Energy Savings in Buildings Using
Air Movement and Allowing Floating Temperatures in Rooms

Syd Spain
Architect/Senior Planner
CRS Sirrine, Inc.
Houston, Tx

ABSTRACT

The purpose of the research study was to determine if building loads could be reduced by using an intelligent controller rather than a thermostatic controller to operate heating and air conditioning equipment. In order to switch the equipment on and off at the proper times, the intelligent controller calculated temperature limits using a mathematical procedure that determined the percentage of people who would be comfortable in rooms of the building. Simulations showed that the annual cost savings from intelligent controllers ranged from 6 to 37 percent for residences and from 6 to 29 percent for offices. An ancillary study showed that a ceiling fan provided comfort in a 112 square foot floor area to 85 F and in a 200 to 250 square foot area to 82 F.

INTRODUCTION

Building energy load savings and cost savings were simulated for an intelligent controller and a thermostatic controller in seven buildings in nine predominately warm climate cities. Since other research has shown that fans provide additional comfort during warm periods, the building simulations included both fan-on and fan-off conditions. The intelligent controller calculated temperature limits using a procedure that considered variables which have been determined from research studies with human subjects to affect people's comfort. These variables of dry bulb temperature, mean radiant temperature, humidity, airspeed, clothing insulation value, and the activity level of the occupants of a room were used to calculate warm and cool temperature limits within which 80 percent of the people would be comfortable.

The simulations showed that comfort controllers saved energy in office buildings and residences in all the cities which were studied. The least savings occurred in the mildest and coldest climates of Los Angeles and Washington, D.C., while the greatest savings were in the warmest climates of Miami and Houston. The energy load and energy cost savings were related to similar buildings with normal thermostatic or temperature controllers. The cost savings ranged from 6 to 37 percent for residences and from 6 to 29 percent for offices of the total annual energy costs for operating the buildings. The findings recommend that the intelligent or comfort controllers should be considered for buildings in cities where the present value of the simulated costs savings is less than the installation costs of fans and controllers.

A separate study analyzed a ceiling fan to determine its effective comfort zone for two temperature conditions. The ceiling fan which had a 52 inch blade diameter provided sufficient airspeed for human comfort to 85 F in a 112 square foot floor area when the fan was operating at full speed and in a 68 square foot floor area when the fan was operating at a low speed of 200 fpm. At a temperature limit of 82 F, the fan provided comfortable conditions in a 200 to 250 square foot floor area when it was operating at both low and high speed.

METHODOLOGY

The buildings were simulated using an energy calculation program for buildings called ENERCALC[1] which estimated the loads and savings. Building loads were also compared for fan-on and fan-off conditions to determine if higher than normal airspeeds from ceiling fans or other air movement equipment would provide additional energy load savings for the buildings. The results were statistically analyzed, tables were prepared to allow comparisons of the loads, and conclusions were made based upon the data.

DESCRIPTION OF THE BUILDINGS AND THE COMPUTER PROGRAM USED FOR THE SIMULATIONS

The residential buildings included four types of buildings found by the National Association of Home Builders Research Foundation Survey of 1979[2] to represent 90 percent of all new single family homes constructed in the United States. The residences had R11 walls and ceilings, double pane glass, standard wood stud construction, aluminum siding, asphalt shingle roofs, and concrete slab-on-grade floors. Their windows comprised 10-12 percent of the floor area, and the size of the residences ranged from 1200-2240 square feet. There were 3.2 occupants per building. The ventilation per person was zero air changes per hour, and the program simulated open windows during mild temperature periods. The heating system was a centralized gas unit with a fixed efficiency of 77 percent, and the air conditioning system was direct expansion residential unit with an EER of 9.2.

All office buildings had a ventilation rate of 10 cfm/person. The economizer cycle was switched on, and a variable air volume unit distributed the conditioned air. The fuel type for heating was gas and for cooling was electricity. The heating systems had an efficiency of 75 percent, and the air conditioning system's EER was 9.0.

The small office building was the same building used in the ASHRAE Handbook of Fundamentals 1981[3] for cooling load calculation problems. It was chosen because it has served as a standard design for the energy analysis of a small office building for several years. The building had an R8 roof, concrete block and brick walls, single pane glass with light-colored venetian blinds, and a concrete slab-on-grade floor. The windows comprised two percent of the floor area, and the building area was 4000 square feet. There were 85 office workers in the building from 8 a.m. to 5 p.m. The fluorescent lights required 17,500 watts and the tungsten lights used 4000 watts continuous from 8 a.m. to 6 p.m.

The medium and large sized office buildings were based on an office building design used by Lawrence Berkeley Laboratory (LBL) in their Passive Cooling Technology Assessment program[4]. The buildings were 40,000 and 100,000 square feet in floor area respectively. They had R26 roofs, R14 curtain walls, double glazing, and a concrete slab-on-grade floor. The windows comprised 29 percent of the exterior wall and were equally divided by compass orientation. The occupancy was 175 square feet per person from 8 a.m. to 5 p.m. and was reduced to 50 percent occupancy from 5 p.m. to 6 p.m. The lighting load was based upon 2.5 watts per square foot.

Electric and gas rates for the cities in the simulations were taken from the Department of Energy's residential and commercial utility rate guides for SOLCOST data bank cities[5,6]. Escalation rates were based upon the Department of Energy's Electric Power Monthly newsletter[7] and the July/August 1984 issue of Solar Engineering and Contracting[8]. The electric escalation rate per year for residential buildings was 5 percent and for offices was 3.3 percent. The gas escalation rate per year for all buildings was 12 percent.

The computer program used for the energy load simulations had to be sufficiently flexible to analyze building properties, controls, and climates. Several programs were considered including the Department of Energy's DOE-2B energy analysis program, the National Bureau of Standards' Thermal Analysis Research Program, and the Texas A&M University Department of Architecture's ENERCALC[9] program. The locally developed program, ENERCALC, was chosen because it met the requirement for flexibility, and it could be easily modified when changes in the program were necessary. This advantage of program modification became the most important factor in the selection of the program, since the thermal load routines in the program were chosen and tested numerous times during the development of the comfort analysis process.

It utilizes ASHRAE algorithms, incorporates a weather simulation model, and performs hourly calculations of the data of both the building and the weather to determine an estimated energy use for heating, cooling, water heating, fans, and lighting on an annual basis. It calculates monthly energy use for the preceding categories and for gas and electric fuel use. The program stores the passive solar energy that enters through windows into the mass of the building. This stored heat offsets heating loads and is listed as passive solar loads on a monthly basis. Yearly totals of these categories are printed, and the total energy budget is provided. Peak loads for heating and cooling are computed and shown for the day and hour in which the load occurs.

Other output data from the program includes weather data; economic information; project and building data by zones; twenty-four-hour profiles of occupancy, hot water use, ventilation, electric energy use, thermostat settings for occupied and unoccupied days; materials; plots of energy demand for peak summer and winter days; peak demand profiles by season; seasonal average hourly demand profiles; a cost analysis; and a weather and energy summary for the year.

The cities chosen for the simulations were selected from the base cities list of the Department of Energy's Affordable Housing Through Energy Conservation program[10]. The cities were Albuquerque, Atlanta, Dallas, Houston, Jacksonville, Los Angeles, Miami, Nashville, and Washington, D.C.

OPERATION OF THE CONTROLLERS

The intelligent comfort controllers allowed the room temperatures to float until comfort calculations indicated that less than 80 percent of the people in the room were comfortable. If the room was warm, then fans were turned on and the comfort level was checked again. If the fans returned the comfort level to greater than 80 percent, then the HVAC equipment was not turned on. If the fans did not provide sufficient comfort, the air conditioner was turned on with a set point temperature which was equivalent to the 80 percent comfort condition. If the room was cool, then the heating system was turned on with a set point temperature which was equivalent to the desired 80 percent comfort condition. When rooms were not occupied, the HVAC equipment was cycled at temperature set points of 55 F and 90 F.

The thermostatic controller used a set point temperature of 68 F and 78 F, which are standard temperature set points for Federal facilities. The night setback temperature for all buildings with the thermostatic controller was 60 F.

RESULTS OF THE BUILDING ENERGY LOAD SIMULATIONS

The simulations and the statistical tests of the data showed that the intelligent controllers saved energy in office buildings and in residences in all climates simulated. Nonparametric statistical tests which analyzed the independent variables of the thermostatic controller, the intelligent controller with fan-off, and the intelligent controller with fan-on indicated with a significance greater than 0.001 that loads were different when the intelligent and thermostatic controller loads were compared.

Statistical tests using the paired-difference test of Friedman's two-way ANOVA by ranks indicated with a 95 percent confidence that significant annual load savings resulted from the intelligent controller with the fan-on in relation to the standard thermostatic controller for all offices. Similar annual load savings were significant for all residences except the two floor house. When the annual loads for intelligent controller with the fan-off were compared with the standard thermostatic controller, the differences were not significant for offices and for the townhouse, but were significant for the ranch house, the two floor house, and the split level residence.

The least savings occurred in the mildest and coldest climates of Los Angeles and Washington, D.C. while the greatest savings were in the warmest climates of Miami and Houston. Climates affected load variations more than the building types. For example, the load variations in MMBTU/100 square feet were 7.4:1.0 for climates and were 1.7:1.0 for building types. Savings percentages for loads and costs by building types are shown in Table 1 and Table 2.

Intelligent Comfort Controller's Annual Savings in Relation to the Thermostatic Controller

Building Type	Heating & Cooling Load Savings Fan Off Min-Max	Fan On Min-Max	Heating & Cooling Cost Savings Fan Off Min-Max	Fan On Min-Max
Ranch House	19%-89%	19%-88%	10%-89%	10%-88%
Townhouse	44%-86%	45%-86%	38%-85%	40%-87%
Two Floor House	36%-93%	36%-93%	30%-93%	30%-93%
Split Level	42%-92%	41%-91%	35%-92%	35%-91%
Small Office	27%-44%	44%-58%	35%-44%	40%-58%
Medium Office	23%-32%	30%-39%	22%-28%	30%-39%
Large Office	22%-31%	29%-37%	19%-31%	25%-36%

Table 1 Maximum & Minimum Load Savings in Percentages by Building Types

Intelligent Comfort Controller's Annual Savings in Relation to the Thermostatic Controller

Building Type	Heating & Cooling Cost Savings As A Percent of Energy Costs Fan Off Min-Max	Fan On Min-Max
Ranch House	7%-31%	7%-31%
Townhouse	6%-29%	6%-29%
Two Floor House	7%-37%	7%-37%
Split Level	8%-36%	8%-36%
Small Office	7%-23%	12%-29%
Medium Office	6%-16%	9%-19%
Large Office	8%-15%	11%-18%

Table 2 Maximum & Minimum Cost Savings in Percentages by Building Types

Note that residential heating and cooling loads for the intelligent controller were similar whether the fans were or were not operating, but the fans provided from 5 to 25 percent more load savings for all office buildings than did the intelligent controller without the fans. When all office building loads were considered, the ceiling fans saved 2 to 7 percent of the annual costs in relation to the intelligent controller without the fans. Statistically, the load variations between the fan-on and the fan-off conditions were too small to indicate a probable difference. The average annual cost savings that ceiling fans provided was $251 for small office buildings, $1209 for medium office buildings, and $2815 for large office buildings.

The ceiling fans did not reduce energy costs in the residences because the warm temperatures were quickly lowered by the air conditioning equipment, and this rapid cooling prevented a sufficient number of hours with warm temperatures for the ceiling fans to be effective. The offices had excess heat during many hours of the day. These heat loads caused temperatures to change more slowly, and there were many hours when the temperatures were near the upper boundary of the comfort zone where the ceiling fans provided cost savings.

Heating loads and costs were substantially lower than cooling loads and costs in all the buildings. A surprising phenomena occurred for all buildings and cities except Miami, which had no heating load. For buildings in climates with less than 2200 heating degree days, the thermostatically controlled buildings had lower heating loads than did the buildings with intelligent comfort controllers. This condition was caused by the 68F thermostat set point temperature which allowed less than 80 percent of the occupants to be comfortable when rooms were cool. The intelligent controllers maintained the 80 percent satisfied condition and used more heating energy.

Cost savings for residences and offices in dollars per 1000 square feet are shown in Table 3 and Table 4, and the ranks by cities for the average cost savings are shown in Table 5 and Table 6. The annual load savings by cities for residences and offices are included in Table 7 and Table 8, and the load values relate to the total energy loads for the buildings. The ranks by cities of the average annual load savings for residences and offices are shown in Table 9 and Table 10.

Cost Savings in Dollars/1000 ft^2 for Intelligent Controllers in Relation to Thermostatic Controllers

CITIES	Residences with Fan Off LOW	AVERAGE	HIGH
ALBUQUERQUE, NM	41.	65.	109.
ATLANTA, GA	39.	62.	101.
DALLAS, TX	98.	181.	279.
HOUSTON, TX	199.	381.	576.
JACKSONVILLE, FL	63.	122.	186.
LOS ANGELES, CA	17.	30.	44.
MIAMI, FL	136.	254.	384.
NASHVILLE, TN	32.	55.	89.
WASHINGTON, D.C.	23.	66.	122.

Table 3 Annual Energy Costs Savings by City for Residences

Cost Savings in Dollars/1000 ft^2 for Intelligent Controllers in Relation to Thermostatic Controllers

CITIES	Offices with Fan On LOW	AVERAGE	HIGH
ALBUQUERQUE, NM	116.	127.	137.
ATLANTA, GA	144.	156.	176.
DALLAS, TX	120.	136.	154.
HOUSTON, TX	136.	163.	188.
JACKSONVILLE, FL	113.	145.	187.
LOS ANGELES, CA	54.	102.	124.
MIAMI, FL	210.	233.	265.
NASHVILLE, TN	67.	85.	95.
WASHINGTON, D.C.	97.	112.	125.

Table 4 Annual Energy Costs Savings by City for Offices

RANK	Residences	Dollars/1000 ft^2
1	HOUSTON, TX	381.
2	MIAMI, FL	254.
3	DALLAS, TX	181.
4	JACKSONVILLE, FL	122.
5	WASHINGTON, D.C.	66.
6	ALBUQUERQUE, NM	65.
7	ATLANTA, GA	62.
8	NASHVILLE, TN	55.
9	LOS ANGELES, CA	30.

Table 5 Rank by City of the Average Annual Cost Savings for Residences for Intelligent Controllers in relation to Thermostatic Controllers

RANK	Offices	Dollars/1000 ft^2
1	MIAMI, FL	233.
2	HOUSTON, TX	163.
3	ATLANTA, GA	156.
4	JACKSONVILLE, FL	145.
5	DALLAS, TX	136.
6	ALBUQUERQUE, NM	127.
7	WASHINGTON, D.C.	112.
8	LOS ANGELES, CA	102.
9	NASHVILLE, TN	85.

Table 6 Rank by City of the Average Annual Cost Savings for Offices for Intelligent Controllers in relation to Thermostatic Controllers

Load Savings in MMBTU/1000 ft^2 for Intelligent Controllers in Relation to Thermostatic Controllers

CITIES	Residences with Fan Off LOW	AVERAGE	HIGH
ALBUQUERQUE, NM	4.25	5.98	7.50
ATLANTA, GA	10.31	13.91	17.28
DALLAS, TX	15.47	20.06	24.36
HOUSTON, TX	17.29	23.62	24.36
JACKSONVILLE, FL	15.37	23.62	29.37
LOS ANGELES, CA	3.90	4.90	5.58
MIAMI, FL	27.21	36.34	44.24
NASHVILLE, TN	10.56	15.21	19.30
WASHINGTON, D.C.	5.20	11.13	14.69

Table 7 Annual Load Savings by City for Residences

Load Savings in MMBTU/1000 ft2 for Intelligent Controllers in Relation to Thermostatic Controllers

CITIES	Offices with Fan On LOW	 AVERAGE	 HIGH
ALBUQUERQUE, NM	9.80	10.05	10.33
ATLANTA, GA	10.34	11.93	13.06
DALLAS, TX	11.49	14.21	15.96
HOUSTON, TX	11.77	15.40	16.83
JACKSONVILLE, FL	11.36	15.32	17.67
LOS ANGELES, CA	4.51	8.22	10.32
MIAMI, FL	18.07	22.61	25.42
NASHVILLE, TN	11.58	12.31	13.06
WASHINGTON, D.C.	11.03	11.48	11.86

Table 8 Annual Load Savings by City for Offices

RANK	Residences	Dollars/1000 ft^2
1	MIAMI, FL	36.34
2	HOUSTON, TX	23.62
3	JACKSONVILLE, FL	20.97
4	DALLAS, TX	20.06
5	NASHVILLE, TN	15.21
6	ATLANTA, GA	13.91
7	WASHINGTON, D.C.	11.13
8	ALBUQUERQUE, NM	5.98
9	LOS ANGELES, CA	4.90

Table 9 Rank by City of the Average Annual Load Savings for Residences for Intelligent Controllers in Relation to Thermostatic Controllers

RANK	Offices	Dollars/1000 ft^2
1	MIAMI, FL	22.61
2	HOUSTON, TX	15.40
3	JACKSONVILLE, FL	15.32
4	DALLAS, TX	14.21
5	NASHVILLE, TN	12.31
6	ATLANTA, GA	11.93
7	WASHINGTON, D.C.	11.48
8	ALBUQUERQUE, NM	10.05
9	LOS ANGELES, CA	8.22

Table 10 Rank by City of the Average Annual Load Savings for Offices for Intelligent Controllers in Relation to Thermostatic Controllers

These tables indicate that the warm climate cities of Houston, Miami, Dallas, and Jacksonville had the greatest energy and cost savings for residences. The cooler climate cites of Washington, Albuquerque, Atlanta, and Nashville had substantially less energy cost savings for residences. The cities with the highest cost savings for offices and residences were in regions with large cooling load requirements. Annual heating and cooling loads for offices are illustrated by city in Fig. 2. The mild climate of Los Angeles had the lowest loads for all building types.

Note that the Washington, D.C. buildings had load and cost savings greater than buildings in Albuquerque and Los Angeles. This suggests that intelligent comfort controllers in cold climate buildings may provide load and cost savings which are slightly less than in warm climate buildings and somewhat higher than the dry and mild climate buildings. The small amount of cost savings for offices in Nashville was caused by the city's low energy cost.

Tests were conducted with a ceiling fan in a 270 square foot test room with airspeed measurement equipment to determine the fan's comfort efficiency. The ceiling fan tests indicated that the zone beneath the fan was the region of highest comfort when room temperatures were warm. The fan's main air plume from the fan was elliptical in shape with proportions similar to the room's proportions. The tests showed that the ceiling fan provided sufficient airspeed at its highest airspeed setting for comfort to 85 F in an area of 112 square foot beneath the fan. At an upper temperature limit of 82 F, the ceiling fan provided comfortable conditions for 80 percent of the test room's occupants essentially throughout the room when the fan was operating at either full speed or at low speed. Airspeed contour drawings of the fan's airspeeds suggested that the size of the main air plume could be enlarged to provide a larger comfortable area beneath the fan.

CONCLUSIONS

1 Intelligent or comfort controllers should be considered for buildings in cities where the present value of the simulated costs savings is less than the installation costs of fans and controllers.

2 The tested 52 inch ceiling fan provided effective comfort in a 100 square foot area to 85 F and a 200 to 250 square foot to 82 F.

3 Future ceiling fans should be designed to create a larger main air plume. New designs for the fan blade, louvers, baffles, or other devices could increase the air plume size and the fan's effectiveness.

LIMITATIONS OF THE RESEARCH

Since the problem related to the reduction of energy loads for buildings, the simulations were designed to minimize loads and not to maximize human comfort conditions. This research decision encouraged higher cost savings, but it did not allow the fans to operate a sufficient number of hours during warm periods to substantially increase comfort conditions within the buildings.

The research methodology allowed fans to operate only when the intelligent controllers permitted floating temperature in a large temperature dead ban. The fans were not simulated with thermostatic controllers to determine if comfort conditions improved.

Time and equipment constraints limited the fan test to one fan in a single room size. Ceiling fan performance should change in relation to fan characteristics and room size.

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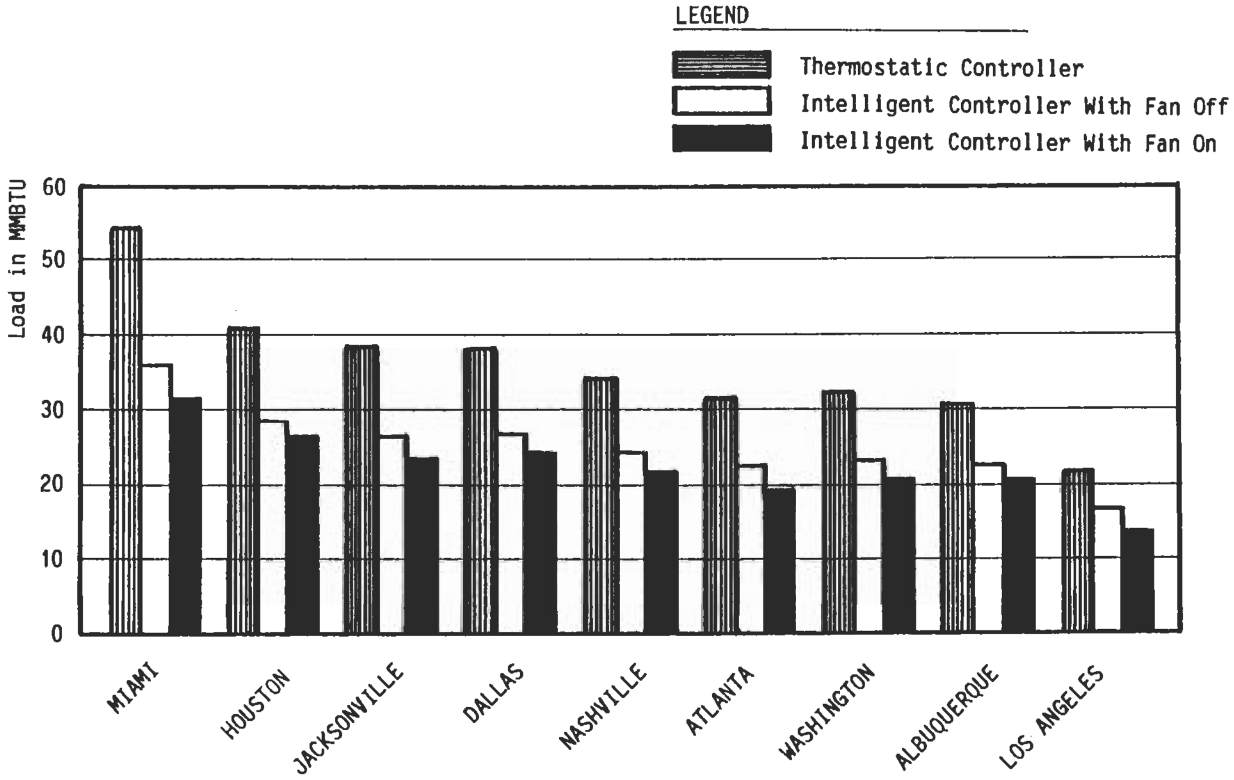

Fig. 1 Annual Heating and Cooling Loads for Offices in MMBtu by Cities