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VENTILATION STRATEGIES FOR NON-RESIDENTIAL BUILDINGS

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Ventilation Strategies for Non-Residential Buildings

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1. Abstract

Ventilation in nonresidential buildings in the United States of America has been traditionally provided by means of mechanical ventilation. The ventilation systems have been designed for the maximum load possible for the building and have been used accordingly. The maximum load for a lot of the nonresidential buildings is determined by the amount of ventilation air intake based on the total occupancy rather than by heat transfer through the building's envelope. Tremendous savings are possible by adjusting the outside air flow according to occupancy of the building, especially for buildings with changing rates of occupancy. In most cases, another potential savings can be experienced just by adding heat recovery devices to the existing air handling system. Heat recovery options using a heat pump to heat domestic hot water should be considered for all-electric buildings with a high hot water consumption. Although a number of strategies to save energy have been discovered, none work well for all possible applications in the different climates to be found in the U.S. A more detailed investigation applying all the possible strategies for a number of building types in all major climates should follow this study.

2. Introduction

The energy consumed for conditioning buildings equals roughly 36% of the overall energy consumption of the U.S. [1], With commercial buildings using approximately 14%. Therefore, commercial buildings are one of the smaller energy users in the country; well behind the residential buildings, industry and transportation. However, since energy use in commercial buildings with mechanical ventilation systems does not necessarily happens at a schedule which would allow an on/off operation, we can expect to experience significant energy reduction by applying the right ventilation strategy.

One of the key parameters for energy savings is the climate, the considered building is set in. Table 1 shows the floor area distribution of nonresidential buildings for the five climate zones (very cold, cold, mild, warm, hot) of the U.S. Although the majority of floor space is located in cold and mild climates (climate zones two and three), there are still roughly 15% of the overall floor space located in very cold climates and almost the same amount in hot climates. Table 1 further shows the uneven distribution of the building types for each of the five zones. In the Sunbelt, for example,

Table 1: Nonresidential Buildings, Floor Area Distribution for the Different Climate Zones. Numbers in Million m^2 [2]					
Type	Climate Zones				
	1	2	3	4	5
Assembly	55	176	163	46	Q
Educational	72	205	160	70	97
Food Sales/Service	30	74	37	31	33
Health Care	20	121	27	40	Q
Lodging	15	73	54	29	Q
Mercentile/Service	132	244	347	149	Q
Office	73	261	203	134	174
Warehouse	75	207	151	150	88
Other	Q	117	61	32	36
Vacant	19	97	55	40	41

office space has a much higher percentage of the overall floor area of this particular zone than in climate zone number one.

Table 2: Nonresidential Buildings, Building Stock Distribution for Buildings that Heat and Air-Condition with Electricity [2]			
Type	Number of Buildings in thousand	Floor Area m^2 in million	Energy Consumption kWh in billion
Assembly	104	153	11
Educational	48	110	11
Food Sales/Service	108	55	23
Health Care	17	37	7
Lodging	43	74	23
Mercentile/Service	193	357	42
Office	214	285	64
Warehouse	82	170	24
Other	39	81	Q
Vacant	33	62	6

The comparison of Table 2 and Table 3 show that approximately 37% of

Table 3: Nonresidential Buildings, Building Stock Distribution for Buildings that Air-Condition but do not Heat with Electricity [3]			
Type	Number of Buildings in thousand	Floor Area m^2 in million	Energy Consumption kWh in billion
Assembly	176	248	18
Educational	74	307	21
Food Sales/Service	194	100	32
Health Care	36	162	29
Lodging	34	99	15
Mercentile/Service	440	475	67
Office	273	454	73
Warehouse	126	331	29
Other	58	130	18
Vacant	55	83	11

the floor area of nonresidential buildings with air-conditioning is heated by use of electricity. The highest portion of all-electric buildings can be found in the lodging sector (43% of the floor area), whereas in the health care sector the percentage is well below 20%.

Furthermore, we find that average floor space per building can be very different between the all-electric buildings and the buildings which are not heated by means of electricity. Whereas for health care buildings we find the average floor space to be approximately 1,400 m^2 per building for both categories, there are marginal differences between the two categories for buildings in the educational sector (2,300/4,100 m^2) and in the health care sector (2,200/4,500 m^2).

Buildings in both categories have almost the same amount of fully air conditioned space (673/764 mio m^2), but electricity is not used for heating those buildings which cover 70% of the partially air-conditioned floor space.

This distribution of energy use and building location is important to determine possible savings due to different ventilation strategies.

3. Ventilation Strategies

Although the number of measures one can take to reduce the energy consumption by means of ventilation is already somewhat limited, some of the measures are furthermore only successful for particular building types.

As described in earlier reports [3,4] heat recovery from the exhaust air flow to the hot water system by means of an air-to-water heat pump shows energy savings only in all-electric houses where hot water is heated otherwise by means of resistance heat. In buildings with gas used originally to heat the hot water, the installation of an exhaust air heat pump would be only economically interesting if the price ratio between gas and electricity was very favourable for electricity. This is even true for buildings with high exhaust air temperatures like restaurants or launderettes. Furthermore, the necessary cleaning of the exhaust air in order to protect the heat exchanger, might not make heat recovery measure economical. This is especially true for fast food restaurants, where the exhaust air is highly polluted with grease. Heat exchangers will clogg up immediately under these conditions and are a major fire hazard.

Many ventilation systems are designed to supply the necessary amount of outside air for dense populated buildings. However, these kind of buildings usually are occupied on a weekly schedule and only for a short time of the day. Most of the ventilation systems for these buildings are designed to operate on the full amount of outside air all year round. Reducing the outside air intake in accordance to the occupancy level, reduces the conditioning load for a number of buildings for most of the time. Further savings can be experienced by using natural ventilation for necessary cooling during unoccupied hours and by reducing the overall air flow by using the CO_2-level and the temperature of the inside air as parameters to control the fan speed in the air handling systems.

Buildings with areas, which could be unoccupied for longer periods of time (lodging, bedrooms in hospitals), ought to be build with components having a high resistance against conductance between zones. This allows the temperature to swing over a wide range without influencing the adjacent areas of the building.

For areas which have to be constantly ventilated mechanically to build up protective pressures or to prevent back streaming in the duct work (operation theatres, clean rooms, etc.) during unoccupied hours, the system ought to be operating under the lowest mode necessary to secure the set target.

Table 4 shows some of the ventilation strategies and the buildings they apply to.

Table 4: Examples for Ventilation Strategies in Non-Residential Buildings	
Typ	Strategy
Restaurants Launderettes	exhaust air to hot water
Theatres Concert Halls Schools Museums Hospitals (Bedrooms)	heat exchange for intake/exhaust air CO_2-sensors to determine necessary intake air
Hospitals (Operation Theatres; outside air only)	heat exchange for intake/exhaust air reduction of air flow during off-hours (fan control)

3.1 Reduction of Air Intake

The conditioning of outside air to meet indoor comfort condition can be one of the biggest single loads for non-residential buildings. Therefore, the reduction of outside air intake is one of the most successfull measures to reduce the energy consumption. This strategy can be used for buildings which are not occupied for the whole day and/or where the number of occupants might change with time. The strategy can be used for all buildings, whether the outside air intake is based on the building's occupants or on a recommended minimum air change rate.

The most common building type for scheduled occupancy is the office building. Here, employees occupy the building on a fixed weekly schedule, including the unoccupied weekends. The number of occupants for office buildings are usually constant during working hours. Therefore, a simple time based controller can open or close the louvers for the intake air supply.

Outside air supply for buildings with no fixed schedule and/or changing occupancy ought to be controlled using sensors to determine the occupancy and its necessary outside air supply rate. As the CO_2-concentration is a reasonable measure for indoor air pollution caused by occupants, sensors tracing the concentration of CO_2 might be installed to determine the outside air supply rate.

3.2 Reduction of Fan Power

In cases where the air flow moved through the duct system by fans is determined by the design heating or cooling load, the air movement can be reduced by reducing fan speed for most of the time. This is also true for unoccupied or partially occupied buildings. Reduction of fan speed reduces the air flow rate and therefore, the pressure losses in the duct system. As the power consumption for fans is proportional to the third power of the volume rate, even small reductions of air flow might have a significant impact on the electricity bill.

Buildings with mechanical exhaust ventilation systems can reduce the depressurization effect by slowing down the fan speed. In addition to the power savings for the fan, this can further lead to significant reduction of fan induced infiltration. Infiltration, however, causes the heat loss due to ventilation for this type of buildings. An example of the use and the savings will be shown later.

4. Examples

4.1 Buildings with scheduled change of occupancy

In principal this group of buildings is represented by office buildings. Here, the occupancy is scheduled for a seven day week and the number of occupants during operation time is close to constant. Control of the necessary outside air intake for this kind of building is relatively easy. Further savings for holydays or vacation time does probably not pay the additional expenses necessary to install CO_2-sensors.

One can assume, that the outside air intake for almost all office buildings is controlled, either manually for smaller buildings or automatically by energy management systems for larger office buildings. Dependend on the climate and internal loads, the installation of air-to-air heat exchangers might or might not be favorable. This can only be decided case by case.

4.2 Buildings with changing number of occupants

4.2.1 Cinemas

Motion picture theatres are usually occupied only a few hours per day, for seven days a week. During performance time occupancy can differ between 0 and 100%, depending on several parameters (weather, starting time, film program, etc.).

The design criteria for the outside air intake is usually the number of possible occupants. Necessary air flows used for space conditioning during unoccupied hours are usually less than half of this air flow. Therefore, the necessary outside air intake, as well as, the overall air flow might change tremendously. This makes cinemas the ideal object to install occupant controlled intake air supply as well as load controlled fan speed control.

A cinema in Bismarck, ND, having a seating capacity of 200, and walls insulated by only R 11 needs a design volume rate of less than 1500 m^3/h to compensate the heat loss due to conduction at design condition. According to ASHRAE 62-81R [5], 5000 m^3/h outside air are necessary for the 4 hours of occupation per day to supply the necessary outside air rate per person for a fully occupied performance. Disconnecting the outside air flow path during unoccupied hours could save over 80% of the energy used for conditioning the intake air. For our example, the savings would be 122 MWh a year. This corresponds to approximately $4,900 per year for an end-use energy price of $0.04/kWh. When using a CO_2-sensor to control the amount of intake air, the energy needed to condition the intake air flow during occupied hours is directly proportional to the number of patrons. Therefore, on average, another 50% of energy savings might be possible, plus the savings due to reduced fan speeds.

Reducing the outside air intake can be obtained easiest by switching off the ventilation system during off-hours. For buildings with high heating or cooling loads, the ventilation system has to run in order to prevent high internal temperature changes. Therefore, the air intake should be reduced by closing the air intake louvers. Only makeup air will then be used for conditioning the building.

The energy savings due to the different ventilation strategies is very much dependend on the outside climate and might be much smaller for milder climates. However, almost 12,000 movie theatres [6] distributed over all five climate zones of the country promise a significant savings potential. Similar strategies could be used for libraries, museums and enclosed sport facilities.

Table 5: Energy Consumption per Year to Condition Outside Air Intake for Cinema in Bismarck, ND.		
Ventilation Strategy	Hours of Operation [h/day]	Energy Consumption [MWh/yr]
100% outside air	24	147
100% outside air	4	25
50% outside air	4	13

4.2.2 Bedrooms in Hospitals

In 1981 there were 6,933 hospitals with 1,362,000 beds in the U.S. [6]. The occupancy rate of hospitals in the U.S. was about 78% at this time. As bedrooms are usually mechanically ventilated, this means that hospitals use approximately 28% more energy to ventilate bedrooms than necessary. At an outside air change rate of 42.5 $m^3/(h\ bed)$ and an average temperature difference of 5 K between inside and outside, this corresponds to 187 GWh/yr ($ 7.5 Mio /yr) for all hospitals in the U.S. However, the specific cost related to a single unoccupied bed corresponds to only $ 25 per year, which makes it unlikely that actions are being taken from the hospital's administration.

4.2.3 Hotels, Motels

In 1977 there were 51,000 Hotels and Motels in the U.S. As mentioned before, this category has a high portion of all-electric buildings. This ought to be kept in mind, as for this group the wasted primary energy for heating is roughly three times the comparable end-use energy. Occupancy rates as well as building sizes for this building category are unknown. From Tables 2 and 3 we learned, that all-electric buildings for this category are usually smaller while having a higher specific energy consumption. However, this category covers the ten room motel on the county road as well as the 50 story high rise in New York. Therefore, general recommendations on how to reduce the unnecessary outside air flow cannot be given. The number of buildings in this category shows, that this is obviously a point for further research.

Conclusion

Energy consumption in non-residential buildings with mechanical ventilation can be reduced by applying the right ventilation strategy. Due to the different uses of buildings, finding the right ventilation strategy is much harder than for residential buildings. Occupancy rate, changes in occupancy, internal loads, hot water demand, thermal storage and the local climate are some of the parameters which determine the best ventilation strategy and its savings potential.

The energy savings possible by applying the most favorable ventilation strategy still might be only as much as $ 25 per year for an unoccupied bed in a hospital or less than $ 15 per day for a movie picture theatre. However, these small savings add up to reasonable numbers if these measures would be applied to the whole building stock.

Studies of several energy studies performed under the Institutional Conservation Program showed very high saving potentials if ventilation strategies and waste heat integration measures are combined. This is particularly successful if heating and cooling is needed at the same time. These saving potentials are used only in a limited number and are often not mentioned in the energy studies.

This concludes that the maximum energy savings for non-residential buildings will only be found by thoroughly studying each building type separately and take ventilation strategies as well as waste heat integration into account.

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