CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Night Ventilation Cooling Compliance Option

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team September 2011

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1. Purpose

This document describes recommended modeling rules, potential compliance credits, and preliminary eligibility criteria for residential night ventilation cooling systems, which are proposed to be added to the 2013 Title 24 – Part 6 Building Energy Efficiency Standards as a compliance option.

2. Overview

Complete the following table, providing responses for each category of information.

a. Measure Title	Night Ventilation Cooling Compliance Option
b. Description	This compliance option proposal presents savings estimates and a methodology for obtaining Title 24 compliance credits for whole house fans (WHFs) and central fan integrated night ventilation cooling systems. Both system types can effectively shift cooling energy use from on-peak hours to off-peak hours. Ventilation cooling is most effective in climates where cooling loads are significant, but nighttime temperatures are low enough so that cool outdoor air can be used to pre-cool the interior building mass. WHFs rely entirely on occupant interactions to operate the system, and open and close windows to control the airflow. The central fan systems are automated as they rely on an outdoor temperature sensor, controls, and an operable damper to control the initiation and termination of the ventilation cooling cycle.
c. Type of Change	The proposed change is a compliance option that would give variable credits, by climate zone and system type. This proposal relies on the current version of the California Simulation Engine (CSE) model to simulate the performance of the various night ventilation strategies. **Modeling** – The current interim CSE model is capable of modeling the ventilation cooling operation. Based on stakeholder feedback and ongoing modifications to the CSE model, additional minor modeling changes may need to be implemented. **Other -** Eligibility criteria will be needed to define minimum requirements for each of the system types. ACM Manuals will need to be updated to reflect the proposed modeling changes. If “default” airflow and fan efficacy values are not assumed in the compliance documentation, HERS inspections are proposed on a sampling basis to verify that the central fan system meets the airflow and Watts/cfm level specified.

d. Energy Benefits

The tables below summarize the projected energy and TDV impacts for the 2,700 ft^2 CEC prototype home. One scenario is shown for the whole house fan (WHF) case, and two each for the fixed speed and variable speed central fan cases. Although three WHF cases were simulated (4000 cfm = 100% airflow, 2000 cfm = 50%, 810 cfm = 20%), only the 50% case is shown here. The 20% and 100% energy use data are shown in the Appendix.

Central fan night ventilation cooling energy results are presented for both "fixed speed" and "variable speed" fan systems (distinction presented in the Methodology and Results section of the template). For each of these system types, two airflow and airflow efficacy levels were assumed: the Title 24 default assumption (300 cfm/ton and 0.80 Watts/cfm) and a "tested" level (350 cfm/ton and 0.58 Watts/cfm).

The reported energy savings ("+" equals savings, "-" represent increased energy use) do not take into account TDV impacts, which strongly value on-peak savings relative to off-peak savings. Increased electrical energy consumption is due to two factors: 1.) ventilation in mild climates (or mild days in other climates) where little on-peak cooling is offset, or 2.) For the Fixed Speed cases, excessive annual run times (at fairly high W/cfm levels) resulting in improved indoor comfort, but higher energy use. The energy penalty is most common in milder climates where significant (unnecessary) over-cooling is projected to result. Small natural gas increases in virtually all cases are again due to ventilation during mild spring/fall months leading to minor increases in heating energy use.

Whole House Fans (50% airflow)

Climate Zone	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)
1	0	-3.5
2	55	-3.2
3	-142	-3.0
4	161	-3.5
5	-63	-4.6
6	95	-1.6
7	-129	-2.4
8	388	-3.5
9	451	-3.8
10	522	-3.2
11	496	-3.2
12	567	-3.5
13	504	-4.3
14	353	-4.3
15	174	-3.0
16	171	-6.2

Fixed Speed Central Fan (Default= 300 cfm/ton, 0.8 Watts/cfm; Tested = 350, 0.58)

	Default Assumption		Tested Assumption	
Climate Zone	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)
1	0	0.0	0	0.0
2	-978	-0.5	-636	-0.8
3	-1347	-0.8	-1010	-1.1
4	-1071	-0.8	-686	-1.1
5	-446	-1.6	-335	-2.2
6	-1814	-0.8	-1274	-1.1
7	-2302	-0.8	-1727	-1.4
8	-1883	-1.9	-1134	-2.4
9	-1580	-2.2	-883	-2.4
10	-1271	-1.6	-554	-1.9
11	-752	-0.8	-200	-1.1
12	-889	-1.4	-324	-1.6
13	-994	-2.4	-411	-2.7
14	-786	-1.4	-287	-1.4
15	-1332	-2.2	-804	-2.7
16	-1305	-0.3	-810	-0.5

<u>Variable Speed Central Fan (Default= 300 cfm/ton, 0.8 Watts/cfm; Tested =350, 0.58)</u>

	Default Assumption		Tested Assumption	
Climate Zone	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)
1	0	0.0	0	0.0
2	-69	-0.5	-26	-0.5
3	-90	-0.3	-71	-0.5
4	42	-0.8	108	-1.1
5	-55	-0.8	-50	-1.4
6	203	-0.5	256	-0.5
7	-61	-0.3	-8	-0.5
8	419	-1.9	533	-2.2
9	364	-1.9	490	-2.2
10	556	-1.6	717	-1.9
11	425	-1.1	593	-1.1
12	380	-1.4	527	-1.6
13	353	-2.4	509	-2.4
14	356	-1.4	496	-1.4
15	227	-2.4	303	-2.4
16	388	-0.3	461	-0.3

e. Non-Energy Benefits

Night ventilation cooling system operation will result in improved thermal comfort, as homes will be maintained during the summer at lower average indoor temperatures than the air conditioner setpoint. Ventilation cooling provides IAQ benefits by introducing large volumes of outdoor air to conditioned space. (In some localized areas, local air quality situations (e.g. nearby industrial facility) may make added outdoor air delivery undesirable.) Central Fan systems offer filtration of outdoor air, while WHFs do not, resulting in increased delivery of allergens to indoor space.

f. Environmental Impact

Night ventilation cooling generates TDV benefits by shifting energy use from on-peak to off-peak periods. As shown below, the NOx and CO_2 impacts are generally positive, although the fixed speed cases shown do show increased energy consumption and therefore increased emissions. The table below averages impacts over all climate zones and is based on emission rates of 0.00175 lbs of NOx per therm of natural gas and 0.00585 tons of CO_2 per therm, and 681 lbs/MWh and 6.23 lbs/GWH for carbon dioxide and NOx, respectively[1].

Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year-house)

	Mercury	Lead	Copper	Steel	Plastic	NOx (lbs/yr)	CO2 (lbs/yr)
WHF 50% Airflow	NC	NC	NC	NC	NC	0.23 (D)	215 (D)
WHF 100% Airflow	NC	NC	NC	NC	NC	0.44 (D)	435 (D)
WHF 20% Airflow	NC	NC	NC	NC	NC	0.06 (D)	38 (D)
Fixed Speed Central Fan (default)	NC	NC	NC	NC	NC	0.72 (I)	799 (I)
Fixed Speed Central Fan (tested)	NC	NC	NC	NC	NC	0.36 (I)	415 (I)
Variable Speed Central Fan (default)	NC	NC	NC	NC	NC	0.21 (D)	213 (D)
Variable Speed Central Fan (tested)	NC	NC	NC	NC	NC	0.29 (D)	296 (D)

Water Consumption and Water Quality:
No impact.

[1] http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2010V1_0_year07_SummaryTables.pdf

g. Technology Measures	**Measure Availability:** WHFs are available from a wide range of manufacturers. Currently there is one manufacturer of fixed speed central fan systems and one manufacturer of variable speed central fan systems. The introduction of Title 24 credits should spur interest in central fan systems from major HVAC manufacturers. HERS inspections will be required. The inspections will be visual verification, as well as airflow and W/cfm testing for central fan system. The HERS industry is versed on these procedures. **Useful Life, Persistence, and Maintenance:** Central fan systems require more regular outdoor air filter replacement than conventional HVAC systems.
h. Performance Verification of the Proposed Measure	HERS inspections are necessary to insure that the installed central fan systems meet the airflow and Watts/cfm level specified. All system types will have eligibility criteria.
i.Cost Effectiveness	Not needed for compliance option.
j. Analysis Tools	The current working version of the CSE simulation model was used to complete performance evaluations for the various night ventilation cooling strategies.
k. Relationship to Other Measures	Night ventilation cooling is effectively a load-shifting measure. Nighttime fan energy is used to partially or fully offset the next day's on-peak air conditioner operation. The energy savings impact is magnified by TDV, resulting in significant compliance credits. This increases the tradeoff potential with other measures.

3. Methodology

3.1 Technology Overview

The objective of night ventilation cooling is to transfer heat from building mass elements (wall board, masonry, and furnishings) to cool outdoor ventilation air, and to discharge it from the house. Of course this can only occur while outside air is cooler than indoor air. During the daytime, the building mass absorbs heat from the air, moderating the rate and overall rise in indoor temperature. Under some conditions, the indoor air temperature will not rise above the thermostat cooling setpoint during the next afternoon, fully eliminating air conditioner operation. More typically, the start of the air conditioner cooling operation is delayed and the peak cooling loads are reduced.

The effectiveness of night ventilation cooling is dependent upon how much cooling can be achieved and how much indoor temperature swing the occupant will tolerate (from morning low to early evening peak temperature). Concrete slab floors with hard coverings (not carpet) and drywall provide a convenient source of thermal mass that has a large surface area and high density allowing for significant thermal storage capability.

In its simplest form, night ventilation cooling can be accomplished by opening windows. A small, open floor plan house design can be effectively ventilated in cool nighttime climates by intelligent window operation. This becomes more complicated in larger, more conventional production homes with many interior walls and where doors are often shut at night, eliminating any cross-flow ventilation effect. Warmer climates also are frequently less breezy at night, limiting a key driving force. In addition, many occupants have noise, security, or allergy concerns and therefore keep their windows closed. A 2006 LBNL study found that 20% of households never open windows, and 50% rarely opened windows.

Whole House Fans

Whole house fans (WHFs) offer a low-cost means to generate an efficient driving force for night ventilation. Traditional whole house fans (shown in Figure 1 below) have a simple barometric damper and a belt or direct drive motor driving a prop fan. Figure 2 shows a newer style of fans which move less air, but provide an insulated damper between the attic and conditioned space. These units also are generally designed to fit between standard rafter spacing, simplifying retrofit installations. A third type of WHF (Figure 3) removes the fan further from indoors, reducing the noise impact during operation.

When WHFs operate, they pull indoor air though open windows and exhaust the air to the attic and then outside. As a manually operated system, whole house fans require the homeowner to be present to open windows throughout the house[2], and keep the windows open as long as the fan is operating. Air is not easily filtered, resulting in dust and potential allergens to be delivered indoors. If the fan is

[2] To obtain uniform airflow throughout.

operated all night long, which is preferred for pre-cooling building mass, security may be compromised since windows must remain open.

The California Energy Commission requires whole house fans to be tested and listed in their appliance directory database[3]. WHFs are listed in terms of their rated airflow and fan motor Watts. Historically WHFs have been primarily a retrofit product, due to various reasons including lack of Title 24 credits, builder uncertainty of mass market acceptance, and a perception that the technology represents a poor man's cooling system (analogous to the clothes line for drying clothes). A 1988 Davis Energy Group study for SMUD tested a set of whole house fans for airflow, power, and noise issues (DEG, 1988). What is not well known about whole house fans, is how well they will be accepted as part of a standard new home package, and how effectively they will be operated given concerns over noise, dust, security, allergens, etc. When properly used, they are highly effective, but Title 24 credits must reasonably derate their performance to insure that the ultimate benefits will balance the level of credits offered.

Figure 1: Whole House Fan Barometric Damper and Motor/Fan in Attic

Figure 2: Insulated and Dampered Whole House Fan

[3] Under Fans and Dehumidifiers at http://www.appliances.energy.ca.gov/AdvancedSearch.aspx

Figure 3: Ducted Whole House Fans

Central Fan Systems

Central fan ventilation cooling systems utilize the furnace or air handler fan to deliver outdoor air to conditioned space. By adding an automated damper, outside air duct, temperature sensors and controls, these central fan systems can automatically deliver filtered outdoor air to occupant set comfort levels when outdoor conditions warrant the use of ventilation. This automated operation represents an improvement over WHFs, which rely entirely on the occupant being available to initiate operation. A disadvantage of the central fan systems is that they typically move much less air and consume more energy per cfm due to restrictive duct systems.

Figures 4 and 5 render how the systems are configured in conventional return air operating mode (Figure 4) and in outdoor air mode (Figure 5). In Figure 4, the damper is positioned to direct return air to the air handler for normal heating and cooling operation. In Figure 5 (night ventilation cooling mode), the damper position is reversed so that air entering the air handler is now pulled from the outside air duct, and then delivered to the house, with relief air provided through the damper to the attic. Windows do not need to be opened with these systems, increasing overall home security.

Figure 4: Central Fan System in Return Air Mode

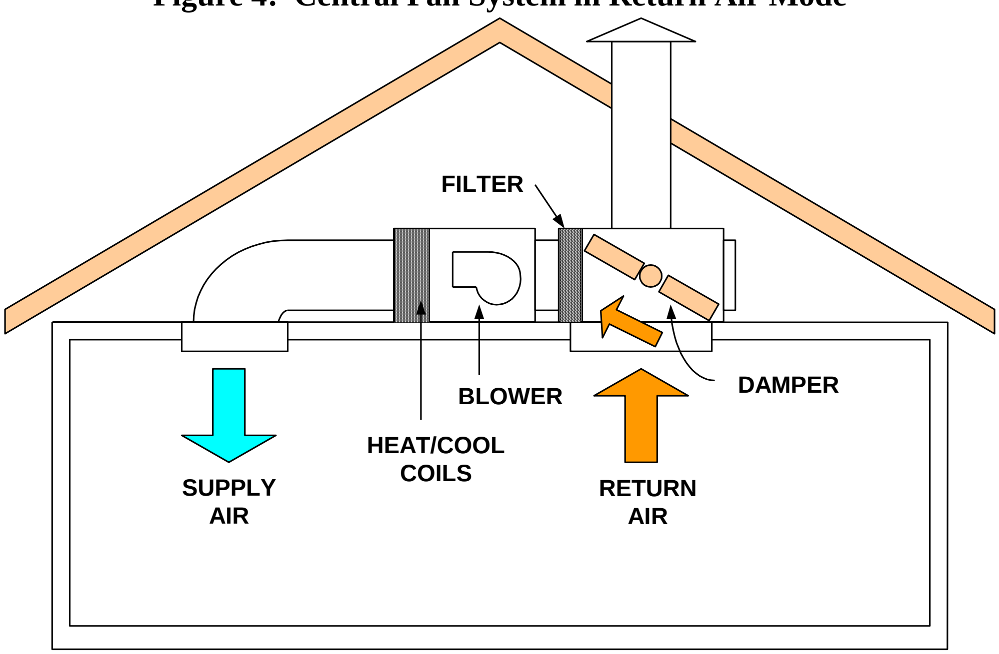
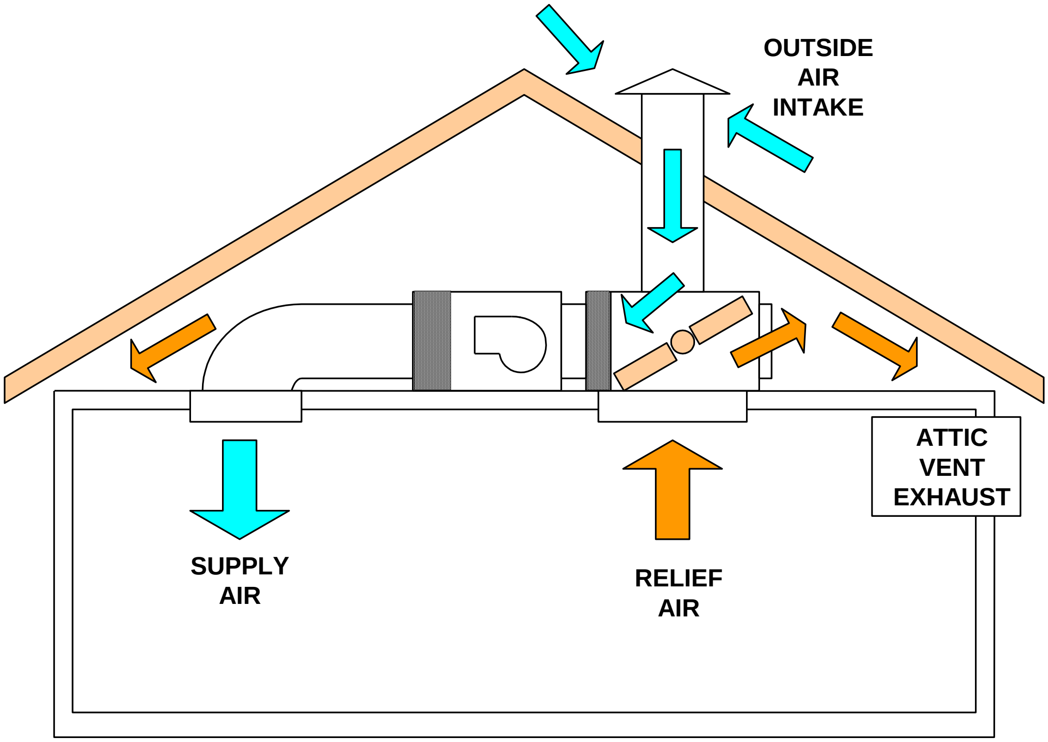


Figure 5: Central Fan System in Outdoor Air Mode



The central fan systems respond to outdoor air conditions and a homeowner programmed ventilation cooling target temperature (lower than the air conditioner cooling setpoint) to determine when to operate. Typically operation ensues when the outdoor air temperature falls 5ºF below the current indoor temperature. When this condition is met the damper position is set to ventilation cooling mode, and the air handler fan is energized, delivering cooler air to the house. The unit will run until either the ventilation cooling target is achieved, or until the outdoor temperature starts to warm up post-sunrise. For this study we are distinguishing performance between two central fan system types: Fixed speed and variable speed.

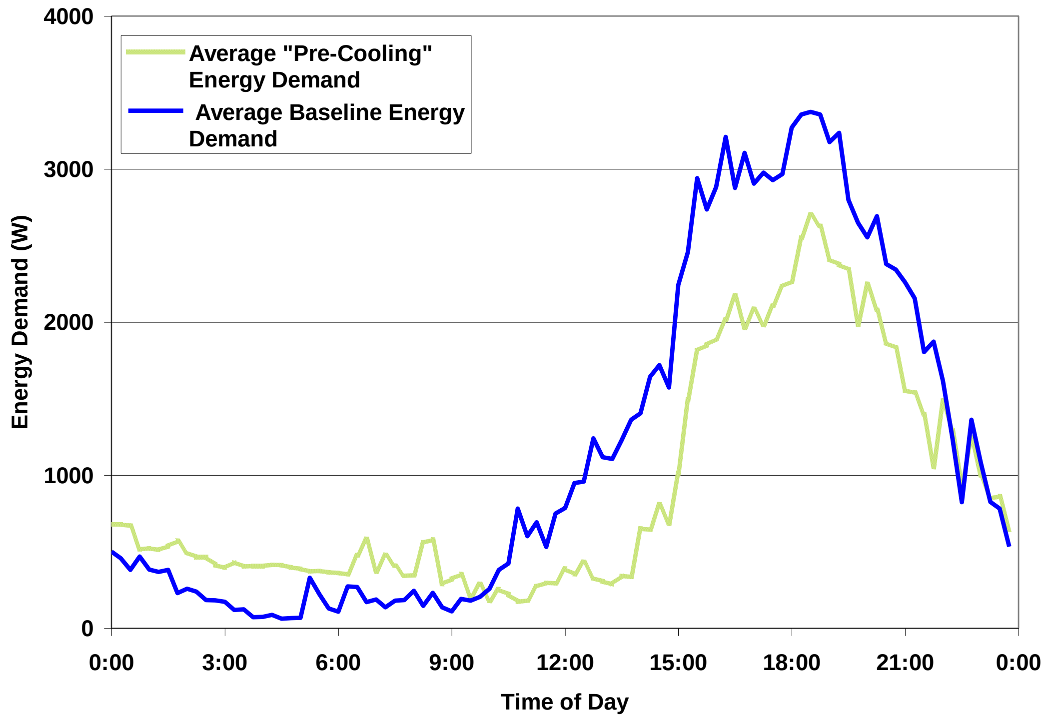
Fixed speed central fan systems operate the air handler fan at a fixed airflow level, consistent with either cooling operation or "manual fan" operating mode. Variable speed central fan systems feature an electronically commutated motor variable speed motor that allows for ventilation to occur at not a specified "fixed" fan speed, but on a variable basis which is determined daily based on weather patterns, indoor temperature conditions, and the desired ventilation cooling target. The advantage of the variable speed approach is the ability to achieve much higher airflow efficacies than the fixed speed approach. Currently there are two products on the market, one meeting each category. The SmartVent[4] represents the fixed speed product, and NightBreeze[5] represents the variable speed product.

[4] https://www.beutlercorp.com/heating_prod_smartvent.asp
[5] http://www.davisenergy.com/technologies/nightbreeze.php

The central fan systems have been evaluated in the field by various researchers over the years (Matrix, 2007, Springer 2007). A monitoring summary of NightBreeze performance at a 3,553 ft^2 Stockton, CA home can be found in Appendix (7.2). This work, completed by the Building Industry Research Association (BIRA) Building America team, showed that over a six month period[6] a total of 1,290 kWh was consumed for night ventilation and vapor compression cooling, of which only 221 kWh was used by the condensing unit.

The 2007 Matrix study[7], completed for PG&E, evaluated three SmartVent and three NightBreeze systems installed in occupied homes in Woodland, CA (near Sacramento). Based on alternating periods of "base case AC " and "AC + night ventilation" monitoring, Matrix projected annual cooling season Noon to 6 PM energy use reductions of 48-50% for the SmartVent and NightBreeze systems. Overall cooling energy use was projected to be 16% higher for SmartVent relative to the base case, and 2% lower for NightBreeze. Looking only at days with outdoor dry bulb temperatures exceeding 92ºF, savings of 14% and 30% were projected for SmartVent and NightBreeze, respectively, signifying over-ventilation on milder summer days. Figure 6 presents a graph from the report highlighting the overall load shifting impact, averaged over the six houses, on days with outdoor maximum dry bulb temperatures between 100 and 105ºF. Key points to highlight is the increase in pre-cooling demand after midnight, the mid-day savings, and the early afternoon delay in cooling startup.

Figure 6: Monitored Ventilation Cooling and Base Case Demand Profiles



Source: Matrix, 2007

[6] June-Sept 2004 and June0July 2005
[7] http://www.etcc-ca.com/component/content/article/29-Residential/2813-residential-night-ventilation-cooling-field-monitoring-project

3.2 Night Ventilation Cooling Modeling

Our first ventilation cooling assessment under this CASE project relied on the ACM modeling rules implemented in 2008 Title 24. Fixed program assumptions and modeling methods resulted in little or no benefit for ventilation cooling due to a variety of issues related to mass modeling, natural ventilation assumptions, and unlimited air conditioner cooling capacity assumptions. DEG reviewed these shortcomings with CEC staff and stakeholders to try to resolve these issues in 2008. At the same time, there was an increasing desire by the CEC and others to significantly upgrade overall residential ACM model capabilities. Bruce Wilcox and his consultant team embarked on a major revamping of the simulation model, ultimately arriving at the California Simulation Engine (CSE) model currently being used for 2013 Standards development. DEG continued to work with Wilcox and the CEC in the model development to insure that it would be able to model ventilation cooling accurately. The CSE model was used to generate the results presented in this Template.

Key CSE program input assumptions related to ventilation cooling are highlighted below:

1. All three ventilation strategies have been modeled to night ventilate to a fixed 68ºF lower limit setpoint, consistent with natural ventilation assumptions when the thermostat is in “cooling” mode[8]. The central fan systems are both programmed to initiate night ventilation operation when the outdoor temperature is 5 degrees cooler than the indoor temperature. Night ventilation continues until either the 68ºF lower limit temperature is achieved, or the 5ºF minimum temperature difference no longer exists as outdoor temperature starts to rise.

2. WHFs are assumed to operate in a similar fashion as windows: non-operable from 11 PM to 6 AM.

3. WHFs were modeled at various airflow levels to assess the performance impact on both energy and TDV. A nominal 4000 cfm WHF was modeled as a 100% system. Two additional runs were completed at 2000 cfm (50%) and 810 cfm (20%) to explore performance sensitivity.

4. Both fixed speed and variable speed central fan systems were modeled under “default” and minimum “tested” airflow and W/cfm conditions. The default value represents a worst case performance scenario, while the tested condition represents expected performance when verified by a HERS rater. Default fan efficacy was fixed at 0.80 Watts/cfm with airflow specified at 300 cfm per nominal ton, as determined by the ACM cooling sizing procedure[9]. Tested fan efficacy was fixed at 0.58 Watts/cfm with airflow specified at 350 cfm per nominal ton. Conceptually, the values to be used in compliance will not be fixed, but will need to be field-verified on a sampling basis.

[8] During spring/fall periods, the ACM modeling rules may cause the thermostat to swing back and forth from heating to cooling mode. This will result in some “cooling thermostat” days with ventilation cooling and subsequent days without, leading to small incremental heating loads.
[9] See residential ACM appendix RA1.

5. NightBreeze fan efficacy was represented by a performance relationship defined in lab testing with realistic static pressures (see Appendix 7.3). At maximum airflow, fan efficacy was fixed at 0.80 W/cfm (or 0.58, if tested), but ramped downwards to as low as 0.08 Watts/cfm, in recognition of the improved performance of electronically commutated motors under low airflow conditions. The implemented control algorithm in the software also represented the NightBreeze midnight fan speed calculation, which adjusts the airflow rate based on recent weather and indoor conditions.

4. Analysis and Results

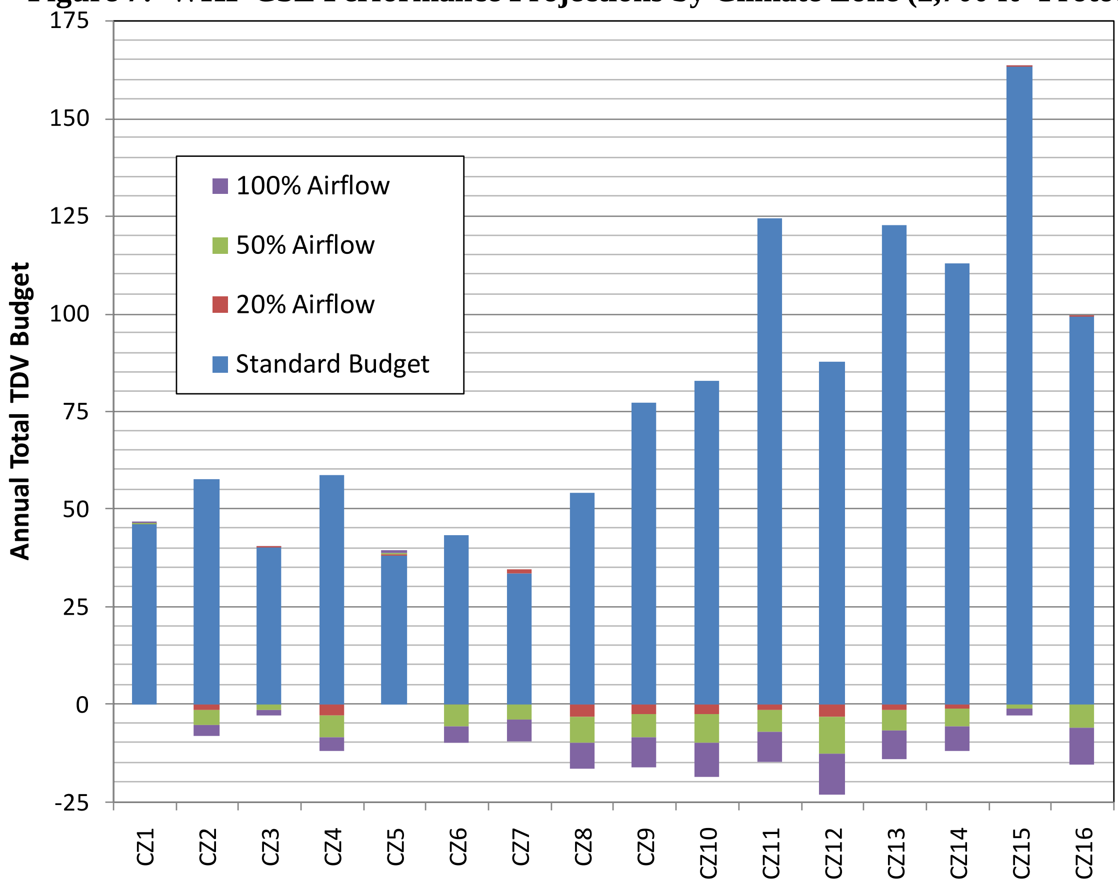
Results were generated using the CSE model for the 2,700 ft^2 CEC prototype in each of the sixteen California climate zones. Runs were completed for whole house fans, fixed speed central fan systems, and variable speed central fan systems. The following sections present results on each of the technologies. Section 4.4 addresses the proposed ACM modifications.

4.1 Whole House Fans

As previously discussed, whole house fans can be very effective in providing efficient off-peak cooling and reduced on-peak cooling energy consumption. This attribute, common to all night ventilation strategies, is magnified with the current proposed 2013 TDV values, which are even more "spiky" than the 2008 values. Recognizing that any projected performance benefit is accentuated by TDV, and that WHF operation is, on average, much less persistent than an automated central fan system, there must be a mechanism within the ACM to derate performance. The first step in looking at derating was to run the WHF at the three airflow levels (100%, 50%, 20%).

Figure 7 plots CSE performance projections for the 2,700 ft^2 prototype for each of the sixteen climate zones. The blue bar represents the Standard total budget (no ventilation cooling) and the red bar represents the incremental improvement for the 20% airflow case, with impacts similarly shown for 50% and 100%.

Figure 7: WHF CSE Performance Projections by Climate Zone (2,700 ft^2 Prototype)

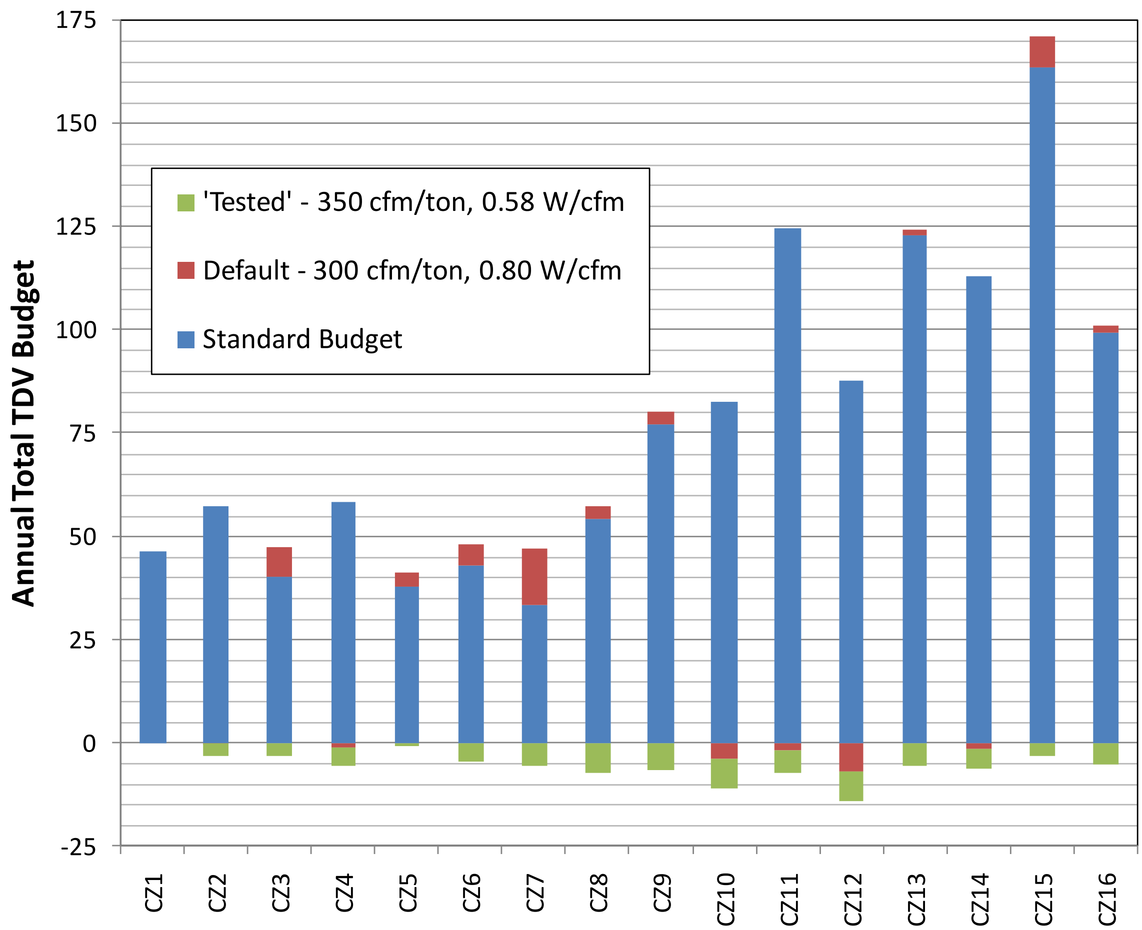


In the case of CZ7, the 20% case actually increases the total TDV budget slightly, although the 50% and 100% WHF cases do show an improvement. Projected WHF performance is most favorable in CZ12, with all zones but 1, 3, 5, and 15 demonstrating total TDV savings of greater than 10% for the 100% airflow cases.

4.2 Fixed Speed Central Fan Systems

Figure 8 plots CSE Fixed Speed performance projections for the 2,700 ft^2 prototype for each of the sixteen climate zones. Again, the blue bar represents the Standard total budget (no ventilation cooling), the red bar represents the incremental impact for the "default" case, and the green bar for the "tested" case. The much higher assumed W/cfm relative to WHFs for the default case is clearly evident as highlighted by the number of zones where the TDV budget actually increased. Despite shifting energy use from on-peak to off-peak, the overall impact in those zones is not favorable when assuming performance at 300 cfm/ton and 0.8 W/cfm. The tested case shows more favorable results, again with climate zones 8, 10, and 12 demonstrating the best performance.

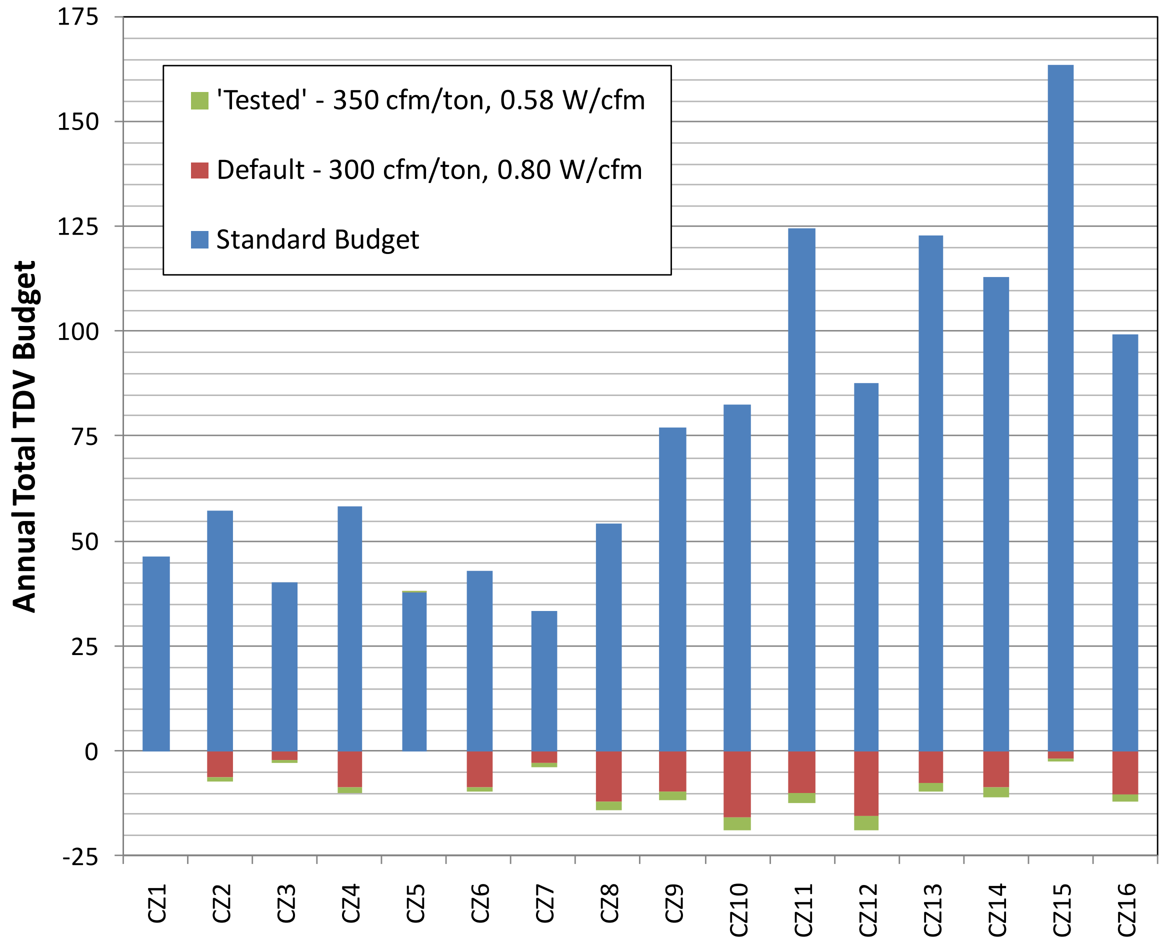
Figure 8: Fixed Speed CSE Performance Projections by Climate Zone (2,700 ft^2 Prototype)



4.3 Variable Speed Central Fan Systems

Figure 9 plots CSE Variable Speed performance projections for the 2,700 ft^2 prototype for each of the sixteen climate zones. Results are presented similar in format to Figure 7. Performance at both the default and tested levels are more favorable than the fixed speed projections, since the variable speed operating strategy (outlined in the Appendix) provides for much higher airflow efficiencies for many summer nights. Since the algorithm utilizes a lower than maximum airflow for many nights, the relative performance advantage of tested vs. default is much smaller than for the fixed speed case. Overall TDV savings in the favorable climates (4, 6, 8, 10, and 12) are in the 20-25% range.

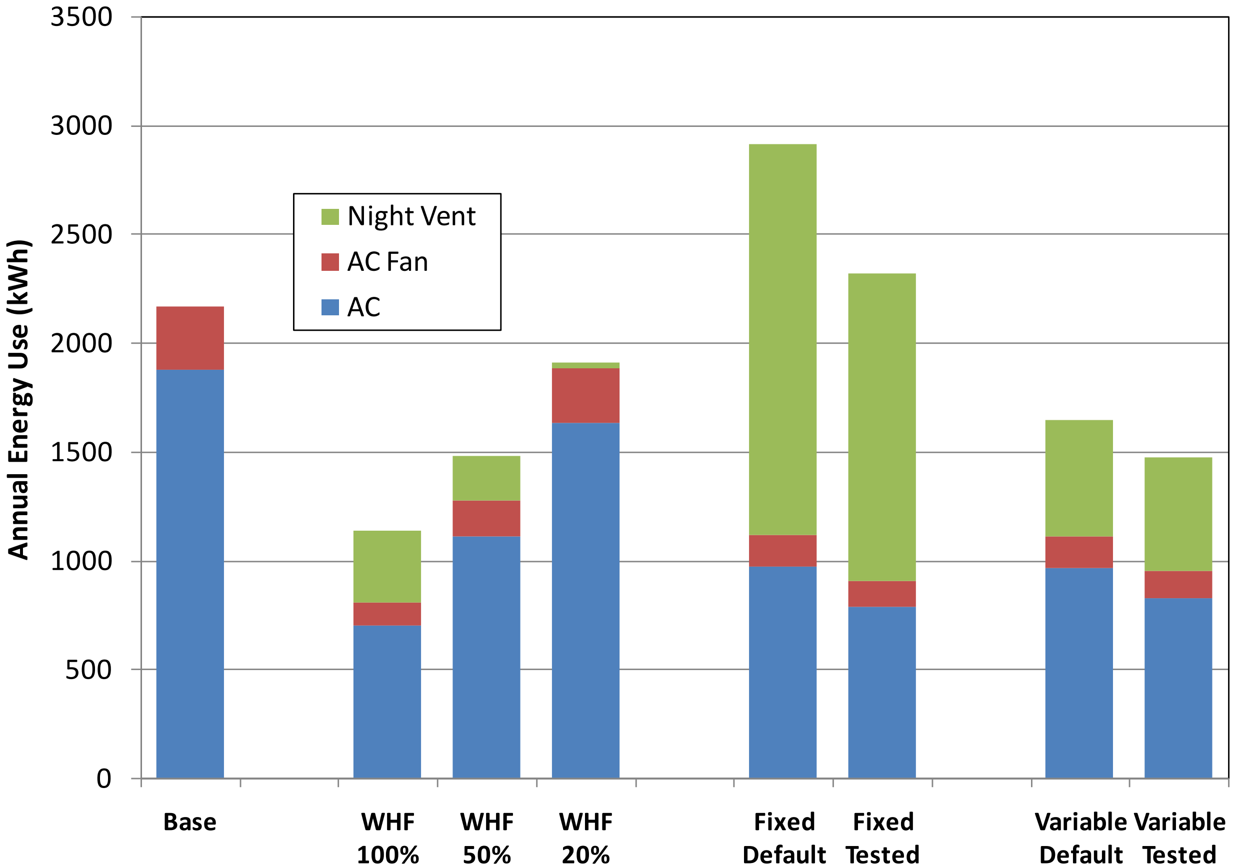
Figure 9: Variable Speed CSE Performance Projections by Climate Zone (2,700 ft^2 Prototype)



4.4 Comparison Among System Types

The true energy impacts in Figures 7-9 are obscured by TDV. To more clearly represent the kWh impacts, Figure 10 shows energy use for each of the ventilation cases for climate zone 12. Energy use is broken down into condensing unit energy (“AC”), air handler fan during AC operation (“AC Fan”), and fan energy associated with night ventilation cooling. The effectiveness of the 100% WHF is evident, as well as the impact of "default" fan speed assumption on the Fixed speed case. The Variable speed case shows a much smaller vent cooling fan penalty since the system is more often than not operating at a lower airflow level, at a much higher fan efficiency. The projections shown in Figure 10 for the central fan systems are roughly consistent with the findings from the 2007 PG&E/Matrix monitoring study.

Figure 10: CSE Performance Projections for 2,700 ft^2 Prototype in Climate Zone 12



4.5 Post-Stakeholder Workshop Feedback

Based on workshop concerns and further discussions, an eligibility requirement was added to verify damper operation for central fan systems. Proposed criteria are presented in Section 5.

Bruce Wilcox, the lead CEC consultant, proposed that WHF derating be set at 25% of nominal airflow.

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

Proposed eligibility criteria are listed below, highlighting some of the key issues for the various system types.

Whole House Fans

1. Must meet combustion air safety requirements related to indoor gas-fired appliances
2. Whole House Fans modeled for Title 24 credits must be listed in the CEC Appliance Database.
3. Homeowners who have WHFs installed must be provided with a one page "How to operate your whole house fan" informational sheet.
4. Verify that adequate attic ventilation, consistent with manufacturer's installation instructions, is provided.

Central Fan Systems

5. Central fan night ventilation systems will be required to meet Title 24 duct leakage requirements (with system operating in return air mode).
6. Central fan night ventilation systems that assume a non-default Title 24 airflow and/or Watts/cfm value (default = 300 cfm/ton and 0.80 Watts/cfm) will be required to have third party verification of the non-default parameters.
7. In addition to sensing temperature at the thermostat, central fan system shall have an outdoor temperature sensor (used to initiate and terminate night ventilation operation) and a temperature sensor sensing the air temperature entering the air handling unit (used for damper position verification)[10].
8. Central fan systems will be treated as "fixed speed" systems, unless the manufacturer can provide documentation to the California Energy Commission that demonstrates the critieria listed below. The Commission will review the submittal and make a determination that the system adequately meets the qualifying criteria.
    a. The installed fan motor is a variable speed motor
    b. The motor is controlled in night ventilation mode to vary in a continuous range between full air flow (100%) and a minimum airflow of no more than 25% of full airflow.
    c. The manufacturer will provide written documentation on how their control strategy is implemented, how night ventilation fan speed is controlled, and how ventilation cooling rates are determined. The ventilation cooling rate calculation will occur at a time interval of 24 hours or less, to insure that the system responds in a timely manner to changes in weather patterns.

[10] The temperature readings will verify damper position in both ventilation and air conditioning mode by comparing indoor temperature, outdoor temperature, and air handler unit inlet temperature. A fault condition will result in a warning light being illuminated on the thermostat display.

6. Bibliography and Other Research

Architectural Energy Corporation. *Life-Cycle Cost Methodology*. *2013 California Building Energy Efficiency Standards*. January 16, 2011. Prepared for California Energy Commission.

Davis Energy Group, 1988. *SMUD Whole House Fan Evaluation Project Final Report*. Prepared for the Sacramento Municipal Utility District.

KEMA, Inc. 2010. *2009 California Residential Appliance Saturation Study.* California Energy Commission. Publication number: CEC- 200-2010-004-ES.

Freitag, E. 1998. *Automated Nighttime Pre-Cooling of Development Residential Housing*. Masters Thesis in Architecture, Graduate Division, University of California, Berkeley.

Givoni, B. 1998. *Effectiveness of Mass and Night Ventilation in Lowering the Indoor Daytime Temperatures*. Energy and Buildings, 28, 25-32.

Loisos, G., M.S. Ubbelohde. 2004. *Alternatives to Compressor Cooling, Phase V: Integrated Ventilation Cooling*. Attachment 4 to the final project report: Advanced Comfort Criteria. California Energy Commission Contract No. 500-04-009. Sacramento, California.

Loisos, G., D. Springer, et al. 2000. *Alternatives to Compressor Cooling Project Phase IV Final Report*. Project report, California Energy Commission Contract No. 500-97-013. Sacramento, California.

Lutzenhiser, L., B. Hackett et al. 1994. *Alternative Cooling Technologies for California Social Barriers, Opportunities and Design Issues*. Universitywide Energy Research Group. UER-289. University of California.

Matrix, 2007. *Residential Night Ventilation Monitoring and Evaluation.* PG&E Emerging Technologies Program Application Assessment Report # PGE0710.

Roucoult, J.M., O. Douzane, T. Langlet. 1999. Incorporation of Thermal Inertia in the Aim of Installing a Natural Nighttime Ventilation System in Buildings. Energy and Buildings, 29, 129-133.

Springer, D. 2004. Alternatives to Compressor Cooling, Phase V: Integrated Ventilation Cooling. Final project report, California Energy Commission Contract No. 500-04-009. Sacramento, California.

Springer, D., L.I. Rainer, W.L. Dakin. 2005. *Development and Testing Of an Integrated Residential Night Ventilation Cooling System.* ASHRAE Transactions, Vol. 111, Pt. 2.

Springer, David. 2007. SMUD Off-Peak Over-Cooling Project Final Report. California Energy Commission, PIER Renewable Energy Technologies Division. CEC-500-00-034.

7. Appendices

7.1 CSE Model Energy Impact Projections for 100% and 20% WHF Cases

	100% Airflow		20% Airflow	
Climate Zone	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)
1	0	-8.9	0	-3.0
2	127	-4.3	16	-2.7
3	-150	-6.8	-74	-1.6
4	264	-4.3	82	-3.0
5	-74	-11.9	-26	-1.9
6	206	-4.1	-50	-0.8
7	-87	-4.1	-148	-0.8
8	651	-4.3	161	-2.2
9	815	-4.3	161	-2.4
10	955	-4.1	150	-1.9
11	994	-4.1	142	-3.0
12	941	-4.3	174	-3.0
13	992	-5.4	145	-3.2
14	738	-5.1	84	-3.5
15	422	-3.8	21	-1.6
16	525	-11.3	-55	-4.9

7.2 BIRA/ConSol Building America Monitoring Data

A NightBreeze unit was installed in a ConSol Building America project home in Stockton, California in early 2004. The 3,553 ft^2 two-story house incorporated cooling energy efficiency measures including low-SHGC windows, attic radiant barrier, buried ducts, largely fluorescent lighting, and a 12 SEER 3.5 ton cooling system. The combination of energy-frugal homeowners (typical cooling tsetpoints ~80°F) and the favorable Stockton-area climate made it an ideal NightBreeze application. ConSol has been monitoring temperatures and equipment current draw using HOBO dataloggers from May 2004 through 2005. Results from the summer months of June 2004 through September 2004 and June 2005 through July 2005 show a total of ***only 221 kWh*** of condensing unit energy consumption and 1069 kWh of air handler energy consumption.

During typical summer weather patterns, the NightBreeze system was able to reduce indoor temperatures from about 78.5°F at the start of the ventilation cooling cycle to 72°F in the morning. On the hottest days (>95°F), the system reduced the indoor temperature from an average of 81°F to 76°F. These impressive results demonstrate the value of the NightBreeze system and its ability to shift energy consumption from on-peak to off-peak periods. Table 3 summarizes key site monitoring data.

Table 1. Stockton NightBreeze Site Data Summary

	Outdoor Temperature (F)		Cooling Energy Consumption (kWh)		
	Max > 90	**Max > 100**	**Cond Unit**	**Air Handler**	**Total**
June 2004	17	1	6	120	126
July 2004	24	4	36	204	240
August 2004	21	6	24	197	221
September 2004	14	4	26	143	169
June 2005	12	3	3	91	94
July 2005	24	11	126	314	440
Total	112	29	221	1069	1290

7.3 Variable Speed Energy Calculation Methodology

METHOD FOR DEVELOPING FAN ENERGY USE FOR A VARIABLE SPEED VENTILATION COOLING TITLE 24 MEASURE 8/16/10

Background

Estimation of fan energy for variable speed furnaces and air handlers is more complicated than simply assigning a fixed watt per cfm value as can be done with some confidence for non-variable speed systems. Variable speed ventilation cooling has been shown to produce greater energy savings than similar systems using constant speed fans[11]. Variable speed ECM driven fans have two characteristics that distinguish them from permanent split capacitor (PSC) fans: (1) They have a higher efficacy (lower Watts/CFM) than constant speed PSC powered fans when operated under identical conditions; (2) Unlike PSC fans, they deliver a relatively constant airflow over a wide range of external static pressures and respond to increasing static pressure by ramping up torque and RPM and use more power. Therefore, proper distribution system design is needed to insure the higher efficacy is realized.

NightBreeze systems use a complex algorithm to predict the current day's cooling demand based on previous day's temperature trends, and adjust the fan speed so it is varies with cooling demand. They also adjusts the low limit temperature to prevent over-cooling, but for simplicity it is proposed that a fixed 68°F low limit temperature be used with compliance models.

Method Assumptions and Derivation

<u>Duct Pressure Drop</u>
The proposed method assumes that the system is installed in accordance with NightBreeze installation instructions, which include sizing ducts for an airflow of 0.6 cfm per square foot of conditioned floor area. This should result in a maximum supply side pressure drop of not more than 0.45" ESP (external static pressure), which is similar to the average ESP value found from California field studies by Wilcox.

<u>Maximum Fan Power</u>
The proposed method assumes that the maximum distribution system pressure drop is the same for all houses of identical floor area, and that the relationship between airflow and pressure drop is unique for each house size. Laboratory tests were completed to measure NightBreeze fan power at supply

[11] Demonstrated through modeling and an outcome of field tests commissioned by PG&E.

pressures at specific airflow rates corresponding to five different house sizes at 0.45" (112.5 Pa) supply ESP. Airflow was adjusted by modifying the "Manual Fan" cfm settings on the NightBreeze control. A TrueFlow flow grid was used to measure airflow. The TrueFlow imposes static pressure on the return side of the fan, and it was assumed a filter would introduce a similar amount of static pressure. Actual pressures on the supply and return sides were measured and recorded, and are listed in Table 1.

Since conditioned floor area (CFA) is a directly accessible ACM input, a correlation between CFA and maximum fan power was developed using the Table 1 data. The result is shown in Figure 1.

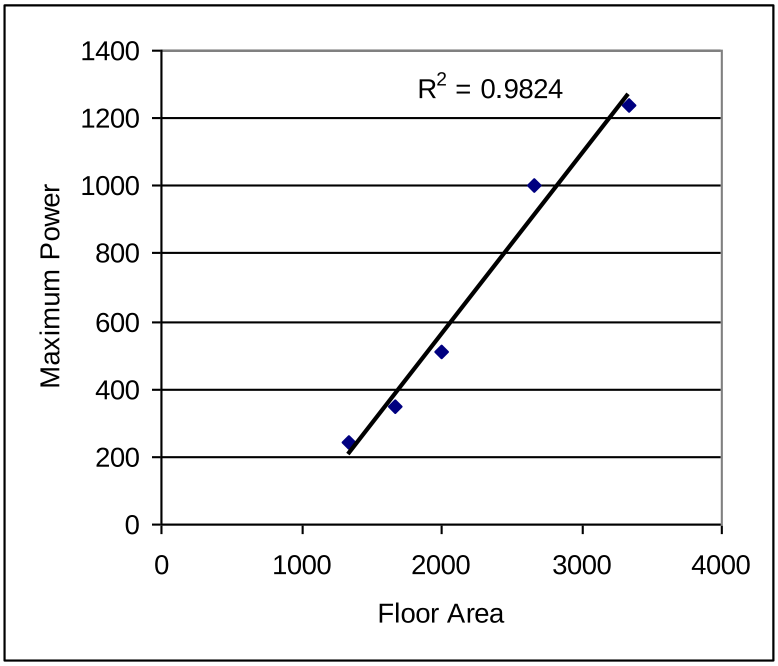


Figure 1: Correlation Between Conditioned Floor Area and Maximum Fan Power

The equation for the regression line in Figure 1 is listed in Equation 1 and is valid for all CFA's greater than 1000 ft² and less than 3334 ft².

E_1 = -505.443 + 0.5332 x CFA **Equation 1**

Where: E_1 = maximum ventilation cooling fan power
CFA = conditioned floor area of the house

For houses greater than 3333 ft² it must be assumed that two systems are installed. The floor area should be divided by two and fan power at the reduced airflow calculated as below and the power for each half doubled.

<u>Power at Reduced Airflows</u>
Data from the same series of laboratory tests were used to identify power at reduced airflows for each of the theoretical house sizes. The settings were adjusted using the Manual Fan control input. These measurements are also provided in Table 1.

To develop a simple equation to estimate the power corresponding to reductions in airflow it was assumed that power varies with airflow raised to some power. If fan laws were strictly applied this exponent would equal 3, but since fan efficiency varies with speed it was necessary to identify the closest approximation for this exponent. The coefficient was found by calculating fan power using the following equation and varying the exponent until the sum of the standard deviations between measured and calculated values was minimized.

$$E_2 = (E_1 \times Q_2^n) / Q_1^n \qquad \textbf{Equation 2}$$

Where: E_1 = fan power at "maximum" airflow for given house size/airflow setting
Q_1 = maximum airflow for given house size
Q_2 = airflow at reduced speed setting for given house size
n = exponent

A coefficient of 2.791 yielded the lowest sum of standard deviations. The linear correlation when the measured and calculated power values are compared is 0.9989.

Table 1: Measured Airflow and Power for Five Theoretical Houses

"House Size"	Manual Fan CFM Setting	Measured CFM	Set Static Pres. Pres. (Pa)[1]	Meas. Static Pressure Supply	Meas. Static Pressure Return	Watts
3333	2000	2067	112.5	124	117	1239
"	1600	1935		111	104	1005
"	1200	1429		61	55	409
"	800	916		24	23	126
"	400	550		8	8	39
2667	1600	1923	112.5	110	101	1000
"	1200	1454		62	58	431
"	800	921		25	24	129
"	400	539		8	8	40
2000	1200	1477	112.5	112	59	510
"	1000	1196		73	40	283
"	800	916		44	23	151
"	600	715		14	25	74
"	400	523		14	9	39
1667	1000	1209	112.5	112	40	348
"	800	952		72	26	189
"	600	732		40	15	86
"	400	504		20	9	42
1333	800	964	112.5	114	25	241
"	600	728		64	14	110
"	400	501		31	7	50

[1]California field studies indicate the median pressure drop for residential duct systems is 0.18" and for cooling coils is 0.27", resulting in a static pressure downstream from the blower of 0.45", which equates to 112.5 Pa.

<u>Estimation of Airflow as a Function of Climate Conditions</u>

One of the outputs of NightBreeze predictive algorithms is the ratio of airflow (or "airflow fraction") for the current period relative to the maximum ventilation airflow (based on 0.6 cfm/ft² of floor area). Rather than employ the complex proprietary NightBreeze equations, a simplified method which uses only the previous day's maximum outdoor temperature was developed to serve as a proxy. Using typical summer temperature profiles from TMY files and a PG&E reference[12], values of other weather parameters that are used in the NightBreeze algorithms were estimated for corresponding maximum daily outdoor temperatures. The NightBreeze algorithm was applied to these variables to calculate airflow fractions for a range of maximum outdoor temperatures. The following equation provided the best fit of the maximum outdoor temperature (Tmax) to the airflow fraction (AF).

$$AF=1 / (17.91554 - 3.67538 \times \ln(Tmax)) \qquad \textbf{Equation 3}$$

Proposed Method

For each prototype house:
Calculate the maximum fan power (E_1) from the CFA using Equation 1. If the CFA is greater than 3333 ft², use 0.5 x CFA in Equation 1.

For each day:
Calculate the airflow fraction (AF_d) using Equation 3 and the previous day's maximum outdoor temperature.
Calculate the adjusted fan power (E_2) using Equation 2 and E_1 from Step 1, and using $Q_1 = 1$ and $Q_2 = AF_d$. If the CFA is greater than 3333 ft², multiply E_2 by two.

For each hour when the outdoor temperature is 5°F below the indoor temperature:
Sum the values of E_2 to get the daily fan energy use.
Apply a ventilation rate equal to AF_d x CFA x 0.6 in the model. If the CFA is greater than 3333 ft² multiply the result by two.

[12] Mean Hourly Temperatures and Procedures for Calculating Full-Load Equivalent Operating Hours for Northern and Central California.

7.4 Tabular Results Summary

Cooling TDV Budget Impact (Positive value = savings)

	Whole House Fans			Fixed Speed		Variable Speed	
	20%	50%	100%	Default	Test	Default	Test
CZ1	0%	0%	0%	0%	0%	0%	0%
CZ2	13%	**43%**	65%	**0%**	**26%**	**49%**	**57%**
CZ3	-3%	**19%**	38%	**-95%**	**-54%**	**29%**	**36%**
CZ4	15%	**41%**	60%	**6%**	**27%**	**42%**	**49%**
CZ6	2%	**30%**	53%	**-27%**	**-2%**	**45%**	**51%**
CZ7	-7%	**20%**	55%	**-89%**	**-52%**	**18%**	**26%**
CZ8	11%	**31%**	53%	**-10%**	**12%**	**38%**	**45%**
CZ9	5%	**17%**	31%	**-6%**	**7%**	**18%**	**23%**
CZ10	5%	**18%**	33%	**7%**	**20%**	**28%**	**34%**
CZ11	2%	**8%**	17%	**2%**	**8%**	**11%**	**14%**
CZ12	7%	**27%**	48%	**14%**	**29%**	**32%**	**39%**
CZ13	2%	**8%**	16%	**-2%**	**4%**	**9%**	**11%**
CZ14	1%	**8%**	16%	**2%**	**8%**	**12%**	**14%**
CZ15	0%	**1%**	2%	**-5%**	**-3%**	**1%**	**2%**
CZ16	0%	**15%**	38%	**-4%**	**9%**	**26%**	**29%**
Average of key CZs CZ 2,4,8-10,12,14,16	8%	**27%**	47%	**1%**	**19%**	**33%**	**39%**

Total TDV Budget Impact (Positive value = savings)

	Whole House Fans				Fixed Speed			Variable Speed	
	20%	50%	100%		Default	Test		Default	Test
CZ1	0%	0%	-1%		0%	0%		0%	0%
CZ2	3%	**9%**	14%		**0%**	**6%**		**11%**	**13%**
CZ3	-1%	**4%**	7%		**-18%**	**-10%**		**5%**	**7%**
CZ4	5%	**14%**	21%		**2%**	**9%**		**15%**	**17%**
CZ6	1%	**13%**	23%		**-12%**	**-1%**		**20%**	**22%**
CZ7	-3%	**9%**	25%		**-40%**	**-24%**		**8%**	**12%**
CZ8	6%	**18%**	31%		**-6%**	**7%**		**22%**	**26%**
CZ9	3%	**11%**	21%		**-4%**	**5%**		**12%**	**15%**
CZ10	3%	**12%**	23%		**4%**	**13%**		**19%**	**23%**
CZ11	1%	**6%**	12%		**1%**	**6%**		**8%**	**10%**
CZ12	4%	**15%**	27%		**8%**	**16%**		**18%**	**22%**
CZ13	1%	**6%**	12%		**-1%**	**3%**		**6%**	**8%**
CZ14	1%	**5%**	11%		**1%**	**5%**		**8%**	**10%**
CZ15	0%	**1%**	2%		**-5%**	**-3%**		**1%**	**1%**
CZ16	0%	**6%**	16%		**-2%**	**4%**		**11%**	**12%**
Average of key CZs CZ 2,4,8-10,12,14,16	4%	**12%**	22%		**0%**	**9%**		**15%**	**18%**