New Health Hazards In Sealed Buildings

Findings from recent research.
By Elia and Theodore Sterling and David McIntyre

Adler & Sullivan's Wainwright Building in St. Louis, constructed in 1891, contained all of the new technical elements that would become standard features of the high-rise office for the next 50 years: raft footings, fireproof tile covering structural steel, movable interior partitions, and fully operable windows for ventilation and daylighting. The Wainwright Building represented Louis Sullivan's deliberate attempt to create a special form for the multistory office block.

However, more importantly, the Wainwright offered a supremely logical solution to the technical and environmental problems important to the success of this new building type, the large office block. It introduced working and workable structural use of the steel frame; building anchoring techniques; provisions for heating, ventilation, and airconditioning; provisions for daylight penetration into individual room type offices; fire-safety; vertical circulation by elevator.

The Wainwright functioned as an organic unit, providing light, air, and temperature control to the interior office and commercial space. The skylit ground floor and U-shaped plan of the office floors above maximized daylight penetration and provided outer exposure for all offices. Fully operable windows allowed adjustable fresh air ventilation, while steam radiators provided a clean, adjustable heat source. The Wainwright lacked the sophisticated, mechanical airconditioning system we now rely on, yet for nearly a century of constant use, until major renovation in 1981, it satisfied the spatial and environmental needs of office tenants.

The glass curtain wall, the deep floor plan, and the open office entered the American scene with a vengeance after the Second World War. These new architectural elements, combined with Willis Carrier's invention of the airconditioning system, provided the raw material from which the new mechanistic esthetic, the fully sealed, airconditioned building, evolved. One of the earliest buildings representative of the effects of these changes is Pietro Belluschi's Equitable Savings & Loan Building in Portland, Ore., opened in 1949. The Equitable Building was one of the first sealed, glass, mechanically serviced, and fully airconditioned office buildings in the U.S. In 1980 it was designated a National Historic Mechanical Engineering Landmark by ASHRAE and last year was honored with AIA's 25-year award (see July '82, page 84). Considered a landmark in the transition to sealed, glass, airconditioned buildings, its office space incorporated year-round airconditioning, good natural illumination and artificial light sources, sound control, attractive durable finishes, and a structure and utilities easily adaptable to change in office partitioning.

The design of the airconditioning system is of admirable simplicity. Each floor has its own fresh air supply through louvered intakes on the stair tower. Air is conditioned by a separate system on each floor. Incoming air is distributed through ceiling outlets. Return air is removed through slotted window sills into the plenum of the floor below. Perforated ceiling panels allow air, heated by the light fixtures, to be removed directly into the return air plenum. The building skin functions as a passive environment modifier. Heat absorbing glass was used not so much to reduce the solar heat load, but more to cut sky glare so that blinds or shades would not be needed for comfort. Similarly, double glazing was intended primarily to reduce cold drafts off exposed glass surfaces. Economically the use of a mechanical system was justified to allow an increase in leasable space over earlier window ventilated buildings. The Equitable was so successful that it became the model for a generation of American high performance, sealed office buildings.

Elia Sterling, research director for the Vancouver research firm of TDS Limited, is coauthor of the forthcoming book, *Modern Buildings and the Public Health.* **David McIntyre** is senior researcher for TDS Limited. **Theodore Sterling** is a professor, faculty of interdisciplinary studies, Simon Fraser University, Burnaby, British Columbia.

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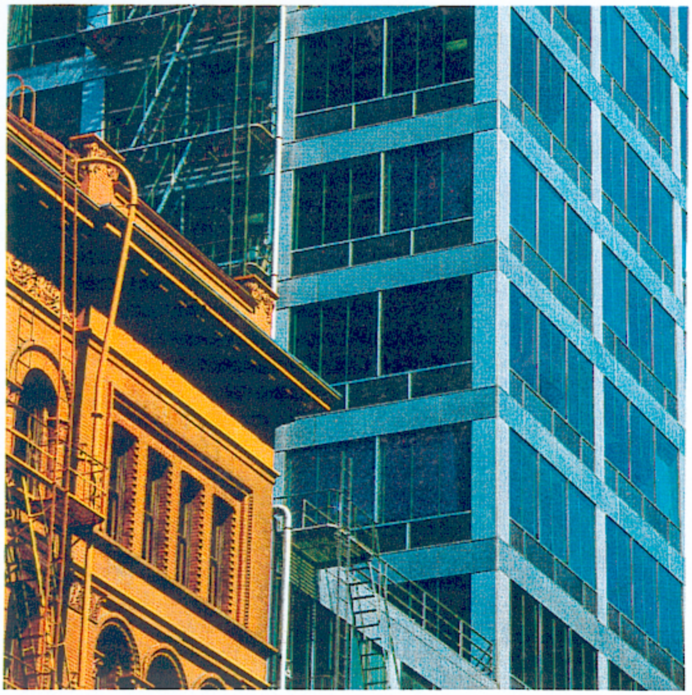

But much of its success was based on a variety of conditions that no longer exist for the subsequent generation of sealed buildings, including stable, mostly natural materials and durable interior finishes; lighting by cold cathode tubes with good color balance, no flicker, and minimal ultraviolet radiation emissions; a constant supply of fresh, outside air; an airconditioning system designed for good circulation by placing exhaust returns under the windows near the floor with supply vents in the ceiling; perforated ceiling panels allowing heat to escape from the lighting fixtures directly into the return air plenum; and an abundance of inexpensive energy that frees the design from constraints imposed by climate.

With the rapid rise of energy costs in the 1970s, which brought to an end the era of the high performance, sealed building, the search began for new design solutions responding to energy constraints and performance requirements. The Gregory Bateson State Office Building in Sacramento, Calif., designed and implemented under successive state architects Sym Van der Ryn and Barry Wasserman, FAIA, is a prime example of recent energy conserving office buildings.

Approximately of the same scale as the Equitable Building (267,000 square feet), the Bateson was designed to respond to a wide variety of functional and esthetic constraints, including energy use and employee working conditions. Wasserman has been described as uncommonly sensitive to the impact of workplace upon worker, often pointing out that employees spend more of their waking hours in the office than anywhere else and that lower level employees are particularly affected since they have so little administrative control over their own working conditions. The Bateson, like the Equitable, is for all practical purposes sealed, with the environment created and controlled by a mechanical system. The focus of the building is an interior atrium, designed as a flexible energy management device that redistributes heat and provides natural light to interior office space.

As a means to minimize energy use, the Bateson, like the Wainwright a century before, uses the structure and massing to passively control the indoor office environment. A massive, exposed concrete frame stores daytime heat and slowly releases it at night. The many terraces, stepbacks, and re-entrant corners increase the surface area available for thermal transfer and provide daylight penetration. On the interior, the suspended ceiling has been eliminated to permit heat stratification and indirect ambient lighting. Solar collectors for hot water, computer monitoring of electrical use, and an underground heat storage system using 600 tons of rock are technological features integrated into the building to enhance energy conservation.

Despite the architects' desire to design an office environment sensitive to the needs of the worker, the Gregory Bateson has been plagued by environmental quality problems since it opened in 1982 (see Sept. '82, page 18). Complaints of respiratory, gastrointestinal, skin, and eye problems began soon after the first occupants moved in. Some occupants complained of suffering dizziness, loss of balance, occasional sore throat, and itchy skin. There were reports of unpleasant odors. Most complaints seemed to come from areas with the lowest ventilation rates. More complaints occurred when the ventilation system was operated only in the daytime than when operated around the clock. Complaints were sufficiently insistent to lead public health authorities to study conditions. In fact as a result of the problems, contractors, subcontractors, and suppliers have been sued and the state faces worker compensation and class action suits, claiming health damages from poor air quality inside the building.

Air quality tests conducted by the California Occupational Safety and Health Administration found slightly elevated levels of formaldehyde, carbon dioxide, and other pollutants. Fun-

Across page, glass wall addition to the Wainwright Building; left, detail of the curtain-walled Equitable Building; below, atrium of the Gregory Bateson California State Office Building.

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gal spores were found present in the air exhausted from the rock bed thermal heat storage.

Inspection of the ventilation system revealed that up to 80 percent of the induction boxes (a strategic component that controls the mix of air to diffusers) were found to be defective. Office space divider partitions were identified as a major inducer of formaldehyde and contributors to air stagnation.

All indications pointed to inadequate ventilation and poor air circulation and filtration as the most serious sources of occupant complaints. By good fortune, declining energy costs have allowed the ventilation system to be put back on 24-hour operation, providing a maximum fresh air supply without severely increasing operating costs. Better ventilation has resulted in dramatic reductions in both complaints and contaminant levels. This solution, however, is not permanent. When energy costs again escalate, the increased cost will force the choice between comfort and energy conservation.

With the best of intentions (to provide optimum environmental quality conditions within the context of an energy conserving office building), the architects stumbled upon the dilemma of modern, airconditioned office buildings. Major changes in building technology and energy supply that have occurred over the past decade and are still in progress may reduce the capacity of airconditioned office buildings to provide conditions fit for human habitation. These changes have included sealed building envelopes; dependence on mechanical heating, ventilation, and airconditioning to provide acceptable thermal comfort and air quality; introduction of unstable synthetic materials, maintenance products, and finishes that off-gas toxic contaminants such as formaldehyde, chlorinated hydrocarbons, and respirable particles or that leave dust residues; dependence on fluorescent and other gas vapor lighting that emit nonionizing radiation and may be a major catalyst of photochemical reactions indoors; technological advances in office equipment such as photocopiers and video display terminals that emit radiation and airborn contaminants and may require specially designed environments for safe use; and increased cost of energy and possible shortages at times of greatest demand that have become major incentives for reduction of fresh air ventilation.

In many ways the sealed, airconditioned, energy conserving building with minimum ventilation resembles a submarine, in that its indoor atmosphere must be kept fit for human lungs through the extensive use of sophisticated, mechanical equipment. The quality of the ambient environment depends primarily on inside activities, and materials, and on ventilation procedures that clean and refresh the air. Filtration of many contaminants is often neither economically practical nor technically possible. For this reason many maintenance products containing volatile chemicals commonly used in buildings are no longer allowed in submarines. Air quality problems in sealed buildings and submarines differ in specific instances but are often similar in kind. For example, there is a parallel between experience in submarines where deadly phosgene gas was produced by accidental combinations of leaking gases and the failure of the ventilation equipment in the Bateson Building leading to increased exposure of occupants to formaldehyde and other fumes.

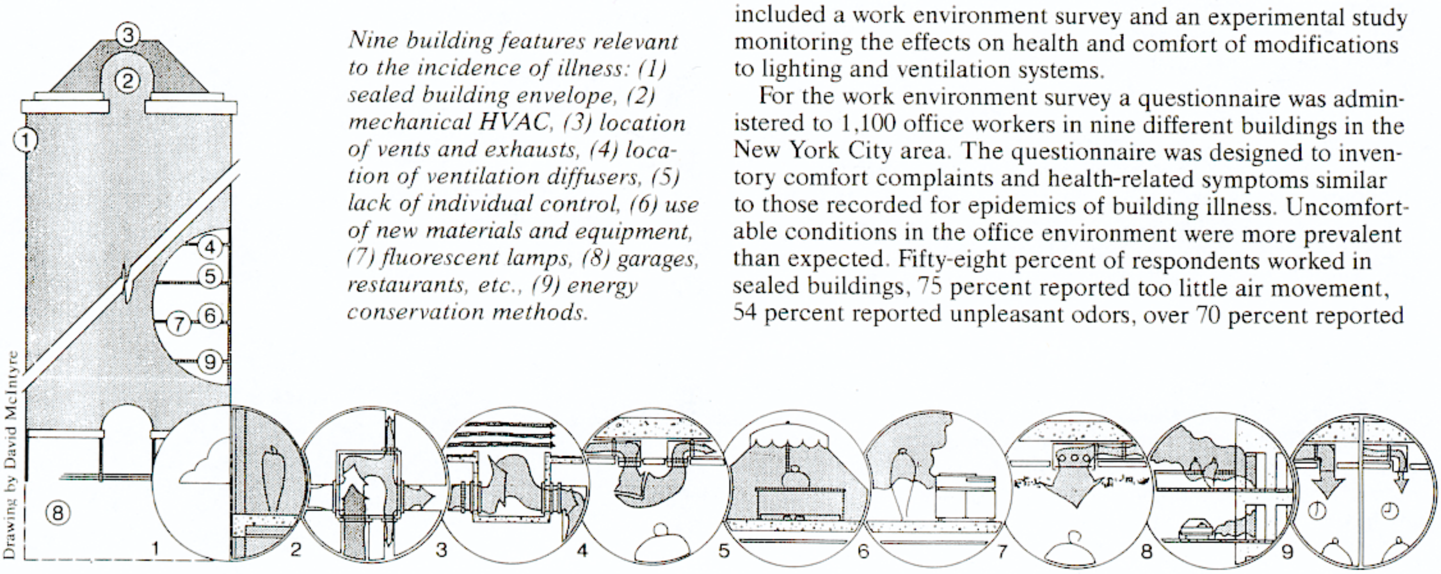
There are now nearly 200 investigations on record across North America of building-associated epidemics of illnesses and comfort complaints similar to those experienced by the occupants of the Bateson Building. Investigations were undertaken by government agencies, research institutes, and private consultants. Complaints ranged from minor to serious reports of reproductive system and pregnancy problems. Almost all instances have occurred in new or refurbished buildings in which conditions of ambient air and ventilation are completely mechanically controlled and lighting is supplied by fluorescent lamps. The overwhelming majority of these investigations coincided in time with a concerted effort to minimize building energy use by reducing fresh air ventilation rates and increasing the operational comfort ranges for acceptable temperature and humidity.

Tight building syndrome, insulated building illness, office building syndrome, and often simply building illness, all refer to epidemic complaints of illness or discomfort including headache, burning eyes, irritation of the respiratory system, drowsiness, and fatigue. The symptoms are generally experienced over an extended period of time and recur during occupancy in sealed buildings. The cause is rarely definitely determined, but is often suspected to be related to components of the building or air supply system. A few of investigated epidemics have been explained by specific causes such as carpet shampoo residues, glass fiber from ducting systems, asbestos, or formaldehyde. (Although smoking has been considered in nearly every investigation, no data have been presented that link smoking in buildings to health related complaints.)

In most investigated buildings, specific causes for symptoms have not been determined, yet many investigations have concluded the symptoms to be related to components of the building, particularly the ventilation system, operated at minimum ventilation rates.

In 1979 with the collaboration and support of the Legal Services Society of British Columbia and the British Columbia Government Employees Union in Vancouver and the Office and Professional Employees International Union in New York, TDS Limited began evaluating the effect of contemporary buildings on the health and comfort of office workers. This research has included a work environment survey and an experimental study monitoring the effects on health and comfort of modifications to lighting and ventilation systems.

For the work environment survey a questionnaire was administered to 1,100 office workers in nine different buildings in the New York City area. The questionnaire was designed to inventory comfort complaints and health-related symptoms similar to those recorded for epidemics of building illness. Uncomfortable conditions in the office environment were more prevalent than expected. Fifty-eight percent of respondents worked in sealed buildings, 75 percent reported too little air movement, 54 percent reported unpleasant odors, over 70 percent reported



Nine building features relevant to the incidence of illness: (1) sealed building envelope, (2) mechanical HVAC, (3) location of vents and exhausts, (4) location of ventilation diffusers, (5) lack of individual control, (6) use of new materials and equipment, (7) fluorescent lamps, (8) garages, restaurants, etc., (9) energy conservation methods.

that the temperature was either too cold or too hot, 65 percent reported the air too dry, and 74 percent reported the air too stuffy. Building illness symptoms experienced more than once a week were also prevalent: 37 percent reported headaches, 51 percent reported fatigue, 59 percent reported sleepiness, 31 percent reported nasal irritation, and 34 percent reported eye irritation.

A consistent association was found of all relevant symptoms with ability to control ventilation. A more detailed evaluation of the work environment survey (reported at the recent Second International Conference on Building Energy Management) showed building illness symptoms to be significantly associated with ventilation, air movement, and lighting. As could be expected, of the nine office buildings surveyed, fewer health and comfort complaints were reported in buildings with functional windows. This "I can open the window" effect agrees with other studies. In 1982, pollster Louis Harris conducted "comfort and productivity" survey (commissioned by Steelcase) that found 46 percent of office workers believe air circulation through open windows is better than in offices where only the HVAC system circulates the air. The study also found a profound negative impact on the comfort of white collar workers of the contemporary office workplace and concluded that office comfort has a direct impact on job performance.

An experimental study was undertaken to determine the effect of ventilation and lighting on symptoms reported by occupants of one sealed building. Office workers in the sealed building were paired with occupants of an older building with operable windows. A comparison of symptoms showed 60 percent more complaints of eye irritation, 25 percent more complaints of headaches, and 40 percent more complaints of sleepiness and fatigue among occupants of the sealed building. The cause was suspected to be indoor-produced smog generated by ultraviolet emitting, full spectrum (sunlight simulating) fluorescent lighting impinging on indoor pollutants. Ultraviolet radiation is known to enhance the production of photochemical oxidants, a major component of atmospheric smog believed to be responsible for eye and respiratory irritation.

Next, symptoms were monitored while experimentally modifying lighting and ventilation conditions. In a blind test (subjects were not aware that conditions were being modified) the ventilation was increased to the maximum fresh air supply, and in half the offices the existing full spectrum lamps were replaced by cool white lamps. When only ventilation was increased, eye irritation diminished by 7 percent; when only lighting was changed, eye irritation diminished by 8 percent; but when both lighting and ventilation were modified, eye irritation diminished by a significant and substantial 32 percent.

All the necessary conditions exist in offices to produce photochemical smog— ultraviolet radiation (from fluorescent lamps and photocopiers), formaldehyde (off-gassing from particle board, insulation, and other materials), hydrocarbon vapors (from infiltrated auto exhaust and off-gassing from paints and plastics), benzylic monoalcylbenzenes including toluene and styrene (ingredients coming from glues, solvents, and cleaning materials), and even trichlorothylene (contained in white-out materials used by typists). Thus the decreased eye irritation could very well be the result of reduced photochemical smog production when ultraviolet radiation is decreased and fresh air supply increased.

Overall, we have identified nine features common to office buildings where health and comfort have been problems.

• A sealed building envelope: Generally the amount of fresh air drawn into a mechanically, environmentally controlled building is minimized, as it is energy efficient to recirculate as much of the building air as possible.

• Mechanical heating, ventilation, and airconditioning: The HVAC system aids dispersal throughout a building of the many irritants and pollutants generated by materials and equipment. The system also may incubate and spread fungi, bacteria, and viruses. (A mechanical ventilation system was, in part, responsible for the spreading of Legionnella Pneumophilia bacteria that caused 21 deaths in the incident of legionnaires disease at the Bellevue Stratford Hotel in Philadelphia in July 1976.)

• Location of vents and exhausts: Air supply vents can introduce outdoor contaminants into a building. For example, supply vents located overlooking a busy street or transit stop are often the source of entry for auto or diesel exhaust. Also poor placement of supply and exhaust vents can prevent exhaust from escaping. Exhaust air may even be reintroduced directly back into the air supply.

• Location of ventilation diffusers: Both inlet and exhaust diffusers are commonly located in the ceiling. This often creates stratification and short circuiting of supply air at the ceiling level, which may result in pockets of dead air and poor circulation.

• Lack of individual control over environmental conditions: All people are not equally comfortable in the same environment. Elimination of the possibility to modify the environment tends to contribute to discomfort, stress, strain, and minor health problems.

• Use of new materials and equipment: Synthetic materials and modern office equipment as well as the industrial soaps, detergents, and waxes used for maintenance generate many irritating and sometimes toxic fumes and dusts, including formaldehyde, hydrocarbons, amines, ozone, and respirable particulates.

• Fluorescent lamps: The new popular sunlight simulating type as well as the standard fluorescent tubes emanate ultraviolet light. These lamps may provide energy for photochemical reactions among pollutants, thus forming the basis for indoor photochemical smog production. While the photon path length is quite short, affecting only a small amount of air around the fluorescent fixture, many ventilation systems circulate air around and over the light fixtures and even through vents built into them. This practice exposes a very large volume of air to photon bombardment.

• Parking garages, restaurants, and other nonoffice space use: Many large office developments also contain within the same building parking garages, access to transportation (such as buses and subways), restaurants, health clubs, and laundry and recreation facilities. These spaces may add substantial amounts of combustion byproducts, including carbon monoxide, oxides of nitrogen, carbon dioxide, and diesel exhaust to the indoor environment.

• Energy conservation methods: These usually involve reduction of fresh air ventilation rates. Reduction of the fresh air supply increases the rate of accumulation of pollutants by reducing the volume of air exhausted. The efficiency of standard air filters and their ability to control contaminants is reduced substantially as the velocity of the ventilation air is lowered. Many buildings now use a variable air volume system, which only introduces fresh air when cooling or heating is required. Occupants of buildings with this type of system often complain of stale, stuffy air, an indication of insufficient ventilation.

Today an estimated 25 percent of the U.S. workforce can be found in office buildings. Sealed, airconditioned buildings no longer provide occupants sanctuary from air pollutants and often do not even provide adequate thermal comfort. Yet new laws and standards now being considered to promote energy conservation, including ASHRAE series 100 energy conservation standards and the building energy performance standards proposed by DOE, are likely to cause severe discomfort, possibly leading to reduced productivity and even illness in the office workplace.

The 1980s are a transitionary period for architecture. The human health and comfort component of the building, in addition to energy conservation, new technology, and new materials, has begun to define a new design esthetic. Height, massing, and material use are the key architectural elements, combined with ingenuity and imagination, that will chart the course back to an architecture that serves rather than irritates. ☐