Energy Conservation and Thermal Comfort in a New York City High Rise Office Building

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ABSTRACT / Detailed analysis of an energy conservation program implemented on a 46 story government building is presented. Conservation was achieved by reduced lighting, changes in building operating hours, thermostat settings of 20°C (68°F) in the winter and 27°C (80°F) in the summer, and the elimination of air conditioning reheat. As a result, energy consumption in the summer was reduced by 54 percent. A survey of the occupants' thermal comfort and the insulating value of their clothing was taken. In the summer 68 percent were comfortable compared with 80 percent in the winter. The insulating value of the clothing worn by the women was consistently less than that of the men; the difference was largest in the summer. Though the temperatures in the occupied spaces were not as cold or as warm as the thermostat settings, the survey indicates that comfort could be improved if occupants dressed more appropriately for the expected thermal environment of the work place.

An energy analysis with a building simulation program (NBSLD) was also undertaken. The simulated energy consumption was within 5 percent of the measured values. Additional large savings may be achieved in this and similar buildings through a reduction in the energy cost of transporting air and chilled and hot water around the building for the environmental control systems.

Introduction

In 1974 the Federal Energy Administration (FEA) developed guidelines for energy conservation in buildings. These guidelines were imposed on government buildings. The John B. Pierce Foundation Laboratory under contract from FEA studied the energy saving and thermal comfort impact of these guidelines on the General Services Administration (GSA) Building, 26 Federal Plaza, New York City (Gagge and Nevins 1976).

The 1974 energy conservation program consisted of reductions in the lighting level, changes in the building operating schedules, altered thermostat settings, and the elimination of air conditioning reheat. The energy flows before and after the implementation of conservation measures were analyzed and compared. The thermal environment was measured during mid-winter and summer for temperature, thermal radiation, air movement and humidity. A large sample of the building's occupants were polled to ascertain the level of thermal comfort and the insulation value of the clothing worn.

The Building

The building (Fig. 1) has 46 floors above ground. The exterior walls consist of glass plates, masonry units, granite and limestone. About 15 percent of the exterior is glass; three sides have 21 percent and the back has none. A large addition is currently being added through the windowless back wall. The average thermal conductance of the walls (U_0) is 2.78 W/(m^{2}K). The nominal overall dimensions of the building are 92 by 37 m with a height of 168 m (300 × 120 × 550 ft).

The interior is primarily office space with the following major exceptions. The basement houses a parking garage, loading dock and mechanical equipment; the first floor is a reception and information hall area. The second floor contains four courtrooms and the sixth floor has a cafeteria. Each floor has a gross floor surface area of 3,400 sq m (36,000 ft^2) and is occupied by 40 to 300 people.

Environmental Control System

The primary energy source for environmental control is purchased 862 kPa (125 psi) steam. Mechanical equipment centers are located in the basement and on the 3rd, 15th, 16th, and 42–46th floors. Steam turbine driven centrifugal water chillers (20.4 MW or 5,800 tons) are located on the 42nd floor. The leaving chilled water temperature of 6°C (42°F) in 1973 was raised to 10°C (50°F) in 1974. The high pressure steam is reduced to 69

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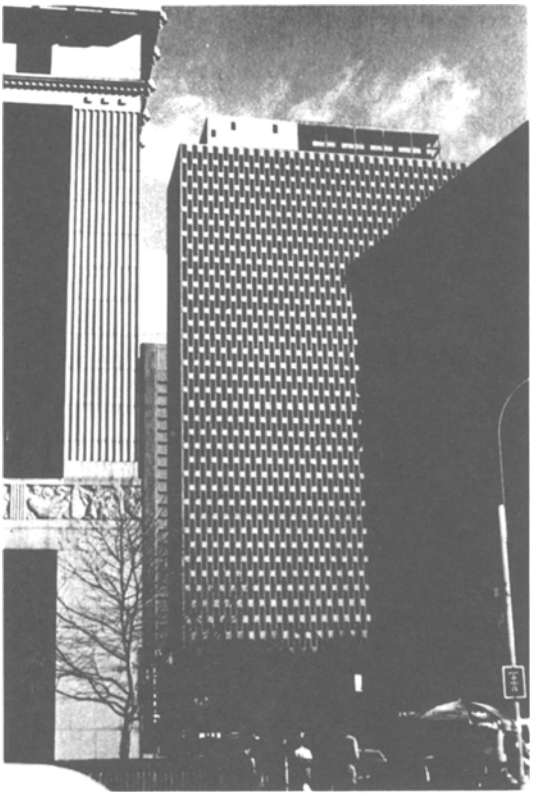

Figure 1. General Services Administration Building, 26 Federal Plaza, New York City.

kPa (10 psi) at the basement, 3rd, 15th, and 44th floors for heating water. The basement equipment room provides the heating and cooling service for the basement and first floor. The 3rd floor equipment services only the four courtrooms on the 2nd floor (the only rooms with humidification). The 15th floor provides hot water for the 2nd through 21st floors and the primary air for heating, cooling, and ventilating the 2nd to 28th. The 44th floor provides hot water and air for the remaining floors. Each machine room contains preheat and chilled water coils for conditioning the primary air. Each space has about 7 air changes per hour of which 10 percent is fresh outside air (about 0.34 m^3/min (12 cfm)/person based on 300 people per floor, though typically there are less than 100). When the outside temperature is less than 18.3°C (65°F) and the inside is 28°C (82°F) or greater the fresh air fraction is increased (economizer cycle). The sixth floor cafeteria uses 345 kPa (50 psi) steam for cooking.

Each floor is divided into interior and exterior heating-cooling zones (Fig. 2). The single outside wall of the interior zone has no fenestration. This zone typically requires cooling all year. All of the external walls of the exterior zone are 21 percent glass. The thermal environment in the exterior zone is controlled by two pipe air induction units along the perimeter. Three adjacent induction units are linked to a single thermostat. The thermostat regulates the flow of hot or chilled water through the coil in the induction units.

The temperature of the interior zone is controlled by air supplied through light fixtures in the ceiling. Of the 1000 fluorescent light fixtures (two 40 W lamps each) per floor one fourth supply air and ¾ exhaust air. The interior zone is subdivided into 4 smaller zones to better control the different loads of the interior zone.

Energy Conservation

In 1974 certain operational measures were undertaken to conserve energy as a result of the FEA Guidelines. The lighting was reduced by one half. Instead of 13 hours of illumination only 11 hours were scheduled. The air conditioning time was reduced to 10½ hr per day from 18. All of the reheat coils were disconnected from the air conditioning system. Thermostats originally set at 23°C (73°F) were reset at 26.7°C (80°F) for the summer and 20°C (68°F) for the winter. The altered system in 1974 required a good deal of daily manual adjustment of air dampers and circulating water temperatures to control the building's temperature. As a result, the building engineer was usually faced with a daily load of complaint slips asking for adjustment of the air temperature in various parts of the building.

The electrical energy consumption per month during the 1974 summer was estimated (Table 1) by summing the needs of the various operating appliances and equipment. The actual average consumption per month in the summer of 1974 was 1,668,000 kWh. Thus the difference between actual and estimated was 4.7 percent. The extra consumption for the summer of 1973 was estimated as:

Fans and pumps (8 hr daily)	639 000 kWh
Illumination (2 hr more daily and twice the intensity)	534 000
	1 173 000
Total per month summer 1973	2 920 000 kWh

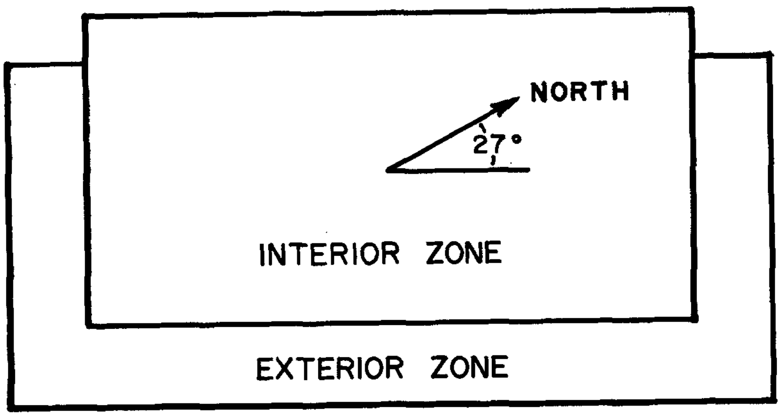

Figure 2. Floor plan outline of GSA Building showing interior and exterior heating-cooling zones.

In the summer of 1973 the monthly consumption was 10,478,000 kg (23,100,000 lbs) of 862 kPa (125 psi) steam. In 1974 even with warmer weather steam consumption per month dropped to 4,355,000 kg (9,600,000 lbs). It is estimated that the 1973 summer consumption when adjusted for the more severe weather conditions of 1974 would have been 13,970,000 kg (30,800,000 lbs) per month. Disconnecting the reheaters accounted for an estimated 1,814,000 kg (4,000,000 lbs) or 13 percent of this reduction.

Computer Simulation

The computer program NBSLD developed by the National Bureau of Standards (Kusuda 1976) to dynamically model the energy consumption and thermal conditions of buildings was used to simulate the GSA building during July 1974. New York weather data for July were used for the outside conditions. The survey of the interior environment revealed that though the thermostats were set at 26.7°C (80°F) in accordance with the FEA Guidelines, the actual interior temperature was 24°C (75°F) in July. With these inside and outside conditions together with all the building's thermal properties, dimensions and its orientation, NBSLD calculated the July steam consumption at 5,126,000 kg (11,300,000 lbs). The actual consumption that month was 4,900,000 kg (10,800,000 lbs). Thus the computer simulation erred by only 4.6 percent.

Using the NBSLD program, the energy consumption for the whole year of 1962 was simulated. 1962 is the National Weather Bureau's reference year for New York. The total steam consumption calculated for 1962 is given in Table 2.

The simulation shows that about 8 times as much steam is used for cooling as for heating. This is because the interior zone (Fig. 2) requires cooling most of the year. The simulation also shows that the building's annual steam consumption is more sensitive to the summer thermostat setting than to the winter's. A one degree change in summer results in a 4.5 percent change in annual steam use while the same change in the winter thermostat setting results in only a 0.9 percent change.

Table 1 Estimated electrical power consumption in kWh per average month during the summer of 1974

Kitchen (freezers, coolers, and stoves)	72 000
Elevators (21 days)	92 000
Computer (26 days of 24 hr, includes cooling)	100 000
Illumination (21 days @ 11 hr)	475 000
Fans (80% eff, 21 days @ 10½ hr)	406 000
Pumps (90% eff, 21 days @ 10½ hr)	443 000
Condensate pump (21 days @ 10 hr)	3 000
Typewriters, calculators (5000 @ 100 W each 21 days for 9 hr)	94 000
Coffee machines and water coolers (39 floors, 10 per floor, 500 W each)	37 000
Trash compactor	25 000
	1 747 000

Thermal Comfort

Four typical floors (23, 26, 33, and 39) were surveyed for occupant comfort and environmental conditions. The summer survey was taken intermittently during July and

Table 2 Simulated annual steam consumption for 1962 under two sets of interior temperatures

	Winter	Summer	Winter	Summer
Interior temperature	16°C	29°C	21°C	24°C
Cooling	14 500 000		22 500 000	
Heating	1 600 000		3 100 000	
	16 100 000		25 600 000 kg	

Please mark how you feel at this moment	
______ comfortable	______ hot
______ slightly uncomfortable	______ warm
______ uncomfortable	______ slightly warm
______ very uncomfortable	______ neutral
	______ slightly cool
	______ cool
	______ cold

Figure 3. Comfort and thermal sensation ballot.

August of 1974. The occupants were asked to indicate on individual ballots (Fig. 3) how they felt. Responses from 460 people were obtained. The responders also indicated the type and amount of clothing worn by filling out a clothing check list. While the subjects completed the ballot and check list, measurements of air temperature, humidity, thermal radiation, and air velocity were made. The air temperature ranged from 22.5°–25.5°C (72.5°–78°F) with the average about 23.3°C (74°F), unfortunately far from the desired 25.5°–26.7°C (78°–80°F) range sought by the Guidelines. Thermal radiation was assessed with a 15 cm diameter black globe thermometer. Radiation from lights and windows raised the globe's temperature 0.6°C on the average over its surrounding air temperature. Air velocity was about 0.15 m/s (30 fpm) and the dew point averaged 14.4°C (58°F). The outside temperature during the survey period averaged 24°C (75.3°F). The outside dew point averaged 16.1°C (61°F). Thus the conditions inside and outside were very similar, a situation that may have aggravated the attempt to control the building to the Guideline temperatures.

The percent of those voting "slightly cool, neutral, or slightly warm" and those voting "comfortable" constituted 68 percent of the sampled population. Thus either grouping may be considered a good index of occupant acceptability. Of those voting "comfortable" there was a tendency to prefer a parallel slightly cool sensation over warm. This voting combination was especially true for women.

The clothing survey found that in the summer the women wore less clothing than the men. The clothing ensembles were evaluated from the clothing check lists that accompanied the comfort ballots. Their insulation levels were determined in terms of the *clo* unit. The average level for the women was 0.43 clo while the average for the men was 33 percent higher at 0.57 clo. A typical winter weight business suit has an insulation value equal to about 1.0 clo, a bikini bathing suit about 0.1 clo.

The winter survey was conducted in a similar manner between January 15 and February 5, 1975. The inside temperature ranged from 21.7°–29°C (71°–84°F) with an average of 25°C (77°F), far from the FEA Winter Guidelines of 20°–21°C (68°–70°F). The average dew point was 6.7°C (44°F). The air velocity was similar to the summer value of 0.15 m/s. The average globe temperature was 25.5°C (78°F). The one degree elevation above air temperature is primarily due to the fluorescent lights. The outside temperature ranged from −8°–7°C (17°–45°F) with an average of 1.1°C (34°F). The average outside dew point was −5°C (23°F).

A total of 514 responses to the comfort ballot and clothing check list were obtained from people during the winter survey. This time 80 percent voted comfortable and neutral. Interestingly, the clothing level was heavier than in the summer even though the working environment was warmer. The men wore 0.9 clo and the women 0.81. Thus it appears that the people dressed according to the outside weather conditions rather than those in the office. Statistics based on the winter survey data project showed that at 21°C (70°F), 70 percent of those surveyed would probably vote "comfortable" assuming that their clothing remained the same. At 20°C (68°F) the percent comfortable would probably drop to 50 percent.

Though the inside conditions fell outside of the FEA Guideline targets of 20°–21°C (68°–70°F) in the winter and 25.5–26.7°C (78°–80°F) for the summer, Pierce Laboratory studies indicate that comfort would be possible at these guideline temperatures if the population were appropriately dressed. The winter guideline requires about 1 clo and the summer about 0.4 clo.

Other Energy Conserving Possibilities

In addition to the substantial energy savings already realized by implementing the Guidelines in the New York Federal Plaza GSA building, the study revealed other areas for potential additional savings. One is the need to continue adjusting the heating and cooling system so it will control the interior to the Guideline levels. However, the biggest remaining area for energy savings is through a reduction in the energy used by pumps and fans for transporting fluids. In the current mode nearly half the building's electrical energy is used to drive pumps and fans. As a result, 20 percent of the steam consumption is used to remove the heat generated by chilled water pumps and fans. A reduction in the air flow through the building can be achieved by lowering the air's temperature for cooling and raising it for heating. If the temperature of the air conditioning air is lowered by 1.7°C (3°F) then the amount transported could be reduced by 20 percent, reducing the power consumption of the fans by about 50 percent. The lower air temperature would in turn require colder chilled water reducing the chiller's coefficient of performance and increasing its steam consumption by 6 percent. However, because less fan work is being dissipated into the cool conditioned air, the cooling load and net steam consumption should decrease by about 5 percent. These alterations to the heating and cooling fluid transport system would primarily reduce the consumption of usually expensive electrical power.

The water chillers are currently dirven by single stage turbines. If these were changed to multistaged ones the steam consumption for cooling could be reduced 30–50 percent. In addition, more energy could be extracted from the 66°C (150°F) steam condensate leaving the preheat coils. The minimum fresh air for ventilation could perhaps be reduced. The 1974 ventilation rates appear to be based on a higher building population than actually observed.

Proposed legislation being considered by many states, modeled after ASHRAE Standard 90–75 (ASHRAE 1975), sets minimum insulation levels for the exterior walls of new buildings. Though this legislation would not apply to existing buildings like the GSA building, it is worthwhile to compare this building with the proposed future Standards. As stated earlier, the walls of the GSA building have an overall thermal conductance of about 2.78 $W/(m^2K)$. ASHRAE 90–75 would require new buildings in this locality to have an overall thermal conductance of 2.04 or less. This reduction would bring additional energy savings in heating and cooling of exterior zones.

This study has been helpful in identifying and quantifying the energy savings impact of the FEA Guidelines on a high rise office building. Occupants working in the Guidelines' summer and winter environments can be thermally comfortable if they dress for the expected interior environment. The same energy conservation measures implemented or recommended for this building can be used to improve the energy efficiency of other existing buildings and the design of future buildings.

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