Natural Ventilation: It's as Easy as Opening the Windows; Or Is It?

Gary W. Siebein

October 1984

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AS OPENING THE WINDOWS; OR IS IT?

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SUMMARY

The research consisted of an evaluation of the existing technologies available for passive cooling with an emphasis on strategies related to the use of natural ventilation.

OBJECTIVES

The research was designed to achieve three major goals:

1. To make a preliminary determination of the extent to which natural ventilation is used or could be used within the context of the existing US building stock and occupant energy usage patterns.
2. To gain insight into the reasons why natural ventilation has or has not been widely accepted by either the architectural community in the design of buildings or the users and operators of buildings.
3. To outline the areas for future research based on the results of 1 and 2 above.

METHODOLOGY

A preliminary data base for the study was established by three major efforts:

1. An extensive literature search of the architectural press was undertaken to ascertain the degree to which passive cooling strategies in general and natural ventilation in particular are designed into buildings at the present time.
2. An investigation of existing building stock profiles was undertaken to identify the existing and potential obstacles or advantages to the implementation of natural ventilation as a passive cooling strategy. The EIA Nonresidential Buildings Energy Consumption Survey and two previous PNL studies were reviewed.

3. Components 1 and 2 were followed up with telephone interviews and site visits with the architects, building owners and operators of selected buildings from 1 and 2 above to gain more specific insights into the problems and pleasures typically associated with natural ventilation.

RESULTS

An outline of the perceptions of the designers, users and operators of the buildings identified above describes a partial list of the obstacles and advantages of using natural ventilation in nonresidential buildings at this time. A significant number of popular misconceptions regarding the use and limits of the natural ventilation strategy have been documented in four major categories:

1. Environmental Factors. This includes those concerns related to the exterior environment, climate, etc.
2. Architectural/Engineering Concerns. This includes those factors relating to the design and construction of naturalventilation systems.
3. User and Comfort Concerns. This includes those factors that relate to the people who use and operate the buildings.
4. Successful Applications of the Natural Ventilation Strategy. This includes discussions relative to the points raised in items 1 to 3 above.

It seems that while there are a number of obstacles that are perceived by the designers and users of buildings at this time to the use of natural ventilation, that in the case studies these objections disappeared when a successfully designed environment was used and enjoyed by large numbers of people. This implies that a part of the problem is of a very fundamental architectural nature that is not currently being addressed in research programs.

ACKNOWLEDGEMENTS

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INTRODUCTION

This report represents an initial inquiry to determine the state of the art in the use of natural ventilation in nonresidential buildings today. It is an exploratory effort to provide insight into the problem area and to define areas for future study.

This research was made possible by a faculty summer appointment at PNL by the Northwest College and University Association for Science (University of Washington) under contract with the U.S. Department of Energy.

BACKGROUND

At this point in time an assessment of passive cooling techniques and their applications in nonresidential buildings raises more questions than it provides answers for several reasons.

1. Research agendas outlining passive cooling programs that were proposed several years ago are yet to be implemented in many areas. (Carroll, 1982; ABBE, 1982; Bowen in DOE, 1980)
2. The research to date has been component oriented looking at small segments of the total picture. Research in natural ventilation for example has focused on the refinement of convection coefficients, qualitative model testing procedures, and comfort levels with ceiling fans. (Shandra, 1984; Shandra, 1983; Rohles, 1982; Boutet, 1983)
3. There are many indications that what finally occurs in a building represents the complex interaction of many components. There is a need for an integrated overview approach to this problem to understand more fully the dynamic response of both the building systems and building users relative to the issues of passive cooling.
4. There are many problems that are encountered in the design and use of passive cooling systems that are related more to the perceptions and actions of the building users than to the technology itself. These factors will determine to a large degree the ultimate success or failure of the systems.

These items are more difficult to identify and quantify than those relating strictly to the technological performance of a component, but must be considered due to the peculiar nature of passive cooling. Several of these constraints such as the relatively small capacity of environmental heat sinks, the more pronounced effects of humidity, air movement and mean radiant temperature (MRT) on comfort, the difficulties of integrating passive and mechanical systems for optimum performance, the reliance on intelligent intercession of the building occupants, and the relative state of infancy of many of the technologies all play an important role in the performance of passive cooling strategies.

Several conclusions from the Passive Cooling Technology Assessment: Synthesis Report serve to highlight the need for a concentrated research effort in this area. Cooling is the dominant cause of peak electric power demand. The ratio of peak to total electric consumption is greater in northern climates where compatibility with passive techniques would be greatest. While both heating and cooling have been shown to be climate sensitive, utility rate structures, especially demand charges, have a great effect on the energy costs of commercial buildings. For this reason the regional energy use profiles do not correlate with the regional energy cost profiles. Furthermore, the passive strategies that were examined showed enough energy savings potential across climate zones to warrant further study. Daylighting showed the greatest potential energy and cost savings. Major research efforts have been initiated in this area and recently constructed buildings show a renewed concern for implementing daylighting strategies. Ventilation strategies showed the second greatest potential for energy savings in the office buildings studied. Other strategies showed significantly less savings potential (Carroll 1982).

PASSIVE COOLING SURVEY

An extensive literature search was conducted to identify the state-of-the-art in the use of passive cooling techniques in buildings today. Over sixty buildings nationwide were described by the architectural press as having significant use of passive cooling strategies. A matrix of the buildings, their designers, size and a survey of the passive cooling techniques employed are presented in Figure 1.

The passive cooling strategies were divided into four basic groups for analysis:

1. Daylighting and control strategies
2. Envelope load reduction strategies
3. Passive cooling strategies
4. Passive heating strategies

The specific items included in each of these categories are shown in Figure 1.

Daylighting was claimed to be a major consideration in all of the buildings. Forty one percent of the buildings in the sample used light shelves or other architectural means to cast daylight further into rooms. Almost one half of the buildings used some form of automatic switching or dimming device to control the electric lighting system in response to varying levels of daylight.

All of the published buildings were very sensitive to orientation and site planning concerns as well as providing adequate levels of insulation. Seventy two percent of the buildings used some form of fixed shading device. Twenty of the buildings were reported to use interior shading and 13 of the buildings used movable or operable exterior shading devices. Twenty four of the buildings (38%) used multiple shading techniques. This represents an interesting contrast to the EIA data, presented later for the US building stock as a whole, where only 23% of their sample used exterior shading devices in 1979. Ten buildings (16%) were reported to use landscaping techniques to reduce cooling loads (it should be noted that earth berming was considered under the Earth Shelter category). Landscaping has been presented in many texts as an economical way to reduce cooling loads. Many consider the aesthetic value of landscaping and outdoor space to be more important than any energy savings that are attributable to it.

Only three of the buildings provided the occupants with the opportunity to move out of doors as a part of their normal use of the building. One of these buildings did not have a sufficient budget to complete the outdoor spaces. The potential energy savings of migration strategies, as well as the enhancement in the quality of the work environment, goes largely unnoticed today. Several of the California office buildings did use exterior courtyards and circulation spaces however.

					LIGHTING & DAYLIGHTING					BUILDING ENVELOPE							PASSIVE COOLING								DESIGN/CONFIGURATION		MECHANICAL SYSTEMS					PASSIVE HEATING				
					TASK LTG.	DAYLIGHT	SWITCHING/DIMMING	EFFICIENT SOURCES	LIGHT SHELF	ORIENTATION	INSULATION	SPECIAL GLAZING	LANDSCAPING	SHADING (FIXED)	SHADING (INTERNAL)	SHADING (OPERABLE)	MIGRATION	COMFORT VENT.	NIGHT VENT.	MASS	EVAP. COOLING	EARTH SHELTER	COOL TUBE	WIND TOWER	VENT. SKIN	HEAT VENTS	ATRIUM	SUNSPACE	ICE STORAGE	ROOF SPRAY	SPECIAL HVAC	SOLAR COOL	FANS		CLERESTORY	PASSIVE HEAT
NO.	BUILDING NAME	LOCATION	SQUARE FOOTAGE	ENERGY DATA AVAILABLE																																
1.	KIEFFER STORE	WAUSAU, WI	3,200	YES		●			○	●				●	○								○		○								○	○		
2.	JOHNSON CONTROLS, INC.	SALT LAKE CITY, UT	15,000	YES		●			○	●	●			●	○			○	○								○						○	○		
3.	MT. AIRY PUBLIC LIBRARY	MT. AIRY, NC	13,500	YES	●	●			○	●	○		●	○				●															○	○		
4.	VISITORS INFORMATION CENTER	TROY, NY	5,200	SOME	●	○	●	●		○	○				○		○		○		○				○			○						○		
5.	SPRINGFIELD FIRE STATION	SPRINGFIELD, OR	4,400	NO		●				○	○			○	○			○															○	○		
6.	DONOHUE CORP. OFFICE	SHEBOYGAN, WI	25,000	SOME		○	●	●	○	○	○	○		○	○	○			○					○				○					○	○		
7.	ANTELOPE VALLEY VISITOR CTR.	LANCASTER, CA	2,100	NO		●				○	●			●				○		○	○											○	○	○		
8.	EUGENE ELEMENTRY SCHOOL	EUGENE, OR	?	NO		○			○	○	●			○																				○		
9.	CALIFORNIA FARM BUREAU FEDERATION BUILDING	SACRAMENTO, CA	LARGE	NO		○				○	○	○					○	○									○									
10.	ENERGY SHOWCASE PROGRAM HQ.	SACRAMENTO, CA	7,600	NO		○	○			○	○			○		○	○	○	○	○													○		○	
11.	FORT SNELLING VISITOR CENTER	MINNEAPOLIS, MN	?	NO		○			○	○	○		○	○				○				○		○		○		○						○		
12.	GENERAL SERVICES INSURANCE	MANILA, PHILIPPINES	1,350,000	NO		○			○	○	○		○	○								○											○	○		
13.	MUSEUM OF SCIENCE/INDUSTRY	TAMPA, FL	60,000	NO		○				○				○		○							○										○			
14.	MISSISSIPPI COUNTY C.C.	BLYTHEVILLE, AR	53,500	NO		○	○			○				○	○							○		○								○		○		
15.	ONE UNIVERSITY PLAZA	FAIRFAX, VA	18,000	NO		○	○			○	○			○		○		○				○											○	○		

FIGURE 1. Passive Cooling Survey Summary

					LIGHTING & DAYLIGHTING					BUILDING ENVELOPE						PASSIVE COOLING								DESIGN/CONFIGURATION		MECHANICAL SYSTEMS					PASSIVE HEATING				
					TASK LTG.	DAYLIGHT	SWITCHING/DIMMING	EFFICIENT SOURCES	LIGHT SHELF	ORIENTATION	INSULATION	SPECIAL GLAZING	LANDSCAPING	SHADING (FIXED)	SHADING (INTERNAL)	SHADING (OPERABLE)	MIGRATION	COMFORT VENT.	NIGHT VENT.	MASS	EVAP. COOLING	EARTH SHELTER	COOL TUBE	WIND TOWER	VENT. SKIN	HEAT VENTS	ATRIUM	SUNSPACE	ICE STORAGE	ROOF SPRAY	SPECIAL HVAC	SOLAR COOL		FANS	CLERESTORY
NO.	BUILDING NAME	LOCATION	SQUARE FOOTAGE	ENERGY DATA AVAILABLE																															
16.	IPS HEADQUARTERS	SIOUX CITY, IA	168,000	NO																															
17.	IBM REGIONAL OFFICE	SOUTHFIELD, MI		NO																															
18.	W. MONROE OFFICE BUILDING	CHICAGO, IL		NO																															
19.	ARGONNE NATIONAL LABORATORY	ARGONNE, IL	215,000																																
20.	HOOVER OFFICE BUILDING	NIAGARA FALLS, NY	200,000	YES																															
21.	CALIFORNIA STATE OFFICE BUILDING SITE 1 - 1A	SACRAMENTO, CA	289,000	SOME																															
22.	TERMAN ENGINEERING CENTER	PALO ALTO, CA		SOME																															
23.	ENERPLEX	PRINCETON, NJ	260,000	SOME																															
24.	OCMULGEE REGIONAL LIBRARY	EASTMAN, GA	13,500	SOME																															
25.	FT. STEWART DEPENDENTS SCHOOL	FT. STEWART, GA		SOME																															
26.	PATERSON ELEMENTARY SCHOOL	PATERSON, GA		SOME																															
27.	STATE OFFICE BUILDING	SAN JOSE, CA	125,000	NO																															
28.	TVA OFFICE BUILDING	CHATTANOGA, TN	1,300,000	SOME																															
29.	UNIVERSITY OF PUGET SOUND LAW CENTER	TACOMA, WA		SOME																															
30.	STILLICUM HIGH SCHOOL	STILLICUM, WA	100,000	SOME																															

FIGURE 1. (cont'd)

					LIGHTING & DAYLIGHTING					BUILDING ENVELOPE							PASSIVE COOLING								DESIGN/ CONFIG-URATION		MECHANICAL SYSTEMS					PASSIVE HEATING				
					TASK LTG.	DAYLIGHT	SWITCHING/DIMMING	EFFICIENT SOURCES	LIGHT SHELF	ORIENTATION	INSULATION	SPECIAL GLAZING	LANDSCAPING	SHADING (FIXED)	SHADING (INTERNAL)	SHADING (OPERABLE)	MIGRATION	COMFORT VENT.	NIGHT VENT.	MASS	EVAP. COOLING	EARTH SHELTER	COOL TUBE	WIND TOWER	VENT. SKIN	HEAT VENTS	ATRIUM	SUNSPACE	ICE STORAGE	ROOF SPRAY	SPECIAL HVAC	SOLAR COOL	FANS		CLERESTORY	PASSIVE HEAT
NO.	BUILDING NAME	LOCATION	SQUARE FOOTAGE	ENERGY DATA AVAILABLE																																
31.	FANUEIL HALL	BOSTON, MA				●							●			●	●	●	●																	
32.	CAMPUS CREDIT UNION	GAINESVILLE, FL		SOME	●	●				●	●	●		●	●									●				●	●			●	●			
33.	ENERGY CONCEPT OFFICE BUILDING	HOUSTON, TX		NO		●	●		●	●	●		●				●	●			●		●						●	●				●		
34.	CIVIL/MINERAL ENG.	MINNEAPOLIS, MN	142,000	NO		●			●	●	●	●	●				●		●			●	●			●									●	
35.	CRAY RESEARCH HEAQQUARTERS	MENDOTA HTS., MN	65,000	NO		●	●																			●									●	
36.	MONTESSORI SCHOOL	MINNEAPOLIS, MN		NO		●				●	●		●					●																	●	
37.	CALIFORNIA STATE OFFICE BUILDING 1B	SACRAMENTO, CA	130,000	YES		●	●	●		●	●		●		●		●												●			●		●		
38.	CALIFORNIA DEPARTMENT OF JUSTICE	SACRAMENTO, CA	350,000	YES		●	●			●	●	●		●			●	●					●						●			●	●	●		
39.	LONG BEACH STATE OFFICE BUILDING	LONG BEACH, CA	156,000	YES		●	●	●		●	●		●																						●	
40.	CALIFORNIA STATE OFFICE BUILDING SITE 1C	SACRAMENTO, CA	160,000	YES		●	●	●		●	●		●				●																		●	
41.	CALIFORNIA OFFICE COMPETITION	SACRAMENTO, CA	237,000	SOME		●				●	●		●		●		●	●	●								●			●	●					
42.	HEREFORD/WORCESTER COUNTY HALL	ENGLAND	180,000	NO		●	●			●	●	●		●			●	●	●																	
43.	SERI HEADQUARTERS	GOLDEN, CO	243,000	NO		●	●			●	●		●	●	●		●	●	●				●	●		●			●			●		●	●	
44.	LIBRARY	NEW ROCHELLE, NY	67,000	NO	●	●	●	●			●	●				●	●																	●		●
45.	MINNESOTA HIGH SECURITY C.I.	OAK PART HTS., MN	275,000	NO		●				●	●								●										●							

FIGURE 1. (cont'd)

					LIGHTING & DAYLIGHTING					BUILDING ENVELOPE							PASSIVE COOLING										DESIGN/CONFIGURATION		MECHANICAL SYSTEMS					PASSIVE HEATING			
					TASK LTG.	DAYLIGHT	SWITCHING/DIMMING	EFFICIENT SOURCES	LIGHT SHELF	ORIENTATION	INSULATION	SPECIAL GLAZING	LANDSCAPING	SHADING (FIXED)	SHADING (INTERNAL)	SHADING (OPERABLE)	MIGRATION	COMFORT VENT.	NIGHT VENT.	MASS	EVAP. COOLING	EARTH SHELTER	COOL TUBE	WIND TOWER	VENT. SKIN	HEAT VENTS	ATRIUM	SUNSPACE	ICE STORAGE	ROOF SPRAY	SPECIAL HVAC	SOLAR COOL	FANS	CLERESTORY	PASSIVE HEAT		
NO.	BUILDING NAME	LOCATION	SQUARE FOOTAGE	ENERGY DATA AVAILABLE																																	
46.	MILFORD CENTER	MILFORD, PA	17,000	NO		○				○	○			○	○			○																			
47.	FLOYD ELEMENTARY SCHOOL	MIAMI, FL	70,000	SOME		○		○			○							○											○								
48.	CRYSTAL CATHEDRAL	GARDEN GROVE, CA		YES		○					○						○	○															○				
49.	BENEDICTINE MONASTERY	SCHUYLER, NB		YES		○				○	○			○				○		○														○			
50.	CORVALLIS AQUATIC CENTER	CORVALLIS, OR	31,000	YES		○									○	○																		○			
51.	SANTA ROSA OFFICE BUILDING	SANTA ROSA, CA	96,000	YES		●	○			○	○		●	○																							
52.	SOUTHWEST WOODBRIDGE ELEMENTARY SCHOOL	IRVINE, CA	43,000	SOME		○			○	○	○		○	○			○		○													○	○				
53.	WILLOW PARK COMMUNITY CENTER	HOUSTON, TX	4,130	SOME		○				○	○			○			○		○													○	○	○			
54.	SHELLY RIDGE GIRL SCOUT CENTER	PHILADELPHIA, PA	5,700	SOME						○	○			○		○									○									○			
55.	PRINCETON SCHOOL OF ARCH.	PRINCETON, NJ	13,535	SOME		○			○		○						○		○						○								○	○	○		
56.	PRINCETON PROF. OFFICE PARK	PRINCETON, NJ	64,000	SOME		○	○		○	○							○							○			○						○	○			
57.	COMMUNITY UNITED METHODIST CHURCH CLASSROOM	COLUMBIA, MO	5,500	SOME		○			○	○	○			○			○															○	○	○			
58.	DEADWOOD CREEK COMMUNITY CENTER	DEADWOOD, OR	900	SOME		○				○	○			○																				○	○		
59.	ESSEX DORSEY SENIOR CENTER	ESSEX, MO	13,000	SOME		○			○	○	○		○	○		○								○										○	○		

FIGURE 1. (cont'd)

The techniques usually referred to as "passive cooling" were typically used in combination with a variety of other strategies. Sixty three percent of the buildings were reported to use natural (daytime) ventilation and 47% were designed to use night (structural cooling) ventilation. These represented the most used strategies. Seventeen percent of the buildings used some type of fans (usually either ceiling fans or exhaust fans) to assist the ventilation systems. Forty-four percent utilized thermal mass, usually in conjunction with a passive heating system. Sixteen of the buildings (25%) were earth sheltered to varying degrees, from those that were partially bermed to those that used totally underground construction.

Thirty four percent of the buildings had a special HVAC system or control system to allow optimum performance with the passive systems. These ranged from setback thermostats to off peak cooling and storage and a variety of techniques in between.

Twenty three percent of the buildings were designed with atriums and another 9% were designed with sunspaces that were used for a combination of passive heating, cooling, and lighting. Ten of the buildings (16%) used heat venting systems of various types. These were usually used in conjunction with either an atrium or a sunspace.

Clerestories were employed in 30 of the buildings for a combination of lighting, ventilation and passive heating functions. Passive heating was designed in various forms into 75% of the buildings. Other techniques listed in the matrix were used far less frequently.

Nineteen of the buildings were reported to be monitored in various ways. Twelve of the monitored buildings were part of the DOE Commercial Buildings Demonstration Program. Design energy data was available for some of the buildings, but outside of the DOE effort, little in the way of feedback on the actual performance and use of buildings and systems is being obtained from these potentially fruitful resources.

Multiple passive cooling strategies were used in the majority of the buildings sampled. Eighty percent of the buildings used more than one strategy and 47% of the buildings used more than three strategies. This is likely to be a result of the performance limits of most passive cooling systems, the limited experiences of the building community with many of these strategies and a

series of user oriented concerns that affect the performance of several of these systems. It is interesting to note, however, that several of the most successful buildings in the group rely entirely on the natural ventilation strategy for cooling.

Passive cooling strategies were coupled with a mechanical refrigeration "backup" system with an economizer cycle in all but four of the buildings (two of these buildings were "energy demonstration centers" and are not typical cases).

One of the major problems that was encountered during the literature search was a general bias of the architectural press towards visual criteria as opposed to actual performance and use of buildings. On the whole, the reporting was very noncritical in nature. It was very difficult to discern adequate information from the articles alone to assess system and building performance.

A similar study by Booz-Allen and Hamilton with the DOE reached a similar set of general conclusions. Sixty-five Owens-Corning Fiberglass Annual Energy Design Awards winners that were built over the past 11 years were analyzed. The Booz-Allen study identified several general trends in energy conserving design during this time period (Booz Allen, 1982).

1. The most commonly used strategies involved the modification of the building envelope by the use of insulation, double glazing and other special glazing types. The next largest group of improvements were in the use of innovative HVAC systems such as VAV systems, heat recovery systems and heat pumps.
2. Active solar systems were used on some of the earlier buildings. Their use is declining.
3. Passive solar design, especially daylighting, has been increasing in recent years.
4. There has been a small percentage of buildings that have used natural ventilation (10%). This trend has been increasing in recent years.
5. The final conclusion is that there appears to be a shift from a mechanical systems emphasis in the award winners to a

more integrated architectural approach to the solutions. This includes the use of multiple strategies for daylighting, envelope design, earth berming, etc., along with the use of sophisticated mechanical systems.

It should be emphasized with both the sample presented in Figure 1 and the Booz-Allen building sample, that these buildings represent the state-of-the-art and are many years ahead of the mainstream of architectural design practice (Booz-Allen, 1982). The trend towards the use of multiple techniques and more architecturally based solutions is clear in both building samples.

NATURAL VENTILATION

Natural ventilation was selected as the focus of this study after this initial analysis revealed that:

1. A number of state-of-the-art buildings proposed using natural ventilation.
2. Until the advent of mechanical refrigeration in the middle of this century, natural ventilation was the major source of cooling buildings.
3. A significant energy savings is predicted both in terms of consumption and peak load reduction by the use of the strategy.
4. It is an area where the technology is extremely simple (by opening windows or using fans) and relatively well developed, but where the successful implementation of the strategy is hindered by a number of misconceptions on the part of building designers, owners, and users that require further clarification and resolution.
5. The performance of natural ventilation systems is linked with a series of complex interactions among the exterior environment, building shell, building mechanical systems, human comfort and the characteristics of the building owners and occupants which are not well understood at this time.

Once the natural ventilation strategy was selected, it became necessary to identify and clarify the issues stated in items 1 to 5 above on two levels:

1. To look at general building stock profiles to make a preliminary determination of the overall feasibility of pursuing the study on the macro level.
2. To identify and clarify specific areas requiring further study at the level of the individual building.

BUILDING STOCK PROFILE ANALYSIS

The EIA Survey

The EIA data was reviewed to gain a preliminary insight into the potential compatibility of the characteristics of the existing building stock and energy consumption patterns in the U.S. with natural ventilation strategies.

Thirty-six percent of the EIA building sample consisted of non-air conditioned buildings. Another 20% of the building sample used window air conditioning units as the source of cooling. The profiles of the use of cooling systems to building size, age and occupancy types are shown in Appendix 1. The 1/3 of the building stock that is not air conditioned is evenly spread across the building age categories (with a 31% figure in the 1974-1979 period). As the scale of the buildings increase, more buildings are air conditioned. However, up to the 25,000-50,000 square foot category there is still 24% non-air conditioned buildings. The non-air conditioned buildings are also spread across a surprisingly wide range of building types. Thirty-nine percent of the assembly group, 65% of the automotive sales and service group, 33% of the educational group, 33% of the industrial group, 34% of the lodging group, 34% of the residential group, 30% of the retail/service group, and 65% of the warehouse group are non-air conditioned. The buildings show a response to climate in that 48% of the buildings in the extreme heating climate (>7000 HDD) are non-air conditioned while 22% of the buildings in the extreme cooling climate (>2000 CDD) are not air conditioned. A large number of buildings in the survey had <10 occupants and over one-half of the buildings were occupied by the owner.

This represents a significantly large building sample that demonstrates existing usage patterns that would be compatible with the natural ventilation

strategy. Whether the buildings themselves could accommodate natural ventilation is another issue.

The average yearly energy costs for these buildings is presented in Figure 2. The energy costs of the non-air conditioned buildings and the buildings that are cooled by window units are relatively similar, while the energy costs for buildings with other cooling systems are substantially larger. Does this start to define some degree of energy efficiency due to the control of the building occupants over their environment? The data is not specific enough to allow any conclusions of this nature to be reached, but it certainly raises several poignant questions relating to building use, occupant control, and passive cooling.

<u>AIR CONDITIONING SYSTEM</u>	<u>BUILDING SIZE</u>		
	<u><5000 s.f.</u>	<u>5-10,000 s.f.</u>	<u>>10,000 s.f.</u>
No Air Conditioning	\$ 1,200 (44) ^(a)	\$ 2,800 (30)	\$ 6,600 (18)
Window Units	\$ 1,700 (55)	\$ 2,200 (23)	\$ 8,400 (19)
Package Units	\$ 3,700 (102)	\$ 4,700 (46)	\$ 19,100 (41)
Central System	\$ 3,300 (107)	\$ 3,900 (38)	\$ 30,200 (55)
Combination/Other	\$ 2,400 (68)	\$ 3,400 (33)	\$ 49,100 (67)

Source: EIA 1983

(a) The numbers in parentheses are the average electrical consumption of the building in 1,000 Btu/(sq. ft. per year).

FIGURE 2. 1979 Building Electrical and Consumption Costs
Based on Square Footage and Air Conditioning
Systems for Buildings that Use Electricity

The real question that arises from reviewing the EIA data is just how are all those non-air conditioned buildings really working? What are the operational and usage characteristics that differ between the buildings with central a/c systems vs. window units? Do the buildings fall into discrete socioeconomic groups? What are the comfort levels of the occupants in each of the groups? What portion of the energy bills are dedicated to cooling? How are the non-air conditioned buildings cooled?

More specific building characteristics would have to be known before any of these questions could really be answered. Future work in this area is necessary. Case studies of non-air conditioned buildings that could be identified from the EIA data could provide useful information into the energy, comfort, operational, use, and financial issues that cloud the use of natural ventilation and other passive cooling strategies today.

The Battelle Survey

In 1980, Construction Market Information, Battelle PNL and DOE amassed a building stock profile of 400 buildings that were advertised for bid or under construction in 1979-1980. The original purpose of the study was to "develop a preliminary assessment of the degree of change in current commercial building design practices related to energy conservation" (Nieves 1982). The building sample was obtained by performing quantity surveys from the bid documents. An examination of this data base was undertaken to define more specific building characteristics than could be discerned from the EIA survey relating to the use of natural ventilation in current buildings. Several interesting results of this analysis are:

1. Only two of the 400 buildings (0.5%) were designed for the shutdown of the HVAC system when weather permits to allow natural ventilation (one was a transmission assembly plant and the other a prison kitchen).
2. Forty-six percent (184) of the buildings had either an enthalpy or dry bulb economizer cycle on the HVAC system which seems to be the extent to which most buildings are naturally ventilated today.

3. Two hundred seventeen of the buildings (54%) were designed with no operable glass.
4. Using a rule of thumb relating the percentage of operable glass to floor area that is used in many building codes to prescribe minimum openings for health ventilation requirements of 4%, only 42 (10.5%) of the buildings in the sample could meet this minimum requirement.
5. 11.5% of the buildings (46) had between 1.5-3.9% operable glass/floor area. The remaining 78% had <1.4% operable glass /floor area ratios.

The largest single building type meeting the code requirements were the non-residential housekeeping group with 16 (52%) buildings, all located in the heating dominated climates, having >4% operable glass/floor area. Surprisingly only 11% of the elementary schools, 8% of the secondary schools, and 10% of the college and university buildings in the sample had enough operable windows to meet the code requirements. This contradicts a common conception that schools which are usually not in full use during the warmest times of the year are typically cooled by natural ventilation.

Whether these trends have changed during the past three years is difficult to say. It should also be cautioned that this is not a statistical sample and therefore extrapolations of building characteristics from this small sample to the building stock at large are difficult to make. However, if this sample is at all indicative of the buildings that were constructed during the time period, there are very few building occupants who can open their windows!

This data implies that there are a large number of recently constructed buildings that could not be used during the summer months if for some reason such as a dramatic rise in energy costs or another energy shortage or even equipment failure prohibited extensive use of air conditioning. At least buildings that have been constructed with some operable windows could continue to operate during these periods.

Building Analysis

Telephone interviews were held with the architects, building owners and operators of buildings selected from the literature search presented in Figure 1 and the Battelle survey to gain more specific insights into the issues involved with the use of natural ventilation in buildings. This represents a

partial discussion of the many contradictory advantages and obstacles that arise with the use and design of natural ventilation systems. They are grouped in four major categories:

1. Environmental Factors
2. Architectural/Engineering Factors
3. User and Comfort Concerns
4. Successful Applications of Natural Ventilation

The comments that follow are the opinions of the architects, building owners and operators who were interviewed by the researcher. In many cases these comments have been generalized to maintain the confidentiality of the sources. They are presented to outline many of the issues that must be resolved if the use of natural ventilation will return to a standard operating practice in non-residential buildings. The order in which they are presented is not hierarchical, as a determination of the relative importance of each issue was beyond the scope of this study.

Environmental Factors

The outdoor air, especially in urban areas where the greatest concentration of buildings are located, is unsuitable for unfiltered use in buildings. Pollen, dust and dirt as well as polluted air cause disturbances to the occupants and rapid deterioration of room finishes.

The humidity is too high in most of the U.S. to use outside air during the summer months. The obvious counter-argument is that the use of natural ventilation does not have to exclude the use of mechanical refrigeration. The possibility exists to open the windows when weather permits particularly during the intermediate seasons.

Recent climatic analysis of exterior conditions for cities typical of 4 major climatic zones in the U.S. shows that in all areas of the country the potential for cooling by ventilation exists in outdoor and partially enclosed spaces for large portions of the year (Brown 1981).

A similar analysis for 29 cities in the U.S. reveals that a surprising portion of the cooling requirements across the U.S. can be met by various combinations of passive strategies (Watson 1983).

A major problem with the findings of both of these studies is that the results are applicable only to exterior conditions or relatively small structures. There is no comparable design guide for commercial buildings at this time. Issues of thermal mass, internal loads, varying occupancy schedules, etc. must be considered. This makes a simplified analysis difficult at this time.

Noise from exterior sources is a particular problem in urban areas or locations near highways, etc. Noise from fans located within spaces is also a problem. The acoustical considerations of passive systems are just beginning to emerge.

Insect screens must be used in the U.S. Insect screens reduce the air velocity of incoming air especially at low air velocities, offer a maintenance item and an initial cost item that must be considered. Experience in New York City during the pre-air conditioning era indicated that neither mosquitos or noise was a considerable problem above 10-15 stories.

There is a lack of reasonable microclimatic wind data available to designers. Wind data is typically collected at airports 30 feet above the ground. Significant variations have been found to occur between data collected at weather stations and specific building sites. Topography, bodies of water vegetation and buildings all serve to alter both wind direction and velocity. Fred Dubin installed a \$15,000 weather station at a building site in Kenya where microclimatic design data was needed. This is clearly outside the budget of most architectural projects.

A low cost site weather station could be developed to monitor site conditions to assess the degree to which they vary from published data. This would be particularly useful if there were published guidelines as to the significance of variations from weather data and its impact on building design and energy use.

There is also a need for understanding the impact of buildings, particularly large buildings, on the microclimate. Studies have shown significant alterations in wind speed and direction, solar radiation and daylight due to the presence of large structures.

Ventilation is too variable and unpredictable. Because the primary motive force of most natural ventilating systems is the wind, buildings would be subject to uncontrollable fluctuations at the mercy of the wind. This could be overcome to a degree by the use of fans and stack ventilators where appropriate. (Is there anything wrong with perceiving environmental changes inside buildings?)

Architectural/Engineering Factors

The primary problem encountered from an architectural point of view is the integration of the natural ventilation system with the building mechanical system, especially where the building is comprised of several zones that have common air volumes.

The use of economizer cycles which are widely used at this time provides energy savings through the use of 100% outside air when weather permits. This is not the same as natural ventilation. While the economizer provides cleaner, more controlled air, a lower outside air temperature must be used due to the limitations on the volume of air that can be brought into the building by the fans and ductwork. There is also a qualitative difference that is difficult to assess.

A research thrust directed at developing mechanical systems that are more compatible with natural ventilation systems would seem to be a natural step in this direction.

Many buildings have too many internal spaces to allow the use of natural ventilation. This could be the result of either particular building types or architectural design decisions. It is very difficult to retrofit natural ventilation into a building that was not designed for it.

This problem should be ameliorated in the future, as a renewed concern for daylighting design in the profession is tending to produce buildings that have more perimeter spaces, more glazing and consequently less internal spaces than buildings built in the past decade. These designs are more compatible with natural ventilation than their predecessors built during the past decade.

Many architectural firms used natural ventilation as a one time concept. Subsequent buildings were designed from a totally different point of view. There has been little or no follow-up, such as post occupancy studies or

monitoring of the systems, to understand why they work in some cases and don't work in others. As a result, even in the few buildings that have been recently constructed that utilize natural ventilation, there has been no feedback to the profession as to whether all those little blue arrows that show up in various publications actually perform the way in which they were intended! Each architectural firm (with the exception of the "energy" firms) must relearn the basics in a field guided by popular misconceptions of design, use, and operation. "They seem to work" was a common response.

As a result, most architectural firms develop their own experience based on a progression of designs, each one improving on the next - the "build it better the next time" approach. They typically go through a learning process based on a combination of research, education and intuition. The experiences with the first generations of passive solar buildings shows that at least initially, this ad hoc approach does not always yield satisfactory results.

There have been a number of buildings that have been designed for natural ventilation to be used in the future, during periods of energy shortages or when energy prices increase beyond the financial capabilities of the clients.

There is a common feeling that natural ventilation is "only for use in small buildings".

There is a lack of design tools available for serious designers. Several architects referred to heating and ventilating texts that were written 50 years ago to find rules of thumb and background information during their design process. Many of the currently published design tools, etc., are applicable only to small buildings. Smoke testing of models and diagrammatic analysis provides only qualitative data that is of some use in complex building configurations.

There is a lack of computer algorithms for design and energy estimation purposes that can account for the complex behavior of natural ventilation in any but the most simple architectural configurations. Natural ventilation was a SEE (Special Energy Evaluation) item during the extensive BEPS research meaning that it could not be accounted for in the computer models that were used.

Cooling is not perceived as a major problem in many areas, although it is the major cause of peak electrical loads and charges.

Operable windows cost more than fixed glass. In addition insect screens are needed and infiltration losses are increased during times when the building is not pressurized. Parametric analysis would be required to identify the points at which these concerns are offset by energy savings.

Several small scale multiple story buildings have been built with operable windows as part of the window cleaning system. Every third pane of glass was operable on a recent office building project in Oak Ridge, TN for this reason. This represents an additional operational saving that should be pointed out in the financial arguments.

Several buildings also used operable glass for fire access and escape purposes.

These attitudes are contrasted by remarks of Wolfgang Finklestein that (in Germany) "there is a move away from air conditioning". Recent trends in German architecture have shown a reduction in air conditioning due to increased insulation, the perception of the public that "air conditioning is not a necessity for many," and design trends towards smaller buildings with operable windows (Finklestein, 1983).

Comfort Requirements and Use Patterns of Buildings

The most common concern voiced about the comfort potential of natural ventilation was that "there will be too many complaints" and that "people won't be either comfortable or productive". This argument has its root in the pre-air conditioning era when there was no alternative when the weather got very hot and muggy except to perspire or to "go home". Many times in large cities office workers were sent home on hot summer afternoons when their offices became too hot to work in. This argument was a persuasive factor in convincing many building owners to incur the additional expense of installing the early air conditioning systems. The potential exists for a natural ventilation system to complement the use of an HVAC system when weather permits. It should not be an either-or situation.

The design of natural ventilation systems was not without its problems. Drafts in naturally ventilated spaces were as much of a problem as the hot, muggy weather that made comfort impossible. Natural air movement is difficult to control with the precision that is expected from modern air distribution

systems. This is an area in need of further development. Drafts in the cooler weather and a lack of comfort in hot weather were two of the major factors that made the shift to mechanical refrigeration systems occur so rapidly once the technology was available.

There are also a number of comfort and interaction problems that arise between workers in naturally ventilated spaces. One person is comfortable with the window open while the next person is too cool, etc.

Sam Davis cites occupant control as a major potential factor in energy efficiency. However "this theory does not always work. Control of temperature comfort levels and energy use by some workers may lead to the discomfort of others". Furthermore "there is no way for some workers to open windows and not disturb the designed balance of the centrally controlled mechanical systems" (Davis 1983, p.22). This conclusion was reached after an in-depth series of energy analysis case studies on eight of the much publicized California State Office Buildings recently constructed.

The complaints from building users do not go away when a central air conditioning system is used either. A recently constructed energy award winning building with a sophisticated computerized control system was plagued by complaints during its first year of operation. The complaints were a result of two intertwined problems. The first was that to save the energy that was predicted during the extensive computer analysis during the design phase, the thermostats were set for 68°F during the heating season and 78°F during the cooling system. In this case, many people were simply not comfortable at these temperature settings. The project architect commented that "people should have more control over their surroundings than the central HVAC system is programmed to give". Furthermore, "people are very vocal when their comfort is concerned". A second problem that has since been corrected was the fine tuning of the HVAC system. During the first few months of occupancy the conditions fluctuated widely on any given floor.

In this case people expressed a desire to participate in controlling their environment. Whether this is the exception or the rule is difficult to say. It seems that the complaints associated with comfort soon die out. Whether that means that the problem has been solved or that people have given up the hope of ever being comfortable is uncertain.

Another point that arose in this area was that papers will blow all around the office and disrupt the workers.

Some research efforts have been directed at human comfort in cooling situations. The use of ceiling fans to increase the temperature at which most people are comfortable has resulted in extensions of the defined comfort zone (Rohles, 1982). These efforts have been in relatively simple architectural configurations using only one fan in a small space. The problems that are encountered in complex spaces with multiple fans must be assessed in more detail. All of the costs involved must be tabulated before any firm conclusions can be reached. Federal standards have also been revised to account for workers wearing lighter clothing in the summer.

These feelings are contrasted by increasing reports of "Tight Building Syndrome" (TBS) in the press. More and more people are complaining of various types of sickness they feel are associated with sealed buildings and poor ventilation rates (Cantor 1983).

Energy costs are not high enough yet to warrant consideration. According to the BOMA Experience Exchange Report for 1980, energy costs for heating, cooling and electrical power represented 22% of the total expenses for private sector office buildings in the U.S. These costs have been steadily rising from an average of \$0.988/square foot in 1976 to \$1.486/square foot in 1980 (BOMA 1981). This cost is still a very small percentage of the rental costs for the space. Tax deductions for energy costs, etc., make the dollar cost relatively insignificant to many building owners at this time.

There are a number of socioeconomic perceptions of commercial building owners that affect energy consumption. One building owner remarked that "we're not desperate enough yet" to turn off the air conditioning system and open the windows. Store owners are afraid that people won't buy clothing, etc. if they are not in an air conditioned environment. "The clothes will mildew", "food will go stale", "people won't come in to my store", etc. were all concerns voiced by commercial building owners when asked about using natural ventilation.

There are also definite social and economic class associations that segments of the population have towards the use of air conditioning. The attitude was expressed that a successful business can afford to pay for air conditioning.

The architectural profession has no organized feedback on whether those buildings that are designed with natural ventilation systems are actually used and furthermore, if they are used, do they provide the comfort that their designers expected? The telephone interviews conducted during this study indicated that of those buildings that were designed with both a natural ventilation system (that the architect/engineers intended to be used as part of the normal operating procedure of the building) and an air conditioning system (that was to be used when the weather got too hot for the ventilation system), very few, if any of the buildings surveyed actually opened the windows at all!

This is contrasted by the opinion of a researcher at an energy laboratory that "everyone opens the windows, it's done all the time". This point of view was also shared by several architects. His feeling was that current thrusts in ventilation research should focus on development of the technology itself because opening of windows and turning off the air conditioning system was a generally accepted practice in buildings today. This might be true of some residential buildings, but even within the residential sector the trend appears to be towards closing up the house and turning on the a/c.

Most mechanical engineers questioned felt that the problems involved in introducing large quantities of outside air into the building and its effect on the mechanical system as discussed earlier preclude its use in large commercial buildings at this time.

When there is no alternative air conditioning system, there is a tendency for the natural ventilation systems to be used more frequently.

People don't know when or how to open the windows in a building to obtain optimum energy performance. As a result, the HVAC system must work overtime to compensate for poor operating procedures and actually use more energy than a well designed air conditioning system. A recently constructed building that was published in a Passive Solar Meeting Proceedings ran into so many problems due to conflicting comfort requirements among the occupants and their not knowing when to open and close windows, etc, that the windows were shut after a very short time and a relatively inefficient air conditioning unit has been running in an area that has an extremely mild summer climate (214 CDD above 78 ET*). The building operator is currently seeking funding for a higher efficiency air conditioning unit. He is also considering trying to develop a system that would automatically open and close the windows at the right times.

This highlights a common concern that "a building manager would probably be needed to develop a schedule for opening and closing the windows for optimum performance and then to actually open and close them!" There were many comments that centered around "it is too inconvenient for people to open the windows," "my workers don't have time to open the windows," and "my people have better things to do with their time than open and close the windows."

This problem is compounded by the commonly expressed concern that building energy costs are a low priority item with building users as well as building owners as mentioned above. From the telephone interviews, there appears to be a greater degree of concern when the utility bill is paid by the consumer. One such building operator actually spent a good deal of time and research to optimize the performance of his building. In this case, due to severe budgetary limitations, any money spent on energy would not be available to spend in other more critical areas.

Successful Applications of Natural Ventilation in Nonresidential Buildings

Despite the largely negative comments outlined above, there have been a number of highly successful nonresidential buildings that have been built in recent years that use natural ventilation as the primary source of summer cooling. More detailed case studies of several of these buildings will be presented to demonstrate not only the energy savings that are possible through the use of natural ventilation, but also the enhancement of the quality of everyday life that is possible.

Faneuil Hall Market Place, Boston, MA. The recently renovated Quincy Market is housed in buildings that are over 150 years old. "Hardly the state of the art" in the words of the building operator, Walter Hauer. The building is heated by a central steam system that is turned off when the weather begins to warm up in the spring and isn't turned on again until the chill returns in the fall. From April or May until October or November, the building is conditioned by natural means. Windows on the north and south sides of the building pop up and the sides of the new additions roll up to let the entire structure open up to the outside air. Ceiling fans in many of the shops and restaurants provide added comfort during the middle of the summer. The interesting point is that in this pleasant, commercially successful environment, many of the complaints and objections mentioned above disappear. People

experience the vitality and spirit of a well designed urban center. The Quincy Market is a highly successful shopping mall that saves energy by quality architectural design. The result is a pleasure to behold. It stands as a fresh breath when the standard internally focussed shopping malls have become a national prototype.

It is interesting that the owners and operators of the Quincy Market do not perceive themselves as particularly energy conscious and that the motivation for this very successful design was architectural in nature.

Terman Engineering Center, Palo Alto, CA. The Terman Engineering Center was designed as a response to a relatively mild climate. In the words of Jerry McElvain of Harry Weese Associates, the architects of the building, the design of the natural ventilation system for the building was a response to the "ideal climate" and the unique architectural program offered by the project. A variety of individual controls are provided in the offices that form the perimeter of the building. Small balconies and operable louvred doors (windows) on the outside of each office allow outdoor air to be drawn into the building. It is exhausted through louvred doors on the interior corridor where the air is drawn up and out of the building through operable skylights. The offices in the building all operate in this manner and are not air conditioned. The classroom library, laboratory and computer spaces within the building are air conditioned.

A large amount of the designers time was spent "convincing the owner" that the system would work and be accepted by the building users. The building bears some resemblance to residential structures in the Mediterranean countries. The sizing of the windows, etc. was done by the architects without any special engineering design. The concept for the offices was again architectural in nature. The desire was to create a work and study place that was linked with nature and could provide the optimum environment for the graduate engineering students and faculty that were housed in the building. Again, there was no energy budget or computerized analysis performed during the design of the building.

A recent case study was conducted by the researcher to evaluate the degree to which the natural ventilation system was utilized by the occupants of the building. This study is fully documented in (Siebein, 1984) and summarized in Apendix 2.

The small scale spaces and personal identification with each office contributed to this behavior. Personalization of the offices by large plants, pictures, furniture, etc., was noticed in many of the offices. The widespread use of the natural ventilation system is necessary because most of the building is not air conditioned. The acceptance and use of the system contradicts many of the opinions expressed earlier (that people will not use energy saving devices, take an active role in conserving energy or feel comfortable in a non-air conditioned building). The scale of the building and sense of personal territory created by the individual offices contributes heavily to this acceptance.

Most of the people interviewed did not even realize that they were saving energy. Windows were opened and lights were turned on and off as part of a daily routine, much the same as plants were watered and the coffee pot turned on. The large diurnal temperature savings and cool breezes that characterize the climate in the region enhance the performance of the building. Yet even in this mild climate, the Terman Center stands out as a rather unique non-residential building. Most of the other recently constructed buildings in the area are sealed, air conditioned structures that do not permit any contact between the interior and exterior environments.

It was the architectural concept that led to the creation of a successful building that happened to use natural ventilation. Whether natural ventilation would work in a building that was not designed as well as the Terman Center is an interesting question for speculation.

CONCLUSIONS

The case studies presented above demonstrate that the impetus to use the natural ventilation strategy comes more from an architectural requirement to create delightful spaces that are "in tune" with their environment rather than from a need to save Btu's (although the Btu's are certainly saved). The objections that have been expressed by numerous other building designers, owners and users all seem to vanish when they (building users)/are pleasurably immersed in their environment. It seems that the issue of the success of natural ventilation might be more tied to good design quality than to energy requirements. People will travel all over the world on their vacations to have

a cup of coffee in St. Marks Square in Venice or a cocktail on an outdoor patio under a roof trellis in the stifling heat of the Caribbean or to read a book on a small porch outside a cabin in the cool mountain air, but cannot duplicate this evidently sought after experience in their normal daily lives.

The State of Florida is currently reviewing a "Natural Ventilation Standard for Public Schools in Florida". The proposed standard prescribes health and comfort ventilation requirements for classrooms used in combination with ceiling fans. The standard allows for downsizing or eliminating the air conditioning equipment in buildings designed to provide health and comfort ventilation through natural or low energy means. This is the first such attempt to bring natural ventilation back into the standard operating procedures of modern buildings. With the excessively hot and humid climate that much of Florida experiences, if the standard works there, it should be very easily adapted to less severe cooling climates.

It would be hoped that this type of legislation would spur equipment manufacturers and mechanical engineers to develop mechanical systems that could coexist with natural ventilation systems to maintain the highest potential quality in the environment that operates as an optimal energy system.

It is hoped that this research will provide the basis for future studies that further define the limits of natural ventilation given the existing confusing and contradictory state of the art. The approach to the problem seems to lie primarily in the issues relating to user acceptance and the quality of the designed environment rather than in documented energy savings. The exploitation of the building as a part of the environmental control system and the vast potential for energy savings in this area have barely been touched. This concept extends far deeper into the nature of architectural design than adding insulation or sun shades to the building envelope. The building represents a substantial expenditure of capital, resources, time and energy on the part of many people over an extended period of time. Research efforts need to develop the full potential of this vast untapped energy reserve in the future.

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APPENDIX 1*

*The data presented in Appendix 1 are from EIA 1981 and EIA 1983. Climate zones are defined as:

- 1 = <2000 CDD and >7000 HDD
- 2 = <2000 CDD and 5500-7000 HDD
- 3 = <2000 CDD and 4000-5499 HDD
- 4 = <2000 CDD and <4000 HDD
- 5 = >2000 CDD and <4000 HDD

AIR-CONDITIONING SYSTEM TYPES

FOR NON-RESIDENTIAL BUILDINGS

NONE

WINDOW UNITS

PACKAGE
UNITS

CENTRAL
SYSTEM

COMBINATION/
OTHER

PERCENTAGE DISTRIBUTIONS

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COMBINATION/
OTHER

PERCENTAGE DISTRIBUTIONS

ALL

ASSEM

AUTO

EDUC

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HEALTH

INDUST

LODG

OFF

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RETAIL

STOR

OTH

VAC

BUILDING TYPE

APPENDIX 2

Case Study Summary of the Terman Engineering Center, Stanford, California

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Case Study Summary of the Terman Engineering Center, Stanford, California

INTRODUCTION

This study represents a preliminary evaluation of the degree to which manual energy saving devices were used by the occupants of the Terman Engineering Center, Stanford, CA on two warm summer days in July, 1983. The opening and closing of the exterior shutters, windows, interior louvered doors, and the turning on and off of the electric lights were recorded over a two day period at 2 hour intervals. The exterior temperatures were warm for the area, reaching the high 80's during the afternoon. The nighttime low temperatures were in the middle 50's. Cool breezes were blowing throughout most of the day and especially in the morning and evening. This represented near ideal conditions for the use of a natural ventilation system. By mid-afternoon the interior of the building, especially on the upper floors was relatively warm.

METHODOLOGY

Data were collected for 266 rooms at 12 noon, 2 p.m., 4 p.m., 6 p.m., 10 p.m. and 8 a.m., 10 a.m. and 12 noon the following day noting whether:

1. the exterior shutters were opened or closed
2. the windows were opened or closed
3. the interior doors were opened or closed
4. the electric lights were on or off.

The data were analyzed by a computer program written by John Battle, a graduate student in architecture at the University of Florida.

In addition, many of the occupants of the building were interviewed to understand their perceptions of the success of the system.

Results

A total of 8512 observations were recored with 1991 changes in the state of devices noted indicating that 19% of the observations denoted a change in state

of the device. This overall observation indicates a relatively high degree of usage of these devices which is contrary to what one would expect based on the conservation with the architects, engineers and building operators recorded earlier.

55% of the observations (1166) indicated that the rooms were not occupied during that time period or occupied only briefly enough for someone to enter, stay for a few minutes and leave. There were only a few cases noted where rooms were occupied and no physical evidence of the occupancy (such as turning on the lights) was observed. There were also several instances observed where the occupancy and state of the energy device changed in a period of time that was less than the data recording period. The data recording process took 1 1/2 hours for each cycle. Several observations were made where someone would enter a room, turn on the lights, open the window and interior door, type a letter or work for 1/2 - 1 hours, and leave closing the door and window and turning off the lights on the way out. This was due to several factors. The graduate students and faculty who occupy many of the offices operate on diverse schedules, especially during the summer. The administrators and staff tend to hold more regular hours. This varying pattern of occupancy was clearly reflected in the use of the energy devices.

Generally, the building was slow to start up in the morning, with people entering the building between 8 a.m. and 11 a.m. and slow to close up in the evening, from 4 p.m. to 9 p.m. There was only a minimum of night use of the building during the study period.

The people who were in their offices for longer periods of time tended to operate these devices more frequently than those who used the offices only briefly (between classes, etc.).

It is difficult to draw too many quantitative conclusions from this preliminary study. Much of the data speaks for itself. Many questions are raised by implications from the data that point the way towards future research directions.

Observations of the state of each of the four devices coincided with the occupancy pattern of the building. The shutters were closed for 37% of the observations, the windows were open for 34% of the observations, the lights were on for 30% of the observations and the interior doors were open for 22% of

the observations. The use of all the devices was greatest on the south and west orientations and least on the north and east orientations. This usage pattern reflects both the harsher solar influence on the south and west requiring more modification of the external environment and the occupancy characteristics of the building. The offices oriented to the south and west tended to be occupied more of the time and for longer periods of time than those on the north and east. (Also the east facade is shaded by a row of relatively large trees and the morning sun was welcome to take away the chill from the previous night.)

A total of 1591 changes in state of the devices were recorded during the study period. The offices oriented towards the south showed a relatively uniform operation of all the devices with 21% of the observations showing a change for the exterior shutters, 25% of the observations showing a change for the windows and lights and 20% of the observations showing a change for the interior doors. In the offices oriented to the north and east, the lights were turned on or off considerably more (approximately twice as much) as the other devices indicating the less severe solar and climatic influences on these facades.

Overall, the lights were the most frequently operated device (24% of the observations) indicating that the lights were turned on as people entered and left the offices. The exterior shutters were operated the least of all the devices showing a change in state during 10% of the observations.

The peak use of the windows, interior doors and lights coincided for all orientations. As people arrived at work in the morning (from 8-11 a.m.) these devices were turned on and then turned off as they left in the afternoon. A secondary peak in the operation of these devices was observed during the lunch hour. As people left for lunch, the lights were turned off and interior doors and windows closed and then opened up again when they returned. For many people, this indicated that opening the doors and windows and turning on the lights was a part of their daily routine.

The exterior shutters were operated independently of the other devices. In some cases, the movement of the shutters appeared to be on a cycle that was longer than the period of study due to the random pattern of their operation. The shutters were operated more frequently in the south and west facades than

on the north and east. Peaks of activity were observed during the late morning/early afternoon as the shutters were closed when the midday sun began to strike the building. Later in the evening two divergent trends were observed. Some offices on the south and west facades opened the shutters as the sun began to set. The more dominant situation was people closing the exterior shutters as they went home in the evening, leaving the windows partially open behind them. Further analysis and complete statistical data from this study is presented in (Siebein, 1984).

CONCLUSIONS

The general conclusion from this study is that the manual energy saving devices are used extensively at the Terman Engineering Center. Why do people use these devices here when so many other studies have shown this is not generally the case is a complex question. It has much more to do with many of the more intangible aspects of the situation than with any indication of energy savings.

The personalization of space and sense of responsibility for the individual offices, the self motivated and generally flexible work hours of the students and staff, and the architectural qualities of the spaces all contribute to the effectiveness of the scheme. People open the windows and turn on the lights just as they water the plants that hang in many of the terraces. They do not consciously realize what they are doing. The casual dress of many people at the university also contributes. The fact that there is no air conditioning system necessitates that the natural ventilation system be used. However, the main point here is that it works and these manual devices are extensively used.

The reasons that it works have little to do with factors that can be considered in an energy analysis of the building, but more so with the way in which people interact with and use the building and with the overall quality of both the interior and exterior designed environment.

From a conceptual point of view, it is the people not the buildings that use energy and our efforts should be directed in this direction. There is a tremendous existing laboratory available for study in the large percentage of buildings that have been identified by the E.I.A. study as non-air conditioned that could provide significant amounts of data to begin to form answers to these complex questions.

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