A gas-fired vented zone heater has recently been developed by the Alta Cooperation for Colorado State University (CSU) under a Gas Research Institute (GRI) contract. The unit was developed for auxiliary heating applications in passive solar buildings. An early prototype was tested at Alta and operated as expected. The final model was shipped to CSU in December 1983 for testing in the RH-EAT Facility at CSU.

A heat pipe extends through the wall to the outside of the building. It has a modest water charge which can freeze repeatedly with no damage, since the heat pipe is only partially filled. Firing efficiency at 4,000 Btu/h (1.17 kW thermal) is approximately 80%. The unit features a 3 foot by 3 foot radiator mounted inside the room to be heated, and is thermostatically controlled. Ignition is accomplished with an electronic spark (pilot). The radiator typically operates at 150-180°F (65-82°C), and has been operated at between 2,000 and 5,000 Btu/h (0.5-1.47 kW). Results of testing the vented heat pipe zone heater at CSU are presented.

Also, a method for determining the optimal combination of zone heater, passive solar heating and energy conservation measures has been developed. Homeowners have been developed that may be used by a building designer to determine the optimal combination of zone heater size, passive solar system size, and energy conservation measures for given types of passive solar heating systems in selected locations. A representative nomenclature is presented along with a design example.

ABSTRACT

Spending on energy-efficient products and services amounted to approximately $9 billion in 1980, approximately $20 billion in 1982, and it has been estimated that approximately $50 billion per year will be spent in this area by 1990 (1). Residential energy conservation business activities have represented a significant portion of the spending on energy efficient products and services. Approximately $45 billion were spent in this area in 1982, and it has been estimated that the spending in the residential energy area will amount to approximately $50 billion per year by 1990. Some batters have represented a significant portion of the spending in this area.

There were rather dramatic sales of portable electric space batters in the 1970's in the United States, with several million units being sold annually. Few, however, are being sold today. The reason is primarily due to the relatively high cost of electricity in most locations throughout the United States. Residential batters have also experienced rather large price increases and decreases. For example, approximately 35,000 units were sold in 1974 and 2 to 4 million units per year were sold between 1981 and 1983 but sales of these units have also decreased. There are numerous disincentives to become batters. These include the inconvenience of fuel handling (collecting for fuel and filling the fuel tanks), the high cost of batters relative to that of natural gas, odors from fuel and combustion products inside the conditioned space, manual operation, dangerously hot surface temperatures, and ventilation requirements (1).

The topic of this paper is the use of gas-fired heat pipe zone batters in very well insulated (superinsulated) buildings. Traditional type central heating plants are not appropriate for superinsulated buildings. In superinsulated buildings, the internal gains provide a significant amount of the energy required to maintain adequate comfort levels in the buildings. That is, the internal gains will raise the temperature inside the space to a value close to the desired value. Therefore, it may not be necessary to have a large, central heating facility. Instead, small zone batters may be used to provide the additional energy required in order to maintain the inside temperature at the desired value. Electric resistance batters are already available for this purpose. However, the costs for electricity are high compared with the costs for natural gas in many locations in the United States. Hence, the need exists for a gas-fired zone batter that may be used with superinsulated buildings. A zone batter of this type is described in this paper.

The gas-fired heat pipe zone batter described below represents a significant improvement over previous zone batters in that combustion takes place outside the conditioned space, the zone batter uses natural gas or propane as a fuel, it has safe operating temperatures, no fumes or odors are inside the conditioned space, and it is fully automatically controlling.

A description of the gas-fired heat pipe zone batter is given in the following section. This is followed by a description of a procedure for determining the optimal combination of zone batters, passive solar heating, and energy conservation measures for a building.
The Altar Corporation developed a small, vented gas-fired space heater that was designed for heating only one room or section of a building. The firing rate was 2,000-5,000 Btu/h (approximately 0.5-1.5 kW thermal) and the firing efficiency was approximately 80%. It consisted of a heat pipe device which penetrates the outside wall of a building, with a combustion chamber evaporator assembly unit outside of the building, and a convector-radiator inside. The unit is thermostatically controlled and uses an electronic pilot. The condenser-radiator is a one meter by one meter square vertical copper plate which is mounted a few centimeters away from the inside surface of an outside wall of a building. Copper tubes were soldered to the plate at approximately 3 centimeter intervals and joined to a header at the bottom. The header is joined by a 0.91 centimeter (0.35 inch) diameter tube, referred to as the adiabatic tube, to the evaporator, which consists of a single tube with external fins. The insulated combustion chamber, the controls, the electronic pilot, and the flow control valves are in a box which is to be mounted on the outside of the building. The system is illustrated in Figure 1.

Figure 1
Pictorial Representation of Heat Pipe Zone Heater

The heat pipe behaves essentially as a thermal diode. When the burner is on, a large amount of heat will be transferred into the building at a very small temperature difference. When the burner is off there will be a large temperature difference (approximately 35°C) between the inside and the outside and yet there will be very little heat transfer out of the building. The heat pipe fluid used in the present device is water. A very small amount of water (approximately 50 ml) is used; hence the tubes outside the building are only partially filled, and the device can freeze without damage. However, if the water in the evaporator is frozen at start-up, it must first be thawed and then evaporated. This represents a transient loss in the system and this can be minimized by using a small charge of water and longer firing periods.

Several configurations are shown. The present configuration is designed for heating a single zone in a building. One could also design a device to heat two adjacent zones by placing the device in the wall dividing the two zones close to the point where the separating wall meets the outside wall of the building. The heat transfer to the zones could be by natural convection through registers placed in each side of the separating wall. One could also use standard hydronic heaters for the condenser. It is also conceivable that several units could be installed in separate zones of a building and each unit could be individually controlled. Numerous possibilities exist.

RESULTS OF ALTAR TESTING

A prototype of the zone heater was tested in the Altar laboratories and operated for several days in order to assure proper operation. It was found to operate reliably through many on-off cycles. The heat pipe vapor pressure reached about 7 psia during steady state operation in the 65°F laboratory. Steady state conditions were reached after approximately 30 minutes. The flue gas temperature was 280°F with a CO₂ content of approximately 6%.

Table 1
HEAT PIPE ZONE HEATER TEST RESULTS

<table>
<thead>
<tr>
<th>Firing Rate (Btu/h)</th>
<th>Panel Temp. (°F)</th>
<th>Vapor Press. (psia)</th>
<th>Ambient Temp. (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>155</td>
<td>3.6</td>
<td>77</td>
</tr>
<tr>
<td>2000</td>
<td>124</td>
<td>4.5</td>
<td>73</td>
</tr>
<tr>
<td>1000</td>
<td>176</td>
<td>6.0</td>
<td>78</td>
</tr>
<tr>
<td>4000</td>
<td>165</td>
<td>8.3</td>
<td>75</td>
</tr>
</tbody>
</table>

RESULTS OF CSU TESTS

Several tests of the Altar Zone Heater were performed between March 3 and May 4, 1984, in the "mystery zone" at the Indoan Heat Test Center (CHT). The objective in performing these tests was to develop an engineering characterization of the zone heater. The characterization was to include:

- transient and steady state thermal efficiencies of the zone heater,
- relative contributions of radiation and convection to the heat flux from the zone heater,
- a preliminary data base from which recommendations for refinements of the present design, as well as possible control schemes, may be made.

Proceedings of the First Symposium on Improving Building Systems in Hot and Humid Climates, August 1984
The tests consisted of bench tests, transient field tests, and a 3 day steady state field test. Optimization of the fuel-air ratio was performed during bench testing by recording temperature data on the condenser while varying the primary air supply in order to produce the largest average plate temperature. During the bench testing the radiation and convection heat flux contributions were determined and are shown in Figure 2.

All field testing of the zone heater was done in an environment which was relatively free from extraneous inputs. The "mystery room" of the RESEED facility at the CSU Solar Village provided such an environment. The doors, walls, windows, and ceilings were insulated with 2 inches of styrofoam and then tightly sealed in order to minimize the thermal effects of outside temperature variations. Aluminum foil was placed on the outside of the windows to insulate the room from solar gains. The room was instrumented such that the remaining thermal flux between the interior of the room and the outside environment was determined. The test arrangement is illustrated in Figure 3. Commercial grade bottled water was used as fuel during the field tests.

An average flow rate of 3.6 cubic feet per hour, at a pressure of 3 inches of water, was used during the tests. The condenser plate was divided equally into six vertical sections; each section was monitored separately using 33 equally spaced thermocouples.

The transient tests consisted of firing the burner and then recording temperature data at 2 minute intervals until the condenser plate temperature reached steady state conditions. This took approximately 30 minutes, comparable with the test conducted by Atlas. The gas was then shut off while data collection continued until the plate temperature for the run had returned to its initial value. This process was then repeated for each section of the plate. The data collected during these tests were then used to determine thermocouple placements to be used during the steady state field test.

The steady state field test was performed for 72 hours. The mystery room was continuously monitored during this time and temperature data were collected at 15 minute intervals. The following temperature measurements were made:

- wall, ceiling, and floor temperatures
- dry bulb air temperature inside and outside the mystery room
- black globe temperatures inside the mystery room
- temperatures of the adiabatic pipe and the heater housing

These data were then used to determine the steady state efficiency of the zone heater, as well as the convective, radiative, and conductive heat fluxes from each surface during the steady state operation. The zone heater efficiency was found to be 13%. The system pressure was estimated to be about 10 kPa when the plate was at room temperature. The mass of air in the system was estimated to be 1.72 x 10^-4 kg; it was found that the amount of air in the system tended to reduce the height to which the water could rise, which in turn resulted in a lower temperature.

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Based on minimizing the life cycle cost, where the life cycle cost may be written as

\[ LCC = \left[ \sum_{t=0}^{t_{max}} A_t + \frac{B_t}{r} \right] (1 + r)^{-t} 
+ \left[ \frac{C_{aux} + d}{r_{aux}} \right] - \left[ \frac{C_{aux} + d}{r_{aux}} \right] \]

where:

- \( r \) is the base cost for passive solar
- \( A_t \) is the incremental cost for active solar
- \( B_t \) is the present worth factor of the energy conservation
- \( d \) is the incremental cost for the zone heater
- \( C_{aux} \) is the auxiliary fuel cost
- \( C_{heater} \) is the zone heater fuel cost
- \( r_{aux} \) is the auxiliary fuel cost rate
- \( r_{heater} \) is the zone heater fuel cost rate
- \( E \) is the present value of the future fuel costs

Using an energy balance between the auxiliary heater and the heating requirements (for the lower base temperature), the energy provided by the auxiliary heater is obtained:

\[ Q_{aux} = (1 - SSF) L_0 \]

where

- \( SSF \) is the solar savings fraction

The zone heater energy output may also be obtained using an energy balance:

\[ Q_{heater} = (L_0 + L_1) ADD = L_1 (1 + F) ADD \]

where

- \( F \) is the difference between the higher and lower bases.

Using a heat transfer analysis the zone heater area required is determined:

\[ A_{heater} = \frac{Q_{heater}}{U A} = L_1 (1 + F) A/D(24k) \]

where \( k \) represents the product of the zone heater heat transfer coefficient and the temperature differential between the zone heater and the zone 1 air temperature. That is,

\[ k = \frac{Q_{heater}}{(T_{heater} - T_1)} \]

Two economic factors are introduced in Kibele and Varr (2):

\[ \frac{C_{aux} + d}{r_{aux}} = \frac{C_{heater} + d}{r_{heater}} \]

Substituting (2), (3), (4), (5), and (7) into (1) results in

\[ LCC = \frac{C_{heater} + d}{r_{heater}} L_0 \]

where

- \( LCC \) is the present value of the future fuel costs

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The conservation factor may be expressed as:

$$CF = \frac{1}{L_{0}} \left( \frac{1}{\sqrt{R}} \right)$$  \hspace{1cm} (13)

Substituting (6), (7), (10), and (13) into (13) provides:

$$CF = \left[ \frac{1}{L_{0}^{2}} + \left( \frac{1}{L_{0}} + \frac{A}{L_{0}} \right) \left( \frac{1}{L_{0}} + \frac{B}{L_{0}} \right) \right]^{0.5}$$  \hspace{1cm} (14)

where

$$R = \frac{(C_{f}^{2}/c_0^{2})}{(C_{f}^{2}/c_0^{2})_{\text{opt}}}$$  \hspace{1cm} (15)

The optimal insulation values for walls, ceiling, perimeter and windows may be determined from:

$$R_{s} = CF \left[ \frac{1}{L_{0}^{2}} \right]$$  \hspace{1cm} (16)

The square root of the ratio of $s$ and $p$ must be determined for the building component in question. Multiplying this value by the conservation factor provides the optimal $R$-value. Perimeter insulation conversion is used (4), and the optimal $R$-value equation becomes:

$$R_{s} = 2.04 CF \left( \frac{1}{L_{0}^{2}} \right)$$  \hspace{1cm} (17)

Combining (4) and (13) yields:

$$\frac{T_{w}}{A_{w}} + \frac{T_{p}}{A_{p}} = \frac{1}{A_{w}} \left( \frac{1}{L_{0}} \right) + \left( \frac{1}{L_{0}} + \frac{1}{L_{0}} \right)$$  \hspace{1cm} (18)

This may be multiplied by the value of \( \left( \frac{L_{0}}{A_{w}} \right) \) \( \frac{1}{L_{0}} \) to obtain the optimal passive heater area. The optimal passive solar area can be expressed as the optimal building load coefficient divided by the load-to-collector ratio (LCR):

$$A_{p} = \frac{L_{0}}{A_{w}} \frac{1}{LCR}$$  \hspace{1cm} (19)

Reexpressing (13) and substituting into (19) results in:

$$A_{p} = \frac{1}{CF} \left( \frac{1}{L_{0}} + \frac{1}{L_{0}} \right)$$  \hspace{1cm} (20)

which can be reexpressed as:

$$A_{p} = \frac{1}{CF} \frac{1}{LCR}$$  \hspace{1cm} (21)
The optimal infiltration rate can be obtained from (4):

\[ \text{ACH} = \frac{24 \times \text{post increase in CF}}{\text{CF}} \]  

The above results may be used by a building designer to determine how many square feet of south-facing glazing should be installed for the given type of passive solar heating system, the zone heater area, and the energy conservation measures. The modified fuel leveling factor (B) for 50% of the incremental cost for passive solar is 0.05 \$/ft^2 for system type WHR (4). Using the nomograph (Figure 4) the following data were extracted:

\[ \text{SFN} = 0.73 \]
\[ \text{CF} = 2.75 \]
\[ \frac{\text{Cost}}{\text{Energy}} = 0.125 \]
\[ \frac{\text{Cost}}{\text{Energy}} = 0.0071 \]

Using the windows:

- \( R_{\text{window}} = 2.8 \) \$/\text{ft}^2
- \( R_{\text{wall}} = 0.045 \) \$/\text{ft}^2, \( \text{wall} = 0.019 \text{\$/ft}^2 \) and \( \text{ceiling} = 0.019 \text{\$/ft}^2 \), and infiltration = 0.033 \$/\text{ft}^2.

As the incremental costs for each energy conservation component of the house, the following optimum resistances were determined:

- \( R_{\text{window}} = 5 \)
- \( R_{\text{wall}} = 45 \)
- \( R_{\text{ceiling}} = 69 \)
- \( \text{parameter} = 2.2 \)

The optimum infiltration is 1.39 ACH and B is 0.73. The optimum passive solar area and zone heater area are:

- \( A_{\text{pas}} = 150 \text{ ft}^2 \)
- \( A_{\text{zh}} = 1.5 \text{ ft}^2 \)

**SUMMARY**

A gas-fired heat pipe zone heater for use in superinsulated buildings has been described. Results from bench tests and field tests have been presented. The efficiency of the zone heater has been determined to be approximately 50%. In addition, a method for determining the optimal size of zone heater to be used in a superinsulated passive solar building has been presented. A nomograph has been developed for designers to use in determining the optimal levels of insulation, the optimal size of zone heater, and the optimal size of the solar component in a passive solar building. An example of the use of the nomograph has been presented.

It should also be noted that the method presented in this paper may be applied to central heating systems only and to some heating systems only. This may be done by setting the cost of the heating system proportional to the design heating load for the building and then following the same procedure described above in order to determine the optimal combination of energy conservation measures, passive solar heating, and heating from either a central heating system or zone heating system.
ACKNOWLEDGMENTS

This research has been partially supported by the Gas Research Institute under contract number 5082-243-0728. This support is gratefully acknowledged. In addition, the authors wish to acknowledge the excellent work done in testing the heat pipe zone heater and in plotting the nomographs by the students in the Mechanical Engineering senior design class at Colorado State University.

REFERENCES


