOT to use Innovative Technologies, what were your main reasons for not using them?**

____

26. **Would you say you are positively, negatively, or neutrally inclined toward Innovative Technologies?** *
Mark only one oval.

- ( ) Very positively inclined
- ( ) Somewhat positively inclined
- ( ) Neutral
- ( ) Somewhat negatively inclined
- ( ) Very negatively inclined
- ( ) Other: ____________________

27. **Why? ***

28. **In general, do you think that Innovative Technologies save as much ENERGY as claimed? ***

Mark only one oval.

- Save MORE energy than claimed
- As claimed
- Save LESS energy than claimed
- Don't know

29. **How do you think the PAYBACK TIMESCALES of Innovative Technologies compare to claims? ***

Mark only one oval.

- SHORTER paybacks than claimed
- As claimed
- LONGER paybacks than claimed
- Don't know

Part IV: Motivations

On a scale of 1 to 10, with 1 being most important, how influential to your work are the following?

30. **Project Influences** *
[Each ranking may be chosen only once]
Mark only one oval per row.

	1 (MOST important)	2	3	4	5	6	7	8	9	10 (LEAST important)
Owner Preferences										
Aesthetic Considerations										
Using Innovative Technologies										
Project Cost										
Occupant Comfort										
Energy Efficiency										
Economic Payback										
Ongoing Operations and Maintenance										
Using Trusted Vendors										
Using Familiar Technologies										

Part V: Additional Information

31. **Additional comments / feedback**

32. **Would you be willing to provide more information as necessary?** *
Mark only one oval.

- Yes
- No

33. **If YES, please enter email address (all survey responses will remain anonymous)**

Appendix D. Baseline Energy Plus Models

School

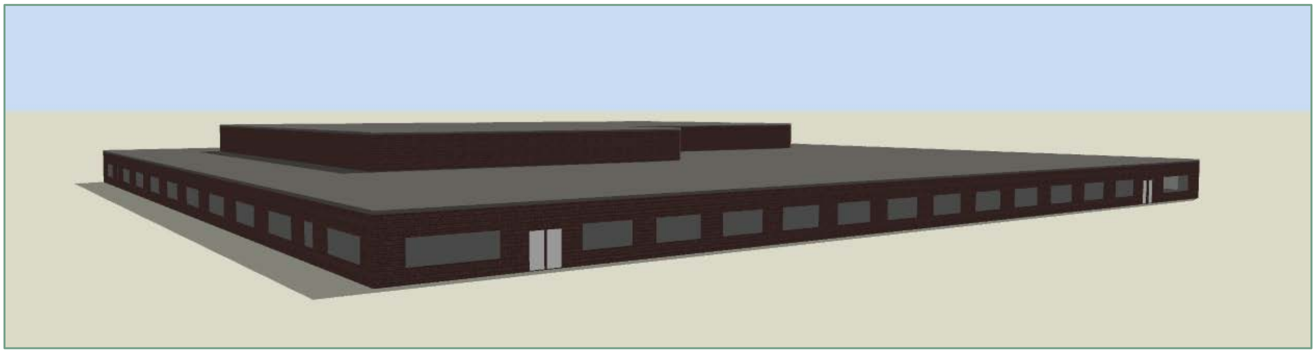

Figure 20: School Model.

The school model was sized based on Minnesota average school enrollments of approximately 500 students (U.S. Department of Education, 2000). Using a local estimate of 110-220 ft^2 per student (MN Dept. of Children, Families, and Learning, 2003) resulted in a ~73,000 ft^2 facility. The Energy Plus model of the school is shown in Figure 20.

Occupancy schedules are based on a typical school year, with no use during summer months. The model was designed to be independent of orientation by creating a square building with classrooms located on all four exterior walls. The school includes the following space types: classrooms, kitchen, administrative areas, bathrooms, 15,000 ft^2 gymnasium, locker room, cafeteria/auditorium, and mechanical room. The school floor plan is shown in Figure 21

The school is served by a Variable Air Volume (VAV) HVAC system with a Direct Expansion (DX) cooling coil and hot water reheat in individual zones. A Constant Air Volume (CAV) system serves the gymnasium.

The school model was calibrated to a combination of typical Minnesota energy use and typical educational energy end use distribution using CBECS data. Compared to the average obtained using combined building types, educational buildings use more heating, cooling, and ventilation and less lighting, hot water, and miscellaneous plug loads. Entering specific model characteristics into the ENERGY STAR Target Finder tool, the resulting median energy use intensity (EUI) of a similar Minnesota middle school is 93.4 kBtu/ft2. Our code-minimum model has a site EUI of 95.6, within 3% of median energy use. The energy end use distribution is also reasonably well matched. Table 15 lists target estimation data, expected energy consumption and modeled energy use.

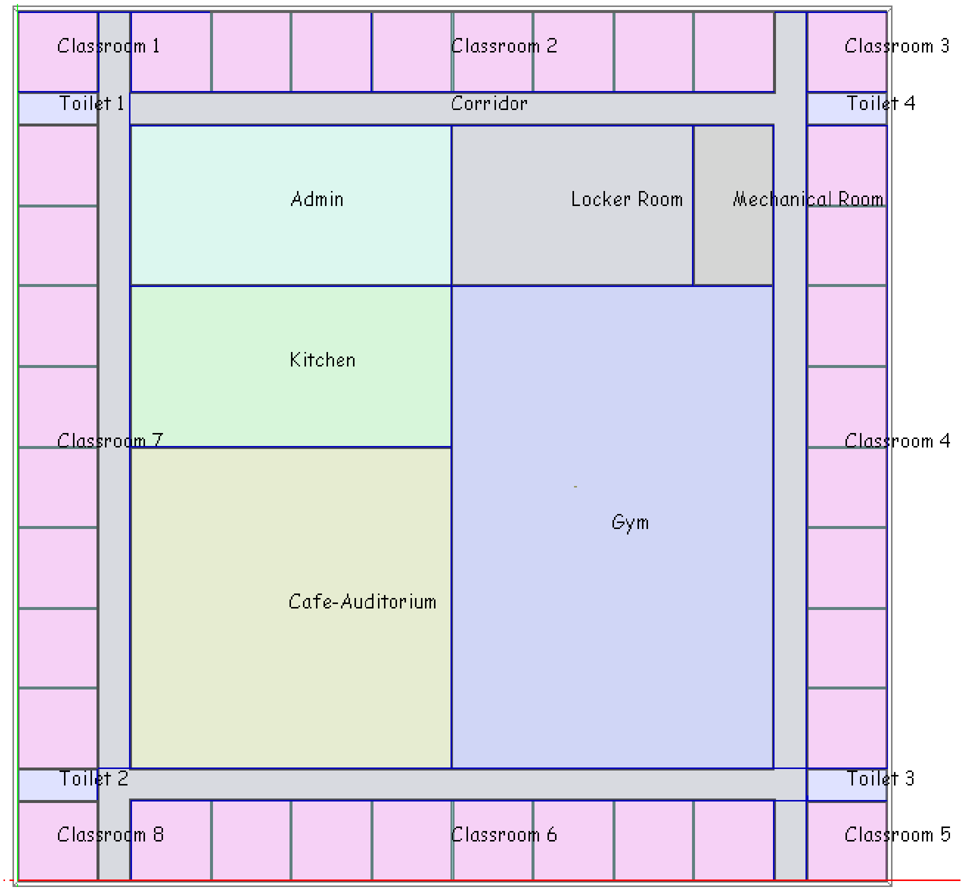

Figure 21: School Floor Plan.

Table 15: Energy Calibration Results for K-12 School Model

	SCHOOL ADJUSTMENT CALCULATION			TARGET ESTIMATION		MODEL
	All U.S. Buildings	U.S. Schools	School Adjustment	Midwest Average	**MN School Target**	**Modeled School**
EUI (KBTU/FT^2)	--	--	--	--	**93.4**	**95.6**
HEATING	38%	47%	19%	49%	**58%**	**64%**
COOLING	7%	10%	30%	4%	**5%**	**5%**
VENTILATION	7%	10%	30%	6%	**8%**	**6%**
LIGHTING	20%	14%	(-30%)	17%	**12%**	**11%**

	SCHOOL ADJUSTMENT CALCULATION			TARGET ESTIMATION		MODEL
	All U.S. Buildings	U.S. Schools	School Adjustment	Midwest Average	**MN School Target**	**Modeled School**
DHW	8%	7%	(-13%)	6%	**5%**	**5%**
MISC	21%	12%	(-43%)	18%	**10%**	**10%**

Office

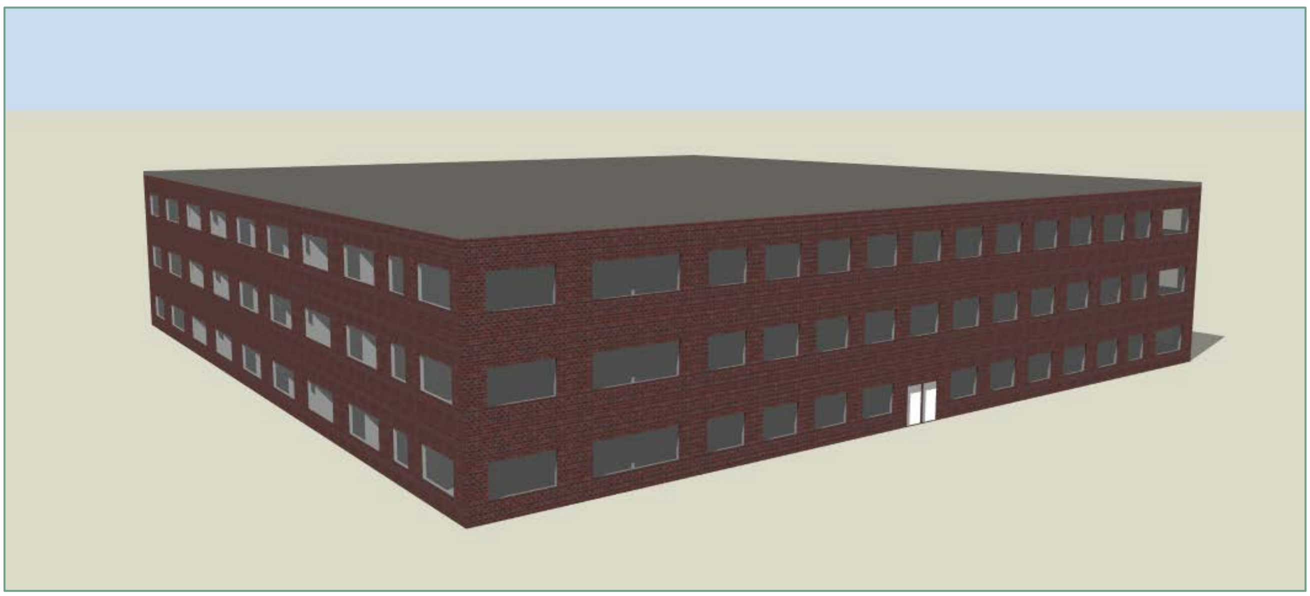

Figure 22: Office Model

Figure 22 shows the 73,200 ft^2 office Energy Plus model. The office is conditioned with a VAV system with DX cooling and hot water reheat in individual zones.

The office model was designed to represent common office layouts. Peak occupancy schedules are based on a traditional 9am-5pm Monday through Friday workweek, with the building open from 7am-6pm on week days and no use on weekends or holidays. The model was designed to be independent of orientation by creating a square building with offices located on all four exterior walls. The office floor plan template includes the following space types: offices, break rooms, copy rooms, bathrooms, conference rooms, storage, data center, and mechanical room. The office floor plan is shown in Figure 23.

The baseline office model has a site EUI of 106, consistent with ENERGY STAR Target Finder estimations. End use distributions are also well matched. Table16 lists target and modeled energy use.

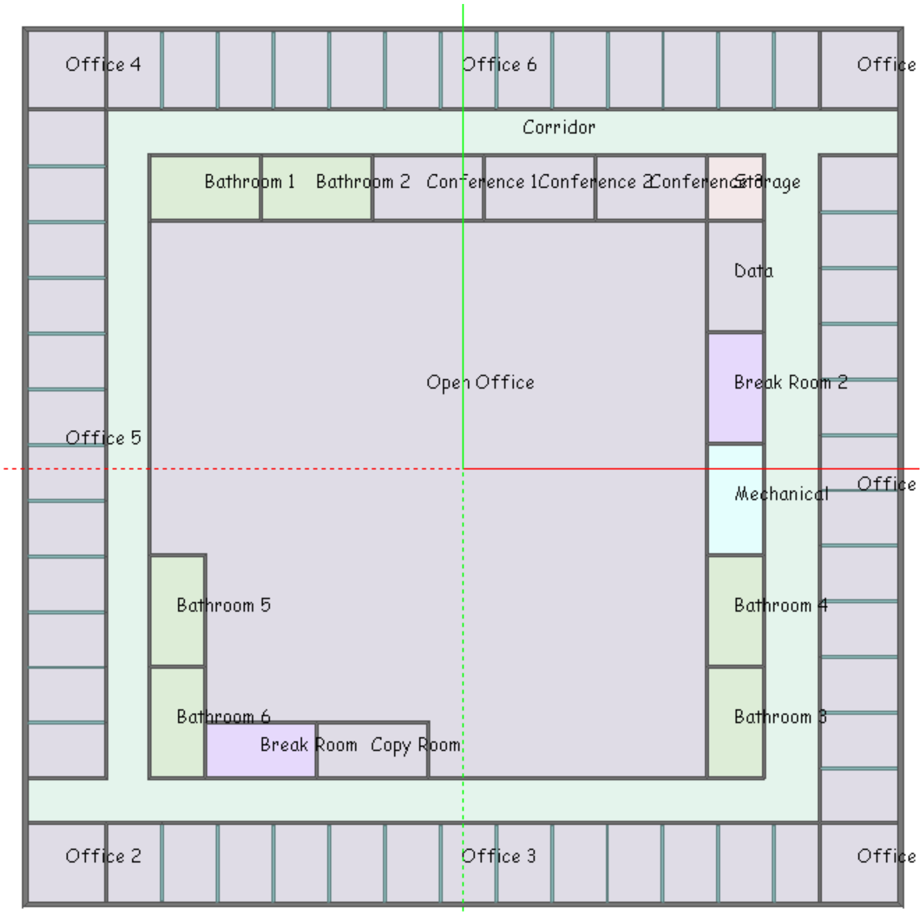

Figure 23: Office Floor Plan

Table16: Office Energy Calibration Results

	CBECS				TARGET	MODEL
	All U.S. Buildings	U.S. Offices	Office Adjustment	Midwest Average	**MN Office Target**	**Modeled Office**
EUI (KBTU/FT^2)	--	--	--	--	**106**	**106**
HEATING	38%	35%	(-8%)	49%	**45%**	**48%**
COOLING	7%	10%	30%	4%	**5%**	**7%**

	CBECS				TARGET	MODEL
	All U.S. Buildings	U.S. Offices	Office Adjustment	Midwest Average	**MN Office Target**	**Modeled Office**
VENTILATI ON	7%	6%	(-14%)	6%	**5%**	**4%**
LIGHTING	20%	25%	20%	17%	**20%**	**20%**
DHW	8%	2%	(-75%)	6%	**2%**	**2%**
MISC	21%	22%	4.5%	18%	**19%**	**19%**

Appendix E. Sample Energy Star Target Finder Output

LEARN MORE AT energystar.gov

ENERGY STAR® Statement of Energy Design Intent (SEDI)[1]

N/A

ENERGY STAR® Design Score[2]

Primary Property Function: Library
Gross Floor Area (ft^2): 15,097
Estimated Date of Certification of Occupancy: __________

Date Generated: November 14, 2014

1. This form may be used to apply for the ENERGY STAR Designed to Earn. This form was generated from Portfolio Manager's target finder: http://www.portfoliomanager.energystar.gov/targetfinder.
2. The ENERGY STAR Score is based on total source energy. The scale is 1-100. A score of 75 is the minimum to be eligible for the ENERGY STAR.

Property & Contact Information for Design Project

Property Address	Project Architect	Owner Contact
________________ ________, Minnesota 55330	__________ , (___)___-_____ ________________	__________ , (___)___-_____ ________________
Property ID: 4222827	**Architect Of Record** ________________ ________________ __________, ________ (___)___-_____	**Property Owner** ________________ , (___)___-_____

Estimated Design Energy

Fuel Type	Usage	Energy Rate ($/Unit)
Electric - Grid	217,120 kWh (thousand Watt-hours)	$ 0.11/kWh (thousand Watt-hours)
Natural Gas	234 therms	$ 1.09/therms

Estimated Design Use Details

Library	
Gross Floor Area	15,097 Sq. Ft.
Number of Computers	19
Number of Workers on Main Shift	13
Weekly Operating Hours	57.25

Design Energy and Emission Results

Metric	Design Project	Median Property	Estimated Savings
ENERGY STAR Score (1-100)	**N/A**	50	N/A
Energy Reduction (from Median)(%)	**-33.9**	0	N/A
Source Energy Use Intensity (kBtu/ft²/yr)	**155**	235	80
Site Energy Use Intensity (kBtu/ft²/yr)	**50**	76	26
Source Energy Use (kBtu/yr)	**2,350,724**	3,557,583	1,206,859
Site Energy Use (kBtu/yr)	**764,213**	1,156,559	392,346
Energy Costs ($)	**23,269**	35,215	11,946
Total GHG Emissions (Metric Tons CO2e)	**153**	232	79