Ventilation, Air Distribution and Air Quality: A State-of-Practice in Warehouses and Light Industrial Buildings

A RESEARCH REPORT

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The Buildings Energy Technology Transfer Program (BETT) of EMR has been created to assist building owners, users and practitioners active in the design, construction and operation of buildings in identifying technical obstacles to energy conservation. Through a nationwide network of research agencies and private sector consultants, BETT carries out research and development projects and provides the audiences mentioned above with technical reports, how-to manuals, training manuals, audio-visual aids and data bases to help them overcome these obstacles.

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ABSTRACT/RESUME

The state of practice as described in available literature concerning ventilation, air distribution and air quality in warehouses and light industrial buildings is reviewed. There is little documented field information available. Modelling processes have not been developed which can provide the necessary detail. Measurement of air flows both in the field and in models is difficult. The regulatory environment allows considerable innovation in developing conservation procedures and is quite similar in the various provinces.

* * *

Ce rapport évalue la documentation disponible au sujet de la ventilation, la distribution et la qualité de l'air dans les entrepôts et les structures industrielles légères. On ne trouve que peu d'information en provenance de la littérature spécialisée. Les processus de modélisation qui pourraient offrir un niveau satisfaisant de désagrégation n'ont pas encore été développés. Il est trés difficile de mesurer les débits d'air sur place ou par modélisation. L'environnement réglementaire permet d'innombrables innovations en ce qui a trait au processus d'économie d'énergie. Cet environnement réglementaire est semblable dans les différentes provinces.

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The Building Technology Support Program (BTSP) was initiated by the Department of Energy, Mines and Resources (EMR) of the Government of Canada in late 1981. The principal objectives of this program are:

- to identify the potential for energy conservation in both new and existing buildings
- to determine R, D and D requirements and their priority in order to exploit this potential
- to perform and/or expedite the necessary R, D and D
- To effectively transfer the necessary technology to the appropriate individuals, groups or agencies
- to provide technological support to EMR in the development of policy and programs

The Building Engineering Group (BEG) was selected* by EMR to develop and execute a comprehensive R, D and D program for energy conservation in the warehousing and light industrial building sector. BEG is a semi-autonomous, non-profit agency associated, through the Waterloo Research Institute (WRI), with the University of Waterloo. This multi-disciplinary group attempts to provide a comprehensive range of R and D services to the building industry.

The warehouse and light industrial building sector is particularly important because:

- the square footage of building space encompassed by this category is second only to that of the residential building category
- to date very little R and D, energy-related or otherwise, has been directed towards this building category
- the nature of these buildings, both new and existing, makes them particularly amenable to some degree of energy conservation

* DSS Number 02SQ.23380-1-6665-4 Serial 0SQ81-00137 and Proposal Number WRI 109-01, September 20, 1981

In the initial phase of the R, D and D program developed by BEG, the priorities were to:

- establish a statistical profile of the building category
- develop a comprehensive review of the current state-of-practice
- initiate the development of a portfolio of representative case histories

Ten related studies are being undertaken in this initial phase, Seven of these studies provide either supporting documentation or input for a comprehensive state-of-practice report.

This report entitled "Ventilation, Air Distribution and Air Quality: The State-of-Practice" was prepared by Gordon Bragg and Robert Ward of the University of Waterloo. While the report provides a stand-alone review of the topic it should be read in conjunction with the other six reports, especially the report entitled "Air Infiltration in Warehousing and Light Industrial Buildings".

This report is an early product of what is intended to be a concerted multi-year program of research, development, demonstration, dissemination and evaluation. Feedback with regard to the report or related issues is welcomed and should be directed to the undersigned.

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1. INTRODUCTION

The objective of this report is to describe briefly the current state of published knowledge with regard to air quality, air movement and ventilation insofar as it pertains to warehousing and light industrial buildings. The regulatory environment under which safe clean air is provided is discussed and the effect of these practices and procedures on energy consumption is considered.

In any energy conservation program for buildings the effect of air quality and its maintenance must be considered. The air provided to the building interior must have suitable temperature and moisture properties and should not produce drafts or unacceptably high air velocities. The air must be free of dangerous substances, particularly those which may be generated during any manufacturing process in the building. It is unlikely that warehouses and light industrial buildings will be susceptible to problems such as those occasionally found in houses where restricted infiltration can allow carbon monoxide and similar chemicals to build up. Rather, the air quality problems are likely to be caused by the generation of chemicals and dusts during manufacturing processes.

1.1 Current Approaches

The provision of air at a suitable temperature, moisture level, and velocity follows basic well-known air conditioning principles and is accomplished using equipment in common use. Where toxic fumes, dusts, or gases are generated, air quality is commonly maintained either by diluting the contaminated air with fresh intake air or by providing local exhaust ventilation around the contaminating process. The use of dilution air is restricted to less dangerous pollutants such as methyl alcohol fumes and low toxicity solvents. Regulations require that local exhaust ventilation be provided around processes which are liable to produce dangerous air contaminants. These local ventilation systems can require 1000 to 2000 cubic feet per minute (cfm) of exhaust air per work station compared to 25 to 50 cfm under normal circumstances. As a result, heated and conditioned makeup air must be provided in the workplace.

These requirements are considerably higher than those required for normal comfort air and, hence, can dominate the air supply requirements.

1.2 Measurement

Any assessment of normal air quality requires that the air temperature and relative humidity be measured. Carrying out these measurements is fairly straightforward although proper statistical information on their time dependence is seldom documented in the literature. It is much more difficult to measure air velocities at the very low values which provide comfort, and at the present time research quality instruments are frequently necessary in order to obtain this air velocity information. The measurement of toxicity is even more difficult. Small, single-sample instrumentation is available for many different chemicals and dusts, but problems remain in many areas. Proper monitoring of air quality where chemicals may be present can be expensive and difficult.

In buildings with processes that contaminate the air, maintenance of acceptable quality depends upon regular monitoring and constant attention to the factors affecting the air budget. Air quality can be significantly changed by:

- wind (direction, speed, and prevalence)
- infiltration (rates, leakage characteristics)
- activities inside the building
- level of activity
- opening and closing of doors and windows
- location of polluting activity

1.3 Legislation

Provision of safe air is required by the various labour codes in each province. Every province has a legal framework within which detailed regulations for various contaminants are provided as well as a system of government inspection of the work environment.

In the last five years air standards have been consistently improved as a result of legislation in most provinces. Compliance has been extremely difficult and expensive for several types of industry. The provision of suitable makeup air in these plants has become an important factor in their energy costs.

1.4 Modelling

Detailed understanding of air flows within a building is necessary for good design of ventilation equipment. No detailed design methods are available to accommodate the very large number of variables which are present, particularly with respect to the location of equipment. Physical modelling is commonly resorted to in other fields with similar air flow problems. For example, physical modelling is common in the analysis of wind loading on structures, the design of large ducting systems, and in automobile design. Similar procedures could be used for designing large spaces with specific ventilation needs. There has been considerable research activity in this field over the last five years. This work has been largely directed towards investigating the contamination of residential buildings where infiltration is low; however, the procedures and methods which should be followed are poorly understood at the present time. Effective progress in this field will depend, in part, upon development of proper physical modelling procedures.

Typical processes, all of which appear in light industry or warehousing and which require ventilation, are shown in Appendix A. In the light industrial and warehousing field we are not aware of concrete data which gives the total amount of space where local ventilation dominates normal heating and ventilating requirements. However, we would estimate that possibly 5% of space in this category has major problems. Examples would be welding shops, paint spraying areas, operations with bag packing or emptying of dusts, and grain handling operations. In addition to this small proportion of buildings where these processes dominate, we would estimate that at least 50% of light industrial buildings have some specific area where local exhaust ventilation is required. In these cases welding, paint spraying, grinding and sanding would be the most common processes.

1.5 Sources

Those studies which were found to provide a good basis for this study have been mentioned throughout the report. Additional references listed in Appendix B deal with particular aspects of important ventilation subjects. The literature on air conditioning and ventilation is quite large, and the majority of fundamental references are included as well as a number of key recent research papers. The specific application to light industrial buildings and warehousing is, however, severely limited, and most references to the subject are only made in passing.

Air quality has to be examined from two points of view: its effect on comfort and on health.

2.1 Comfort

The combination of temperature and humidity which provides comfortable working conditions is summarized by the concept of effective temperature. The "effective temperature" (ET) is an index of comfort determined for various combinations of temperature, humidity and air movement and is based upon the subjective impression of people immediately upon entering the work space. The numerical value of the ET for any given air condition is obtained from the temperature of slowly moving saturated air which gives a similar sensation of warmth or coolness. For air moving very slowly, that is, 15 to 25 feet per minute (fpm), the effective temperature condition is summarized in Figure 1. For labouring levels which are met in light industry or warehouses the effective temperature, which is dependent upon air velocity, is summarized in Figure 2.

For given wet bulb temperatures, dry bulb temperatures* and air velocity in fpm, the effective temperature may be obtained. In the absence of significant radiation effects, such as would occur in heat-dependent processing, this analysis is suitable for determining the degree of comfort achieved in any working environment. A discussion of the physiological basis for comfort as well as other comfort indices is given in the ASHRAE Handbook of Fundamentals (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1981).

*Dry bulb temperature is the normal thermodynamic temperature. Wet bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature.

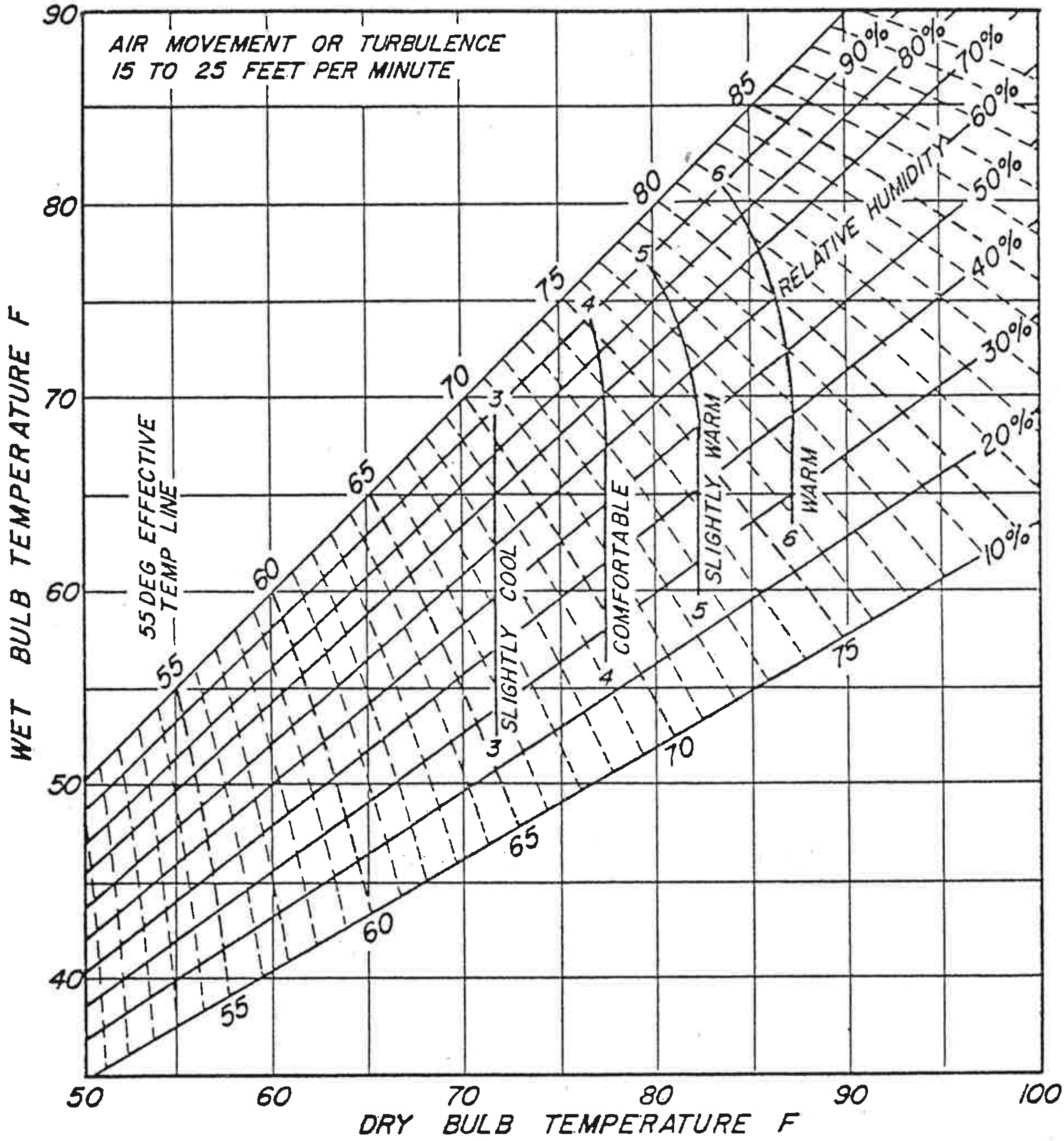
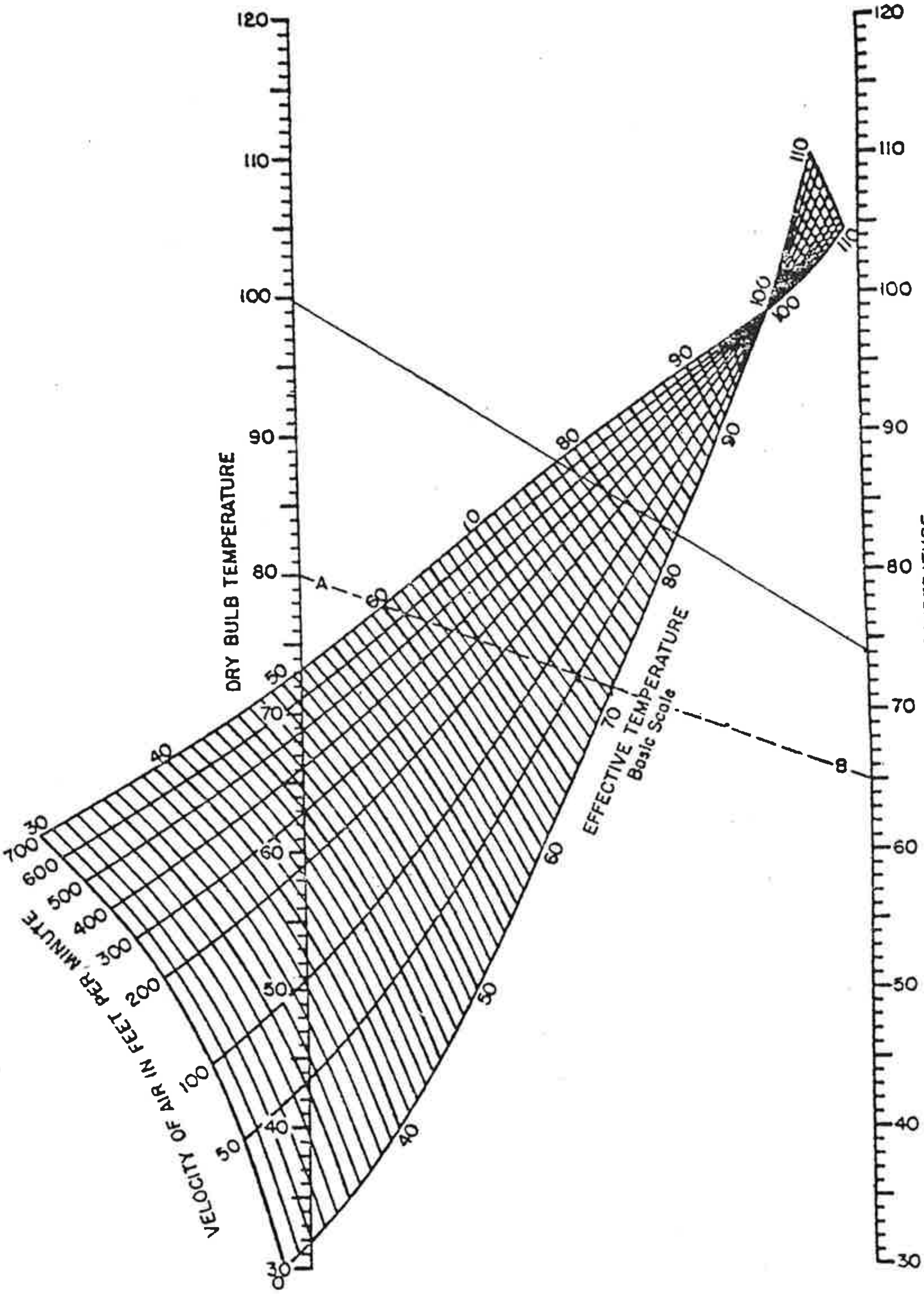


Figure 1

Comfort chart for still air.
1. Effective Temperature (dashed) lines indicate sensation of warmth immediately after entering conditioned space.
2. Solid lines 3, 4, 5, and 6 indicate sensations experienced after three-hour occupancy.
3. Both sets of curves apply to people at rest and normally clothed.
Source: American Society of Heating, Refrigeration and Air-Conditioning Engineers (1981).



At rest or doing light physical work in rooms heated by convection methods.

Figure 2 — Effective Temperature. Basic scale of effective temperature applicable to men stripped to the waist. Source: American Society of Heating and Ventilating Engineers.

The situation with regard to air contaminants is considerably more complicated. Air contaminants include dusts, gases, vapours, fumes, or mists that can be dangerous when breathed, ingested or contacted by the eyes or skin.

2.2 Health

The commonly accepted safe level for these contaminants is defined by a "threshold limit value" (TLV). Threshold limit values are the airborne concentrations of substances to which it is believed that nearly all workers may be repeatedly exposed over their working lives without adverse effect. The condition normally applies to the general worker and not to those who, for some reason, are particularly susceptible, those who already have pre-existing illnesses or those who have already developed an occupational illness. There are three specific categories of threshold limit value. They are:

(a) Threshold limit value - time weighted average (TLV-TWA): This is the time weighted average concentration for a normal eight-hour day and forty-hour work week. Most workers can be repeatedly exposed to this level without adverse effect.

(b) Threshold limit value - short term exposure limit (TLV-STEL): This is the maximum concentration to which workers can be exposed for a period of up to fifteen minutes continuously without suffering from irritation, irreversible damage, or narcosis sufficient to impair work efficiency or to increase accident proneness.

(c) Threshold limit value - ceiling (TLV-C): This is the concentration that should not be exceeded even instantaneously.

For example, irritant gases which cause only discomfort should be analyzed using the TLV-C. If any of the three TLV's is exceeded, a potential hazard is presumed to exist.

The most comprehensive list of recommended TLV's is prepared by the American Conference of Governmental Industrial Hygienists (Threshold Limit Values of Substances, 1980). These values are based on the best available information from industrial experience, from human and animal studies, and, when possible, from a combination of the three. The bases on which they are established may differ from substance to substance. For many substances the primary concern is health impairment. For others, such as wood dust, the primary concern may be freedom from nuisance or other forms of stress. These values are constantly being revised and the number of substances under consideration increased. Some typical examples of TLV's are given in Table I.

There are many ways of achieving a TLV in an industrial process or storage area. They include such methods as substitution of the contaminant material, alteration of the basic process of manufacturing, isolation or enclosure, and similar methods. However, the two methods which have the greatest effect on energy conservation are the provision of local exhaust ventilation and the provision of dilution air. These are also the most common control methods and they are well described in Strauss (1975) and McDermott (1977). The basic handbook in the field is Industrial Ventilation (American Conference of Governmental Industrial Hygienists, 1981). The object of engineering controls is to keep exposures below the TLV. In all cases local exhaust ventilation and dilution require far more air to be provided than ordinary conditions require.

Table I

Threshold Limit Values for Typical Toxic Dusts, Fumes and Mists

Substance	Adopted Values TWA* ppm	mg/m^3
Acetic Acid	10	25
Aluminum welding fumes	--	5
Ammonia	25	18
Benzene	10,A2	30,A2
Beryllium	--	0.002,A2
Bromine	0.1	0.7
Butane	(600)	(1,430)
Calcium hydroxide.	--	5
Carbon monoxide	50	55
Chlorine	1	3
Copper fume	--	0.2
Dusts & Mists	--	1
Cotton dust, raw	--	0.2
Iodine	0.1	1
Manganese fume	--	1

Source: American Conference of Governmental Industrial Hygienists, 1980

*See page 10.

Responsibility for occupational health and safety in Canada belongs to the provinces. As a result, the regulatory activity controlling ventilation varies from province to province.

There is an important difference between the regulatory environment in the United States and that in Canada. In the United States, the Occupational Safety and Health Administration controls the working environment through an extensive series of regulations. These regulations are extremely detailed and include the actual methods of construction for all types of ventilating equipment. Because of this strict definition of details, there is little room for innovative ventilation procedures and design approaches. In all Canadian provinces, on the other hand, the regulations specify only that the air must be safe. For certain substances which are cancer causing, a TLV is also stated. The methods of achieving this are not specified. The intent is to provide an opportunity for innovative solutions in the provision of clean air. As a result of this difference in approach, a significant proportion of the large body of American research which is available is not directly applicable to the Canadian situation.

An example of the regulation of ventilation air is given by the Ontario Occupational Health and Safety Act, 1978 which includes the following regulations:

"131. An industrial establishment shall be adequately ventilated by either natural or mechanical means such that the atmosphere does not endanger the health and safety of workers.

132.
(1) Replacement air shall be provided to replace air exhausted.

(2) The replacement air shall,

(a) be heated, when necessary, to maintain at least the minimum temperature in the work place specified in section 133;
(b) be free from contamination with any hazardous dust, vapour, smoke, fume, mist or gas; and

(c) enter in such a manner so as,

(i) to prevent blowing of settled dust into the work place,

(ii) to prevent interference with any exhaust system, and

(iii) not to cause undue drafts.

(3) The discharge of air from any exhaust system shall be in such a manner so as to prevent the return of contaminants to any work place.

133.
(1) ..., an enclosed work place shall be at a temperature,

(a) suitable for the type of work performed; and

(b) not less than 18° Celsius.

(2) Clause b of subsection 1 does not apply to a work place,

(a) that is normally unheated;

(b) where the necessity of opening doors makes the heating of the area to the temperature specified in clause b of subsection 2 impracticable;

(c) where perishable goods requiring lower temperatures are processed or stored;

(d) where radiant heating is such that a worker working in the area has the degree of comfort that would result were the area heated to the temperature specified in clause b of subsection 1;

(e) where the process or activity is such that the temperature specified in clause b of subsection 1 could cause discomfort; or

(f) during the first hour of the main operating shift where process heat provides a substantial portion of building heat."

The Ontario code (a small part of which is quoted above) is the most comprehensive of the provincial regulatory structures. A number of other provinces have tended to follow Ontario's lead in divising regulations.

All provinces watch the American literature closely on questions of the toxicity of materials and adjust recommended TLV's accordingly.

In the normal heating and ventilating environment air quality measurement presents no problems except for the measurement of air velocity. Air velocities under 50 fpm must be measured, and this is the lowest measurable value for normal measuring equipment. Expensive hot wire anemometers of research quality are capable of measuring values down to approximately 10 to 20 fpm. This difficulty is the major reason for the lack of information on the detailed circulation of air in rooms; a few of the current studies are mentioned in section 5. Such studies tend to concentrate on temperature distribution and relative humidity distribution since the measurements are considerably easier to obtain. Since in most cases temperature and humidity distribution are determined by the air flows, the inability to measure these air flows is a fundamental problem in obtaining better knowledge of the ventilation process.

The measurement of contaminants is usually accomplished by either grab sampling or monitoring. Grab samples are single samples taken at one location and time, which are then analyzed. This method can be used for any substance. Monitoring implies continuous measurement of the contaminants, and this approach enables dangerous levels to be detected and improvements in control to be observed. Many contaminants cannot be continuously monitored and, therefore, it is often difficult to tell whether optimum control has been achieved. The development of instrumentation in this field is a high priority. A description of equipment which is presently available, along with the procedures for its use, can be found in Air Sampling Instruments (American Conference of Governmental Industrial Hygienists, 1972) and Linch (1974).

The principles controlling the motion of air as it is forced by fans through ducting, diffusers, exhausts and inlet systems are well understood. The interaction of these devices with the air in a room or workspace is considerably more complex and less well understood. Such motion is inherently three-dimensional and turbulent, which causes considerable variability in the air flow patterns. However, some flow visualization studies are available (Fitzner, 1981; Moog, 1981; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1981). As has been pointed out previously, control of the air movement is essential in order to maintain a comfort zone within specific parameters; because design ranges are narrow, precise understanding and control of the air patterns are necessary.

Air contaminant concentrations can vary according to the placement of the exhaust and supply outlets. Stratification effects must be controlled so that high levels of concentration do not occur. This effect is demonstrated in Figure 3. The level of concentration is not likely to be constant and may vary considerably over time. This variability makes necessary the use of the time-weighted average, short-term exposure and ceiling TLV's described earlier. An example of the fluctuation of carbon monoxide gas with time is shown in Figure 4 which shows a typical situation common to most processes generating a pollutant. The graph illustrates the fluctuation of contaminant concentration around a general shipping area work station in a large consolidated warehouse in which gasoline-powered lift trucks are used.

The literature contains very little information of this nature concerning the local properties of the air in these facilities. For example, heavy gases may become concentrated near floor areas, lighter fumes may collect in the area near ceilings, and most contaminants can diffuse from the source to other work stations. Such behaviour degrades the ventilation system performance, but very little in the way of measurement and analysis has been done in this area. In addition, the behaviour of contaminant concentrations over time has been little studied in the actual working environment.

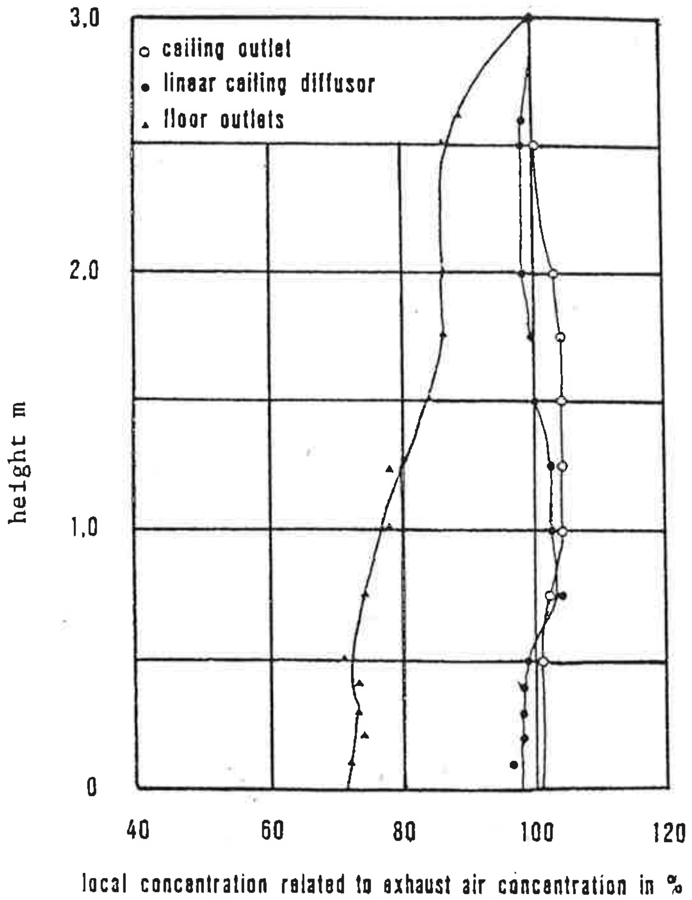


Figure 3

Concentration averaged in a horizontal plane of the room in different heights for floor outlets and two different types of ceiling diffusors. The concentration is related to the exhaust air concentration.
Source: K.F. Fitzner, Air Flow Experiments in Full Scale Test Rooms, ASHRAE Transactions, Vol. 87, Part 1, p. 1151, 1981.

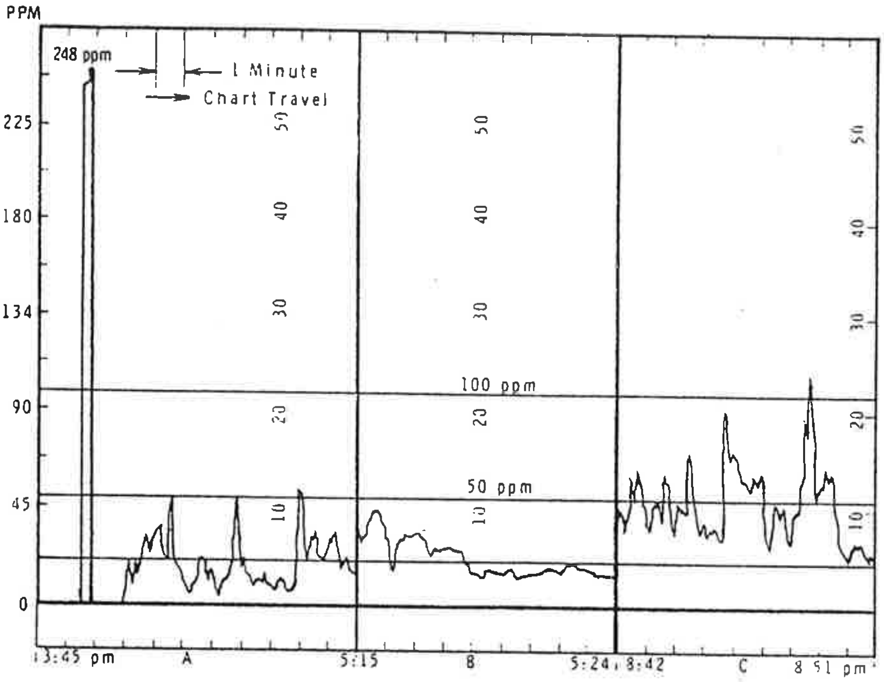


Figure 4 Carbon monoxide in air by nondispersive infrared (NDIR) analysis. (From Linch, A.L. and Pfaff, H., American Industrial Hygienists Association Journal, 32, 745, 1971.)

The availability of such information would make it possible to effect considerable savings in energy and control costs.

In recent years vertical draft recirculating fans have been increasingly used to move warmer air away from ceiling areas in large rooms and to improve general circulation. The use and effectiveness of these devices have been studied only in the most superficial way. We have been able to obtain no information on optimum placement, optimum numbers, and best design. A measurement and analysis procedure studying the air budget could measure performance of these fans as a part of the same program.

Thermal stratification within a room or building not only affects the quality of the air, and hence the worker performance, but can also result in increased energy costs. In industrial buildings with high ceilings, warmer air close to the roof has the effect of increasing the effective number of degree heating days due to the elevated temperature difference between this zone and the building exterior.

To date, research on air motion in open spaces has been limited to idealized or controlled room conditions. The limitations of such studies can be appreciated when one considers the generally more complex and varied activities associated with manufacturing or processing. Our experience with a number of industries experiencing problems with control of pollutants in plants and warehouses is that the vast majority have concentrated on installation of local exhaust ventilation. Some have arranged provision of conditioned makeup air, but none have considered the interaction between the two or the room air dynamics. While it is possible that studies of this type have been undertaken, we are not aware of them. The difficulty of measuring velocities below 50 fpm would make such a study extremely complex. However, without this information, proper optimization of energy usage is not possible in the presence of contaminants.

In order to fully determine ventilation system behaviour in a building where air quality is of concern, the air budget would need to be established. This consists of accounting for all air sources and sinks in terms of mass flow rates, the locations and rates at which contaminants are entering the air system, and the volume flow rates of recirculating devices within the building. With such information it is possible to determine the best location of inlet air flows, the optimum degree of recirculation, and the amount of contaminated exhaust air which must be removed. Although such information has been gathered in individual cases, it has not, to our knowledge, been presented in an organized way to determine in detail the energy consequences of ventilation systems or to determine optimum operating modes for equipment.

As an example of the costs associated with extensive local exhaust ventilation, consider the following comparison between an industry which uses asbestos to make brake drum pads and shoes and one which does only assembly operations of non-toxic materials. The brake manufacture is based upon an actual case. Both companies are taken to employ 80 people; of these 80 the plant utilizing ventilation may have 20 people involved in processes requiring 2000 cfm of exhaust. Heating and associated hydro costs are estimated at approximately $1.00 to $1.50 per cfm per year.

Plant requiring general ventilation (50cfm/person):

$$80 \times 50 \times \$1.50/\text{cfm} = \$6{,}000$$

Plant requiring both general and local ventilation:

$$[(60 \times 50) + (20 \times 2000)]\$1.50/\text{cfm} = \$64{,}500$$

We are aware of a brake plant in Canada employing 70-90 people per shift whose energy costs in 1980 were $72,000. The cost of heating the makeup air required for each plant is substantially higher in the asbestos case. The need to control and optimize the exhaust system is clearly demonstrated.

With increasing energy costs for heating makeup air, the recirculation of air through cleaning systems is being increasingly considered. An evaluation of the air purification equipment necessary for such systems has been carried out by NIOSH (1981). In the past, some of the regulatory agencies have prohibited the use of such systems, but this restriction may be lifted if adequate cleaning systems are installed.

Methods of costing purification systems are described in Strauss (1975) and Kinkley and Neveril (1976). The cost of achieving a desired level of air quality can be estimated, but very little data appears to be available for establishing the exact costs for heating during recirculation. Accurate information is required to determine heating requirements for makeup air used for contaminant control in various types of light industrial and warehousing buildings.

The presence of significant amounts of local ventilation can dramatically increase makeup air heating costs, lower the internal static pressure of the workspace (occasionally to the point of making doors hard to open), increase infiltration dramatically, and dominate any stratification effects due to the large convective currents induced.

Although these effects occur only in a minority of buildings, they can dominate the normal processes in these cases.

The design and optimization of ventilation systems requires a base of information on existing buildings, physical knowledge of ventilation system behaviour, and mathematical and physical models with a predictive capacity in order to make it possible to generate new designs or control processes.

Normal ventilation practice and design is founded on an extensive base of information about existing buildings. There is also a fair to good physical basis for describing normal ventilation practice. Recently there has been considerable activity in mathematical and computer modelling of normal ventilation behaviour (for examples see Thompson and Chen, 1979). As a result, a considerable body of knowledge is available to designers of standard buildings. For buildings in which exhaust ventilation is present, however, there is considerably less information; in particular, little is known about the total air flow systems in these buildings. Such information is essential as a base for both the physical and theoretical modelling of full-scale performance.

Physical modelling has seldom been used in this field. The approach is, however, extensively used in wind loading, infiltration, and air pollution studies. The lack of this work is rather surprising since the procedures are well known (Baturin, 1972 and Moog, 1981). In the case of mathematical modelling, the design procedures for the localized ventilation systems and the exhaust ducting are well established. We are not aware, however, of any procedures for incorporating these models into the broader context of energy budgeting. Possibly the availability of this information should be publicized among those doing energy modelling.

1. The proportion of buildings in the warehousing and light industrial category where exhaust ventilation is important is fairly small; but in cases where exhaust is necessary, it is of critical importance both to safety and to energy costs.

2. No adequate mathematical modelling procedures presently exist to aid in the design of air quality control systems in the presence of exhaust ventilation.

3. Very little work has been done on air quality in light industrial buildings considering the entire facility as a unit.

4. Air quality is subject to strong variability, and the pertinent regulations specified accommodate this fact.

5. Accurate information is required to determine heating requirements for makeup air used for contaminant control in various types of light industrial and warehouse buildings.

6. Further studies on spaces dominated by local ventilation where air quality is important would lead to improved methods of assessment and control of both safety factors and energy costs.

9.1 Recommendations

The recommendations for further study in the areas of ventilation and air quality are as follows:

1. Development of a system for field measurement of the air budget in warehouses and light industrial buildings where ventilation is a significant parameter.

2. Field testing and refinement of data gathering in a spectrum of buildings for which ventilation is significant, with eventual development of a data base for this type of structure.

3. Analysis of the data obtained through steps 1 and 2 in order to draw general conclusions concerning the importance of the problem, the economic consequences of the problem, and suggestions for optimal design where ventilation is significant.

4. Based on the results of the above program, development of a quantitative method of assessing the relative air quality of buildings where dilution and local exhaust ventilation are present. The use, effectiveness, and economic consequences of dilution in the general case could also be assessed.

5. (Provisional): Development of a physical modelling process to duplicate in the testing laboratory the conditions found in the above studies. Such a process would considerably simplify the testing and optimization of proposed solutions to energy optimization problems.

9.2 Results Expected

At present the economic consequences of exhaust ventilation are not clearly understood from the energy conservation point of view, and procedures for analyzing and testing before installation of systems are not available. This program of study, if successfully accomplished, would provide a quantitative assessment of the problems and economic consequences of both dilution and local exhaust ventilation and their influence on the economics of energy conservation in buildings of the types being studied. A method for quantitative assessment of the quality of ventilation systems under these circumstances would be made available, as would a physical modelling procedure for the study of proposed optimal solutions.

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Typical Processes which Require Local Exhaust Ventilation and which may be found in Light Industry and Warehousing.

(Heat-dependent processes are not listed. Source: Industrial Ventilation, 16th Ed.)

Group	Operation
1. Foundry	Abrasive Blasting Core Grinder Mixer and Muller Hood Mixer and Muller Ventilation Pouring Station Shakeout Tumbling Mills Shell Core Holding Core Making Machine; Small Roll-over Type
2. High Toxicity Materials	Dry Box Laboratory Hood Lathe Metal Shears Milling Machine Shaft Seal Enclosure Sampling Box
3. Material Handling	Bag Filling Bag Tube Packer Barrel Filling Bin and Hopper Bucket Elevator Conveyor Belt Screens Belt Wiper
4. Metal Working	Abrasive Cutoff Saw Buffing and Polishing Belts Wheels Grinding Disc Wheel

Group	Operation
4. Metal Working (con't)	
	Metal Spraying
	Welding Bench
	Surface Grinder
	Metal Cutting Bandsaw
5. Open Surface Tanks	
	Degreasing - Solvent
	Solvent Vapor Degreasing
	Dip Tank
	Open Surface Tanks
	Table Slot Hood
	Open Surface Tank Data
6. Painting	
	Auto Spray Booth
	Spray Booth
	Large Drive-through Spray Paint Booth
7. Wood Working	
	Jointer
	Sanders
	Belt
	Disc
	Drum-Multiple
	Single
	Saws
	Band
	Swing
	Table
	Radial
8. Low-Volume High-Velocity	
	Cone Wheels
	Cup Wheels & Brushes
	Pneumatic Chisel
	Radial Grinders
	Disc Sander
	Vibratory Sander
9. Miscellaneous	
	Banbury Mixer
	Calender Rolls
	Service Garages-Overhead Underfloor

Group	Operation
9. Miscellaneous (con't)	
	Fuel Powered Lift Truck
	Granite Cutting & Finishing
	Kitchen Range
	Dishwasher
	Charcoal Broiler and Barbeque
	Pistol Range (indoor)
	Fluidized Beds
	Torch Cutting
	Clean Room Air Flow
	Cold Heading Machine
	Outboard Motor Test
	Fumigation Booth
	Fumigation Booth Data
	Asbestos Fiber Bag Opening
	Asbestos Fiber Belt Conveying
	Grain Industry

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