Energy Conservation Potential of Displacement Ventilation in Minnesota Climate Conditions

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Introduction

Displacement ventilation (DV) has been purported to both reduce energy use and significantly improve air quality (e.g., Holland and Livchak, 2002; Chen and Glicksman, 1999). As seen in Figure 1, when cool (~65 ˚F) low-velocity air enters an occupied zone, it flows horizontally until a warm object causes an upward air flow, creating a plume. As the warmed air rises it carries pollutants with it through a ceiling outlet.

This technology has the capability of providing enhanced air quality by delivering fresh air directly to the occupants and removing contaminants more efficiently than other HVAC systems, potentially resulting in less school or work absence due to illness.

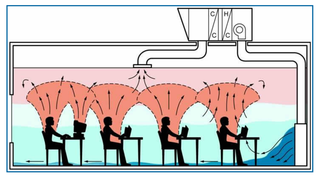

Figure 1. Diagrammatic Representation of Displacement Ventilation (Source: Energy Design Resources, 2010).

In their 2002 study, Bourassa et al. find impressive whole building energy savings of 30-60% (compared to a typical VAV system) from utilizing displacement ventilation. The purpose of this CARD study is to measure and evaluate the performance of displacement ventilation in Minnesota.

Methods

Buildings utilizing DV technology were identified through professional contacts and available resources. A brief survey was distributed to building owners which collected:

- Building characteristics (e.g., size, hours of operation)
- DV and HVAC operating parameters
- Added energy conservation measures
- Utility use and cost
- Comfort and satisfaction data

Energy use intensity (EUI) was determined for each participating building using reported utility data. Expected median EUIs were obtained from the CBECS database via Energy Star Target Finder, utilizing gathered physical and operational parameters.

Statistical analysis was performed on the resulting database using a python-based analysis pipeline. Overall technology performance was estimated using a weighted average based on the fraction of each building served by DV. Comfort and satisfaction data were similarly analyzed.

Energy Use Results

Table 1. Building Sample and Energy Use Results

OPERATIONAL GROUP	ID	PERCENT DV [%]	SITE EUI [kBTU/ft^2/yr]	MEDIAN SITE EUI	CO_2 SAVINGS [%]	SITE ENERGY SAVINGS [%]
School District 1	1	10%	95.0	103	8.1%	7.7%
	2	62.7%	61.4	83	26.3%	26.0%
	3	54.5%	73.2	96	23.8%	23.7%
	4	40.3%	46.1	69	34.4%	33.2%
	[W_AVG]	51.5%	63.6	85.1	26.4%	25.9%
Individual Buildings	5	100%	50.6	76	34.1%	33.4%
	6	97%	66.3	87	24.0%	23.8%
	7	100%	69.2	87	21.1%	20.4%
	8	99%	38.5	43	12.4%	10.6%
	9	90%	72.4	70	-2.9%	-3.5%
	10	95%	97.4	124	21.5%	21.4%
	11	100%	86.2	90	4.8%	4.2%
School District 2	12	100%	81.3	81	3.1%	-0.3%
	13	100%	143.7	74	-93.8%	-94.1%
	14	100%	130.7	87	-48.7%	-50.2%
	15	100%	141.6	83	-70.4%	-70.6%
	16	100%	122.8	85	-44.2%	-44.5%
	17	100%	140.7	83	-67.9%	-69.5%
	18	100%	195.1	82	-136.2%	-137.9%
	19	100%	126.5	87	-44.2%	-45.4%
	20	100%	113.6	85	-32.8%	-33.6%
	21	100%	135.1	82	-63.7%	-64.8%
	22	100%	126.4	85	-47.9%	-48.7%
	23	100%	87.2	76	-13.3%	-14.7%
	24	100%	113.0	82	-37.4%	-37.8%
	[W_AVG]	100%	127.5	82	-53.6%	-54.8%
WEIGHTED AVERAGE	Operations Independent	-	75.3	82.5	8.8%	8 ± 10%
	Statistically Consistent	-	**68.1**	**82.5**	**17.3%**	**17 ± 6%**

Table 1 lists energy consumption and CBECS comparison data for 24 buildings, along with their estimated site energy and CO_2 savings. Statistically consistent subsample analysis shows that displacement ventilation technology reduces annual energy use by 10-20% in Minnesota buildings.

Monthly Savings Analysis

Displacement ventilation is expected to primarily produce electric savings, stemming from reductions in fan and cooling energy use. Monthly electric consumption data from 33 non-DV buildings were compared to the data from four DV-served buildings in School District 1. Results of this analysis are shown in Figure 2.

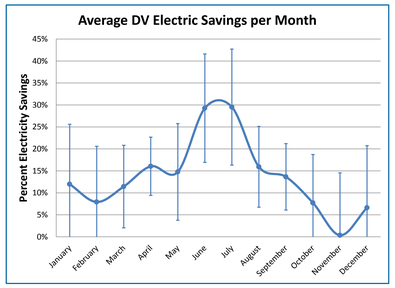

Figure 2. Electric Savings by Month

This figure illustrates that savings from displacement ventilation technology are greatest during summer months, with DV-served buildings performing 25% better than non-DV buildings, on average. This is expected given that cooling savings can be most effectively achieved during summer months. Measured energy savings in winter months are likely due to reductions in fan energy use.

Comfort and Satisfaction Results

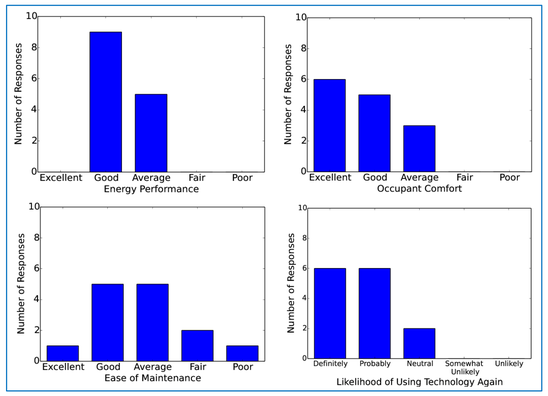

Figure 3. Owner Satisfaction with Displacement Ventilation Technology

Owners have generally positive feedback about this technology (Figure 3). Although DV is perceived to produce only moderate energy savings, occupants are viewed as more comfortable and most owners would use the technology again. Maintenance is the only category for which owners exhibited any dissatisfaction.

Operational Influences

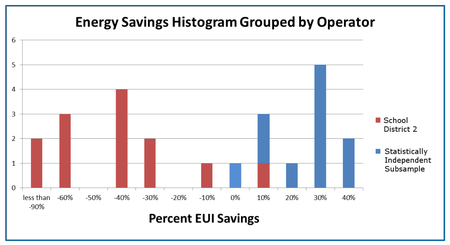

Figure 4. Energy Savings Histogram.

The importance of building operation to achievement of energy savings is illustrated in Figure 4. Buildings in School District 2 perform very poorly compared to typical buildings. K-S tests performed on the subsamples indicate a <0.1% chance that School District 2 data is statistically related to (i.e., representative of) the general sample of DV-served buildings.

Conclusions

- ❖ When operated correctly, displacement ventilation can reduce total building energy consumption by 10-20%
- ❖ Savings from DV technology are highest during the summer months
- ❖ Most owners are satisfied with DV, and would use the technology again
- ❖ Effective building system operation is crucial for obtaining energy savings

Next Steps

– More closely investigate operational parameters of the school district exhibiting high EUIs

– Re-adjust energy savings using EnergyPlus modeling to correct for additional ECMs (e.g., envelope upgrades)

– Evaluate technology cost effectiveness

– Assess potential cognitive and/or economic barriers to technology acceptance via surveys of building owners, architects, and engineers

– Integrate findings on energy impacts, comfort, operation, cost effectiveness, and market readiness in comprehensive final report

References

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Chen, Q., Glicksman, L.R., Yuan, X., Hu, S., Hu, Y., and Yang, X. "Performance evaluation and development of design guidelines for displacement ventilation," Final Report for ASHRAE RP-949, 1999

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