ZETA HVAC System and Control Strategy

From:	John Straube and Kohta Ueno, Building Science Corporation	Date:	March 23, 2009
To:	ZETA Team	Re:	ZETA HVAC System and Control Strategy

Introduction

The ZETA home includes a number of features that are intended to reduce space heating and cooling energy consumption, enhance the collection of free solar heat in cold weather, and take advantage of free cooling when possible. At the same time, enhanced thermal comfort and indoor air quality are targeted.

To accomplish these ambitious goals, a number of standard products have been combined in a unique way, controlled by a customized controller, and coupled to a semi-active thermal mass store that is part of the foundation system.

The performance of most aspects of the ZETA system can be easily modeled, and the results predicted based on experience and standard computer programs. However, there are two novel aspects that require a prototype to be built and the performance measured and monitored.

The purpose of BSC's involvement in the ZETA prototype is develop a monitoring and control system, install it, analyze the results, and report back to ZETA. It is expected that several iterations will be needed before the prototype functions at its optimum, and before the final products, systems and controls are chosen for mass production.

Each of the components will be briefly reviewed below.

Heating Cooling and Ventilation System

The heating cooling and ventilation system makes use of a standard two-ton high efficiency SEER16 heat pump system (Goodman SSZ16-024A outdoor unit; Goodman MBE1200 air handler; Goodman CHPF 3642 coil) for both heating and cooling. Although the loads would only require a small 1 ton system, there are no commodity-priced high-efficiency systems with less than 2 ton capacity. In the climate of the Bay Area, the chosen unit provides a COP of about 3.75 in cooling mode, and around 4.0 in heating mode. As the goal is Net Zero Energy production, the cost of a high efficiency system is justified relative to the cost PV production.

The originally recommended ventilation design is to draw a small controlled stream of fresh outdoor air into the return side of the air handling unit when it operates, thereby delivering fresh air to all parts of the home via the ductwork and grilles. When the air handler has operated for long enough to meet the fresh air requirement (5 minutes in 30 minutes for this house), the damper in the outdoor fresh air duct is closed by an Air Cycler FR-V controller and over-ventilation is prevented. Further information and recommended installation directions for this controller are available at http://www.aircycler.com. If the air handler is not commanded to operate by the thermostat, the Air Cycler FR-V controller will operate the air handling unit and open the outdoor damper to draw in the amount of fresh air needed.

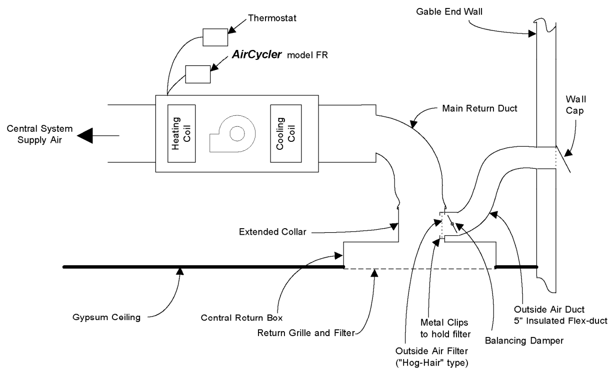

Figure 1: Central fan integrated supply system (shown with horizontal attic mounted unit as example)

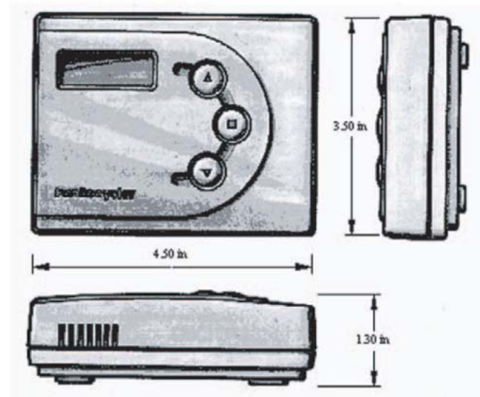

Figure 2: AirCycler FR-V Controller

An additional system to be implemented in Prototypes 1 and 2 is a heat recovery ventilator (HRV; Suncourt HE100 or HE150) with the exhaust ducts connected to the bathrooms, and the supply ducts providing outside air near the second-floor return. Note that this system still requires a fan cycling controller (AirCycler FR-V or equal). The combination of the AirCycler and HRV this will result in ventilation air distribution throughout the house, as well as thermal mixing (equalization of temperatures). When combined with Fantech Ventech VT20M/VT20A controllers, the HRV will act as point-source exhausts from the bathrooms. One limitation to this system is that it would be ideal to disable its operation during “free cooling” operation (see below), while still leaving bathroom exhaust enabled.

Ventilation and heated and cooled air is delivered via ductwork directly to the second floor and discharged to the space via diffusers. The air returns via a second floor grille and ductwork to the air handler.

The air destined for the first floor first enters the thermal basement, where its temperature may be tempered (increased or decreased slightly depending on the temperature of the supply air and of the thermal mass) and then delivered to the main floor space via floor grilles. The floor grilles are sized to limit the pressure difference between the basement and the outdoors to less than 5 Pa. The air from the first floor also returns through a duct to the air handler where it is mixed completely with the return air from the second floor.

The air handler will operate periodically (initially 5 minutes of every 30 minutes) to mix the air under the control of the Fan Cycler or ZETATherm controller. This mixing or stirring will help homogenize the temperature and air quality in the home, ensuring that even “distant” corner rooms have temperatures close to the average temperature and that point sources of indoor pollution are diluted and eventually removed. To provide fresh air, the outdoor ventilation damper will be opened for 5 minutes during fan operation per 30 minutes. If the fan has not operated in the past 30 minutes, the air handler will be energized to draw air in and mix it. The 5 min of 30 minutes are adjustable, and may be part of the ZETATherm (although IP rights may need to be negotiated with AirCycler).

Thermal Basement

The role of the thermal basement is to increase the thermal mass that is available to store night cool and daytime solar gains. Most framed homes do not have significant thermal mass, and in the climate of the Bay Area, the wide temperature swings between day and night make thermal mass an attractive energy-saving option.

The thermal basement is designed much like any full basement except that it is well insulated on the outside and under the slab, thereby ensuring the thermal mass in the concrete structure is available. It is also not full-height, to reduce unnecessary foundation costs and encourage mass-coupling air flow interactions. In the prototype homes, the basement is about 32" high, but it can be a range of heights and still provide mass storage benefits. The prototype also has the advantage that the first floor uses a concrete topping. This further increase thermal mass in the home but may not be part of the production series of homes.

Control

For the prototype home, we plan to use a standard thermostat from Honeywell (RTH6400D) complete with setback timing, and "away" settings as the input device from the occupant.

The control signals (e.g., 24VAC) that normally go directly to the HVAC system will be intercepted by the programmable monitoring and control module (the Campbell Scientific CR1000). The control module will decide what HVAC actions to take depending on the exterior air and humidity conditions, the temperature of the thermal storage, and the need to store heat or reject heat. This combination of control and input is termed the ZETATherm.

A physical switch will be set up so that a service person can disconnect the CR1000 controller and operate the system under the control of the thermostat alone.

The control sequence operates based on two setpoint temperatures (set by the occupant via the RTH6400D thermostat), a Cooling Setpoint and a Heating Setpoint. The controller will add or subtract a Delta to these setpoints, which are termed the Cooling Set point High and the Heating Set point Low. Delta may be in the range of 2 to 5° F and will initially be set remotely via the internet through the CR1000 controller, and, in the production model, by the ZETATherm itself.

The most basic control strategy is shown in the table below: this will be the starting control scenario. More advanced strategies that consider the operation of the thermal mass and fan over the last several days and adjust the control strategy accordingly will be tested over time, as we gain information about actual performance. The control strategy can be modified by uploading new programs via the Internet connection to the CR1000.

Cooling Set point High T_{cool2} $T_{cool2}= T_{cool1}$+Delta, Delta set to 2-5F.	If T_{out} -5 < T_{in} and NoRain • Open free cooling damper and operate fan on high speed Else If T_{out} >= T_{in}-5 • Energize air conditioning system and operate fan Outdoor ventilation damper operates as required (5 minutes every 30 min)
Cooling Set point T_{cool1} Set by User via Thermostat	If $T_{basement}$< T_{in} • Operate fan to circulate Else if T_{out} -5 < T_{in} and NoRain

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	• Open free cooling damper and skylight and operate fan (low speed if T_{out}<55 F) Outdoor ventilation damper operates as required (5 minutes every 30 min)
Deadband	Outdoor air is drawn in and house air mixed for 5 minutes if no fan operation has occurred in the last 30 minutes.
Heating Set point T_{heat1} Set by User via Thermostat	If $T_{basement} > T_{in}$ • Operate fan to circulate Else If $T_{out} > T_{in}$ and NoRain • Open free cooling damper and skylight and operate fan on low speed Outdoor ventilation damper operates as required (5 minutes every 30 min)
Heating Set point Low T_{heat2} $T_{heat2} = T_{heat1}$ - Delta, Delta set to 2-5F.	• Energize Heat pump and fan Outdoor ventilation damper operates as required (5 minutes every 30 min)

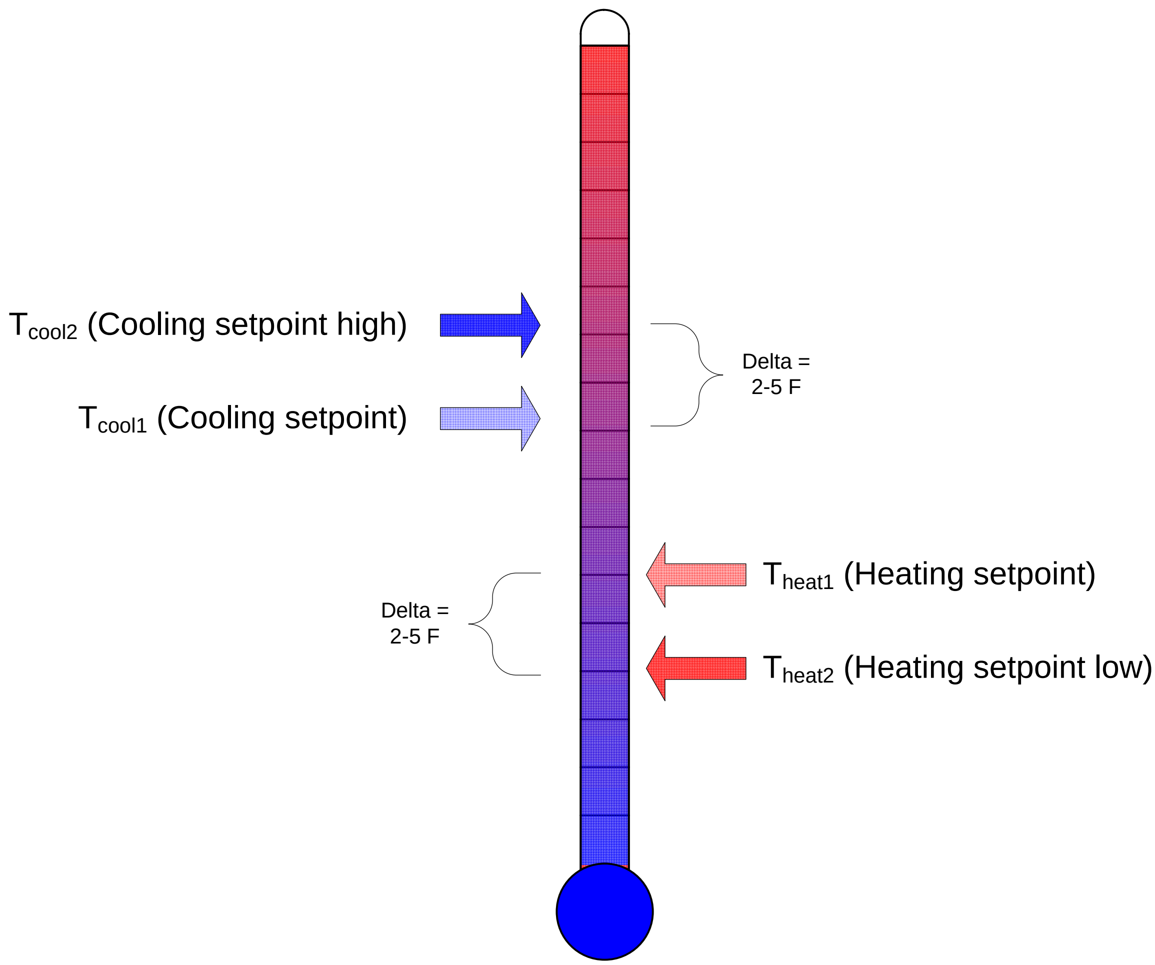

Figure 3: Schematic relationship of heating and cooling setpoints

DataLogging

The CR1000 will collect and store a range of operational and environmental variables. This data will be accessible via the internet connection. The environmental variables include indoor temperature, outdoor temperature, crawlspace slab temperature. The operational variables include fan run times, damper open times, heating and cooling run times, skylight operation, etc.

All of the data will be stored and subsequently downloaded via the internet connection.

Operational Scenarios

Some examples of scenarios are provided to aid in the understanding of the system.

Winter Operation

On a cold winter morning (e.g. 40° F), the temperatures in the house and thermal basement will likely all be within a few degrees of one another (e.g. 65° F). As the sun rises solar heat gain and internal heat will warm the home. If the heat gain is sufficient to reach the cooling set point (e.g. 76° F), the air handler will operate and begin mixing the air in the home. The heat from the sun will therefore be moved (i.e., “harvested”) to the thermal basement and all north side rooms to lower the south side room temperatures. This operation will warm the north side rooms and increase the thermal storage temperature. If the solar gain is very high, and/or the outdoor temperatures rise quickly (to say 55° F), and the interior temperature continues to rise to Cooling Set Point High (e.g. 80° F, Delta=4° F). In that case, the free cooling damper would open and the fan would drop to low speed, mixing air through the house until the temperature dropped and the air handler began circulating throughout the house again.

At the end of the day as the sun sets, the house will cool off slowly. The air in the house will be mixed 5 minutes every 30 minutes to add fresh air and redistribute air throughout the home and homogenize temperature. Hence, some of the heat from the thermal basement will be delivered to the living zone.

As the temperature falls through the Heating Set Point, the fan will operate to redistribute heat from the thermal basement to the living zone.

If the heat from the thermal basement is exhausted (e.g. equal to the indoor temp of 69° F, for instance), the temperature of the house will slowly drop all at the same temperature until the lower setpoint (e.g. 66° F in this example) is reached, and the heat pump is activated. For the last few hours of the cold night, the heat pump will operate to keep the temperature above 65° F and below 69° F.

Summer Operation

In summer mode, if the Cooling SetPoint is exceeded the air handler would operate with the skylight open and the free cooling inlet vent to ensure cool night air (e.g. at a temperature of, say, less than 76° F- 5° F = 71° F) will flow through the house. When the sun rises and the house begins to heat up the home above 76° F while outdoor temperatures rise above 71° F, air will circulate through thermal basement (cooled to around 71° F overnight) and deliver this cool air into the home. Air circulation will also remove heat from hot spots and make best use of the thermal mass in the structure of the home.

As the temperature rises further (to 80° F), and outside temperature remains above 75° F, the air conditioning system would be energized and the entire house cooled to between 80° F and 76° F.

Actions for ZETA

The HVAC subcontractor shall install the Honeywell 6400D thermostat to control the Goodman heat pump system as one normally would for a heat pump space conditioning system.

The AirCycler FR-V controller should be installed and set up to periodically cycle the air handler. In the non-HRV installations (as per the originally recommended ventilation design) the FR-V would also be connected to the motorized, spring-return ventilation damper in the small ventilation air duct. That damper was to be spec'd and sourced by Steve Spademan and we believe it was to be a Honeywell model.

The large rectangular free cooling duct and motorized damper should be installed as well. The BSC team will connect the controls. A louver will also need to be specified at the exterior termination of this duct, and a 1" filter slot (for a MERV 4-5 range filter) will be needed to pre-filter outside air (thus protecting the main MERV 13 filter). These items (as well as other updates) are shown in BSC's markup of the MEP sheet (MEP1.1.03.17.09 KU Markup.pdf).