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A CASE STUDY OF ENERGY SAVINGS DUE TO THE ECONOMIZER SYSTEM IN MONTREAL

RADU ZMEUREANU

Centre for Building Studies
Concordia University, Montréal, Québec
Canada H3G 1M8

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Abstract - We present a comparison, based on computer simulation, between an economizer and a conventional cooling system for a fixed amount of outdoor air, operating in the Montréal climate for interior spaces which require cooling during 12 months per year. We compare the cooling-coil load and the energy consumption, using hourly weather data over ten years (1974-1983). The results show that the reduction of the cooling-coil load is about 7800 kWh/(1000 m^3/h) per year and the energy savings are about 3300 kWh/(1000 m^3/h) per year.

1. INTRODUCTION

In large commercial buildings, interior spaces such as computer rooms, offices or stores require cooling for 12 months of the year. Accordingly, the air-conditioning systems use a large amount of energy to produce chilled water. Moreover, the chillers work continuously, even during the periods of peak electrical demand, including heating and lighting, which usually coincide with the coldest winter temperatures.

The use of ambient energy for cooling will reduce both the energy consumption and the electricity bills. For an all-air system, the use of free-cooling through an economizer system can provide such savings.

The economizer system controls the dampers on the outdoor- and return- air ducts, i.e., amount of outdoor air brought in, which varies from minimum value of 20% of the total supply air, up to a maximum value of 100%, in terms of the temperatures and the enthalpies of fresh and return air. The objectives are the following: (a) To obtain a mixing temperature equal to or lower than the leaving coil temperature (T_S) [e.g. 13 C (55F)]; at this point, the cooling coil is shut off and no chilled water is required. (b) To reduce the cooling-coil load when the outdoor temperature is higher than the leaving coil temperature. The increase of admission of outdoor air may reduce or even completely eliminate indoor air pollution.

There are two types of economizer systems defined in terms of the measured parameters on outdoor- and return-air ducts. These are the dry-bulb temperature-economizer and the enthalpy-economizer. The dry-bulb temperature-economizer system controls mixing dampers and a cooling-coil valve in response to measurements of the dry-bulb temperatures of the outdoor and return air. The following summary statements apply: (a) When the dry-bulb outdoor-air temperature T_{DB} is lower than the supply-air temperature T_S (e.g., 13 C), no cooling is required and the outdoor air-flow rate is increased to obtain the desired supply temperature. (b) When the dry-bulb outdoor air temperature T_{DB} is higher than the supply air temperature T_S but is lower than the return air temperature T_R (e.g., 22 C), then the position of the mixing dampers is changed to close the recirculated air duct completely and bring in only outdoor air. (c) When the dry-bulb outdoor-air temperature T_{DB}

is higher than the return-air temperature T_R, mixing is performed by using a minimum outdoor-air flow rate. A drawback of this system for the case $T_S < T_{DB} < T_R$ is an increase of the cooling coil load when the enthalpy of the outdoor air is higher than the return-air enthalpy.

In order to obtain savings from the economizer system, even under unfavourable conditions, the sensors on the return-air duct are set for $T_{SW} < T_R$, which is called the switchover or cutoff temperature. At this temperature, the position of the dampers is suddenly changed, thereby reducing the percentage of outdoor air from 100% to the minimum value. An appropriate selection of the temperature T_{SW}, which depends on local weather conditions, reduces the risk of increasing the energy needs when the dry-bulb temperature-economizer system is used.

The enthalpy-economizer system controls the mixing dampers and the cooling coil valve in response to measured values of the dry-bulb and wet-bulb temperatures of the outdoor and return air. The only difference between this system and the dry-bulb-economizer system is that the position of dampers is changed to the minimum outdoor air when $T_S < T_{DB} < T_R$ and $h_O < h_R$.

The use of the economizer systems in Montréal has a large potential for energy savings, because the dry-bulb temperature is lower than 13 C almost 60% of time during a year and it is between 13 and 22 C about 24% of the time (Table 1). In Table 1, we present the yearly average number of hours of occurrence of different temperature bins in order to emphasize the climatic conditions in Montréal, and eventually to provide basic information for comparison with results obtained under other weather conditions. The data are based on hourly temperatures measured at Montréal between 1974-1983[1].

Table 1. Yearly average number of hours of occurence of different temperature bins in Montreal between 1974-1983.

Dry-bulb temperature bin (C)	Number of hours of occurrence	Mean coincident wet-bulb temperature (C)
-36.4/-33.6	0	-
-33.6/-30.8	2	- 16.2
-30.8/-28	6	- 29.4
-28/-25.2	22	- 26.7
-25.2/-22.4	51	- 24.0
-22.4/-19.6	90	- 21.5
-19.6/-16.8	161	- 18.7
-16.8/-14	237	- 15.9
-14/-11.2	299	- 13.3
-11.2/-8.4	335	- 10.7
- 8.4/-5.6	417	- 8.0
- 5.6/-2.8	483	- 5.4
- 2.8/0	562	- 2.7
- 0/2.8	776	- 0.1
- 2.8/5.6	627	2.3
- 5.6/8.4	617	4.9
- 8.4/11.2	627	7.6
- 11.2/14	643	10.0
- 14/16.8	715	12.6
- 16.8/19.6	727	14.9
- 19.6/22.4	667	17.0
- 22.4/25.2	407	18.6
- 25.2/28	212	20.1
- 28/30.8	67	21.9
- 30.8/33.6	10	24.2
- 33.6/36.4	0	-

Previous studies have indicated important reductions of the cooling-coil load for spring to fall operation when the economizer system is used. Zmeureanu[2] found that the reduction of the cooling load produced by the enthalpy-economizer is 1700-4900 kWh/(1000 m^3/h) per year (for 24 hours of operation per day) and 1120-2700 kWh/(1000 m^3/h) per year (for 12 hours of operation per day). The savings are expressed in units of energy consumption per year (kWh/year) divided by the units of the air flow rate (m^3/h or cfm). Using these units, the results obtained for a particular capacity of the HVAC system, expressed in m^3/h or cfm, can be extrapolated for any other capacity. The ratio of the load reduction caused by the dry-bulb temperature economizer to that caused by the enthalpy economizer was found to be between 0.69 and 0.94.

Other data for Montréal indicate the expected energy savings of about 1835 kWh/(1000 m^3/h) per year for 10 hours/day and 5 days/week operation with a minimum outdoor air of 20%.[3]

Although several other papers have examined the energy savings due to the economizer systems, they do not apply directly to the Montréal climate, which is characterized by the cold and relatively long winters, and by the hot, humid and relatively short summers. From this point of view, the present analysis provides specific data for this particular location.

The reduction of the cooling coil-loads can affect the operation of other components of the systems such as the chiller or the cooling tower. Hence, the energy savings for the entire system may be different from the reduction of the cooling-coil loads.

We present next a comparison, based on computer simulation, between the energy consumption for a conventional cooling system with a fixed amount of outdoor air and for the cooling system with use of the economizer. The major components are properly taken into account. The analysis was performed over the ten year period (1974-1983) for Montréal climatic conditions.

2. DESIGN CONDITIONS

The air-conditioning system used in this analysis has, on the air side a mixing box, a cooling coil, and supply and return fans. On the chilled-water side, it has a chiller, a cooling tower and circulating pumps (Fig. 1).

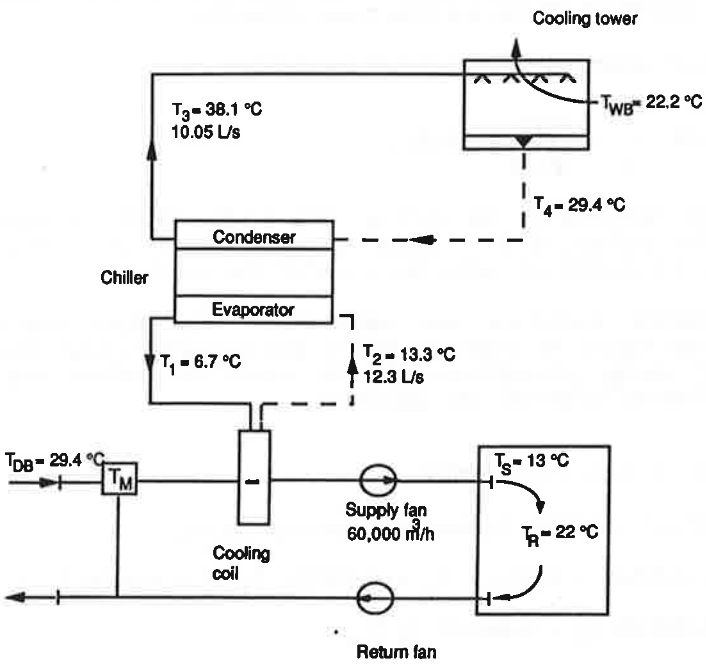

Fig. 1. Design parameters used in the selection of HVAC equipment

An air flow rate of 60,000 m^3/h (35,000 cfm) with 20 % outdor air is supplied continuously at 13 C (55F) to the rooms, to keep the indoor air at 22 C (72 F) and 50% R.H.

The design load in kW of the cooling coil is given by

$$Q = \dot{m} (h_M - h_S), \tag{1}$$

where $\dot{m}$ = air flow rate (kg/s), h_M = enthalpy of the air entering the cooling coil which equals the enthalpy of the mixed air (KJ/kg), $h_M = \alpha h_o + (1-\alpha) h_R$, α = proportion of outdoor air, h_o = enthalpy of outdoor air for the design conditions of Montréal, (T_{DB} = 29.4 C, T_{WB}= 22.2 C), h_o = 65 kJ//kg (35.8 Btu/lb), h_R = enthalpy of the return air = 44 kJ/kg, h_s = enthalpy of air leaving the cooling coil = 34 kJ/kg. For these numerical values, we obtain a design load of 284 kW (80.8 ton).

The temperature of the chilled water entering the cooling coil is selected to be 6.7 C (44 F). The chilled-water flow rate is calculated to be 12.3 l/s (195.1 gpm) for a temperature rise of 5.6 C (10 F).

The nominal capacity of the selected chiller is 286.6 kW (81.5 ton), and the nominal compressor power input is 80.5 kW. The condenser is cooled by water from a cooling tower, the entering design temperature is 29.4 C (85 F), and the temperature of the air leaving the system is 38.1 C (100.5 F).

The cooling tower was selected on the basis of needed range R and approach A. The range is the temperature difference between water entering and water leaving the cooling tower, i.e., R = 38.1 - 29.4 = 87 C (15.5 F). The approach is the difference between the temperature of the existing water and the wet-bulb outdoor temperature, i.e., A = 29.4 - 22.2 = 7.2 C (13F).

A cooling tower was selected with a rating factor of 0.9, a fan power of 5.6 kW and a water-flow rate of 10.05 l/s (159.3 gpm).

3. ESTIMATION OF ENERGY CONSUMPTION

Since the outdoor conditions change, the load on the cooling coil (Q) varies from its design value (Q_n). The energy consumption by the chiller and cooling tower vary with the load, and also because of modifications in the climatic conditions that affect the operation of the cooling tower directly.

The electrical energy in kWh consumed by chiller is

$$E_{CH} = Q_n \; NFLPR \sum_{i=1}^{n} \left(\frac{FLPR}{NFLPR} \; FFL\right)_i, \tag{2}$$

where Q = nominal capacity of the chiller (286.6 kW), NFLPR = nominal full load power ratio (0.281 kW/kW), FLPR = actual full-load power ratio, FFL = fraction of full-load power, n = number of operating hours of the chiller.

A curve-fitting technique was applied to the data available in the manufacturer's catalogues in order to obtain the parameters that had been used in the estimation of energy consumption. For the particular chiller and cooling tower selected the following relations are obtained:

$$FLPR/NFLPR = 1.54 - 0.587 \; ANCR, \tag{3}$$

where ANCR = actual capacity to nominal capacity ratio,

$$ANCR = - 0.37645 + 0.018131 \; T_4 - 0.000103 \; T_4^2 + 0.018134 \; T_1 + 0.000128 \; T_1^2 - 0.000117 \; T_1 \; T_4, \tag{4}$$

T_1 = temperature of the chilled water leaving the evaporator (Fig. 1). The temperature of water leaving the cooling tower and entering the condenser (Fig. 1) is

$$T_4 = 0.798851 - 0.114572\, T_{WB} + 0.005742\, T_{WB}^2 + 1.11855\, T_3 - 0.002585\, T_3^2 - 0.003257\, T_3\, T_{WB} \cdot \qquad (5)$$

The statistical analysis indicated for Eq. (3) a correlation coefficient R^2 of 70.4%. The standard error in estimating the intercept and the slope in Eq. (3) was about 3.7%. For Eq. (4) the correlation coefficient was 96.2%, and the standard error was about 2.8%. For Eq. (5), the correlation coefficient was 99.9% and the standard error about 12%. Since Eqs. (3) and (4) are derived from catalogues in which I-P units are usually used, the temperatures are expressed in F.

The part-load performance is not currently available. Consequently, the default curve for the chiller that is used in the DOE program was integrated in the present analysis.[4] In this manner, we find

$$FFL = 0.088065 + 1.137742\, PLR - 0.225806\, PLR^2, \qquad (6)$$

where

$$PLR = Q/Q_n \cdot \qquad (7)$$

The power (kW) rejected to the cooling tower is

$$Q_{TWR} = E_{CH} + Q_n. \qquad (8)$$

Since the condenser temperature T_4 depends first on the heat rejected to the cooling tower Q_{TWR}, and then also on the temperature T_3 of the air entering the cooling tower, an iterative procedure must be used for each hour of simulation to calculate these temperatures.

The chilled water and condenser water flow rates are assumed to be constant and equal to the nominal value.

4. NUMERICAL RESULTS

As previously stated, the estimation of hourly, monthly and annual cooling coil loads and energy consumption was performed for the period 1974-1983. Average annual values are presented in Table 2.

The ratio between the annual energy use and annual cooling-coil load is 0.276-0.303 for the dry-bulb-temperature economizer, 0.304 for the enthalpy-economizer and 0.353 for the conventional system. Thus, energy consumption represents only about 30% of the cooling coil load. This result corresponds to an average coefficient of performance of the entire system of about 3.33.

The reduction of the cooling-coil load due to the enthalpy-economizer is 1,104,473 - 636,493 = 7800 kWh/(1000 m^3/h) per year. The ratio of the energy used by the enthalpy-economizer system to that used by the conventional system is about 0.50 and indicates that significant savings can be obtained through the use of ambient energy for cooling. These savings are estimated to be about 3300 kWh/(1000 m^3/h) per year.

Since the ratio of the energy used by the system with dry-bulb-temperature economizer to that with enthalpy-economizer varies between 1.00 and 1.14, we can conclude that by making appropriate selection for the switchover temperature, the dry-bulb-temperature system will provide as much energy saving as the enthalpy system. The smallest amount of energy is used by the dry-bulb-temperature economizer when the switchover temperature is 17 C, i.e., 5 C lower than the return air temperature. For this value of the switchover temperature, the energy consumption almost equals that of the enthalpy economizer.

Table 2. Annual cooling load and energy consumption

System	T_{sw} (C)					
	22	21	20	19	18	17
DBT Economizer						
Load (kWh)	800,872	746,226	708,957	672,367	649,492	640,048
Energy (kWh)	220,875	212,717	206,670	200,282	196,003	194,156
Energy/load	0.276	0.285	0.292	0.298	0.302	0.303
ENT Economizer						
Load (kWh)			636,493			
Energy (kWh)			193,421			
Energy/load			0.304			
CONVENTIONAL						
Load (kWh)			1,104,473			
Energy (kWh)			389,527			
Energy/load			0.353			
$(DBT/ENT)_{load}$	1.26	1.17	1.11	1.06	1.02	1.01
$(DBT/ENT)_{energy}$	1.14	1.10	1.07	1.04	1.01	1.00
$(DBT/Conv.)_{load}$	0.617	0.575	0.546	0.518	0.50	0.493
$(DBT/Conv.)_{energy}$	0.567	0.546	0.53	0.514	0.503	0.498
$(ENT/Conv.)_{load}$			0.576			
$(ENT/Conv.)_{energy}$			0.497			

Table 3 shows that the enthalpy-economizer system provides large savings between 50 and 100% from September to May, when it is compared with the conventional system. We observe that, from November to March, the enthalpy-economizer uses per month less than 5% of the energy consumed by the conventional system, i.e., there is a demand on the chiller for only a few hours. Moreover, if the dynamic responses of the HVAC and control systems, which were neglected in this analysis, are taken into consideration, then, because of the slower response, it may happen that no energy at all is consumed by the equipment. This operation increases the energy savings due to the enthalpy-economizer. During the summer months (June to August), the savings are between 5 and 20% for both the cooling load and energy consumption. Hence, due to the particular climatic conditions in summer and in winter in Montréal, as previously described, the economizer system provides larger energy savings from fall to spring, while during the summer months the energy savings are between 5 and 17%.

The monthly energy-to-load ratio for both the economizer and the conventional systems approaches its nominal value (NFLPR = 0.281) from May to September. During the cold months (December to February) and because of the lower loads on the cooling coil, the chiller works less efficiently and, therefore, the energy-to-load ratio increases more than 100%.

Table 3. **Monthly cooling loads and energy consumptions (kWh) of the enthalpy economizer as compared with the conventional cooling system**

Month	Loads (kWh)			Energy (kWh)			Energy/Load	
	Econ.	Conv.	Econ/Conv. (%)	Econ.	Conv.	Econ./Conv. (%)	Econ.	Conv.
Jan.	-	22,845	-	-	15,814	-	-	0.692
Feb.	12	24,406	0.05	10	15,368	0.07	0.83	0.630
Mar.	438	39,836	1.10	177	20,327	0.9	0.404	0.510
Apr.	9,481	69,504	13.6	3,451	27,470	12.6	0.364	0.395
May	64,068	124,901	51.3	20,612	40,850	50.5	0.322	0.327
June	131,454	158,515	82.9	39,811	47,912	83.1	0.303	0.302
July	180,789	190,419	94.9	52,382	55,113	95.0	0.290	0.289
Aug.	160,626	177,101	90.7	47,604	52,398	90.8	0.296	0.296
Sep.	72,657	128,605	56.5	23,396	41,420	56.5	0.322	0.322
Oct.	14,239	85,224	16.7	4,948	31,715	15.6	0.347	0.372
Nov.	2,690	54,301	5.0	1,013	23,710	4.3	0.377	0.437
Dec.	39	28,816	0.14	17	17,424	0.1	0.436	0.605
Total	636,493	1,104,473	57.6	193,421	389,527	49.7	0.304	0.353

The reduction of the electrical demand is important during the winter months, which coincide with higher demand for heating. Therefore, the maximum expected electrical demand for the entire building is reduced and the subscribed power to the utility company is diminished. This reduction will help the utility company to reduce the peak load, and to operate under more uniform conditions.

The cost of electrical energy in the province of Québec for medium size consumers is:[5] \$0.0549/kWh for the first 120 hours of consumption, \$0.0336/kWh for the next 78,000 kWh, \$0.0233/kWh for the remaining energy consumption. Using these rates, the savings for the present case study are evaluated to be \$5414 per year.

The acquisition cost of an economizer system, including components such as outdoor air sensors, motor-valve actuator, dry-bulb and enthalpy changeover controller, modulating water valve or minimum position potentiometer, is about \$800.00. Therefore, the payback period is evaluated to be about 2 months.

One can conclude that even under the low price of electrical energy in the province of Québec, the installation of an economizer system is a very efficient measure for the building owners, with a very fast return of investments.

REFERENCES

1. Atmospheric Environment Service, "Documentation of the Digital Archive of Canadian Climatological Data (Surface) identified by Element", Canadian Climate Centre, Data Management Division, Ontario, Canada (1985).

2. R. Zmeureanu, International J. of Ambient Energy 9, 2, (1988).

3. Honeywell Corp., "Energy Conservation with Comfort," The Honeywell Energy Conserver's Manual and Workbook, p. 111, Minneapolis (1979).

4. DOE-2 Engineers Manual, Version 2.1A, Energy and Environment Division, Building Energy Simulation Group, Lawrence Berkeley Laboratory, University of California, Berkeley, CA and Group Q-11, Solar Energy Group, Energy Division, Los Alamos National Laboratory, Los Alamos, NM (November 1982).

5. Hydro-Québec, Mémoire sur la tarification proposée pour 1988, Montreal, Québec, Canada (Mars 1988).