ASHRAE JOURNAL

1997 ASHRAE Technology Award

This project won in the category for Residential

Exterior of the House residence, a 6,463 ft^2 two-story home in Greensboro, N.C.

Total System Approach Saves Energy

By Harry John Boody
Member ASHRAE

George and Sara House wanted their new lakeside residence in Greensboro, N.C. to have high ceilings and large glass windows. However, they also required their heating and cooling bills to be less than $100 a month. The "Total Systems Design Approach" met their requirements for energy efficiency and improved indoor air quality without sacrificing comfort. The project's goals were:

- To produce a guaranteed, performance-based, energy-accountable "Total System Design."
- To create a comfortable, energy efficient, and environmentally-sensitive structure.
- To use ASHRAE standards for the efficient use of energy to produce a "healthy house."
- To construct a model "Energy Efficient Structure" for engineering schools and others in the HVAC-related industry.
- To produce a project yielding immediate positive cash flow making this project an excellent return on investment.

The House's new, two-level, residential structure consists of 6,463 Equivalent Square Feet (1,349 ESF of heated and cooled area are attributable to the high cathedral ceilings throughout the house). The total conditioned volume is 51,704 ft^3 (1464 m^3).

The objectives were to minimize the effect of conduction, convection, radiation and infiltration on the total heating and cooling design loads. Detailed analysis indicated that because of the large area of glass (that at 36% or 1,821 ft^2 [169 m^2] is three times greater than the average home) the cost-effective choice would be to use Low-E^2 clear glass for this project.

All insulation materials (R-13 walls, R-5 perimeter insulation around concrete floor system and R-30 ceilings) were carefully installed per manufacturer's specifications, i.e. without gaps and with minimized compression. An aluminized vapor barrier installed over the insulation was used to take advantage of improved water vapor resis-

About the Author

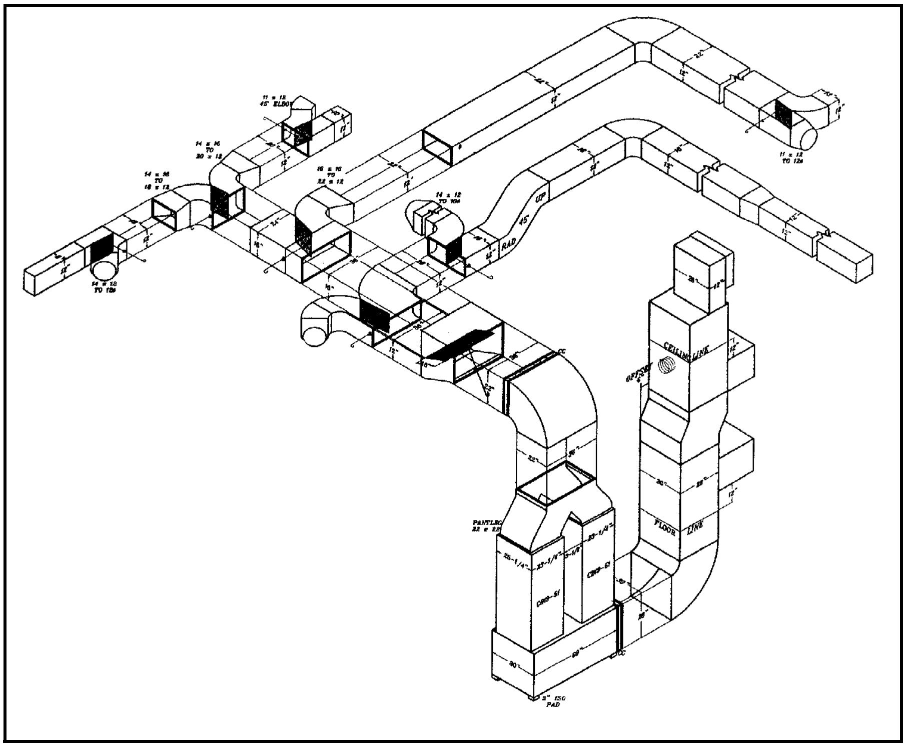
Harry John Boody is founder and president of Energy Innovations by Harry Boody. He has earned a series of state and national awards, including two 1997 ASHRAE Technology Awards. He has been a member of the North Piedmont Chapter of ASHRAE since 1986. Boody specializes in the Total Systems Design Approach.

tance and reflective dead air spaces that occur in new residential structures.

One of the innovative aspects of this project was the ability to reduce the heating design load from 12.37 tons to 7.79 tons (43.5 kW to 27.4 kW), a savings of 4.6 tons (16.18 kW) or 37.5%. The cooling design load was reduced from 9.5 tons to 6.9 tons (33.41 kW to 24.27 kW), a savings of 2.6 tons (9.14 kW) or a 27.3% reduction.

Next, this load was matched to an HVAC system with an acceptable cost/benefit ratio. A performance analysis incorporating all available fuel types found that the heat pump offered the best match of source vs. load.

Although the design loads had been greatly reduced, the airflow needed to condition 51,704 ft^3 (1464 m^3) of space had to be maintained. This presented a difficult design challenge. The "Maximum Power Transfer" theorem states: If one matches the source (HVAC system) to the design load (total thermal envelope and internal loads), maximum energy transfer will be achieved. If 6.9 tons (33.41 kW) is the worst case design load, then for 89% of the year this building can be conditioned with considerably less capacity.



Three-stage heating/two-stage cooling central HVAC system filtration.

One of the design solutions was to place two 3.5 ton (12.3 kW) heat pumps in parallel, feeding into one air distribution system to create three stages of heating and two stages of cooling without affecting proper air distribution. The operating modes of the HVAC system are as follows:

Stage One Heating & Cooling: Activates both air handlers simultaneously and the first 3.5 ton (12.31 kW) compressor (51,704 ft^3 [1464 m^3] of conditioned space requires the sum of both air handlers).

Stage Two Heating & Cooling: Controls the second 3.5 ton (12.31 kW) compressor

Stage Three Heating: Controls auxiliary heating 5.5 tons (19.2 kW) which is divided into two stages 2.73 tons (9.6 Kw each) and is further controlled by two outdoor temperature sensing thermostats set at 18°F (–8°C) and 0°F (–18°C) respectively (required only if stage three is activated). No auxiliary heating is required until the outdoor temperature falls below 17.5°F (–8° C).

The desired airflow for this 6,463 ESF structure was approximately 3,600 cfm (1699 L/s) (for improved air filtration and circulation), which equates to 9.0 tons of air handling at 400 cfm/ton. Simulations indicated that one 3.5 ton (0.822 Btu/h per cubic foot of space) heat pump would satisfy the entire load approximately 82% of the year, which would normally lead to insufficient dehumidification. Bypassing a portion of the airflow around the active cooling coil produced adequate dehumidification.

For example, in the stage one cooling mode, 50% of the entire airflow is bypassed through the second air handler. This allows the first air handler's active coil to dehumidify the required amount of airflow. A secondary air/coil bypass achieved further dehumidification.

• The HVAC system is separately sub-metered to trace the energy consumption in order to keep the structure at 72°F (22°C) all winter and 75°F (24°C) throughout the summer. The homeowners have found that no temperature setback is necessary to achieve energy efficiency even though the system has this capability. After one year of operation, the actual cost for heating and cooling the 6,463 ESF averaged $74.85 per month (1.069 kWh @ $0.07/Kwh). This equates to:

- 43.79 MBtu/year
- 12,831 kWh/year
- 1.99 kWh/ft^2/year

Indoor air quality (IAQ) was of primary importance. To achieve the high airflow desired at low-capacity requirements, a low-velocity air distribution system was designed to deliver the required cfm's to each location. Low-velocity air movement improved the indoor comfort (at a lower temperature setting) by reducing the draft effect associated with higher-velocity air distribution. High-density (low static pressure drop) air cleaners (+90% ASHRAE rated) were used because they do not consume energy and require only annual filter replacement.

To ensure adequate ventilation in this tightly constructed home, an energy recovery ventilation (ERV) system was incorporated with 85% effectiveness. Fresh, pre-filtered, outside air is drawn into the ERV's energy core while the indoor stale air is exhausted across the energy core. This reclaims the exhaust energy into the incoming fresh air that is fed directly into the main return air system. This air is further filtered, conditioned, and distributed throughout the structure through the main air distribution system. Indoor CO_2 levels have been monitored and have never exceeded 450 ppm (1000 ppm is the acceptable EPA level).

Part of the innovative approach that achieved a 52.6% reduction in energy consumption was a source vs. load design management utilizing three-stage heating/two-stage cooling. One 3.5 ton (12.31 kW) capacity unit heats and cools this 6,463 ESF home (82% of the year) yielding an average oper-

Energy recovery ventilation system heats and cools the house for less than $75 per month.

ating cost of only $74.85 per month with fresh air inducement for good IAQ. A key element in achieving these results is the attention to detail (quality control) throughout the construction process. The fact that this structure is insulated to only the minimum code and that the glass area exceeds the local power company's energy efficient guidelines, is excellent testimony to the importance of HVAC design.

This innovative system requires no special maintenance. The filter media in the return system only requires annual replacement. The energy recovery ventilation system requires no maintenance other than pre-filter replacement every other month.

By using high-efficiency heat pumps with a SEER rating of 13.25, the project was entitled to $1,009 in rebates from the local power company. The additional cost to implement environmentally-sensitive, energy-efficient features was only $8,509. This cost was included in the 8.5% interest rate mortgage, increasing the mortgage payment by $83.79 per month. The first year average monthly energy and interest tax savings equaled $95.34. This project also provides the owners with a tax free return of 12% over the 15 years of the mortgage. ■

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