OVERALL BUILDING ENCLOSURE EVALUATION IN COLD CLIMATES: A GENERIC METHODOLOGY FOR FIELD MEASUREMENT

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ABSTRACT

The term transdisciplinary diagnostics is used to describe a variety of activities, including the use of IR radiation sensing systems in conjunction with other techniques to inspect buildings. For the purpose of this paper, the term 'thermography' is used in acordance with the Canadian General Standard CGSB 149-GP-2MP. The test procedures include simultaneous testing for; thermal resistance of typical enclosure assemblies using time weighted averaging formulae, comparative testing of air tightness characteristics (by fan pressurization methods) and infiltration rates (by tracer gas method), thermographic inspections of the enclosure (both interior and exterior) during high pressure differential conditions (mechanically induced), monitoring of average pressure differential measurements during air leakage testing, specific mechanical system settings and mechanical system testing, monitoring of individual pressure differential measurements at specific locations through the enclosure to determine affects of wind direction and speeds on pressure differentials, and monitoring of micro-climate around the test building (by means of a remote weather station). These investigative procedures, combined with appropriate thermologic and building science follow-up, make it possible not only to diagnose building enclosure problems in cold climates, but also to recommend remedial action and propose energy-efficient design and construction for the future.

INTRODUCTION

There is an increasing requirement within the government and the private industry to establish diagnostic techniques and procedures for evaluating the performance of building enclosures, as well as the building's interior environment and the building's suitability to accommodate their occupancies. The resulting understanding will contribute to improved forecasting of the overall performance for new, energy - and occupancy - effective buildings.

Dramatic changes have occurred in how we build buildings and how many people we accommodate. Recently, the need to evaluate the technical performance against user satisfaction has generated precedents for improvement on how we design, construct, operate, and maintain buildings. For example, significant deficiencies in building enclosure performance include failure to meet the functional needs of the occupants. In addition, there is unintentionally excessive energy consumption, accelerated enclosure deterioration, and high maintenance cost (Figure 1).

The last decade has seen a building industry inundated with the need for new knowledge, technology and repeatable diagnostics and quality control practices (e.g., thermography)

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(Mill 1979). All have culminated in varying responses from the disciplines that are responsible for generating operatives and maintaining our existing building stock. When building deficiencies arise, the traditional practice is for all participants to blame each other.

It is no longer useful to merely point out that the system is at fault or that a particular person/group is responsible. It is the design-build-team's combined effectiveness and ability to diagnose and predict a building condition at the microenvironment level that will overcome our ever increasing problem of building debilitation. Debilitation of any building, its material, or its environment is generated at the microenvironment level, and in the majority of instances is not an acute phenomena, but a gradual process culminating in chronic conditions which, if left unattended, terminate in serious failures (Lemer and Moavenzadeh 1972).

EMERGENCY OF A CONCEPT

In the provision of shelter, building enclosure integrity can be defined as sustaining the material, component, and assembly properties to withstand external and internal forces over time. Critical properties that must be sustained include

1. the mechanical properties of overall geometric stability (component parts and joints), including structural strength and stability (such as compression, tension, and shear) with levels of degradation varying from marking, denting, and stretching, to buckling and collapse;

2. the physical properties of watertightness and airtightness, with levels of degradation ranging from staining to flooding; the physical properties of transmission, reflection and absorption of heat, light, and sound, as necessary for the occupancy function;

3. the visible properties of color, texture, and surface finish, with levels of degradation varying from slight discoloration and soiling to a complete change in overall visual appearance. The degradation of visible properties is often a clear (not necessarily early) indication of the degradation of mechanical and physical properties.

Degradation of these properties of building integrity can vary from an entirely superficial stage, with no implications for health, safety, or welfare, to a debilitating stage, endangering both comfort and welfare, to a devastation stage imperiling human safety and health.

To understand the fundamental principles and concepts of overall building enclosure performance, it is necessary to question how people construct buildings, why buildings perform the way they do, and what we really know about their performance. The overall performance and functioning of the facility must be addressed as a whole, rather than only examining the performance of individual parts such as air handling systems, air distribution, and other individual components in isolation. To achieve this end, the principles of architectural and building science must be applied in a transdisciplinary manner to the design and construction process. In order to achieve a collective competence in overall building enclosure performance, the transdisciplinary approach is required (Mill 1982).

TOTAL BUILDING PERFORMANCE

Building quality control requires analysis from a comprehensive and detailed definition of the building performance criteria that must be met by building policymakers, programmers, architects, engineers, contractors, owners, and managers. For the sake of discussion, this definition can be divided into two areas. First, the building must be structurally sound and protected from degradation caused by moisture, temperature, air movement, radiation, chemical and biological attack, and environmental disasters (e.g., fire, flood, earthquake). Established by concerns for health, safety, welfare, resource management (energy, money), and image, the requirements for building integrity are set by the limits of "acceptable" degradation (of the visual, mechanical, and physical properties) ranging from slight decay, to debilitation in the ability to provide weather tightness or environmental conditioning for the function, to total devastation or destruction. Second, the criteria that are associated with interior occupancy requirements (human, animal, plant, artifact, machine) and the basic needs for safety and comfort, including thermal, acoustic, visual, air, and functional spatial comfort, must be met (Markus and Morris 1980; Farant 1985).

Providing a total building performance (also known as "whole performance" and "overall building performance" in the research community) is based on both the functional and comfort needs of the occupants within the integrated setting of the occupied building, and building integrity over time. The programming, design, construction and operation of buildings should ensure the immediate suitability of the setting for the building occupancies and functions (all performance qualities), as well as the long term reliability (maintainability) and flexibility, over the life cycle of the building which is established by the client (Drake 1985).

To address the complexity of issues which face building owners today, and to cut across disciplinary boundaries in the delivery of satisfactory building environments, it is necessary to develop a discrete list of performance qualities of equal weight. The outline in Table 1 introduces the subsets of six critical performance thresholds (criteria):

A performance failure, which in most instances require nondestructive diagnostic techniques to be identified, can result from decisions made at any step in the building delivery process, because of isolated disciplinary decisions that reduce the alternatives for each succeeding step, in that the final product has less chance for success. The concept might be titled 'cumulative stress factors,' or the introduction of a decision in any stage of the project delivery system that significantly narrows the range of effective decisions possible in successive stages towards the delivery of functional/ spatial, thermal, air, acoustic, and visual quality and building integrity (Kaplan 1985) (Fig. 2).

A client may dictate in conception that money should be allocated to decisions that "show," e.g., facades and lobbies, resulting in tremendous restraints on roof and foundation budgets. The feasibility study and program may dictate that skylit spaces are of critical importance. In preliminary design, the architect may put forward an expression in which flat roofs are an important component, with skylights dotted across the expanse. The specifier in working drawings may produce a detail that requires precision construction, without assurance of the matching investment in quality materials while the contractor has been asked to fast-track, making the work that "shows" must be impeccable. Finally, the project manager who conscientiously is "putting out project schedule fires" while quality control of trade sequencing is continuous during the laying of the built-up-roof or, at a later date, the building manager, who is "dealing" with building operational crisis that occur during preventative maintenance of drainage channels and flashing valleys on the roof, both sets of activities are left to less hectic times. The result? A massive roof leak during the first thaw. A performance failure is a result of "cumulative stress factors" that can happen either at the conception of the project or during its construction, making it increasingly difficult for the occupant or succeeding decisionmakers to ensure satisfactory performance. The solution may be a level of comprehension of building science and building performance that spans the entire building delivery process, and a commitment to relieving stress factors at each stage of decisionmaking.

THE NEED FOR TRANSDISCIPLINARITY

Transcisciplinarity is the development of decisionmaking procedures for the elimination of gaps between professional design disciplines and gaps in the project delivery system in the delivery of total building performance (functional/spatial, thermal, air, acoustic, visual qualities and building integrity). Transdisciplinary procedures include total building performance design standards matched with field measurement and assessment techniques for compliance at each stage in the project delivery system; team decisionmaking with advocacy, iterative, and matrixed decisionmaking methods for building system integration and the reduction of stress factors; and "post-occupancy" evaluation to narrow the gap between the building's design directives and an occupancy's physiological, psychological, and sociological needs (Hartkopf et al 1983).

The transdisciplinary process must be based on establishing a full design team at the time of conception, capable of making collaborative, informed decisions. The full design team must include experts in each performance quality area and experts in critical stages of the project delivery system (programming, design, working drawing/specification, construction, occupancy), with emphasis on those performance areas most important to the functions and occupancies of the project. During the early design stages, each team member articulates the building performance criteria for which they are responsible so that performance stress factors are understood in the siting, massing, organization of spaces, enclosure and opening design, and the integration of system decisions in design stage (Public Works Canada 1984). For collective decisionmaking, an advocacy process would be based on verbal negotiations and requires the interested and vocal participation of each team member. An iterative process would be based on written (including drawing annotations) round-robin negotiations. A matrixed process would be more deliberate, conducted in a series of meetings, first chaired by the performance quality experts, then by project delivery experts (programming, design, working drawing/specifications, construction, occupancy), and finally by design disciplines (architects, engineers, consultants) (Loftness et al 1986).

Ultimate design decisionmaking can be hierarchical (based on lines of accountability) or shares (with multiple accountability) reflecting the complexity of integrating building structural, enclosure, interior, and servicing systems for the delivery of total building performance. The team highlights the most critical performance qualities required in the building, establishes thresholds or limits of acceptability, and selects appropriate field testing procedures for each stage of the project delivery system.

Finally, transdisciplinary diagnostic methods can be used in the commissioning (Public Works Canada 1984) and post-occupancy evaluation of buildings, incorporating functional/spatial, thermal, air, acoustic, and visual quality experts as well as building integrity experts, resulting in recommendations for change in a specific building or new building programs, the entire building stock, or the project delivery system. Thermography is one of these transdisciplinary diagnostic methods.

Each level of the building quality control measurement involves the use of different tools and procedures to go with those tools. Depending on which performance qualities are being tested at which building scale, each level of measurement may also vary according to cost, level of expertise needed, repeatability, depth of evaluation achieved, and assurance or reliability of results (Table 2). The Canadian government and the building diagnostic center at Carnegie Mellon University are trying to determine whether (and when) there are clear relationships between these five levels of measurement. For example, does one measurement clearly depend on another; clearly reveal the scale of the problem or the percent of building coverage needed; give identical results as another with high percentage frequency; allow quantifiable enhancement of another.

Each level of evaluation measurement will feed into records as an independent measurement or combinations of various levels and various performance qualities. Checklists, counts, annotated plans, photos or videos, plots (curves, histograms), and tables may be carried away from a field evaluation as records of diagnostic measurements (Mill 1979, Mill et al 1981).

This increasing requirement for established diagnostic techniques and procedures has prompted the study group to establish a program that has evolved primarily around the use of nondestructive techniques (such as thermography) as a means for identifying initial expressions of building debilitation based on a building's occupancy and thermal patterns. The objective of the current diagnostic program has been to establish the potential of thermography to aid in the evaluation of total building performance with a focus on building enclosures in the diverse climates of Canada (Figure 3).

Innumerable investigations of building enclosure systems with the aid of thermography has led to the following conclusions.

1. A transdisciplinary knowledge base that emphasizes how enclosures perform in relation to the overall building performance, rather than their construction, is required in order to encourage new ideas in total building performance and enclosure design.

2. Qualitative and quantitative results of nondestructive diagnostic methods such as thermography in connection with air pressure, tracer gas, heat flow meters, and moisture meters, should contribute to this knowledge base.

3. The use of transdisciplinary building science quality control procedures in conjunction with diagnostic methods (e.g., thermography) reduces as-built thermal resistance inaccuracies in air seal and insulation placement by locating with infrared imaging the thermal variances and subsequent measuring surface temperatures and quantifying air leakage (pressurization, tracer gas, and heat flow methods).

4. Air movement at surfaces and interstitial spaces of a wall system with or without moisture presence are primary mechanisms affecting the thermal effectiveness of a wall

and its surface temperature, which in turn affects occupancy comfort and overall building enclosure integrity.

The previous conclusions have established a building enclosure methodology that utilizes transdisciplinary diagnostic methods (Appendix 1). These methods address five building enclosure requirements that are fundamental in attaining overall thermal integrity of a building enclosure performance.

CONCLUSION

The suggested methodology extends the term "building enclosure diagnostics" to cover various applications and levels of infrared (IR) technology in conjunction with other techniques for diagnosing the performance of building enclosures in relation to total building performance. Basic to these thermographic applications is the ability to produce repeatable procedures, which guarantees stable thermal images of the radiant energy emitted by all objects. However, the majority of building enclosure diagnostics require techniques guaranteed with an operator's expertise in building science, enabling correct interpretation of thermal patterns on the IR images. The IR thermal patterns represent the dynamics of thermal interactions between a material's physical and chemical properties. This interaction occurs in all objects by virtue of their capabilities of heat transfer and retention expressed by the material's surface emissions of electromagnetic radiation patterns in the wave length range of 0.1 um to 100 um.

The function of a wall or roof as a separator of dissimilar environments is an example of the complexity of applying current methods of building diagnostics. Because there are many components and disciplines involved in construction, the general function of a component will include many subfunctions. In the case of a wall, these subfunctions are determined by the difference between the two environments (interior and exterior) and the degree of separation required. Unlike the traditional trial-and-error approach to construction, today's building situation demands an immediate nondestructive evaluation of performance without the benefit of hindsight or even of tried and true materials or methods.

To understand why and where in the overall building certain materials and methods either succeed or fail to provide appropriate enclosures or environments is important. In many instances this understanding can only be attained from post-occupancy evaluation. Three factors -- function, material properties, and environment -- must all be evaluated and manipulated in order to maintain an optimum performance within any of the previously discussed six building quality thresholds. A change involving any one factor will influence the other two; consequently, all three must be considered collectively when one examines building enclosure performance for a particular building occupancy and its environmental requirements.

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APPENDIX

A Building Enclosure Methodology for Five Levels of Transdisciplinary Diagnostic Measurement

General Framework

Common to the following recommended levels of investigation, a preliminary understanding of the building enclosure performance is obtained by the examination of the as-built construction details. Particular attention is given at intersections since this can provide an indication of the location and characteristics of possible cause of deficiencies. In addition, it is recommended that a continuous "red pen" outline be made on all air barrier locations since building enclosure degredation is created primarily by air leakage paths through the enclosure, generating the potential for accumulation of moisture or its entry and removal. The thermal characteristics of the component can be established on the basis of the indoor conditions to be maintained and the climate of the region.

The following is a recommended building enclosure methodology for transdisciplinary diagnostic measurement.

Level I. Plan/Archive Analysis
Analysis of likely performance from an examination of working drawings and

specifications; as-built documents; construction progress reports and correspondence; drawings and correspondence for building regulatory approvals; design drawings and specifications; documents for modification at initial occupancy; project management documents; field photographs; maintenance logs and printouts; utility bills; complaint and health records; prior post-occupancy evaluations; prior building studies.

Level II. Expert Walkthrough Analysis
One or more individuals with expert knowledge of relevant architecture, engineering, building technologies, and sciences walk through a building to identify potential problems and causes of problems in performance. Interviews with occupants and building managers may be included. The experts participate in a collective process to develop recommendations for change.

Level III. Occupancy and Use Analysis
Data from occupants derived from focused interviews, questionnaires and observations of behavior, complaint logs, and behavioral traces, to determine the perceived amenities and problems in an occupied building.

Level IV. Simple Instrumentation Analysis
Use of kit of instruments that can be hand-carried by a single person and give data in real-time for air quality, sound levels and spectrum, illumination, air leakage and condensation, temperature.

Level V. Complex Instrumentation Analysis
(a) Use of instruments that can be transported to the building for long-term, concurrent data collection (day, week, month, season) for operation by trained personnel. Laboratory analysis of samples may be required.
(b) Use of specially-built physical models and/or symbolic (e.g., mathematical models which represent the building, or selected components, or subsystems.

The previous five levels of diagnosing for determining a building enclosure integrity can be progressive and entirely based on decreasing transdisciplinary observations while increasing undisciplinary instrument measurements. These measurements develop from findings of previous levels of evaluation that conclude in a need for synthesis and recommendations that are again completely transdisciplinary. The levels can also be iterative or reiterative in combinations (Figure 3). This depends on whether the method is used for quality control before occupancy or as a post occupancy evaluation of a larger complex building. The measure of choice will depend on the building complexity and problem context (Fig. 4). The following are building enclosure requirements that benefit directly by these recommended levels of evaluation.

A. Visual Analysis for Detecting Material Durability
- specific photographs of exterior staining patterns of other evidence of moisture effects (wetness, efflorescence, spalling)
- progressive photographs of wetting patterns on facades.

B. Thermographic inspections
- aerial, ground and interior surveys for surface temperature detection of thermal anomalies (Fig. 5).

Thermographic inspection will determine the apparent surface temperatures for any wall surface. The findings, (i.e., thermal patterns) are then integrated with other performance criteria from the previous and following methods by applying a variety of computer-aided building science analyses to interpolate the significance of these causal mechanisms.

C. Air leakage and pressure monitoring for determining a building enclosure's air tightness
- location and characterization of leakage paths (IR and pressurization)
- location and characterization of opening in facades in regard to rain penetration and condensation (IR and tracer gas).

D. Evaluation of moisture (detection and accumulations)
- location and determination of moisture conditions
- specific sample moisture measurements
- records of humidity and air temperature during occupancy and non-occupancy in areas where moisture problems occur
- moisture gradients and accumulations.

E. **Thermal resistance and interia of the building enclosure's thermal effectiveness**
- location and characterization of thermal effective enclosures
- specific measurements of heat flux and surface temperatures
- temperature gradients and heat flow records through the building envelope.

TABLE 1
Six Building Performance Thresholds

I. Functional/Spatial Quality

Based on knowledge of the building occupancies, occupancy functions, and organizational structures

a. Individual space layout quality: useable space, furnishings, layout efficiency access, anthropometrics, erognomics, image flexibility/growth, occupancy controls

b. Aggregated space layout quality: promimities, access, compartmentalization useable space, layout efficiency image, amenities, flexibility/growth

c. Building siting layout quality: access, public interface/image indoor-outdoor relationships, outdoor space layout flexibility/growth

c. Quality of conveniences and services: sanitary, fire safety, security transportation, electrical, telephone information technology flexibility/growth

Performance Issues Addressed

Mechanical/electrical "noise"
Disability/discomfort glare/spectrum
Brightness/ratios/contrast
Ambient temperature at work station
Air distribution at work zone group
Air circulation at neck - velocity and temperature
Fresh air CO_2
Radiant emmissions
Function/energy use
Vibration
Wayfinding/signage
Waiting room use
Population profile
Accessibility
Workstation/workgroup layout
Firesystem
Telecommunication/services
Vertical transportation
Conveniences and amenities
Personalization and control
Functional energy effectiveness
Toxicology
Ingestion
Absorption
Inhalation
Mutagens, carcinogens, tetrogens
Poisons
Other epidemicological issues

II. Thermal Quality (ASHRAE 1981)

a. Air temperature

b. Radiant temperature

c. Humidity

d. Air speed

e. Occupancy factors and controls

Ambient temperature (laminer effects)
Wall heat flow
Relative humidity
Air circulation and hydronic balancing
Air circulation at neck - velocity and temperature
Air leakage - smoke pencil
Thermal energy efficiency
Radiant emmissions

III. Air Quality

a. Outside air

b. Outside air supply, distribution

c. Mass pollution: gases, vapors, micro-organisms, fumes, smokes, dust

d. Energy pollution: ionizing radiation,

Air circulation and hydronic balancing
Fresh air CO_2 counts (+800 ppm)
Pollution migration/air leakage
Miran/mass pollution
Radon emissions
Energy/radiant emissions
Systems air distribution

microwaves, radio waves, light waves, infrared

e. Occupany factors and controls

Water quality
Refuse study
Air quality/energy efficiency
Mutagens, carcinogens, tetrogens
Poisons
Other epidemicological issues

IV. Aural Quality

a. Sound source - sound pressure levels and frequency

b. Sound source - background noise

c. Sound path - noise isolation (air and structure borne)

d. Sound path - sound distribution absorption, reflection uniformity, reverberation

e. Occupancy factors and controls

Ambient sound
Sound distribution
Sound transmission loss
Articulation index
Reverberation time
Structure-borne sound
Mechanical/electrical 'noise'
Vibration

V. Visual Quality (Egan 1983)

a. Ambient light levels (artificial and daylight)

b. Task light levels (artifical and daylight)

d. Contrast and brightness ratios
e. View, visual information
f. Illuminaire quality
g. Occupancy factors and controls

Ambient light levels
Disability/discomfort glare/spectrum
Brightness ratios/contrast
Colour
Luminaire input/output
Daylight contribution
Lighting energy

Illuminaire
VDT parameters

VI. Building Integrity (ASHRAE 1981)

Based on knowledge of loads, moisture conditions, temperature, wind, radiation conditions, and chemical biological attack, fire, man-made and natural disasters

a. Quality of mechanical/structural properties: compression, tension, shear, abuse

b. Quality of physical/chemcial properties of watertightness, air-tightness transmission, reflection, absorption of heat, light, and sound energy firesafety

c. Visible properties: colour, texture, finish form durability, maintainability

Mechanical/electrical integration
Luminaire integration
Lighting integration
Wall heat flow
Air circulation and balancing
Thermal energy effectiveness
Air distribution leakage
Water systems integration
Refuse systems integration
Wall moisture flow
Vibration
Thermal pattern recognition
Interior/exterior pressure differentials
Building enclosure energy efficiency
Fire systems integration
Telecommunication/service systems integration
Sound transmittance & resistance building enclosure integration

TABLE 2

Levels of Evaluation Measurement

1. Plan/archive
2. Expert walkthrough
3. Occupancy and use
4. Simple instrument
5. Expert Instrument
   assign $/time/
   level of confidence

what looked at:
1. Documentation
2. Comp.-component
3. Occupant-comp.
4. Occupant-occ.
   % of building
   % of occupancy

records kept:
1. Checklists
2. Counts
3. Annotated plans
4. Photos/Videos
5. Plots
6. Tables
   total $/time level
   of confidence

Levels of Evaluation Assessment

1. Expert/informed judgement
2. Pattern recognition
3. Simple algorithms
   - scalar
   - curve fit
4. Statistical assessment
5. Complex algorithms
6. Expert systems
7. Mock-up sensory assessment
   assign $/time/
   level of confidence

thresholds compared to:
1. Codes/Standards
2. Guidelines
3. Project brief
4. Norms
5. Research results

recommendation type:
1. Specific retrofit
2. Organize/use
   change
3. M&O change
4. Generic retrofit
5. PDS change
6. Codes and
   standards change
7. Data base
   development
8. Further testing
   total $/time

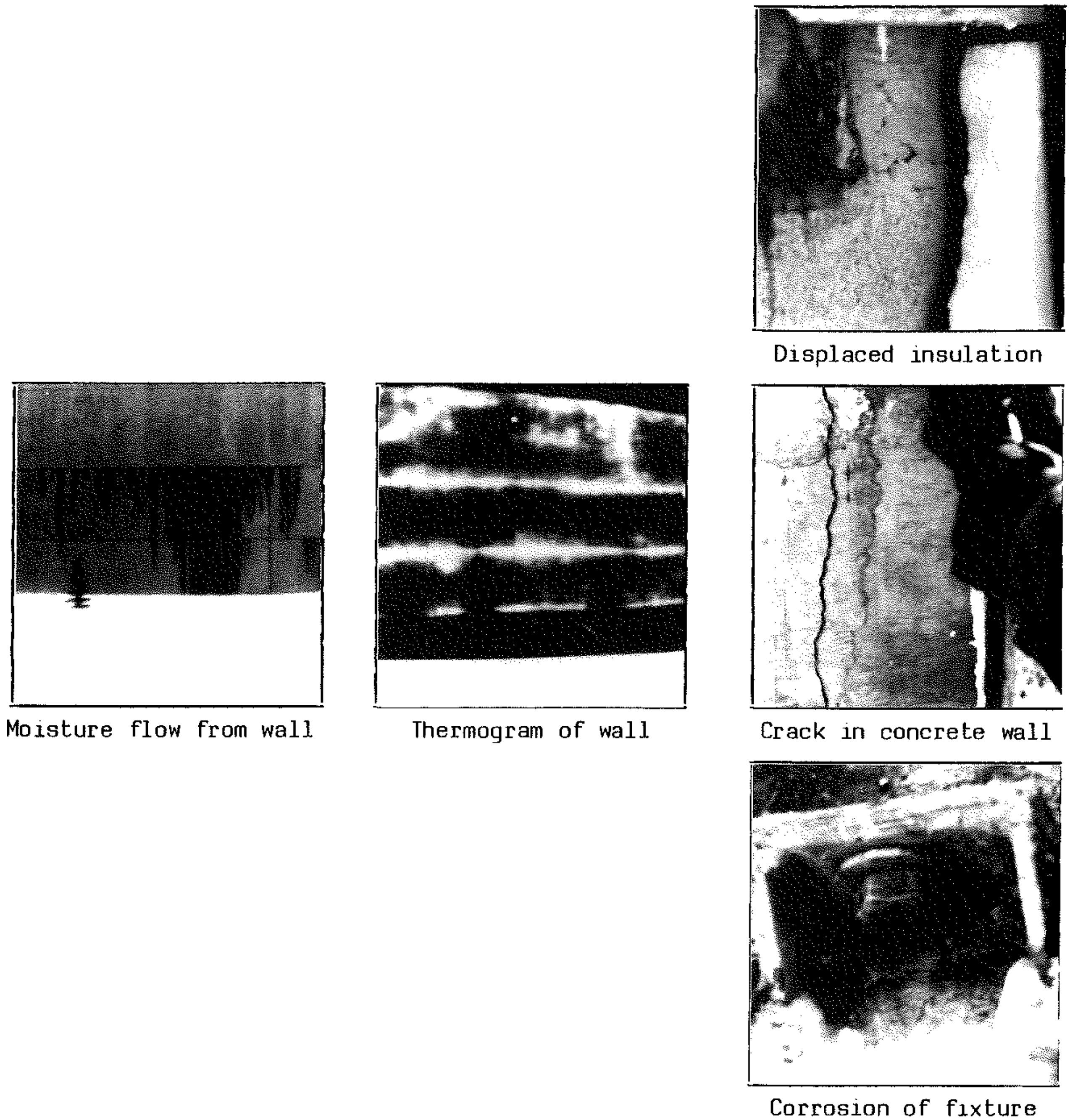


Figure 1. (a) Moisture flow from wall at flashing joint during mild winter temperature; (b) thermogram of wall showing air leakage at cracks, displaced insulation, and moisture; (c) crack at concrete pour joint, seen in thermogram as vertical flare; (d) displaced insulation and shrinkage crack at in-situ concrete floor and concrete block junction, shown as horizontal flare in thermogram; (e) corrosion of precast anchor due to excessive wetting from condensation

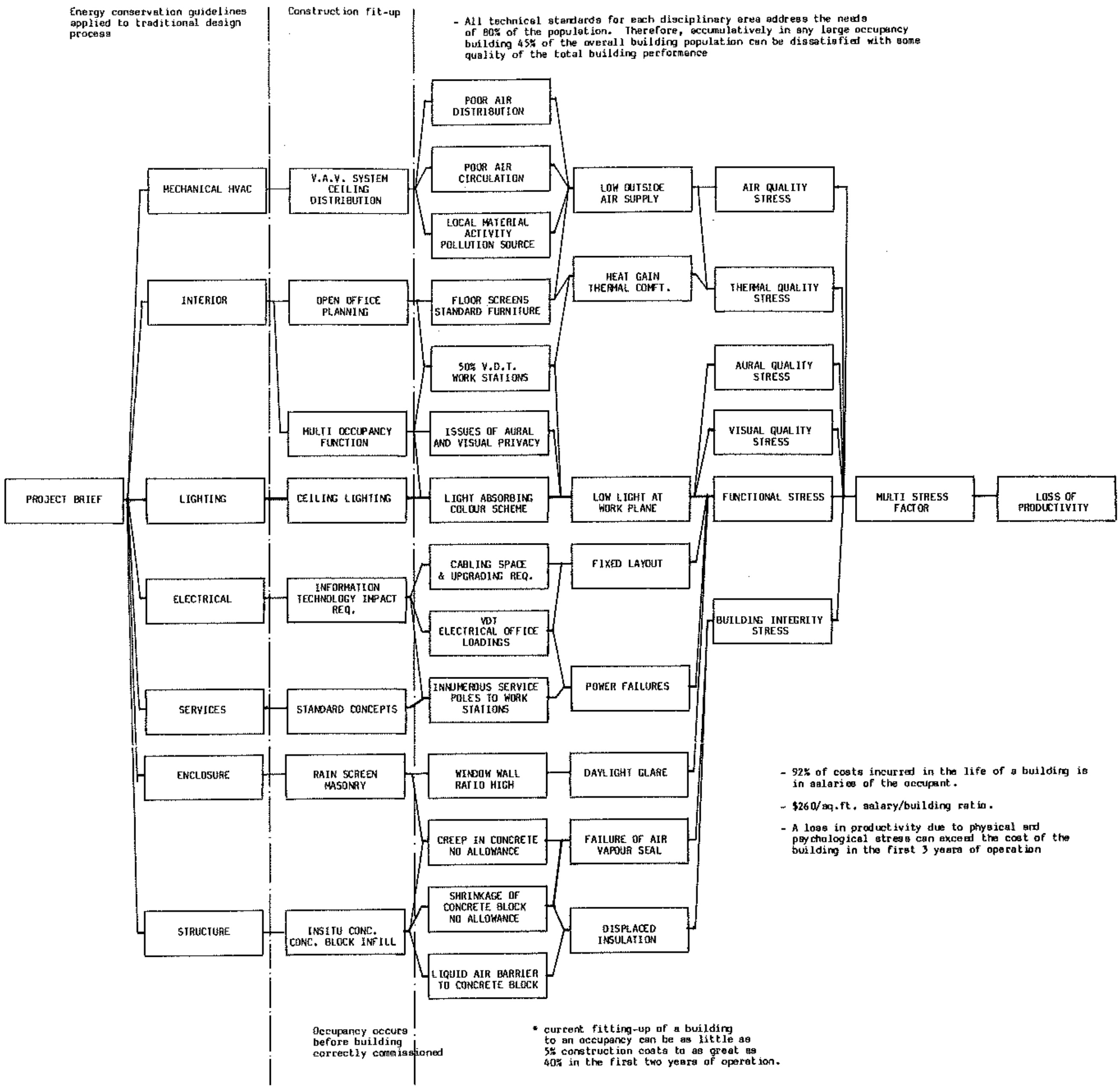


Figure 2. The multiple performance aspects of multi stressor problems facing owners, managers, and occupants of large occupancy, electronic offices today do not imply that building evaluation must be extraordinarily time consuming or complex. They do imply that offices in cold climates must be approached from the basis of overall performance, with recommendations made accordingly

BUILDING PROBLEMS

DIAGNOST. LEVEL	NON DESTRUCTIVE METHOD OF DETECTION	Warping of alignment movement	Spalling of masonry	Paint peeling	Cladding Damage/Corrosion	Condensation in wall cavities	Moisture in wall cavities	Frost buildups	Ice damming	Attic condensation	Sealant failing	Surface water run-off	Basement and crawlspace condensation	Frame rotting	Window condensation	Dirt mark on interior surfaces	Mould & mildew on inside surfaces of ext. walls	CONSTRUCTION AND ENVIRONMENTAL CAUSES
IV	INFRA RED/THERMO				●			●					●				●	Cold interior wall surfaces due to the missing insulation
1 IV	IR + VISUAL		●		●	●	●	●			●		●	●		●	●	Thermal bridging
1 I, IV	VISUAL INSPECTION INFRA RED/HEATFLOW MEASURING							●			●			●	●			Thermal resistance of glazing too low
I II IV	VISUAL/IR & MOISTURE METER	●	●									●	●					Poor drainage
I II IV	IR, PRESURIZATION, TRACER.			●	●	●	●	●	●	●			●	●				Faulty air barrier
I II IV,V	IR + VISUAL		●	●	●	●	●	●	●	●			●	●				Faulty vapour barrier
I II IV	IR + VISUAL		●	●	●	●	●				●		●	●				Improper flashings
I II IV	IR + VISUAL	●										●	●					Cracked foundations
I II IV	IR, MOISTURE METER											●	●					Blocked drain tile
I II IV	TRACER DECAY					●		●		●								Poor attic ventilation
I II IV V	IR									●								Increased insulation
I II IV V	PRESURIZATION, IR TRACER DECAY				●		●				●			●				Faulty rain screen
																		Climate
I II	DOCUMENTATION.SITE		●			●		●	●	●	●		●		●	●		Cold weather
I II	DOCUMENTATION.SITE				●		●							●				Driving rain - Little sunshine
I II	DOCUMENT. REVIEW SITE	●											●					High water table
I II	DOCUMENT. REVIEW SITE												●					Rain
I II	DOCUMENT. REVIEW, SITE			●						●			●					Mild weather
I II IV	MOISTURE & RH EQUIP									●			●	●				High outside relative humidity
I II	DOCUMENT. REVIEW, SITE	●	●		●		●	●	●	●	●							Very cold climate
I II	DOCUMENT. REVIEW, SITE	●			●								●					Cold weather during spring
																		Indoor environment
I II IV	MOISTURE & RH MEASUREMENT	●	●	●	●	●	●	●	●				●	●		●	●	High relative humidity levels
I II IV	DWYER AIRFLOW, INFRA RED,		●	●	●	●			●				●	●	●		●	Positive pressurized interior
I II IV	DWYER AIRFLOW, INFRA RED,				●		●											Negative pressurized interior

Figure 3. Building in cold climates demands unusually good building integrity against degredation in structural, physical, and visual properties of performance. In order to capably address all performance mandates, however, the designer must establish priorities for building functions with regard to occupancy requirements. When performance mandates are not met, the above problems will occur

Figure 4a. Component depressurization and pressurization test for air leakage control and specification requirements

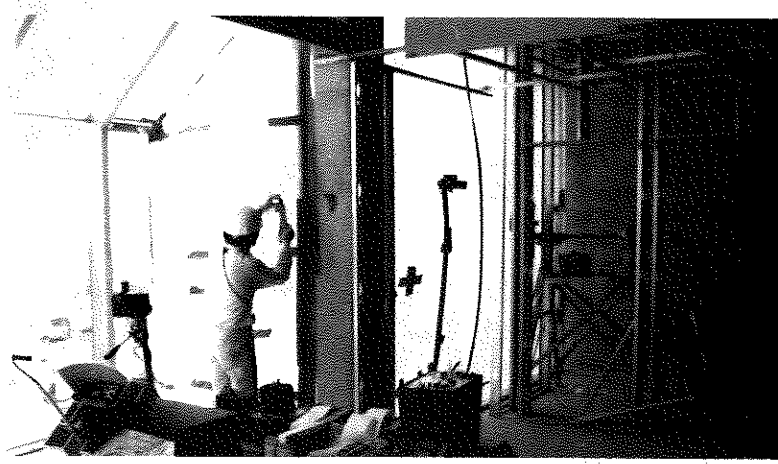
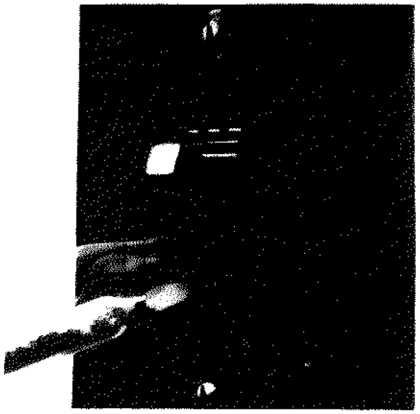


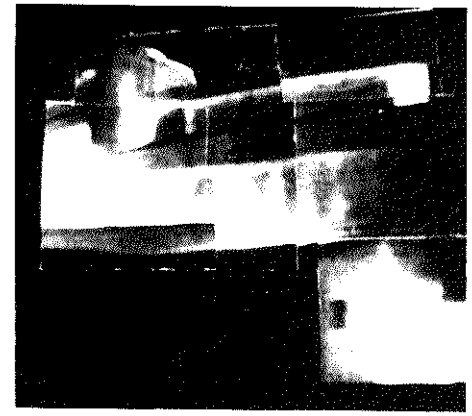
Figure 4b. Similar pressure test using infrared and tracer decay methods simultaneously

In the next case example a demonstration of a field test using combinations of pressurization tracer gas (SF_6) and infrared detection. The infrared (long wave) detection is used during the depressurization of the test cavity to locate the air leakage paths because the polyethylene is transparent in the 10 to 12 micron infrared threshold. The tracer gas is used during pressurization to check the tightness of the plastic test enclosure and the air tightness of the components' air seal.



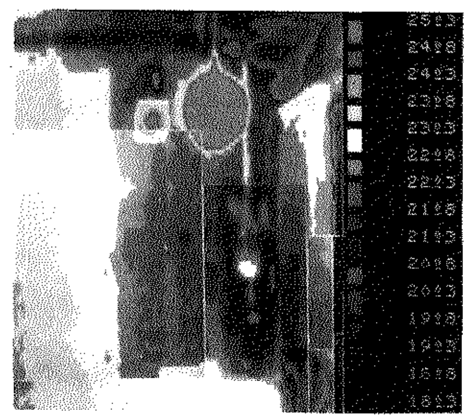
(a) Smoke pencil testing for air leakage

(b) Frost accumulations at rafter bridge joists due to air leakage



(c) Exterior infrared image showing excessive heat loss due to excessive air leakage from natural stack conditions

(d) Interior infrared image showing excessive infiltration during depressurization at 50 pascals



(e) A digitally processed image of the interior infrared frame showing the apparent thermal range on the right-hand side of the image. This is the first step in obtaining gradient and condensation simulation

Figure 5. This case example shows a high density housing unit being tested using the fan pressurization test, tracer gas decay, infrared field detection, and laboratory infrared synthesis. Laboratory synthesis using digital analysis relates further a building's performance. By attempting to show apparent temperature conditions between walls around this building, an index of worst to best conditions was interpolated. The location of worst and best conditions was subject to different methods of apparent surface temperature analysis. The value of post field laboratory synthesis allows intersynthesis between pressurization tests, tracer decay tests, and infrared detection in relation to different wall sections of the building under analysis