NIGHTBREEZE PRODUCTS

DEVELOPMENT PROJECT

FINAL REPORT

CONSULTANT REPORT

Prepared For:

California Energy Commission

Public Interest Energy Research Program

Prepared By:

Davis Energy Group

December 2005
PUBLICATION # HERE

CALIFORNIA ENERGY COMMISSION

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LEGAL NOTICE

ACKNOWLEDGEMENTS

This project represents a collaborative effort of Davis Energy Group and a team of subcontractors including:

- Michael Kuhlmann and Chris Aughinbaugh of Residential Control Systems
- Pete Alexander and Darryl Warren of Amana (Goodman Manufacturing Co.)
- Bob Radcliff of Beutler Corporation
- Allen Amaro of Amaro Construction Services

The foundation of this project was developed under the Alternatives to Compressor Cooling (ACC) projects. Of the many contributors to the ACC projects over the years, we would like to specially thank Karl Brown, George Loisos, Susan Ubbelohde, Eric Heien, Eehern Wong, Jeff Jacobs, and John Suppes.

Finally we would like to acknowledge the continuing support from the California Energy Commission. In particular we would like to thank our project managers in this project, Chris Scruton and Phil Spartz, and the PIER Buildings Office managers Ann Peterson and Nancy Jenkins.

TABLE OF CONTENTS

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the NightBreeze Products Project, Contract No. 500-02-026, conducted by the Davis Energy Group (DEG). The report is entitled "NightBreeze Products Development Project." This project contributes to the PIER Buildings End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Energy Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Energy Commission's Publications Unit at 916-654-5200.

EXECUTIVE SUMMARY

Background

Residential air conditioning has a significant impact on California's electrical infrastructure. Residential buildings are responsible for 35% of California's peak electrical load, and air conditioning accounts for 43% of residential peak load but only 6% of residential energy use (Brown and Koomey, 2003). A range of solutions are needed to effectively address this problem. Prior results from the Alternatives to Compressor Cooling (ACC) projects have demonstrated that mechanically ventilating homes with cool night air can significantly reduce cooling energy consumption as well as reduce on-peak cooling electrical demand. The NightBreeze ventilation cooling system developed under ACC projects optimizes ventilation cooling (and fresh air ventilation) operation without occupant interaction, while minimizing compressor and fan energy use. The current hydronic NightBreeze system includes the following components:

- an air handler equipped with a variable speed electronically commutated motor (ECM)
- a damper that is controlled to provide full return airflow (normal HVAC operation) or 100% outdoor airflow (for fresh air or ventilation cooling operation)
- integrated controls that provide optimal fresh air and ventilation cooling control
- a hot water coil for delivering hydronic space heating
- an optional evaporator coil for providing vapor compression cooling

Although the NightBreeze hydronic technology has been demonstrated in numerous research projects (DOE's Building America, ACC, Zero Energy New Homes, PIER, and utility sponsored field tests), the hydronic version of the system is confronted with several market barriers including system cost, production builder resistance to hydronic systems, and lack of zoning capability. To address these barriers, the California Energy Commission's Public Interest Energy Research (PIER) program sponsored a final project with the main objective of developing a multi-zone furnace-based NightBreeze system.

Objectives & Approach

The *NightBreeze Products* project had four key research objectives:

1. Develop production capability for the NightBreeze hydronic system
2. Integrate NightBreeze advanced algorithms with the SmartVent system currently being successfully marketed by Beutler
3. Develop a version of NightBreeze compatible with variable speed gas furnaces (with electronically commutated motors) and with a multi-zone control strategy
4. Pursue commercialization activities to foster NightBreeze implementation in the production builder market

To complete these tasks Davis Energy Group assembled a team including the Beutler Corporation, Residential Control Systems (the developer of the SmartVent controls), and

Amana/Goodman. A brief discussion of the project approach in each of the four areas follows.

Develop NightBreeze Hydronic Production Capability
Davis Energy Group has tried for several years to develop a preferred approach for producing and marketing the NightBreeze hydronic system. To date, no major HVAC manufacturers have demonstrated interest in producing a low volume product such as NightBreeze "hydronic". To help facilitate production capability, this project completed cost match tasks directed at completing a production air handler design, built ten NightBreeze hydronic units, completed air handler airflow testing to verify system performance at a variety of airflow levels and external static pressures, and prepared owners and installation manuals.

Integrate NightBreeze Algorithms with SmartVent
SmartVent is a ventilation cooling product similar in configuration to the NightBreeze system. Beutler has had increasing success marketing SmartVent to the production home market with nearly 20,000 systems installed in the past 10+ years, with current sales at about 3500-4000 units annually. Two key performance limitations of the SmartVent system are its use with relatively inefficient (low cfm/Watt) permanent split capacitor (PSC) motors and simplistic ventilation control logic that provides limited energy savings. To provide a performance boost to this product, DEG integrated the advanced NightBreeze low limit vent temperature logic with the SmartVent controller.

Develop Multi-Zone Variable Speed NightBreeze Furnace Controls
NightBreeze "hydronic" utilizes the electronically commutated motor (ECM) to provide precise airflow control and much greater efficiency than standard PSC motors. Airflow control is a critical element in NightBreeze's efficiency advantage, since it allows the system to vary airflow on a daily basis based on current indoor and outdoor conditions. Decreasing the ventilation airflow rate under mild conditions when maximum airflow is not needed can significantly reduce fan energy use. To date, ECM motors are commonly found only in the higher end line of furnaces due to motor costs. Working with an Amana line of condensing furnaces, DEG and RCS worked together to merge NightBreeze control logic with existing SmartVent logic and to develop a capability for two-zone control. DEG developed a detailed functional specification defining the control characteristics and RCS developed the "NB2" firmware prototype that was jointly tested in both lab and field environments.

Commercialization Activities
Successful commercialization depends on reducing market barriers and stimulating market demand. In this project commercialization activities centered on facilitating building department approvals (by obtaining an ETL or UL safety evaluation and product listing) and developing technology transfer opportunities. Technology transfer activities focused on exploring program opportunities with California utilities, and state and federal programs, exploring marketing and manufacturing opportunities with key industry players, and promoting the product through press releases and other avenues.

Project Outcomes

The NightBreeze Products PIER project achieved success in each of the four targeted areas. A key project outcome was the integration of NightBreeze control logic with current SmartVent hardware. This integration insures that as hardware evolutions occur within the controls industry, NightBreeze capabilities will not be left behind. Specific outcomes are listed below.

Develop NightBreeze Hydronic Production Capability

The cost match portion of the project included tasks related to developing NightBreeze hydronic production capability. Ten units were built, and eight were sent to southern California for use in Habitat for Humanity new construction projects (two sites were monitored for Southern California Edison). The two remaining units were installed in Northern California custom homes, one of which is a monitored DOE Building America site. Detailed air handler design drawings were developed and sent to Waterfurnace International for their use in fabricating a prototype NightBreeze air handler unit.

Integrate NightBreeze Algorithms with SmartVent

NightBreeze lower limit ventilation algorithms are considerably more sophisticated than the fixed ventilation target used by SmartVent. The NightBreeze logic allows for the user to specify a low limit indoor temperature that the system attempts to achieve on the hottest days. The logic then raises the user-defined lower limit on milder summer days, eliminating excessive fan operation and homeowner comfort complaints of overcooling on cool mornings. The algorithm was added to the SmartVent logic, lab tested, and then field tested to verify performance. The “Enhanced” SmartVent offers improved performance and is currently available for the new construction market.

Develop Multi-Zone Variable Speed NightBreeze Furnace Controls

Early in the hardware development effort it became clear that a single hardware solution could be developed that would satisfy NightBreeze control requirements. This includes one or two-zone operation, single or two-stage vapor compression cooling, and three heating system types (gas furnace, multi-stage heat pumps, and variable speed hydronic heating.) Concurrent with developing the hardware solution, DEG developed a functional specification defining the control characteristics of the advanced NB2 control. Beutler and RCS provided significant input based on real world experience of thousands of SmartVent customers. This perspective was invaluable in developing a final control specification. Prototype controls were developed and tested both in the lab and in the field using variable speed furnaces and two-stage condensing units donated by project partner Amana/Goodman. Performance of the prototype controls was found to be consistent with the design intent.

Commercialization Activities

An ETL safety evaluation and product listing was completed. This will help win building department approval for the installation of NightBreeze. In 2004, Davis Energy Group formed a new corporation specifically for the purpose of commercializing low energy cooling and heating products. This company, Advanced Energy Products Corporation

(AEP), is currently marketing pre-production units of NightBreeze Hydronic. Resources and capital are needed to enable AEP to properly market and commercialize NightBreeze and other technologies. Consequently financial advisors were retained to assist with capitalizing the company. Growth Capital Group of Sacramento, has been fulfilling this function for AEP.

Efforts to capitalize AEP are ongoing, and venture capital firms have been approached. In general, the feedback from those in the venture community that are interested in clean technologies has been encouraging, but they first want to see sales to major homebuilders. This will not be possible until the gas furnace version of NightBreeze is for available in quantity, since production builders utilize gas furnace equipment, not hydronic fan coils. Nonetheless, AEP is pursuing commitments, letters of interest, and letters of intent to make visible progress in this arena and demonstrate it to the venture community. A preliminary commitment has been received for approximately eight gas furnace NightBreeze units from a builder developing a 92-unit subdivision in Woodland, California. If the initial eight installations proceed smoothly and homeowner reaction is favorable, it is likely that the builder will include NightBreeze units in the majority of the remaining subdivision. In addition, Grupe Homes has expressed interest in installing the gas furnace version of NightBreeze in a 140-unit subdivision to be built in Rocklin. At the same time, efforts are underway to sell NightBreeze Hydronic to custom homebuilders.

Next Steps

Advanced Energy Products is taking a dual approach to marketing NightBreeze for the future. It is working with Beutler Corporation toward having that company offer NightBreeze, particularly the gas furnace version, to its builder clients. Beutler has agreed to this in principle, and the details are under discussion. Arrangements will be finalized in 2006 when the gas furnace version is complete and available in volume. DEG and AEP are continuing to work with PG&E and other utilities to develop new construction incentives for NightBreeze. PG&E has committed to provide incentives beginning in 2006, although the exact incentive level has yet to be finalized.

In addition, AEP is retaining a manufacturers representation firm to market and sell both hydronic and gas furnace versions of NightBreeze in California and Nevada. Action Sales of Sacramento, CA specializes in introducing innovative products to the homebuilding industry. An example would be the Vanguard Manibloc manifold system that efficiently delivers domestic hot water from a manifold located adjacent to the water heater. Action Sales took the Manibloc from entry to nearly 70% market share in Northern California over a two-year period. Action Sales is quite selective about taking on new product lines, and agreed to add NightBreeze in November, 2005. AEP is optimistic that this arrangement will begin to yield significant sales results starting in approximately a year.

ABSTRACT

Residential cooling represents a significant problem for California's electric utilities and planners since peak cooling loads are coincident with peak electrical loads. As residential and commercial construction growth continues in California, the strain on the state's transmission and distribution grid increases. Nighttime ventilation cooling is a technology that offers significant potential to improve cooling performance, especially in newer homes designed with features such as spectrally selective glass and attic radiant barriers that extend the pre-cooling benefit through all or most of on-peak periods.

The NightBreeze ventilation cooling system developed through the Alternatives to Compressor Cooling project was effectively demonstrated to reduce peak cooling load and overall cooling energy use. However, it has been limited by several market barriers including lack of production capability, absence of a furnace-based product attractive to production home builders, and applicability to only single zone systems. To help further the technology, the NightBreeze Products project was developed with the following key objectives:

- Design and build ten NightBreeze hydronic air handlers for field demonstrations
- Improve the capabilities of the existing SmartVent ventilation cooling system by including partial NB functionality
- Develop and test an advanced two-zone variable speed furnace-based NightBreeze system targeted for the production builder new construction market
- Pursue NightBreeze commercialization activities including product listings, incentive programs, and marketing studies

Davis Energy Group (DEG), in collaboration with subcontractors RCS and Beutler Corporation, met each of the four project objectives. At the conclusion of the project, DEG and it's product marketing arm (Advanced Energy Products) have demonstrated initial success in introducing the NightBreeze gas furnace system to the new construction market. Eight gas furnace NightBreeze units are being installed in a 92-unit subdivision in Woodland, California. In addition, Grupe Homes has expressed interest in installing the gas furnace version of NightBreeze in a 140-unit subdivision to be built in Rocklin. DEG is continuing to work with PG&E and other California utilities to provide new construction incentives beginning in 2006.

1. BACKGROUND

New California homes are becoming increasingly energy efficient due to tightening state Building Energy Standards and continual improvements in both building components and installation practice. Countering this improvement in efficiency is a trend towards larger houses[1]. Interestingly, the 2004 Residential Appliance Saturation Study (KEMA-XENERGY, 2004) data suggests that although the natural gas heating use of newer homes is decreasing relative to older homes, cooling energy consumption is increasing (about 16% higher in newer homes). This trend can be attributed to factors including more home construction in hotter inland areas, larger house size, higher comfort expectations, higher internal gains due to more electronic gadgets (computers, large screen TV's, etc.), and greater solar exposure in new houses (less tree shading of windows and roofs).

An additional factor that has not to date been adequately quantified, is a perceived reduction in the operation of windows for nighttime natural ventilation. In many areas of California, nighttime ventilation pre-cooling, either natural or mechanically (fan-driven) induced can significantly reduce next day cooling loads. Pre-cooling becomes more effective as "anti-solar" building components such as spectrally selective glazing and attic radiant barriers become more commonplace. With lower daytime heat gains, pre-cooling can play a significant role

Whole house fans, installed in about 6% of California homes (PG&E, 1997 RAEUS), can be effective ventilation cooling devices, however they do require active homeowner interaction to achieve effective pre-cooling benefits. In addition, whole house fans are fairly noisy which often limits their use during the coolest early morning hours when people are asleep. Other whole house fan concerns include a lack of air filtration that results in the introduction of dust and allergens indoors. An ideal ventilation cooling system would operate without daily homeowner interaction and provide filtered outdoor air to the house without disturbing the occupants.

Although the energy efficiency of new homes has been improving, indoor air quality concerns have been mounting due both to tighter homes and improved scientific knowledge on indoor air quality issues. Newer, tighter houses have lower infiltration rates resulting in less dilution of internally generated moisture, CO_2, and other contaminants contained in homes. Without introduction of outdoor air, indoor air quality can be compromised contributing to problems including mold growth and respiratory problems. ASHRAE has developed the 62.2 ventilation standard to address the growing indoor air quality problem. Builders and mechanical contractors are still formulating strategies to meet the 62.2 ventilation standards, but they are becoming increasingly cognizant of the issue and realize that ignoring potential problems may lead to significant liability exposure.

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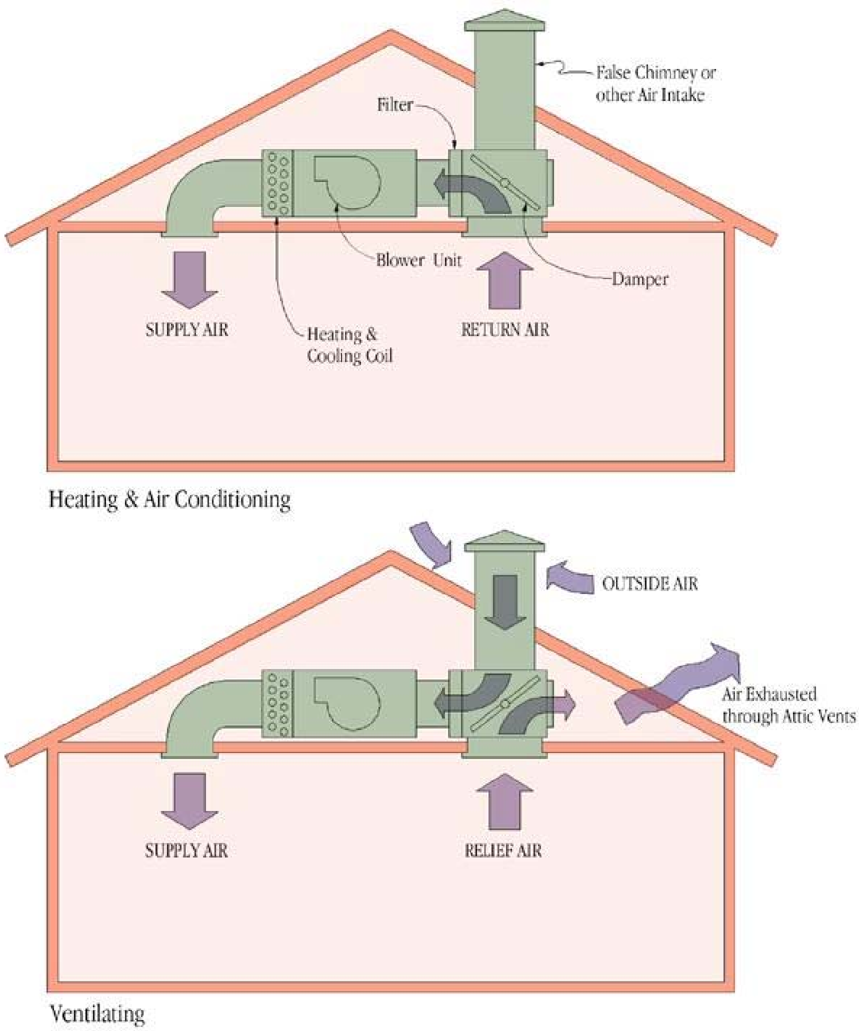
[1] The 2004 Residential Appliance Saturation Study reports the average existing California single family home is 1,787 ft^2 vs. 2,528 ft^2 for homes built between 2001 to 2003 (KEMA-Xenergy, 2004).

The benefits of an integrated fresh air ventilation and ventilation cooling system have been gaining increasing attention over the past ten years. The Beutler Corporation, the second largest residential HVAC contractor in the country, has marketed an integrated "residential economizer" in Northern California since 1990. The "SmartVent"[2] system features a diversion damper, outside air duct, and controls enabling the HVAC air handler to operate either in conventional space conditioning mode or in residential economizer mode (see Figure 1). SmartVent sales have grown from several hundred units per year initially to several thousand in 2004[3]. The primary attraction for most SmartVent buyers is the fresh air ventilation benefit. Although SmartVent sales have demonstrated strong growth within Beutler's service territory, the system's ventilation efficiency (in terms of fan energy per unit of airflow, or "Watts per cfm") is limited by the relatively low airflow efficiency of conventional furnaces that utilize permanent split capacitor (PSC) blower motors. PSC motors cannot move air as efficiently as a whole house fan or an air handler equipped with an efficient electronically commutated motor (ECM).

Figure 1: SmartVent System Operation (conventional and ventilation modes)



[2] http://www.beutler.com/smart_vent.htm
[3] Beutler has sold roughly 15,000 to 20,000 SmartVent units over the past 14 years.

The Alternatives to Compressor Cooling Project, funded in several phases by the California Institute for Energy Efficiency and the California Energy Commission's Public Interest Energy Research (PIER) program, resulted in the development of a promising advanced residential ventilation cooling technology, called NightBreeze. This technology, developed by Davis Energy Group, was originally designed to work with hydronic heating systems. NightBreeze attributes include:

- Automatic night ventilation cooling that filters outdoor air while not requiring windows to be opened
- Integrated controls to optimize ventilation cooling benefits
- A user-friendly thermostat that displays the predicted "next day" indoor air temperature range
- Variable air volume hydronic heating that reduces fan energy use and improves winter comfort by tighter control of thermostat setpoints
- Ability to provide automated fresh air ventilation level that can be tuned to match house ventilation requirements (e.g. ASHRAE 62.2)

Current NightBreeze and SmartVent functionality is comparable with the primary distinction being SmartVent's compatibility with furnaces and the original NightBreeze being exclusively a hydronic space heating system. The NightBreeze air handler does utilize a high efficiency ECM motor in contrast to the PSC motors common to the SmartVent system. In cooling mode, NightBreeze varies both the rate of outdoor air delivery and the ventilation target temperature as a function of the predicted need for cooling for the next day. This logic was developed to minimize fan energy consumption and maximize ventilation benefits, while assuring that the house won't be over-cooled during mild weather. Key NightBreeze enhancements over SmartVent are:

1. Efficiency advantages due to the ECM motor and variable speed capability
2. Daily optimization of ventilation airflow rate (reduced fan energy use)
3. Daily adjusted vent target temperatures based on weather conditions

Cooling energy savings vary with climate and also the extent to which the homeowner uses windows for natural ventilation. The DOE-2 building energy simulation model projects cooling energy savings of 13-57% in the Sacramento climate, depending upon whether the base case assumption is homeowners keeping the windows closed (higher savings) or if maximum natural ventilation benefit is assumed[4] (lower savings). Peak demand savings of roughly 20% are predicted regardless of how the homeowner operates windows, since it is the still hot summer nights when mechanical ventilation is most effective relative to natural ventilation.

[4] Ideal operation assumes all windows are opened when cooler outside and closed when warmer outside.

Although the NightBreeze technology has demonstrated success in various R&D projects, the technology faces a number of obstacles that must be overcome before it can be successfully introduced into the marketplace. These include:

- <u>System Configuration</u>: The original NightBreeze system includes a hot water coil air handler. Although this configuration offers significant energy advantages in terms of variable air volume heating, the vast majority of systems installed in new California homes are gas furnaces, not hydronic air handlers.
- <u>First Cost</u>: The installed cost of a NightBreeze heating and cooling system is significantly higher than that of a typical gas furnace system, and the production home construction market is extremely cost sensitive. A furnace-based NightBreeze design is needed to successfully impact the market.
- <u>Builder-Model HVAC Equipment</u>: NightBreeze was currently designed to operate with a variable speed ECM blower motor. Common builder-model furnaces use lower efficiency multi-tap permanent split capacitor (PSC) blower motors. A PSC compatible NightBreeze version could significantly broaden the potential market.
- <u>Two-Zone Systems</u>: Many California builders are installing multi-zone systems, particularly in two-story homes. The original NightBreeze controls are compatible with single zone delivery.
- <u>NightBreeze Hydronic Production Capability</u>: Although there is a growing niche market for hydronic heating systems, none of the air handler manufacturers previously contacted have expressed interest in producing an air handler that meets NightBreeze specifications. For DEG, the only alternative has been to independently design and produce a NightBreeze air handler.
- <u>Safety Listing</u>: An Underwriters Laboratory or ETL listing is required for residential heating and cooling products in most jurisdictions.

Recognizing both the considerable benefits of the NightBreeze technology, as well as the market barriers, the Energy Commission's Public Interest Energy Research (PIER) program agreed to support a development project geared towards bring NightBreeze to the production home market.

2. OBJECTIVES

The primary goal of this project was to bring the benefits of the NightBreeze technology within reach of the production home market. Specific project objectives included the following:

1. Incorporate NightBreeze ventilation target logic into the existing SmartVent product. This redesigned "Enhanced SmartVent" would allow a more efficient SmartVent product to immediately enter the provides marketplace. The more sophisticated NightBreeze ventilation target algorithm allows the user to aggressively select a lower limit venting temperature, with the confidence the system won't overcool on mild days.

2. Develop the hardware and firmware needed to control a variable speed (ECM motor) gas furnace. The resulting control package ("NB2") should be designed to operate with both one- and two-zone HVAC systems.

3. Complete detailed laboratory and field-testing of the newly developed NB2 hardware to insure that the control operates properly and consistent with the design intent.

4. Complete production capability for the existing NightBreeze hydronic version. This cost-match element of the project included developing production air handler design drawings, building ten hydronic NightBreeze systems, and completing product documentation.

5. Provide marketing support for the NightBreeze products developed in this project to assist in technology commercialization. These efforts include marketing activities including high profile field demonstrations, obtaining ETL or UL listing, exploring and developing technology transfer opportunities, and developing linkages with state, federal, and utility energy efficiency programs.

3. METHODOLOGY

This report is organized to present an overview of key project methods, results, and conclusions. More specific discussion of project details can be found in interim project reports.

3.1. Project Organization

Davis Energy Group assembled a highly qualified project team, including a leading national HVAC manufacturer and the controls firm that develops and markets SmartVent controls and damper hardware.

Amana/Goodman is the second largest manufacturer of residential and light commercial HVAC products in the U.S. Amana's interest in keeping abreast of advanced HVAC developments spurred their participation in the project. Their role as project observer included technical support and donation of HVAC equipment for testing. Residential Control Systems (RCS) is a Sacramento-area specialty controls outfit and developer of the SmartVent control system. Davis Energy Group worked closely with RCS during prior ACC projects to develop the original NightBreeze hydronic control. This close working relationship has been vital in the firmware development process. Beutler Corporation provides an excellent mechanism for NightBreeze system commercialization since they understand both the value of the residential economizer technology and how to successfully market the technology. Beutler's advisory role in this project provides a strong link to the production home market and the needs and desires of today's homebuyers. DVBE consultant, Amaro Construction, was used to assist in field-testing of the prototype control and fabrication of prototype NightBreeze systems.

3.2. Enhanced SmartVent Development

The SmartVent system currently marketed by Beutler has several limitations that compromise its overall energy efficiency value. The SmartVent control operates the air handler fan for ventilation cooling at the manual "fan on" setting. Airflow effectiveness at this setting is typically on the order of 0.5 Watts/cfm, resulting in lower ventilation efficiencies than the NightBreeze system. (At reduced airflow levels, the NightBreeze with ECM motor can move air 5 to 10 times more efficiently than the SmartVent system.)

A second SmartVent shortcoming is its reliance on a single ventilation target temperature. Once the control has been programmed with a preferred target temperature (Beutler's default setting is 70°F), the system will strive to achieve that target every day, regardless of outdoor temperature patterns. The sophisticated NightBreeze algorithm accounts for recent weather trends and indoor temperature conditions in determining the daily ventilation target temperature. It also allows the occupant to set a target based on comfort expectations on the hottest day without concern of overventing on milder days.

To improve SmartVent capabilities, DEG supplied RCS with the algorithms needed to implement the NightBreeze lower limit logic. The "Enhanced" SmartVent was then tested under lab conditions and in the field to verify proper implementation of the algorithm.

3.3. Multi-Zone Variable Speed Furnace-Based Controller Development

The multi-zone, gas furnace-based control system developed in this project represents a significant advancement over the control developed for the original NightBreeze, hereafter referred to as NB1. Figure 2 schematically represents the hardware evolution necessary for the advanced NightBreeze (NB2) control. Each layer of the "onion" represents an added layer of hardware and software complexity. The innermost "core" in Figure 2 represents basic control capability. Each layer adds complexity including heat pump reversing valve control, multi-stage heating and cooling operation, ventilation damper control, variable speed air handler control logic, zone damper controls, and finally communications capability for diagnostics, data acquisition, and ultimately provide remote control capability for use in utility dynamic load control programs.

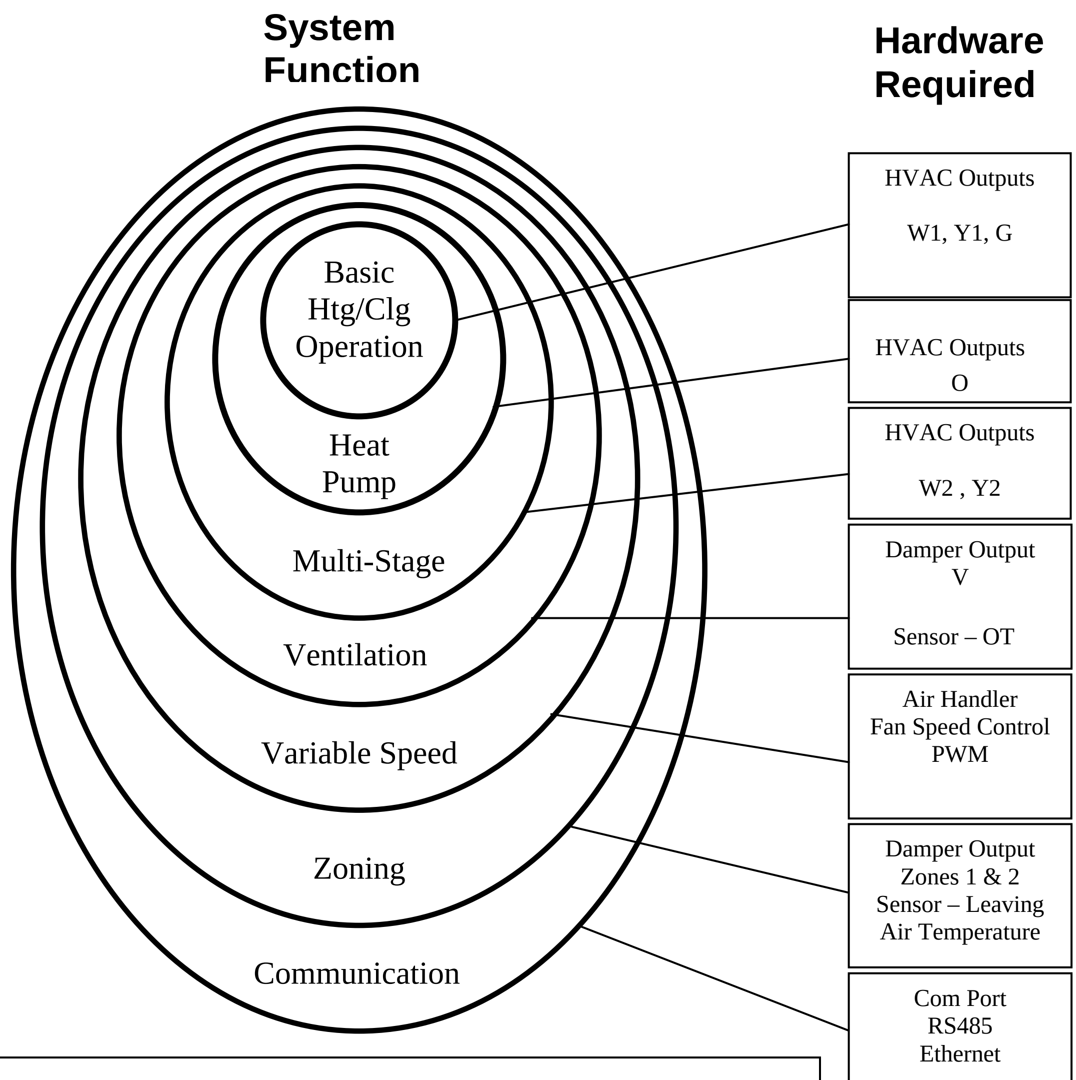
The proposed NB2 control offers the following advantages over the existing NB1 control:

- Capability to control furnaces, heat pumps, and hydronic air handlers
- Addition of zoning capability and multi-stage heating and cooling
- User interface improvements simplifying thermostat scheduling & other functions
- Addition of enhanced communications capabilities

Figure 3 documents the chronology of NightBreeze hardware development. The original NB1 hydronic version was conceived in 1997 with additional development under the ACC project between 1999 and 2002. In a parallel development effort, RCS and Beutler were continuing to upgrade hardware as evolutions within the controls industry took place. Software modifications were also undertaken to improve system operation and control reliability in response to feedback from both Beutler and customers in the field.

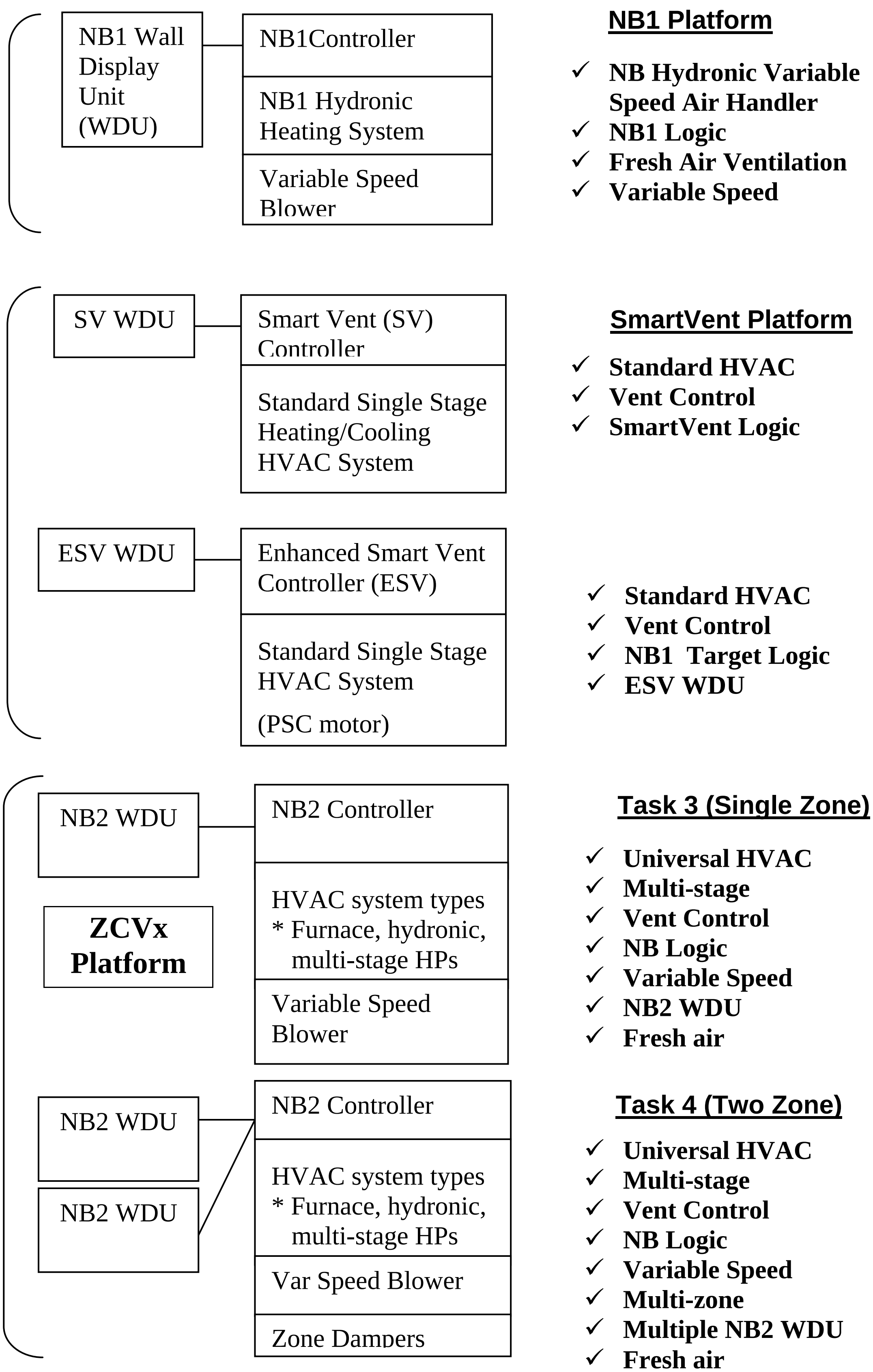
This NightBreeze PIER development project involved melding the basic SmartVent hardware and communications platform with NB1 control logic. Two-zone operation, not currently available in SmartVent or NB1, required significantly expanded capability to accommodate the control complexities including staging of heating and cooling, zone control, communication protocol, fresh air ventilation, and diagnostics.

Figure 2: Hardware Requirements Evolution



Legend:
W1 & W2 = first and second stage heating; Y1 & Y2 = first and second stage cooling; G = fan on; O = reversing valve control; V = vent damper; OT = outdoor temperature sensor; PWM = pulse width modulated signal for ECM motors

Figure 3: NightBreeze Hardware Platform Evolution



3.4. Lab Testing

The primary objective of the laboratory testing tasks (both for the ESV and NB2 control) was to exercise the prototype control under a wide range of operating conditions, document the system response, record and fix anomalies, retest, and summarize the findings. Lab testing occurred in parallel with field-testing as both approaches provide valuable feedback in insuring reliable and consistent controller operation. Lab testing allows for methodical testing to verify operation consistent with the functional specification by stepping through a series of input conditions and operating modes. Field-testing captures real world performance where a wider and more random range of input conditions will be experienced.

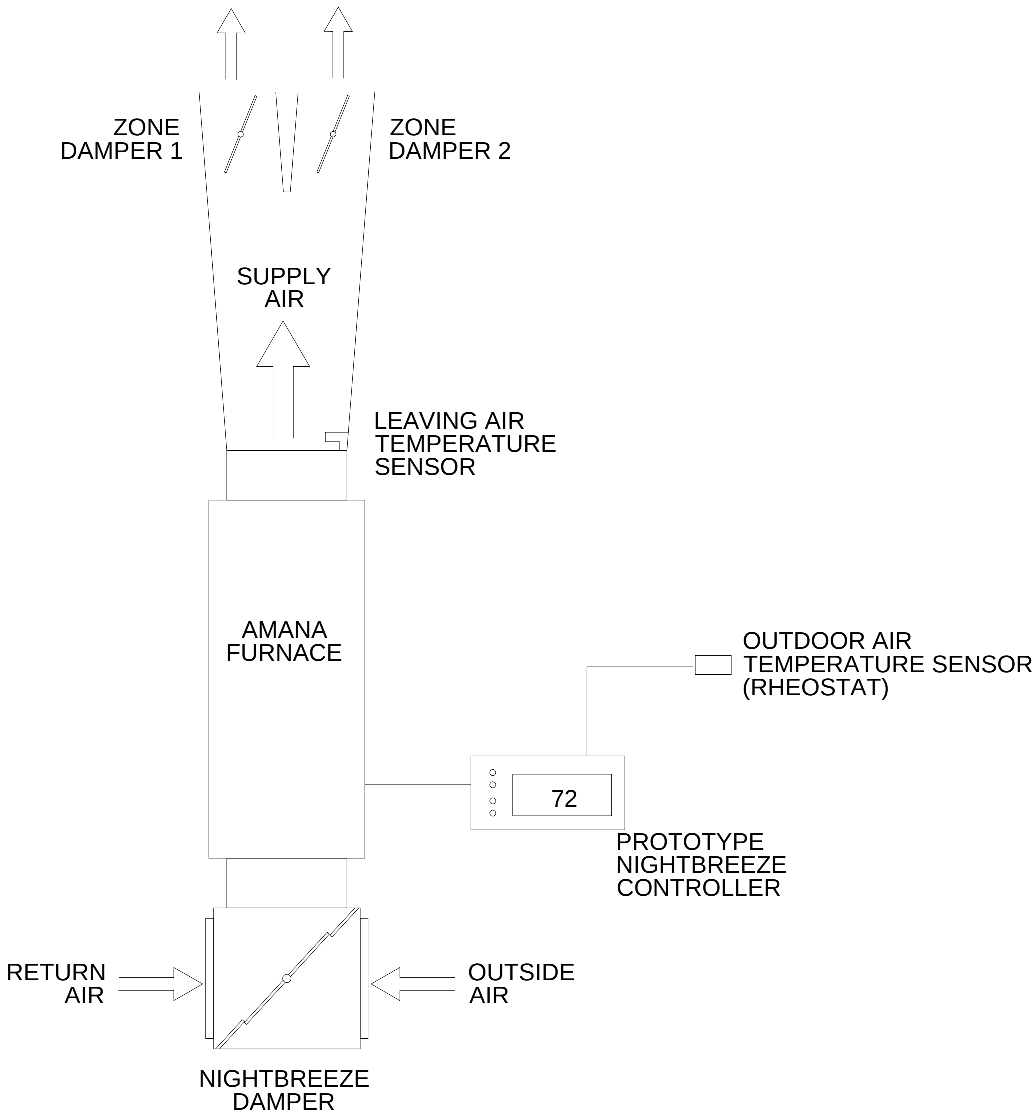
The functional specification serves as the yardstick defining expected performance of the NB2 controller. Deviations from the functional specification were documented and evaluated to determine if a fix was warranted. Complex control interactions were reviewed with RCS to determine the optimal resolution of the problem.

Initial lab testing involved basic user interaction with the WDU. (Figure 4 shows the configuration of the lab test setup used at the RCS offices.) Testing verified the ability to access, modify, and verify the technician settings, advanced settings, and thermostat schedules.. The NightBreeze controller was then exercised in each of the following modes: heating, cooling, ventilation mode, precooling, vacation mode, and Hold mode. In addition lab testing assessed the following:

- Staging time delays, minimum and maximum cooling first stage run times, & overall control logic evaluation
- Airflow levels and fan speed modulation were tested based on mode of operation, zone calls, and staging
- On-board diagnostics were evaluated (e.g. test filter/service interval counters and leaving air temperature controls)
- The controller’s response to zoning conflicts (e.g. how the control responds when one zone goes from heating to cooling)

Proper NightBreeze operation was evaluated based on variations in lower limit targets, fan speed selection, interruption of NightBreeze cycle by a cooling call, fresh air scheduling (heating season), etc.

Figure 4: Lab Test Configuration at RCS' Offices



3.5. Field Testing

The house of RCS principal Michael Kuhlmann was used as the NB2 field test site. This testing approach offered the advantage of having someone familiar with the technology directly involved in the monitoring process. The occupant's familiarity with the expected system operation will be useful in providing valuable subjective feedback to complement the quantitative data. The 3,500 ft^2 single-story test house located in the Gold River area of Sacramento is served by two HVAC units. In the fall of 2004, one of the units was replaced with a new Amana variable speed furnace, two-stage cooling system, and NightBreeze hardware. The field test system could be operated as a single-zone or two-zone system allowing testing of both NB2 prototype controller modes.

To verify operation of the prototype NB2 control, the following data points were monitored:

- indoor temperature (at each zone)
- outdoor temperature
- damper status (NightBreeze vent damper and each of the two zone dampers)
- HVAC supply blower power
- condensing unit power

Sensors were logged on a 5 second interval, resulting in a high-resolution data stream. Anomalies observed in the field monitoring were noted. DEG and RCS reviewed these anomalies, discussed the need for fixes, and implemented fixes if required.

4. RESULTS

Project results focus on three key areas:

1. ESV and NB2 development, testing, and demonstration
2. Advancing NightBreeze hydronic production readiness
3. NightBreeze marketing efforts

The following sections provide a brief overview of project results in these areas.

4.1. Enhanced SmartVent (ESV)

The ESV represents the near term alternative to the existing SmartVent product. It provides an incremental performance improvement to SmartVent, but its benefit is limited by the relative efficiency of the standard PSC motor. Since it doesn't rely on an ECM motor, it is compatible with virtually all standard furnace models. The NightBreeze algorithm was incorporated into the SmartVent controller and then tested over an eleven-day period. The controller was manually interrogated each morning to determine the values stored in internal memory. The parameters used in the vent target calculation include:

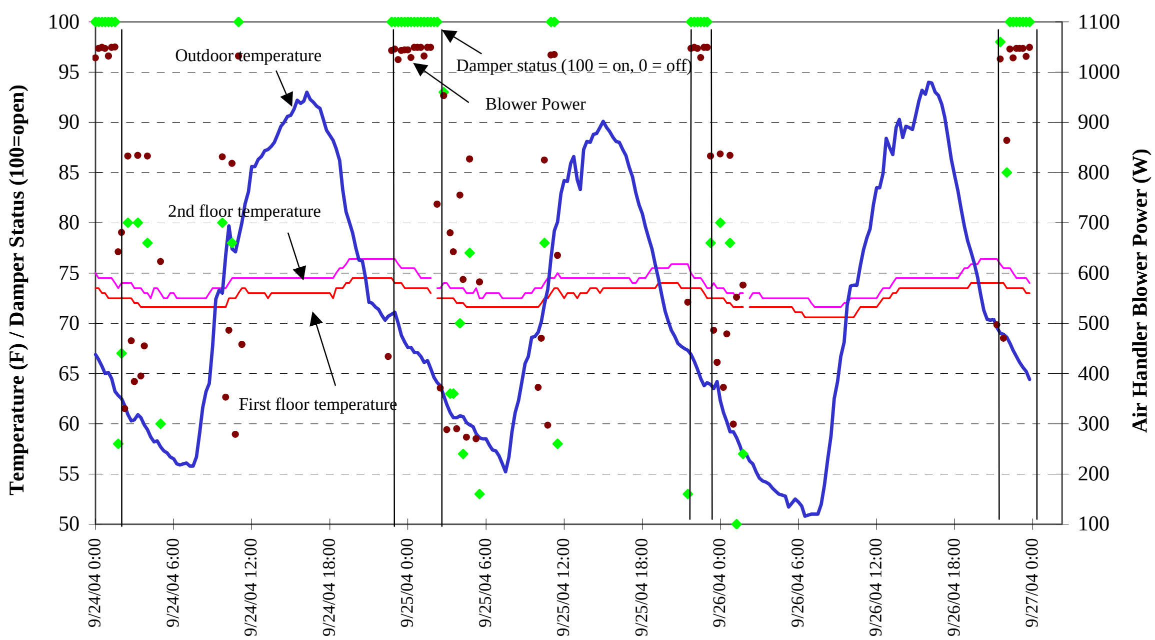
- the outdoor minimum and maximum temperatures over the previous 24 hours
- the outdoor temperature drop from 8 to 10 PM
- the trend in outdoor temperature from the current to the preceding day

The controller calculations for target temperature and other intermediate values were compared to an EXCEL spreadsheet using the same inputs and the NightBreeze vent target algorithm. Since the NightBreeze algorithm and spreadsheet approach both calculate parameters as integers, numerical round-off may result in deviations up to 1°F. Six of the eleven cases demonstrated a 1°F deviation in the daily vent target, while five of the eleven demonstrated an exact equivalence. Based on the 1°F resolution in the input values, we concluded that the NightBreeze algorithm was correctly implemented in the Enhanced SmartVent control.

In addition to the laboratory testing, a prototype Enhanced SmartVent controller was installed at a model home at Centex' Zero Energy Home project at the Lunaria subdivision in San Ramon, California. The prototype control was installed during July 2004. The control initially appeared to operate properly, but within a week the system fan speed (during night ventilation operation) dropped and stayed at a very low level, as evidenced by the blower power dropping from around 1000 Watts to 170 Watts. Repeated efforts to diagnose the problem by both Davis Energy Group and the installing HVAC contractor did not remedy the situation. The problem was finally solved after reviewing the situation with the local Carrier equipment distributor who indicated that the installed thermostat has the capability to change the "fan only" mode airflow by toggling the fan setting at the thermostat. Apparently someone passing through the model home had inadvertently adjusted the "fan only" fixed airflow to a minimum level by repeatedly pressing the fan button. In mid-September 2004, the fan speed setting was corrected.

Sample field data after the airflow problem was solved is shown in Figure 5. Data plotted includes outdoor temperature, indoor temperature (at both the first and second floor), SmartVent damper status (100 = open for the entire 15 minute interval, 0 = fully closed), and air handler blower power. The three-day stretch of weather was fairly seasonable for late September with cool morning temperatures and warm afternoons. The model home was typically open for touring from 10 AM to 6 PM. Typical indoor cooling setpoints were 74°F during "open" hours and 78°F during unoccupied times. The ESV programmed lower limit temperature was set at 68°F. The plotted data shows four nights of ESV operation with ventilation start times ranging from about 9:30 PM to around midnight. The start time was determined based on the indoor temperature relative to the daily calculated target temperature and to a minimum "delta T" between outdoor and indoor temperature. The default "delta T" was set to 5°F and each day plotted demonstrates a temperature difference of approximately 5° before ventilation is initiated. Ventilation run times varied from about 1 hour to 3.5 hours before the lower limit target was satisfied. (Note that with the mild weather, the vent target algorithm relaxes the target temperature upwards from the programmed 68°F lower limit.) After the target temperature was initially satisfied, there was further damper cycling as the control worked to maintain the setpoint target.

Figure 5: ESV Field Operating Data (9/24/04 - 9/26/04)



4.2. NB2 Development Effort Summary

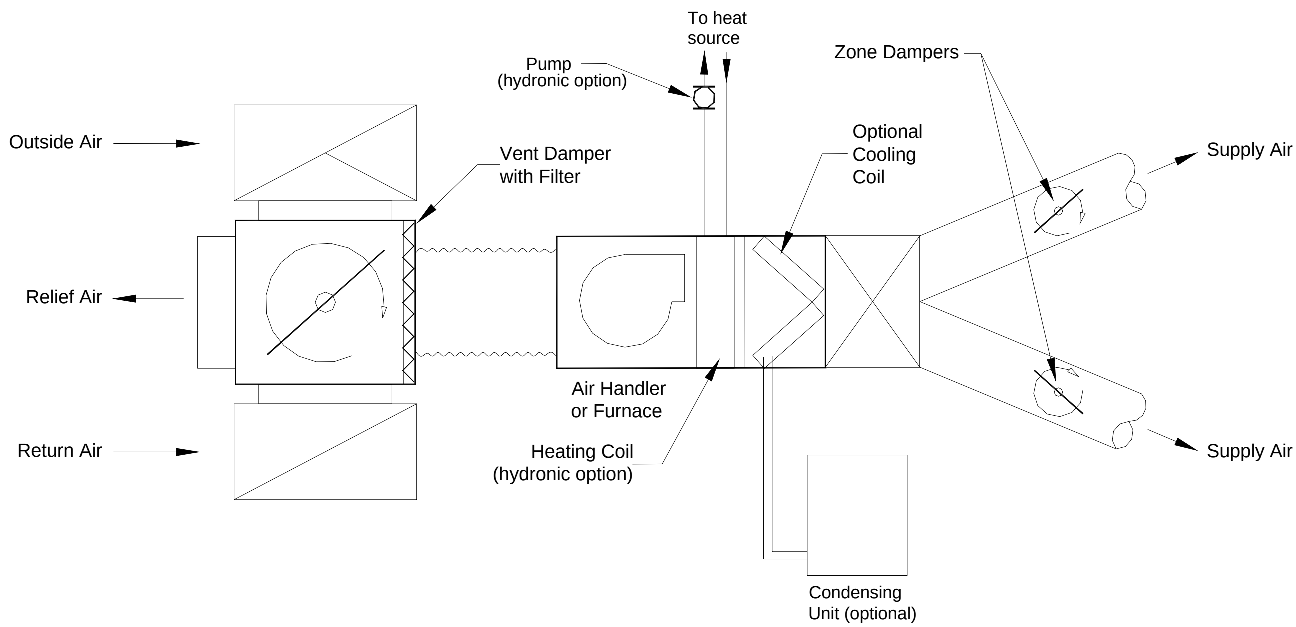
NB2 control development was a coordinated effort between Davis Energy Group (DEG) and Residential Control Systems Inc. (RCS). The first version of the functional specification was developed by DEG and delivered to RCS in December of 2003. The functional specification was based on integrating advanced NightBreeze functionality with the existing SmartVent foundation resulting in a control compatible with Amana variable speed gas furnaces, heat pumps, and hydronic heating systems. In addition two-zone functionality was added. Figure 6 shows the components controlled by the newly developed ZCV2NB control board and Figure 7 depicts the functionality. Controller inputs include three temperature sensors:

- Outdoor air temperature is measured by a remote thermistor and is used for ventilation calculations and damper operation
- Leaving (supply) air temperature is measured by a thermistor located in the supply plenum and is used for verifying system and damper operation
- Indoor air temperature is measured at each wall display unit (WDU) by a solid state sensor.

The control board has six outputs to operate the system in space conditioning or ventilation modes. The outputs include:

- the vent damper to either recirculate house air or provide outside air
- independently controlled zone dampers (one or two)
- the heating output controls either the pump for hydronic air handlers, two stages of heating operation for gas furnaces, or three stages for heat pumps
- the cooling output provides for two stages of compressor operation
- air handler fan speed in ventilation mode is controlled by a pulse width modulated (PWM) output signal

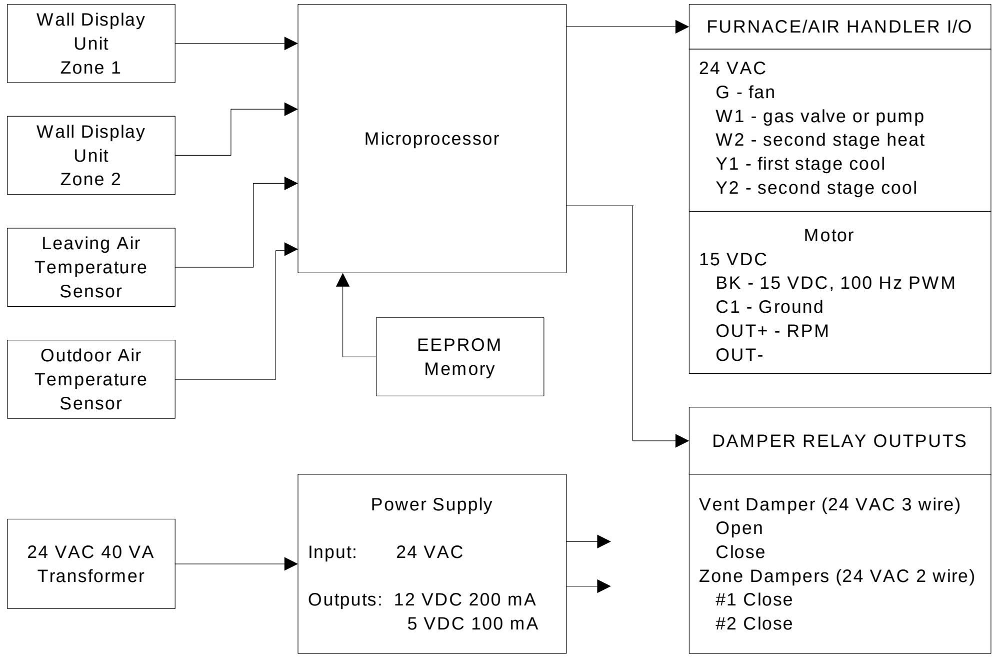
Figure 6: Controlled Components



The functional specification defines physical and operational criteria for the NB2 control Primary control components include a wall display unit for each zone that communicates digitally with a central control unit (CCU), and an outdoor temperature sensor. Both the WDU and CCU have individual microprocessors that are programmed in ‘C’ to perform their specific functions. The WDU controls screen graphics and manages inputs and outputs to the CCU. The CCU program manages all control decisions.

Components controlled by the CCU include a gas furnace, heat pump, or hot water air handler, a ventilation damper, supply air dampers for each zone, and an (optional) air conditioner. The damper shown is representative of a ZTECH SmartVent Model 2030DD. The fan for both the furnace and air handler options is driven by a 1 hp General Electric ICM2 variable speed ECM motor. The layout of the final CCU is shown in Appendix A.

Figure 7: Block Diagram of Control System



Certain characteristics are required of furnaces used with this control. First, the furnace must have an ECM motor factory programmed in "Autoswitch" mode. This mode enables the motor to be controlled either by standard HVAC controls or directly by the NightBreeze control. Most furnace fan motors are factory programmed in "Tstat Only" mode, preventing the NightBreeze from selecting the fan speed during night ventilation operation without having the motor program modified. The second requirement is that furnaces with heating and/or cooling staging must use external control for staging (for use with two-stage thermostats)[5]. The Amana GUVA / GCVA line of condensing furnaces meet these criteria.

The primary characteristics that distinguish the current control from conventional HVAC controls include:

- The ability to vary heating and cooling airflow as a function of the number of zones calling. Furnaces, and air handlers used with air conditioners, are limited to two discreet airflows. Hydronic air handler airflow can be continuously varied to exactly match heating mode zone requirements.
- The ability to continuously vary airflow for ventilation cooling and fresh air ventilation applications. For furnaces this is accomplished by controlling the ECM motor directly, facilitated by a wiring harness installed between the furnace controls and the ECM motor controller.

[5] Some furnaces utilize only one heating or cooling signal and provide internal staging by limiting low stage run time. This is true of some Carrier products.

The RCS TS36 wall display unit was selected as the development platform for the zone thermostats. The WDU, shown in Figure 8, includes an LCD display, four push-buttons mounted below the display, and two push-buttons to the right of the display. Descriptive labels for the push-buttons (e.g. "help", "fan", "set", and "mode") are displayed on the LCD screen next to each button. The function of the four push buttons varies with where the user is in the WDU hierarchy. The screen display, control logic, and communications are managed by an Atmel 8-bit microcontroller, with 512 kbytes of RAM and 64 kbytes of flash memory.

Unlike conventional thermostats, the WDU does not provide direct switching. Instead it communicates with the CCU located at the air handler, which contains relays for controlling the standard HVAC components (furnace gas valve, reversing valve, hydronic pump, fan, dampers, and condensing unit). The CCU uses a Texas Instruments M430F437 microprocessor with 32 kbtyes of flash memory and 1024 kbytes of SRAM. An outdoor temperature sensor connects to the control unit, which can also accept optional inputs from a second thermostat and provide optional outputs for zone dampers.

Figure 8: Prototype User Interface Display (Cooling Mode)

The wall display unit programming incorporates bitmap images of display screens for each operating and user input mode. Operating modes include *cooling*, *heating*, and *off*. Sub-menus are also provided for heating and cooling temperature overrides, vacation mode, and optional pre-cooling. Cooling setpoints include the desired minimum temperature for ventilation cooling. Figure 8 displays the *Cooling Mode* screen with indoor and outdoor temperatures shown. Lights on the left side display the status of the fan, A/C, heater, and any service problems.

Each zone has its own WDU for local control. All zones must be in the same mode operating mode (heating or cooling) or in "off" mode. If the user changes the mode of one zone the other zone mode will also be changed unless that zone is in the "off" mode. This prevents "fighting" between zones that may be concurrently set to heating and cooling.

Inputs consist of five categories:

1. Long-term settings - inputs used for routine system operation.
2. Short-term settings – inputs which override automatic operation for a short period.
3. Menu selections – clock, filter, pre-cooling, and diagnostics.
4. Advanced settings – inputs used for basic system set-up and accessible to the user
5. Technician settings - inputs used by the technician for system configuration, inaccessible to the user.

<u>Long-term User Settings</u>

- Ventilation cooling low temperature preference
- Air conditioner setpoint temperature (or ventilation cooling high temperature preference)
- Optional detailing heating thermostat schedule settings (4 per day, 7 days)
- Optional detailing cooling thermostat schedule settings (4 per day, 7 days)

<u>Short-term User Settings</u>

- Short-term heating set point and duration
- Short-term cooling set point and duration
- Manual fan and damper operation for recirculation or outside air ventilation (airflow set in *Advanced Settings*, default 1 hour operating time)

<u>User Menu Selections</u>

- Clock settings (date and time)
- Filter change reset
- Diagnostic screen (time since last filter change & last service, outdoor and LAT sensor status, vent damper operation)
- Pre-cooling settings
- Advanced settings

<u>Pre-cooling Settings</u>

Pre-cooling settings are accessed from the *Menu* screen and apply to all zones. Pre-cooling allows for reduced indoor temperature setpoints for user-defined period prior to the utility on-peak period. The following table describes the inputs.

Menu Item	Description	Default	Range
Pre-Cooling	Run A/C pre-cooling routine?	No	Yes, No
Start Hour	Hour of day pre-cooling starts	6 am	4 am to 10 am
Stop Hour	Hour of day pre-cooling stops	12 pm	8 am to 12 pm

Advanced Settings

Advanced settings are accessed from the *Menu* screen and apply to all zones. Key advanced settings sub-menus include the heating and cooling thermostat scheduling capability allowing for a “simple” or “detailed” programming capability.

Menu Item	Description	Default	Range
Screen Time-out	Idle seconds before screen reverts to home screen	30	0 to 90 by 10s
Back Light Time-out	Idle seconds before back light turns off	30	0 to 90 by 10s
Heating Schedule	Heating schedule type	Simple	Simple, Detailed
Cooling Schedule	Cooling schedule type	Simple	Simple, Detailed
Synchronize Zones	Synchronize zone schedules	Yes	Yes, No
Man Fan Time	Length of time fan will run when the *Fan* button is pressed, hours	1	0 to 4

Technician Settings

Technician settings are accessed from the *Advanced Settings* screen. The number and type of inputs required vary by system type (furnace or air handler), the number of heating and cooling stages, and the number of zones. To allow a single control to be used for both one and two-zone systems, and systems using single and two-stage furnaces, multiple inputs are required for specification of the proper system type. The CCU determines the number of zones by sensing the number of WDUs connected. All settings apply to the system as a whole, except for the “Tin Offset” input, which only aplies to the zone it is being set from.

Menu Item	Criteria/Description	Default	Setting Range
System Type	Type of heating system	Furnace	Furnace, AH
Max CFM	Maximum ECM fan speed	2200	0 to 3000 by 100s
Furnace Stages	System = Furnace	1	1,2
AC Installed	Air conditioner operating mode	Yes	Yes, No
AC Stages	AC Installed = Yes	1	1,2
AC First Stage CFM	System Type = AH, AC Installed = Yes, and AC Stages = 2	800	100 to Max CFM by 100s
AC Second Stage CFM	System Type = AH, AC Installed = Yes, and AC Stages = 2	1600	100 to Max CFM by 100s
AC Fan CFM	System Type = AH, AC Installed = Yes, and AC Stages = 1	1600	100 to Max CFM by 100s
AC on Delay	Time delay between condensing unit cycles, minutes. AC Installed = Yes	5	0 to 9

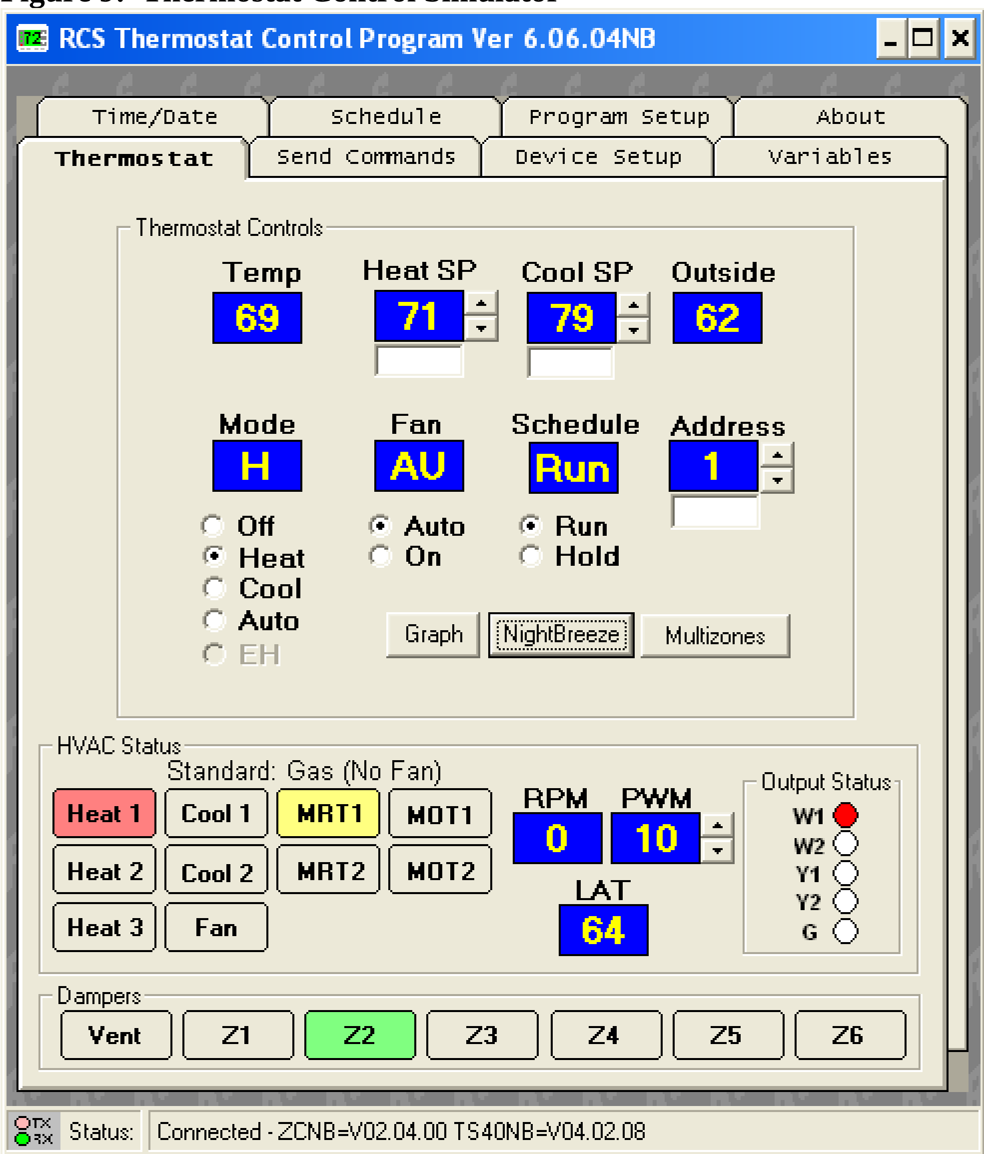
Menu Item	Criteria/Description	Default	Setting Range
Vent Delta Temp	Indoor-outdoor temperature difference at which ventilation cooling will be initiated, °F.	5	0 to 9
Vent Fan CFM	Maximum airflow for ventilation cooling, CFM	2000	100 to Max CFM by 100s
Man Fan CFM	Maximum airflow for manual fan operation, CFM.	1500	100 to Max CFM by 100s
Heat First Stage CFM	System = Furnace and Furnace Stages = 2	600[6]	100 to Max CFM by 100s
Heat Second Stage CFM	System = Furnace and Furnace Stages = 2	1200[5]	100 to Max CFM by 100s
Heat Fan CFM	System = Furnace and Furnace Stages = 1 or System = AH	1200[5]	100 to Max CFM by 100s
Ventilation Rate	Average hourly airflow rate for heating mode fresh air ventilation, CFM.	50	0 to 95 by 5s
Heating Pickup	Pickup time after setback, minutes.	30	0 to 60 by 5s
Inter Stage Temp	Differential at which to switch stages, if Furnace Stages = 2 or AC Stages = 2	3	1 to 5
Max First Stage Run Time	Maximum first stage run time, minutes, if Furnace Stages = 2 or AC Stages = 2	10	0 to 20
Min First Stage Run Time	Minimum first stage run time, minutes, if Furnace Stages = 2 or AC Stages = 2	5	0 to 20
Comfort Adjust	Preferred comfort range, °F.	0	-5 to +5
Pre-Cool Offset	Delta T between vent target temperature and pre-cooling setpoint	3	0 to 5
Tout Offset	Outdoor temperature sensor calibration, °F.	0	-9 to +9
Tin Offset	Indoor temperature sensor calibration, °F.	0	-9 to +9
Minimum Fresh Air Temp	Minimum LAT allowed during fresh air ventilation, °F.	50	35 to 70 by 5s
Filter Interval	Time between filter replacements, hours.	500	0 to 1000 by 100s
Service Interval	Time between service calls, months.	12	0 to 36
Last Service Date	Date of last HVAC service	00/00/00	Date

[6] This values are used to calculate the fresh air ventilation rate during cooling, not to set the heating fan speed.

4.3. NB2 Laboratory and Field Test Results

The prototype NB2 control was tested in a variety of methods. After development of individual sections of code, RCS would perform initial testing and debugging on the code using the test setup in the RCS lab (as shown in Figure 4). As certain milestone sections of code were completed and verified by RCS, the code would be sent to DEG for further testing. DEG would test the software using a PC-based thermostat control program simulator developed by RCS. The simulator included a rheostat for setting outdoor temperature and LAT. Figure 9 shows a screen capture of the thermostat simulator. The bottom of the Figure shows the outputs based on the current conditions. In this example, the control is operating in first stage heating for Zone 2 and is still under control of stage 1 minimum run time.

Figure 9: Thermostat Control Simulator



The simulator allowed for interrogation of the following parameters:

- system inputs (temperatures, setpoints, heating/cooling schedules, WDU setup characteristics, etc.),
- outputs (operating mode, zone and vent damper status, heating/cooling control and staging status, fan speed, diagnostics, etc.), and
- intermediate variables (e.g. run and off timer status)

In the course of preliminary screening, DEG completed a detailed list of observed problems/anomalies that was then sent to RCS. A majority of the issues involved fairly simple programming changes for RCS to implement. Some issues required more involved discussions of control capabilities and limitation before a resolution was achieved. Once all of these identified issues were resolved, DEG completed a systematic verification of controller output characteristics in each operating mode: heating, cooling, ventilation (both night and fresh air modes), vacation mode, and air conditioner pre-cooling modes.

An Amana variable speed gas furnace, two stage condensing unit, and NightBreeze damper and controls were installed in the field test house in October 2004. The system was initially installed with basic SmartVent software with NB2 hardware. RCS would upgrade the control firmware as significant control changes were implemented. Most of the 2005 summer testing utilized controls that were close to the final NB2 firmware[7]. Finally in September 2005, the beta NB2 controls with variable speed capability were installed. Figures 10-13 plot field performance data results.

Figure 10 plots hourly interval data from the test site during the week of August 19th through 25th. Weather conditions were fairly typical during the week with high temperatures from the mid 90's to the low 100's and lows around 60°F. Indoor temperatures and supply air temperatures are also plotted, as are indoor temperatures from another DEG residential monitoring site ("control") in Sacramento. Air handler run fraction is plotted on the right-hand Y-axis. Air handler operation is seen mid-day coincident with air conditioning operation. In addition NightBreeze operation at night is shown with ventilation operation typically starting around 10 PM to midnight and ending around 8 AM. During NightBreeze operation the supply air temperature is approximately two degrees warmer than outdoor temperature due to motor heating of the supply air. NightBreeze operation results in indoor temperature reductions of 5 to 8°F, while the control house (with windows closed) shows indoor temperature reductions of 1 to 3°F.

Figure 11 plots average hourly characteristics during the July 29th through August 30th period with the NB2 control without variable speed capability. This period included hotter than normal weather conditions. The NightBreeze operated consistently through the midnight to 8 AM period and achieved average indoor temperature reductions of about 5°F.

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[7] The one significant difference was the lack of variable speed airflow capability.

Figure 10: NightBreeze Field Test Site Data
(August 19 - 25, 2005)

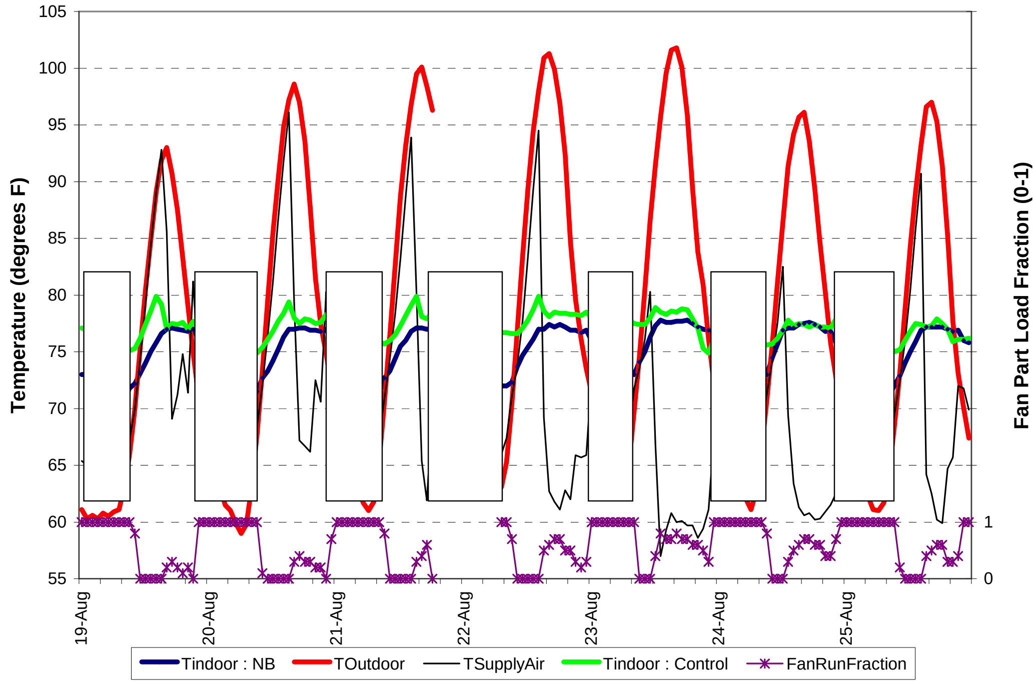


Figure 11: NightBreeze Field Test Data
Hourly Average Conditions 7/29/05 - 8/30/05

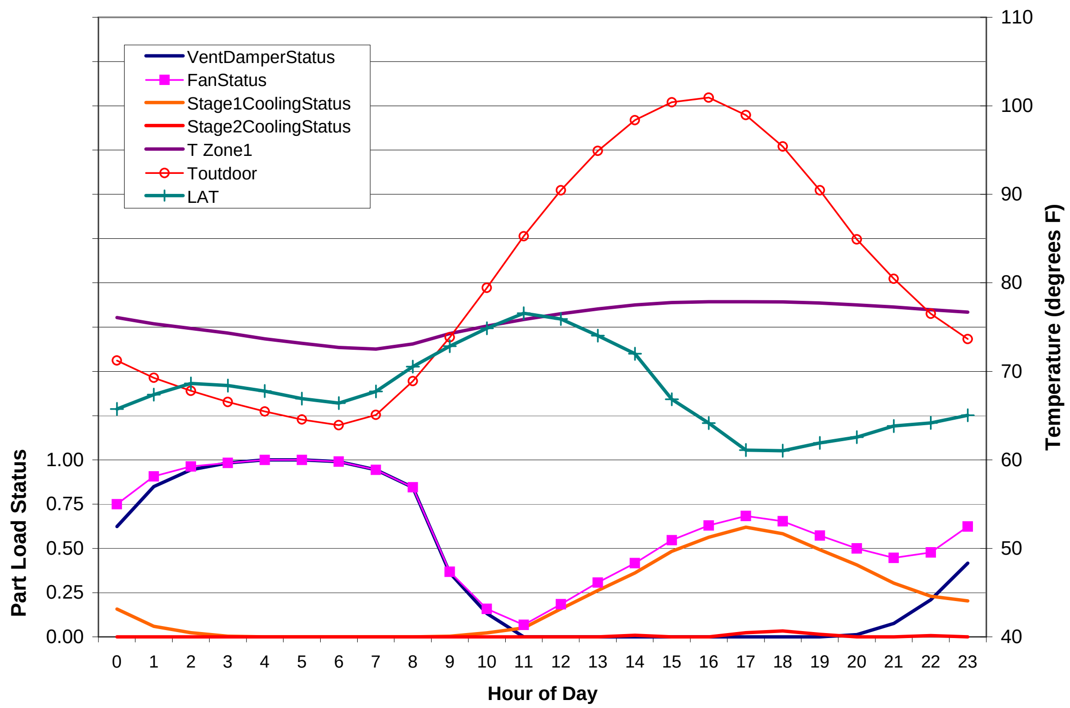


Figure 12 plots similar data to that shown in Figure 11 for the NB2 control with variable speed capability. Data included are from September 17th through October 10th and represents considerably cooler weather conditions. NightBreeze operation largely occurred from 8 PM to midnight during this milder weather[8].

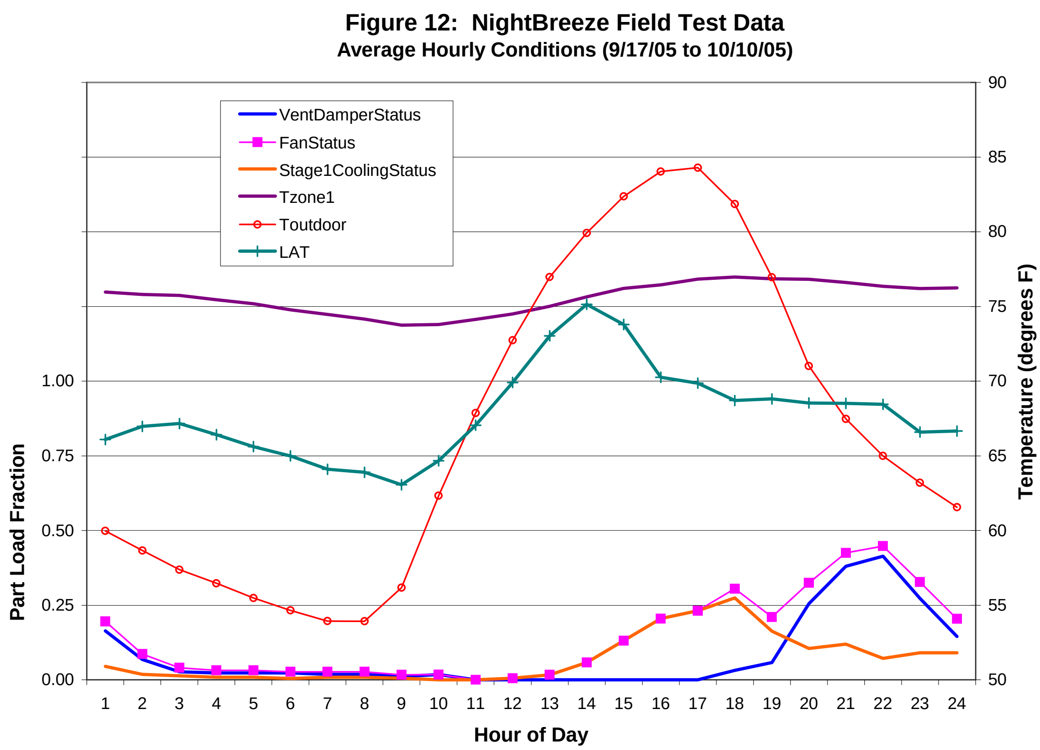


Figure 13 plots high resolution 5-second interval data to demonstrate the NB2 performance under situations with multiple zone calls. The data clearly shows the NB2 control correctly handling alternating zoning calls for cooling.

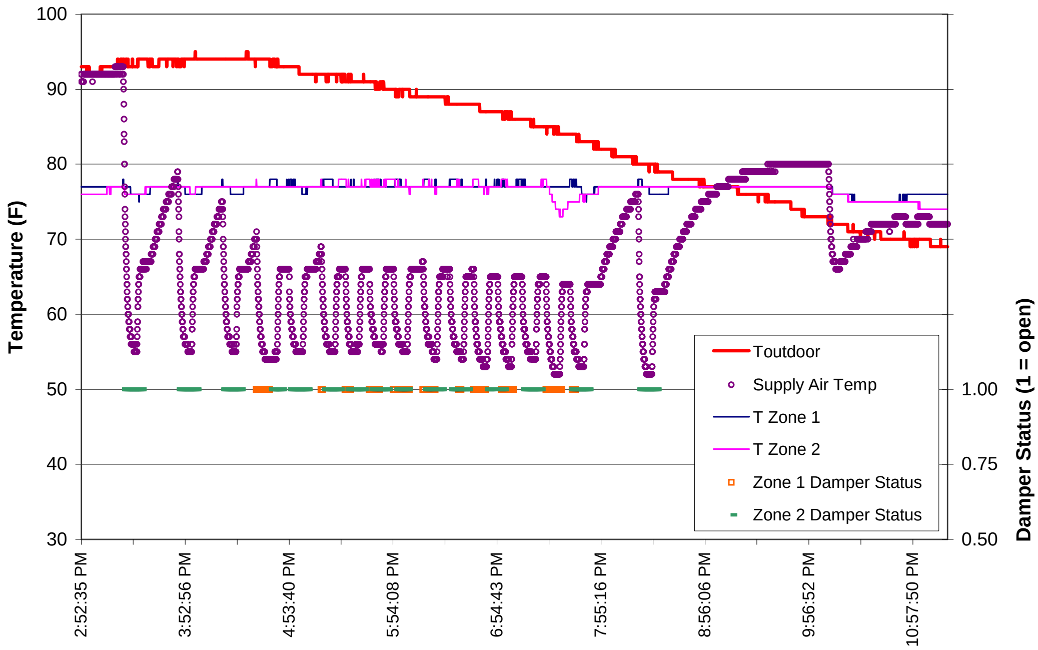
Occupant response was useful in identifying some control issues that needed to be addressed. One issue related to frequent zone damper cycling during night ventilation cooling operation. As the zone thermostat would achieve the target temperature, the zone damper would close. Under certain conditions when the ambient conditions and attic were still warm, the zone temperature would then rise causing the zone damper to open. This could happen fairly frequently (on the order of 5 to 10 minutes) under certain conditions, resulting in occupant perceived changes in supply airflow[9]. To remedy this, two fixes were implemented. First, minimum zone damper "open" and "closed" intervals were added to reduce the damper cycling frequency. Second, a supply airflow reduction

[8] A small calculation error in the NightBreeze logic resulted in higher venting target setpoints, shortening the NightBreeze ventilation cycle.

[9] The NightBreeze system selects a ventilation rate nightly and operates at that rate regardless of whether one or two zones are calling for ventilation cooling.

strategy was implemented to reduce fan speed as the zone temperatures approach the vent target temperature. This results in a more gradual transition towards satisfying the thermostat.

Figure 13: August 14, 2005 Field Test Data
(Zoning Operation)



5. MARKET TRANSFORMATION ACTIVITIES

Market transformation is an essential step in bringing a new product to the marketplace. Although NightBreeze has had fairly high visibility in the R&D community through the Alternatives to Compressor Cooling projects, Zero Energy Homes, and Building America, it has not yet achieved significant attention from the production builder community. To help advance the technology, market transformation efforts within this project focused on four key areas:

- Demonstration projects
- Pursue utility incentives
- Coordination with potential NightBreeze manufacturers
- Broad marketing efforts

5.1. Demonstration Projects

A NightBreeze hydronic unit was installed in a ConSol Building America project in Stockton, California. The 3,553 ft^2 two-story house was completed in 2004. The house incorporates cooling energy efficiency measures including spectrally selective window glazing, attic radiant barrier, buried ducts (~R-13 duct insulation), largely fluorescent lighting, and a 12 SEER 3.5 ton cooling system. The combination of energy-frugal homeowners (typical cooling setpoints are ~80°F) and the favorable Stockton-area climate makes it an ideal NightBreeze application. ConSol has been monitoring temperatures and equipment current draw using HOBO dataloggers since May 2004. Results from the summer months of June through September 2004 and June through July 2005 show a total of only 221 kWh of condensing unit energy consumption and 1069 kWh of air handler energy consumption[10]. Reviewing a sample of the data suggests that on typical summer days, the NightBreeze system is able to reduce indoor temperatures from about 78.5°F at the start of the cooling cycle to 72°F when the system turns off in the morning. On the hottest days (>95°F), the system reduces the indoor temperature from an average of 81°F to 76°F in the early morning. These impressive results demonstrate the value of the NightBreeze system and its ability to shift energy consumption from on-peak to off-peak periods.

Southern California Edison purchased a total of eight NightBreeze hydronic units for Habitat for Humanity projects in Southern California. Six of the eight units were installed in a Habitat project in Long Beach and the remaining two units were installed in a project in Westminster. SCE contracted with Davis Energy Group to monitor the two Westminster units as well as two adjacent control houses that did not have NightBreeze units[11]. The goal of the study was to document the comfort improvement and energy impact of operating the NightBreeze system. The units have been installed since early 2005. As the time of completion of this report, Davis Energy Group was in the process of finalizing the monitoring report for Edison. The primary conclusion of the Edison project report was that once early problems were corrects (system installation problems, incorrect ECM motor programming, and homeowner reluctance to rely on "automatic" NightBreeze operation), the system operated as intended. The very mild climate in Westminster during the 2005 summer (only six days exceeded 90°F outdoor temperature) precluded demonstrating definitive NightBreeze performance advantages as seen in the ConSol Building America project.

5.2. Utility Incentives

In 2005, the California Public Utilities Commission adopted a policy calling for the investor owned utilities (IOU's) to meet at least half of their growth in electrical demand through energy efficiency. Davis Energy Group worked with the IOU's (particularly PG&E) to include NightBreeze in their new construction energy efficiency programs. When PG&E filed its proposed 2006-2008 energy efficiency programs with the CPUC in June 2005, the filing included night ventilation cooling (NightBreeze and SmartVent) as one of only seven technologies it intends to promote.

[10] The reported energy use is based on assumed nominal voltage and HOBO-recorded current draw and therefore does not include the effect of power factor. The reported quantities are therefore high, however they are indicative of the relative consumption of the condensing unit and air handler.
[11] All four Westminster units do not have air conditioner.

5.3. Manufacturer Coordination

Currently, NightBreeze Hydronic pre-production units are being assembled at Davis Energy Group's shop facilities. The air handler cabinet is being built to DEG's specifications by El Dorado Precision Company located in Shingle Springs, CA. Arrangements were completed with Beutler Corporation to provide the diversion damper and with RCS to supply the indoor and outdoor temperature sensors, wall display unit and controller.

Discussions were initiated with WaterFurnace International regarding volume production of the fan coil for NightBreeze Hydronic. WaterFurnace International is an established manufacturer of quality HVAC equipment, and it is hoped that they can provide fan coils at a reduced price once volume increases.

A meeting was held with Lennox International at their headquarters in Dallas, Texas, to discuss use of Lennox gas furnaces with the gas furnace version of NightBreeze. Although these discussions were inconclusive, we will continue the dialogue with Lennox.

Goodman Manufacturing[12] of Houston, Texas has been providing technical input and equipment for the development of NightBreeze – Gas Furnace. A meeting was held with Goodman at their headquarters to discuss the use of their equipment as part of NightBreeze – Gas Furnace. Goodman expressed continued interest in the technology and discussions are ongoing as of this writing.

5.3.1. Motor Programming Compatability

There are three requirements that variable speed furnaces (with GE ICM2 motors) need to meet to be compatible with NightBreeze:

1. The motor must be programmed with Flag 9 = AUTOSWITCH which allows the ECM motor to be controlled by the thermostat (i.e. NightBreeze controller) when operating in ventilation mode. During heating and cooling operation, the air handler and existing controls are used to select and maintain airflow levels.

2. The programmed maximum air handler airflow (or MAX CFM) must be available to the installing HVAC contractor.

3. The manufacturer may have to approve the application to keep warranties valid.

The current status Amana's furnace requires motor reprogramming, but they appear to be willing to modify their programming or add a model that has the correct programming

Preliminary indications from Lennox indicate that their furnace motors also probably have the required programming. They initially expressed interest in cooperating with us, but haven't always responded to us in a timely manner. The local American Standard

[12] Parent company of Amana

distributor informed Davis Energy Group that their motors are programmed correctly, but we have had no other contact with them.

5.4. Advanced Energy Products

In 2004, Davis Energy Group formed a new corporation specifically for the purpose of commercializing low energy cooling and heating products. This company, Advanced Energy Products Corporation (AEP), is currently marketing pre-production units of NightBreeze Hydronic. Resources and capital are needed to enable AEP to properly market and commercialize NightBreeze and other technologies. Consequently financial advisors were retained to assist with capitalizing the company. Growth Capital Group of Sacramento, (www.growthcapitalgroup.com) has been fulfilling this function for AEP.

The first step in the capitalization process was development of a business plan for AEP. Starting in the fourth quarter of 2004, significant outreach efforts were undertaken with the venture capital community. In general, the feedback from those in the venture community that are interested in clean technologies has been encouraging, but they first want to see sales to major homebuilders. This will not be possible until the gas furnace version of NightBreeze is for sale, since production builders utilize gas furnace equipment, not hydronic fan coils. Nonetheless, AEP is pursuing commitments, letters of interest, and letters of intent to make visible progress in this arena and demonstrate it to the venture community. A preliminary commitment has been received for approximately eight gas furnace NightBreeze units from a builder developing a 92-unit subdivision in Woodland, California. If the initial eight installations proceed smoothly and homeowner reaction is favorable, it is likely that the builder will include NightBreeze units in the majority of the remaining subdivision. In addition, Centex Homes has strong interest in using the gas furnace NightBreeze in 30 homes in a new subdivision planned in the East Bay. At the same time, efforts are underway to sell NightBreeze Hydronic to custom homebuilders.

Advanced Energy Products is taking a dual approach to marketing NightBreeze for the future. It is working with Beutler Corporation toward having that company offer NightBreeze, particularly the gas furnace version, to its builder clients. Beutler has agreed to this in principle, and the details are under discussion. Arrangements will be finalized in 2006 when the gas furnace version is complete and available in volume. In addition, AEP is retaining a manufacturers representation firm to market and sell both hydronic and gas furnace versions of NightBreeze in California and Nevada. Action Sales of Sacramento, CA specializes in introducing innovative products to the homebuilding industry. They took the Vanguard Manibloc residential plumbing system from entry to nearly 70% market share in Northern California in a two year period. Action Sales is quite selective about taking on new product lines, and agreed to add NightBreeze in November, 2005. AEP is optimistic that this arrangement will begin to yield significant sales results starting in approximately a year.

5.5. NightBreeze Hydronic Safety Testing

One task of the project involved obtaining either UL or ETL approval for the hydronic version of NightBreeze system. The lack of safety approvals from one of these two agencies can be a significant implementation barrier for the technology from local building jurisdictions. DEG submitted a NightBreeze system to ETL for their evaluation. Additional materials provided to ETL included owners and installation manuals, a wiring diagram, photos, product specifications, current product labeling, and general product information. During the course of ETL's review, they requested minor modifications to electrical wiring within the air handler cabinet. DEG completed the modifications and ETL delivered a Listing Report on September 7, 2004. The NightBreeze hydronic unit is listed under the following standard:

ANSI/UL 1995 Safety Standards for Heating and Cooling Equipment, Second Edition; CAN/CSA C22.2 No. 236-95; Reprint with Revisions Through and Including 8/31/1999.

6. CONCLUSIONS

In this project Davis Energy Group and its subcontractors have designed, developed, and tested enhanced versions of the NightBreeze ventilation cooling and fresh air ventilation system. At the end of this project the Enhanced SmartVent controller is ready for immediate large-scale implementation and the NB2 hardware and firmware (compatible with Amana variable speed gas furnaces) is operational and ready for limited introduction in demonstration projects.

Key project successes include:

Integration of the NightBreeze lower limit ventilation target temperature logic into the SmartVent control. The resulting Enhanced SmartVent control offers improved ventilation cooling efficiency and comfort. The ESV represents a product with immediate potential to impact the production home market.

Development of a single controller hardware solution (NB2) for one- and two-zone NightBreeze systems compatible with ECM-motor equipped gas furnaces, heat pumps, and hydronic air handlers. Working with RCS, we have integrated advanced night ventilation control logic that is compatible with a full range of HVAC systems and can control two zones. These features are fully integrated with RCS' control product line and will therefore evolve as hardware solutions change in the coming years.

Lab and field testing of both Enhanced SmartVent and NB2 controllers. Lab and field test results for both the ESV and NB2 control indicate operation consistent with the design intent. Further monitoring of the NB2 control is recommended during initial demonstration projects to further verify system operation under a wider range of operating scenarios.

ETL safety testing and certification. We submitted a unit to ETL for testing and certification. ETL tested the unit in accordance with "ANSI/UL 1995 Safety Standards for Heating and Cooling Equipment, Second Edition; CAN/CSA C22.2 No. 236-95" and prepared a listing report showing compliance with the standard.

Marketing & manufacturing. Advanced Energy Products continues to maintain a small inventory of NightBreeze hydronic units for demonstration projects. The current situation allows for small-volume production of units. DEG has worked with WaterFurnace International to produce a sample unit with the potential of becoming a larger volume manufacturer of NightBreeze air handlers. DEG has had continuing discussions with project partner Amana regarding technical and marketing issues related to NightBreeze. We are confident that we can develop good working relationships with manufacturers to co-market and distribute NB2 technology.

Utility incentives. PG&E included night ventilation cooling as one of seven technologies to promote and incent in its proposed 2006-2008 New Residential Construction Program.

7. NEXT STEPS

In summary, Davis Energy Group is working diligently to commercialize NightBreeze by:

- Strengthening existing supplier relationships and developing new supplier relationships with larger, well known HVAC companies
- Marketing NightBreeze Hydronic directly to builders and contractors
- Developing distribution channels to increase sales volume of all versions of NightBreeze
- Working with utilities to put incentive programs in place
- Taking advantage of utility and government programs to demonstrate and publicize NightBreeze technology
- Capitalizing a new company who's first objective will be the commercialization of NightBreeze

We are committed to these efforts and confident that they will yield the desired results, providing enhanced comfort and energy savings throughout California and beyond.

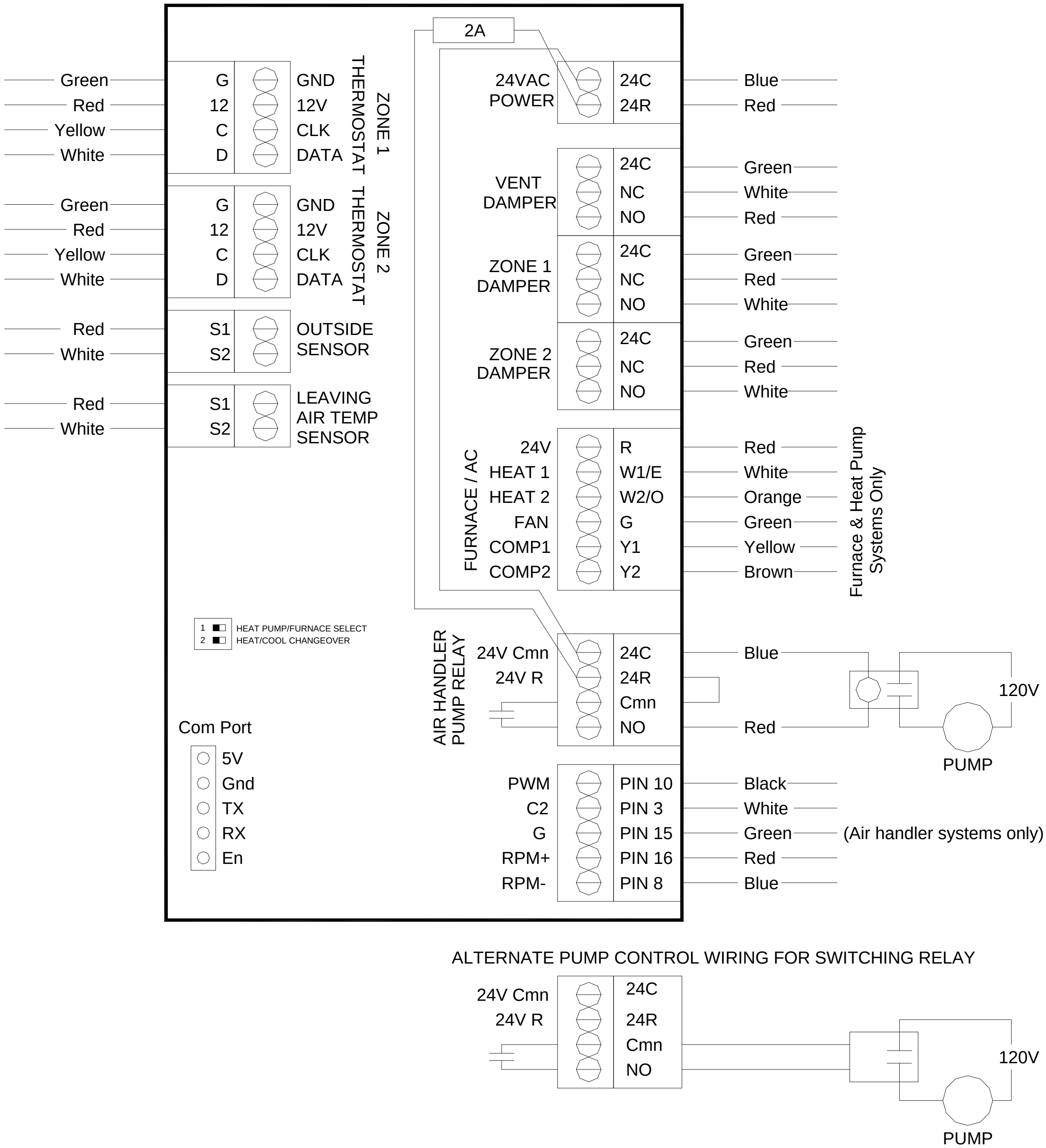
8. REFERENCES

1. Brown, R.E., Koomey, J.G., 2003. Electricity Use in California: Past Trends and Present Usage Patterns. Energy Policy 31 (2003) 849-864.

2. KEMA-XENERGY, 2004. California Statewide Residential Appliance Saturation Survey Final Report. California Energy Commission publication # 400-04-009.

Appendix A:

NB2 Control Board Layout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Green
Red
Yellow
White
G
12
C
D
GND
12V
CLK
DATA
ZONE 1 THERMOSTAT
Green
Red
Yellow
White
G
12
C
D
GND
12V
CLK
DATA
ZONE 2 THERMOSTAT
Red
White
S1
S2
OUTSIDE SENSOR
Red
White
S1
S2
LEAVING AIR TEMP SENSOR
1 HEAT PUMP/FURNACE SELECT
2 HEAT/COOL CHANGEOVER
Com Port
5V
Gnd
TX
RX
En
24VAC POWER
24C
24R
Blue
Red
VENT DAMPER
24C
NC
NO
Green
White
Red
ZONE 1 DAMPER
24C
NC
NO
Green
Red
White
ZONE 2 DAMPER
24C
NC
NO
Green
Red
White
FURNACE / AC
24V
HEAT 1
HEAT 2
FAN
COMP1
COMP2
R
W1/E
W2/O
G
Y1
Y2
Red
White
Orange
Green
Yellow
Brown
Furnace & Heat Pump Systems Only
AIR HANDLER PUMP RELAY
24V Cmn
24V R
24C
24R
Cmn
NO
Blue
Red
120V
PUMP
PWM
C2
G
RPM+
RPM-
PIN 10
PIN 3
PIN 15
PIN 16
PIN 8
Black
White
Green
Red
Blue
(Air handler systems only)
ALTERNATE PUMP CONTROL WIRING FOR SWITCHING RELAY
24V Cmn
24V R
24C
24R
Cmn
NO
120V
PUMP