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Industrial Energy Conservation: In-Plant Recirculation of Cleaned Exhaust Air

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* INDUSTRIAL ENERGY CONSERVATION:

IN-PLANT RECIRCULATION

OF

CLEANED EXHAUST AIR

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Abstract

The concept of recirculation as a means of energy conservation and reducing initial investment costs has received increased attention in the technical literature in recent years. This paper will demonstrate the energy savings potential for recirculation systems and will present industrial hygiene measurements to document the performance of an actual system operating in an industrial environment. Operating experience has shown that the dual goals of industrial hygiene and energy conservation are not easily achieved.

1. INTRODUCTION

Outdoor air used for ventilation is often a major portion of a building's heating and cooling load, with large quantities of energy expended to temper outside air to room conditions. Because of this, justifiable reduction in the quantity of outside air brought into a temperature controlled environment can achieve a significant reduction in the energy consumption of heating, ventilating, and air conditioning (HVAC) systems.

Reducing outside air quantity in industrial HVAC systems is complicated by the need to protect workers from exposure to chemical compounds and substances emitted from various operations and processes. These emissions occur in the form of dusts, fumes, gases, mists, etc., and are usually controlled through localized hood exhaust systems and general dilution ventilation. Outdoor replacement air to balance exhaust is extremely important

* This paper is based on work performed at the Oak Ridge Gaseous Diffusion Plant, operated by Union Carbide Corporation, Nuclear Division, for the Department of Energy.

to prevent backdrafting flues and impaired ventilation so that personnel will have a safe, controlled atmosphere. Therefore, it is difficult to justify a reduction in outdoor air required for makeup because of the associated health hazards of imbalanced building supply and exhaust air.

Recirculation is one method by which the high cost of heating and cooling large volumes of outside air may be curtailed. This method involves the effective cleaning of contaminated air and the subsequent return of this air to the workspace.

This paper will document the energy conservation and industrial hygiene aspects of an existing recirculation system which has been operated by Union Carbide Corporation, Nuclear Division, in Oak Ridge, Tennessee for the last four years. Included are the results of an hour-by-hour energy analysis to compare energy consumption trends as well as industrial hygiene measurements of contaminant levels. The latter will indicate problems that have occurred during system operation and the subsequent corrective engineering actions will be discussed. The paper will conclude with an attempt to provide recommendations for others.

2. RECIRCULATION SYSTEM DESCRIPTION

Figure 1 depicts the recirculation system layout. A dry, fine sized particulate is captured at the work table via a local exhaust hood and the dust laden air is conveyed to a fabric filter dust collector, with a centrifugal fan providing the motive power. Downstream of the fan is a secondary filter housing containing high efficiency filters which serve as a back-up in the event of a fabric rupture in the primary collector. This precaution minimizes the possibility that particulate will be returned to the workspace.

The primary collector utilized is a high efficiency bag house with polyester felted fabric which is cleaned periodically with a high pressure air pulse. This procedure is automatic and very convenient in that it allows continuous collector operation.

The secondary filter system is composed of 95% efficient NBS rated filters. Unlike the primary system, these filters are of a fiberglass media and replacement is necessary once full loading is attained. In addition to being a safeguard, these filters also act as a monitoring device. An alarm attached to a differential pressure monitor alerts the operator to shut down the hood exhaust system whenever the pressure drop exceeds the minimum or maximum setpoint of the alarm.

The original system design in 1974 did not provide for a secondary filter system. Because of light dust loads and high collection efficiency of the baghouse, it was not included as a required design feature. A retrofit program to provide secondary filters for all hood exhaust systems began construction in July 1978. The reason for this retrofit arose from operating problems which will be discussed in a later section covering performance measurements. Figure 1 shows the system as it will be configured upon completion of construction in December 1978.

3. ENERGY CONSERVATION

3.1 ENERGY ANALYSIS

To evaluate energy consumption patterns of the building with and without recirculation, a computer analysis was performed utilizing a version of NASA's Energy - Cost Analysis Program (NECAP). (1) This program performed an hour-by-hour calculation of the thermodynamic heat gains and losses from the building according to a typical year of Oak Ridge weather data. The predicted results of a recirculation case were compared to a base case, which assumed no recirculation.

The building, which encompasses about 100,000 ft^2 of floor area, is of metal curtain wall construction with a steel deck and built-up roof. Both walls and roof have 1" insulation. The workspace is in continuous use three shifts a day, every day of the year. Both heating and cooling are required, with summer and winter thermostat settings of 78°F and 72°F, respectively.

Figure 2 presents the differences between the base case and recirculation case energy analysis models. The 82,500 CFM difference in outside airflow rate represents the savings potential of the recirculation system.

The internal heat load in the base case is the heat from lighting and equipment within the space. The additional 1.6 watts/ft^2 in the recirculation case is the equivalent internal load due to the fan heat of compression from the recirculated air.

As stated earlier, the actual recirculation system installed in 1974 did not have a secondary filter, and the energy analysis reported herein was performed to predict whether or not significant operational cost savings would be derived from the recirculation system in its 1979 configuration.

Figure 3 presents a profile of predicted energy requirements for the two cases in the typical weather year. The peak monthly requirement for the base case was 4×10^9 BTU in July while the peak monthly requirement for the recirculation case was 2.6×10^9 BTU, or 35% less. Energy requirements for the base case reached a second peak during winter, but continued to slope downward in the recirculation case. This is attributable to the difference in internal heat loads and outside air quantities.

The values plotted indicate the total amount of BTU required for the particular month. Not shown are the peak hourly load requirements which are utilized to size the heating and air conditioning equipment. The computer model indicated that the base case would require 800 tons of installed chiller capacity, as opposed to less than 400 tons capacity for the recirculation case.

The diagram in figure 4 shows the existing HVAC system in the manufacturing area. Large air handling units that operate continuously are supplied with chilled water and steam from a central source not shown. A thermostat in the workspace calls for proportional heating or cooling as required. In addition, a humidity controller overrides the thermostat to provide adequate cooling in order to reduce the latent heat in the air. Since overcooling of the space would occur in some instances, the thermostat will call for reheat to maintain a stable workspace temperature.

Figures 5 and 6 present the transient energy consumption curves for steam and electricity, respectively. Note that steam usage for wintertime heat in the recirculation case is zero, and is only used for reheat purposes during the summer. Cooling is required year-round for recirculation, but the peak monthly demand is about 40% less.

Figure 7 gives a tabular summary of annual energy usage predicted by the computer program. The recirculation scheme will save 15,400,000 lbs. of steam or 90%, while electricity for cooling is reduced by 94,000 KWH, or 5%. Because of higher fan horsepower required for the added resistance to airflow of the secondary filter, equipment electrical consumption for the recirculation case is increased by 233,000 KWH annually.

In terms of an energy index, the recirculation scheme is predicted to reduce overall building energy consumption by 37%, or 160,000 BTU/ft^2 per year at the facility.

3.2 ECONOMIC ANALYSIS

Figure 8 shows a cost savings for the recirculation system. The annual saving due to energy conservation is $58,700 based on delivered rates of $4.00 per 1000 lbs. of steam and 2.1¢ per kwh in Oak Ridge. Subtracted from this is the added maintenance of $17,200 annually to maintain the secondary filter system, leaving a net annual savings of $41,500 for operation and maintenance. The maintenance estimate is based on a secondary filter changeout schedule of four months.

Figure 9 indicates the economic payback on a recirculation system installed today is immediate. The $92,000 added cost of the recirculation system is immediately offset by a $300,000 savings in installed air conditioning capacity. The capacity savings is based on 400 tons of chiller plant savings and did not include potential savings in steam coils and lines. Following the initial year, an annual operation and maintenance dividend of $41,500 would accrue.

The investment history of the actual system is somewhat complicated and a simplified economic model is presented so that the advantages of first cost savings and O & M dividends may be clearly shown.

The results of the energy and economic analysis demonstrate that the energy conservation potential for recirculation is very significant because of savings in both initial investment and annual operation.

4. INDUSTRIAL HYGIENE MEASUREMENTS

Prior to the presentation of industrial hygiene measurements, it is necessary to introduce the concept of Threshold Limit Value, or TLV. (2) The TLV discussed herein is a time weighted average concentration for a normal 8-hour workday or 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect. The TLV is typically used as a guide in the control of health hazards, but is not meant as an exact boundary line between safe and dangerous concentrations.

Contaminant measurements were obtained by sample analysis of particulate collected on a membrane filter of 0.8 micrometer porosity. The filter was part of a portable unit worn by the worker with an air inlet adjacent to the worker's face, hose to connect the filter, and a battery operated air pump attached to the belt.

Of approximately 300 samples systematically collected from personnel since 1974, weight analysis indicates that the particulate level has averaged 46% of the TLV guideline. Industrial hygiene measurements during four years of operation indicate time intervals in which the TLV was occasionally exceeded. A total of 18 such excursions above the TLV have been recorded.

The investigation of industrial hygiene anomalies in 1975 revealed two problems with the recirculation system: viz., particulate leakage through the baghouse and lower than design airflow.

Leakage problems were attributed to rubber gasket shrinkage around the bag seals, structural gaps in the bag assembly and improper installation of bags. These problems were corrected by providing a different gasket material, welding of gaps, and improved bag installation procedures.

Low hood exhaust airflow was a result of higher than predicted pressure drop across the baghouse dust collector. Improvements to the exhaust hood were made to increase particulate capture to compensate for the lower airflow.

These changes improved the efficiency of the recirculation system, but industrial hygiene measurements in 1976 again indicated further problems. This prompted another investigation for baghouse leakage and futile attempts to quantitatively determine baghouse efficiency. At this time, additional design was performed to add a prototype secondary filter system with a higher capacity fan for one baghouse.

Upon installation of a secondary system with high efficiency filters, the selected baghouse was found to be operating at low efficiency. Subsequent investigation utilizing a fluorescent dust test revealed leakage around bag attachment points within the baghouse and also small holes worn in the bag material. These problems were corrected with a new bag assembly design.

All baghouses are currently being retrofitted with the new bag assembly and secondary filter system. Construction is 30% complete at this time and completion is expected in December 1978, such that the significance of these design changes from an industrial hygiene aspect will not ultimately be known until early 1979.

5. CONCLUSIONS

Based upon analysis and actual experience, the following conclusions have been made regarding performance of the recirculation system.

(1) The economic incentive for recirculation as a means of energy conservation is very significant. The energy and economic model of the recirculation system located in Oak Ridge predicted a 37% savings in annual energy requirements. A 50% savings in installed air conditioning capacity would more than offset the increased first cost of the recirculation system.

(2) Adequate industrial hygiene has been difficult to achieve. Although employees have not been exposed to hazardous contaminant levels, repeated improvements to operation of the fabric filter collector have been necessary to maintain particulate concentration safely below the TLV guideline.

(3) A high efficiency secondary filter system is necessary as a safeguard for inadvertent particulate leakage through the baghouse. It is expected that the secondary filter will enhance overall dust collection efficiency

and also serve as a reliable monitor of baghouse operation.

6. RECOMMENDATIONS

Based upon excessive engineering effort required to maintain a safe working environment, the recirculation of cleaned exhaust air cannot be emphatically recommended. Problems that could eventually have led to hazardous conditions in the working environment have repeatedly occurred during the four year life of the dust collection system. Although the expense of this effort to correct these problems has only partially offset the energy conservation advantages, an in-house multi-disciplined staff dedicated to design, maintenance, and surveillance of the recirculation system has been required.

This experience should not preclude the investigation of recirculation by other engineering design organizations. Recirculation is unquestionably a means for energy conservation, but because the primary consideration must be the health of the worker, the importance of adequate planning and precautions cannot be understated.

Recent research and development of technical design criteria by official health agencies will help to eliminate many design uncertainties, but improvements to air cleaning equipment are also required. (2, 3). The wide acceptance of recirculation will only occur when the goal of industrial hygiene is as easily achieved as that of energy conservation.

References

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Author's Information

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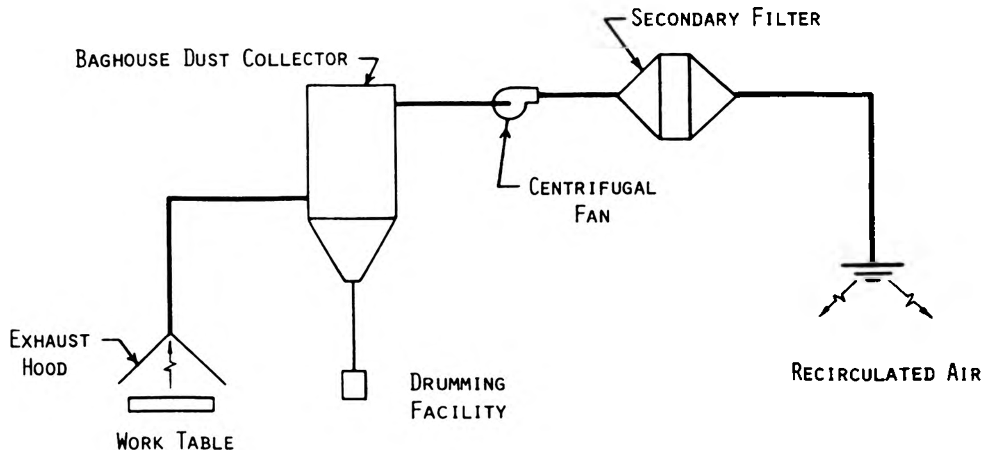

FIGURE 1. RECIRCULATION SYSTEM SCHEMATIC

	OUTSIDE AIR (CFM)	INTERNAL HEAT LOAD (WATTS/FT.^{2})
BASE CASE (NON-RECIRCULATING)	96,400	4.7
RECIRCULATION CASE (WITH SECONDARY FILTER)	13,900	6.3
DIFFERENCE =	82,500	1.6

FIGURE 2. DIFFERENCES IN ENERGY ANALYSIS MODELS

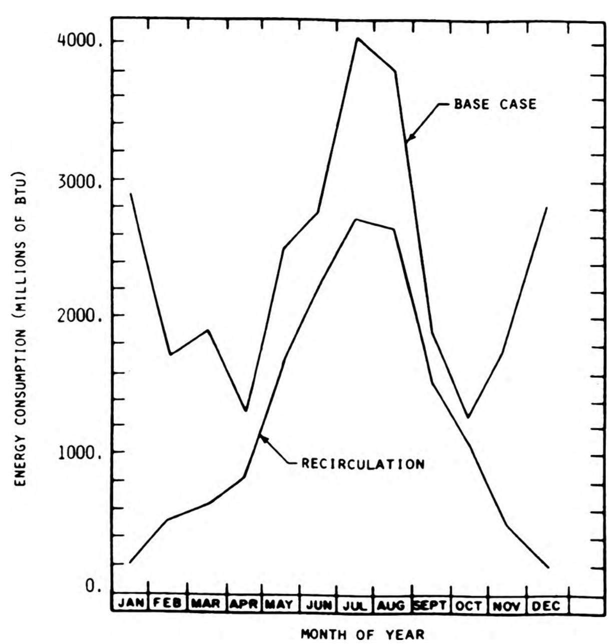

FIGURE 3. TOTAL HEATING AND COOLING ENERGY REQUIREMENTS

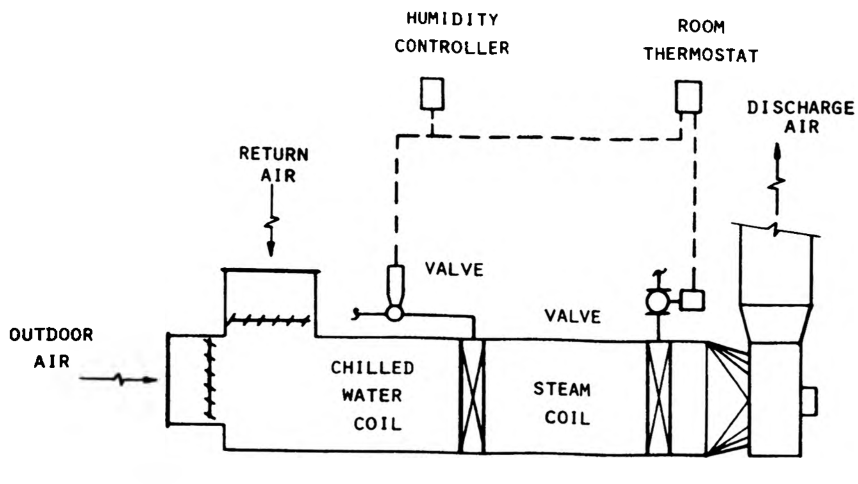

FIGURE 4. WORKSPACE AIR HANDLING SYSTEM

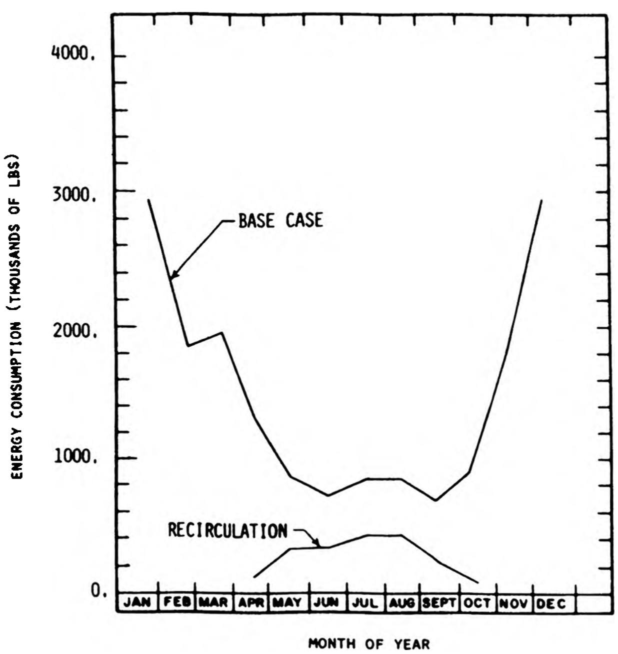

FIGURE 5. PREDICTED HEATING ENERGY CONSUMPTION (STEAM)

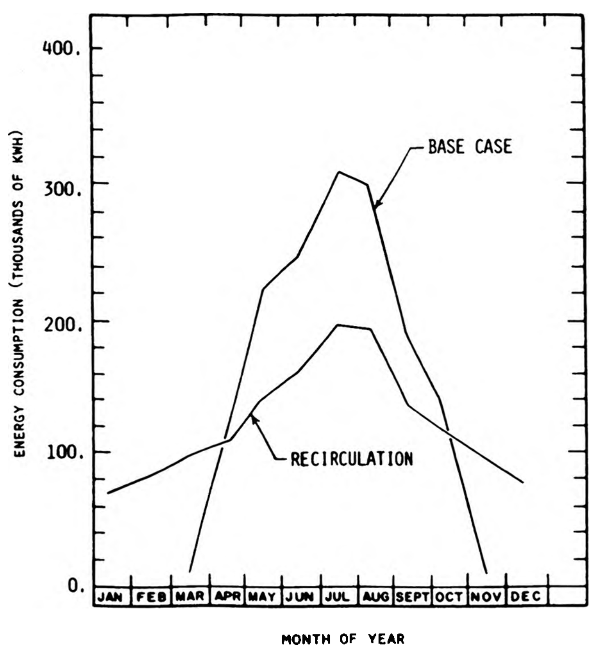

FIGURE 6. PREDICTED COOLING ENERGY CONSUMPTION (ELECTRICITY)

ENERGY SOURCE	BASE CASE	RECIRCULATION	SAVINGS
STEAM HEATING (LBS)	17,100,000	1,700,000	15,400,000 LBS
ELECTRIC COOLING (KWH)	1,876,000	1,782,000	94,000 KWH
LIGHTS/EQUIPMENT (KWH)	4,822,000	5,055,000	(233,000)KWH

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ENERGY INDEX (BTU/FT^2-YEAR)	433,000	273,000	160,000 (37%)

FIGURE 7. ANNUAL ENERGY USE SUMMARY

STEAM SAVINGS @ $4.00/KLBS	=	$61,600
ELECTRICAL COSTS @ 2.1¢/KWH	=	-2,900
TOTAL ENERGY SAVINGS	=	$58,700
LESS ADDED MAINTENANCE	=	-17,200
ANNUAL NET SAVINGS	=	$41,500

FIGURE 8. NET ANNUAL O & M SAVINGS

PRESENT WORTH OF HVAC EQUIPMENT (400 TONS)	=	$300,000
PRESENT WORTH OF ANNUAL SAVINGS (10 YEARS)	=	324,000
TOTAL PRESENT WORTH OF SAVINGS	=	$624,000
ADDED FIRST COST OF RECIRCULATION SYSTEM	=	$ 92,000

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SIR (SAVINGS/INVESTMENT RATIO) = $\frac{624,000}{92,000}$ = 6.8

PAYBACK = IMMEDIATE

ASSUMED: DISCOUNT RATE = 10%
DIFFERENTIAL ESCALATION RATE FOR FUEL = 5%

FIGURE 9. ECONOMIC ANALYSIS