INDOOR AIR 90
INDOOR AIR QUALITY -
16 YEARS AFTER THE ENERGY CRISIS

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Whether it be in operating a business, creating art work, or practicing engineering, there is an inherent tendency to set aside many of the seemingly insignificant bits of basic knowledge upon which our expertise is structured and base our daily functioning and decisions only on selected parameters. This developmental process comes with experience and is a prerequisite to effective production. From time to time, however, with changing conditions, we should re-evaluate the parameters upon which we are basing our decisions. This re-evaluation is not an automatic process; it must be taken consciously and with an open mind.

After the energy crisis (AC) of the 70's, energy conservation considerations dominated many projects. The construction industry continued to work with the same selected parameters used before the energy crisis (BC), not realizing that this was a significant change requiring re-evaluation of these parameters. The result is that today, the bottom line of many buildings suffers from indoor air quality (IAQ) problems. This paper will explore some of these areas, attempt to identify potential problems in relation to the ramifications of energy conservation on both commercial building Heating Ventilation and Air Conditioning (HVAC) systems, and on IAQ, and suggest solutions.

FOSTERING OCCUPANT PRODUCTIVITY

When considering energy conscious design, it is important to remember that the primary objective of any commercial building system is to provide an environment that will foster tenant productivity and, ultimately, increase the profitability of the business conducted inside. The architectural planning, the aesthetics, ergonomics, office equipment, and the lighting and comfort level provided by careful mechanical and electrical systems design are invisible but significant ways to improve productivity. In their attempts to reduce initial and operating cost of building systems, many executives often forget the sine qua non of having the systems at all: to provide an indoor environment that will positively impact employees productivity. When conditions change, as happened during the energy crisis, engineers should step back, re-evaluate the parameters involved, and remind themselves, as well as their clients, of the productivity aspect, so that energy conservation goals can be accomplished without sacrificing this primary objective.

INDUSTRY CHANGES DUE TO ENERGY CONSERVATION AFTER THE ENERGY CRISIS

The construction industry energy conservation changes that effect IAQ are very basic:
- lower lighting levels with a corresponding impact on HVAC load and total air quantity;
- extensive use of variable air volume (VAV) systems;
- lower minimum outside air ventilation rates;
- tighter buildings resulting in reduced infiltration rates; and,
- other heating and cooling load reduction measures such as better insulation and shading.

Each one of the above items contributed to reducing the rate of dilution of contaminants inside our buildings, some directly and some indirectly. The combined effect of all of these changes, on the indoor environment, is so drastic that many buildings have been labeled sick.

THE IMPACT OF LIGHTING LOAD REDUCTIONS (Figures # 1 and 2)
BC, lighting load in an interior office space of 5watt/ft^2(54watt/m^2) and supply air quantity of 1cfm/ft^2(4.7L/sm^2) were considered normal. About 80% of the conditioned air quantity was needed to balance the heat dissipated by such lighting load. One of the most effective energy conservation measures happens to be the reduction of lighting loads. AC, lighting load in an office space was considered "normal" at a level of under 2watt/ft^2(22watt/m^2). At this level, the supply air quantity needed to balance the heat dissipated by lights and same miscellaneous loads in an interior office is reduced to about 0.52cfm/ft^2(2.5L/sm^2). Since this 50% reduction in air quantity saves fan energy in addition to the lighting energy savings many considered this (and some still do) as a positive step forgetting the negative impact on contaminants dilution.

In the past, designers have found another way to reduce the lighting system load on air conditioning. The solution was the heat extract light fixture. This fixture allows return air to flow through it, recovering the heat from lights before it is emitted into the office space. Many such light fixtures recover 50% of the lights energy. Applying return-air heat-recovery light fixtures to post-energy-crisis lighting loads reduces supply air delivered to the space by the air conditioning system to about 0.36cfm/ft^2(1.7L/sm^2) (64% reduction). Again, many considered this a positive effect since a further reduction in air quantity saves even more fan energy and the impact on IAQ was ignored.

A BASIC PARAMETER WHICH SHOULD HAVE BEEN RE-EVALUATED
The basic parameter used in calculating the supply air quantity is the temperature difference between the supply air and the room temperature. For years, 20F(11C) was the norm. AC when the cooling loads were substantially reduced due to energy conservation, this parameter should have been re-evaluated. A lower temperature difference, such as 10F(5.5C), would result in a supply air quantity closer to the BC air quantity and will ensure that the building was adequatly ventilated. Unfortunately, many building systems have been designed with reduced load and the BC 20F(11C) temperature difference resulting in very small air quantity supplied to the space. The air quantity could have been sufficient to ensure a thermodynamic balance but, in many cases, insufficient to dilute contaminants and create an air movement that reaches the occupants. The first line of each case shown in Table Ā, demonstrates the use of 20F(11C) and 10F(5.5C) temperature difference.

THE VARIABLE SUPPLY AIR QUANTITIES (TABLE A)
In addition to the reduction in the maximum supply air quantity, VAV systems have been extensively used after the energy crisis. VAV systems decreas the air quantity as a function of the room temperature. When the room temperature falls, the supply air quantity decreases from its maximum. As described above, the maximum supply air was reduced due to load reduction and VAV systems decrease the air flow from that point. Some systems incorporate a minimum point below which the air is not allowed to be decreased. Unfortunately, some systems do not even provide such a minimum point and the supply air could be completely dampered off. Many justify this by saying that in interior spaces the cooling load is constant and the air will never be dampered-off. The fact is that, early in the morning, when occupants arrive, lighting and people loads do exist but, if the building is cooled down at night, the temperature in the space is already so low resulting in minimum or no supply air flow into the space. It can take quite some time for the space temperature to rise to the level that activates the thermostat to open the VAV terminal. During that period the building goes through one of its sick syndrome episods.

In mild weather locations, many times it is assumed that there is sufficient heat in the return air to preheat the outside air by mixing it with return air and many systems have been operating without a preheat coil at the air handling unit. It was appropriate for BC constant volume systems. Unfortunately this assumption was not re-evaluated when applied to AC VAV systems. When the VAV system decreases the supply air quantity the percentage of outside air in respect to the supply air increases. The result is that the mixed air temperature ends up below the supply air temperature set point. Table A demonstrates the mixed air temperature when the supply air is reduced. The lightly shaded lines in table A demonstrate the air quantity that will result in mixed air temperatures below supply air set point. This is where a preheat coil normally comes into play- warming the mixed air to achieve the supply air set point. Without a preheat coil, supply air is delivered at temperature below the set point. The combination of reduced lighting load, VAV system and no preheat makes the situation even worse. In addition to this many buildings do not include a heating coil in the VAV terminals of interior rooms. If we talk about sick buildings this one could be labeled a "terminal case". Without a heating coil in the air handling unit or in the terminal box, there is no way for the air to be warmed up. Furthermore, since the supply air temperature is below the set point, it takes less air to cool down any existing loads which, in turn, decreases the air quantity and, which in turn, further lowers the mixed air temperature. At some point spaces in the building get too cold due to the low supply air temperature. When the complaints about the cold get to the operating engineer, the only thing that he can do to cure the cold is to damper the outside air. He responds to the cold symptom by choking the patient. In a way if the supply air continues to modulate, the system might choke itself, reducing the total air below the minimum outside air as represented by the darker shaded lines on Table A.

ROOM AIR DISTRIBUTION

Insufficient room air distribution was identified as one of many reasons for low IAQ. Most of today's commercial buildings are built with the supply air diffusers as well as the return/exhaust inlets mounted in the ceiling. This sometimes result in short circuit of supply air directly to the return/exhaust inlet. In VAV systems, during the summer, the high velocity and cold air, which has the tendency to drop down, help blend the supply air with the room air. However, when the VAV terminal decreases the air quantity, the velocity is reduced and there is less chance for the supply air to reach an occupant. In the winter, when both the air quantity and velocity are reduced and the supply air is warm, the supply air stays at the ceiling high above the occupant and is short circuited out of the room via the return/exhaust inlet without ever reaching the occupant. Tests have recorded that temperature stratification of up to 13F(7C) exists in some buildings demonstrating that warm supply air does not reach the occupant. Thus, a parameter which should have been re-evaluated is VAV system winter supply air temperature .

OUTSIDE AIR QUANTITIES

As a result of the energy crisis, the infiltration of outside air was reduced by tighter buildings design and the ventilation standard for minimum outside air quantity was reduced from 15cfm/P(7.5L/s/P) to 5cfm/P(2.5L/s/P). This drastically reduced the dilution of indoor contaminants. In 1989, it was re-revised increasing the minimum outside air flow up to 20cfm/P(10L/s/P). However, we must remember that even the present ventilation standard is based on "air in which... a substantial majority (80% or more) of the people exposed do not express dissatisfaction". That means that 20% of the people might perform at lower levels due to the IAQ. This may not be economically acceptable to some businesses.

ERGONOMICS AND ECONOMICS

As ergonomics becomes an important factor in building design, business clients are becoming more and more aware of the contribution indoor environment makes to employee performance. When air conditioning was first introduced, it was intended that its initial and operating costs would be recovered by an increased volume of business. In many cases improved IAQ will result in more ventilation and, consequentially more energy consumption. In many buildings, the IAQ was reduced to such levels, due to energy conservation work, that it actually affected productivity in the building. One survey concluded that about 40% of the occupants in office buildings stated that poor IAQ was a factor in their work place, and 20% stated that the IAQ problems were serious enough to affect their performance. From this survey we can conclude that initial cost savings or energy conservation which effects the IAQ have an adverse reaction on the office financial performance. A review of several recent projects helps to put the initial HVAC system cost and the building energy cost in the context of the business conducted in an office building and shows the following:

- Initial cost of HVAC system for an office building is in the range of $10/ft²($100/m²).
- Energy bills associated with the operation of an office building's mechanical and electrical systems are under $2/ft²/year($20/m²/year).
- The average salary in an office building is in the range of $300/ft²/year($3000/m²/year), assuming $30,000/yr salary and 100ft²/person (10m²/person) occupancy.

The initial cost of the HVAC system is very small in comparison to the cost of the occupants' average salary and the energy cost to operate the building is even lower; therefore, the occupants' performance as a function of IAQ must be weighed in this context. Cost effective HVAC system option that saves 10% of the initial cost ($1.00/ft²) should have an adverse impact on IAQ and office worker performance of less than 1/3 of one percent (1/3% of $300/ft²/yr =$1.00/ft²/year) of employees' salary during one year. If we measure it in time, 1/3% of a normal business day of eight hours is about 1. 5 minutes/day! See Chart #1.

When comparing energy cost to salary cost in an office building, we really have to get our stop watches ready. Cost effective energy conservation measures that saves 10% of the energy cost ($0.20/ft²/year) should have less then $0.20/ft²/year or less then 0.067% adverse impact on the business conducted in the office space. If we measure it in time, 0.067% of the time business is conducted in an office is about 20s/day! This means that in an office building of 100,000ft² a $0.20/ft² energy savings per year will result in a $20,000 energy cost saving. On the other hand, loss of production of 20s/day due to IAQ impact on 1,000 employees (100ft²/person) at $30,000/yr average salary result in a loss of about $20,000 per year. Thus the 10% energy cost saving has been wiped out by the loss in worker productivity. Such energy cost saving measures should not be implemented. For example, in some extreme cases, office IAQ has been so bad that workers had to stay at home. One lost day, out of 250 work days per year, due to IAQ problem, equals 0.4% of the employees' working hours in one year. Entering Chart #2 at 0.4% of working hours, projecting to the right to the $300/ft²/yr($3000/m²/yr) average salary line and down, we can see that this is the equivalent of $1.20/ft²/yr of energy cost. The loss of one work day equals 60% of the cost of energy to operate a building for a full year. It is obvious that savings from a reduction of outside air ventilation, which results in a sick building, are not economically sound.

TENANTS AND LANDLORDS

Sometimes both energy conservation and IAQ are sacrificed for even greater forces: the real estate forces. In some parts of the country, the landlord can include the area of the mechanical room in the rentable area if the mechanical room is located on a rented floor. The landlord can not include a proration of the central mechanical room located in the basement or on the roof. Thus, the building is designed with fan rooms on each floor; and since fan room cannot be located on a prime exterior space, it ends up buried inside the core of the building where connection to outside air is very costly. The result is a building that is ventilated with a bare minimum outside air year around. Even when the outside air quality is fine, and the temperature outside is so cool that the building could be air conditioned by the use of outside air (air economizer), it will receive only the minimum outside air with cooling provided by refrigeration machines. If it was designed when the outside air ventilation rate of 5cfm/P(2.5L/s/P) was an acceptable standard, it could be considered "sick" today.

Many landlords and tenants do not realize the connection between the location of the fan room and the capability of the system to fully ventilate the building, as well as the high energy consumption implication of such design. From the real estate point of view, it appears that the landlord's bottom line is improved by locating a fan on each floor, and energy-conscious design and IAQ are put aside - but not for long. Some business tenants are becoming smarter and are studying several rental possibilities, to find the one which provide IAQ that will increase employee performance. So far there are very few landlords who advertise their property as having better IAQ than the competition.

CONCLUSIONS

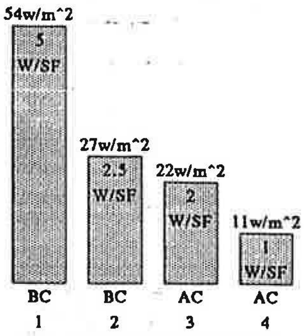
Energy and IAQ conscious design cannot be achieved by engineers alone; it requires teamwork among the owner, the user, the real estate professional, as well as the architect and the engineer. In order for owners and users to receive what they expect from a building, they must become involved early in the building systems decision making process. When conditions change this team should be capable to evaluate past parameters and adjust to the new situation. Now, 16 year AC, we can conclude that for an initial or energy cost cut to be economically sound, it should have no negative impact on occupant's productivity. We may add that investment in a better IAQ may well result in avoidance of employees' down time, and a substantial return on investment.

It is very difficult to monitor productivity as a function of HVAC system performance and IAQ. Judgment calls must be made in specific applications and a chart like Chart #2 could demonstrate the relationship between the incremental energy cost and the potential time or cost avoidance. The question the decision making executive should ask himself, is: Can the down time wipe out the energy cost savings? If the answer is positive, the energy conservation measure should not be implemented. All of us should remember that the bitterneess of poor IAQ lingers long after the sweetness of energy cost savings is forgotten.

THE IMPACT OF LIGHTING LOAD REDUCTION

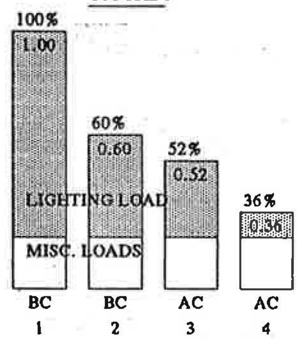
TOTAL SUPPLY AIR	*TOTAL SUPPLY AIR*		*OUTSIDE AIR AT 15CFM/P*		*OUTSIDE AIR*	*MIXED AIR TEMP.*	
%	cfm	L/s	cfm	L/s	%	F	C
1.BC VAV, 5.0 WATTS/SF LIGHT LOAD, 20F TEMP. DIFF.							
100	100000	47200	15000	7080	15.0	64.6	18.1
50	50000	23600	15000	7080	30.0	59.2	15.1
40	40000	18880	15000	7080	37.5	56.5	13.6
36	36000	16992	15000	7080	41.7	55.0	12.8
30	30000	14160	15000	7080	50.0	52.0	11.1
25	25000	11800	15000	7080	60.0	48.4	9.1
20	20000	9440	15000	7080	75.0	43.0	6.1
2.BC VAV, 5.0 W/SF LIGHT LOAD, 20F TD, 50% RECOVERY FIXTURE							
100	60000	28320	15000	7080	25.0	72.5	22.5
50	30000	14160	15000	7080	50.0	67.3	19.6
40	24000	11328	15000	7080	62.5	61.8	16.6
33.7	20220	9544	15000	7080	74.2	55.0	12.8
30	18000	8496	15000	7080	83.3	48.5	9.2
25	15000	7080	15000	7080	100.0	34.0	1.1
20	12000	5664	12000	5664	100.0	34.0	1.1
3.AC VAV, 2.0 WATTS/SF LIGHT LOAD, 20F TD.							
100	52000	24544	15000	7080	28.8	59.6	15.3
69.2	35989	16987	15000	7080	41.7	55.0	12.8
50	26000	12272	15000	7080	67.7	49.2	9.6
40	20800	9818	15000	7080	72.1	44.0	6.7
30	15600	7363	15000	7080	96.2	35.4	1.9
25	13000	6136	13000	6136	100.0	34.0	1.1
20	10400	4909	10400	4909	100.0	34.0	1.1
4.AC VAV, 2.0 W/SF LIGHT LOAD, 20F TD, 50% RECOVERY FIXTURE							
100	36000	16992	15000	7080	41.7	61.0	16.1
71.6	25765	12161	15000	7080	58.2	55.0	12.8
50	18000	8496	15000	7080	83.3	43.4	6.3
41.7	15001	7081	15000	7080	100.0	34.0	1.1
40	14400	6797	14400	6797	100.0	34.0	1.1
30	10800	5098	10800	5098	100.0	34.0	1.1
5.AC VAV, 2.0 WATTS/SF LIGHT LOAD, 10F TD.							
100	104000	49088	15000	7080	14.4	64.8	18.2
50	52000	24544	15000	7080	28.8	59.6	15.3
40	41600	19635	15000	7080	36.1	57.0	13.9
30	31200	14726	15000	7080	48.1	52.7	11.5
20	20800	9818	15000	7080	72.1	44.0	6.7
6.AC VAV, 2.0 W/SF LIGHT LOAD, 10F TD, 50% RECOVERY FIXTURE							
100	72000	33984	15000	7080	20.8	66.5	19.2
76	54720	25828	15000	7080	27.4	65.0	18.3
50	36000	16992	15000	7080	41.7	61.0	16.1
40	28800	13594	15000	7080	52.1	57.4	14.1
30	21600	10195	15000	7080	69.4	50.2	10.1
20.8	15005	7082	15000	7080	100.0	34.0	1.1
20	14400	6797	14400	6797	100.0	34.0	1.1

TABLE A



LIGHTING LOAD REDUCTION

FIGURE 1



% OF SUPPLY AIR REDUCTION

FIGURE 2