The Health Impacts of the Building Environment and How an Intelligent Building Can Help

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ABSTRACT
No universal definition of an "intelligent building" exists; it has been an ambiguous term since its conception in the 1980s. The course, AE790 *Intelligent Buildings* taught by Professor James E. Mitchell, introduced us to the "intelligent building" by discussing sensors, robotics, and developments in research in other industries. This paper summarizes the work of this semester, from my initial understanding of what an intelligent building is to a final understanding, and also my exploration of one aspect of an intelligent building that we did not have time to cover in class. I chose to explore building-related health issues because I believe the result of my graduate work should be beneficial to society. The intelligent building can aid in the improving of occupant health by using sensing technologies to control the operation of a central ventilation and air conditioning system, namely a carbon dioxide-based demand controlled ventilation system.

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1.0 Introduction[1]

The concept of an intelligent building began in the early 1980s, yet no standard definition has been agreed upon. Up to 1985, the definition of intelligent buildings was “buildings automatically controlled to function”, then from 1986 to 1991, an addition to the previous definition was “buildings capable of responding to the changing needs”, and finally, from 1992 to present day, the definition became “buildings with features effectively satisfying the changing needs” [1]. Whatever the definition may be, intelligent buildings have the potential to address issues plaguing the current building industry. These issues are Costs & Time (§2.1.4), Environmental Impact (§2.1.5), Building Life (§2.1.6), and Health (§2.1.7), with further development on the last issue in §3.0.

1.1 Summary of Work

This final assignment is a great opportunity to organize the semester’s work into one concise document. First, I went through each assignment and added more concepts and links. These addendums were taken from class discussions, guest lectures, class CMaps, and subsequent assignments. On each of my past CMaps, you will see dark maroon boxes to indicate the new links. The following is a summary of the additional work:

CMap1 – What is an intelligent building?

- Recording the design process for use in the Building Integration Model (BIM) (class discussion).
- Considering the roles and importance of stakeholders (class CMap).
- Introducing sensors, their characteristics, and the range of possible measurements they take (class CMap).
- Using a database for data collection (Assignment 3).
- Using proper control algorithms to make use of data from sensors in order to make proper adjustments to building systems (guest lecturer).

CMap2a – What challenges in current buildings can intelligent buildings alleviate?

- Introducing building-related health issues.
- Reducing time not only for construction, but for planning as well (guest lecturer).
- Identifying the stages of the building life cycle (class CMap).
- Using models like Graphisoft’s Constructor 2005 for many tasks (guest lecturer) [2].

CMap2b – What are the challenges that face intelligent buildings?

- Questioning the length of time for intelligence in the building to be fully operational.
- Questioning the potential consequences of creating intelligent buildings and technologies (class discussion).

I created two CMaps for the final assignment. The first one, Chen-Final CMap1, outlines my final understanding of an intelligent building. It encompasses the knowledge I have gained as a

[1] Section 1.0 taken directly from write-up for Assignment 2: Problems Facing the Current Building Industry.

result of this course. Following student presentations in class, I have also added links to other students' work. My other CMap, Chen-Final CMap2, outlines the deeper topic of Building related health issues (§3.0).

2.0 Defining an intelligent building – Initial

My initial understanding of an *intelligent building* would have read (refer to CMap1):

> "…a building that provides many benefits for its owners/operators, end users, and the environment, such as by reducing operation time and costs, reducing maintenance, reducing the manpower required to manage and maintain itself, reducing the environmental impact, and providing a comfortable working and home environment, through the use of a building automation system (BAS) that monitors the building by collecting data on the various building systems and adjusting the building systems to run only when needed, in order to save energy yet still maintain acceptable indoor air quality (IAQ)."

Taking into account the topics covered in this course, subsequent assignments, and the opinions of classmates, I have broadened and deepened my understanding of what an intelligent building is. I have broadened my definition to include the people who make the intelligent building, and I have deepened my understanding by exploring a few of the critical elements that make a building "intelligent". My current overall understanding of an intelligent building is illustrated in Final-CMap1, entitled "What is my overall understanding of an intelligent building?" The ensuing discussion, on my final understanding as a result of this course, is based on the organization of this CMap.

2.1 Defining an intelligent building – Final

My final understanding of an intelligent building now reads (refer to Chen-FinalCMap1):

> "…*ideally*, a building that is created by effective interaction between *stakeholders* during the building's entire life cycle <u>and</u> uses *technological advancements* to benefit each stakeholder, such as by reducing *costs*, reducing *time* spent in various stages of the building life cycle, reducing *environmental impact*, increasing *building life*, and improving the *health* of building occupants."

This definition incorporates elements from my initial understanding and now also includes key concepts such as "stakeholders" and "technological advancements" or more hardware. These, and other italicized key concepts, will now be discussed.

2.1.1 Ideally

In order for a building to fit the "intelligent" category, it would have to meet all of the criteria in the definition just given; this would be an *ideal* situation. However, to meet each criterion is difficult and nearly impossible, given the current knowledge and technology; therefore, the question, "Which buildings can truly be called 'intelligent'?", is still a decision to be made by each individual.

2.1.2 Stakeholders

The class identified several stages in the building life cycle, including definition of needs, formation of design teams, production of conceptual, schematic, and construction, construction, and operation. Key *stakeholders* in the building industry were also identified, including policy makers, owners, investors, designers, builders, and end users. Currently, interaction between the stakeholders is compartmentalized according to the stage in the building life cycle. Buildings can begin to be planned and constructed more intelligently by involving more stakeholders in more stages of the building life cycle. Instead of calling on a specific stakeholder only when a problem arises, stakeholders can meet together to prevent such problems from occurring (referred to as "effective communication" in my definition). Stakeholders should discuss the likely *challenges* that will face the realization of their intelligent building (refer to CMap2b) and discuss how to meet them. Theses *challenges* include questions such as (refer to CMap2b):

- Does anyone want an intelligent building?
- Does anyone want to pay for it? Can anyone pay for it?
- Can anyone design it? Are the technologies available?
- Can anyone build it?
- How long before the "intelligence" is fully operational?
- Who will provide the training to manage the "intelligence"?
- What will be the cost to benefit ratio?
- Will the intelligent building be used correctly?
- What are the long term consequences?

These are difficult questions that cannot be answered independently, and thus, should not be answered by only a few stakeholders. For a building to perform "intelligently", it should first be conceived "intelligently" by attempting to answer all, and many more, questions such as these.

This is not only personal opinion but is desirable as a standard for the building industry. A national initiative is underway to create an environment for increased integration between stakeholders. Standardized practices and methods of storing, viewing, and sharing building information is the core of this initiative, called the National Building Information Model (BIM) Standard [3].

2.1.3 Technological advancements

The use of one or all of the following technological advancements will distinguish an intelligent building from a "normal" one: the use of computer models, smart materials, and sensors, all of which have been discussed in class.

Computer models can be used in the planning stages of an intelligent building to simulate construction. One such model, developed by Graphisoft, is Constructor 2005 [2]. Because the model is actually the proposed project schedule in motion, potential construction delays and conflicts can be identified, and appropriate changes made, before construction even begins. Computer models can also be used to simulate operating conditions. For instance, the air flow simulation model, CONTAM (developed by the National Institute of Standards and Technology [4]), can simulate IAQ resulting from the various operating modes of a heating, ventilation, and air conditioning (HVAC) system. Thus, design parameters, such as air flow rates, can be adjusted for improved IAQ before a large investment is made in purchasing, installing, and testing the equipment [5].

Smart materials [6], discussed briefly by Dr. Emin Aktan, may be able to adapt to operating conditions, environmental changes, and other transient factors experienced throughout the life of a building. Even now, the glass in windows can automatically increase its shading during bright hours of the day [7] to lessen the load on the air conditioning system and reduce glare that is disruptive to occupants. The use of smart insulating materials that change with the seasons also helps to lessen the load on the HVAC system throughout the year. Designers are no longer limited to designing for only one particular "peak load" season. Furthermore, materials which adapt can increase the life of the material itself and of other materials and equipment because they most appropriately meet the needs of the building instead of over- or under-compensating, as is usually the current situation.

Lastly, and one of the topics of greatest discussion in this course, is the use of sensors. Sensors form networks, whether hard-wired or ad-hoc as Dr. de Oliveira explained, which are linked to a central control station, in the case of a building, the BAS. The data collected by the sensors, such as temperature, humidity, pollutant levels, and fire status (refer to Assignment 3 on databases), are used by the BAS to control the operation of the HVAC and other building systems. Furthermore, collection and storage of this data is vital to “describing the facility information” in the BIM [3].

The advantages of these technological advancements will be elaborated in the following sections: Costs & Time (§2.1.4); Environmental Impact (§2.1.5); Building Life (§2.1.6); and Health (§2.1.7). The last topic, *Health*, will be further expanded on as required for this final assignment.

2.1.4 Costs & Time[2]

According to a study by Hendrickson et al. in 2000 [8], the four major construction sectors in the United States are 1) highway, bridge, and other horizontal construction; 2) industrial facilities and commercial and office buildings; 3) residential one-unit buildings; and 4) other construction. Respectively, these sectors made up 0.6%, 1.5%, 1.9%, and 2.4% of the 1992 Gross Domestic Product (GDP); in absolute dollars, they are $38 billion, $94 billion, $119 billion, and $150 billion, respectively, for a total of approximately $400 billion dollars being poured into the building industry. Remembering these dollar amounts do not include monies associated with other phases of the building process, such as design, litigation, inspection, etc., one can see that there are large opportunities for savings. The factors related to costs are: communication, design, construction, operation, and maintenance.

2.1.4.1 Communication & Computer Models

Even with the advent of email, teleconferencing, cellular phones, text and instant messaging, there is still a lag time in communication. One party may not be able to respond to another promptly, thus, delaying the completion of the current task.

[2] Introductory paragraph taken directly from write-up for Assignment 2: Problems Facing the Current Building Industry.

Furthermore, miscommunication and misunderstanding occur because we do not all speak a common language. This can be remedied by the use of a common language, namely video, as suggested by Mr. Don Henrich of Graphisoft [9]. The use of video allows both owners and builders to obtain a more vivid sense of the events which are occurring and how fast they will occur, all before construction even begins.

Following Steven Worton-Cross' presentation regarding "Concurrent Engineering" on May 30, I see that video is not the only common language available for use in the building industry. Steven spoke on sharing data in common formats, so that not only different computer languages and software can read the data, but also so that stakeholders from various disciplines will be able to understand one another. Prof. Mitchell also asked me to consider the words, photographs, drawings, and numbers that describe a building as common languages also. It seems that for clarity, all of the descriptive methods should be used to complement and support one another.

2.1.4.2 Design & Computer Models

Design at every stage, conceptual, schematic, and construction, can be further aided by the use of "intelligent" technologies. Often times the designer fails to fulfill a clients' desires because the client failed to express that desire clearly. Using computer models to portray the finished product allows the clients and designers to make design changes in the pre-conception phase instead of during the construction, or worse, during the operation stage [5].

2.1.4.3 Construction & Computer Models

Factors that delay construction are either out of our control, such as weather conditions, or may be under our control, such as being better equipped to avoid potential problems. To avoid potential problems, first, stakeholders can address difficult questions early (§2.1.2). In addition, we can more easily identify potential problems using computer models, such as Graphisoft's Constructor 2005 [2], and minimize them. Furthermore, as Mr. Keith Sevcik's presentation on robots pointed out, robots and automation can be used in the construction of buildings in order to perform repetitive tasks or tasks which require precision. Examples are: Integrated Control System for Diaphragm Wall Excavation, Digging Work Robot, Self-rising Dam Form, Tunnel Swift Lining Robot, and Steel Frame Welding Robot (refer to [10] for more examples).

2.1.4.4 Operation & Sensors

When I first hear the phrase "intelligent building", I immediately think of operational-related technologies, especially those which aid the operation of the HVAC system. For instance, the BAS monitors and controls the various systems and "decides" how to run each piece of equipment, when to run them, and for how long. Because the BAS would "know" the electrical demands and rates, it could calculate, in real time, the cost of operation and thus minimize energy consumption. Simultaneously, the BAS is receiving information from the sensors about occupancy, temperature, pollutant levels and other parameters describing IAQ, and would use this information to strike a balance between comfort and energy use. Often times, an HVAC system is designed to operate at a constant air flow rate, whether or not the load exists. Therefore, in an intelligent building, rooms with low occupancy would receive lower ventilation rates and rooms with higher occupancy higher rates. This example is only one building system taking advantage of intelligent building design; other systems benefit as well. For example, Berkeley is conducting research on the use of motes in energy-saving lighting controls for commercial buildings [11].

2.1.4.5 Maintenance & Sensors

Maintenance is related to operation. If a piece of equipment is operated less (to save energy when it is not needed), it requires less maintenance, such as replacement of individual components or of the whole. In addition, if equipment are maintained intelligently, such as on a defined schedule (and really maintained then), the life of the equipment would be extended. Data from sensors inside equipment can be also be fed to the BAS so that not only is the environment monitored, but the equipment as well. Equipment can be serviced long before a disastrous and costly event occurs. Since the building environment and the equipment are monitored from a central location, fewer personnel are required to circulate throughout the building to check operating conditions. Furthermore, as we can rely on sensors to gather data from each individual room, this technology can even be useful during commissioning when the equipment is checked for functionality and that the design conditions inside the building are met.

"Time is money", and with regards to creating and operating an intelligent building, the potential for minimizing both spans all stages of the building life cycle, from pre-conception to operation. Savings can be realized by more effective communication, improved design methods, better planning and execution of construction, optimized operating modes, and reduced maintenance. These goals can be reached through the use of the technological advancements to be used in intelligent buildings.

2.1.5 Environmental Impact[3]

Carbon emissions and global warming are growing concerns not just here in the U. S. but around the world. Large corporations such as IMB and DuPont have curbed their energy use and have seen savings in the millions and billions. Even more is that their production has not suffered and they have saved on their manufacturing costs. Companies such as Wal-Mart, 3M, Advanced Mirco Devices, and Gap have also voluntarily reduced their emissions. The incentive to reduce emissions is not only financial but also related to company image. Companies benefit from reducing emissions because the public will see them as "environmentally friendly" and continue to be their consumers [12]. Therefore, the construction industry can also do the same.

The total emissions of a few selected pollutants from the construction industry are listed below [8]. Keep in mind that these emissions do not account for those released in the making of energy or in the operation of equipment. They also do not show the related health costs associated with persons being sickened by the atmosphere or the indoor environment. Therefore, there is a large opportunity for decreasing the environmental impact that the building industry makes [13].

[3] Portions taken from the write-up for Assignment 2:Problems Facing the Current Building Industry

We can reduce the impact on the environment through the wider use of intelligent building technologies. First, we can reduce emissions because as equipment is operated only when needed, the consequences of producing the electricity to run that equipment is also reduced. The building industry will also consume less of the world's supply of natural, non-renewable resources. With the coming of intelligent buildings, I believe we can also start to push for more use of alternative and renewable energy sources. According to a study by the Worldwatch Institute, wind and solar power are the world's fastest-growing energy sources [14]. Furthermore, the advantages for the owner/operator are that he/she is not consuming as much energy and can save on energy costs. Lastly, the use of biodegradable materials can be advantageous when it is time to replace components or even the entire machine.

Table 1. Selected Pollution Emissions from Major U.S. Construction Sectors (Highways and Commercial)

Pollutant	Per total sector output, tons (% of U. S. total)
Sulfur dioxide	86,678 (0.4)
Carbon monoxide	141,767 (0.2)
Volatile organic compounds	22,509 (0.1)
Global warming potential	28,383,581 (2)

Table 2. Selected Pollution Emissions from Major U.S. Construction Sectors (Residential and Other New Construction)

Pollutant	Per total sector output, tons (% of U. S. total)
Sulfur dioxide	249,372 (1)
Carbon monoxide	476,809 (0.6)
Volatile organic compounds	87,742 (0.4)
Global warming potential	80,108,446 (5)

2.1.6 Building Life

As with the discussion on smart materials (§2.1.3), the life of the building will increase when materials which adapt to changing environments are used. As for operation (§2.1.4.4) and maintenance (§2.1.4.5), equipment which is run less and well-maintained will last longer.

2.1.7 Health

Section 3.0 takes a deeper look into the health issues related to building environments, namely Sick Building Syndrome (§3.1). Because this health issue is related to underventilation, Ventilation Rates and Energy Costs (§3.2) are discussed next to show that increasing ventilation, and thus improving IAQ, does not sacrifice energy savings. Sections 3.3, 3.5, and 3.6 discuss the current intelligent building technologies and areas for future research.

2.2 Defining Intelligence

Professor Mitchell, in lecture eight, defined an intelligent building as possessing two distinct characteristics; intelligent buildings 1) use adaptive computer technology and 2) are "intelligent".

Adaptive means that the technology will learn from experience. The necessity of computer technology in the intelligent building is twofold: 1) computers are used in almost every industry, and we can't get away from them; the things we would like intelligent buildings to do will require the use of computer technology (i.e., sensors, control algorithms, collection and organization of data), and 2) if intelligent buildings are to be "intelligent", they need to do something, and computer software is the tool for the job. Professor Mitchell believes that "intelligence" sets the intelligent building apart from "dumb" buildings. He believes that intelligence can come into play in every stage of the building life cycle (e.g., computer modeling using programs such as Graphisoft's Constructor 2005), but that the building must itself be intelligent (i.e., do something), and not just be intelligently created.[4] The class went on to discuss autonomy and if this was the same thing as intelligence. By the end of the class, I was almost convinced that that *was* what Professor Mitchell meant by intelligence, but it was not.

Therefore, I agree with Professor Mitchell's assessment of the intelligent building. Adaptability will set apart the intelligent building from ordinary buildings. For instance, in the HVAC industry, air flow rates are constant, though scheduled off during non-occupied hours. Even in variable air volume (VAV) systems, by which the total air flow rate from the air handling unit is reduced according to demand, problems with low demand and reduced outdoor air flow rate at the supply end can create problems with IAQ [15]. Therefore, an adaptable system will be able to deliver appropriate and adequate air flow in all situations.

The adaptable system will require the use of computer technology in the form of sensors, processors, and management programs. Today, the BAS can integrate almost all of the building systems into one manageable interface; however, most BA systems are only monitoring and not controlling. Furthermore, even with the little control that the BAS does offer, control is manually performed by a person; the building systems are not self-adjusting, which is what the industry should be moving to.

As for intelligence versus autonomous, I think the ability to adapt is sufficiently intelligent. If we can implement only that, I would be satisfied and could say that the intelligent building has arrived. However, we have much research, testing, and validation to perform in order to prove that the design for adaptability is not just a dream but a reality.

3.0 Building related health issues

The energy crisis of the 1970s lowered outdoor air ventilation rates in order to reduce expenditure of resources and to lower utility bills. Furthermore, new construction methods created more airtight buildings that improved energy efficiency but reduced ventilation air flow through the building envelope. Insufficient fresh outdoor air ventilation indoors has created a health epidemic called "sick building syndrome" (SBS). Health studies conducted in schools, office buildings, residential homes, and other types of buildings have shown that many occupants experience SBS symptoms while inside these sick buildings. Moreover, studies have shown that increasing ventilation rates, which improves the quality of indoor air, can reduce the prevalence of SBS. Here, the intelligent building can utilize data from sensors to control the outdoor air ventilation, which is able to improve occupant health.

[4] Taken directly from Week 8 log entry.

3.1 Sick Building Syndrome

SBS is characterized by the following symptoms: eye, nose and throat irritation; a sensation of dry mucous membranes and skin; skin redness; mental fatigue; headache; a high frequency of airway infections and cough; sensitivity; nausea and dizziness; nasal dryness; nasal congestion; nasal excretion; pharyngeal symptoms; difficulty in concentration; difficulty in breathing, and tight chest. Agents causing these symptoms are unidentified and do not indicate a specific known disease [16]. In addition, SBS symptoms are identified as those that occur one to three times a week in a particular indoor environment and improve when one is away from that environment [17].

SBS symptoms are experienced by up to 40% of all workers depending on the symptoms [18]. The widespread occurrence of these symptoms demands improvements to IAQ. Furthermore, substantial reductions in health effects and significant economic savings can be realized (Table 3).

Table 3. Potential reduction in health effects and corresponding potential economic benefits.

Health effect	**Estimated potential annual reduction (% and no.) in health effect**	**Estimated economic benefits possible**[a]
Communicable respiratory infections: (e.g., influenza, common cold)	10% to 14%; 5-7 million cases	\$3 to \$4 billion
Asthma, hypersensitivity pneumonitis, and allergic disease	6% to 15%; asthma episodes 0.3-0.7 million cases; allergy episodes 1-3 million cases	\$200 to \$600 million
Nonspecific building-related symptoms (incl. SBS)	20% to 50%; 8-30 million cases	\$4-70 billion
Respiratory infections: building sources (Legionnaires' disease, Pontiac fever)	Unknown, probably >50%; Legionnaires' disease 1400-3000 cases, including >70 deaths	Tens of millions of dollars
Health effects of environmental tobacco smoke	100%; 2000-11000 cardiovascular disease deaths; 100-600 lung cancer cases including 90-530 deaths	\$30 to \$140 million

Source: Abstracted from [19].
[a]Estimated economic consequence includes estimated health care costs, value of absence from work, and value of productivity decreases at work when health effect is experienced.

By improving IAQ, the potential number of workers who could experience better health is between 29 and 81 million. The total potential savings from SBS-related health care costs, absences from work, and productivity losses is between \$7 and \$70 billion. Given the fact that worker salaries exceed building energy and maintenance costs by a factor of approximately 100, even a 1% increase in productivity would be sufficient to justify an expenditure to a doubling of energy or maintenance costs and improvements to IAQ [18]. Epidemiological studies have shown that the best method for reducing SBS is by improving IAQ as a consequence of controlling outdoor air ventilation rates.

3.2 Ventilation Rates and Energy Costs

The conditioning (heating, cooling, dehumidifying, or humidifying) of outdoor air consumes about 30% or more of the annual heating and cooling cost [20]. Most HVAC systems utilize fixed ventilation rates. During periods of low occupancy, however, excess conditioning of outdoor air results in over-ventilation and thus, wasted energy. Figure 1 shows the fixed ventilation as the upper line (100% outdoor air) and the rising and falling plateaus as the needed (and also lower) ventilation rate based on variations in occupancy. The potential energy savings is the difference between the fixed rate and actual ventilation rate needed.

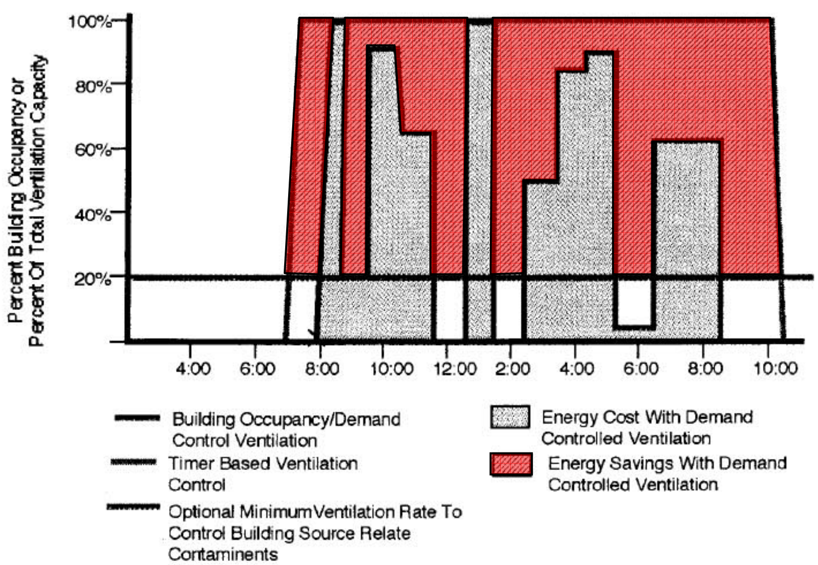

Figure 1. Opportunity for energy savings in a classroom. Source [21].

3.3 Computer Modeling

Air flow simulation models, such as CONTAM [4], can be used, in conjunction with energy analysis models, to analyze HVAC system operation with regards to equipment response, energy usage, and IAQ. As ventilation rates are varied in the model, changes in the IAQ parameters can be clearly seen [5]. Furthermore, charts such as that in Figure 1 can be produced from the results of the simulation, indicating potential energy savings from particular ventilation strategies. The following sections focus on one type of ventilation strategy, the carbon-dioxide based demand controlled ventilation (DCV) system.

3.4 CO_2-Based Demand Controlled Ventilation Systems

Standards for minimum outdoor air ventilation rates seek to ensure acceptable IAQ. In the past, these standards were based on design occupancy levels, thus, providing a minimum amount of outdoor air per person. However, because occupancy rates actually vary throughout the day, the ventilation rate is often in excess, thereby increasing energy costs. To account for variable occupancy rates, DCV systems have been developed. While occupancy schedules and particle and occupancy sensors have been employed to control such systems, CO_2-based systems have proven to be relatively flexible and affordable. Because CO_2 levels can be directly related to the number of occupants, a CO_2-based DCV system adjusts outdoor air ventilation rates based on measured CO_2 levels, thereby supplying the necessary ventilation per person. This saves energy because we reduce the amount of excess ventilation air that is normally unnecessarily conditioned.

One reason CO_2 is used as an occupancy indicator is all humans generate CO_2 at a predictable rate, given occupant age and activity level [22]. Therefore, by measuring CO_2 concentration in a space, a mass balance relationship can be used to determine the outdoor air ventilation rate per person required to maintain acceptable IAQ. Whereas ventilation rates for fixed-rate ventilation systems are based on relatively constant CO_2 generation rates, i.e., constant occupancy rate and activity level, CO_2-based DCV systems utilize changing CO_2 levels (actual changes in occupancy and activity level) to adjust ventilation rates.

In addition to the energy savings and improvements to IAQ mentioned above, benefits of implementing a CO_2-based DCV system also include [23]:

- In buildings where infiltration air or open windows are a significant source of outdoor air, CO_2 sensors are more accurate indicators of the ventilation air that is needed. A system utilizing fixed ventilation rates may not be able to account for these sources of outdoor air, as they vary with seasons, occupant habits, and aging building envelopes.
- Where CO_2 levels differ among building zones, information from sensors has the potential to control a ventilation system to redirect more ventilation air to critical spaces, leaving the remaining spaces at lower ventilation rates.
- A CO_2 control strategy can be used to maintain any per-person ventilation rate. As a result, this approach is highly adaptable to changing building uses and to possible changes to standards governing recommended ventilation rates.

3.5 Sensors

The performance of a CO_2-based DCV system relies on the accuracy of the CO_2 sensors used. Shortcomings of currently available sensors include time-consuming calibration processes, sensitivity to humidity, and cross-sensitivity to voltage, temperature and tobacco smoke [24]. Furthermore, appropriate locations must take into account nonuniformities in air distribution; air samples taken should reflect occupancy levels as accurately as possible. See also reference [25] for a performance report on a particular manufacturer's CO_2 sensors. This report emphasizes the importance of improved sensing technologies to the success of sensor-based ventilation systems.

Identifying the quantity and location of sensors is also a difficult task. For instance, buildings with multiple zones and only one ventilation system choose either: (1) a single sensor sampling the average of all the spaces, or (2) numerous sensors, preferably one in each zone, collecting multiple readings of pollutant concentrations. The former approach cannot ensure target per person ventilation rates in all of the spaces because some zones may have higher or lower pollutant concentrations than the averaged value of all the zones. On the other hand, the latter approach ensures that the critical zone, i.e., that with the highest pollutant concentration, receives adequate ventilation. However, this results in over-ventilation in the remaining zones, and thus wastes energy [23]. One can see that discussing the questions of "Can anyone design it?" (§2.1.2) and "Will this work" are legitimate ones to ask.

Furthermore, the BAS can combine basic data from sensors, such as that on temperature, humidity, and pollutant concentration, with information about a tenant's clothing and physical activity in order to determine the appropriate ventilation rate [26]. Honeywell has incorporated measurements of IAQ and thermal comfort in their assessment of the indoor environment (Figure 2).

3.6 Future Research

Since CO_2 is only thought of as a surrogate for other occupant-generated pollutants, future research should consider, in addition to the use of CO_2 sensors, the use of sensors for non-occupant generated pollutants. Using only CO_2 sensors to control ventilation rates may not be able to account for elevated levels of non-occupant related pollutants [20, 27].

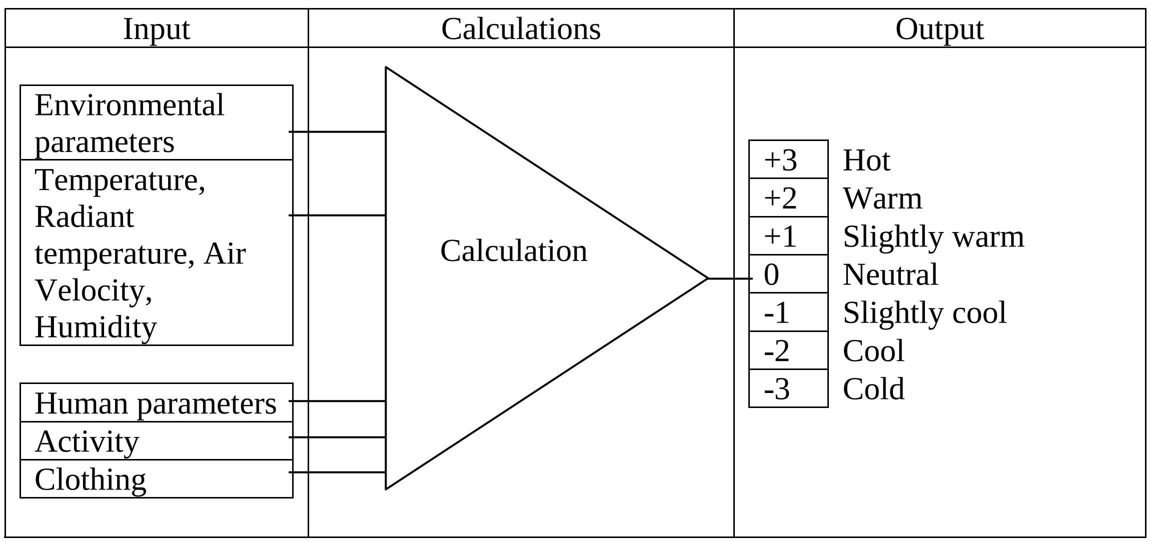

Figure 2. Control algorithm accounting for both IAQ and measures of thermal comfort. Source [26].

4.0 Conclusion

The goals of this paper were to formulate a personal definition of what an intelligent building is and also to develop one aspect in depth. My final understanding of an intelligent building was presented in §2.1. I then expounded on the key concepts found in my definition in §2.1.1 to §2.1.7, with the final section on *Health* being the topic I chose for this final assignment.

The widespread occurrence, adverse health effects, and economic impact of SBS were discussed. By improving IAQ, the potential number of workers who could experience better health is between 29 and 81 million and the total potential savings in reduced health care costs, absences from work, and productivity losses falls between \$7 and \$70 billion. The best method for improving IAQ, and thus reducing the prevalence of SBS symptoms, is by controlling outdoor air ventilation rates, i.e., diluting indoor pollutant levels. Studies have shown that as the ventilation rate is increased, the occurrence of SBS symptoms decreases in a dose-response relationship. By utilizing sensors and the BAS, the intelligent building can regulate the ventilation rates as required, thus, improving occupant health.

Ventilation rates need not remain constant throughout the day since the number of occupants, those affected by IAQ, does not remain constant. Strategies for modulating outdoor air ventilation rates according to actual occupancy have shown to decrease energy costs without sacrificing IAQ. Carbon dioxide-based DCV systems use measured CO_2 concentrations to determine appropriate per-person ventilation rates. These systems are flexible, adaptable, and cost effective, and are only one example of how the intelligent building will make a significant impact on the building industry and improve the quality of lives for its occupants.

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