

EFFECTS OF WINDOW SIZE AND MASS ON THERMAL COMFORT USING AN INTELLIGENT VENTILATION CONTROLLER

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ABSTRACT

A microcomputer-controlled thermostat has been designed that manages airflow according to cooling needs in a building and resources in the environment. This system is an intelligent control system with both indoor and outdoor temperature sensors that uses rules to control a whole-house fan, in addition to the furnace and air conditioner. No such thermostat is currently available commercially. The most effective rule, proposed in a previous paper, was used to determine the effects of modifying the window area and the amount of mass. Results demonstrate the importance of adding mass and controlling solar radiation on a venting system that uses outdoor air -economizer cooling-.

1. INTRODUCTION

The greatest potential source of FREE cooling energy in most California climates is outdoor air. Typically in much of California, summer daytime temperatures are too hot but night temperatures are quite comfortable. This controller knows how much night-time air should be brought in to cool down the building's interior mass so that it can 'coast' comfortably through the next day. The need for air conditioning can be greatly reduced or even eliminated. In a previous paper (1), we demonstrated the feasibility of a new kind of intelligent ventilation controller that can minimize cooling energy costs and proposed a rule, derived experimentally, to operate it. Nevertheless, the performance of this system can be seriously compromised if certain design considerations are not taken into account regarding the amount of mass and the control of solar radiation.

2. EXPERIMENTAL SYSTEM

The experimental system consists of a Controller-Processor with thermistors to measure temperature, a Laptop computer connected to the Microcomputer which contains the control programs and collects and stores experimental data, the two test cells and an active ventilation system, which consists of a 4-inch inlet and on the outlet side a four-inch constantly running fan and a reducer to match the diameter of the anemometer. The inlet damper is opened and closed in the experimental cell by a signal from the microcomputer, and the damper is fixed in the closed position on the control cell. The "closed" position is actually open slightly to allow the same controlled amount of infiltration in each cell. The tests and system are explained in more detail in (1), (2) and (3).

Two identical test cells were built simulating the characteristics of typical California slab-on grade houses. They are 4 ft wide by 8 ft long and 8 ft high and are oriented with the longest facade towards the east and west. The cells have 3" foam R12 insulation on the outside and ¼" gypsum inside the walls and roofs. The floor is hardboard placed on top of an insulation panel and the roof has two layers of insulation, one on top of each other for R24. There is a 2 x 2 ft (4 ft²) double pane window on the south side with a Solar Heat Gain Coefficient of 0.72 and a U value of 0.75. The ratio of the glazing to floor area is 12.5 %. The east and west walls are shaded by another layer of insulation separated by about 3 inches from the wall. The walls and windows are carefully sealed so that infiltration is controlled only by the fan and damper system.

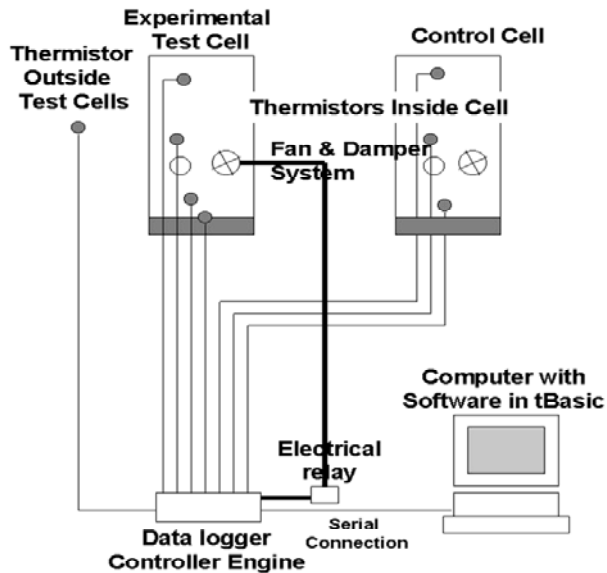


Fig. 1: The Experimental System

The flow rate is adjusted to 3.9 air changes per hour when the damper open and 0.7 air changes when it is closed, representing infiltration. In the control cell the damper is kept closed with a fixed airflow rate of 2.4 cfm (0.7 air changes per hour). One series is performed with a maximum air change rate of 15-air changes hour in the experimental cell and an indeterminate minimum air change rate close to 0.5 air changes per hour. With a high capacity whole house fan, up to 30 air changes per hour can be achieved.



Fig. 2: The Test Cells

The objective of the controller rules that were tested in the first part of this project was to use the outdoor air to achieve comfort with minimum energy consumption. Since both cells are built identically, performance could be evaluated by comparing the results of the experimental cell with the control cell. The most effective rule that was tested was:

If $t_o < t_i$ and $t_i > C_{f_low}$ and $t_i < C_{f_high}$ then activate fan else fan off. (1)

Where: t_o is the temperature outside; t_i is the temperature inside; C_{f_low} is comfort low and C_{f_high} is Comfort high. Comfort low and comfort high are adjustable by the user and the most effective values tested were $C_{f_low} = 18.33$ C (65 F) and $C_{f_high} = 25.55$ C (78 F).

Several series were performed with the equivalent of different size windows and two amounts of mass inside the building.

The window size was modified by covering either the whole window with insulation, covering 50% or leaving it completely uncovered, approximating the effect of modifying the size of the window.

Each cell has 106 cement bricks distributed evenly in the floor simulating a concrete slab. The bricks are 4" x 8" x 2.5" and are spread evenly over the surface of the floor with a thickness of 2.5". 110 bricks were added to the experimental cell to determine the effect of increased mass.

3. EXPERIMENTAL RESULTS

Several tests were performed in the summer of 2002 and seven of them are presented in this paper to explain the effects of modifying the amount of mass, the size of the window and the air change rate.

TABLE 1: TESTS PRESENTED IN THIS PAPER

Series	Difference from Previous	Experimental Cell	Control Cell
1	No Controller	Window: 50% Air Change: 0.7 mass: 760 lbs brick	Window: 100% Air Change: 0.7 mass: 760 lbs brick
2	Added shade to experimental	Window: 0% Air Change: 0.7 mass: 760 lbs brick	Window: 100% Air Change: 0.7 mass: 760 lbs brick
3	Windows added and controller activated	Window: 100% Air Change: 0.7-3.9 mass: 760 lbs brick	Window: 100% Air Change: 0.7 mass: 760 lbs brick
4	Eliminated window in experimental	Window: 0% Air Change: 0.7-3.9 mass: 760 lbs brick	Window: 100% Air Change: 0.7 mass: 760 lbs brick
5	Added Mass	Window: 0% Air Change: 0.7-3.9 mass: 1560 lbs brick	Window: 100% Air Change: 0.7 mass: 760 lbs brick
6	Added window	Window: 100% Air Change: 0.7-3.9 mass: 1560 lbs brick	Window: 100% Air Change: 0.7 mass: 760 lbs brick

3.1. Series 1: 2 ft² Window compared to no Window

In the first series the window of the control cell is 2 ft² and the window of the experimental cell is 4 ft². The venting system is set at a fixed infiltration rate of 0.7 air changes/hour, and the amount of mass, 106 bricks.

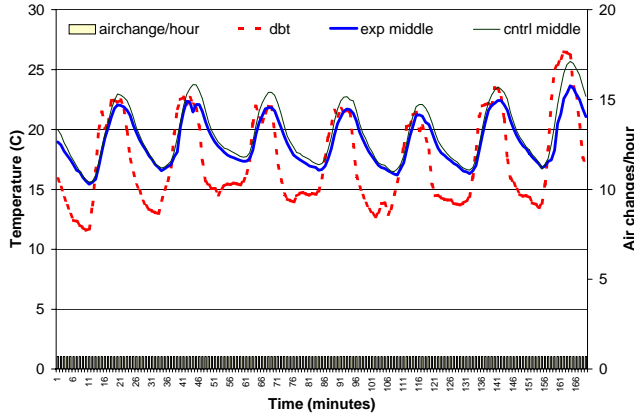


Figure 3: Series 1, 50% Shade versus Unshaded.

3.2. Series 2: 4 ft² Window compared to no Window

The same setup is used except that now the window is eliminated in the experimental test cell.

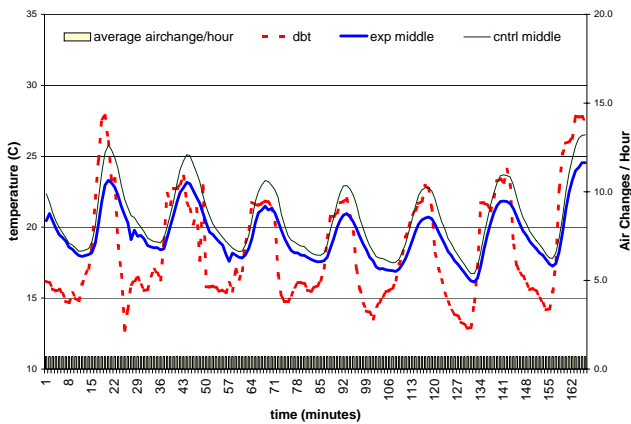


Fig. 4: Series 2, 100% Shade versus Unshaded.

3.3. Series 3: Window and vented

In this series the venting system in the experimental cell is activated with the rule indicated in section 2, which will not be modified in any of the series. The control cell has a fixed infiltration rate of 0.7 air changes/hour. Both test cells have 4 ft² windows unprotected from solar radiation and the same amount of mass, so that the only different variable is the operation of the venting system.

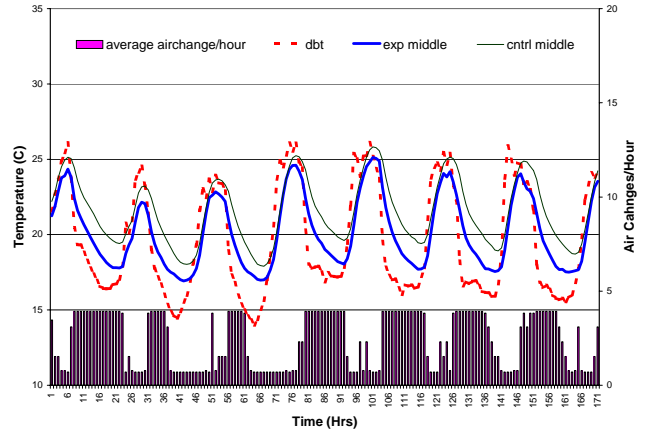


Fig. 5: Series 3, Window and vented

3.4. Series 4: Eliminate window

The window is eliminated in the experimental cell to determine the effect of reducing solar radiation on the performance of the venting system. The other variables are similar to those in series 3.

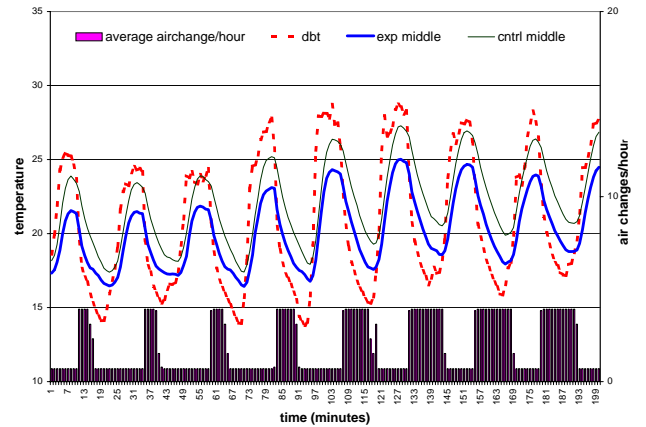


Fig. 6: Series 4, Eliminate Window

3.5. Series 5: Additional Mass

In this series 110 bricks are added to the experimental cell.

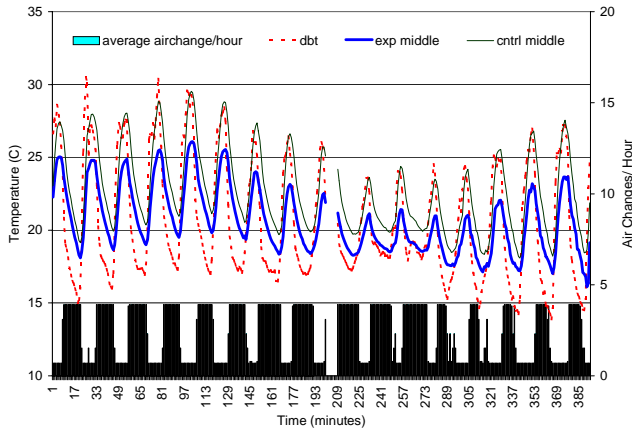


Fig. 7: Series 5, additional mass

3.6. Series 6: Increasing window size

The window size is 4 ft² in both cells.

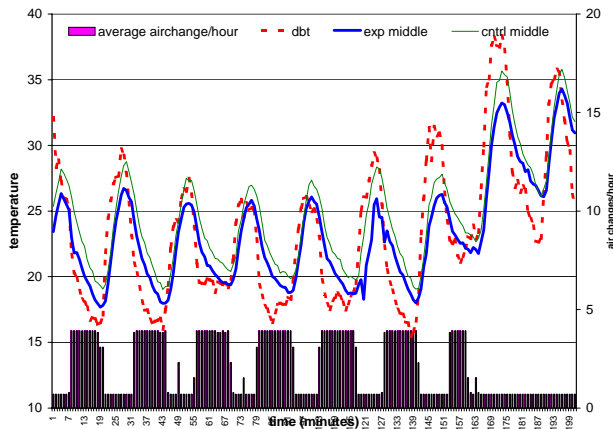


Fig. 8: Series 6, Increasing Window Size

4. RESULTS

Comparison of the average maximum temperatures in the cell with the average maximum outdoor temperatures gives a preliminary idea of the performance of the system (Table 2). The larger the difference between the maximum averages in both cells, the better the performance of that specific series.

TABLE 2: Average Maximum Temperatures in the Series

Series	Outdoor	Experimental Cell	Control Cell	Experimental minus Control Cell
1	22.9	22.0	23.4	1.4
2	24.3	22.3	24.3	2.0
3	25.4	23.9	24.7	0.85
4	27.0	23.4	25.6	2.2
5	27.7	24.0	27.2	3.3
6	30.7	27.8	29.6	1.8

Table 1 shows that the largest reduction in the average outdoor maximum temperature is 3.3 C in series 5, when the test cell has no windows, the venting system is working with a maximum air change rate of 3.9 changes/hour, and the mass of bricks is double that of the other series.

But, comparison of the temperature reduction without considering the swing or its relationship to the outdoor value is not a reliable indicator of performance. To compare them with more reliability, another variable, the system performance variable must be used.

4.1. Comparison using Temperature Difference Ratio

The series are compared with each other with a ratio that permits the comparison across different series, performed at different times. This number is called the temperature difference ratio and is determined by comparing the average reduction of the maximum temperature inside the cell with the average swing as expressed in the following equation:

$$T_{\max\text{out}} - T_{\max\text{in}} / T_{\max\text{out}} \quad (2)$$

Where:

$T_{\max\text{out}}$: maximum temperature outside

$T_{\max\text{in}}$: maximum temperature inside

$T_{\min\text{out}}$: minimum temperature inside

The numerator expresses the reduction of the maximum temperature and the denominator is the outdoor swing. The closer the performance variable is to one unit, the more efficient the specified set-up is for cooling the space. A value of one means that the reduction of the maximum temperature inside the space as compared to the outdoor temperature is equal to the outdoor swing.

For this equation to be valid there must be a good correlation between the outdoor swing and the reduction of the outdoor dry bulb temperature. This is the case in these series; as the swing increases, so does the temperature reduction.

TABLE 3: PERFORMANCE OF THE DIFFERENT SERIES.

Series	Performance Experimental	Performance Control	Improvement over Control (Numerical)
S 1	0.094	-0.052	0.147
S 2	0.197	0.001	0.196
S 3	0.163	0.075	0.088
S 4	0.312	0.124	0.188
S 5	0.319	0.045	0.273
S 6	0.228	0.087	0.141

S 7	0.292	0.132	0.161
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The analysis of this data is performed by comparing the performances of the experimental cells between them in the different series or by comparing the performance of the experimental cells with the performance of the control cell in each series. The first case gives an indication of the overall performance of the series and the effects of modifying the variables from one series to another. The second case provides additional information on how the variables can affect the performance of the test cell while providing additional options for comparison.

4.1.1 Comparison of Performances in Experimental Cells

The best overall performance, 0.319, is in the experimental test cell in series 5. The performance of this cell is 62% better than the performance in series 2, which has the same window size but with the venting system off and less mass.

Series 1 and 2 have a fixed infiltration rate with the same amount of mass. When the south-facing window is reduced from 2 ft² in series 1, to 0 ft² in series 2, the performance of the system increases from 0.094 to 0.197, or 109%. The performance of series 1 is about 29 % of the best series and in series 2, about 60.8% of the best series, demonstrating the effect of reducing solar radiation in the performance of the system. Figure 10 indicates the correlation between the window to floor ratio and the performance with a predictive equation for the performance of the system with a given window to floor ratio.

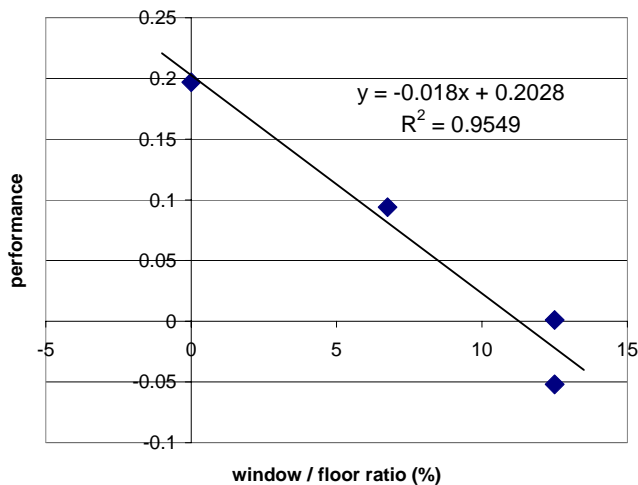


Fig 10: Correlation between window to floor area (%) to performance.

When the window size is increased from 0 ft² in series 5, to 4 ft² in series 6, the performance is reduced by 28.5%. With the venting system working, the changes in the performance

of the system have a similar slope but with a performance .109 better than when the venting system is off:

$$y = -0.0119x + 0.312$$

Series 7 has a higher air change rate, up to 15 air changes/hour compared to 3.9 in the other series. Its performance is 48% better than the performance of series 2 that has similar characteristics but no venting system. The difference between a 48% and a 62% improvement, when comparing series 2 and 5 and 2 and 7 could be the difference in the air change rate, from 3.9 to 15 air changes/hour.

Series 7 checks the effect of increasing the air change rate. There are no windows and the same amount of mass in both cells. The experimental cell in series 4 and 7 have the same conditions except for the air change rate and both have very similar performances, but the performance difference between series 2 and 4 and between series 5 and 7 are about 62%.

4.1.1 System Performance of the Experimental Cells compared to the control cells

In series 1, the difference between the experimental cell and the control cell is 1.4 C and 0.147 points. The performance of the control cell is 35% of the performance of the experimental cell.

In series 2, the difference between the experimental cell and the control cell is 2 C, and 0.196 points. The performance of the control cell is 0% of the performance of the experimental cell.

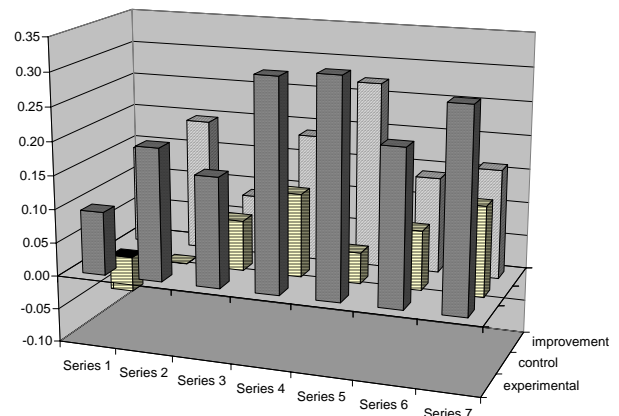


Fig. 10: Performance of the Different Series.

In series 3, the difference between the experimental cell and the control cell is 0.85 C and 0.088 performance points. The

performance of the control cell is 46% of the performance of the experimental cell.

In series 4, the difference between the experimental cell and the control cell is 2.2 C and 0.188 performance points. The performance of the control cell is 40% of the performance of the experimental cell.

In series 5, the difference between the experimental cell and the control cell is 3.3 C and 0.273 performance. The performance of the control cell is 14% of the performance of the experimental cell.

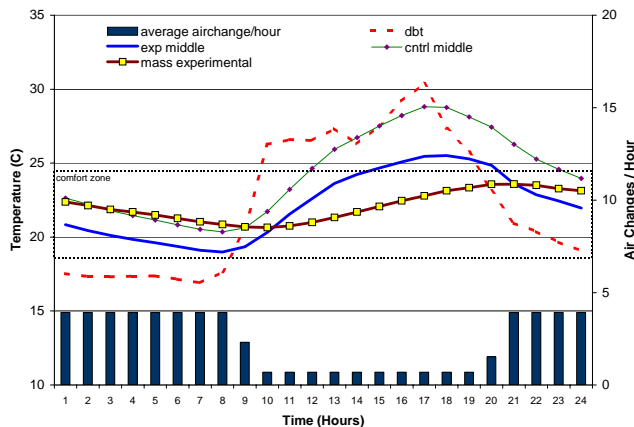


Fig. 11: One day in series 5

In series 6, the difference between the experimental cell and the control cell is 1.8C and 0.141 performance points. The performance of the control cell is 38% of the performance of the experimental cell.

In series 7, the difference between the experimental cell and the control cell is 2C and 0.161 performance points. The performance of the control cell is 45% of the performance of the experimental cell.

5. CONCLUSIONS

The most important single factor that reduces the performance of a cooling system operating with natural ventilation is solar radiation. This is proven in all the series that have different window sizes, and the reduction in performance is proportional to the window size. In a non vented test cell the performance decreases about .018 points per 1% increase in window to floor ratio, and in a vented cell it decreases about 0.012 points per 1% increase.

Because the temperature of the supply air into the building can be higher than the temperature of the air that is supplied by mechanical cooling systems, a higher air change rate must be established to achieve the same cooling. The largest difference in performance was measured between the fixed

air change rate of 0.7 and the venting system working with a maximum of 3.9 air changes/hour. When the air change rate was increased to a maximum of 15 air changes an hour there was no noticeable difference. More series need to be performed to determine a predictive equation.

Increasing the amount of mass also increased the performance of the system, but more series need to be performed to determine a predictive equation.

The different series show that a smart thermostat and a whole house fan would provide significant savings to Southern Californian ratepayers, but several design features, especially solar control, must be taken into consideration for the venting system to work appropriately

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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