Title
The role of emerging energy-efficient technology in promoting workplace productivity and health: Final report

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The Role of Emerging Energy-Efficient Technology in Promoting Workplace Productivity and Health[1]: Final Report

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Introduction

Research into indoor environmental quality (IEQ) and its effects on health, comfort, and performance of occupants is becoming an increasing priority as interest in high performance buildings and organizational productivity advances. Facility managers are interested in IEQ's close relationship to energy use in facilities and employers want to enhance employee comfort and productivity, reduce absenteeism and health costs, and reduce or even eliminate litigation by providing excellent indoor environments to employees. The increasing interest in this field as architects, engineers, facility managers, building investors, health officials, jurists, and the public seek simple and general guidelines on creating safe, healthy, and comfortable indoor environment, has put additional pressure on the research community. In the last twenty years, IEQ researchers have advanced our understanding of the influence of IEQ on health and productivity, but many uncertainties remain. Consequently, there is a critical need to expand research in this field, particularly research that is highly multidisciplinary. In addition, there is a strong need to better communicate knowledge currently documented in research publications to building professionals in order to encourage implementation of designs and practices that enhance health and productivity.

Against this background, the Indoor Health and Productivity (IHP) project aims to develop a fuller understanding of the relationships between physical attributes of the workplace (e.g. thermal, lighting, ventilation, and air quality) in non-residential and non-industrial buildings and the health and productivity of occupants. A particular emphasis of the IHP project is to identify and communicate key research findings, with their practical and policy implications, to policymakers, design practitioners, facility managers, construction and energy services companies, and building investors.

The IHP project has a steering committee of sponsors and senior scientists. Advisory committees are also established for specific efforts. NIST provides an administrative role for some federally supported efforts, i.e., sponsors provide money to NIST which then funds the work. The preferred mode of operation of the IHP Project is to pool modest amounts of support from multiple sponsors to achieve objectives, with projects selected by the IHP Steering Committee. Additional information on the IHP Project is available at the project web site www.IHPCentral.org.

Objectives

The objective of this particular IHP project is to improve the communication of research findings in the indoor health and productivity area to scientists and building professionals (e.g. architects and engineers) and, thus, to help stimulate implementation of existing knowledge.

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[1] Please note that Workplace Productivity and Health project has been renamed as Indoor Health and Productivity project. Consequently, Indoor Health and Productivity and IHP will be used in place of Workplace Productivity and Health and WPH respectively throughout this report.

Methods

Task 1: Compilation of an IHP bibliography

The first task in the project was to substantially expand and improve a bibliography of IHP papers, to make this bibliography publicly available on the web, and to add links on this web site to other related web sites. The papers were identified by searching through PubMED, which includes MedLINE and other databases of interest, and extracting the relevant papers. Apart from PubMED, a broader internet search also helped in adding some magazine and newspaper articles to the IHP bibliography.

Task 2: Communication of key research findings

Under this task, we selected five key IHP papers published in the last ten years or so, prepared paper summaries, and arranged to have them published in a journal widely read by architects and engineers. The criteria for the selection of the papers were that they should make important contributions towards a better understanding of the influence of IEQ on indoor health and productivity and should provide valuable information for architects and engineers – the primary intended audience for this project. The five papers were selected through a peer review process. To introduce this series of papers, we also wrote an overview paper that describes the IHP project, explains how the subsequent papers were selected, and identifies IHP knowledge gaps.

The accomplishment of this task involved a series of steps that are described in greater detail below:

Selection of Peer Reviewers

The project started with a meeting of the IHP Steering Committee in Washington, DC in February 2001. The steering committee members, based on their familiarity with the indoor health and productivity literature, nominated researchers to the IHP Peer Review panel. The IHP Peer Review panel was charged with the following responsibilities:

- To help identify candidate papers which have been published in the last ten years.
- To recommend five papers from the candidate list based on criteria to be developed by the IHP Steering Committee.
- To help write a short summary of the paper if one or more of the peer reviewers were authors or co-authors of the final five papers selected after the review process.

The following group of international experts agreed to serve on the IHP peer review panel:

1. Bill Cain, USA
2. Michael Hodgson, USA
3. Jouni Jaakkola, Finland
4. Hal Levin, USA
5. Vivian Loftness, USA
6. Mark Mendell, USA
7. David Mudarri, USA
8. Jan Sundell, Denmark
9. Jennifer Veitch, Canada
10. Pawel Wargocki, Denmark
11. Jim Woods, USA
12. David Wyon, Denmark
13. Kay Kreiss, USA
14. Gary Raw, UK

Identifying Journal for Publishing Summaries of Selected Papers

We identified the ASHRAE Journal as the forum in which to publish summaries of the five papers. ASHRAE Journal was chosen because of its wide circulation (approx. 30,000) and because its subscribers include architects, HVAC designers, and facility managers – the intended audience for disseminating the findings of this research project. We established an agreement with the editor of the ASHRAE Journal to publish the overview paper and paper summaries in sequential issues during 2002.

Development of Evaluation Criteria for Candidate Papers

Following the constitution of the IHP Peer Review panel, the IHP Steering Committee developed the evaluation criteria for the candidate and final papers. Each member of the peer reviewer committee was then asked to nominate two or three research papers satisfying the criteria set forth by the IHP Steering Committee and to explain his/her rationale for the selection of each paper in a paragraph. To aid in the selection of candidate papers, seven candidate papers (with full bibliographic information, abstract, and a paragraph explaining why they were included) were provided to peer reviewers. The recommended criteria for the selection of candidate papers, as well as of the final five papers, are listed below:

1. Relevance to the IHP project
2. Importance or value of the finding
   - Is this an original contribution not reported previously in other studies?
   - Are the findings generalizable to other situations/buildings?
   - Is the statistical analysis rigorous enough to instill confidence in the results?
   - How much control was exercised to identify/eliminate the confounding factors that could have affected the conclusions of the study?
   - How easy is it to incorporate the findings in general construction, O&M practice and/or in building standards?
   - Does the paper contain important new hypothesis or concepts that can help in better understanding or analyzing the field of IHP?
3. Quality/novelty of approach used in the study

Selection of the Five Papers

The previous exercise resulted in a pool of twenty-six candidate papers. Three candidate papers nominated by one reviewer could not be included because the recommendations were not made on time. All the twenty nine candidate papers along with explanations provided by peer reviewers for their selections, if provided, are included in *Appendix A*. The peer reviewers were then sent a packet consisting of the following documents:

- The final list of candidate papers based on the nominations received from the reviewers. The final tally of twenty-six papers included the seven papers that were nominated by the IHP Steering Committee. The explanation for nominating the papers (if provided by the reviewer) was also included.
- Full text of all the candidate papers to help the reviewers in selecting their top five recommendations.

To eliminate the appearance of conflict of interest, peer reviewers were not allowed to include their own papers in the short list. Although not required, many reviewers included a brief explanation for selecting each paper. The IHP Steering Committee made the final selection of five papers based on peer reviewers' recommendations and thoughtful comments explaining the rationale behind their decision. The thoughtful responses reflected the substantial time that peer reviewers devoted to the effort.

Guidance to Authors for Writing Summary Papers

The first authors of the five selected papers were requested to write a short summary of their paper. They were also informed that the IHP steering committee reserved the right to request or make any changes necessary to satisfy the requirements of the project. The following guidelines were provided to the authors to facilitate their task:

- The summary article was not to exceed ~1500 words and was to be turned in by November 1, 2001.
- Authors were strongly encouraged to include simple graphical/visual elements (charts, tables, figures, etc.) to convey key concepts or explain study findings. Use of research jargon not easily understood by the audience was discouraged.
- The intent of the summary papers was to convey the findings of the research to building professionals, especially architects, engineers, and facility managers in an objective and balanced manner. Authors were encouraged to convey the practical implications of their research in a form that the architects and engineers would find helpful in designing better indoor environments. At the same time, authors were asked to explain any important weaknesses, limitations, or uncertainties that may limit the applicability of the research findings.
- In a discussion, authors were encouraged to use this opportunity to briefly describe or reference subsequent research that they or others may have conducted on the same topic, if such an expansion would be helpful for building designers.

Four authors agreed to write the summary article for publication in ASHRAE journal. The summary for the remaining paper (Milton et al.) was co-authored by two steering committee members and reviewed and approved by the first author of the original paper.

Results

Task 1

The IHP bibliography was expanded from approximately 600 to 900 records, drawing primarily from approximately 100 leading national and international indoor environment and health journals and international conferences. A few of the records represent articles in newspapers and popular magazines. For approximately 720 of the cited papers, abstracts are provided, within the bibliography. Most of the remaining citations refer to documents that do not have abstracts. The online bibliography can be searched for an occurrence of a word in the Title, Authors, or Abstracts field. Moreover, users can also find out if the article was published in a peer-reviewed journal, appeared in a conference proceeding, or in a magazine. It can also be searched by keywords or publication year. The updated bibliography as well as the links can be found at the IHP web site (www.IHPCentral.org). The list of links added to the web site are included in *Appendix C*.

Task 2

The final five papers selected by the IHP Steering Committee are listed below.

a) Fisk WJ (2000). Health and productivity gains from better indoor environments and their relationship with building energy efficiency. Annual Review of Energy and the Environment 25(1): pp. 537-566.

   This paper summarizes many areas of research to provide a rationale for research and practice for better indoor environmental quality. It translates the science into a context in which practitioners may be motivated to read more, understand the implications of their choices, and consider changing existing practices. The estimated potential health and productivity gains from improved IEQ are of interest to designers who wish to convey to their clients the importance of these factors in decisions related to building environmental performance.

b) Heschong Mahone Group (1999). Daylighting in schools: an investigation into the relationship between daylighting and human performance. Report submitted to Pacific Gas & Electric.

This study relates a physical environmental parameter (daylighting) in schools to standardized test scores of students (at a time when test scores are driving school budget decisions) and found significant results. While there are some questions concerning the statistical methods and controls which need to be acknowledged, this study is extremely provocative and could lead to increased interest in the relationship between environmental parameters and school performance.

c) Milton DK, Glencross PM, Walters MD (2000). Risk of sick leave associated with outdoor ventilation level, humidification, and building related complaints. Indoor Air, 10(4): pp. 212-21.

When selecting minimum ventilation rates, employers need to strike a balance between the well-recognized energy costs of providing higher minimum ventilation rates and the expected, but less well quantified, health benefits from higher rate of ventilation. The study suggests substantial reductions in short term absence from increasing ventilation rates above the minimum rates specified in current standards. These findings should be considered in future revisions of the standard. Because building energy efficiency is important for environmental protection and for the nation's energy security, future research is needed to identify other less energy intensive methods of reducing sick leave.

d) Seppanen OA, Fisk WJ, Mendell MJ (1999). Association of ventilation rates and CO_2 concentrations with health and other human responses in commercial and institutional buildings. Indoor Air, 9(4): pp. 226-52.

While ventilation rates do not directly affect occupant health or perception outcomes, they affect indoor environmental conditions including air pollutant concentrations that, in turn, may modify the occupants' health or perceptions. The review aims to provide a better scientific basis for setting health-related ventilation standards. Because increases in ventilation may increase building energy consumption, research is also needed to identify practical methods of decreasing minimum ventilation requirements by reducing indoor pollutant emissions or by increasing the effectiveness of ventilation in controlling pollutant exposures.

e) Sieber WK, Staynor LT, Malkin R, Petersen MR, Mendell MJ, Walligford KM, Crandall MS, Wilcox TG, Reed L (1996). The National Institute for Occupational Safety and Health Indoor Environmental Evaluation Experience. Part Three: Associations between environmental factors and self-reported health conditions. Applied Occupational and Environmental Hygiene, 11(12): pp. 1387-92

This paper provides strong evidence of preventable building problems related to HVAC system cleanliness or maintenance or to locating of outside air intakes near pollutant sources, that are likely to increase occupants' health problems. Since building design and management is always driven by economic and time tradeoffs, it is extremely valuable to study the relative importance of multiple factors on health conditions. The information in this paper, particularly if replicated in future studies, should stimulate better HVAC design and maintenance.

The first and the fourth paper in the above list received seven recommendations each, the fifth paper received six, and the third one received five. The second paper tied with two other papers with four recommendations each but was chosen by the IHP Steering Committee as it covered an indoor environment domain that was not already covered within the first four papers. The steering committee members also believed that the subject matter addressed in the fifth paper would be highly relevant to the intended audience.

The five summary papers were sent to ASHRAE during December, 2001 for publication in sequential issues of ASHRAE Journal starting June 2002. The overview paper was sent to ASHRAE in early January, 2002 for publication in May 2002 and will precede the five summary papers. Copies of the five summary papers along with the overview paper are enclosed in *Appendix B: Overview paper and summaries of the five short-listed papers* of this report.

Summary

The IHP web site now contains a bibliography with citations for approximately 900 articles, and abstracts are provided for more than half of the articles. The online bibliography can be searched for occurrence of a word in the title, authors, or abstracts field or by keywords or publication year.

Five important IHP papers were selected by a peer review committee and short summaries of each article were written. The overview summarizes the methodology employed to select the five papers, briefly summarizes the message of each paper, and discusses the practical implications for architects and engineers. In 2002, these summaries along with the overview paper will be published in ASHRAE Journal, which has a circulation of approximately 30,000 readers, primarily architects, HVAC engineers, and facility managers.

Acknowledgments

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Appendix A: List of Candidate Papers

Final List of Candidate Papers Nominated by Reviewers With Explanatory Text (if provided)

1. Apte MG, Fisk WJ, Daisey JM (2000). Associations between indoor CO2 concentrations and sick building syndrome symptoms in U.S. office buildings: an analysis of the 1994-1996 BASE study data. **Indoor Air** 10(4): pp. 246-57 (nominated by Mark Mendell)

   Explanation: Not provided

2. Boyce PR, Beckstead JW, Eklund NH, Strobel RW, and Rea MS (1997). Lighting the graveyard shift: The influence of a daylight-simulating skylight on the task performance and mood of night-shift workers. **Lighting Research and Technology,** 29(3), pp. 105-134. (nominated by Jennifer Veitch)

   Explanation: I noted that I seem to be the only review panelist in the lighting domain, so I focused on papers in that area to ensure that it gets some coverage.

3. Brunekreef B (1992). *Associations between questionnaire reports of home dampness and childhood respiratory symptoms*. **The Science of the Total Environment** 127: pp. 78-89 (nominated by Jan Sundell)

   Explanation: It is an early and well executed questionnaire study on dampness and health, from a time when dampness was not well known as a risk factor for health effects.

4. Cooper K, Demby S, Hodgson M (1997). *Moisture and lung disease: population-attributable risk calculations*. **IAQ 97/Healthy Buildings: Design, Construction, and Operation of Healthy Buildings**, 1: pp. 213-8 (nominated by Michael Hodgson)

   Explanation: Not Although studies have consistently identified moisture problems in the home as a strong predictor of symptoms, the strength of the association between moisture and symptoms, i.e., odds ratios or relative risks, differed considerably. In a number of such studies, the association did not reach statistical significance. The paper below explores reasons for the inconsistency and documents that, as exposure assessment strategies improved, the strength of the association improved, suggesting a causal relationship.

5. Dales RE, Zwanenburg H, Burnett R, Franklin CA (1991). *Respiratory health effects of home ""dampness"" and molds among Canadian children*. **American Journal of Epidemiology** 134: pp. 196-203 (nominated by Jan Sundell)

   Explanation: Even this is an early large questionnaire study, which now belongs to the classic studies.

6. Fisk WJ (2000). *Health and productivity gains from better indoor environments and their relationship with building energy efficiency*. **Annual Review of Energy and the Environment** 25(1): pp. 537-566 (nominated by Mark Mendell and Vivian Loftness)

Explanation: Not provided

7. Garrett MH, Hooper MA, Hooper BM (1996). *Low levels of formaldehyde in residential homes and a correlation with asthma and allergy in children*. **Proceedings of Indoor Air,** 1: pp. 617-22 (nominated by David Mudarri)

   Explanation: Evidence to date suggests that the respiratory effects of formaldehyde are limited to high levels of exposure such as in occupational settings. However, this paper presents good evidence that a dose-response exists for low level formaldehyde exposure and respiratory symptoms, and also for allergen sensitization and the onset of asthma. This is an important finding in that formaldehyde is a common ingredient in building materials and furnishings. In addition, it has been unclear whether formaldehyde induces an immunologic/sensitization response or an irritant response in its association with asthma. Evidence in this paper suggests that formaldehyde may potentiate the effects of allergen exposure.

8. Gyntelberg F, Suadicani P, Nielsen JW, Skov, PS, Valbjørn O, Nielsen PA, Schneider T, Jørgensen T, Wolkoff PW, Wilkins CK, Gravesen S, and Norn S (1994). *Dust and the Sick Building Syndrome*. **Proceedings of Indoor Air,** 4: pp. 223-38 (nominated by Pawel Wargocki)

   Explanation: This is perhaps a best study exploring the importance of dust for SBS symptoms. It provides number of interesting findings , hypotheses and suggestions for future studies.

9. Heschong L. *Daylighting in schools: an investigation into the relationship between daylighting and human performance*. 1999 (nominated by IHP Steering Committee, Vivian Loftness, and James Woods)

   Explanation: The association of lighting conditions with performance and learning is an area of much discussion; however, very limited information has been available from work settings that are not unusually demanding of visual performance. This study of daylighting in schools in two school districts found very large increases in learning to be associated with increased daylighting in schools, while controlling for some confounders. The study was one that looked at the conveniently available data; therefore, the study has some weaknesses with respect to control for confounding and characterization of lighting conditions. However, the results are provocative and not easily dismissed. If even a significant portion of the observed association turns out to be causal, the potential educational benefits from more daylighting would be substantial. The report illustrates the need for further research in this area.

10. Hodgson MJ, Frohliger J, Permar E, Tidwell C, Traven ND, Olenchock SA, Karpf (1991). *Symptoms and microenvironmental measures in nonproblem buildings*. **Journal of Occupational Medicine**, 33(4): pp. 527-33 (nominated by Michael Hodgson)

    Explanation: Chamber studies have clearly documented that complex mixtures of volatile organic compounds may cause mucosal irritation in human subjects (Molhave, Wolkoff). The mechanism has been worked out, based on quantitative structure activity relationships (Abraham, Alarie, Cain). The paper below was the first publication to document that these effects, identified in experimental settings, are applicable to non-problem buildings and that the effects are robust enough to consider population effects. VOCs were the single most important environmental parameter predicting symptom development. It is the only paper suggesting a dose-response relationship in a field study of non-problem buildings, suggesting that VOCs are in fact a major, broad issue.

11. Jaakkola JJK, Oie L, Hafstad P, Botten G, Samuelsen SO, Magnus P. *Interior surface materials in the home and the development of bronchial obstruction in young children in Oslo, Norway*. **American Journal of Public Health**

1999; 89(2): pp. 188-92 (nominated by IHP Steering Committee)

Explanation: This paper is one of three published recently by Jaakkola and his colleagues reporting an association between interior surface materials, particularly those made from PVC or other plastics, and bronchial obstruction or asthma symptoms. While further research is necessary to confirm these findings, this paper is nominated because it has identified a potentially important risk factor that previously received minimal attention.

12. Mendell M. *Non-specific Symptoms in Office Office Workers: A review and Summary of the Epidemiologic Literature*. **Proceedings of Indoor Air**, 3: pp. 27, ISSN 0905-6947 (nominated by Gary Raw)

    Explanation: Not provided

13. Milton DK, Glencross PM, Walters MD (2000). *Risk of sick leave associated with outdoor ventilation level, humidification, and building related complaints*. **Indoor Air,** 10(4): pp. 212-21 (nominated by IHP Steering Committee)

    Explanation: This paper reports a strong association of higher estimated ventilation rates with a lower rate of sick leave from work. Although the ventilation rate characterization was imprecise, the paper is nominated because: 1) it focuses on the sick leave outcome which has received insufficient attention despite its health and economic significance; 2) the findings are of direct practical interest for engineers, architects, and employers.

14. Newsham GR and Veitch JA (2001). *Lighting Quality recommendations for VDT offices: A new method of derivation.* **Lighting Research and Technology**, 33(2): pp. 115-143 (nominated by Jennifer Veitch)

    Explanation: I noted that I seem to be the only review panelist in the lighting domain, so I focused on papers in that area to ensure that it gets some coverage.

15. Park JH, Gold DR, Spiegelman DL, Burge HA, Milton DK (2001). *House dust endotoxin and wheeze in the first year of life*. **American Journal of Respiratory Critical Care Medicine**, 163(2): pp. 322-8 (nominated by Michael Hodgson)

    Explanation: Asthma and endotoxin: office workers are at risk for asthma, based on several data sets. The question has long been whether this risk results from infections or moisture. The paper below strongly suggests that environmental factors increase sensitization potential

16. Peat JK, Dickerson JL (1998). *Effects of damp and mould in the home on respiratory health: a review of the literature*. **Allergy: European Journal of Allergy and Clinical Immunology,** 53: pp. 120-8 (nominated by IHP Steering Committee)

    Explanation: Over the last two decades, a large number of studies have investigated the association of moisture and mold problems in residences with respiratory health. This paper provides a recent review of the state of knowledge and shows that a large majority of these studies have found an increased risk of wheeze, cough, and asthma with dampness and mold problems. Odds ratios, indicating the magnitude of increased risk, have generally been between 1.5 and 3.5, and statistically significantly above unity in studies of considerable size. This paper in nominated because of the importance of communicating the risks associated with the very commonly occurring problem of moisture in buildings.

17. Raw GJ, Roys MS, Whitehead C (1993). *Sick building syndrome: cleanliness is next to healthiness*. **Proceedings of Indoor Air,** 3: pp. 237-245 (nominated by Gary Raw)

    Explanation: Not provided

18. Seppanen OA, Fisk WJ, Mendell MJ (1999). Association of ventilation rates and CO2 concentrations with health and other human responses in commercial and institutional buildings**. Indoor Air**, 9(4): pp. 226-52 (nominated by IHP Steering Committee)

    Explanation: Minimum ventilation requirements are an important policy issue for organizations responsible for ventilation standards and guidelines. To date, these standards have had a weak scientific underpinning. Seppanen et al (1999) realized that the quantity and quality of scientific information on the relationship of ventilation rates with health had increased in recent years and completed this new critical review of the state of knowledge. The review helped us to realize that lower ventilation rates are significantly associated with increased health effects in the large majority of studies meeting study quality inclusion criteria and that there is no evidence of a threshold ventilation rate above which further increases in ventilation rate are not beneficial. The review should serve as an important source of new information for policy makers as well as building designers and operators.

19. Sieber WK, Staynor LT, Malkin R, Petersen MR, Mendell MJ, Walligford KM, Crandall MS, Wilcox TG, Reed L (1996). *The National Institute for Occupational Safety and Health Indoor Environmental Evaluation Experience.* Part Three: Associations between environmental factors and self-reported health conditions. **Applied Occupational and Environmental Hygiene**, 11(12): pp. 1387-92 (nominated by IHP Steering Committee)

    Explanation: Anecdotally, HVAC maintenance deficiencies and HVAC contamination have long been a suspected risk factor for health symptoms. This paper, the first to explore this hypothesis in detail, found moderate to strong associations of lower respiratory symptoms with a number of HVAC maintenance and cleanliness metrics. Although the analyses did not control for confounding, except by age and gender, this paper is recommended because it has broken new ground and should stimulate the necessary future research.

20. Skov P, Valbjørn O, DISG (1987). *The "Sick" Building Syndrome in the Office Environment*. **Environment International**, 13: pp. 27 (nominated by Gary Raw)

    Explanation: Not provided

21. Skulberg KR, Skyberg K, Kruse K, Huser PO, Levy F, Djupesland P (1999). *Dust, Allergy and Health in Offices: An Intervention Study on the Effect of Cleaning*. **Proceedings of Indoor Air,** 1: pp. 92-3 (nominated by David Mudarri)

    Explanation: This paper reports a reduction in mucous membrane symptoms and nasal airway congestion from intensive office cleaning relative to superficial cleaning in a controlled intervention study. This, combined with similar findings in a related study from the same research using both subjective symptoms and acoustic rhinometry measurements of the nasal passage, provide strong evidence of the health benefits associated with thorough housekeeping practices.

22. Sundell J (1994). On the Association Between Building Ventilation Characteristics, Some Indoor Environmental Exposures, Some Allergic Manifestations, and Subjective Symptom Reports. **Indoor Air,** Suppl. 2: pp. 1-49 (nominated by Pawel Wargocki)

Explanation: This is an extensive paper summarizing large study in Sweden exploring different environmental effects on SBS symptoms. Even though the study is relatively old (from the beginning of ninties), it still contains an extremely interesting findings regarding e.g., the effects of dry air on perception of dryness and ventilation rate on SBS symptoms.

23. Wargocki P, Wyon DP, Fanger PO (2000). *Pollution Source Control and Ventilation Improve Health, Comfort, and Productivity*. **Proceedings of Cold Climate HVAC 2000, Sapparo, Japan**; pp. 445-450 (nominated by IHP Steering Committee and Vivian Loftness)

Explanation: This paper summarizes the results of three studies using a new laboratory-based research approach pioneered at the Danish Technical University to study under controlled conditions the relationship of the indoor environment with occupant perceptions, health symptoms, and performance. The research has found that removal of a carpet taken from a complaint building or increasing the ventilation rate with the carpet present improve IAQ perceptions, decrease some symptoms, and increase task performance. This paper is nominated due to the significance of both the findings and the new research approach.

24. Wyon DP (1996). *Indoor Environmental Effects on Productivity*. **Proceedings of IAQ '96: Paths to Better Building Environments**, pp. 5-15 (nominated by Pawel Wargocki)

Explanation: This is a paper summarizing current (at 1996) knowledge of the effects of indoor environment on productivity and suggesting plausible mechanisms. The value of the paper is very high for IHP as it summarizes the data on the thermal effects of productivity.

25. Wyon DP (1993). *Healthy Buildings and Their Impact on Productivity*. **Proceedings of Indoor Air '93,** 6: pp. 3-13 (nominated by David Wyon)

Explanation: It is a review of this and other evidence for an effect of heat stress on productivity. In 1993, there were no published reports of an effect of IAQ on productivity, and this is stated.

26. Wyon DP (1974). *The Effects of Moderate Heat Stress on Typewriting Performance*. **Ergonomics**, 17(3): pp. 309-18 (nominated by David Wyon)

Explanation: Re-analyzed data obtained in the New York State Commission experiments, and documents a sensitive effect of very moderate heat stress on an important aspect of office work, obtained in quite long exposures and on simulated work, i.e. in experiments which are in every way comparable to the experiments summarized in our HB2000 paper.

The following three papers were nominated but did not make it to the list of candidate papers because it was received after the deadline for sending nominations has elapsed.

27. Levin, H., (ed.) 1995. Workshop Proceedings: Indoor Environment and Productivity." Atlanta: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. (nominated by Hal Levin)

Explanation: Not provided

28. Dolden, Mary E., and Robertson Ward, Jr., 1985."Proceedings, The Architectural Research Centers Consortium Workshop on The Impact of the Work Environment on Productivity." Washington, DC: The Architectural Research Centers Consortium, Inc. (nominated by Hal Levin)

Explanation: Not provided

29. Arnoff, Stan, and Audrey Kaplan, 1995. Total Workplace Performance; Rethinking the Office Environment. Ottawa, Ontario, Canada: WDL Publications, PO Box 8457, Station T, Ottawa, Ontario, Canada K1G 3H8. (nominated by Hal Levin)

Explanation: Not provided

Appendix B: Overview paper and summaries of the five short-listed papers

Relationships Between Indoor Environments and the Health and Productivity of Workers in Non-residential, Non-industrial Environments: A Review

December 27, 2001

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Introduction

Research into indoor environmental quality (IEQ) and its effects on health, comfort, and performance of occupants is becoming an increasing priority as interest in high performance buildings and organizational productivity grows. Facility managers are interested in IEQ's close relationship to energy use in facilities. Employers, by providing excellent indoor environments, hope to enhance employee comfort and productivity, reduce absenteeism and health care costs, and reduce risk of litigation. The increasing interest in this field has put additional pressure on the research community as architects, engineers, facility managers, building investors, health officials, jurists, and the public seek practical guidelines on creating a safe, healthy, and comfortable indoor environment.

Research on the relationships of IEQ to the health, comfort, and productivity of occupants has advanced considerably within the last decade. One of the primary goals of the Indoor Health and Productivity (IHP) Project is to communicate the results of this research, currently reported primarily in research publications, to building professionals. Consequently, the IHP project has worked with a peer review panel to select five key IHP papers and prepare summaries of these papers for publication in ASHRAE Journal.

This article precedes those five summary articles, which will appear in the next five issues of the journal. This article summarizes the methodology employed to select the five papers, briefly summarizes the message of each paper, and discusses the practical implications for architects and engineers.

More information about the objectives of the IHP project, results of research conducted under this project, and project sponsors and partners can be found at www.IHPCentral.org. The web site also has an online bibliography of approximately 900 papers on the topic of indoor health and productivity, drawn primarily from approximately 100 leading international journals and international conferences.

Methodology

The IHP Project has a Steering Committee representing the sponsors of the IHP project, a small technical staff (the authors of this article), and advisory committees established for specific tasks. For this task, the IHP Steering Committee developed criteria for selecting the five papers, including the following: relevance to IHP goals; originality; novelty; quality of research approach; and value of the paper to architects and engineers. The last of these criteria was considered most important. With input from the IHP technical staff, the Steering Committee also selected an international panel of fourteen peer reviewers, who are highly respected scientists and engineers with knowledge of the IHP field. The IHP technical staff nominated several papers and each peer reviewer nominated 2-3 papers resulting in a pool of twenty-six candidate papers. All the candidate papers are listed in the *References* section. Each candidate paper plus written justifications for the nominations were distributed to all peer reviewers. Each peer reviewer then selected five papers from the 26 candidate papers. To avoid any conflict of interest, peer reviewers were requested not to include their own papers in the short list. Finally, the Steering Committee, seeking a broad portfolio, selected the final five papers from the seven papers receiving the highest number of recommendations.

Identifying Current Research Priorities and Knowledge Gaps in the IHP Literature

To gain insight into the current IEQ literature rated very highly by the peer review committee, all twenty-six candidate papers submitted were classified based on the indoor environment variables being investigated (shown along the rows in Table 1) and on the associated health/productivity outcomes (shown along the columns in Table 1). The numbers in each cell of Table 1 refer to the candidate papers listed in the reference list at the end of this article. The last row and the last column show the total number of distinct papers appearing under each row and column.

Ventilation rate/CO2 concentrations, thermal conditions, and moisture or dampness were the IEQ factors investigated most often in the pool of candidate papers. Among the health/productivity outcomes, sick building syndrome symptoms were discussed in an overwhelming number of studies (18 out of 26) followed by evaluation of task performance, and occurrence of allergy/asthma symptoms. Only two papers from the pool estimated economic gains from improvements in health and productivity, and inclusion of both in the short list emphasized the importance of this topic and the need for more research on these outcomes. Although eight studies discussed enhancement of task performance from improved indoor environments, they focused on either component skills that represent a very small subset of the range of activities performed by people in work environments or on performance metrics such as standardized test scores of school students that cannot be used in many indoor environments. Very few studies have investigated the effects of indoor environmental parameters on the overall productivity of non-industrial workers. The gaps in Table 1, where the peer review committee identified no or very few top-rated papers, highlight areas of research need.

Table 1: Classification Scheme for Candidate Papers to Identify Research Trends and Knowledge Gaps in the IHP Domain. The numbers within the table refer to specific papers in the reference section. The numbers of the five selected papers are shown in bold type.

IEQ Variables	Health/Productivity Outcomes					
	Sick Building Syndrome Symptoms[a]	Allergy and Asthma	Communicable Respiratory Illness (Short-term Sick Leave)[b]	Task Performance or Productivity	Economic Gains	Total Papers
Ventilation Rate/CO2 Concentrations	(1, 12, **18**, 22, 23)	(22)	(**13**, **18**)	(23)	(**6**, **13**)	7p
HVAC System Characteristics	(12, 17, **19**)	(**19**)			(**6**)	4p
Building material and furnishings	(12)	(11[c])				2p
Volatile Organic Compounds	(10, 20, 22)	(7[c])			(**6**)	5p
Moisture/dampness	(3[c],4, 5[c], 16[c])	(3[c], 4, 5[c])	(5[c], **13**)		(**6**)	6p
Dust on surfaces	(8, 15, 17, 21)	(21)				4p
Daylighting/Lighting	(10)			(2, **9**, **14**)	(**6**)	5p
Thermal Conditions	(10, 12, 20, 25, 26)			(24, 25, 26)	(**6**)	7p
Crowding	(12)		(**13**)		(**6**)	3p
Total Papers	18p	8p	3p	8p	2p	

[a]Lower respiratory symptoms such as cough, wheeze, tight chest, and difficulty breathing are included.

[b]Examples include common cold, influenza – illnesses that may be responsible for some short-term sick leaves.

[c]These studies were conducted in home environment and were included as candidate papers because reviewers believed that the findings of the papers may have some relevance to non-industrial work environment as well.

Commentary on the short-listed papers

Of the five final papers, one estimated potential health benefits and economic gains from practical improvements in IEQ (Fisk 2000), one investigated the relationships of daylighting with students' performance in schools (Heschong 1999), two (Milton et al. 2000; Seppanen et al. 1999) addressed the relationships of ventilation rate to the health of building occupants, and the last paper reported associations between characteristics of HVAC systems and self-reported health symptoms (Sieber et. al. 1996). All of these papers were published in the last five years.

> Fisk (2000) summarizes available research on the major indoor environment factors affecting human health and productivity. For the U.S., this paper estimates that health effects experienced by millions of people annually could be significantly reduced by improving IEQ, with associated annual economic benefits of tens of billions of dollars. The paper indicates that improvements in lighting and thermal conditions may lead to additional, even larger, productivity gains. The paper reviews the literature on the relationships of IEQ with communicable respiratory disease, allergies and asthma, and sick building syndrome symptoms and also briefly reviews the literature on the relationships of thermal conditions and lighting with productivity. Since the design, construction, and operation of buildings is often driven by the desire to minimize costs, the economic estimates in this paper should be of great interest to architects, engineers, facility managers, and employers.
>
> The paper by Heschong (1999) relates a physical environmental parameter, daylighting in school classrooms, to standardized test scores of students at a time when test scores are driving school budget decisions. The findings of this study, ~ 20 percent larger increases in test scores in classes with more daylighting, if replicated in future studies, would provide a compelling case for increased daylight in classrooms.
>
> Minimum ventilation requirements are of much interest to building engineers and operators and have been a controversial topic within ASHRAE. To date, these minimum ventilation standards have had a limited scientific underpinning. The papers by Seppanen et al. (1999) and Milton et al. (2000) help to consolidate and solidify the scientific basis for the development and refinement of ventilation standards. They are particularly useful in light of current energy shortages and the renewed interest in reducing ventilation rates in buildings to save energy. These papers indicate that higher ventilation rates will, on average, improve occupants' health, reduce absence from work, and improve perceived air quality. The papers provide considerable evidence of benefits from increasing ventilation rates above those specified in ASHRAE Standard 62-1999 for offices.
>
> HVAC maintenance deficiencies and HVAC contamination have long been suspected risk factors for health symptoms, but the related scientific research has been quite limited. The paper by Sieber et al. (1996), based on a study of complaint buildings, is one of the few indicating the importance of HVAC cleanliness and maintenance for human health. The paper also reported that pollutant sources located near outside air intakes increased the risk of adverse health effects. The analyses controlled for the effects of age and gender on health symptoms but the study was not able to identify which HVAC cleanliness or maintenance conditions actually caused an increase in health effects.

Taken together, these five papers increase the strength of available scientific evidence that IEQ substantially affects health and productivity. Each of these studies had some limitations that will be discussed in the summary articles to be published in the subsequent issues of this journal. While more research is clearly needed, the message to architects and engineers is to pay attention to IEQ, in particular to assuring minimum ventilation rates, because numerous studies have found that ventilation rates influence health, satisfaction with indoor air quality, or absence.

Future Research

In the last twenty years, IEQ researchers have substantially advanced our understanding of links between enhanced health and productivity and improved IEQ, but many uncertainties remain about the costs and benefits of specific measures. Consequently, there is a critical need for more research to quantify the relationships of IEQ to health and productivity, define acceptable IEQ, and the best methods and costs of improving IEQ. The most effective research in this field will be highly multidisciplinary, involving building engineers, physical scientists, health scientists, economists, etc. In addition, we need research on how to best stimulate building professionals to use available scientific knowledge to create healthful building environments.

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Health and Productivity Gains from Better Indoor Environments

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Introduction

This article, a summary of Fisk (2000a, 2000b), estimates the nationwide improvements in health and productivity potentially attainable by providing better indoor environmental quality (IEQ) in U.S. buildings. Estimates include the potential reductions in three categories of health effects, the associated economic benefits, and the potential direct improvements in productivity not mediated through health. Expected costs and benefits of improving IEQ are compared, with a brief discussion of energy implications.

Methods

Potential percentage reductions in health effects from changes to buildings and IEQ were estimated from the results of epidemiologic (i.e., population health) studies that identified risk factors for health effects and quantified the risks. For example, many studies have found that the prevalences of respiratory symptoms associated with asthma are increased by 20% to 100% among occupants of houses with moisture problems, implying that elimination of these moisture problems would diminish symptoms by 17% to 50% in these occupants [e.g., 20%/120%=17%]. The degree to which these risk factors could be reduced through practical measures was estimated from published data, using engineering judgements. For example, it was considered technically feasible and practical, but not necessarily easy or inexpensive, to double ventilation rates in offices or to improve prevention and expedite repair of water leaks in buildings. Consequently, the "potential" reductions in risk factors in this paper are those considered both technically feasible and practical, recognizing that implementation costs and other barriers will sometimes make these gains difficult to realize.

To calculate health benefits, potential percentage reductions in health effects were multiplied by the size of the affected population or by the number of health effects experienced. To estimate economic benefits, the percentage reductions in health effects were multiplied by the annual costs of the health effects. The costs in the U.S. of acute respiratory illnesses and of allergies and asthma were based on published estimates incorporating both direct health care costs and indirect productivity costs (e.g., value of lost work). Estimating the costs of sick building syndrome (SBS) symptoms was more difficult and produced more uncertain estimates. No comprehensive data were available on the costs of SBS-related investigations, remediations, or litigation; however, three studies have measured small but statistically significant decreases in worker performance linked to SBS symptoms. Therefore, the estimated cost of SBS symptoms was based on these measured decreases in work performance (adjusted downward as explained in Fisk (2000a)) and on the economic output of office workers, since SBS is most commonly reported for office workers.

A similar procedure was used to estimate the potential direct productivity gains from improved indoor temperature control and better lighting quality. All estimates were adjusted to 1996 dollars and to the size of the U.S. population in 1996.

Results

Acute Respiratory Illness (ARI)

No high quality studies identified had investigated but failed to find a link between building characteristics and acute respiratory illnesses (ARIs) such as influenza and common colds. Eight studies reported statistically significant 23% to 76% reductions in ARIs among occupants of buildings with higher ventilation rates, reduced space sharing, reduced occupant density, or irradiation of air with ultraviolet light. These changes to buildings or building use were considered technically feasible and practical, given sufficient benefits. One study found a 35% reduction in short-term absence, a surrogate for ARI, in buildings with higher ventilation rates. Because some of these studies took place in unusual building types, such as barracks and a jail, reductions in ARIs were adjusted downwards, and ranged from 9% to 20%. Multiplying this range by the annual cases of common colds and influenza resulted in an estimated 16 million to 37 million potentially avoided cases of common cold and influenza. Given the $70 billion annual cost of ARIs, the associated potential productivity gains were $6 billion to $14 billion.

Allergies and Asthma

The scientific literature reports statistically significant links between prevalences of allergy and asthma symptoms and a variety of changeable building characteristics or practices, including indoor allergen concentrations, moisture and mold problems, pets, and tobacco smoking. The reported links between these risk factors and symptoms were often quite strong. For example, parental smoking was typically associated with 20% to 40% increases in asthma symptoms. In numerous studies, mold or moisture problems in residences were associated with 100% increases in lower respiratory symptoms indicative of asthma. These moisture and mold problems are common; for example, about 20% of U.S. houses have water leaks. Based on these data, the estimated potential reduction in allergy and asthma symptoms from improved IEQ was 8% to 25%, among a large population -- 53 million with allergies and 16 million asthmatics. Given the $15 billion annual cost of allergies and asthma, the potential economic gains are $1 billion to $ 4 billion.

Sick Building Syndrome (SBS) Symptoms

SBS symptoms are acute symptoms, such as eye and nose irritation and headache, associated with occupancy in a specific building, but not indicating a specific disease. Risk factors for SBS symptoms identified in many studies include lower ventilation rates, presence of air conditioning, and higher indoor air temperatures. Increased chemical and microbiological pollutants in the air or on indoor surfaces, debris or moisture problems in HVAC systems, more carpets and fabrics, and less frequent vacuuming were risk factors in a smaller number of studies. One large study suggests that a 10 cfm per person increase in ventilation rates would decrease prevalences of the most common SBS symptoms on average by one third. Practical measures could diminish all these risk factors . Based on these data, the estimated potential reduction in SBS symptoms was 20% to 50%. The affected population is very large – in a survey of 100 U.S. offices, 23% of office workers (64 million workers) frequently experienced two or more SBS symptoms at work. The estimated productivity decrement caused by SBS symptoms in the office worker population was 2%, with an annual cost of $60 billion. A 20-50% reduction in these symptoms, considered feasible and practical, would bring annual economic benefits of $10 billion to $30 billion.

Direct Productivity Gains

Published literature documents direct linkages of worker performance with air temperatures and lighting conditions, without apparent effects on worker health. Many but not all studies indicate that small (few ^{o}C) differences in temperatures can influence workers' speed or accuracy by 2% to 20% in tasks such as typewriting, learning performance, reading speed, multiplication speed, and word memory. Surveys have documented that indoor air temperature is often poorly controlled, implying an opportunity to increase productivity. Wyon (1996) estimated that providing $\pm$ 3^{o}C of individual temperature control would increase work performance by 3% to 7%. A smaller number of studies have documented improvements in work performance with better lighting, with benefits most apparent for visually demanding work. Increased daylighting was also linked in one study to improved student learning. Based on these studies and recognizing that performance of only some work tasks is likely to be sensitive to temperature and lighting, the estimated potential direct productivity gain is 0.5% to 5%, with the factor of ten range reflecting the large uncertainty. Considering only U.S. office workers, the corresponding annual productivity gain is $20 billion to $200 billion.

Benefits and Costs of Improving Indoor Environments

Two example calculations compared estimated productivity gains with costs for increasing ventilation rates and increasing filter system efficiency. The benefit-to-cost ratios were 14 and 8, respectively. Milton et al. (2000) estimated benefit-to-cost ratios of three to six for the reduced absence obtained with increased ventilation, neglecting diminished health care costs. For many other measures that increase productivity, we would expect similarly high benefit-to-cost ratios. For example, preventing or repairing roof leaks should diminish the need for costly building repairs in addition to reducing asthma symptoms. Some measures, such as removing pets from houses of asthmatics, have negligible financial costs.

Productivity Gains and Energy Efficiency

In many non-industrial workplaces, the cost of workers' salaries and benefits exceeds energy costs by approximately a factor of 100. Consequently, businesses should be strongly motivated to change building designs or operations if these changes improved worker performance by even a significant fraction of a percent or reduced sick leave by a day or more per year. While employers may be tempted to neglect energy efficiency when seeking to improve health and productivity, the most desirable measures or packages of measures are those that improve IEQ and simultaneously save energy. Examples of such measures are provided in Fisk (2000a).

Summary

Table 1 summarizes the estimated potential health and productivity gains from improved IEQ. While uncertainty in the magnitude of potential gains is high, even the lower bounds of the estimated benefits are very large from a societal perspective.

Table 1. Estimated potential productivity gains from improvements in indoor environments.

Source of Productivity Gain	Potential Annual Health Benefits	Potential U.S. Annual Savings or Productivity Gain (1996 $U.S.)
Reduced respiratory illness	16 to 37 million avoided cases of common cold or influenza	$6 - $14 billion
Reduced allergies and asthma	8% to 25% decrease in symptoms within 53 million allergy sufferers and 16 million asthmatics	$1 - $4 billion
Reduced sick building syndrome symptoms	20% to 50% reduction in SBS health symptoms experienced frequently at work by ~15 million workers	$10 - $30 billion
Improved worker performance from changes in thermal environment and lighting	Not applicable	$20 - $160 billion

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Daylighting and Human Performance

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Summary by Lisa Heschong

Background

Daylighting is the practice of using natural light from the sun or sky to provide illumination in interior environments. Fifty years ago practically all schools, and indeed, all workplaces used daylight as their primary illumination source. With the advent of inexpensive electricity and widespread use of fluorescent lighting in the 1950s and 60s, states began to abandon requirements for minimum daylight illumination requirements in their building codes. As energy costs soared, starting with the energy crises of the 70s, the glazed areas of buildings came to be regarded by many as an energy liability, seen as increasing both heating and cooling loads. Since cooling loads typically dominate in non-residential buildings, solar gain through windows became a driving concern. New buildings, no longer optimized for daylight, were constructed with lower ceilings and lower skin to volume ratios, and older buildings were often retrofitted with dropped ceilings, heavily tinted glass or insulating panels designed to reduce heat gain from windows. The net result has been a dramatic reduction in the amount of daylight available in our schools and workplaces over the past half-century.

Two forces are currently working to reverse this trend. First, we have realized that when lighting electricity consumption is considered along with heating and cooling as part of a whole building energy equation, daylighting typically provides a net energy benefit. Daylight is intrinsically more efficient than any electric source because it provides more lumens per unit of heat content. Therefore, if appropriate daylighting techniques are used to displace electric illumination, the savings for both lighting and cooling can be dramatic.

Secondly, a growing interest in the influence of indoor environments on health and productivity has resurrected interest in the potential health and productivity benefits of daylighting. Reductions in worker absenteeism, higher retail sales, and better student health were associated with increases in daylight in anecdotal reports; however, few formal scientific studies have addressed the relationship of daylight with these outcomes. Accordingly, we have been studying the association of increased daylight with student performance and retail sales. This summary article, describes the methodology and findings from our study in schools.

Methodology

We identified three large school districts that had a range of daylighting conditions in their classrooms. We collected test scores and demographic information for all second through fifth graders in the districts, and classified their classrooms for the amount and quality of daylight available. We choose to work with data on elementary school children since they typically spend all year in one classroom. Thus, we could directly isolate the effects of that one classroom. We also specifically selected districts that had a number of classrooms lit from above with skylights or roof monitors (“toplighting”). We reasoned that daylight provided through windows might have a number of complicating factors, such as the quality of view, whereas daylight provided from above typically had fewer other qualities that might influence results, thus we would be more likely to be looking at a pure “daylighting” effect.

The three districts were located in San Juan Capistrano, (Southern) California; Seattle, Washington; and Fort Collins, Colorado. These three districts have very different climates, different school building types, different curriculums and different testing protocols. The districts also provided us with information about student demographic characteristics, special school programs, size of schools, etc. We added information to these data sets about the physical conditions of the classrooms to which these children were assigned. We reviewed architectural plans, aerial photographs and maintenance records and visited a sample of the schools in each district to classify the daylighting conditions in over 2000 classrooms. Each classroom was assigned a series of codes on a 0-5 scale indicating the size and tint of its windows, the presence and type of any skylighting, and a daylighting code indicating the overall quality and quantity of daylight expected. Ultimately the study analyzed test scores performance for 8000 to 9000 students per district. We looked at both math and reading scores in all three districts, and analyzed data from each district separately, alternately using the holistic daylight code and the separate window and skylight codes, for a total of twelve statistical models.

The Capistrano Unified School District proved to be our most interesting study site for a number of reasons. The District administers standardized tests both in the fall and spring, allowing us to compare the change in students' math and reading test scores while they spent the year in one classroom environment. Because the District, like most in California, has a number of nearly identical portable classrooms at every elementary site, we were able to use these portables as a standardized condition controlling for the influence of individual school sites or neighborhoods. We also collected additional information at this district about the HVAC and ventilation conditions of the classrooms, which was also included in the statistical models used for data analyses.

Results

In Capistrano, using a regression equation that controlled for 50 other variables which might effect student performance, such as socio-economic status, special programs and school size, we found that students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% on reading tests in one year than those with the least daylight. Similarly, students in classrooms with the largest window areas were found to progress 15% faster in math and 23% faster in reading than those with the least window areas. Students that had a well-designed skylight in their room, one that diffused the daylight throughout the room and which allowed teachers to control the amount of daylight entering the room, also improved 19-20% faster than those students without a skylight. Classrooms with a skylight that allowed direct beam sunlight into the classroom and did not provide the teacher with a way to control the amount of daylight were actually seen to have a negative association with student performance. In addition, in three of the four Capistrano models, the presence of an operable window in the classroom was also seen to have a positive effect on student progress, associated with 7-8% faster learning. In statistical analysis of this type, variables of interest will sometimes be associated with the outcome variable only by chance. However, statistical tests indicated that a probability of 1% or less that the observed associations (of daylight and operable windows) to improved student performance was the result of chance.

Table 1: Improvements in Test Score (Fall to Spring in Capistrano School District) of Students in Classrooms with Better Daylighting

Daylighting Conditions in Classrooms	**Percent Average Improvement (Probability that Observed Association with Improved Test Scores is due to Chance)**	
	Reading	**Math**
Classrooms with most overall daylighting (from skylight and windows) relative to classrooms with least overall daylighting	26% (0.1%)	20% (0.1%)
Classrooms with most window area compared to classrooms with least window area	23% (0.1%)	15% (0.1%)
Skylight A (diffused illumination with manual operation for controlling illumination level) relative to no skylight	19% (0.3%)	20% (0.1%)
Skylight B (direct illumination with no controls) relative to no skylight	-21% (5.1%)	------
Operable windows, relative to classrooms without operable windows	8% (0.4%)	7% (0.1%)

The Seattle and Fort Collins school districts administer only one standardized test at the end of the school year. In these districts, the study used the final scores on math and reading tests at the end of the school year. We also had less detailed information about the schools; thus, the statistical models used to analyze the data had only 20 variables. In both of these districts we also found improved test scores associated with increased daylighting. Students in classrooms with the most window area or daylighting were found to have 7% to 18% higher scores on the standardized tests than those with the least window area or daylighting. The analyses indicated that that probability that these associations were chance associations was less than 1%.

Conclusions, Limitations and Further Work

The three districts have different curricula and teaching styles, different school building designs, and very different climates. And yet, the results of the studies show consistently positive associations of increased daylighting with improved test scores with a very low probability that the associations are the result of chance. This consistency across such diverse school environments persuasively argues that there is a valid and predictable effect of daylighting on student performance or that some other unidentified factor consistently linked with daylighting improves student performance.

There are also important limitations that should be considered. The models used to analyze the data explained about 25% of the natural variation in student performance. Thus, the other 75% of unexplained variation might be purely random or explained by other factors not included in our models, such as teacher quality, home life, health, nutrition, individual talents and motivation, etc. There always remains the possibility that some other variable left out of the equation is influencing results.

Reviewers of the school study asked if "better" teachers were more likely to be assigned to the more daylight classrooms, thus influencing the results. To answer this question, we collected additional data about the teachers in our Capistrano study that might be a measure of "better" teachers, such as years of experience, education level, and special awards. We found that these teacher characteristics only explained 1.4% of the variation in the assignment to daylit classrooms. Adding this information about the teachers to the original analysis did not significantly change the daylight effects in magnitude or significance, and only increased the models' explanation of variation (R^2) in student progress by about 2%.

Finally, these types of statistical studies show strength of association between variables, but cannot prove a causal relationship, such as between daylight and improved human performance. Other types of studies are necessary to prove a causal mechanism. Daylight is actually quite a complex phenomenon, involving variations in the intensity, spectrum, distribution, duration, and timing of light exposure. A number of potential mechanisms (alone or combined) that may have been responsible for the positive association between daylight and improved performance of students are listed below:

- *Improved Visibility Due to Higher Illumination Levels*
- *Improved Visibility Due to Better Light Quality*
- *Mental Stimulation*
- *Improved Mood, Behavior or Well-being*

A more exhaustive discussion on these issues can be found in the original report (Heschong Mahone Group, 1999). The potential energy savings from daylighting can be substantial. While twenty five percent of the existing non-residential building stock in the United States is amenable to side-lighting from perimeter windows, an additional sixty percent could potentially be reached from above, via skylights or roof monitors. If the link between increased daylight and improved human performance holds true with additional studies, it strongly suggests that we should act to reverse our current building trends that are reducing the presence of daylight in the workplace.

Acknowledgements

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Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints: A Summary

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Introduction

When selecting minimum ventilation rates, employers need to strike a balance between the well-recognized energy costs of providing higher minimum ventilation rates and the expected, but less well quantified, health benefits from higher rate of ventilation. This is a summary of the paper by Milton et al. (2000) that found low employee sick leave associated with high ventilation rates in a set of buildings located in Massachusetts. A simple cost-benefit analysis is also presented.

Methodology

As part of an evaluation of occupational and environmental health programs at Polaroid Corporation, the authors analyzed the sick leave records of 3720 hourly workers for calendar year 1994. The study population worked in 115 independently-ventilated work areas located within 40 buildings. Because an analysis of total sick leave was dominated by the extended periods of leave of a small number of workers, a second analysis considered only short-term sick leave. Sick leave data were determined from time cards. Corporate records were used to identify the personal and job characteristics of each worker (e.g., age, gender, work shift, years of employment, work location), to determine building characteristics (e.g., presence of humidification), and to determine if occupants of each space had filed a formal IAQ complaint within the past three years.

An industrial hygienist rated different work areas as having either “moderate” ventilation (~25 cfm/person) or “high” ventilation (~50 cfm/person) based on his knowledge of the ventilation systems and on average end-of-day CO_2 measurements. Ventilation rates were estimated from CO_2 measurements based on a steady state mass balance calculation. Although there are several sources of errors when ventilation rates are estimated from CO_2 data, this approach does enable the identification of two sets of work areas with clearly different average ventilation rates.

A statistical analysis technique, called Poisson regression, was employed to analyze the relationship of sick leave with ventilation rate category. . The analysis controlled for potential confounding by age, gender, seniority, hours of non-illness absence, work shift, ethnicity, crowding, and type of job (office, technical, or manufacturing worker) by including demographic variables in the regression equations. Crowding was defined as less than 100 ft^2 per employee. To eliminate the possibility of uncontrolled confounding of sick leave by occupational factors, a separate analysis considered only 636 office workers.

The average cost of outside air ventilation in the buildings that were studied was based on estimates of Polaroid Corporation staff as $3.22/cfm per person per year.

Results

Ventilation was rated as "moderate" in areas occupied by 17.5% of workers and high for the remaining workers. Humidification was provided to the spaces occupied by 90% of workers. Smoking was not permitted inside any building.

Higher total and short-term sick leave rates were associated with moderate ventilation rate (relative to high ventilation rate) and with humidification. Complaint areas were associated with increased short-term sick leave but not with increased total sick leave. Crowded areas tended to have lower sick leave rates. Key results are summarized in Table 1.

Lower ventilation rate was associated with a +130% greater rate of total sick leave, with 95% confidence limits of +54% to +244%. These results imply that 57% of total sick leave in the population with a lower ventilation rate (~ 5 days per year) was attributable to lower ventilation rate. Humidification was associated with a +96% greater rate of total sick leave, with 95% confidence limits of +25% to +208%. However, results of analyses of total sick leave are dominated by a small number of outliers; hence, the analyses of short-term sick leave among office workers may be more informative.

For the analyses of office workers, the power to examine the effects of humidification was low; therefore, data from the 36 office workers in non-humidified areas was excluded. In the resulting population, with approximately an equal number of employees in moderate and high ventilation spaces, lower ventilation rate was associated with a +53% greater rate of short-term total sick leave, with 95% confidence limits of +22% to +92%. These results imply that 35% of short term sick leave in the office worker population with the lower ventilation rate (~ 1.5 days per person per year) was attributable to lower ventilation. Complaint area status was associated with a +52% greater short-term total sick leave rate, with 95% confidence limits of +18% to +97%.

Table 1. Association of suspected risk factors with sick leave.

Risk Factor	**Percent Change (95% Confidence Limits)**	
	Total Sick Leave Within Hourly Workers	Short-Term Sick Leave Within Office Workers
Lower ventilation rate	+130% (+54% to + 244%)	+ 53% (+22% to +92%)
Humidification	+96% (+25% to +208%)	Not analyzed
Complaint area	No association	+52% (+18% to +97%)
Crowding	-46% (-39% to – 76%)	Not analyzed

An economic analysis (Table 2), assuming that the association observed was causal, indicated that the annual cost of increasing ventilation rates by 25 cfm per person ($80 per employee) would be easily offset by the savings from reduced sick leave ($480 per employees), for a net savings of $400/employee per year. Assuming that the 93.5 million full-time workers in the US are being provided the currently recommended ventilation rates (~ 20 cfm per occupant for offices), and applying these results, the estimated lost productivity would be $23 billion, and $15 billion in net savings per year could be obtained by doubling ventilation rates.

Table 2: Potential Economic Costs and Benefits of Increasing Ventilation Rate By 25 cfm per Person

Outcome	Annual Cost (Saving) per Employee*
Ventilation Energy Costs 25 cfm/ workers x $3.22/cfm/year	$80
Sick Leave Costs Sick Leave avoided (1.50 days per workers)	($480)
Net Savings	($400)

*Assumes hourly compensation of $40.

Discussion and Limitations

There are two likely mechanisms for a causal association of increased sick leave with lower ventilation rate and humidification: 1) irritant and allergic reactions to pollutants that decrease with ventilation and increase with humidification; and 2) increased respiratory illness due to either airborne spread of infection or an increase in susceptibility. This study cannot confirm either mechanism; however, the results more strongly support the second mechanism because controlling for complaints did not reduce the association of sick leave with either lower ventilation rate or humidification. A few prior studies have found lower prevalences of respiratory illnesses with higher ventilation rates and many prior studies have found that that higher ventilation rates are associated with a reduction in irritant and allergic-like health symptoms (Seppanen et al. 1999).

The method used to estimate ventilation rates (CO_2 data and expert judgment) is one of the limitations of this study. While there is little doubt that that the “high” ventilation rate spaces in this study have a higher average ventilation rate than the “moderate” ventilation rate spaces, the average ventilation rates presented are rather rough estimates.

Confirmation of these study results in a study with better ventilation rate measurements is highly desirable. An experimental study, i.e. one that modifies ventilation rates, would be stronger than another observational or cross sectional study. Objective tests to confirm respiratory infections are recommended to elucidate the underlying mechanisms.

Practical Implications

This study shows that the energy cost of providing additional ventilation may be more than offset by the savings that result from reduced sick leave. The study suggests substantial benefits from increasing ventilation rates above the minimum rates specified for offices in ASHRAE Standard 62-1999 “Ventilation for Acceptable Indoor Air Quality” (ASHRAE 1999). These findings should be considered in future revisions of the standard. Because building energy efficiency is important for environmental protection and for the nation’s energy security, future research is needed to identify other less energy intensive methods of reducing sick leave.

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Association of Ventilation Rates and CO_2 Concentrations with Health and Other Responses in Commercial and Institutional Buildings: A Summary

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Introduction

This article summarizes the review by Seppänen et al. (1999) of current literature on the relationship of ventilation rates and carbon dioxide concentrations in non-residential and non-industrial buildings (primarily offices) with the health of the building's occupants and with the occupants' perceptions of indoor air quality (IAQ). While ventilation rates do not directly affect occupant health or perception outcomes, they affect indoor environmental conditions including air pollutant concentrations that, in turn, may modify the occupants' health or perceptions. The review aims to provide a better scientific basis for setting health-related ventilation standards. Space constraints prohibit a detailed description of both ventilation rate and carbon dioxide concentration studies; therefore, this summary focuses primarily on the ventilation rate studies.

Methodology

The review considered the following three human responses due to their widespread occurrence and potentially great economic impact: (1) communicable respiratory illnesses such as common colds and influenza; (2) sick building syndrome (SBS) symptoms such as eye, nose and throat irritation, headache, tight chest, and wheeze, which decrease when the individual leaves the building; and (3) perceived unacceptability or poor quality of air.

The review included almost 30,000 subjects in 20 ventilation rate studies, and more than 350 buildings. Most studies included male and female office workers, but some studies were performed with special groups: army trainees, elderly people in a nursing home, inmates in a jail, pupils in schools, and hospital personnel.

Two types of field studies were included in the review. In cross-sectional studies, data on health (or perceived IAQ) outcomes, ventilation rates, and other relevant factors that may influence health or perceived IAQ were collected from multiple buildings or building spaces and analyzed with statistical models. A major weakness of this study design is that many factors other than ventilation rate, which vary among the buildings, may influence the health outcomes, confounding the association of ventilation rate with the health outcome. The criteria for including cross-sectional studies in the review were: (1) at least three buildings or ventilation zones, (2) statistical analysis of results, and (3) control in the statistical analyses for confounding by personal factors such as gender. Many of these studies also controlled for potential confounding by some job, building, and indoor environmental factors.

The second major type of study is an experimental or intervention study. In one or more buildings or spaces, the ventilation rate was set sequentially at two or more values and the health outcomes were recorded at each ventilation rate. Much of the potential confounding was eliminated with this type of study; for example, personal, job, and most building characteristics are unchanged when ventilation rates are modified. Some residual confounding may occur due to parameters that may change which may vary among the experimental periods, such as indoor temperature. The review included only experimental studies that met study quality criteria, as described in the original paper.

As a primary indicator of the magnitude of ventilation rate, this review used outdoor air flow rate per person (cfm per person). This was the most commonly reported ventilation rate metric in the reviewed studies, and the metric often used in codes and standards. In many studies, only the rate of mechanical outside air supply was measured, thus, the measurements did not account for additional ventilation caused by air infiltration.

Many studies assessed the association of ventilation rates with multiple health or perception outcomes (e.g, influenza and also total respiratory illness) or performed multiple analyses using different categories of ventilation rates or different subsets of study data. Consequently, many studies provided multiple “assessments” of the associations of ventilation rates with human outcomes. Therefore, in the subsequent discussion we often refer to assessments.

Studies used statistical models to quantify the strength and statistical significance of the associations between ventilation rates and health outcomes. As a measure of strength of associations, we use the percentage change in the prevalence of the health outcome estimated from results presented within the original papers. When we use the term “statistically significant”, it means that there is a less than 5% probability that the reported association between ventilation rate and a health outcome is the result of chance.

Results

Communicable respiratory illnesses and ventilation rates

Only three studies of communicable respiratory illnesses were included in the review. These studies took place in a military barracks, a nursing home, and a jail. All found a statistically significant increase in the prevalence of illness in the group with a lower ventilation rate. The percentage increases in respiratory illness with a lower ventilation rate varied between 50% and 120%, with one outlier of 370%. A fourth study within a set of office buildings found a statistically significant 53% increase in short-term absence with lower ventilation rates. Short-term absence may be a surrogate for communicable respiratory illness.

SBS symptoms and ventilation rates

Twenty of 27 assessments found a statistically significant increase in the prevalence of one or more types of SBS symptoms as ventilation rates decreased. Sixteen of these assessments found a statistically significant increase in the prevalence of more than half of the reported types of SBS symptoms. The results of several studies suggested that the risk of SBS symptoms continues to decrease as ventilation rates increase above 20 cfm per person, the minimum rate for offices in ASHRAE Standard 62-1999. However, the benefits of increasing ventilation rates above 20 cfm per person were less consistent than the benefits of increasing ventilation rate up to 20 cfm per person. The percentage increase in SBS symptoms with lower ventilation rates varied widely. In 9 assessments, the prevalence of at least one symptom increased by more than 80%. The results of one of the largest studies implies that, on average, a 10 cfm per person increase in ventilation rate would reduce the prevalences of the most common SBS symptoms by more than one third.

Three assessments found a significant *increase* in the prevalence of SBS symptoms with increases in ventilation rate. Each of these studies took place during winter in a cold dry climate. We hypothesize that the very low indoor humidities that occur with high ventilation rates in such climates may have caused the increase in symptoms.

Perceived IAQ and ventilation rates

Seven of eight studies found a statistically significant worsening in perceived IAQ as ventilation rates decreased, while one study had the opposite finding.

Carbon Dioxide Studies

The review included 21 carbon dioxide concentration studies involving more than 30,000 subjects in over 400 buildings. Over half of the assessments found that a higher CO_2 concentration was significantly associated with a worsening of at least one outcome, generally SBS symptom prevalence or perceived air quality. As such, the results of the studies on the association of CO_2 concentrations with health and perceived IAQ outcomes support the findings of an association of ventilation rates with outcomes.

Discussion and Limitations

This review provides persuasive evidence that health and perceived air quality will usually improve with increased outside air ventilation. The full paper examines several potential sources of bias, but identified none likely to explain the overall findings. Nevertheless, there are several important limitations in the current data and associated knowledge. Most studies were performed in Europe and most were in office buildings. Very few studies have been performed in hot humid climates. Relatively few studies of communicable respiratory illness have been reported. The benefits of increasing ventilation rates above 20 cfm per person are less certain than the benefits of increasing ventilation rates up to 20 cfm per occupant. Existing data do not indicate whether outside air supply per person or per unit floor area is more strongly associated with health and perceived IAQ. Finally, the reasons for improved health and perceived air quality with increased ventilation are uncertain.

Practical Implications

The available data indicate that occupant health and perceived IAQ will usually be improved by avoiding ventilation rates below 20 cfm per occupant and indicate that further improvements in health and perceived IAQ will sometimes result from higher ventilation rates up to 40 cfm per person. These findings are relatively consistent for office buildings located in cold or moderate climates, but less certain for other building types and climates.

The limitations in the existing data point to several research needs. Some of the pressing needs include research on the benefits of increasing ventilation rates above 20 cfm per occupant, research involving schools and retail buildings, and research within hot humid climates. Because increases in ventilation may increase building energy consumption, research is also needed to identify practical methods of decreasing minimum ventilation requirements by reducing indoor pollutant emissions or by increasing the effectiveness of ventilation in controlling pollutant exposures.

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Table 1. Summary of major findings.

Outcome	Number of Studies or Assessments	Number finding a Statistically Worsening (Improvement) in Outcomes at lower Ventilation Rates	Increase (Decrease) in Outcome With Lower Ventilation Rates
Communicable Respiratory Illness or Short-Term Absence	4	4 (0)	51%, 53%, 94%, 120%-370% ---
SBS Symptoms	27	20 (3)	Usually 10% -100% >80% in 9 assessments (54% - 420%)
Perceived Less Satisfactory IAQ	8	7 (1)	60% to 180% (53%)

The NIOSH Indoor Environmental Evaluation Experience. Part Three: Associations Between Environmental Factors And Health Outcomes

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Introduction

In recent years, the increasing numbers of health complaints among workers in indoor, nonindustrial environments have prompted research to identify factors associated with these health complaints. This paper briefly summarizes a study [1,2], based on surveys including 2,435 workers in 80 complaint office buildings, of the associations between HVAC design and maintenance characteristics or building maintenance characteristics and work-related lower respiratory symptoms, allergic symptoms, and asthma development.

Methods

Study data were collected in the Health Hazard Evaluations (HHE) program of the U.S. National Institute for Occupational Safety and Health (NIOSH). Following publicity from an October 1992 national television news broadcast, NIOSH received numerous requests for HHEs in indoor work environments. Limited resources of the HHE program allowed evaluations of 160 buildings, selected systematically from 500 requests received by February, 1993. The primary evaluation area typically was a floor or section of the building of primary concern to the evaluation requesters. The environmental evaluation consisted of an observational walk-through survey, with completion of information checklists regarding the entire building, the evaluation area, and the components of the heating, ventilation, and air conditioning (HVAC) systems. In addition, health questionnaires were completed by all occupants present in the evaluation area of the building on the day of the survey. All symptom data were self-reported. All evaluations were conducted between April and July 1993. This analysis includes data from the 80 office buildings, of 105 office buildings evaluated, for which complete, correctly collected data were available.

Among the 2,435 respondents providing health questionnaire data, 814 (34%) were male, 1,607 (66%) were female, and 1,304 (54%) were non-smokers. Respondents ranged in age from less than 20 years to over 60 years. Overall, they had worked a median of four years in the office building, although this time varied between less than a year to 35 years.

A “work-related symptom” was defined as one reported at least once per week in the previous four weeks and which improved when the employee was away from the work site. Two symptom groups were defined. The “multiple lower respiratory symptom” group required having at least three of the following work-related symptoms: shortness of breath, cough, chest tightness, and wheezing. The “multiple allergic symptom” group required all three of the following:

sneezing, eye irritation, and stuffy/runny nose/nasal congestion. Diagnosis of asthma by a physician after the respondent began work in the building was also determined.

Certain HVAC and building characteristics, e.g., poor drainage from coil drain pans, as noted on checklists by NIOSH staff during walk-through surveys, were considered potential risk factors or protective factors for health outcomes. These HVAC and building characteristics were included as variables in statistical analysis models. This summary discusses variables related to HVAC system design, HVAC maintenance, and building maintenance.

The statistical models determined the strength and statistical uncertainty of associations between health outcomes and the building and HVAC characteristics. The models calculate values of relative risk (RR). The RR represents the magnitude of the increase (or decrease) in the prevalence of a health outcome among occupants of buildings with particular HVAC or building characteristics, relative to the prevalence of the health outcome in buildings without that HVAC or building characteristic. The models produced values of RR adjusted for the effects of age and gender. As examples, a RR of 1.5 indicates that the prevalence of the health outcome is increased by 50% in buildings with the risk factor, while a RR of 0.7 indicates that the prevalence of the health outcome is decreased by 30% in buildings with the risk (or protection) factor. To convey results using familiar terminology, results are presented as percent increases or percent decreases in prevalence of health outcomes.

Suspected risk (or protection) factors will sometimes be associated by chance with increased or decreased health outcomes in the sample included in the study (in this case, 80 office buildings), despite the absence of an association in the larger population (in this case, all office buildings). Consequently, the statistical models that calculated values of RR also calculated the probabilities that the observed associations were merely chance associations. The results presented in Table 1 include only increases or decreases in health outcomes that have a 10% or smaller probability of being the result of chance (denoted by $p \le 0.10$). For most of these results there is a 5% or smaller probability that the increase or decrease in the health outcome is due to chance ($p \le 0.05$).

Results

The percentage increases or decreases in health outcomes, adjusted for age and gender, are shown in Table 1.

Lower respiratory symptoms

Fifteen HVAC variables hypothesized to be risk factors were associated ($p \le 0.10$) with 60% to 210% increases in prevalence of lower respiratory symptoms. Most of these HVAC conditions were indicators of debris, moisture, or other pollutant sources within 25 feet of the outside air intake of the HVAC system or within the HVAC system. The two HVAC conditions most strongly associated with increased lower respiratory symptoms were debris in the outside air intake and poor or no drainage from the cooling coil drain pan. Three building maintenance variables were associated ($p \le 0.10$) with a *reduced* prevalence of lower respiratory symptoms: daily vacuuming; application of interior pesticides; and monthly floor stripping and waxing.

Allergic symptoms

One HVAC design variable, presence of a cooling tower, was associated ($p \le 0.10$) with a 70% reduction in allergic symptoms. Three HVAC maintenance variables (no test and balance report, poor HVAC cleanliness, air ductwork never cleaned) and two building maintenance variables (daily surface dusting, application of interior pesticides) were associated ($p \leq 0.10$) with 30% to 80% increases in allergic symptoms.

Asthma diagnosed after beginning work in the building

Two HVAC maintenance variables (dirty filters, debris in outside air intake) and one building maintenance variable (recent renovation including new drywall) were associated ($p \leq 0.10$) with 100% to 150% increases in asthma diagnosed after beginning work in the building. Three variables (ductwork never cleaned, daily surface cleaning with solution, daily surface dusting) were associated with a decrease in asthma diagnosed after beginning work in the building.

Discussions

Limitations

When considering the results of this study, it is important to remember that an association does not prove causation and that some of the reported associations are still likely to be chance associations, e.g., if one performs 100 statistical tests, ten chance associations with $p \leq 0.1$ would be expected. In fact, some of the findings are contrary to expectations. For example, it seems unlikely that a renovation including new drywall within the last three weeks could cause an increase in asthma diagnosis, since medical examinations and diagnoses for asthma would usually take more than three weeks. Some findings are apparently contradictory, e.g., air ductwork never cleaned is associated with an 80% increase in allergy symptoms and a 40% decrease in asthma diagnosis, an apparently contradictory set of findings since allergy underlies most cases of asthma.

Another limitation is that the analyses did not account for correlation among risk factors. Many of the risk factors in this analysis existed in combination with multiple other risk factors, as is commonly found in investigations of complaint buildings. For example, in the 19 buildings with no scheduled air handler inspections, lack of cleanliness in the HVAC system was noted in 17 buildings, problems with the particulate filtration system were noted in 14 buildings, testing and balancing reports were not available in seven buildings, and the air ductwork had never been cleaned in six buildings. A health outcome that is statistically associated with one risk factor may actually be caused by another associated risk factor.

Since this study included only office buildings where environmental evaluations have been requested, the buildings may not accurately represent office buildings as a whole. Other limitations are mentioned in the papers on which this summary is based[1,2].

Interpretation of results

Despite these limitations, this study identified many suspected risk (or protection) factors and it is unlikely that such a large number of relatively strong associations are the result of chance. The findings of this study suggest that adverse health outcomes among building occupants may be reduced through improvements in HVAC system design and maintenance and by maintaining outside air intakes distant from potential pollutant sources. Consequently, the overall results of this study provide support for the implementation of available guidelines for maintenance and design of HVAC systems[3]. The implications for building maintenance are less clear because several of the building maintenance variables are associated with both decreases and increases in health outcomes. The most consistent findings were for daily surface cleaning with solution and for daily vacuuming, which were suggested as being health protective.

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Table 1. Increases and decreases in health outcomes associated with variables of HVAC design and maintenance and building maintenance. The table lists only increases or decreases in health outcomes that have a 10% or smaller probability of being chance findings. When there is a 5% or smaller probability that the increase or decrease in the health outcome is a chance finding, the increase or decrease is shown in bold type.

Category	Variable	Increase in Multiple Lower Respiratory Symptoms	Increase in Multiple Allergic Symptoms	Increase in Asthma Diagnosed after Beginning Work in Buildings
HVAC Design	***Outdoor air intake within 25 ft. of :***			
	Standing water	**+130%**	---	---
	Exhaust vents	**+140%**	---	---
	Sanitary vents	**+120%**	---	---
	Cooling tower	---	**-70%**	---
	Vehicle traffic	**+80%**	---	---
	Trash dumpster	**+110%**	---	---
HVAC Maintenance	***No scheduled air handler inspection***	+100%	---	---
	No testing and balancing report available	---	**+80%**	---
	Particulate filtration system:	---	---	---
	Filters not secure in place	**+120%**	---	---
	Dirty filters	**+90%**	---	**+100%**
	HVAC cleanliness*	**+80%**	+30%	---
	HVAC condition:			
	Debris inside air intake	**+210%**	---	**+100%**
	Residue/dirt in drain pans	**+60%**	---	---
	Poor or no drainage from pans	**+200%**	---	---
	Dirty ductwork	**+110%**	---	---
	Presence of moisture in HVAC system	**+120%**	---	---
	Air ductwork never cleaned	+180%	**+80%**	-40%
Building Maintenance	***Daily surface cleaning with solution***	---	---	**-50%**
	Daily vacuuming	**-50%**	---	---
	Daily surface dusting	-40%	**+30%**	**-50%**
	Interior pesticides have been applied	**-50%**	**+50%**	---
	Floor stripping and waxing done monthly	-60%	---	---
	Renovation including installation of new drywall within last three weeks	---	---	**+150%**

* Any of 10 conditions in the HVAC system: dusty air handler, dirty sound liner, presence of debris inside air intake, moist sound liner, dirty coils, residue/dirt in drain pans, poor/no drainage from drain pans, dirty or mist ductwork, or dirty duct liner.

Appendix C: List of Links Added to the IHP Web Site

This page lists the links to other resources on the internet that are relevant to the IHP project. It is broken down into different categories for easy navigation and can also be accessed at www.IHPCentral.org. This is a dynamic list that will grow in future as more resources will be added.

Publications (Journals, Conferences, Publishing Houses)

- American College of Occupational Environmental Medicine
- American Journal of Health Promotion
- Business and Health Magazine
- International Journal of Productivity & Quality Research
- International Journal of Indoor Air Quality and Climate
- International Society of Indoor Air Quality and Climate
- Journal Titles, and Abbreviations
- National Library of Medicine - Entrez-PubMed
- On-Line version of the ILO's Encyclopedia of Occupational Health and Safety

Organizations (Public and Private)

- Aerias, Better Health through Indoor Air Quality Awareness
- Aerotech Laboratories, Inc.
- Air Infiltration and Ventilation Centre
- American Lung Association (indoor air pollution in the office)
- American Industrial Hygiene Association (AIHA)
- Environmental Protection Agency's IAQ homepage
- Health Enhancement Research Organization
- IAQ homepage for Environmental Health Center/National Safety Council
- IEQ Strategies
- National Institute for Occupational Safety and Health
- National Lighting Bureau
- Office Productivity Network in the United Kingdom
- Workplace Productivity Consortium

Research Centers

- Center for Environmental Design Research
- Center for Building Performance and Diagnostics
- Danish Building and Urban Research Homepage
- Lawrence Berkeley National Laboratory - Indoor Environment Department
- Lighting Research Office Home Page