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HVAC Equipment Design Options for Near-Zero-Energy Homes — A Stage 2 Scoping Assessment

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HVAC Equipment Design Options for Near-Zero-Energy Homes (NZEH) — A Stage 2 Scoping Assessment

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Introduction

Although the energy efficiency of heating, ventilating, and air-conditioning (HVAC) equipment has increased substantially in recent years, new approaches are needed to continue this trend. Conventional unitary equipment and system designs have matured to a point where cost-effective, dramatic efficiency improvements that meet near-zero-energy housing (NZEH) goals require a radical rethinking of opportunities to improve system performance. The large reductions in HVAC energy consumption necessary to support the NZEH goals require a systems-oriented analysis approach that characterizes each element of energy consumption, identifies alternatives, and determines the most cost-effective combination of options. In particular, HVAC equipment must be developed that addresses the range of special needs of NZEH applications in the areas of reduced HVAC and water heating energy use, humidity control, ventilation, uniform comfort, and ease of zoning. This report describes results of a scoping assessment of HVAC system options for NZEH homes.

ORNL has completed a preliminary adaptation, for consideration by The U.S. Department of Energy, Energy Efficiency and Renewable Energy Office, Building Technologies (BT) Program, of Cooper's (2001) stage and gate planning process to the HVAC and Water Heating element of BT's multi-year plan, as illustrated in Figure 1. In order to adapt to R&D the Cooper process, which is focused on product development, and to keep the technology development process consistent with an appropriate role for the federal government, the

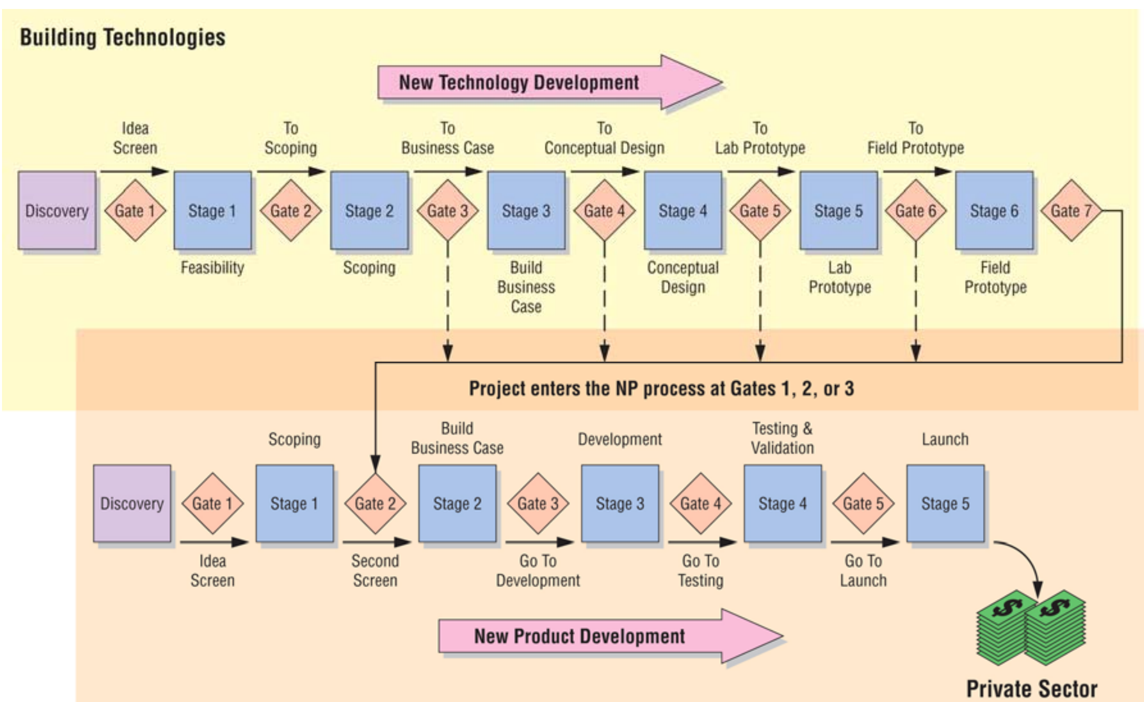

Fig. 1. HVAC and Water Heating Stage Gates for Technology and Product Development

number and content of the stages and gates needed to be modified. The potential federal role in technology development involves 6 stages and 7 gates, but depending on the nature and status of the concept, some or all of the responsibilities can flow to the private sector for product development beginning as early as Gate 3.

In the proposed new technology development stage and gate sequence, the Stage 2 “Scoping Assessment” provides the deliverable leading into the Gate 3 “Scoping Assessment Screen.” This report is an example of a Stage 2 deliverable written to document the screening of options against the Gate 3 criteria and to support DOE decision making and option prioritization. The objective of this scoping assessment was to perform a transparent evaluation of the HVAC system options for NZEH based on the applying the Gate 3 criteria uniformly to all options.

As proposed, technology options can advance through Gate 3 via one of two paths. The first path is for options that are

- already commercially available or
- represent incremental improvements that are already in field-testable hardware, or
- represent incremental improvements that could be in field-testable hardware at very modest cost to the program.

Options passing through the gate on this path may be recommended for a field-test in a Building America (BA) prototype house, for example, with the field test sponsored by Residential Integration. The criteria that must be met before this type of option advances through Gate 3 consist of one must-meet criterion and one should-meet criterion:

Must-meet —
One or more BA teams have expressed a desire for this incremental improvement to baseline commercially available equipment.

Should-meet—
Has potential for significant energy savings with the sum of utility and mortgage costs in new housing construction remaining the same, or enables other technologies in a whole-house package to do so. (The single criterion is scored 1-100, and criterion scores are averaged across all scoring participants. The best possible score is 100.)

Technology advancement options that will require significant HVAC and Water Heating program element resources to bear fruit follow the second path. The criteria that must be met before this type of option advances through Gate 3 consist of four must-meet criteria, and ten should-meet criteria:

1. Must-meet:
    a. In alignment with one of the components of strategy for achieving the HVAC and water heating objective.

b. Has potential for significant energy savings with the sum of utility and mortgage costs in new housing construction remaining the same, or enables other technologies in a whole-house package to do so.

c. Unlikely to be developed by the private sector alone.

d. Technically feasible (there is a reasonable likelihood that the product can be developed and produced).

2. Should-meet:
   (The 10 criteria are each scored 1-10, criterion scores are averaged across all scoring participants, then the criterion weights are applied to arrive at an overall project score. The best possible score is 100.):

   a. (Weight: 2.5) Equipment has the potential to achieve 50% energy savings versus baseline in a range of climates (all climates would get best score).

   b. (Weight: 1.25) Equipment can meet ZEH energy service needs (e.g., cooling/heating/dehumidification/fresh air ventilation/domestic hot water), which may be quite different in magnitude and relative proportions from those of current buildings, and come with additional expectations for uniform comfort and indoor environmental quality (IEQ).

   c. (Weight: 1.25) There do not appear to be any high costs, such as high-cost components or other factors, that would preclude the use of the equipment in new housing construction by 2015, with the sum of utility and mortgage costs remaining the same versus baseline.

   d. (Weight: 1.0) Private sector enterprises can be identified that should have an interest in the new product concept based on degree of strategic fit, competitive advantage, in-house core competencies, existing business units, market niches served, existing paths to market, entrepreneurial track record, etc.

   e. (Weight: 1.0) The program element has prospects for resources of sufficient critical mass to fund early phase research and to cost-share the mid-phases in order to attract private partners for the new product concept.

   f. (Weight: 0.75) Equipment is based on off-the-shelf components that are mass produced now, or are likely to become common and mass produced due to the support of markets other than NZEH (i.e., Building Technologies program resources are not expected to be needed in order for the components to reach this level of commercialization).

   g. (Weight: 0.75) Equipment is easily installed and maintained without necessitating substantial additional training for installers or requiring additional trades personnel.

   h. (Weight: 0.5) Equipment serves the new NZEH market but can also satisfy the conditions for participation in the broad new housing construction market for equipment.

i. (Weight: 0.5) Equipment serves the new NZEH market but can also satisfy the conditions for participation in the broad residential equipment replacement markets, including the immediacy requirement for some equipment replacements upon failure.

j. (Weight: 0.5) Equipment has the potential to achieve significant peak energy demand reduction versus baseline in a range of climates (all climates would get best score).

On either path, failing to meet all the must-meet criteria implies “no-go.” Those options passing the must-meet criteria are assigned numerical scores (maximum of 100) based on the ‘should-meet” criteria and ranked accordingly. DOE can then use the rankings and management discretion to determine which options are “go.” The meaning of “go” depends on the path. As indicated previously, on the incremental path, “go” may mean “field test of existing equipment in a Building America prototype house.” In addition, on the R&D path, the meaning of “go” depends on the technology status of the option. Some options included in the scoping assessment to determine relevance to this program and domestic NZEH markets may be more “developed” than others because research on them has already been sponsored by others, or the concept is commercially available in offshore markets. Therefore, on the R&D path, “go” may mean “detailed investigation of the business case” (stage 3), “develop a conceptual design” (stage 4), “breadboard prototype development and laboratory testing” (stage 5), “prototype development and field testing” (stage 6), or other logical next steps.

This report describes the options, the proposed criteria, and the rankings by priority based on scoring by the team of building equipment researchers at ORNL (John Tomlinson, Keith Rice, Van Baxter, Moonis Ally, and Vince Mei) and independent scoring by William Goetzler of Navigant Consulting, which is one perspective. It is DOE’s prerogative to revisit the criteria and obtain scoring from additional perspectives as part of its decision making process. If the criteria change, the ORNL team will be happy to re-score.

The ultimate desired output of Gate 3 is the set of approved projects or tasks that the program can afford to fund, including budget, a list of deliverables, and a date for the next gate. “go” options that cannot be immediately funded are on hold until funding becomes available. If the hold period persists, these options may be recycled into the next periodic scoping assessment.

Scoping Assessment Approach

This assessment work has involved several steps:

- Collaboration with Building America teams to obtain and analyze data that defines the HVAC needs of NZEH in various key climate regions.

- Collaboration with the National Renewable Energy Laboratory (NREL) to obtain the most recent Building America benchmark house descriptions and descriptions of identically sized prototype NZEH houses at the 50%+ savings level as determined by BEopt analyses at the PV (photovoltaic) take-off point.
- Definition of baseline HVAC and water heating systems and a range of advanced system options. The advanced options included nearer-term systems that may be suitable for early field testing in Building America prototype houses. Longer-term options for meeting the energy services needs of NZEHs while consuming significantly less energy were also considered.
- Using computer analyses (based on TRNSYS simulations of the houses and HVAC options), the hourly space heating, space cooling (latent and sensible), ventilation, and water heating loads that will need to be met by the HVAC equipment were determined.
- Using TRNSYS analyses the energy consumption to meet the Benchmark and NZEH loads was determined for the various options in five locations – Atlanta (mixed-humid climate zone), Houston (hot-humid), Phoenix (hot-dry), San Francisco (marine), and Chicago (cold).
- Using the proposed Gate 3 criteria, the options were priority-ranked by the ORNL equipment research team. The quantitative analysis supported scoring of the primary should-meet criterion, which is potential to achieve 50% energy savings relative to baseline. The other criteria were scored qualitatively based on the expert opinions of the scorers.

House Descriptions

Two different houses have been used in this options assessment. To define a solid baseline for comparison of equipment options, a Building America Benchmark house [Benchmark as defined in Hendron, et al. (2004) and Hendron (2005)] was selected in collaboration with NREL. In addition the latest prototype NZE house at the 50%+ savings level was obtained as determined by NREL's current BEopt analyses (Christensen 2005, Anderson, et al 2004) at the PV (photovoltaic) take-off point.

DOE 2.2 Building Description Language file descriptions of comparable 1800-ft^2 two-story benchmark and prototype NZE houses were provided by NREL in July (Christensen 2005). Two-zone TRNSYS representations were developed for each of these houses as opposed to the one-zone house modeling in DOE 2.2. Thermostat control was single-zone for simulation of central HVAC system options and two-zone (upstairs and downstairs zones for the two-story houses) for simulation of zoned system options.

Thermostat set points for the single-zone (central system) houses were 71F heating, 76F cooling, and 120F water heating as provided in the DOE 2.2 BDL files from NREL. For the two-zone houses the water heating set point was identical but a temperature setback/setup scheme as outlined in Table 1 below was followed for space conditioning equipment control.

Table 1. Zone temperature control set points (°F) used for zoned system analyses.

Zone/time of day	11pm – 7 am	7am –11 pm
Heating season		
Upstairs	68	65
Downstairs	65[a]	71
Cooling season		
Upstairs	76	80
Downstairs	80	76

[a] Downstairs zone ramps up from 65 °F to 71 °F over 2-h period (6-8 am) for electric system options to minimize use of electric resistance backup heat during warm-up period.

Using the Atlanta location as an example, the benchmark house required a 3-ton AC as compared to a 1-1/4-ton AC for the NZE house, per DOE 2.2 sizing calculations provided by NREL. The heating design loads were also reduced by about 58% for the NZE house.

Figure 2 illustrates mortgage plus utility cost results from NREL's BEopt simulation for Atlanta. The y-intercept point on the left vertical axis represents this cost parameter for the BA benchmark. The prototype NZE house for Atlanta is taken from the point on the curve at about 55% energy savings vs. the benchmark.

A key objective of identifying design concepts that can save up to 50% relative to current baseline systems is to move the point of break-even mortgage and utilities cost on Figure 2 from around 55–60% to 70–85% energy savings. This will in turn reduce the net cost premium required to meet the net zero energy goal.

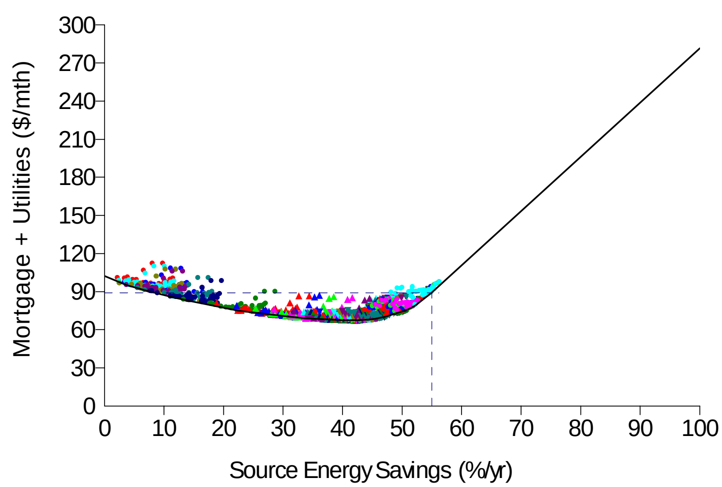

Fig. 2. Net mortgage and utilities cost vs. source energy savings for 1800-ft^2 house in Atlanta with BA benchmark at 0% energy savings point and prototype NZE house at ~55% energy savings point (i.e., take-off point).

Description of HVAC System Options

Central systems

All use central ducted forced air circulation for space heating/cooling distribution, unless otherwise indicated. Ventilation is provided using exhaust fans to meet ASHRAE Standard 62.2 minimum requirements.

Baseline (electric)

A standard split-system (separate indoor and outdoor sections), air-to-air heat pump provides space heating and cooling under control of a central thermostat that senses indoor space temperature. It also provides dehumidification when operating in space cooling mode but does not separately control space humidity. Rated system efficiencies are SEER 13 and HSPF 7.7. Water heating is provided using a standard electric storage water heater with energy factor (EF) of 0.90. All equipment performance levels are as specified in the *Guide for Evaluation of Energy Savings Potential, DOE/EERE, 01/19/2005 version*.

Baseline (gas)

A standard gas furnace with split-system (indoor coil integrated with furnace and outdoor condensing unit) electric air-conditioner provides space heating and cooling under control of a central thermostat that senses indoor space temperature. It also provides dehumidification when operating in space cooling mode but does not separately control space humidity. Rated system efficiencies are SEER 13 and 0.8 annual fuel utilization efficiency (AFUE) (non-condensing). Water heating is provided using a standard gas storage water heater with energy factor (EF) of 0.59. All equipment performance levels are as specified in the *Guide for Evaluation of Energy Savings Potential, DOE/EERE, 01/19/2005 version*.

Gas option 1

A high-efficiency, condensing gas furnace with high-efficiency, two-speed, split-system, electric air-conditioner provides space heating and cooling under control of a central thermostat that senses indoor space temperature. It also provides dehumidification when operating in space cooling mode but does not separately control space humidity. Rated system efficiencies are SEER 18.5 and 0.92 AFUE (condensing). Water heating is provided using a high-efficiency gas storage water heater similar to that used in BEopt analyses, EF~0.62.

Gas option 2

Identical to gas option 1 above except water heating is provided by a gas tankless (instantaneous) system.

Gas option 3

A gas-fired heat pump provides space heating and cooling under control of a central thermostat that senses indoor space temperature. It also provides dehumidification when operating in space cooling mode but does not separately control space humidity. Rated system efficiencies are 1.40 AFUE for heating and 0.70 AFUE for cooling. All residence water heating needs are assumed to be provided via waste heat recovery from the heat pump gas burner (or engine coolant) and condenser reject heat. (Note: As of time of this writing this option had not been incorporated into the TRNSYS simulations. Annual energy consumption has been estimated based on comparison with gas baseline and option 2 performance levels.)

Electric option 1

A high-efficiency split-system, air-to-air heat pump provides space heating and cooling under control of a central thermostat that senses indoor space temperature. It also provides dehumidification when operating in space cooling mode but does not separately control space humidity. System efficiencies are SEER 15 and HSPF 8. Water heating is provided by a premium electric storage water heater with EF=0.95 (same as that used in BEopt analyses).

Electric option 2

A two-speed (or two-capacity), high-efficiency, split-system, air-to-air heat pump provides space heating and cooling under control of a central thermostat that senses indoor space temperature. It also provides dehumidification when operating in space cooling mode but does not separately control space humidity. System efficiencies are SEER 17.9 and HSPF 8.3. The heat pump includes a desuperheater to provide water heating whenever the heat pump is operating with backup provided by a premium electric storage water heater with EF=0.95..

Electric option 3

A geothermal heat pump (GHP) with vertical bore ground heat exchanger (GHX) provides space heating and cooling under control of a central thermostat that senses indoor space temperature. It also provides dehumidification when operating in space cooling mode but does not separately control space humidity. Rated efficiencies for the water-to-air heat pump (WAHP) used for the GHP are approximately EER 18 for cooling and COP 4.0 for heating [as rated per ARI/ISO standard 13256-1 (ISO 1998a) for GHP application]. The heat pump includes a desuperheater to provide water heating whenever the heat pump is operating with backup provided by a premium electric storage water heater with EF=0.95.

Electric option 3a

Same as electric option 3 above except a two-speed WAHP is used. Rated cooling efficiencies for the WAHP used for the GHP are approximately EER 26 and 18 for low- and high-speed operation, respectively. For heating, rated COPs are approximately 4.6 and 4.0 for low- and high-speed operation, respectively. Performance rated per ARI/ISO standard 13256-1 (ISO 1998a) for GHP application. (Note: As of time of this writing this option had not been incorporated into the TRNSYS simulations. Annual energy consumption has been estimated based on simple comparison with Electric option 3 performance levels.)

Electric option 4

This is the same as electric option 3 except a horizontal loop GHX is used in lieu of vertical bore GHX. In this case the GHX is assumed to be limited to the area underneath the house foundation, i.e., no additional excavation or trenching required. We plan to investigate this source/sink option with and without use of an SWS material to enhance its heat transfer performance. The idea here is that the SWS material acts to keep soil moisture in the vicinity of the GHX. This should improve its efficiency through use of the latent heat of vaporization of the moisture and help enable the size reduction needed to limit the GHX size to fit within the area under the house. The approach will involve a parametric analysis by varying the soil thermal conductivity (k) to determine by how much "k" would have to be improved in order to achieve the same GHP heating/cooling energy consumption levels as for electric option 3 with the vertical GHX.

Electric option 5

Similar to electric option 3 with option to heat water on demand. The desuperheater of option 3 is replaced with a larger heat exchanger that can direct the full heating output of the GHP to heat water. Thus the system can provide much more of the annual residence water heating demand than a system with only desuperheater capability. It continues to use a premium electric storage water heater with EF=0.95 as backup to the primary GHP water heating.

Electric option 6

This option is the air-source version of the integrated heat pump (IHP) currently in the breadboard laboratory prototype stage at ORNL. This concept, as shown in Figure 3, uses one variable-speed (VS) modulating compressor, two VS fans, one VS pump, and a total of four heat exchangers (HXs: two air-to-refrigerant, one water-to-refrigerant, and one air-to-water) to meet all the HVAC and water heating (WH) loads.

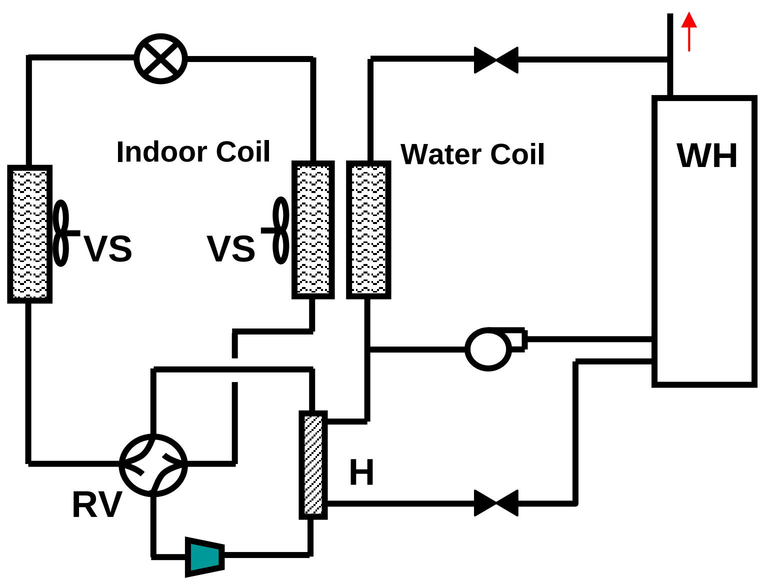

Fig. 3. Conceptual diagram of a central forced-air electric air-source integrated heat pump, electric option 6, space cooling mode operation shown.

One unique aspect is that the ventilation air is conditioned by the heat pump in both space cooling and space heating modes, and on demand if neither heating nor cooling is required. The unit also cycles on demand to dehumidify the space whether or not heating or cooling is required. The air-to-water HX uses waste hot water generated in the space cooling, dehumidification, and ventilation cooling modes to temper the ventilation air, as needed, for space neutral conditions. Compressor, indoor fan, and water pump speed modulation is used to control both indoor humidity and temperature, when needed. (Note that both water heating and ventilation air tempering can be done at the same time.)

We plan to investigate this system with and without an SWS subcooler option on the outdoor air coil. This option is intended to provide better efficiency in cooling operation during high ambient temperatures. The SWS material absorbs ambient moisture during cooler overnight and early morning hours. During peak afternoon hours, refrigerant exiting the main condenser (outdoor air coil) circulates through a coil embedded in the SWS material and is cooled by the moisture-laden material. This additional subcooling improves the system cooling capacity and energy-efficiency ratio (EER) during the peak period. The SWS bed regenerates by reabsorbing ambient moisture the next night.

Electric option 7

Similar to electric option 6 except the outdoor air coil is replaced with a refrigerant-to-water HX and pumped secondary fluid to a GHX, making a ground-coupled version of the IHP. We plan to assess this option with both a vertical bore GHX and a horizontal loop GHX with SWS enhancement.

(NOTE: As of time of this writing options 6 and 7 had not been incorporated into the TRNSYS simulations. Annual energy consumption has been estimated based on loads computed by TRNSYS simulations and measured performance for a laboratory prototype system currently under test at ORNL (Tomlinson, et al, 2005).)

Zoned Systems

All the zoned systems considered here are electric only. Unless otherwise specified in the system descriptions, ventilation is provided using exhaust fans to meet ASHRAE Standard 62.2 minimum requirements.

Baseline

Space heating and cooling is provided by either mini-split or packaged terminal heat pumps (SEER 13 and HSPF 7.7) for each house zone. Water heating is provided using a standard electric storage water heater with energy factor (EF) of 0.90. All equipment performance levels are as specified in the *Guide for Evaluation of Energy Savings Potential, DOE/EERE, 01/19/2005 version*.

Zone option 1

Space heating and cooling is provided by a ductless multi-split heat pump (SEER 13 and HSPF 7.7), a system with a single outdoor compressor-bearing unit and individual heating/cooling fan coil units for each house zone, illustrated schematically in Figure 4.

Each indoor unit is connected to the outdoor unit via refrigerant distribution piping. Water heating is provided by a premium electric storage water heater with EF=0.95.

Zone option 2

Space heating and cooling is provided by a modified version of system 1. The major innovation is that a water-heating condenser module is included for the domestic hot water tank. This module provides water heating on demand with backup provided by a premium electric storage water heater with EF=0.95. Figure 5 provides a schematic of the system concept. All modules are connected to the compressor package via refrigerant distribution piping.

(NOTE: As of time of this writing this option had not been incorporated into the TRNSYS simulations. Annual energy consumption has been estimated based on simple comparison with electric system baseline performance and assumes that water heating performance of this option would be at least equal to that of state-of-the-art standalone heat pump water heaters.)

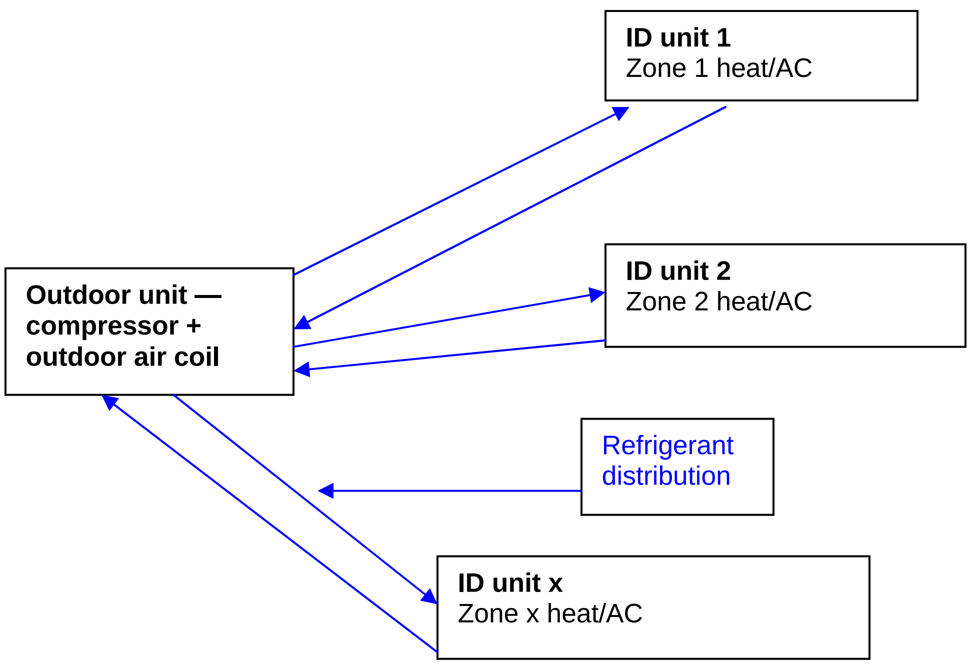

Fig. 4. Schematic of ductless multi-split heat pump system concept (zone option 1).

Zone option 3

This system uses the multi-split heat pump of zone system 1 above for space heating and cooling. It is combined with a small-capacity exhaust air heat pump water heater (or ventilation air-source water heater) to cool, dehumidify, and reheat (to space neutral condition) the incoming ventilation air in the summer and extract heat from house exhaust air in the winter. Heat thus recovered from the ventilation or exhaust air is used for domestic water heating and for reheat of ventilation air. When no water heating is

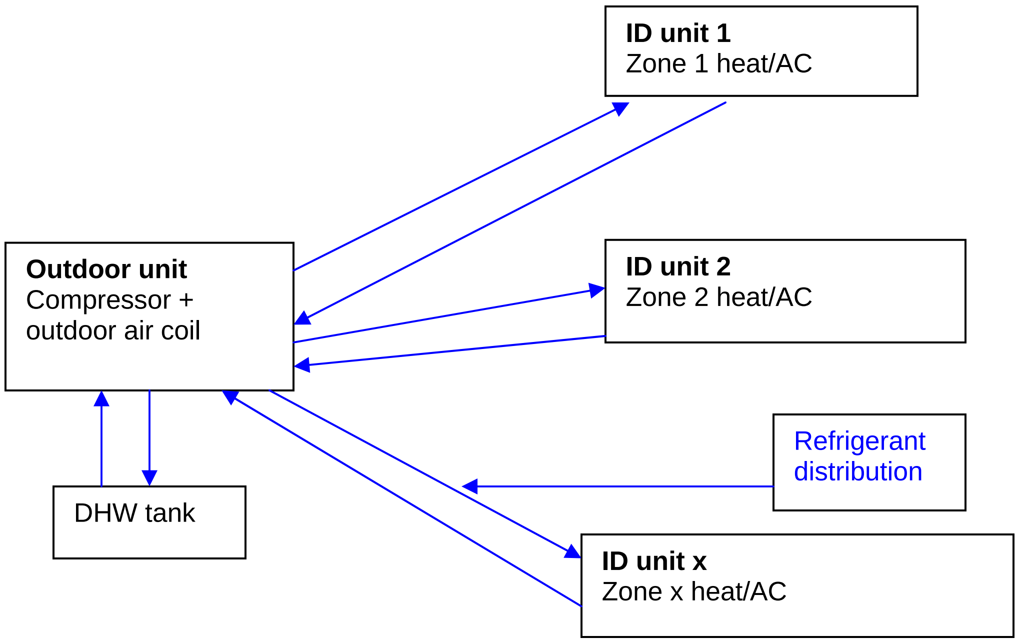

Fig. 5. Schematic of ductless multi-split heat pump/water heater system concept (zone option 2).

needed, the ventilation air-source water heater compressor shuts off and only the fan runs. An air-to-water heat exchanger downstream from the evaporator enables reheat from the hot water tank.

The ventilation air-source water heater is expected to meet much of the water heating needs. Backup water heat if needed is provided by a premium electric storage water heater with EF=0.95. A larger water tank would be used so as to maximize utilization of water heating supplied by the low-capacity ventilation air-source water heater.

Zone option 4

Space heating and cooling is provided by an air-to-water heat pump (AWHP) unit, a system with a single outdoor air coil unit with a compressor and desuperheater package located indoors. Efficiency levels for the AWHP would be comparable to those of the WAHP used in central electric options 3 – 5. The desuperheater provides water heating whenever the heat pump is operating with backup provided by an electric storage water heater with EF~0.95. Figure 6 provides a schematic of the system concept. The heat pump supplies a hot or cold secondary fluid (brine) to individual heating/cooling fan coil units for each house zone.

Zone option 5

This system follows the same schematic as system 4 except that the desuperheater is replaced with a full-size condenser, allowing the heat pump to provide water heating on demand. Backup water heat is provided by a premium electric storage water heater with EF=0.95.

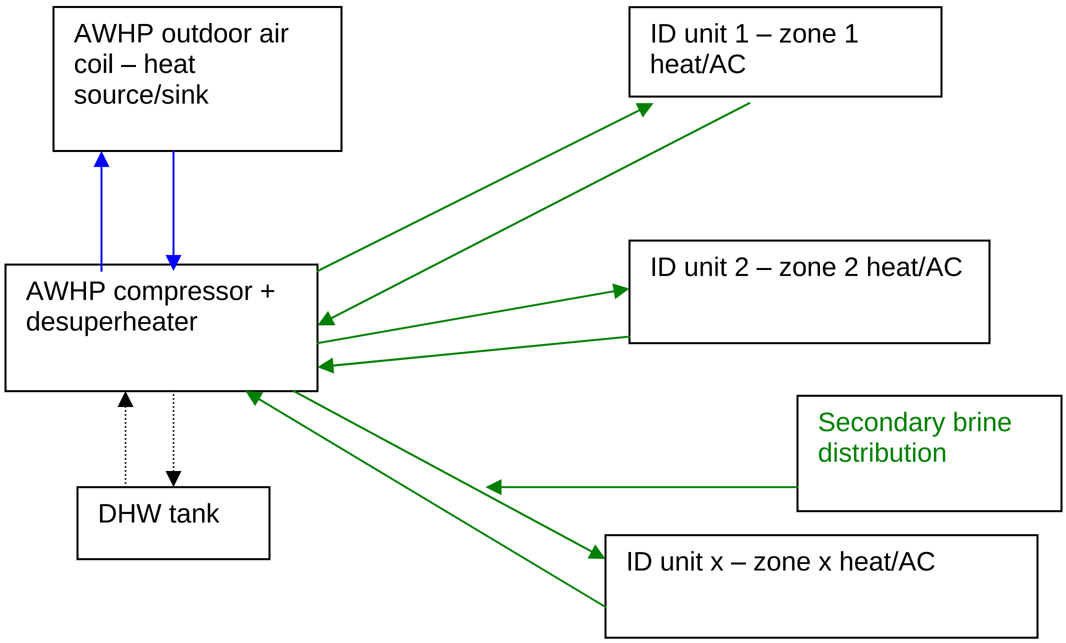

Fig. 6. Schematic of air-to-water heat pump/desuperheater system concept (zone option 4).

Zone options 6 and 7

These are identical to system 4 and 5, respectively, except that a packaged water-to-water heat pump (WWHP) unit is used. Rated efficiencies for the WWHP used for the GHP are approximately EER 17.5 for cooling and COP 3.5 for heating [as rated per ARI/ISO standard 13256-2 (ISO 1998b) for GHP application]. A GHX provides the source/sink component. See schematic in Figure 7.

Zoned option 8

This is basically a ductless version of the air-source central IHP system (central electric options 6). It uses the same refrigerant distribution concept as the ductless multi-split heat pump product (zoned system 1). The outdoor air source/sink version of this concept is illustrated schematically in Figure 8. A single compressor/outdoor air coil unit is connected via refrigerant distribution lines to a number of indoor modules serving different HVAC function and domestic hot water (DHW) loads. Module 1 provides the house water heating needs. Module 2 serves to preheat or precool ventilation air as needed. When precooling ventilation air it also recovers heat for use in water heating mode. Module 3 would provide regeneration energy for a desiccant dehumidifying system (if used). Modules 4-x are individual refrigerant-air fan coils for each zone.

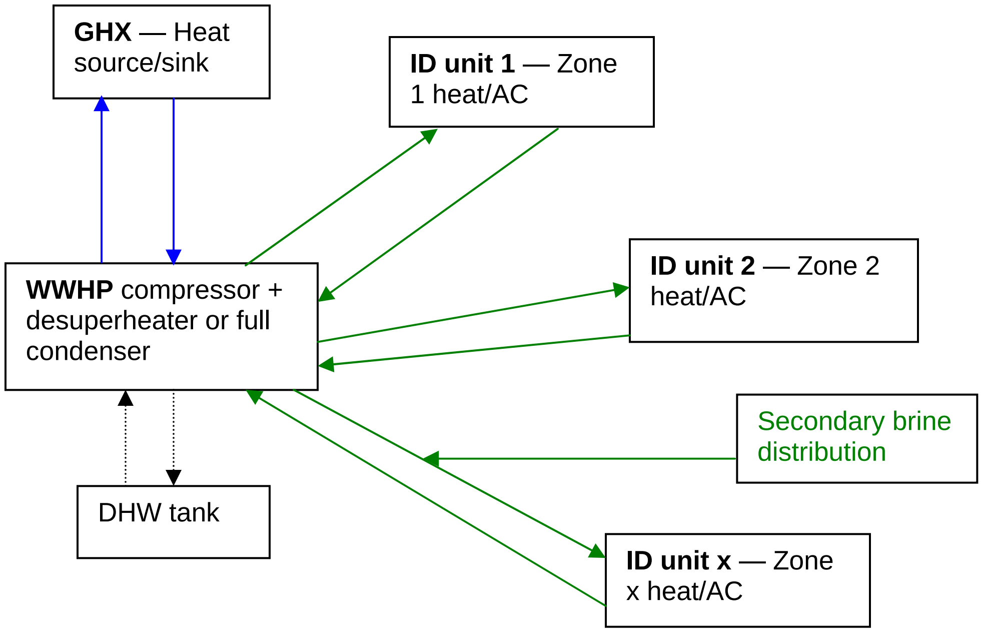

Fig. 7. Schematic of water-to-water heat pump/desuperheater or full condenser system concept (zone options 6 and 7).

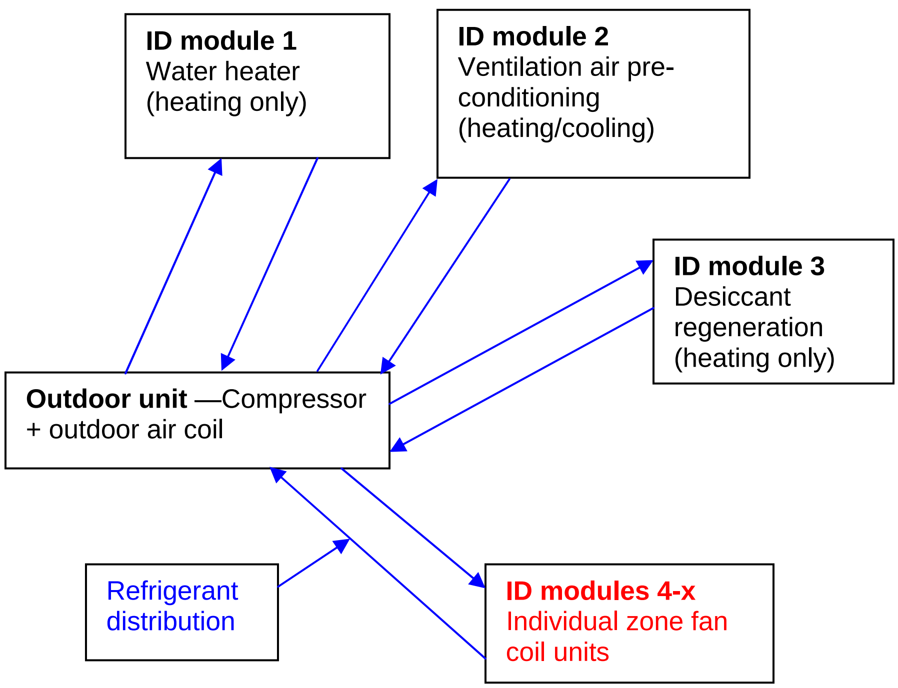

Fig. 8. Schematic of ductless air-source integrated heat pump (IHP) system concept 1, refrigerant distribution with individual zone refrigerant-air heating/cooling fan coil units (the outdoor air source/sink version of zoned system 8).

Figure 9 illustrates another variation on this system. In this case, module 4 is a refrigerant/water (or brine) heat exchanger. It cools (or heats) a brine fluid for supply to individual zone fan coil units or radiant floor/ceiling/wall panels for space cooling (or space heating). If radiant panel distribution is used, a desiccant dehumidifying system (served by module 3) would become a necessity. This option would also eliminate the need for condensate drainage systems for each zone that are normally required for any system using individual fan coil units.

Zoned option 9

This is identical to system 8 except that the outdoor air coil is replaced with a ground heat exchanger as the source/sink component.

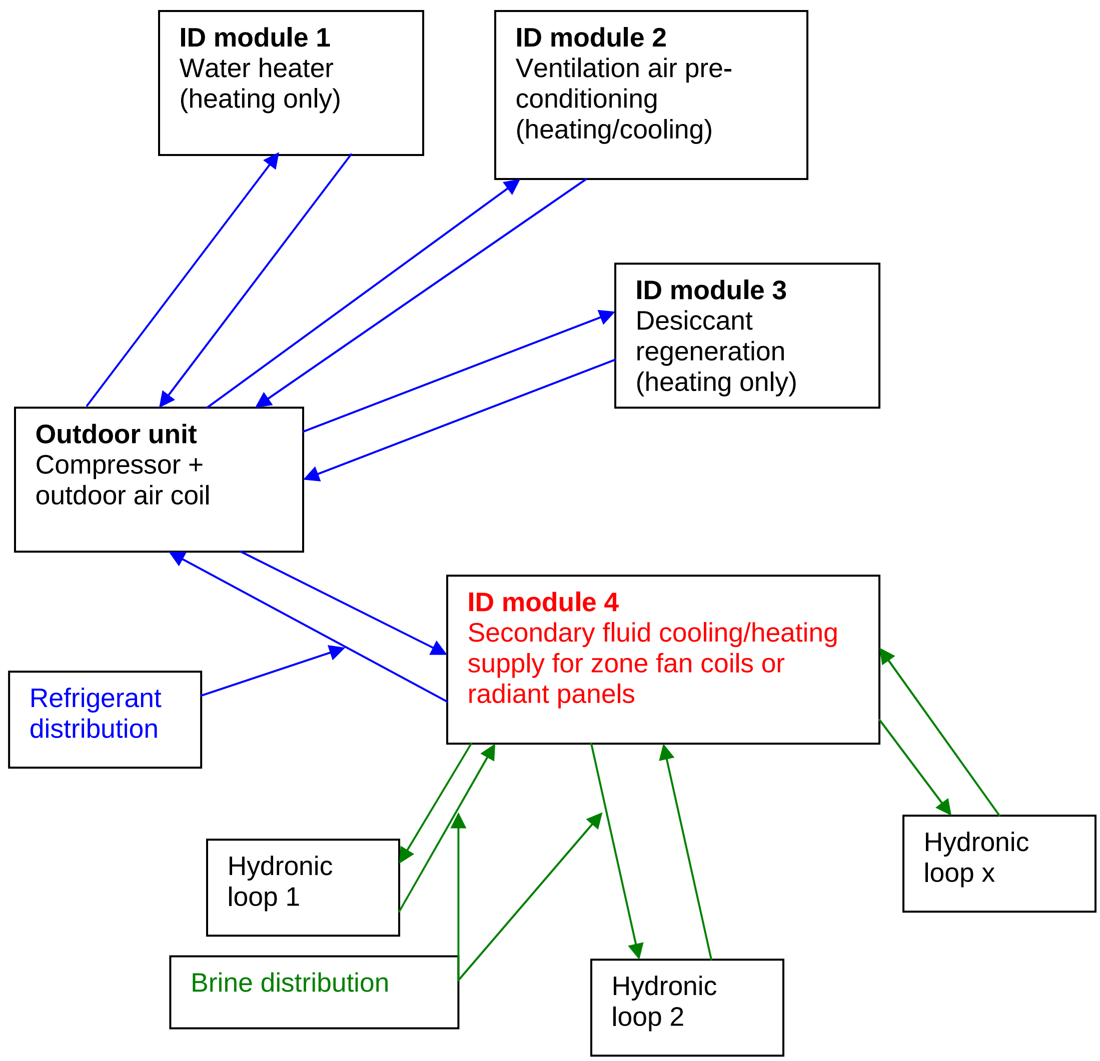

Fig. 9. Schematic of ductless air-source integrated heat pump (IHP) system concept 2, combination of refrigerant distribution and secondary brine loops for zone heating/cooling units (a variation of zoned system 8).

Analysis Approach

The annual energy use simulations for the HVAC system options were performed using the TRNSYS 16 platform (Solar Energy Laboratory, et al. 2005). This required conversion of the 1800-ft^2 Building America benchmark house and prototype NZEH descriptions — DOD 2.2 BDL files provided by NREL (Christensen 2005) — to TRNSYS Type 56 representations. Representations of each of the HVAC baseline systems and most of the advanced system options were prepared. At the time of this writing the following options had not been incorporated into TRNSYS representations: gas central option 3, electric central options 3a, 6, and 7, and zoned options 2, 8, and 9. Annual energy consumption for those options was estimated based on comparison with performance of the appropriate baseline system and similar advanced systems for which TRNSYS simulations were run. For central option 7, experimental performance maps generated for a laboratory prototype IHP at ORNL (Tomlinson et al 2005) were also used to estimated the expected space cooling, space heating, and water heating efficiency over the various operating modes. These were then applied to the appropriate energy requirements calculated from TRNSYS.

Annual, hour-by-hour simulations were performed for each HVAC system for both the Building America benchmark and prototype NZEH buildings for five locations - Atlanta, mixed-humid; Houston, hot-humid; Phoenix, hot-dry; San Francisco, marine; and Chicago; cold).

Systems Energy Consumption Results

Tables 2 through 6 provide results of the TRNSYS simulations for each HVAC option for the BA benchmark house for each of the five locations examined in this study. Tables 7 through 11 provide the same information for the prototype NZEH house.

Table 2. Annual site energy use by HVAC systems for 1800 ft^2 BA benchmark house located in Atlanta – estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC site energy use (vs central baseline)	HVAC peak integrated hourly kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (20,852 kWh)	1/1 (22.06/4.52)
Gas 1	0.883	.92/.73
Gas 2	0.786	.92/.73
Gas 3[a]	1.01	
Central electric options		
Baseline electric	1.00 (10,033 kWh)	1.00 (18.20)
Electric 1	.933	1.00
Electric 2	.773	.87
Electric 3	.668	.39
Electric 3A[a]	.612	.37
Electric 4	.668	.39
Electric 5	.759	.44
Zoned electric options		
Baseline zone system	.780	.81
Option 1	.872	.79
Option 2[a]	.670	.71
Option 3	.639	.77
Option 4	.744	.89
Option 5	.596	.89
Option 6	.704	.49
Option 7	.517	.37

[a] System not yet incorporated into TRNSYS platform.

NOTES:

1. Gas option energy use is combination of gas and electric site energy. Gas option 3 uses more gas than baseline due to low efficiency of gas-based cooling. Hourly peaks given for gas/electric.
2. Difference between central electric and zoned electric baseline systems reflects three effects: 1) load reduction due to elimination of duct losses; 2) thermostat set back; and 3) load reduction due to diversity between the two building zones. ACCA's Manual J, Seventh Edition (1986) in their discussion of multi-zone systems notes the possibility to reduce design cooling loads by about 35% using two zones.
3. Central electric system 4 is geothermal heat pump with horizontal GHX enhanced with SWS backfill material. TRNSYS analyses for Atlanta estimate that if SWS can raise the effective thermal conductivity (k-value) of the soil by a factor of about 15-17, system 4 would achieve the same performance as system 3 (geothermal with vertical bore GHX) and the horizontal GHX would fit in the area underneath the house slab.

Table 3. Annual site energy use by HVAC systems for 1800 ft^2 BA benchmark house located in Houston – estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC site energy use (vs central baseline)	HVAC peak integrated hourly kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (16,342 kWh)	1/1 (21.39/4.42)
Gas 1	.854	.92/.67
Gas 2	.748	.92/.67
Gas 3[a]	1.633	
Central electric options		
Baseline electric	1.00 (9,679 kWh)	1.00 (18.71)
Electric 1	.905	.99
Electric 2	.727	.89
Electric 3	.723	.38
Electric 3A[a]	.605	.36
Electric 4	.723	.38
Electric 5	.762	.38
Zoned electric options		
Baseline zone system	.828	.55
Option 1	.918	.57
Option 2[a]	.742	.54
Option 3	.678	.55
Option 4	.682	.86
Option 5	.623	.86
Option 6	.729	.52
Option 7	.560	.35

[a] System not yet incorporated into TRNSYS platform.

NOTES:

1. Central electric system 4 is geothermal heat pump with horizontal GHX enhanced with SWS backfill material. TRNSYS analyses for Houston estimate that if SWS can raise the effective thermal conductivity (k-value) of the soil by a factor of 15-17, system 4 would achieve the same performance as system 3 (geothermal with vertical bore GHX) and the horizontal GHX would fit in the area underneath the house slab.

Table 4. Annual site energy use by HVAC systems for 1800 ft^2 BA benchmark house located in Phoenix – estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC site energy use (vs central baseline)	HVAC peak integrated hourly kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (17,085 kWh)	1/1 (24.36/5.74)
Gas 1	.817	.91/.71
Gas 2	.724	.90/.71
Gas 3[a]	1.858	
Central electric options		
Baseline electric	1.00 (11,999 kWh)	1.00 (8.95)
Electric 1	.890	.96
Electric 2	.665	.69
Electric 3	.712	.85
Electric 3A[a]	.556	.80
Electric 4	.712	.85
Electric 5	.733	.79
Zoned electric options		
Baseline zone system	.848	.96
Option 1	.925	.98
Option 2[a]	.801	.93
Option 3	.731	1.00
Option 4	.506	1.07
Option 5	.470	1.07
Option 6	.700	1.08
Option 7	.582	.83

[a] System not yet incorporated into TRNSYS platform.

NOTES:

1. Central electric system 4 is geothermal heat pump with horizontal GHX enhanced with SWS backfill material. TRNSYS analyses for Phoenix estimate that if SWS can raise the effective thermal conductivity (k-value) of the soil by a factor of 15-17, system 4 would achieve the same performance as system 3 (geothermal with vertical bore GHX) and the horizontal GHX would fit in the area underneath the house slab.

Table 5. Annual site energy use by HVAC systems for 1800 ft^2 BA benchmark house located in San Francisco – estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC site energy use (vs central baseline)	HVAC peak integrated hourly kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (16,339 kWh)	1/1 (18.58/2.33)
Gas 1	.909	.93/.67
Gas 2	.776	.93/.67
Gas 3[a]	.573	
Central electric options		
Baseline electric	1.00 (6,942 kWh)	1.00 (6.91)
Electric 1	.951	.98
Electric 2	.777	.79
Electric 3	.771	.89
Electric 3A[a]	.729	.85
Electric 4	.771	.89
Electric 5	.741	.85
Zoned electric options		
Baseline zone system	.764	1.06
Option 1	.824	1.09
Option 2[a]	.497	1.01
Option 3	.570	.94
Option 4	.627	.89
Option 5	.438	.79
Option 6	.763	.90
Option 7	.466	.78

[a] System not yet incorporated into TRNSYS platform.

NOTES:

1. Central electric system 4 is geothermal heat pump with horizontal GHX enhanced with SWS backfill material. TRNSYS analyses for San Francisco estimate that if SWS can raise the effective thermal conductivity (k-value) of the soil by a factor of about 10, system 4 would achieve the same performance as system 3 (geothermal with vertical bore GHX) and the horizontal GHX would fit in the area underneath the house slab.

Table 6. Annual site energy use by HVAC systems for 1800 ft^2 BA benchmark house located in Chicago – estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC site energy use (vs central baseline)	HVAC peak integrated hourly kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (30,935 kWh)	1/1 (24.39/3.32)
Gas 1	.874	.93/.73
Gas 2	.821	.92/.73
Gas 3[a]	.643	
Central electric options		
Baseline electric	1.00 (13,459 kWh)	1.00 (14.61)
Electric 1	.951	.99
Electric 2	.788	.90
Electric 3	.686	.86
Electric 3A[a]	.630	.83
Electric 4	.686	.86
Electric 5	.692	.80
Zoned electric options		
Baseline zone system	.799	1.07
Option 1	.884	1.08
Option 2[a]	.697	.91
Option 3	.646	1.00
Option 4	.919	.88
Option 5	.981	.89
Option 6	.722	.63
Option 7	.701	.57

[a] System not yet incorporated into TRNSYS platform.

NOTES:

1. Central electric system 4 is geothermal heat pump with horizontal GHX enhanced with SWS backfill material. TRNSYS analyses for Chicago estimate that if SWS can raise the effective thermal conductivity (k-value) of the soil by a factor of 10-12, system 4 would achieve the same performance as system 3 (geothermal with vertical bore GHX) and the horizontal GHX would fit in the area underneath the house slab.

Table 7. Annual site energy use by HVAC systems for 1800-ft² prototype NZEH house located in Atlanta - estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC system site energy use (vs central baseline)	HVAC peak hourly integrated kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (11,559 kWh)	1/1 (15.69/1.90)
Gas 1	.893	.91/.73
Gas 2	.723	.91/.73
Gas 3[a]	.940	
Central electric options		
Baseline	1.00 (6,082 kWh)	1.00 (9.64)
Electric 1	.941	1.00
Electric 2	.789	.65
Electric 3	.745	.59
Electric 3A[a]	.701	.58
Electric 4	.745	.59
Electric 5	.731	.62
Electric 6[a, b]	.474	≥.6[c]
Electric 7[a, b]	.421	≥.6[c]
Zoned electric options		
Baseline zone	.919	.99
Option 1	.993	1.00
Option 2	.656	.82
Option 3	.693	.49
Option 4	.738	.58
Option 5	.618	.91
Option 6	.876	.66
Option 7	.576	.46
Option 8[a, b]	.451	≥.5[c]
Option 9[a, b]	.401	≥.5[c]

[a] System not yet incorporated into TRNSYS platform.
[b] Energy use only estimated for NZEH building.
[c] Peak for IHP options estimated to be no higher than those for other geothermal systems with fully integrated water heating capability.

NOTES:

1. HVAC and water heating energy usage of central electric and zoned electric baseline systems is much more equal in the tighter, better insulated NZE house. All distribution system components for central systems are contained within the conditioned space in the prototype NZE house.
2. Central electric system 7 and zoned system 9 utilize a GHX (either vertical bore or SWS-enhanced horizontal loop). Parametric analyses for the ZNE house in Atlanta show that if the SWS material can raise the effective thermal conductivity (k-value) of the soil by a factor of about 9-10, a horizontal loop could be small enough to fit beneath the house floor slab significantly reducing the cost of installation .
3. The much lower cooling and heating loads of the NZEH enabled the gas heat pump option (central gas 3) to show about 6% energy savings potential vs. the gas baseline systems in this case.

Table 8. Annual site energy use by HVAC systems for 1800-ft^2 prototype NZEH house located in Houston - estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC system site energy use (vs central baseline)	HVAC peak hourly integrated kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (9,247 kWh)	1/1 (14.53/1.92)
Gas 1	.873	.90/.72
Gas 2	.502	.90/.72
Gas 3[a]	1.441	
Central electric options		
Baseline	1.00 (5,730 kWh)	1.00 (5.99)
Electric 1	.921	.99
Electric 2	.769	.80
Electric 3	.780	.87
Electric 3A[a]	.702	.85
Electric 4	.780	.87
Electric 5	.800	.67
Electric 6[a, b]	.478	≥.7 [c]
Electric 7[a, b]	.436	≥.7 [c]
Zoned electric options		
Baseline zone	.952	.95
Option 1	1.024	.97
Option 2	.765	.80
Option 3	.688	.72
Option 4	.850	1.18
Option 5	.543	.84
Option 6	.878	1.07
Option 7	.600	.59
Option 8[a, b]	.453	≥.6 [c]
Option 9[a, b]	.414	≥.6 [c]

[a] System not yet incorporated into TRNSYS platform.
[b] Energy use only estimated for NZEH building.
[c] Peak for IHP options estimated to be no higher than those for other geothermal systems with fully integrated water heating capability.

NOTES:

1. Central electric system 7 and zoned system 9 utilize a GHX (either vertical bore or SWS-enhanced horizontal loop). Energy consumption is estimated to be the same in either case. Parametric analyses of the horizontal loop case for Houston show that if the SWS material can raise the effective thermal conductivity (k-value) of the soil by a factor of 9-10, the loop could be small enough to fit beneath the house floor slab significantly reducing the cost of installation for new construction.
2. The high cooling load in Houston resulted in much higher energy use by the gas heat pump option.

Table 9. Annual site energy use by HVAC systems for 1800-ft^2 prototype NZEH house located in Phoenix - estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC system site energy use (vs central baseline)	HVAC peak hourly integrated kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (9,520 kWh)	1/1 (13.94/2.53)
Gas 1	.845	.94/.72
Gas 2	.679	.93/.72
Gas 3[a]	1.649	
Central electric options		
Baseline	1.00 (6,581 kWh)	1.00 (6.18)
Electric 1	.906	.99
Electric 2	.690	.83
Electric 3	.738	.89
Electric 3A[a]	.617	.90
Electric 4	.738	.89
Electric 5	.730	.64
Electric 6[a, b]	.501	≥.6 [c]
Electric 7[a, b]	.448	≥.6 [c]
Zoned electric options		
Baseline zone	.939	.95
Option 1	1.007	.96
Option 2	.779	.79
Option 3	.721	.56
Option 4	.732	.80
Option 5	.510	.76
Option 6	.854	1.07
Option 7	.621	.61
Option 8[a, b]	.490	≥.6 [c]
Option 9[a, b]	.438	≥.6 [c]

[a] System not yet incorporated into TRNSYS platform.
[b] Energy use only estimated for NZEH building.
[c] Peak for IHP options estimated to be no higher than those for other geothermal systems with fully integrated water heating capability.

NOTES:

1. Central electric system 7 and zoned system 9 utilize a GHX (either vertical bore or SWS-enhanced horizontal loop). Energy consumption is estimated to be the same in either case. Parametric analyses of the horizontal loop case for Phoenix show that if the SWS material can raise the effective thermal conductivity (k-value) of the soil by a factor of 9-10, the loop could be small enough to fit beneath the house floor slab significantly reducing the cost of installation for new construction
2. The high cooling load in Phoenix resulted in much higher energy use by the gas heat pump option.

Table 10. Annual site energy use by HVAC systems for 1800-ft^2 prototype NZEH house located in San Francisco - estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC system site energy use (vs central baseline)	HVAC peak hourly integrated kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (8,505 kWh)	1/1 (13.38/0.16)
Gas 1	.929	.95/1
Gas 2	.672	.95/1
Gas 3[a]	.456	
Central electric options		
Baseline	1.00 (4,570 kWh)	1.00 (5.68)
Electric 1	.953	.99
Electric 2	.804	.90
Electric 3	.794	.96
Electric 3A[a]	.778	.94
Electric 4	.794	.96
Electric 5	.568	.80
Electric 6[a, b]	.392	≥.8 [c]
Electric 7[a, b]	.379	≥.8 [c]
Zoned electric options		
Baseline zone	.923	.89
Option 1	.949	.92
Option 2	.464	.75
Option 3	.668	.69
Option 4	.766	.93
Option 5	.469	.70
Option 6	.916	1.05
Option 7	.485	.69
Option 8[a, b]	.369	≥.7 [c]
Option 9[a, b]	.357	≥.7 [c]

[a] System not yet incorporated into TRNSYS platform.
[b] Energy use only estimated for NZEH building.
[c] Peak for IHP options estimated to be no higher than those for other geothermal systems with fully integrated water heating capability.

NOTES:

1. Central electric system 7 and zoned system 9 utilize a GHX (either vertical bore or SWS-enhanced horizontal loop). Energy consumption is estimated to be the same in either case. Parametric analyses of the horizontal loop case in San Francisco show that if the SWS material can raise the effective thermal conductivity (k-value) of the soil by a factor of 9-10, the loop could be small enough to fit beneath the house floor slab significantly reducing the cost of installation for new construction.
2. The much lower cooling loads of the NZEH enabled the gas heat pump option (central gas 3) to show about 54% energy savings potential vs. the gas baseline systems in San Francisco.

Table 11. Annual site energy use by HVAC systems for 1800-ft^2 prototype NZEH house located in Chicago - estimated with TRNSYS hourly simulation except as noted[a].

System	HVAC system site energy use (vs central baseline)	HVAC peak hourly integrated kW (vs central baseline)
Central gas options		
Baseline gas	1.00 (21,537 kWh)	1/1 (18.02/1.9)
Gas 1	.948	.92/.7
Gas 2	.872	.91/.7
Gas 3[a]	.467	
Central electric options		
Baseline	1.00 (8,591 kWh)	1.00 (13.65)
Electric 1	.950	1.00
Electric 2	.752	.65
Electric 3	.698	.58
Electric 3A[a]	.638	.56
Electric 4	.698	.58
Electric 5	.577	.57
Electric 6[a, b]	.497	≤.6 [c]
Electric 7[a, b]	.422	≤.6 [c]
Zoned electric options		
Baseline zone	.884	.84
Option 1	1.071	.85
Option 2	.783	.85
Option 3	.679	.84
Option 4	.796	.69
Option 5	.751	.65
Option 6	.696	.72
Option 7	.706	.72
Option 8[a, b]	.418	≤.7 [c]
Option 9[a, b]	.355	≤.7 [c]

[a] System not yet incorporated into TRNSYS platform.
[b] Energy use only estimated for NZEH building.
[c] Peak for IHP options estimated to be no higher than those for other geothermal systems with fully integrated water heating capability.

NOTES:

1. NZE house in Chicago is very heating load dominated. Temperature setback schedule used in analysis resulted in 21% reduction in overall HVAC and water heating energy usage for baseline zoned electric baseline systems compared to central electric baseline system.
2. Central electric system 7 and zoned system 9 utilize a GHX (either vertical bore or SWS-enhanced horizontal loop). Energy consumption is estimated to be the same in either case. Parametric analyses of the horizontal loop case in Chicago show that if the SWS material can raise the effective thermal conductivity (k-value) of the soil by a factor of 10-12, the loop could be small enough to fit beneath the house floor slab significantly reducing the cost of installation for new construction.
3. The much lower cooling loads in Chicago enabled the gas heat pump option (central gas 3) to show about 54% energy savings potential vs. the gas baseline systems in this case.

Scoring of Options Versus Criteria

Twenty different residential HVAC system options have been applied to BA benchmark and prototype NZE 1800- ft^2 houses and their energy savings potential estimated. Seven of the options are on the short-term path, and 13 are on the longer-term path. The criteria for both short-term and longer-term paths both include a should-meet criterion related to energy savings potential, which was quantitatively scored based on the energy savings potential analysis. All other should-meet criteria were scored qualitatively based on the expert opinions of the ORNL team scorers together with those of Bill Goetzler (Navigant Consulting). Table 12 summarizes the scores for the options in rank order by path along with their estimated energy savings potential for Atlanta. Detailed documentation of the scoring of options versus the criteria is presented in Appendix A. Table 13 summarizes the energy savings potential of the highest scoring options for all five locations examined in this study.

Table 12. System ranking (based on composite scores by ORNL staff and Bill Goetzler)

Short-term path			Long-term path		
System	Energy saving potential - Atlanta, %*	Criteria score	System	Energy saving potential – Atlanta, %*	Criteria score
Central electric 3A	39/30	60	Central electric 7	-/58	75.5
Central gas 2	21/28	56	Central electric 6	-/53	74.7
Central electric 3	33/26	50	Zoned electric 9	-/60	73.4
Central electric 2	23/21	42	Zoned electric 8	-/55	71.5
Central gas 1	12/11	22	Zoned electric 3	36/31	64.8
Central electric 1	7/6	12	Central electric 4	33/25	61.2
Zoned electric 1	13/0	0	Zoned electric 7	48/42	59.9
			Zoned electric 5	40/38	58.0
			Zoned electric 4	30/26	58.0
			Zoned electric 2	33/34	57.8
			Central electric 5	24/27	52.9
			Zoned electric 6	30/12	47.2
			Central gas 3	-1/6	36.5

* The two values shown in these columns reflect energy savings relative to the appropriate baseline for the BA benchmark house and the low-energy NZE house, respectively.

Table 13. Estimated energy savings potential of highest-scoring electric HVAC system options for 1800 ft^2 ZNE house (savings expressed as % compared to central baseline)

System	Atlanta	Houston	Phoenix	San Francisco	Chicago	Option type[1]
Central systems						
13SEER heat pump w/ 0.9 EF electric WH (baseline)	-	-	-	-	-	-
18 SEER 2-spd heat pump w/ desuperheater (option 2)	21	23	31	20	25	ST
GCHP w/desuperheater (option 3)	26	22	24	21	30	ST
GCHP w/desuperheater; SWS-enhanced horizontal GHX under slab (option 4)	26	22	24	21	30	LT
2-spd GCHP w/desuperheater (option 3A)	30	30	38	22	36	ST
Air-source IHP (option 6)[2]	53	52	50	61	50	LT
Ground-source IHP (option 7)[2]	58	56	55	62	58	LT
Zoned systems						
13 SEER minisplit heat pump each zone w/ 0.9 EF electric WH (base zoned system)	8	5	6	8	12	ST
Multisplit heat pump (MSHP) w/integrated demand WH module (option 2)	34	24	22	54	22	LT
MSHP + exhaust-air heat pump for WH&V (option 3)[2]	31	31	28	33	32	LT
Zoned IHP, air-source (option 8)[2]	55	55	51	63	58	LT
Zoned IHP, GS (option 9)[2]	60	58	56	66	64	LT

[1]LT – long-term option; ST – short-term option
[2]These systems explicitly treat ventilation air.

Conclusions and Recommendations

Twenty different residential HVAC system options have been applied to BA benchmark and prototype NZE 1800-ft^2 houses and their energy savings potential estimated. The options were assigned to one of two paths for potentially advancing through the Gate 3 scoping assessment screen. The short-term path is for options already commercially available, or which represent incremental improvements already in field-testable hardware, or which could be in field-testable hardware at very modest cost to the program. The longer-term path is for options requiring significant R&D effort with the goal of 50% or greater energy savings potential.

Both short-term and long-term criteria include a should-meet criterion related to energy savings potential, which was quantitatively scored based on the energy savings potential analysis. All other should-meet criteria were scored qualitatively based on the expert opinions of the scorers.

Using the short-term criteria as proposed, and based on scoring by the ORNL team, the priority ranking of short-term options is as follows:

1. First: *Central electric option 3A* (2-speed geothermal heat pump (GHP) with desuperheater water heater and vertical bore GHX).
2. Tie for Second: *Central gas option 2* (92% AFUE furnace, premium gas storage water heater, and 2-speed 18.5 SEER electric air-conditioner) ─ and ─ *Central electric option 3* (single-speed GHP with desuperheater water heater, similar to option 3A).
3. Third: *Central electric option 2* (2-speed air-source heat pump, 18 SEER/ 8.3 HSPF with desuperheater water heater).

Using the long-term criteria as proposed, and based on scoring by the ORNL team, the priority ranking of longer-term options is as follows:

1. Four-way tie for first: *Four integrated heat pump (IHP)* options (central electric 6 and 7 and zoned options 8 and 9 based on the multi-split heat pump concept) have the highest estimated energy savings of all the options evaluated and are ranked fairly closely together, as shown in Table 5.
2. Two-way tie for second: *Zoned option 3.* A multi-split-heat-pump for space conditioning with a small capacity exhaust-air-source heat pump for water heating and ventilation air conditioning ─ and ─ *Central electric option 4.* This is a GHP option with SWS-enhanced horizontal loop GHX. If the SWS enhancement works as well as our current investigations indicate that it will, the size of the GHX loop could be reduced enough to fit underneath a house floor slab. This could potentially provide a very low-cost GHP option for new construction markets.

This report describes the HVAC options, the proposed criteria, and the rankings by priority based on scoring by the team of building equipment researchers at ORNL (John Tomlinson, Keith Rice, Van Baxter, Moonis Ally, and Vince Mei) and independent scoring by William Goetzler of Navigant Consulting, which is one perspective. It is DOE's prerogative to revisit the criteria and obtain scoring from additional perspectives as part of its decision making process. If the criteria change, the ORNL team will be happy to re-score.

Based on the results of this study the two central IHP system options have been approved by DOE/BT for a business case assessment in FY06. Zoned IHP options 8 and 9, though their projected energy savings potential is somewhat greater than the central IHP option, are judged to be not ready for business case assessment until the technical feasibility of incorporating water heating and ventilation air treatment modules to the base MSHP can be sufficiently demonstrated in a lab environment.

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Appendix A

The scoring of options versus the criteria is summarized in the tables below. Table A1 summarizes the scoring of the seven short-term options. Table A2 summarizes the scoring of the 13 longer-term options. In both tables the composite team score is shown in the “criteria” column, the criteria weighting factor is in the “weight” column, and the “score” is the product of the previous two columns.

Table A1. HVAC short-term option assessment scores

	Central Gas Option 1			Central Gas Option 2			Central Electric Option 1			Central Electric Option 2		
Short-term option ranking criteria	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score
Must-meet BA teams expressed desire for this incremental improvement to baseline commercially available equipment	yes			yes			yes			yes		
Should meet Direct energy savings potential versus baseline equipment, or indirect energy savings potential by enabling other energy saving measures	22	1	22	56	1	56	12	1	12	42	1	42
TOTAL SCORE			22			56			12			42

	Central Electric Option 3			Central Electric Option 3a			Zone Option 1		
Short-term option ranking criteria	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score
Must-meet BA teams expressed desire for this incremental improvement to baseline commercially available equipment	yes			yes			yes		
Should meet Direct energy savings potential versus baseline equipment, or indirect energy savings potential by enabling other energy saving measures	50	1	50	60	1	60	0	1	0
TOTAL SCORE			50			60			0

Table A2. HVAC longer-term option assessment scores

	Central Gas Option 3			Central Electric Option 4			Central Electric Option 5			Central Electric Option 6			Central Electric 7		
Longer-term option ranking criteria	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score
Must-meet															
a. Technically feasible	yes			Yes			yes			yes			yes		
b. Aligned w/at least one strategy component	yes			Yes			yes			yes			yes		
c. Potential for Energy savings without additional mortgage, utility cost …	Yes			Yes			yes			yes			yes		
d. Sole private sector development unlikely	Yes			Yes			yes			yes			yes		
Should meet															
a Achieve 50% energy savings w.r.t baseline	1	2.5	2.5	4.7	2.5	11.75	4.9	2.5	12.25	9	2.5	22.5	9.5	2.5	23.75
b. Meets ZEH service needs	4.63	1.25	5.7875	5.5	1.25	6.875	5.88	1.25	7.35	8.25	1.25	10.31	8.75	1.25	10.94
c. No high cost component to jeopardize baseline cost	3	1.25	3.75	7.25	1.25	9.0625	4.75	1.25	5.9375	7	1.25	8.75	6.25	1.25	7.8125
d. Identified private sector interest	3	1	3	7.5	1	7.5	5.5	1	5.5	5	1	5	5.5	1	5.5
e. Resources available for R&D	3.5	1	3.5	5.75	1	5.75	2.5	1	2.5	8.25	1	8.25	8.25	1	8.25
f. Based on off-the-shelf components	7.75	0.75	5.8125	9.5	0.75	7.125	9.5	0.75	7.125	9.25	0.75	6.9375	8.75	0.75	6.5625
g. Equipment easily installed/maintained w/o acquiring new skills	6	0.75	4.5	6.25	0.75	4.6875	6.5	0.75	4.875	6	0.75	4.5	5.75	0.75	4.3125
h. Serves new NZEH and broad residential markets	6.25	0.5	3.125	8.5	0.5	4.25	6.75	0.5	3.375	8.75	0.5	4.375	8.75	0.5	4.375
i. Satisfies immediacy replacement criteria in NZEH and broad residential markets	6.25	0.5	3.125	4.25	0.5	2.125	4.25	0.5	2.125	4.25	0.5	2.125	4.25	0.5	2.125
j. Significant peak demand reduction potential	2.7	0.5	1.35	4.1	0.5	2.05	3.8	0.5	1.9	3.8	0.5	1.9	3.8	0.5	1.9
TOTAL SCORE			36.5			61.2			52.9			74.7			75.5

Table A2. HVAC longer-term option assessment scores, continued

	Zone Option 2			Zone Option 3			Zone Option 4			Zone Option 5			Zone Option 6		
Longer-term option ranking criteria	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score
Must-meet															
a. Technically feasible	Yes			yes			yes			yes			yes		
b. Aligned w/at least one strategy component	Yes			yes			yes			yes			yes		
c. Potential for Energy savings without additional mortgage, utility cost …	Yes			yes			yes			yes			yes		
d. Sole private sector development unlikely	Yes			yes			yes			yes			yes		
Should meet															
a Achieve 50% energy savings w.r.t baseline	6.1	2.5	15.25	5.4	2.5	13.5	4.7	2.5	11.75	6.8	2.5	17	2.2	2.5	5.5
b. Meets ZEH service needs	5.33	1.25	6.6625	8.17	1.25	10.21	6.33	1.25	7.9125	6.17	1.25	7.7125	6	1.25	7.5
c. No high cost component to jeopardize baseline cost	5.33	1.25	6.6625	7	1.25	8.75	5.33	1.25	6.6625	4.67	1.25	5.8375	5	1.25	6.25
d. Identified private sector interest	5.25	1	5.25	5.25	1	5.25	6	1	6	5.33	1	5.33	5.33	1	5.33
e. Resources available for R&D	2	1	2	5.63	1	5.63	5.33	1	5.33	4.33	1	4.33	4.33	1	4.33
f. Based on off-the-shelf components	8.75	0.75	6.5625	7.63	0.75	5.7225	7.33	0.75	5.4975	7	0.75	5.25	7	0.75	5.25
g. Equipment easily installed/maintained w/o acquiring new skills	8.25	0.75	6.1875	7.19	0.75	5.3925	7.67	0.75	5.7525	7.33	0.75	5.4975	7	0.75	5.25
h. Serves new NZEH and broad residential markets	8	0.5	4	8.98	0.5	4.49	8.67	0.5	4.335	8	0.5	4	8	0.5	4
i. Satisfies immediacy replacement criteria in NZEH and broad residential markets	8.75	0.5	4.375	6.69	0.5	3.345	5.25	0.5	2.625	5.25	0.5	2.625	4.25	0.5	2.125
j. Significant peak demand reduction potential	1.8	0.5	0.9	5.1	0.5	2.55	4.2	0.5	2.1	0.9	0.5	0.45	3.4	0.5	1.7
TOTAL SCORE			57.8			64.8			58.0			58.0			47.2

Table A2. HVAC longer-term option assessment scores, continued

	Zone Option 7			Zone Option 8			Zone Option 9		
Longer-term option ranking criteria	Criteria	Weight	Score	Criteria	Weight	Score	Criteria	Weight	Score
Must-meet									
a. Technically feasible	Yes			yes			yes		
b. Aligned w/at least one strategy component	Yes			yes			yes		
c. Potential for Energy savings without additional mortgage, utility cost …	Yes			yes			yes		
d. Sole private sector development unlikely	Yes			yes			yes		
Should meet									
a Achieve 50% energy savings w.r.t baseline	7.2	2.5	18	9.5	2.5	23.75	10	2.5	25
b. Meets ZEH service needs	6.17	1.25	7.7125	8.67	1.25	10.84	9.67	1.25	12.09
c. No high cost component to jeopardize baseline cost	4.33	1.25	5.4125	4.67	1.25	5.8375	4.67	1.25	5.8375
d. Identified private sector interest	5.33	1	5.33	4.67	1	4.67	4.67	1	4.67
e. Resources available for R&D	4.33	1	4.33	7.67	1	7.67	7.67	1	7.67
f. Based on off-the-shelf components	7	0.75	5.25	6.67	0.75	5.0025	6.67	0.75	5.0025
g. Equipment easily installed/maintained w/o acquiring new skills	7	0.75	5.25	6.33	0.75	4.7475	6	0.75	4.5
h. Serves new NZEH and broad residential markets	8	0.5	4	8.33	0.5	4.165	8.67	0.5	4.335
i. Satisfies immediacy replacement criteria in NZEH and broad residential markets	4.25	0.5	2.125	4.67	0.5	2.335	3.67	0.5	1.835
j. Significant peak demand reduction potential	5	0.5	2.5	5	0.5	2.5	5	0.5	2.5
TOTAL SCORE			59.9			71.5			73.4