# Measured Effects of Zoning in Single-Family Houses

**W.P. Levins**


## ABSTRACT

The zoning of sections of a house by closing doors and air supply and return registers in certain rooms is a practice usually thought to conserve energy in households. Previously reported measurements of energy required for resistance heating and heat pump heating made by the author in three unoccupied, well-instrumented, single-family, ranch-style houses in Knoxville, TN, showed that heat pump heating savings were somewhat lower than resistance heating savings. Measurements of heat pump cooling energy usage as well as actual sensible and latent loads were made in the same houses. Temperatures in closed-off rooms floated with the outdoor temperature variations, but no savings were observed in the overall heat pump electrical usage or in the house cooling load. Measurements made on the heat pump operating parameters showed minor effects on airflows and refrigerant operating pressures until about 40% of the house area was zoned off. Formaldehyde measurements in zoned-off rooms were also made during cooling season operation and they did not differ appreciably from those levels in the nonzoned portion of the house.


## INTRODUCTION

It is generally acknowledged that the zoning, or closing off, of an area of a house during either heating or cooling seasons will reduce the respective house loads and hence is an effective energy conservation measure (Nephew and Moyers 1985; Karnitz, et al. 1989). Indeed, the author has previously reported such measured heating season energy savings (Levins 1985). However, no measured information has been presented as to the effect of zoning during the cooling season.

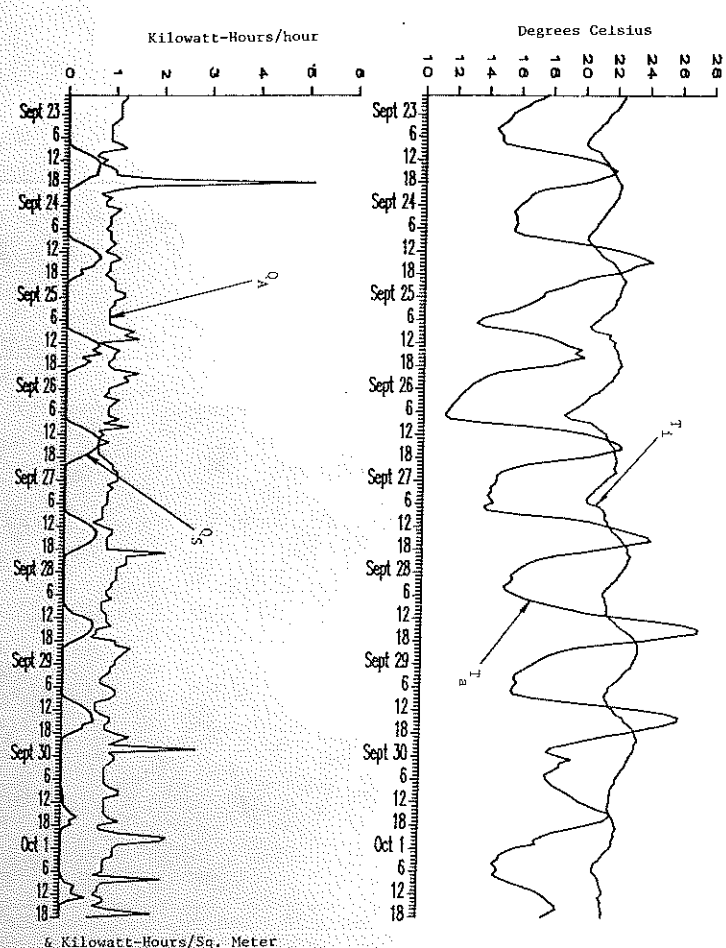


*Figure 1. Typical sample of recorded data to illustrate variations in the four parameters measured. (Data corresponds to House 3.)*

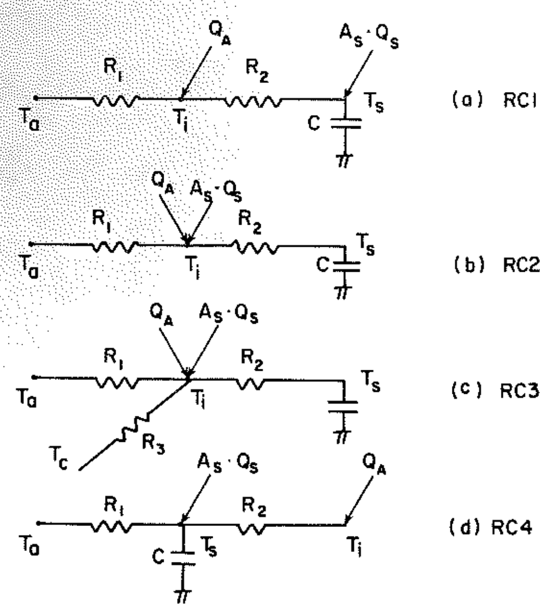


*Figure 2. The four electrical networks considered*

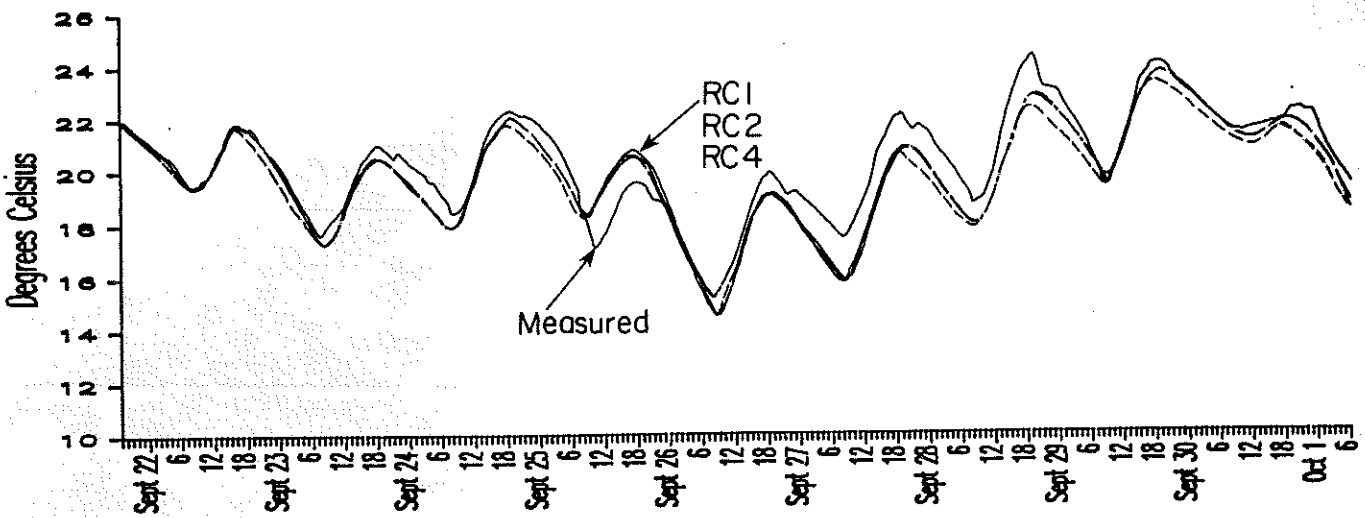


*Figure 3. Tracking ability with respect to $T_i$ of various ETP networks (House 2)*

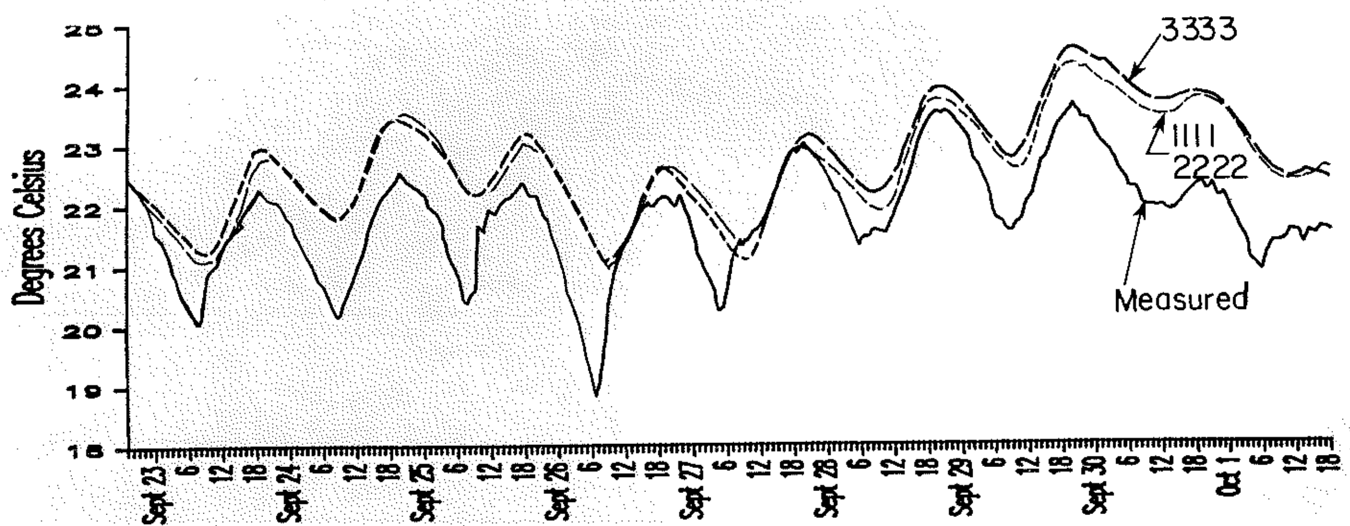


*Figure 4. Tracking ability with respect to $T_i$ of different time series order models (House 3)*

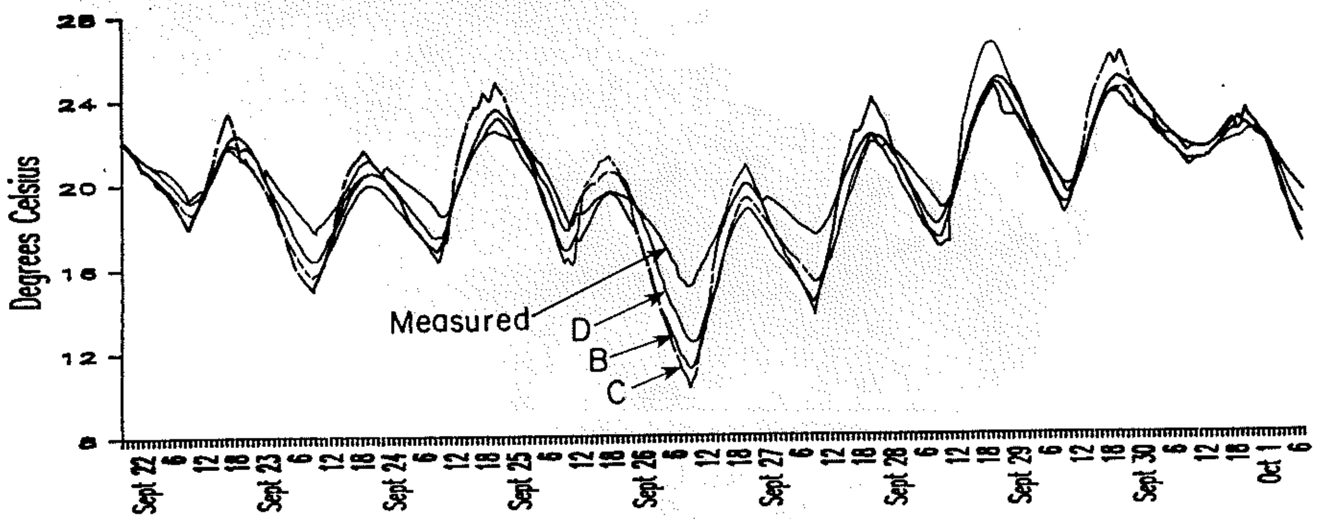


*Figure 5. Tracking ability with respect to $T_i$ of different variants of time derivative models (House 2)*

Experiments were conducted by a national laboratory which allowed the effect of zoning during the cooling season to be determined. The word "zoning" as used in this paper means closing off a room or rooms of a house by taping shut the supply registers from the HVAC system in the affected rooms, closing the doors, and sealing off the area between the door bottom and the floor with a towel. The experiments were carried out in three unoccupied houses in order that the effects of occupant lifestyle would not be imposed upon the results.

## DESCRIPTION OF THE TEST SITE

Three unoccupied houses in the Karns community, located midway between Knoxville and Oak Ridge, TN, were used for the testing. Each identical ranch-style house contained 1200 $ft^2$ of conditioned living area which was located over crawlspaces. Fiberglass batt insulation (R-19) was in the attic and under the floor, while R-11 batts were in the walls. The houses are located next to each other and face due north on treeless lots. Each house is heated and cooled by the same model two-ton, single-speed, single-package heat pump. The houses are referred to as house 1, house 2, and house 3. Table 1 contains a description of the houses, and Figure 1 shows a typical floor plan layout.

The houses were well instrumented, as each house contained its own microcomputer-controlled data acquisition system which monitored approximately 50 data channels. Monitored items included many attic and house temperatures, weather data, total and submetered electrical usages, heat pump mode and run-time data, and actual energy delivered to the house. Each data channel was scanned on a 30-second interval, and the averages of these readings were saved on floppy disks every 15 minutes.

## TEST SETUP AND METHODOLOGY

House 1 was used as a control house during all testing. It was never zoned off, so results from the other two test houses can be compared to house 1 both before and after they were zoned. A nonzoned calibration factor was obtained for houses 2 and 3 which was made relative to house 1 by dividing respective measured loads by the house 1 measured load for the same test period. After the zoning tests were completed, the results were again made relative to house 1 for the zoning test period. The relative zoning results were then normalized by division with the calibration factors for each house. The net result of the normalization is the energy use of a zoned house compared to the same house with no zoning. If the loads for all houses were equal, normalization would not be necessary. However, even our "identical" houses had slightly different loads.

Zoning measurements were made in the cooling mode both with and without radiant barriers present. The effect of radiant barriers laid (1) on top of the attic insulation and (2) along the roof truss members were measured under both no zoning and zoning conditions, the difference being the effect of zoning.

Zoning stagnates the air in a room and the indoor air quality might well deteriorate and become a potential source of undesirable pollutants. Therefore, manual measurements of indoor formaldehyde ($CH_2O$) concentrations were made by health and safety personnel during the zoning tests. Samples were obtained by pumping known volumes of room air through a molecular sieve, which adsorbed any formaldehyde in the sample. After desorbing the formaldehyde with an aqueous rinse solution, a pararosaniline colorimetric analysis was performed (Matthews et al. 1985).

## REVIEW OF HEATING SEASON RESULTS

Savings were measured for both resistance heating and heat pump heating at the Karns houses in data previously reported by the author (Levins 1985).

Measured heating load reductions with heat pump heating were significant and ranged from 9.7% when 20.7% of the house was zoned off to 18.2% when 40.96% of the house was zoned off. These reductions appear to be linear with the zoned-off area.

However, load reductions measured with resistance (IR) heating were different from those with heat pump heating -- 16.8% vs. 9.7%, respectively, when 20.7% of the house volume was zoned off.

One possible reason for this difference is that the infiltration rate in each Karns house is higher when the central HVAC fan is operating than when it is off (Levins 1985). Since the delivered Btu/h value is higher when resistance heat (10 KW, or 34,130 Btu/h) is used compared to the heat pump (24,000 Btu/h @ 47°F), the heat pump must run longer in order to deliver the same amount of energy to the house. This results in a higher infiltration load at a given outdoor temperature when heat pump heating is used at Karns compared to resistance heating.

## COOLING SEASON RESULTS

The cooling season testing was conducted in the same manner as was the heating season testing in that both used house 1 as a control house. Testing was carried out for zoning off one bedroom (11.23% of the house volume) and two bedrooms (20.70% of the house volume). A second configuration was added to the cooling experiments, as zoned testing was also carried out when radiant barriers (RB) were present in the attics of two of the test houses.

Tables 2 and 3 contain results for calibration testing and zoned testing with no radiant barriers present. Tables 4 and 5 are similar to Tables 2 and 3, the difference being that radiant barriers were present. A horizontal radiant barrier (the radiant barrier was laid on top of the attic insulation) was in house 2 during the RB testing, while a truss radiant barrier (the radiant barrier was stapled along the roof trusses parallel to the plywood sheathing used as the roof decking) was in house 3.

Table 6 summarizes the results of both heating and cooling zoned testing. Figures 2 and 3, respectively, depict the heating and cooling results contained in Table 6.

The cooling results are quite interesting in that they show essentially no changes in cooling loads when the house are zoned off. Zoning also showed no effect when radiant barriers were present, as load reductions caused by the radiant barriers were not changed by zoning.

This result is totally unexpected, and the natural question that arises is "Are the rooms really zoned off?" Figures 4a and 4b show temperatures in three rooms of houses 2 and 3 during the calibration testing when no zoning was present. The three temperatures in each house are quite similar. Figures 5a and 5b show the temperatures in the same houses when zoning was present. Figure 5 corroborates that the designated rooms were indeed zoned off, as the temperature floats in the zoned rooms when they are compared with the unzoned great room temperature.

Another possibility is that the heat pump operating conditions changed because of flow reductions over the evaporator coil caused by the closing of the supply air vents in the zoned-off rooms. Table 7 contains results of heat pump suction and discharge pressure measurements as well as airflow measurements in the central indoor return air duct of a Karns house as a function of the zoned-off house volume. The outdoor air temperature increased from 82° to 89°F while the measurements were being made, yet both suction and discharge pressures showed little change. The airflow over the evaporator (indoor coil) did not change until 41% of the house volume was zoned off, at which time it decreased by about 4%. These measurements show that the heat pump (operating in the cooling mode) was rather insensitive to zoning off of the house volume.

## FORMALDEHYDE MEASUREMENTS

One item which has recently been recognized as being very important is the quality of indoor air in a residence. Tight building construction techniques, while effective at reducing energy losses, have amplified the degradation of indoor air quality by reducing house infiltration rates. Since many particle boards use a formaldehyde resin to bond their particles together, and since the Karns houses use much particle board in their flooring members, it was decided to make some measurements of formaldehyde concentrations at our test site during the course of the zoning experiments. It was felt that by zoning off a portion of the house, formaldehyde concentrations might build up in the zoned-off rooms, especially during the heat of the day in the cooling season.

Simultaneous measurements of formaldehyde levels in three zoned-off bedrooms and in an unzoned portion of the house were made in the relatively early morning and later in the afternoon. Table 10 contains the results of these measurements and shows a possible slight average increase in the zoned-off bedrooms (0.14 ppm) compared to the unzoned portion (0.13 ppm) of 0.01 ppm for the three day monitoring period. However, it is felt that no strong effects of formaldehyde buildup are evident from the relatively small amount of data obtained.

ASHRAE recommends 0.1 ppm of formaldehyde as a comfort guideline (Matthews, et al. 1985), so the base concentrations at Karns are slightly higher than these recommendations.

## SUMMARY AND CONCLUSIONS

Previous measurements at the national laboratory have shown that zoning off parts of a house during the heating season saves energy. However, measurements in the same houses during the cooling season showed essentially no change in energy usage.

No explanation is offered for the lack of energy savings in the cooling mode when part of a house volume is zoned off. Interior temperatures of the unzoned portions of the house did not appear to change (drop) enough to account for the apparent insensitivity of the house cooling load to zoning. Air conditioner refrigerant operating pressures and indoor fan (evaporator) airflow rates were not adversely affected when up to 20% of the living area was zoned off. More testing of zoning strategy under cooling conditions is recommended before any definitive conclusions regarding cooling are made.

Measured formaldehyde concentrations in zoned-off rooms were comparable to those levels in unzoned areas of the house. The small amount of data show that zoning did not pose any added danger to human occupants from increased levels of formaldehyde. It is recommended that more measured data be obtained on possible pollutant buildups in zoned portions of residences.

## ACKNOWLEDGEMENT

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## REFERENCES

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Levins, W. P., 1985. "Experimental measurements of heating season energy savings from various retrofit techniques in three unoccupied houses," Proceedings of the ASHRAE/DOE/BTECC Conference, Thermal Performance of the Exterior Envelopes of Buildings III, pp. 425-439, December 2-5.

Matthews, T. G., et al., 1985. Indoor air quality in the Karns research houses: baseline measurements and impact of indoor environmental parameters on formaldehyde concentrations. ORNL/TM-9433, December.

Table 2. Karns Houses 1985 Cooling Data - No Zoning With No Radiant Barriers

| House No. | Hours | Type RB | Rooms Zoned | Sensible Btu/h | Latent Btu/h | Total Btu/h | Electrical Watt-Hr | Cooling COP | Rel Clg Btu/h | Rel A/C Watt-Hr | Norm Clg Load | Norm A/C Elec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 478 | None | None | 7085 | 1218 | 8303 | 1094 | 2.225 | 1.000 | 1.000 | --- | --- |
| 2 | 478 | None | None | 7810 | 1370 | 9180 | 1218 | 2.208 | 1.106 | 1.114 | --- | --- |
| 3 | 478 | None | None | 6859 | 981 | 7840 | 1107 | 2.075 | 0.944 | 1.012 | --- | --- |

Table 3. Karns Houses 1985 Cooling Data - Zoning With No Radiant Barriers

| House No. | Hours | Type RB | Rooms Zoned | Sensible Btu/h | Latent Btu/h | Total Btu/h | Electrical Watt-Hr | Cooling COP | Rel Clg Btu/h | Rel A/C Watt-Hr | Norm Clg Load | Norm A/C Elec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 166 | None | None | 5454 | 738 | 6192 | 806 | 2.250 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2 | 166 | None | 1 | 5711 | 960 | 6671 | 879 | 2.223 | 1.077 | 1.090 | 0.975 | 0.979 |
| 3 | 166 | None | 2 | 5196 | 697 | 5893 | 823 | 2.098 | 0.952 | 1.020 | 1.008 | 1.008 |

Table 4. Karns Houses 1985 Cooling Data - No Zoning With Radiant Barriers Present

| House No. | Hours | Type RB | Rooms Zoned | Sensible Btu/h | Latent Btu/h | Total Btu/h | Electrical Watt-Hr | Cooling COP | Rel Clg Btu/h | Rel A/C Watt-Hr | Norm Clg Load | Norm A/C Elec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 518 | None | None | 5813 | 1214 | 7027 | 884 | 2.329 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2 | 518 | HRB | None | 5215 | 884 | 6099 | 816 | 2.190 | 0.868 | 0.923 | 0.785 | 0.829 |
| 3 | 518 | TRB | None | 5095 | 711 | 5807 | 817 | 2.082 | 0.826 | 0.924 | 0.875 | 0.913 |

Table 5. Karns Houses 1985 Cooling Data - Zoning With Radiant Barriers Present

| House No. | Hours | Type RB | Rooms Zoned | Sensible Btu/h | Latent Btu/h | Total Btu/h | Electrical Watt-Hr | Cooling COP | Rel Clg Btu/h | Rel A/C Watt-Hr | Norm Clg Load | Norm A/C Elec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 118 | None | None | 8145 | 1782 | 9927 | 1260 | 2.309 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2 | 118 | HRB | 1 | 7311 | 1415 | 8726 | 1168 | 2.190 | 0.879 | 0.927 | 0.795 | 0.832 |
| 3 | 118 | TRB | 2 | 7346 | 1054 | 8400 | 1197 | 2.057 | 0.846 | 0.950 | 0.896 | 0.938 |

Note: House #1 No RB, No zoning
HRB = RB on top of insulation, 1 bedroom zoned off = 11.23% of house volume
TRB = RB on roof trusses, 2 bedrooms zoned off = 20.70% of house volume

Table 6. Measured Effects of Zoned-off Rooms on House HVAC Loads

| | Percent Change in House Load | | | |
|---|---|---|---|---|
| (Volume Zoned-Off)-> | (0.00%) | (11.23%) | (20.70%) | (40.96%) |
| Res Htg Zoning | 0.00 | ---- | -16.80 | ---- |
| HP Htg Zoning | 0.00 | ---- | -9.70 | -18.20 |
| A/C Clg Zoning | 0.00 | -2.50 | 0.80 | ---- |
| A/C Clg Zoning w RB | 0.00 | 1.27 | 2.40 | ---- |

Note: HVAC load (delivered Btu/h) changes are relative to same house setup with no zoned-of rooms.

Table 7. Measured Effects of Zoning on Heat Pump Operation and Evaporator Air Flow

| No. Vents Blocked | % House Volume | Outdoor Temperature Dry Bulb | Outdoor Temperature Wet Bulb | Indoor Temperature Dry Bulb | Indoor Temperature Wet Bulb | HP Pressures (psig) Suction | HP Pressures (psig) Discharge | Airflow (ft/min) | % Airflow Change |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00 | | | 75 | 63 | 64 | 215 | 479.30 | 0.00 |
| 1 | 11.23 | 82 | 73 | 75 | 63 | 64 | 214 | 478.80 | -0.10 |
| 2 | 31.40 | | | 75 | 63 | 66 | 218 | 479.50 | 0.15 |
| 3 | 40.96 | | | 75 | 63 | 68 | 225 | 458.50 | -4.38 |
| 0 | 0.00 | 89 | 77 | 75 | 63 | 68 | 228 | 474.00 | 0.00 |
| 2 | 11.23 | | | 75 | 63 | 68 | 231 | 475.20 | 0.25 |

Table 8. Measured Formaldehyde Concentrations (ppm) at Karns During Zoning Cooling Experiments/m

| Date | Time | Gr Room | BR #1 | BR #2 | BR #3 |
|---|---|---|---|---|---|
| 9/24 | 1130 | 0.13 | 0.14 | 0.15 | 0.10 |
| | 1300 | 0.15 | 0.17 | 0.15 | 0.14 |
| 9/25 | 0850 | 0.14 | 0.11 | 0.15 | 0.12 |
| | 1240 | 0.12 | 0.14 | 0.20 | 0.16 |
| 9/27 | 0845 | 0.16 | --- | 0.15 | 0.09 |
| | 1300 | 0.13 | --- | 0.16 | 0.10 |

Notes: BR #1, BR #2, BR #3 all zoned off
Great Room not zoned off
All concentrations +/- .02 ppm

Table 1. MEASURED INSIDE DIMENSIONS OF KARNS HOUSE #2

| ROOM LOCATION | Length (ft) | Width (ft) | Height (ft) | Area (sq ft) | Volume (cu ft) | % of Tot Volume | Windows Area (sq ft) | Windows Facing (Azim) | Windows % of Tot Area |
|---|---|---|---|---|---|---|---|---|---|
| Bedroom #1 (SBB) | 15.63 | 10.96 | 7.92 | 171.2 | 1355.5 | 15.72 | 16.04 | South | 14.46 |
| SBB Bathroom | 7.00 | 4.92 | 7.92 | 34.4 | 272.4 | 3.16 | 0.00 | - | 0.00 |
| SBB Closet | 8.21 | 1.83 | 7.92 | 15.0 | 119.1 | 1.38 | 0.00 | - | 0.00 |
| Bedroom #2 (NBB) | 9.75 | 10.96 | 7.92 | 106.8 | 845.9 | 9.81 | 14.25 | North | 12.84 |
| NBB Closet | 4.96 | 3.13 | 7.92 | 15.5 | 122.7 | 1.42 | 0.00 | - | 0.00 |
| Bedroom #3 (NCB) | 9.75 | 9.63 | 7.92 | 93.8 | 743.0 | 8.62 | 14.25 | North | 12.84 |
| NCB Closet | 4.94 | 1.88 | 7.92 | 9.3 | 73.3 | 0.85 | 0.00 | - | 0.00 |
| Great Room (GR) | 25.58 | 19.27 | 7.92 | 493.0 | 3903.0 | 45.27 | 30.48 | North | 27.47 |
| Kitchen | 10.33 | 3.00 | 7.92 | 31.0 | 245.4 | 2.85 | 35.94 | South | 32.39 |
| Kitchen Closet | 4.96 | 4.96 | 7.92 | 24.6 | 194.6 | 2.26 | 0.00 | - | 0.00 |
| Hallway + Closet | 17.92 | 3.04 | 7.92 | 54.5 | 431.5 | 5.00 | 0.00 | - | 0.00 |
| Main Bathroom | 8.17 | 4.88 | 7.92 | 39.8 | 315.2 | 3.66 | 0.00 | - | 0.00 |
| TOTALS -------> | | | | 1089.0 | 8621.6 | 100.00 | 110.96 | | 100.00 |
| | | | | | | | | | |
| Garage | 23.23 | 11.63 | 8.25 | 270.0 | 2227.8 | | | | |

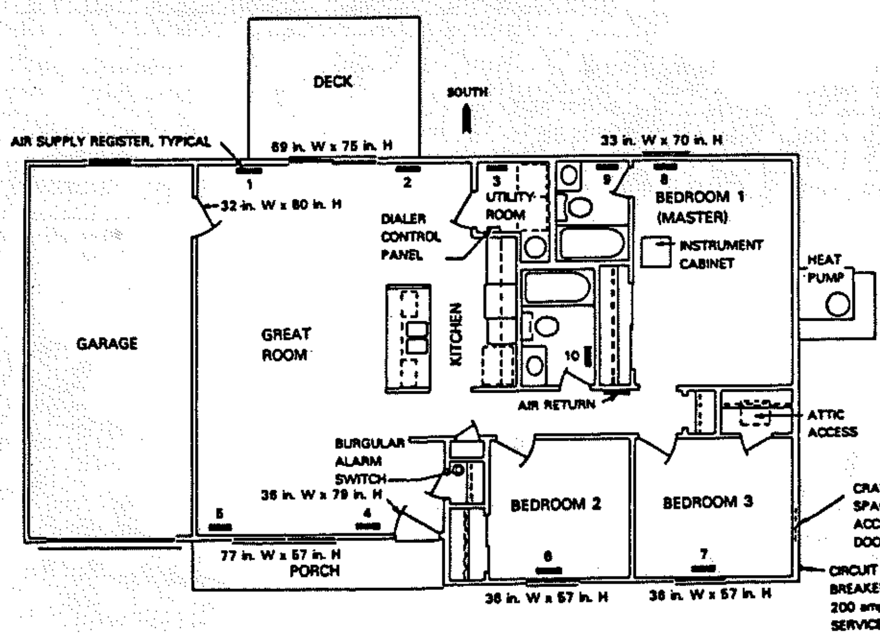


*Figure 1. Floor layout of Karns house*

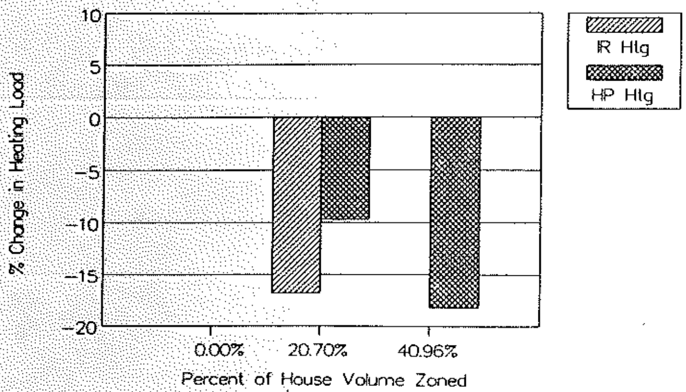


*Figure 2. Effect of zoning on house heating load*

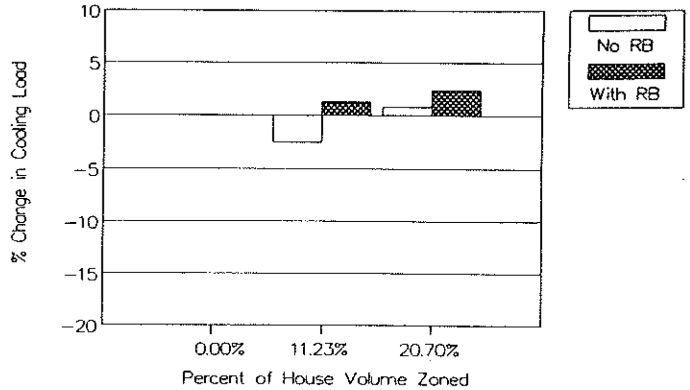


*Figure 3. Effect of zoning on house cooling load*

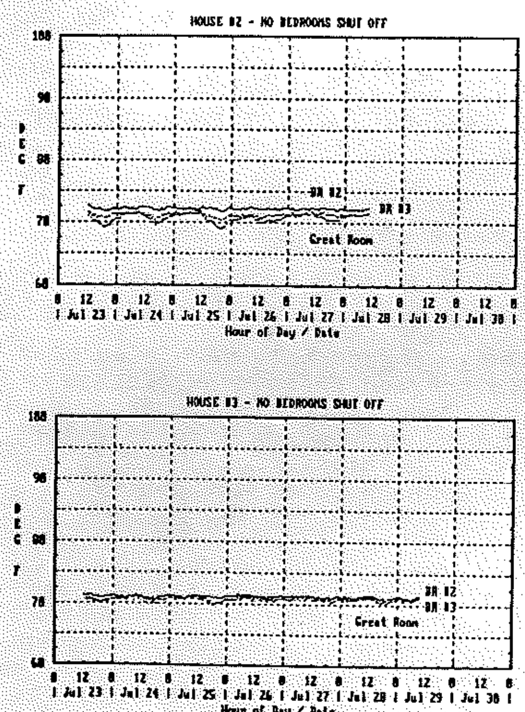


*Figure 4. House Temperatures with no zoned-off rooms*

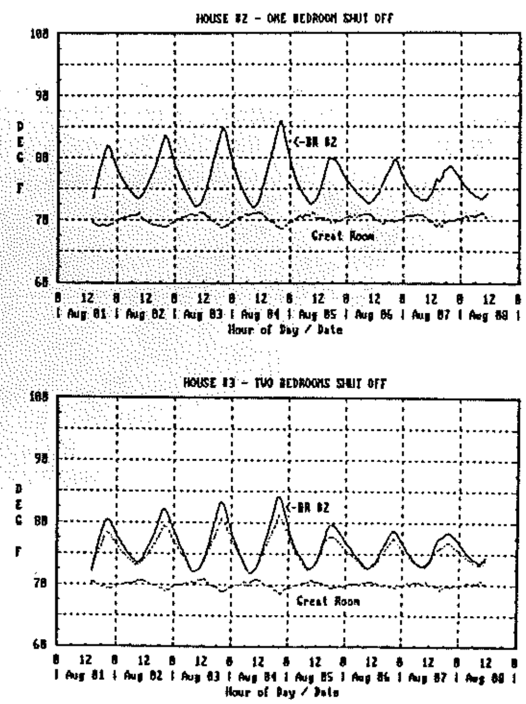


*Figure 5. House temperatures (cooling) with zoned-off rooms*