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SURVEY OF PROTOCOLS FOR CONDUCTING INDOOR AIR QUALITY INVESTIGATIONS IN LARGE BUILDINGS

Roy C. Fortmann, Ph.D

ABSTRACT

Numerous investigations are conducted in large buildings each year to evaluate health and comfort complaints that building occupants perceive to be related to poor indoor air quality. Some guidelines have been developed for conducting indoor air quality investigations, but standardized building diagnostics protocols have not been developed. The purpose of this work was to compile information that might be used to develop standardized protocols. A computerized literature search and a mail-out survey were conducted. A number of reports describing indoor air quality investigation guidelines and protocols were identified. The recently-published EPA/NIOSH Building Air Quality document contained the most comprehensive guidance. A survey of other documents identified many common elements, particularly for the collection of information during the initial walk-through investigation phases. However, there was not a common approach to the measurement of physical and chemical parameters during an investigation. This paper describes common elements and differences in the technical approach to building investigations.

KEYWORDS: Indoor, Indoor Air Quality, IAQ, Sick Building, SBS, Diagnostics, Investigative Protocols

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Numerous investigations are conducted in large buildings each year to evaluate health and comfort complaints that building occupants perceive to be related to poor indoor air quality. Some guidelines have been developed for conducting indoor air quality investigations, but standardized building diagnostics protocols have not been developed. The purpose of this work was to compile information that might be used to develop standardized protocols. A computerized literature search and a mail-out survey were conducted. A number of reports describing indoor air quality investigation guidelines and protocols were identified. The recently-published EPA/NIOSH Building Air Quality document contained the most comprehensive guidance. A survey of other documents identified many common elements, particularly for the collection of information during the initial walk-through investigation phases. However, there was not a common approach to the measurement of physical and chemical parameters during an investigation. This paper describes common elements and differences in the technical approach to building investigations.

INTRODUCTION

In recent years, there has been increased recognition of the importance of air quality indoors for the health, comfort, and productivity of building occupants. As a result of health and comfort complaints by building occupants perceived to be related to poor indoor air

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quality, numerous indoor air quality (IAQ) investigations have been performed in recent years. The technical approaches used to investigate complaints related to the indoor environment have been highly variable. Investigative protocols have often been based on the investigator's background and experience, availability of monitoring instrumentation, and past successes, rather than on well-designed and validated diagnostic practices. This situation has improved in recent years with the publication of a number of documents providing guidelines for indoor air quality investigations in large buildings. However, standardized protocols for building investigations have not been developed.

The purpose of this work was to compile information on protocols that have been used to investigate indoor air quality in large buildings. The objective was to review the available protocol information to identify common elements and differences in the technical approaches to building investigations. Such information may be used in the development of standardized protocols and to identify elements of diagnostic protocols that require additional research and development. Results of this survey, conducted for the U.S. Environmental Protection Agency (EPA), have been summarized in a draft report (Fortmann, 1992). It should be noted that in this project, we did not critically assess the effectiveness of the investigative protocols for identifying the causes of indoor air quality problems. Such an assessment was beyond the scope of the project. A critical assessment of investigative protocols would require a substantially larger effort because many reports published in the open literature do not contain complete information on either protocols or test results.

A computerized literature search covering the last ten years was conducted to compile reports describing guidelines or protocols for conducting indoor air quality investigations in large buildings, such as offices, schools, public access buildings, and other non-industrial work places. A mail-out survey was also conducted in an attempt to obtain unpublished protocol information from investigators who had published case studies in the open literature during the last five years.

This paper summarizes information obtained from the literature survey. Elements of indoor air quality investigations are described and discussed with respect to the types of information that is being collected and the methods of collection. The similarity and the differences in the approaches to information and data collection are described.

SURVEY RESULTS

Published Guidelines and Protocols

A number of reports, listed in Table 1, were identified that provide guidelines or detailed methods for conducting indoor air quality investigations in large buildings. The list should not be considered to be all inclusive. A number of reports of indoor air quality investigations have been published in journals and in the proceedings of the International Conferences on Indoor Air Quality and Climate. Although many of these reports contained useful information, detailed descriptions of the investigative protocols are often not included in these reports because of the limited page length. Exclusion of reports does not imply that they were not identified in the survey or that they were not considered to be useful.

The most comprehensive guidance document for conducting problem-solving building investigations is "Building Air Quality - A Guide for Building Owners and Facility Managers," recently prepared by the U.S. Environmental Protection Agency (EPA) and the National Institute for Occupational Safety and Health (NIOSH) (U.S. EPA, 1991). It provides comprehensive guidance for all stages of problem-solving IAQ investigations.

Relatively detailed guidance is also provided in other reports listed in Table 1. Davidge et al. (1989), for example, provide general guidelines for the preliminary assessment, simple and complex measurement stages and detailed checklists for observations of pollutant sources. Goyer and Nguyen (1989) provide comprehensive guidance for the identification, evaluation, and control of indoor environment problems. Extensive information is provided for four groups of parameters: ventilation system characteristics, comfort parameters, contaminants, and the work environment.

General guidance for conducting building investigations is provided by a number of investigators. Rafferty (1989) provides an overview of the most important elements of a protocol for an initial investigation. The paper includes a comprehensive listing of information that should be collected. Hansen (1991) provides general guidance for conducting IAQ problems, and other factors related IAQ in large buildings.

Lane et al. (1989) and Woods et al. (1989) provide extensive protocol information for building diagnostics in papers published in recent years. Turner et al. (1985) have also published a number of papers that provide guidance on investigative methods and specific measurement methods. There are also numerous case studies reported in the scientific literature that provide information on investigative strategies and measurement methods. However, most case study reports do not contain detailed information on investigative protocols due to space limitations.

Diagnostic Strategies

Practically all problem-solving IAQ investigations are performed using a multi-stage approach that involves information gathering, hypothesis development, and hypothesis testing at each stage. Guidance provided in recently-published documents stresses that many building problems can be solved on the basis of information collected by observation during an initial walk-through inspection. Measurements of physical and chemical parameters are recommended by many investigators only to test hypotheses in later stages of an investigation. The goal of this approach is to minimize the number of stages, and therefore, resources required to identify the problem. Although this is a general approach, investigators differ with respect to how each stage is implemented. Some investigators perform simple, low-cost measurements during the first stage, while others are strongly opposed to any measurements during the initial stage of the investigation.

The solution-oriented, multi-stage investigation approach described by Hansen (1991) that is summarized in Table 2 is typical of the approach used by many investigators. Each phase of the investigation involves observations or measurements of increasing complexity and requires an increasing level of expertise about IAQ and building systems performance. Hansen's approach is similar to that recommended by the U.S. EPA (1991). They recommend a multi-stage approach to building investigations that begins with simple observations by "in-house" personnel to develop hypotheses about the problem that can be easily tested using resources available in-house. As the hypotheses become increasing complex, the investigation may require contractors with specialized knowledge and expertise. The EPA guide for building owners and facility managers provides what they term a "toolbox" of diagnostic activities for collecting information on the basic factors influencing IAQ: the occupants, the HVAC system, pollutant pathways, and contaminant sources.

The Honeywell Indoor Air Quality Diagnostics protocol (Rask, 1991) is a two phase approach. The initial phase consists of on-site review of documents, interviews with facility staff, and on-site inspection. Phase 2 is a more extensive analytical approach.

Lane et al. (1989) and Woods et al. (1989) have described an approach to building diagnostics in which the building is characterized in terms of (1) the type and location of sources of contaminants, (2) the four elements that comprise a building system [structure, envelope, interior spaces, and services], and (3) the performance characteristics during the life of the building. Their approach includes three phases. In the first phase, the consultation phase, the objective is to focus diagnostic procedures on problem areas. The building is characterized in terms of the structure, envelope, occupied spaces and services using available plans and construction documents and by professional observations. The output of this phase is to define the scope and objectives of the investigation, develop a hypothesis, and make recommendations to building management. Qualitative diagnostics are performed in the second phase if required to test a hypothesis or validate a recommendation. This is accomplished primarily through engineering analysis techniques. Lane et al. (1989) emphasize that measured data may not be required during this phase. The third phase is the quantitative diagnostics phase. This phase is implemented only if required for further hypothesis testing or validation of recommendations. Measurements to be performed depend on the hypothesis to be tested. The reports by Lane et al. (1989) and

Woods et al. (1989) provide general guidance, but detailed methods are not included in the reports.

Many investigators (Baldwin et al., 1991; Davidge et al., 1989; Goyer and Nguyen, 1989; U.S. EPA, 1991; and others) do not recommend any physical or chemical measurements during the preliminary assessment and walk-through inspection stage of an investigation. Rafferty (1989), however, recommended a Phase 1 investigation approach that includes low-cost, semi-quantitative analysis. In addition to collection of information on the structure, HVAC, and sources, he recommends measurements of temperature and relative humidity, CO_2, total volatile organic compounds (TVOC) and bioaerosols. He believes these measurements are low-cost and can provide useful information on potential contributors to the problem in terms of airborne contaminants, effectiveness of the HVAC to remove those contaminants, and potential mitigation strategies.

There does not appear to be a consensus on the usefulness of screening measurements during the first visit to a building. Many investigators probably measure temperature, relative humidity, and CO_2 during the first visit because these measurements are low cost and simple to perform. Although the emphasis during the first visit should be on collection of comprehensive information by observation, there may be situations where simple measurements will be useful to the investigator and building management. Gammage et al. (1989) point out that many clients demand some type of immediate testing during the first visit to a "problem" building.

Initial Walk-through Inspection and Collection of Information by Observation

The collection of appropriate background information prior to conducting an IAQ investigation and the collection of information by observation during the initial walk-through investigation are critical to the investigator's understanding of the problem, the building, its occupants, and the factors affecting IAQ. In many cases, this information will be adequate for identifying the problem and developing appropriate solutions. At a minimum, this information will be critical to the development of hypotheses that may be tested. This survey of the literature seems to indicate a general consensus on the types of information that should be collected during the initial stages of an investigation.

The EPA Building Air Quality document (U.S. EPA, 1991) provides extensive guidance on the collection on information during the initial walk-through inspection. Information can be collected on the occupants, HVAC system, pollutant pathways, and contaminant sources using forms provided in the document.

Rafferty and Quinlan (1989) have published a comprehensive listing of background information that should be collected on the building, the HVAC system, contaminant sources, and the occupants. Goyer and Nguyen (1989) also provide comprehensive guidance on the background information that should be collected. They have developed a questionnaire for each of four groups of parameters: the ventilation system, comfort, chemical contaminants and bioaerosols, and the work environment. Another source of questions used to obtain information during the initial walk-through investigation is provided in Public Works Canada's Indoor Air Quality Test Kit: User Manual (Rajhans, 1989). Thirty seven multi-part questions are used to collect information on the building, pollutant sources, the HVAC, and the affected workstation. A strong emphasis in these guidelines is placed on identification of contaminant sources, information which may be used to develop mitigation strategies or for development of hypotheses and protocols for more comprehensive measurements in later stages of an investigation.

The importance of the condition and the performance of the HVAC system is recognized by all investigators. Practically all investigators place a major emphasis on performing a comprehensive evaluation of the HVAC system and ventilation characteristics during the initial walk-through investigation. Although most of the reports listed in Table 1 provide guidance for evaluating HVAC systems, the EPA Building Air Quality document provides the most comprehensive guidance and greatest level of detail for evaluation of HVAC systems of any documents that were reviewed in this survey. Because every building and its HVAC system are different, there is no "cookbook" method for performing an investigation. However, the EPA document provides guidance and details on investigative procedures that should prove to be applicable to most HVAC systems. Both a short, four-page HVAC checklist and a long, 14-page HVAC checklist have been developed by EPA. The guidance document also includes an Appendix that provides introductory material and information on specific systems for building owners and managers.

Employee Survey Questionnaires

Survey questionnaires have been used extensively in research studies with the objective of relating environmental factors in buildings to health and comfort complaints and symptoms. They are used to a varying degree in problem-oriented building investigations. Some investigators use simple questionnaires to collect information during the initial phases of an investigation. Others find questionnaire data of little value during the initial phases. Another group of investigators avoids using any questionnaires for fear of causing hysteria in the population of building occupants.

Examples of questionnaires have been published in a number of reports (Table 3). The list is not all inclusive. Dunteman et al. (1991) also listed questionnaires from the University of California, Hal Levin, Peder Skov, and Biospherics, Inc., in a recent report on questionnaire design.

The questionnaire used for the EPA Headquarters Building (U.S. EPA, 1989) was a comprehensive 20-page questionnaire containing questions relating to the description of the workstation, the employee's health and well-being, the employee's present work environment, characteristics of the job, and demographics. The EPA questionnaire has been modified for use by other investigators (Daisey et al., 1990; GEOMET, 1990). The questionnaires described by Rajhans (1989), Raw et al. (1991), and Quinlan et al. (1989) are also quite comprehensive. Shorter questionnaires have been used by other investigators. Wood et al. (1989) and Rask (1991) recommend use of a short two-page questionnaire to collect information from occupants on the acceptability of the indoor environment in terms of acoustics, air quality, lighting, and thermal attributes.

There is a controversy over the use of a questionnaire during the initial phase of an investigation of a "sick" building. Investigators at Healthy Buildings International (HBI, 1991) for example, recognize that questionnaires may help to identify "clusters" or complaint areas, but they do not believe questionnaires will lead to solutions that cannot be identified by an engineering study of the building. There is also concern that distribution of questionnaires to building occupants may aggravate and heighten awareness of IAQ complaints among occupants. As an alternative to formal questionnaires, informal interviews may be appropriate during the initial assessment phase. In the Building Air Quality guide published by EPA (1991), they suggest that formal questionnaires are useful for IAQ research, epidemiological investigations, complex building investigations, and when litigation is a possibility. EPA advises against development and administration of questionnaires by in-house personnel. They recommend that the questionnaires be designed and executed by consultants with expertise in this area.

Measurement Parameters and Protocols

Although the guidelines for performing some components of a building investigation, for example, inspection of the HVAC, are extensive and quite detailed, the guidelines for performing physical and chemical measurements during an IAQ investigation are much less extensive and usually not as detailed. Some general guidelines have been developed to assist investigators in determining what contaminants should be measured and how the measurements should be performed, but this stage of IAQ investigations requires a higher level of expertise and experience in IAQ than the early stages of an investigation. This is not surprising due to the large number of sources of contaminants in a building, the wide range of measurement methods available, the size and complexity of buildings in which measurements must be performed, and our current, limited, understanding of the relationship between contaminant concentrations and occupant health and comfort complaints/symptoms.

The most frequently used screening measurements for problem-solving IAQ investigations are dry bulb temperature, relative humidity, carbon dioxide, and carbon monoxide. Temperature and relative humidity are used as indicators of comfort. Carbon dioxide is used extensively as an indicator of the adequacy of outdoor air supply. Carbon monoxide is used to determine if combustion pollutants are entering the building from outdoor areas such as parking garages, loading docks, and bus stops. All four of these parameters are easily measured with portable monitors.

Total volatile organic compounds (TVOC) and biological aerosols (fungi and bacteria) have also been used as screening measurements (Gammage et al., 1989; Rafferty and Quinlan, 1989). TVOC measurements with portable monitors may be useful to identify "hot spots" of contaminant sources in a building, but not for ambient air measurements in the work spaces. Measurements of nonspecific airborne microorganisms during initial IAQ investigations are the subject of controversy. Gammage et al. (1989) suggest that such measurements are useful for identifying gross microbial contamination, but not to show a causal relationship to health symptoms. Others believe that gross contamination can be determined by observation and that non-specific measurements may be misleading because the concentrations of specific organisms of concern are not quantified.

According to the U.S. EPA (1991), a chemical sampling strategy should be developed based on a comprehensive understanding of how the building operates, the nature of the complaints, and a plan for interpreting the results. In the Building Air Quality document it is further stated that a program of chemical sampling should begin only if symptoms or observations strongly suggest that a specific pollutant or source may be the cause of the complaint and if sampling results are important in determining appropriate corrective action. This is excellent general guidance. But the Building Air Quality document does not provide specific criteria to be used to determine if a pollutant or source may be the cause of a complaint. To the extent possible, the document does provide guidance on when to measure, and how to interpret results for carbon monoxide, carbon dioxide, and formaldehyde. For other contaminants, such as volatile organic compounds (VOCs), biological contaminants, and particulate matter, the guidance provided is not very specific.

Goyer and Nguyen (1989) provide relatively specific guidance for contaminant measurements. They recommend the sampling duration, measurement technique, and suggested sampling sites for the major categories of contaminants. They also provide a detailed list of measurements to be performed if specific sources are identified. For example, if there were recent renovations, they recommend measurement of VOCs and formaldehyde in office spaces. They do not attempt to relate measurement parameters to complaints, which is more difficult than relating contaminants to sources. Tables are also provided that give relevant standards/guidelines and "typical" contaminant concentrations to assist the investigator in determining if the concentration measured is "abnormally high."

Development of the sampling strategy based on contaminant sources appears to be the most common approach (Baldwin et al, 1991; Davidge et al., 1989; Goyer and Nguyen, 1989; and others). Industrial hygienists have used this approach successfully in industrial workplace environments and have applied the same approach to the non-industrial workplace. This approach is much simpler than attempting to relate measurement parameters to occupant complaints and symptoms. There have been no simple guidelines developed on how to select the contaminants to be measured.

The guidelines for determining when and where to sample are also not well-developed. The simplest, and most widely used guideline for selecting sampling locations is to sample in the affected (complaint) area, a non-affected (control) area, and outdoors. Selection of both the affected and control areas is probably most often based on subjective information. However, more elaborate methods have been used for more complex investigations. At the EPA Headquarters building, employee survey results were used to calculate indexes used for selection of sampling sites. Knoppel and DeBortoli (1989) used a similar "complaint index." Lane et al. (1990) have described a procedure to identify the zones of maximum and minimum potential exposure. Random selection of sampling sites has been used in research studies, but is not typically used in problem-solving building investigations. Turk et al. (1987) determined the minimum number of sampling sites, based on square footage, required to characterize the interior space of interest.

Like selection of sampling sites, there is only limited guidance on when to sample and the frequency of sampling required. The U.S. EPA (1991) suggests that measurements may be made under both "worst case" and "typical" conditions in order to isolate a problem. This may be accomplished by manipulating building conditions. The effect of the day of the week and the time of day on measurement results is well-recognized. Quinlan et al. (1989), Davidge et al. (1989), Rajhans (1989), and others provide recommendations on when to sample for specific contaminants. Morey and Singh (1991) are two of only a few investigators that stress the importance of relating measurements to the operation of the HVAC and the supply of outdoor air which may change from day to day and hour to hour.

The survey of the literature indicated that guidelines for selection of measurement parameters, measurement methods, sampling sites, and sampling duration and frequency area available, but are usually quite general. No simple "cookbook" protocols are available that can be applied to the wide array of building stock, contaminant sources and health and comfort complaints.

CONCLUSIONS

The literature survey identified a number of recently-published reports that provide relatively comprehensive guidance for conducting IAQ investigations in large, non-residential buildings. The guidance available for conducting preliminary assessments and the initial walk-through inspections is most comprehensive. Although investigators may differ slightly in their approach to conducting this phase of information collection, there appears to be a general consensus on the type of information that should be collected on the building, its occupants, the ventilation system, and contaminant sources. The multi-stage approach is recognized to be most cost effective. Although some investigators in the past performed extensive contaminant measurements even during the early stage of an investigation, contaminant measurements are not generally recommended unless there is a well-developed hypothesis. Guidelines for conducting measurements of physical and chemical parameters during a building investigation are not well-developed. For most contaminants, criteria have not been developed that will assist the investigator in selection of the measurement parameters or development of the monitoring/sampling strategy. Due to our current, limited, understanding of the relationship between occupant complaints/symptoms and contaminant concentrations, monitoring and sampling strategies are primarily based on identification of potential sources in the work space. Additional research is required to determine which measurement parameters are most useful for solving

IAQ problems. Protocols for performing those measurements need to be developed and tested.

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TABLE 1

Reports Describing Diagnostic Protocols for IAQ Investigations

Title	Authors	Publication Year
Hewlett Packard Indoor Air Quality Program	Baldwin *et al.*	1991
Indoor Air Quality Assessment Strategy	Davidge *et al.*	1989
Indoor Air Quality Investigations: A Practitioner's Approach	Gammage *et al.*	1989
Strategy for Studying Air Quality in Office Buildings	Goyer & Nguyen	1989
Investigating Indoor Air Problems	Hansen	1991
Indoor Air Quality Diagnostic Procedures for Sick and Healthy Buildings	Lane *et al.*	1989
A Procedural Guide on Sick Building Syndrome	Liebhaber	1987
Indoor Air Quality in Nonindustrial Occupational Environments	Morey & Singh	1991
Guidance for Indoor Air Quality Investigations	NIOSH	1987
Protocol for the Comprehensive Evaluation of Building-Associated Illness	Quinlan *et al.*	1989
A Protocol for Initial Investigations of Indoor Air Quality	Rafferty	1989
The Practitioner's Guide to Indoor Air Quality	Rafferty & Quinlan	1989
Findings of the Ontario Inter-Ministerial Committee on Indoor Air Quality	Rajhans	1989
IAQD Protocols	Rask	1991
HBI Protocols	Robertson & Turner	1991
Elements of a Standard Protocol for Measurements in the Indoor Atmospheric Environment	Thorsen & Molhave	1987
Building Assessment Techniques for Indoor Air Quality Evaluations	Turner *et al.*	1985
Building Air Quality - A Guide for Building Owners and Facility Managers	U.S. EPA/NIOSH	1991
Indoor Air Quality Diagnostics: Qualitative and Quantitative Procedures to Improve Environmental Conditions	Woods *et al.*	1989

TABLE 2

Stages of a Diagnostic IAQ Investigation[a]

Phase 1:	Preliminary Assessment (a) Define nature and scope of the complaints. (b) Conduct a preliminary audit of the facility conditions, systems, maintenance, and operations.
Phase 2:	Walk Through Inspection (a) Conduct more thorough assessment; validate information of preliminary assessment (b) Perform simple measurements - Temperature and relative humidity - Airflows with smoke tubes - Carbon dioxide
Phase 3:	Simple Diagnosis (a) Engineering analysis of HVAC system and building performance (b) Pollutant measurements (c) Ventilation measurements
Phase 4:	Complex Diagnostics
Phase 5:	Monitoring and Recurrence Prevention

[a]Summarizes approach described Hansen, 1991.

TABLE 3

Reports That Contain Copies of Questionnaires Used for Building Investigations

Questionnaire	Notes	Reference
Indoor Air Quality and Work Environment Survey	For EPA Headquarters; 20 pages long	U.S. EPA, 1989
Indoor Air Quality and Environment Follow-up Survey	For EPA Headquarters; 5 pages long	U.S. EPA, 1989
Occupant Interview	EPA Building Air Quality; 2 pages	U.S. EPA, 1991
Comprehensive Indoor Air Quality Questionnaire	6 pages	Quinlan et al., 1989
Human Resource Questionnaire	2 pages	Woods et al., 1989
Indoor Air Quality Survey	Ontario Ministry of Labour; 8 pages	Rajhans, 1989
Occupant Questionnaire for Monitoring	2 pages	GEOMET, 1990
Indoor Air Quality Questionnaire	2 pages	NIOSH, 1987
Indoor Air Quality Questionnaire	2 pages	Baldwin et al., 1991
Office Health Questionnaire	2 pages	Liebhaber, 1987
The Healthy Building Study Questionnaire	13 pages	Daisey et al., 1990
Office Environment Questionnaire	8 pages	Raw et al., 1991
Work Environment Survey	5 pages	Hedge et al., 1989
IAQ Questionnaire	1 page	Mader et al., 1991

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16. ABSTRACT

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ABSTRACT

Numerous investigations are conducted in large buildings each year to evaluate health and comfort complaints that building occupants perceive to be related to poor indoor air quality. Some guidelines have been developed for conducting indoor air quality investigations, but standardized building diagnostics protocols have not been developed. The purpose of this work was to compile information that might be used to develop standardized protocols. A computerized literature search and a mail-out survey were conducted. A number of reports describing indoor air quality investigation guidelines and protocols were identified. The recently-published EPA/NIOSH Building Air Quality document contained the most comprehensive guidance. A survey of other documents identified many common elements, particularly for the collection of information during the initial walk-through investigation phases. However, there was not a common approach to the measurement of physical and chemical parameters during an investigation. This paper describes common elements and differences in the technical approach to building investigations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Indoor Air Quality, Monitoring, Indoor Investigations, Building Studies Sick Building Syndrome		

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