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Relationships Between the Indoor Environment and Productivity: A Literature Review

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ABSTRACT

Results of studies assessing the relationship between indoor environmental quality and productivity are often divergent. Additionally, these results provide little direction to design and construction professionals for achieving environmental quality that supports occupant performance and productivity. The objective of this literature review was to identify commonly used measures of productivity and their links with factors in the indoor environment related to HVAC system performance.

This literature search identified 262 references, 53 of which were found to be relevant in addressing these issues. As a means to analyzing the results reported in the literature, measures of productivity were classified in terms of traditional and nontraditional figures of merit (FOMs). It was found that office environments are the primary focus of current research and that most studies do not address the wide range of factors that may influence productivity. Additionally, contradicting results were found regarding the relationship between human responses, occupant performance, and productivity.

It is concluded from these results that FOMs can be standardized for specific building functional categories (BFCs) but that site-specific modifications may be needed. To identify FOMs that are measurable and controllable, it is important to identify links between occupant performance and productivity and a set of factors including systems, exposures, and human responses. It is recommended that future research focus on defining reliable and valid FOMs, standardizing FOMs for each BFC, and clarifying the links in human responses, occupant performance, and productivity.

INTRODUCTION

Professionals who design, build, and operate buildings, health experts, and building occupants agree there is a link between the quality of the indoor environment and the "productivity" that can be achieved within it. However, there is no consensus on the definition of productivity or on the specific factors in the indoor environment that influence productivity. Correlations between the indoor environment and productivity have not yet been adequately quantified for existing practice or for advanced control strategies.

The objective of this study was to conduct a review of current literature in order to identify commonly used measures of occupant performance and productivity and corresponding factors in the indoor environment related to HVAC system performance. Thus, this paper assesses the reported impacts of heating and cooling systems, ventilation strategies, control systems, and the resulting thermal and air quality conditions on occupant performance and productivity. This paper first presents a set of critical issues to be addressed. Second, it describes three theoretical concepts that were used to develop the methodology for the literature review. Third, it describes the review methodology. Fourth, it discusses the results. Fifth, it presents conclusions, and sixth, it recommends topics for future research.

CRITICAL ISSUES

Evidence from investigations of problematic buildings suggests that when occupants are exposed to environmental conditions that result in illness or discomfort, not only is their health at risk, but unnecessary costs may be incurred (Woods 1989; Lippiatt and Weber 1992). Criteria specified in current ASHRAE standards are based on the assumption that it is practically impossible to provide environmental control that will satisfy all occupants. Thus, these criteria are based on an 80% acceptability criterion (ASHRAE 1992, 1989). However, the potential impacts of lost productivity by occupants who work in environments that have been designed and operated in accordance with this criterion have not yet been adequately quantified.

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Two primary questions were the focus of this literature review: (1) What is known about the effects of existing practice on productivity? (2) What is known about the potential increases in productivity that can be provided by advanced systems and controls?

In order to identify the effects of existing practice on productivity, two of three critical issues have been addressed:

- Issue No. 1: How is occupant performance and productivity in nonindustrial environments defined and measured?
- Issue No. 2: What are the factors that influence occupant performance and productivity in nonindustrial environments?

A third issue, "What is known regarding the impact of environmental control on exposure, human response, occupant performance, and productivity?" has been addressed in combination with issue No. 2, as only those studies that assessed occupant performance and productivity along with human responses and exposures were included in the literature search. Consequently, the search was not exhaustive for exposure and human response.

CONCEPTUAL BACKGROUND

Three concepts formed the basis for the development of the methodology for the literature review, including the identification of keywords and selection of databases. First, the building life-cycle model of procurement and operations emphasizes the need to assess the impacts of decisions made at each stage of a building's life-cycle on occupant performance and productivity. Second, the concept of continuous degradation and its consequences is the basis for including buildings at different levels of degradation. Third, a Model of Rational System Relationships was used as the framework for a scheme to categorize productivity measures and influencing factors. This model illustrates the conceptual relationship between sources, building systems, exposures, human responses, and economics (including productivity).

Building Life-Cycle Model of Procurement and Operation

The four stages of a building's life-cycle are: (1) the preconstruction period, including planning and conceptual design as well as detailed design; (2) the construction period, including commissioning; (3) long-term occupancy and use; and (4) adaptive re-use and eventual demolition (BRB 1985). This literature review includes system parameters that may be critical at each stage of a building's life-cycle, as decisions made at each stage can potentially impact occupant performance and productivity during the operations phase.

Continuous Degradation and Its Consequences

From the concept of continuous degradation (Woods 1989), it has been estimated that 50% - 70% of the stock of nonindustrial buildings may qualify as "healthy" buildings, characterized in terms of acceptable human responses, system performance, and economic performance including productivity. Proactive programs of quality assurance and control, beginning with the planning and design of buildings, and continuing throughout their lifetimes, can be expected to achieve and maintain the "healthy building" status. However, the health of buildings can be expected to degrade if these programs are not adequately implemented. Three levels of degradation have been postulated:

1. *First level of degradation:* ***Ten to twenty percent of the existing building stock can be characterized as buildings with "undetected problems" resulting from human responses, system performance, or service factors that are only marginally acceptable.*** Typically, mitigation takes the form of improved maintenance, housekeeping, control calibration, and system balances. At this level, these procedures do not usually require capital outlay and can be accomplished with minimal disturbance to the function of the occupied spaces.
2. *Second level of degradation:* ***Ten to twenty-five percent of the existing building stock can be characterized as buildings that manifest the Sick Building Syndrome (SBS).*** These are buildings in which the frequency of complaints of SBS symptoms exceeds 20% - 30%; symptoms persist for at least two weeks and are alleviated upon leaving the building. Mitigation for this level is usually more complex and costly. Technical modifications requiring capital outlay and consultants to measure and analyze human responses, exposures, and system performance may all be needed. Significant social, medical, and legal costs may also accrue.
3. *Third level of degradation:* ***Five to ten percent of the existing building stock can be characterized as buildings that manifest building-related illness (BRI) (BRB 1987).*** These are buildings in which the development of frank illness,[1] linked to indoor exposures, is evident in more than one occupant. Mitigation requires the identification of the source of the illness, may involve redesign and reconstruction, and subsequently requires rigorous testing and evaluation to provide assurance that the building is "safe" to reuse. Considerable costs are associated with system modifications, as well as medical and legal costs.

This concept was framed for the existing building stock. However, it is useful in defining productivity measures applicable to a building at each stage in its life-cycle, as it is possible to assess the implications on occupant performance and productivity of noncompliance, marginal compliance, or full compliance with criteria prescribed in current standards. Also, as interventions to system parameters differ for each level of degradation, this concept underscores the importance of

[1] Frank illness is one that has been diagnosed using standard medical practice.

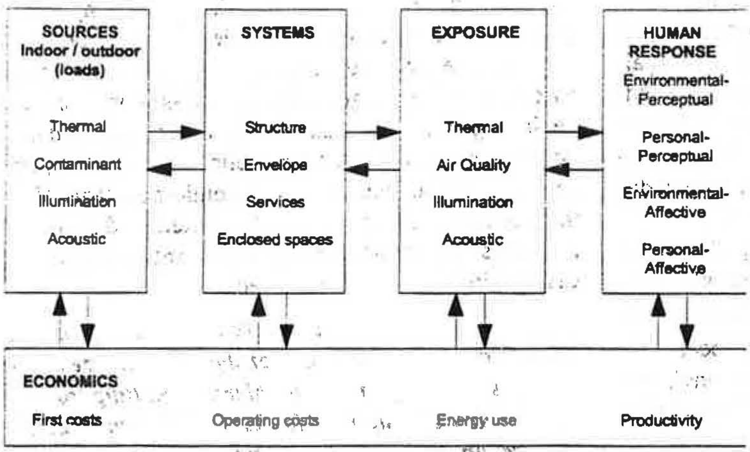

Figure 1 *Rational model of system relationships (Woods et al. 1993).*

operations and maintenance costs, energy costs, and productivity are included in conducting a life-cycle cost analysis to enable a choice between alternative systems.

Based on this rational model, it is possible to translate human response parameters to exposure parameters, which can then be translated into system parameters for use in the design and control of building systems. Changes in systems and controls may then be linked to changes in exposures, human responses, and performance and productivity. As shown in Figure 1, human responses and productivity are directly linked. The model, therefore, provides a framework for (1) distinguishing between measures of human responses and performance and productivity, (2) assessing links between these two factors, and (3) assessing links between diverse system interventions and productivity.

Model of Rational System Relationships

A rational model (see Figure 1) illustrates the conceptual relationship between human responses, exposures, systems, sources, and economics, including productivity (Woods et al. 1993). The links shown in the model are based on a classical epidemiological model enriched by an economic platform. Human responses to indoor environmental exposures are expressed in terms of four human response domains: environmental-perceptual, personal-perceptual, environmental-affective, and personal-affective (Sensharma et al. 1993). These responses result from exposures of the primary physiological receptors that sense four primary environmental stressors: thermal, air quality, illumination, and acoustic. The role of building systems is to provide acceptable exposures by responding to loads (thermal, contaminant, illumination, and acoustic) that accrue from indoor and outdoor sources. Economic implications of these interactions are critical to the acceptable design and operation of these systems. First costs, assessing the chain of linkages between system parameters, exposures, human responses, and performance and productivity.

METHODOLOGY

Preliminary work on the literature review was based on literature available in the library of the investigators. The pertinent references found through this search came primarily from conference proceedings, ASHRAE publications, the reference list generated at the ASHRAE productivity workshop in June 1992, newsletters related to indoor air quality, and other related publications and material. From these references, a preliminary keyword list was generated for the purpose of conducting a systematic and extensive literature search. In Table 1, these keywords are shown in terms of: measures of productivity and human responses, system parameters, exposure parameters, economic parameters, and building functional categories (BFCs). Nine BFCs were identified as follows: mercantile sales/services, offices, public assembly, health care, food sales / services, residential, lodging, educational, and warehouses (OSHA 1994).

TABLE 1
List of Keywords for Productivity Literature Search

Categories	Selected Keywords
Measures of Productivity (including human responses)	Productivity, performance, human response, comfort, acceptability, assenteeism
System Parameters	HVAC systems, air systems, ventilation systems, systems, control
Exposure Parameters	Indoor air quality, indoor environment, work environment, thermal environment, human exposure, environmental temperature, acoustic, lighting, personal
Economic Parameters	Cost, economics
Building Functional Categories	Health care facilities, hospitals, office buildings, schools, educational buildings, lodging facilities, restaurants, retails stores, clothing stores, department stores, public assembly buildings, theaters, auditoriums, multi-family housing, institutional facilities, prisons, jails

For the literature search that was conducted using computerized databases, the keywords were linked with Boolean algebra modifiers ("and," "or," "not") to form sets of keywords for searching. Several databases were searched including ASHRAE, The Science Citation Index, National Technical Information Service (NTIS), INSPEC, Enviroline, Pollution Abstracts, The Engineering Index COMPENDEX PLUS, Environmental Bibliography, and DIALOG.

The critical issues and the list of keywords were used to develop a literature classification scheme. The input sheets based on this classification scheme required the investigators to ask several questions as they reviewed an article for its relevance. The classification scheme and the input sheet are included as Appendix A. Information from the input sheets was entered into two computer programs. Information about the articles, such as title, author, publication, and year, was entered into a bibliographic computer program, and each article was assigned a reference number. Information about the contents of the references was entered into a relational database computer program. The title, author, year, and reference number were used as a link between the two programs. The database program was then queried to obtain the relevant information for this study. As shown in Table 2, combinations of items from the input sheets were used as deemed relevant for each critical issue.

RESULTS

The literature search yielded a total of 262 references. These references were then searched for contents that related

TABLE 2
Critical Search Issues: Combination of Items and Resulting Numbers of Reference

Issues	Combination of Issues	# References
Issue No. 1: Definition of Productivity (FOMs)	Traditional FOMs: 1 + 2 + 3 + 4 (including T or B or O)[a] + 8 (not including N)	9
	Nontraditional FOMs: 1 + 2 + 3 + 4 (including F[b] or B or O) + 8 (not including N)	11
Issue No. 2: Influencing Factors	HVAC System Performance: 1 + 2 + 3 + 4 (not including N) + 8 (not including N) + 11 (not including N)	11
	O & M Procedures: 1 + 2 + 3 + 4 (not including N) + 8 (not including N) + 11 (not including N)	0
	Exogenous Factors: 1 + 2 + 3 + 4 (not including N) + 8 (not including N) + 13 (not including N)	10
	Age of Building: 1 + 2 + 3 + 4 (not including N) + 8 (not including N) + 10 (including D or B)	7
	Age of System: 1 + 2 + 3 + 4 (not including N) + 7 + 8 (not including N) + 10 (including S or B)	1
	Exposures (stressors): 1 + 2 + 3 + 4 (not including N) + 7 + 8 (not including N) + 12 (not including N) 1 + 2 + 3 + 4 not including N) + 7 + 8 (not including N) + 14 (not including N)	14
	Occupant Type (i.e. exposure time) and Phases of Building Life-Cycle: 1 + 2 + 3 + 4 (not including N) + 8 (not including N) + 6 (not including N) + 7 (not including N)	11
	Codes and Standards: 1 + 2 (including C or S) + 3 + 4 (not including N) + 8 (not including N)	5
	Building Functional Category: 1 + 2 + 3 + 4 (not including N) + 8 (not including N) + 5 (not including N)	16

a. Explanation to uppercase letters in parentheses are found in the literature input sheet.

b. The terms "task based" and "FOM" are based on an earlier version of the nomenclature used to define measures of productivity. For the purpose of this paper, "task based" refers to traditional FOMs, and "FOM" refers to nontraditional FOMs.

to the critical issues, resulting in the selection of 53 of the most relevant references. A reference list, including the 262 references, and an annotated bibliography of the 53 most critical references was then compiled. This paper reviews references that are related to two of the three critical issues identified earlier. The number of references identified for each critical issue is also identified in Table 2. Each issue is discussed in relation to reports of empirical studies (including laboratory and field). Then, results of empirical studies are discussed in relation to literature that can be described as theoretical.

Issue One: How Is Productivity Measured in Nonindustrial Environments?

In the literature pertaining to nonindustrial environments, measures of human response have often been confounded with measures of occupant performance or productivity. Goldman (1994) notes that a comfortable state may not be stimulating enough to produce the best performance. Wyon (1993) also reports that empirical evidence related to several studies, including one that assessed the impacts of thermal conditions on typewriting performance, tends to invalidate the usual assumption that performance can be deduced from thermal comfort. Thus, for purposes of this literature review, measures of occupant performance and productivity are referred to as figures of merit (FOMs), whereas measures of comfort, dissatisfaction, and other perceptual or affective responses are considered as measures of human response. We have defined an FOM as *a measurable and controllable parameter that is expressed in terms of occupant performance or productivity related to the function provided in the occupied space*. Examples of FOMs describing occupant performance are "the time taken to process a file" or "absentee rates" (e.g., Kroner et al. 1992). An example of an FOM that describes productivity is the "productivity impact factor" (PIF), defined as a "break-even value" and calculated as a ratio of the expected savings resulting from an intervention compared with the cost at risk (Woods 1989).

Based on a review of the literature, two types of FOMs have been identified: traditional and nontraditional, as shown in Table 3. Traditional FOMs have been defined as task-based measures of output. For this review, traditional FOMs have been characterized in terms of: (1) quantity, (2) quality, and (3) quality and quantity of work output (Drucker 1991). Nontraditional FOMs include parameters other than those measuring output and have been described primarily in terms of (1) absence from work and (2) self-reported productivity. For office environments, other nontraditional FOMs include voluntary extra work and psychological tests.

Traditional and nontraditional FOMs were identified for three of the nine BFCs identified in the literature: offices, educational facilities, and health care facilities. No empirical studies were found that reported FOMs for the other six BFCs: mercantile sales / services, food sales / services, public assembly, residential, lodging, or warehouse facilities. FOMs identified for each of the three BFCs have been categorized as shown in Table 3.

Although industrial facilities were not included in the literature review, five references were identified and are used in the discussion to compare measures of productivity in industrial and nonindustrial environments. These studies refer to measures such as "reduction in accident rates" in assembly plants (Schweisheimer 1962), absenteeism (Schweisheimer 1962; Link and Pepler 1970; Pepler 1973), and worker output rate in terms of the number of hours worked on piecework, number of dozens of articles worked on, and total wage (Link and Pepler 1970).

Office Facilities

Traditional FOMs. More literature was found for FOMs related to office environments than for the other BFCs. The focus on office environments may be linked to the current recognition of the need for different measures of productivity for industrial vs. nonindustrial work environments (i.e., offices), e.g., Drucker (1991) and Aronoff and Kaplan (1995). Quantity and quality of work can be considered traditional FOMs. Quantity is assessed when tasks are defined in terms of discrete actions, such as the amount of filing or data entry. Quality is assessed in terms of the number of errors made in completing a task. A combination of quality and quantity is assessed when speed of work and rate of errors are both factored into the FOM measure.

Measures of costs and benefits also conform to the traditional input-output productivity framework. Although none of the empirical studies reviewed included measures of costs and benefits, Wyon (1993) lists a variety of potential measures, identified at an ASHRAE workshop in Baltimore in September 1992, which include cost-related FOMs such as health costs (including sick leave, accidents, injuries), total unit cost per product or service, insurance reimbursements, worker's compensation or litigation settlements, and costs per square feet of floor area.

Nontraditional FOMs. Absence from work and self-reported productivity are the primary FOMs used in the current literature. Discrete tasks often cannot be defined for "knowledge work," i.e., "tasks that require information to be created, analyzed, evaluated, or acted upon (Aronoff and Kaplan 1995, p.14)." Currently, absence from work has been assessed either in terms of absenteeism due to all causes, or in terms of "sick leave" (e.g., Kroner et al. 1992; Preller et al. 1990; Sterling and Sterling 1983; and Woods 1989). However, it has been suggested that factors such as time actually spent at the workstation (Becker 1985) or time spent away from the work location on days present (EPA 1989) should also be included in the assessment of absence from work. Wyon (1993) proposes additional FOM measures, such as unavailability on the telephone, observed downtime, and interruptions.

Self-assessments of productivity, also considered in this literature review as nontraditional, have been used in several studies (e.g., Hall et al. 1991; H. Technalysis 1985; Woods et al. 1987; Raw et al. 1990) but have been operationalized[2] differently for different studies. Most of the studies reviewed

TABLE 3
Examples of Traditional and Nontraditional FOMs

Traditional FOMs	Nontraditional FOMs
Educational Facilities	**Educational Facilities**
Quantity + Quality • High schools: test scores on ore-tests and post-tests (McNall and Nevins 1967) • Fourth, fifth and sixth grade: scores on diverse learning tasks representative of learning in schools (Schoer and Shaffran 1973)	Absenteeism • Primary schools: general absenteeism and absenteeisms due to colds (Green 1974) Self-reported productivity • Colleges: Faculty: impact on noise, distractions, or interruptions on: ability to do work requiring concentration, length of time spent in office, length of time taken to complete task (Becker et al. 1983) • Colleges: students: availability to faculty for meetings, faculty attitude (Becker et al. 1983)
Health Care	**Health Care**
Quantity (Woods et al. 1981) • Time required / person to complete task • Average time for measured sequence of tasks	Self-reported productivity (Woods et al. 1981) • Impact of indoor conditions on work • Work completed at this time • Work completed today
Offices	**Offices**
Quantity of work • $P_{ijt} = \Sigma_k W_{jk} N_{ijt}/H_{ijt}$[a] (Kronter et al. 1992) • Time to process a file/worker/week (Kroner et al. 1992, Kroner and Stark-Martin 1994) • Number of checks entered/worker (Kroner et al. 1992) • Daily contribution of worker to increases in data entry system file size (Zyla-Wisendale and Stolwijk 1990) Quantity + Quality • Typewriting scores (diminished by one point for each error) (Zyla-Wisendale and Stolwijk 1990) • Sentence comprehension, multiplication, work memory, cue utilization, spelling, vocabulary, creativity, manual dexterity (Wyon et al. 1979) Quality • Average number of mistakes/subject/hour (Berglund et al. 1990)	Absence from work • Normative absentee rates (Kroner et al. 1992) • No. of days of sick leave (total and due to SBS symptoms) (Preller et al. 1990) • Absenteeism (general) (Preller et al. 1990; Sterling and Sterling 1983, Woods et al. 1989) Self-reported productivity • Self-assessment of physical environment on productivity (Burge et al. 1987) • How frequently symptoms reduced ability to work (Hall et al. 1991) • How frequently symptoms caused occupants to leave early/stay home (Hall et al. 1991) • Impact of symptoms on productivity (Hedge et al. 1993) • Determinants of a "productive workplace" (Technalysis. 1985; Woods et al. 1987) • Difficulty doing work because of air quality (Technalysis. 1985; Woods et al. 1987) • Assessment of the % influence of physical environment on productivity (WEP) (Raw et al. 1990) • Difference between individual WEP and mean WEP for building (Raw et al. 1990) Other • Voluntary overtime or extra work Psycho-motor steadiness (or tremor) test, visual-cognitive coordination (t-crossing) test (Sterlin and Sterling 1983)

[a] I = worker, j = department, k = task, P_{ijt} = productivity of worker "I" in department "j" in week "t", W_{jk} = weight given to task type "k" in department "j", N_{ijkt} = No. of type "k" tasks completed by worker in department "j" in week "t" and H_{ijt} = hours worked by worker "I" in department "j" in week "t".

here require subjects to make judgments about the role of the physical indoor environment on their productivity (e.g., H. Technalysis 1985; Hall et al. 1991). Such measures require the subjects to make two types of judgments: (1) judgments about their productivity and (2) judgments about the contribution of the indoor environment to their productivity.

Educational Facilities

Because learning, the primary objective of educational facilities, is widely assessed by testing, test scores can be considered as traditional FOMs that deal with the "output" expected in an educational setting. Two studies (McNall and Nevins 1967; Schoer and Shaffran 1973) compared pre- and post-test scores to assess the impact of varying selected environmental parameters.

Absenteeism, operationalized either as general absenteeism or absenteeism due to colds, was the FOM used in two studies (Green 1974, 1985).[2] Self-reported productivity was assessed in that study for faculty offices within three college settings (Becker et al. 1983). Measures of self-reported productivity were not identified for classroom environments.

Health Care Facilities

One empirical study conducted in a health care facility used both traditional and nontraditional FOMs (Woods et al.1981). However, as this study was conducted in the laundry room of a hospital, the traditional FOMs could be structured in terms of output, much like measures of productivity defined for industrial environments. Self-reported productivity was assessed in this study in terms of the subjects' judgments about the amount of work completed and amount of work to be done compared with the usual quantity of work.

SUMMARY OF OBSERVATIONS FOR ISSUE NO. 1

- Current research on nonindustrial productivity has focused primarily on the assessment of productivity in office facilities. One of the studies included under the category of health care facilities can be more appropriately classified as an industrial facility (Woods et al. 1981) and one included under the category of educational facilities is more appropriately classified as an office facility (Becker et al. 1983).
- Traditional FOMs can be defined for certain types of tasks in office environments. Two large-scale field studies (Kroner et al. 1992; Kroner and Stark-Martin 1994; Zyla-Wisendale and Stolwijk 1990) have used traditional FOMs dealing mainly with the quantity of work. Studies in educational facilities have also used traditional FOMs, such as test scores. Traditional FOMs have not yet been adequately developed for the other BFCs.
- Absenteeism is widely used in industrial and nonindustrial facilities as a measure of productivity. However, it has been operationalized differently for different studies. It is possible that this FOM may not be sensitive to changes in the physical environment if factors such as time spent away from the work station are not accounted for. Absenteeism may be even more difficult to operationalize for work that does not require the occupants' presence at their desks.
- Self-reported productivity is the widely used FOM in office facilities, including faculty offices in three educational facilities (Becker et al. 1983), and has been reported in one study in the laundry room of a health care facility (Woods et al. 1981). Measures of self-reported productivity have not yet been standardized or widely tested for their reliability[3] and validity.[4] As noted above, most studies using this measure, may confound two types of judgments required by the occupant: judgments about productivity and the influence of the physical environment on productivity.
- None of the studies included in this literature review report on the validity of the FOM measures selected to assess occupant performance and productivity. FOMs such as absenteeism can be expected to be useful indicators of occupant performance and productivity for all BFCs. As noted in the preceding discussion, standardization of FOMs for specific BFCs is possible, although site-specific modifications may be needed.
- FOMs have not yet been developed for six of the nine BFCs identified earlier. It is also important to note that other functional categories may be nested within each of the nine BFCs. Thus, almost all BFCs can be expected to include office areas.

ISSUE TWO: WHAT ARE THE FACTORS THAT INFLUENCE PERFORMANCE AND PRODUCTIVITY IN NONINDUSTRIAL WORK ENVIRONMENTS?

To address this issue, a classification of factors that influence occupant performance and productivity has been developed (see Figure 2) based on the rational model presented in Figure 1. HVAC system performance is linked to exposures (thermal, air quality, and acoustic), human responses (perceptual and affective), occupant performance, and productivity. It may therefore be possible to assess the indirect impacts of HVAC system performance on occupant performance and productivity by assessing links between productivity and human responses or exposures. The references deemed to be

2. Operationalization is "the process of devising steps or operations for measuring what we want to study" (Babbie 1989, p.77).

3. Reliability is "a matter of whether a particular technique, applied repeatedly to the same object would yield the results each time" (Babbie 1989, p.121).

4. Validity refers to "the extent to which an empirical measure adequately reflects the real meaning of the concept under consideration" (Babbie 1989, p.124). Face validity, predictive validity, content validity, and construct validity are the four types of validity defined by Babbie (1989).

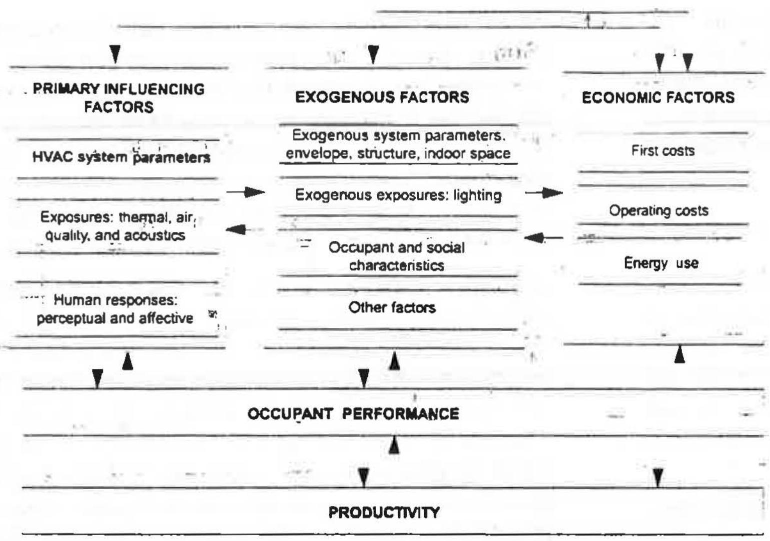

Figure 2 *Classification of factors influencing productivity.*

most relevant to the two critical issues were reviewed to identify those that assessed productivity in terms of traditional or nontraditional FOMs and HVAC system parameters. As shown in Table 4, 20 references reporting on empirical studies (laboratory and field) were found to be most appropriate for examining issue No. 2. The influence of the following factors on productivity was assessed: (1) system parameters, including HVAC system performance, operations and maintenance procedures, age of building or HVAC system, and codes and standards; (2) exposure parameters assessed in terms of three stressors, including thermal, air quality, and acoustics; and (3) human responses, including each of the four domains (Sensharma et al. 1993). In addition to these factors, exogenous factors, i.e., factors other than the ones being assessed, were also identified from the literature (Rossi and Freeman 1989). These include the following: (1) exogenous-system parameters, such as the envelope, structure, other services, and the interior space; (2) exogenous exposure parameters, such as lighting; (3) occupant characteristics, such as age, gender, and other personality factors; (4) characteristics of the social environment, such as the quality of supervision and leadership; and (5) other exogenous factors. Economic factors influence the primary and exogenous factors and thus indirectly influence occupant performance. Although productivity is directly influenced by building-related economic factors, they are not the focus of this review. Table 4 summarizes these findings.

System Parameters: HVAC System Performance

Information on the impact of HVAC system capacity at design load and controllability for part loads was examined. As shown in Table 4, there were several references in which HVAC systems were mentioned or identified, but specifics regarding capacity and controllability were not found in the reviewed literature.

Impact on Absenteeism. Several studies have assessed the influence of system parameters on measures of absenteeism. Spray humidification was linked to a greater incidence of sick leave in a survey of 61 office environments in the Netherlands (Preller et al. 1990). However, that study found no influence of type of ventilation (i.e., natural or mechanical) or the use of recirculated air on absenteeism (general or sick leave). Absenteeism was also found to be higher in a mechanically ventilated building vs. a naturally ventilated building in a study conducted in two office environments (Sterling and Sterling 1983). In comparison, a study assessing the influence of air conditioning on industrial work in an apparel factory found no conclusive link between absenteeism or quantity of work and thermal conditions in air-conditioned vs. non-air-conditioned spaces (Pepler 1973). That study identified an exogenous factor, "attitude" or "motivation," that may have contributed to this finding. Finally, Hedge et al. (1993) report that installation of a breathing zone filtration (BZF) system[5] reduced "certified sickness rates" in an office environment.

Impact on Quantity of Work. Quantity of work was assessed in three studies. One study conducted in an office facility (Zyla-Wisendale and Stolwijk 1990) found that increased distance from a "supply or return vent" was directly related to increased productivity, assessed in terms of the quantity of work (i.e., increases to database). In that study, proximity to different orientations of walls was also examined but could not be conclusively linked to productivity. In another study, an increase in the quantity of work (number of files processed) was found and related to "environmentally responsive workstations" (ERWs) (Kroner et al. 1992; Kroner and Stark-Martin 1994). That study computed net changes in productivity associated with ERWs by considering changes in FOMs associated with a move from an old to a new building (equipped with ERWs) and changes in FOMs associated with randomly disabling ERWs. It was noted that in addition to ERWs, changes in productivity may also have been influenced by exogenous factors such as loss of personal control.

Impact on Quality and Quantity of Work. Only two studies related a measure of quality plus quantity to system parameters. Both were conducted in educational facilities (classrooms). Results indicated that air conditioning influenced complex learning tasks but not simple learning tasks (Schoer and Shaffran 1973). The other study (McNall and Nevins 1967) concluded that there were strong, non-statistically significant trends in academic achievement (assessed in terms of test scores and teachers' marks on recitation) that favored the climate-controlled school. However, possible

[5] A BZF system draws aged office air into the filtration system at work surface height and supplies filtered air above head level at an adjustable rate (Hedge 1993, p. 383).

TABLE 4
Factors Influencing Productivity: Summary of Findings

References	FOMs	Syst.	Exp.	Hum. Resp.	Exogenous Factors				
					Syst.	Exp.	Occ.	Soc.	Other
Schoer and Shaffran 1973	T[a] (qual. + quant.)	■	■						
Preller et al. 1990	NT[a] (absenteeism)	■				■	■	■	■
Dorgan 1993	T (cost) and NT (absenteeism)	■	■	■					
Green 1974	NT (absenteeism)		■				■		
Pepler 1973	T (other) NT (absenteeism)		■				■		
Zyla-Wisendale and Stolwijk 1990	T (quant.)	■				■			
Sterling and Sterling 1983	NT (absenteeism) T (other)	■		■			■	■	■
Kroner et al. 1994; Kroner and Stark-Martin 1992	T (quant.)	■		■				■	■
Technalysis 1985, Woods et al. 1987	NT (self-reported -1)[b] NT (self-reported -2)[c]	■	■	■	■ ■	■ ■	■	■	■ ■
Raw et al. 1990	NT (self-reported)			■			■	■	■
Woods et al. 1981	T (quant.) NT (self-reported)		■ ■						■
Arora and Woods 1992	T (absenteeism and costs)	■		■					
McNall and Nevins 1967	T (qual. + quant.)	■	■						
Hedge et al. 1993	NT (absenteeism and self-reported)	■	■	■					
Berglund et al. 1990	T (qual.)		■	■					
Wyon et al. 1979	T (qual. + quant.)		■						
Wyon 1974	T (qual. + quant.)		■						
Hall et al. 1991	NT (self-reported)			■			■	■	■

[a] T = traditional FOM, NT = nontraditional FOM.
[b] Self-reported productivity assessed as subjects' assessment of environmental contribution to productivity.
[c] Self-reported productivity assessed to reports of difficulty working due to IAQ.

exogenous factors contributing to this result were not adequately assessed.

Impact on Self-Reported Productivity. One study assessed the relationship between self-assessment of productivity (i.e., the number of people who often or sometimes reported difficulty doing work because of air quality in the office or area) and the type of air-distribution system (H. Technalysis 1985; Woods et al. 1987). In that study, 13% of people working in areas served by constant air volume (CAV) systems, 24% of people working in areas served by variable air volume (VAV) systems, and 30% of people working in areas served by "off-on" systems believed that air quality hampered their work.

Impact on Other Productivity Measures. One reference (Dorgan 1993) was a broad-based summary of productivity (defined in terms of FOMs such as increases in work time, reductions in absenteeism, reductions in health and medical costs, daily illness, and comfort), which concluded that if the requirements of *ANSI/ASHRAE Standard 62-1989* were met or exceeded and if space control was improved to exceed the generally accepted requirements of *ANSI/ASHRAE Standard 55-1992*, productivity gains would accrue. System parameters specifically identified were: rate of outside air, quality of outdoor air, local exhaust, ventilation effectiveness, economizer cycle, location of air vents, air filtration, infiltration or exilation, space temperature control, control of humidity, and humidification. However, correlations between system capacity and control and worker productivity were projected by using conservative estimates of increases in productivity for buildings compared to their baseline "wholeness" category and were not obtained from direct empirical evidence. Arora and Woods (1992) describe two cases of problematic buildings in which design deficiencies and inadequate management training for responding to occupant complaints were implicated. Loss of productivity in those two cases ranged from costs of litigation and lost data to the total evacuation of the building.

Although some studies described the HVAC system serving the facilities that were being studied, they did not investigate links between system parameters and productivity. For example, Woods et al. (1981) describe the HVAC system in the laundry room of a health care facility being assessed in that study but do not directly relate it to occupant performance and productivity. The heating in that space was provided by a preheated, 100% outdoor air system. However, internal heat generation by the equipment accounted for most of the heating requirements. For cooling, outdoor air was introduced into some spaces by a duct system for "spot cooling." Other spaces were partially cooled by fan-coil units.

In general, few studies were found that directly linked system parameters to FOMs, traditional or nontraditional. Absenteeism and self-reported productivity were the two nontraditional FOMs assessed, while quantity and quantity plus quality were the two traditional FOMs assessed for their links with system parameters. Issues related mainly to design, such as the role of air conditioning, mechanical or natural ventilation, locations of vents in air-distribution systems, were addressed. Moreover, one broad-based study projected the impact of diverse system parameters on absenteeism and costs (Dorgan 1993).

Exposure Parameters

Several studies assessed the role of thermal and air-quality parameters on traditional and nontraditional FOMs (see Table 4). In two studies that addressed the role of air conditioning on performance and productivity, temperatures were monitored in air-conditioned and non-air-conditioned facilities. In one of these studies, conducted in an educational setting, it was concluded that the selected FOMs (i.e., test scores) were related in a complex way to the thermal environment, i.e., temperature (Schoer et al. 1973). In general, complex tasks were more influenced by the thermal environment than were simple tasks. The second study (Pepler 1973), conducted in an industrial setting, assessed temperature and humidity mainly for the purpose of verifying that there was a difference in the thermal conditions of air-conditioned vs. non-air-conditioned facilities. That study concluded there was no evidence that daily productivity levels, assessed in terms of total "minutes earned" per hour worked per day, in a non-air-conditioned space were affected by daily fluctuation in temperature and relative humidity. Absenteeism, the other FOM used in that study, also was not found to be lower in the air-conditioned facility. The attitudes of workers in that facility were suspected to have contributed to this result. McNall and Nevins (1967) reported that a study conducted in educational facilities could not conclude that thermal environmental control at or near the "comfort" zone facilitates academic achievement of junior high school students. Therefore, other exogenous factors may account for differences found in academic achievement.

A study that assessed the roles of relative humidity and temperature on absenteeism in six primary schools (Green 1974) concluded that increased absenteeism was related to decreased relative humidity but not to temperature. Dorgan (1993) discussed the impact of indoor air quality on occupant comfort, symptom prevalence, and productivity. It was concluded that symptoms and dissatisfaction related to the indoor environment can, in the long term, result in lost productivity and increased health costs. A telephone survey of 600 office workers found that 78% of the respondents rated temperature as being very important in making an office a productive place in which to work (H. Technalysis 1985). Also, almost 20% of the respondents in that study said that they "often" or "sometimes" have difficulty doing their work because of the air quality in the office or work area (Woods et al. 1987). Woods et al. (1981) found no relationship between productivity and thermal stress, assessed in terms of SET*, and concluded that the work load had more influence on performance and productivity than the thermal environment. Finally, Hedge et al. (1993) found that installation of a BZF system improved vertical air mixing and reduced counts of submicronic particles of less than 0.25 μm diameter by 80%, with a decrease in "certified sickness absence" as well as in "self-reported productivity losses."

Three laboratory studies assessing the influence of thermal conditions on human response were identified. One study found that when Standard Effective Temperature (i.e., SET*) was varied, performance, assessed in terms of average number of errors, decreased with increasing SET*[6] (Berglund et al. 1990, p. 216). Wyon et al. (1979) and Wyon (1974) found that productivity, assessed in terms of mental performance using

[6] SET* is the "temperature of an isothermal still air (< 0.1 m/s) environment at 50% relative humidity in which for this case a sedentary person wearing 0.60 Clo of insulation would have the same heat stress and thermoregulatory strain as in the actual environment and clothing" (Berglund et al. 1990. p.216).

diverse tasks and typewriting, respectively, were related in complex ways to thermal conditions.

Human Response Parameters

In the literature reviewed, confounding exists with regard to variables that can be considered as human responses and those that are considered to be indicators of performance and productivity (i.e., FOMs); while human responses such as "comfort" and "symptoms" may be considered as indirect indicators of occupant productivity. Becker (1985) suggests the use of performance indicators such as physiological measures of stress and environmental perception. However, as discussed earlier and demonstrated in several studies, e.g., Woods et al. (1981) and Schoer and Shaffran (1973), human responses such as comfort and symptoms may be related in a complex way to occupant performance and productivity.

From the literature reviewed, eight references reported on the relationship between occupant performance, productivity, and human responses:

- Dorgan (1993) reported on the increases in health costs that can be expected to result from illness or symptoms related to the indoor environment. This paper also referred to estimates from other studies that productivity losses related to at-work illness or reduced productivity may be five to ten times the economic loss from direct absenteeism. However, these losses have not yet been adequately quantified.
- Sterling and Sterling (1983) compared environmental complaints, symptoms, and performance test results for a control building (mechanically ventilated) and a study building (naturally ventilated). Although complaints and symptoms were found to be more frequent in the study building compared to the control building, there was no significant difference between the group scores for productivity or between morning and evening scores.
- Berglund et al. (1990) found that performance decrement assessed in terms of the number of errors was related to discomfort as predicted by SET*.
- Complaints about the indoor environment, symptoms, and sensitization were factors identified in one study as influencing productivity (Arora and Woods 1992). Productivity was defined for two buildings with BRI or SBS problems in terms of costs of litigation, lost data from a computer firm, and evacuation resulting in forced absenteeism.
- Hall et al. (1991) reported that mucosal symptoms and "perceived indoor air quality" (PIAQ) indicators were correlated with self-reported productivity. In that study, respondents were asked to assess the extent to which their symptoms reduced ability to work or caused absenteeism.
- Human responses such as number of symptoms, comfort, environmental-perceptual responses related to temperature and humidity, satisfaction, and perceptions related to air quality, were found to be linked to self-reported productivity, i.e., percent of influence of physical environment on self-reported productivity (Raw et al. 1990).
- Kroner and Stark-Martin (1994) reported a statistically significant positive relationship between one affective response (overall satisfaction with the workspace for an individual worker) and occupant performance (number of files processed).

In another study (H. Technalysis 1985), more than 50% of the respondents who reported that they "often" or "sometimes" had difficulty doing work because of air quality reported that perceptual responses, such as lack of air movement, presence of cigarette smoke, being too hot in summer and too cold in winter, and stagnant or still air, were "very" or "somewhat" serious problems. Also, 56% of these respondents reported that one personal-perceptual response (a tired, sleepy feeling) was a "very" or "somewhat" serious problem.

Exogenous Factors

Exogenous factors, for the purpose of this literature review, are factors that are not related to the HVAC system or its impacts on exposures or human responses in the indoor environment. A review of the literature was conducted to assess the influence of the following factors on FOMs: (1) exogenous system parameters, (2) exogenous exposure parameters, (3) occupant characteristics, (4) social characteristics, and (5) other factors.

Exogenous System Parameters. The size of the office or workspace was identified as being a very or somewhat important factor contributing to the productivity of the indoor environment by 93% of respondents in a telephone survey of 600 office workers (H. Technalysis 1985; Woods et al. 1987). The type of work area (closed, semi-closed, or open) was also identified in that study as a possible influence on productivity (difficulty doing work because of IAQ). Sixteen percent of respondents from fully enclosed offices reported that they had difficulty doing their work "often" or "sometimes" because of IAQ compared to 25% of respondents working in open office areas. Also, 64% of respondents working in open area offices said that improvement in indoor air quality would be helpful in making the work area a more productive place compared to 45% of respondents from fully enclosed offices.

Exogenous Exposure Parameters. The exposure parameter "lighting" is exogenous to this literature review as it is not directly linked to HVAC system performance. Two studies addressed this parameter. One study (Zyla-Wisendale and Stolwijk 1990) found that distance from a fluorescent light fixture was inversely related to productivity. In that study, productivity was assessed for an office space in terms of quantity—the daily contribution by each worker to increases in a data entry system file. A second study (H. Technalysis 1985; Woods et al. 1987) found that 98% of respondents identified lighting as being very or somewhat important in contributing to a productive office environment. An exposure factor, glare (assessed as exposure to VDUs), may be implicated as influencing absenteeism in one study (Preller et al. 1990).

Occupant Characteristics. Several studies assessed the role of occupant characteristics and social characteristics on productivity. Personal characteristics such as age, gender, educational level, smoking status, allergies, and job satisfaction were reported as factors influencing absenteeism in one study (Preller et al. 1990). In another study, assessing absenteeism among school-age children, the socioeconomic level of children was considered as a possible influencing factor but was later found to be an unlikely influence on productivity (Green 1974). That study also raised the issue of the influence of age on absenteeism related to acquiring infections. Other studies identified factors such as "self-reported sensitivity" (Hall et al. 1991), gender (H. Technalysis 1985; Woods et al. 1987), and worker attitudes (Pepler 1973) on productivity defined in terms of absenteeism, self-reported productivity, and quantity of work, respectively. Sterling and Sterling (1983) reported that exogenous factors such as age, type of job, eye impairment, days/hours per week spent in the building, smoking habits, and alcohol or coffee consumption were controlled in a study conducted in two buildings, one sealed and one with operable windows. The gender ratio was different, but the analyses did not compare results for these two groups based on gender. That study did not find a significant difference in performance between the groups.

Exposure time may also be a factor influencing productivity. Two types of occupants can be identified: long term and short term. Occupants who spend time in the space on a regular or extended basis, such as staff in a hospital or teachers in a school, can be considered as long-term occupants. Conversely, patients in a hospital or customers in a retail store can be considered as short-term occupants. However, none of the reviewed studies assessed the relative impact of occupancy type on FOMs.

Social Characteristics. The issue of individual control over the environment has been assessed in several studies. Kroner et al. (1992) and Kroner and Stark-Martin (1994) reported that a productivity increase of about 2% could be attributed to the use of ERWs. However, that study was not able to assess the relative importance of different aspects of the environmental quality being controlled. Wyon (1993) concluded from a study of Dutch office workers (Preller et al. 1990) that sick leave due to SBS was reduced by 34% when individual workers could control their own thermal environment compared to workers for whom individual control was not provided. It is not clear, however, if control is a psychological variable or is linked to "objective" differences in indoor environmental conditions. Work load, job title, and role conflict were other factors that were reported to influence occupant productivity (Woods et al. 1987; Hall et al. 1991). Job satisfaction (Sterling and Sterling 1983) and job type (Raw et al. 1990) were identified as other factors that may influence productivity.

Other Exogenous Factors. Preller et al. (1990) reported that people working in rooms without operable windows reported less sick leave. This is contrary to the conclusions of the study reported by Sterling and Sterling (1983) in which it was concluded that complaints about environmental conditions and reported symptoms varied directly with access to operable windows. Woods et al. (1987) reported that 17% of people who worked in buildings with windows and 23% of people who worked in buildings without windows reported that air quality hampered their performance, but no correlation was apparent between open windows and productivity.

Loss of individual control, resulting from the disabling of ERWs, may have contributed, in part, to the decrease in productivity reported by Kroner et al. (1992) and Kroner and Stark-Martin (1994). Recent redecoration was identified as being a "very" or "somewhat" important factor contributing to the productivity of the workspace by 69% of respondents in a telephone survey of 600 office workers (H. Technalysis 1985). Office furnishings and layout, as well as perceived crowding, were also found to influence productivity in a study conducted by Hall et al. (1990). Raw et al. (1990) found that the number of people sharing a room was inversely related to self-reported productivity. Woods et al. (1981) found that workload was a contributor to two FOM parameters (traditional and nontraditional) that were assessed in that study.

SUMMARY OF OBSERVATIONS FOR ISSUE NO. 2

- As shown in Table 4, 18 studies were identified that assessed the influence of system performance, exposure, or human response parameters related to thermal and air quality on productivity. Only three of these studies included an assessment of systems, exposures, and human responses. There is a need to conduct studies that comprehensively assess a wide range of parameters related to HVAC system performance and to thereby identify parameters that are most sensitive to changes in productivity.
- Five FOMs were identified that are related to self-reported productivity. Absenteeism was assessed in seven studies, quantity of work was assessed in three studies, quality of work was assessed in one study, quality plus quantity of work was assessed in four studies, and costs were assessed in two studies. This reinforces our earlier conclusion that absenteeism and self-reported productivity are the most widely used FOMs in assessing nonindustrial productivity.
- The primary system parameters that were assessed in the studies reviewed here are air conditioning, humidification, and natural vs. mechanical ventilation. Few studies addressed filtration strategies, operations and maintenance, and renovation and retrofitting. Additionally, there are few large-scale comparative analyses incorporating several system types. Such studies can be expected to have value to designers in that findings can be generalized across BFCs and HVAC system types.

- None of the studies reviewed here assessed the range of thermal and air quality factors that can be expected to be impacted by HVAC systems. Only temperature and relative humidity were assessed. Based on the rational model of system relationships (Figure 1), the objective of building systems is to provide acceptable levels of exposures. By monitoring exposures, it is possible to determine if the systems are functioning as intended. There is, consequently, a need to assess the exposures that result from the operation of diverse HVAC systems.
- Current literature presents contradictory evidence about the links between human responses, occupant performance, and productivity in an indoor environment. Additional studies are needed to clarify these linkages.
- Few studies assessed more than one FOM for links with HVAC system parameters. It is necessary to identify FOMs that are "controllable," i.e., sensitive to changes in the functioning of HVAC systems.

CONCLUSIONS

An examination of the literature with respect to the two critical issues identified for this review reveals that of the nine BFCs identified in this paper, most current research on nonindustrial productivity has focused on office environments. Traditional measures of occupant productivity, defined in terms of FOMs, can be categorized as measures that assess quantity, quality, or quality plus quantity. Nontraditional FOM measures can be categorized in terms of absenteeism and self-reported productivity. Based on the diversity of definitions of FOMs within each category and on the diversity of functions of spaces, it is concluded that *FOMs can be standardized for specific BFCs, but site-specific modifications may be needed.*

Current literature has not adequately dealt with the simultaneous assessment of system, exposure, and human response parameters and their impacts on occupant productivity. Additionally, most of the studies reviewed here have focused on one or two aspects of these parameters. For example, temperature and relative humidity were the two exposure parameters assessed in most of the identified studies. Consequently, results obtained from the literature are often divergent. This divergence may be attributed to (1) inappropriate definitions of FOMs or (2) inadequate identification or assessment of the factors that impact these FOMs. It is concluded that FOMs must be measurable and controllable. "Controllable" means that the parameter must be sensitive and responsive to changes in the indoor environment. To select parameters that are controllable, it is important to establish rational links between building systems, exposures, human responses, and occupant productivity. Therefore, it is concluded that *studies assessing the link between indoor environmental control and occupant performance and productivity must assess a set of factors including systems, exposures, and human responses along with the selected FOMs.*

The literature reviewed also indicates that human responses such as symptoms have been used as indirect indicators of occupant productivity. However, some evidence suggests that the link between human responses and occupant productivity may be complex and that adverse human responses may not necessarily result in decreases in productivity. Therefore, it is concluded that *there is a need to clarify the relationships between different measures of human responses and occupant performance and productivity, taking account of exogenous factors that may impact the latter.*

RECOMMENDATIONS

Based on these conclusions, the following recommendations are made for future research efforts to assess the relationship between occupant performance and productivity and indoor environmental control:

- FOMs should be evaluated for appropriateness on a site-specific basis and assessed for reliability and validity.
- The possibility of identifying standardized FOMs for each building functional category should be examined.
- Productivity studies should be conducted in nonindustrial environments that assess the entire range of system, exposure, and human response parameters that are expected to impact occupant performance and productivity.
- Additional research should be conducted to clarify the linkages between occupant performance and productivity and human responses.
- Research efforts should be directed towards the identification of exogenous and economic factors that influence occupant performance and productivity.

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APPENDIX A

Literature Classification Scheme

1. Type of study (field / laboratory / theoretical)
2. Type of literature (codes / standards / guidelines / peer-reviewed papers /research reports / others
3. Country of origin
4. Definition of productivity (task board / FOM based)
5. Functional category (9 building functions)
6. Type of occupants (short-term / long-term)
7. Phase of life-cycle (planning, design, construction, operations, renovation)
8. Type of HVAC system (VAV, CAV, multi-zone, heat pump, window units, fan-coil induction units)
9. System performance (thermal conditions, ventilation rates, air distribution pattern, lighting conditions, acoustic conditions)
10. Age (system, building)
11. Quality of operations and maintenance procedures (adequate and inadequate)
12. Stressors (lighting, acoustic, thermal, air quality)
13. Extraneous factors (ergonomics, job-related or sociological stress, occupant predisposition)
14. Reported exposure (measured or derived values)
15. Reported human response (measured or derived values)
16. Reported costs (for O & M, for ownership, to tenant, to occupant)

LITERATURE CLASSIFICATION INPUT SHEET

Reference number: ______________

Title: ______________________________________

Authors (s):_______________ **Year:** _________

1. Type of study: Field / Laboratory / Theoretical / Combination / NA
2. Type of literature: Codes / Standards / Guidelines / Peer-reviewed paper / Research reports / Others
3. Country of origin: North America / Europe / Both / Other / NA
4. Definition of productivity: Task board / FOM based / Both / Other / NA
5. Functional category: Mercantile/service/ OFfices / Public assembly / Health care / food Sales/service/ Residential / Educational / Lodging / Warehouses / Combination / Other / NA
6. Type of occupants: Short-term / Long-term / Both / NA
7. Phase of life-cycle: Planning / Design / Construction / Operations / Renovation
8. Type of HVAC system: VAV / CAV / Multi-zone / Heat Pump / Window units / Fan-coil induction units / Combination / Other / NA
9. System performance: Thermal conditions / Ventilation rates / Air distribution pattern / Lighting Conditions / Acoustic conditions / Combination / Other / NA
10. Age: System / builDing / Both / NA
11. Quality of operations and maintenance procedures: Adequate / Inadequate/ NA
12. Stressors: Lighting / Acoustic / Thermal / air Quality / Combination / Other / NA
13. Extraneous factors: Ergonomics / Job-related / Sociological stress / Occupant predisposition / Combination / Other / NA
14. Reported exposure: Measured / Derived values / Both / NA
15. Reported human response: Measured / Derived values / Both / NA
16. Reported costs: for O & M / for oWnership / to Tenant / to occuPant / Combination / Other / NA