THE REFINEMENT OF DESCRIPTIVE INDICES CRITICAL TO IMPROVING THE THERMAL PERFORMANCE OF WHOLE BUILDINGS

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ABSTRACT

A committee of the Buildings Thermal Envelope Coordinating Council has recently completed a survey of prominant indices used to describe the thermal performance of whole buildings rather than their component parts. The results of the survey indicate that data describing the thermal performance of whole buildings are being measured and recorded in numerous disparate and often uncomparable units. The most data are available in Btu/ft^2 year, the least in Btu/CDD. The indices voted most valuable for describing the thermal performance of envelope load dominated buildings are Btu/ft^2 yr, percent of glass (!), and air changes per hour. The most valued indices for describing the thermal performance of internally load dominated buildings are Btu/ft^2 yr, peak load, watts/ft^2, equipment size, percent of glass (!), and dollars/ft^2 operating costs. This paper describes the rationale and the results of this survey on indice standards for describing the thermal performance of whole buildings.

INTRODUCTION

The BTECC Committee on the Thermal Performance of Whole Buildings has been searching for research and data relating to the overall performance of occupied buildings rather than their component parts. A subset of this effort has focused on the development of a comprehensive list of indices describing the thermal performance of whole buildings, toward establishing standards for their collection, simulation, and reporting, as well as toward aggregating larger, comparable data bases. More than 50 indices describing the thermal performance of whole buildings have been uncovered in common usage, with a dozen prominant indices. In an attempt to pinpoint the preferred indices, common definitions, and standards for data collection, simulation, and recording, the committee issued a "Survey on Indices Describing the Thermal Performance of Whole Buildings" to the public and private sector. Approximately 60 surveys went out, with 25 responses from: DOE, HUD, NBS, LBL, ORNL and BNL of the federal government; OCF, PPG, Koppers, Armstrong, Honeywell, Martin Marietta, and Mansville of industry; ZBA Engineering, Spielvogel Engineering, Homeraters, and Managed Environments of professional consulting organizations; Forest Products, Manufactured Housing Institute, and Northeast Utilities of representative organizations; and CMU and Drexel Universities. (Space precludes spelling out the names of each of these organizations.) Evaluation of the survey responses reveals that data collection on the thermal performance of whole buildings is ongoing but in a myriad of units, non comparable, and undirected toward any joint federal plus industry data base.

BTECC Committee on the Thermal Performance of Whole Buildings

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RATIONALE FOR WHOLE BUILDING RESEARCH

Field data collection in occupied buildings has revealed that the thermal performance of a building is not a sum of its parts. Indeed, the lack of comparability between the sum of the parts and the whole makes it very difficult to effectively feed data collection back into the design, construction, and operation of buildings. Improving the thermal performance of buildings necessitates techniques for design, simulation, construction and evaluation of overall comfort and resource management within the occupied setting. The rapid introduction of computer aided design capabilities will highlight this need, and provide a vehicle for introducing whole building performance evaluation techniques.

The value of whole building research in thermal performance is multifold:

* First, it allows the comparison of the sum of the parts to the whole, putting relative value (return on investment) on various parts within the whole building's thermal performance - a necessary resource allocation tool.

* Second, it allows for the comparison of the simulated design to the constructed shell and then to the actual occupied building, by providing comparable data about the whole building.

* Third, it ensures evaluation of the building from the occupancy viewpoint, defining thermal performance (comfort and efficiency) in the terms of the individuals who work/live in whole buildings.

* Fourth, it manifests the need to address performance to performance conflicts, such as thermal comfort with reference to energy conservation, thermal comfort with reference to air quality, or energy conservation with reference to building integrity versus degradation.

* Fifth, it provides viable terms for communication to ensure critical performance conditions, such as sustained reductions in energy consumption or minimum occupancy requirements for daylight and fresh air.

* Sixth, it encourages the development of standards for data collection, simulation, and reporting to ensure comparability for this viable communication tool.

* Seventh, given these standards, it allows the collection of significant data bases on the thermal performance of whole buildings to study such influences as climate, internal gains, occupancy type, or building type.

* Eighth, it will create a large enough data base on the thermal performance of whole buildings with which short term, spot measurements can be effectively compared, making simplified field monitoring a reality.

* Ninth, it provides a key to discussing building economics, relating various components and component assemblies in the first cost of buildings to the thermal performance of the whole, as well as relating first costs to long term maintenance and operational costs in the thermal performance of whole buildings.

To a certain extent, these rationale statements for whole building research form the charter of the Committee on the Thermal Performance of Whole Buildings.

RATIONALE FOR ESTABLISHING INDICE STANDARDS FOR DESCRIBING THE THERMAL PERFORMANCE OF WHOLE BUILDINGS

One of the first efforts of the BTECC committee has been to uncover ongoing work in whole building performance and to survey the units, terms, or indices used in this work to describe the thermal performance of whole buildings. The committee attempted to develop a comprehensive list of indices presently in use to describe the thermal performance of whole buildings, as shown in Figure 1. It is assumed that several of these thermal indices will be instrumental in achieving the following goals: improving the thermal performance of whole buildings for the occupancies involved; saving energy in the nation's building stock over the long term; saving money in operation for building owners; saving construction materials; improving cost effectiveness in the building stock and enhancing arguments between first and long-term costs; developing a comparative communication and incentive tool for owners, designers, managers, and occupants: establishing goals for upgrading buildings; promoting quality control in building design, construction, and operation: and critically, speeding data base development.

The first task is identifying those indices describing the thermal performance of whole buildings that will be most instrumental in achieving these goals. The second, more difficult task is identifying unanimous definitions of these indices and standards for their simulation, collection, and reporting. At this time, the BTECC committee on the Thermal Performance of Whole Buildings has attempted to answer the first question as to preferred indices for describing the thermal performance of whole buildings.

SURVEY TO INDENTIFY PREFERRED INDICES FOR DESCRIBING THE THERMAL PERFORMANCE OF WHOLE BUILDINGS

The results of the BTECC survey on indices for describing thermal performance of whole buildings are summarized in Figure 2. Several findings are significant for both public and private organizations involved with energy and buildings. First of all, data about the energy performance of buildings have been recorded in almost every unit innumerated, in many cases noncomparable. The most data on energy performance is in Btu/ft^2 yr, UA of the building, and dollars/ft^2 operating costs. There is, however, extensive commentary on what should be included in the Btu/ft^2 yr index and the dollars/ft^2 yr index (all energy consumption or excluding process electricity consumption), and whether infiltration should be included in the UA of a building. The least data or no data are available for Btu/CDD, aspect ratio, solar load ratio (or equivalent), and percent daylight.

For envelope load dominated buildings (buildings with significant perimeter and/or small internal loads) the most valued indices are Btu/ft^2 yr, UA of the building, percent of glass, and air changes per hour. The inclusion of percent glass as a valuable indice, reflecting the thought that reduced exposure makes more energy conserving buildings, is a major blow to the passive solar heating, daylighting, and natural ventilation proponents. It also devalues recent developments in low emissivity glass and innovation in high R glazings. The lowest valued indices for envelope load dominated buildings are Btu/ft^2 times hrs of occupancy, thermal performance degradation index, lumens/watt, and solar savings fraction(?). The most controversial indices, receiving equal numbers of high and low votes are: Btu/ft^2 HDD, time constant of the building, peak load, UA conduction, and UA infiltration.

For internally load dominated buildings (with significant internal loads from people and process energy) the most valued indices are again Btu/ft^2 yr and percent of glass (again deserving debate). In addition, peak load, watts/ft^2, equipment size, and a comfort index are given high votes. The lowest valued indices are Btu/ft^2 CDD, thermal performance degradation index, thermographic profiles, solar savings fractions, and aspect ratios. The most controversial indices, receiving equal numbers of high and low votes, are balance point temperatures, air quality index, lumens/watt, and UA conduction.

Several respondants included in depth commentary on the usefulness of various indices and the need for standardization.

1. The most preferred index, Btu/ft^2 yr, lacks agreement on whether to include the "free energies" of process and lighting electricity consumption, in addition to the HVAC and hot water energy use. The Btu/ft^2 yr index must be normalized to identify: building type (collection of space functions); internal loads; balance point temperatures; time of use; climate; infiltration; and HVAC system type. Without these same normalizing factors, the Btu/ft^2 HDD index at a classic 65 F base is often not well related to annual consumption.

2. The UA of a building must include an effective UA from infiltration/ventilation, a figure that needs furthur research and standardization (see IDP ASHRAE Standard 119 and Sherman/Grimsrud Method). The title of UA might be changed to clearly reflect the inclusion of the infiltration component. Other commentors, however, voted that the UA infiltration figure should remain separate ($UA_c + UA_i$) so that energy savings do not reflect unhealthy buildings filled with stale air.

3. The Solar Savings Fraction Index needs to be rethought, possibly adopting the Solar Utilization Factor of Canada's National Research Council that incorporates thermal mass (at this time in a heating analysis alone). Before an index such as Percent Glass is furthur promoted, a net energy index should be developed that seasonally tabulates incoming gain versus loss.

4. Balance Point Temperature does not reflect daytime overheating or nighttime overcooling and is prone to large error since internal heat gain is not really well defined. If correctly calculated, balance point temperatures calculations do provide good correlation with DOE 2.1.

5. As yet undiscussed, signatures could be developed as a method of comparing the thermal performance of buildings. T. Kusuda of NBS has put forward a DLDT or Daily Load versus Daily Average Outdoor Temperature Plot. The DLDT signature or diagram shown in Figure 3 would tell the whole building story as well as the weather characteristics. Measured in the field or simulated, daily total energy consumption data (E_i) would be plotted against daily average outdoor temperature (in bins f_i on the x axis). The slope is K or UA total, with the x-axis intercepts providing the heating and cooling balance point temperatures. Most importantly, deviation of the loads from the linearity around the balance points tells the nature of thermal mass, which has been overlooked by most energy analysts. The scatter shown is an indication of daytime overheating (winter) and nighttime overcooling (summer) resulting from the lack of adequate thermal mass. With this index, one could fold UA total, climate, balance point, time constant, thermal capacitance, and a solar utilization factor into one signature.

CONCLUSIONS AND IMPLICATIONS

The overriding conclusion is that a national data base on the thermal performance of whole buildings should focus on standardizing data collection in Btu/ft^2 yr for both envelope and internally load dominated buildings. Climate should not be factored in by automatically dividing by heating degree days (HDD) or cooling degree days (CDD) but recorded in some other manner, at least for envelope load dominated buildings. ASHRAE standard 105P "Standard Method of Measuring and Expressing Building Energy Performance" (8-6-84) should be built upon so that the thermal performance of one building can always be compared to another. The Btu/ft^2 yr index must be normalized to climate, building type (collection of space functions), internal loads, time of use, infiltration, and HVAC system type. For internally load dominated buildings, additional data records should be kept on peak load profiles and watts/ft^2 of internal loads. There would be very strong communication value in developing a dollars/ft^2 operating cost index for both envelope and internally load dominated buildings.

Important research needs to be done into the value of a percent glass index. On one hand, there may be major misconceptions as to the promise of limiting glass area to 10% or 20% for significant energy conservation in both envelope and internally load dominated buildings. On the other hand, a percent glass index could be modified to reflect (no pun intended) the promise of solar contribution to reducing heating energy consumption (typically Solar Savings Fractions [SSF], Solar Utilization Factors [SUF]) or of daylight contribution to reducing lighting energy consumption.

By comparing these most valued indices to the goals originally stated by the BTECC committee, however, one quickly sees that several goals cannot be met through the use of these indices alone (see Figure 4). It may be necessary, therefore, to develop several new, yet untried indices for describing the thermal performance of whole buildings, in an effort to also: improve the thermal performance of whole buildings for the occupancies involved (e.g., comfort index); improve the argument about first versus long term cost effectiveness; save material resources; and promote quality control beyond design into construction and maintenance/operation (e.g., thermal performance degradation index). For the energy community, there may be great value in developing a diagrammatic building signature, such as the one proposed by T. Kusuda at NBS. This "index" might offer greater insights into the consumption of various building types in various climates, toward limiting long-term energy demands through improved design.

At this time, it may also be necessary to reconsider a title for the committee that better reflects its efforts, since the Thermal Performance of Whole Buildings does not explicitly incorporate the balanced thinking involved with including lighting, air quality, and process energy consumption.

Finally, there needs to be furthur federal and collaborative industry efforts in cataloging the range of indices in use internationally for describing the energy performance of whole buildings and a united support for a limited number of indices for various building types. Efforts must then be made to institutionalize these select indices, adopting definitions, and standards for collection, simulation, and recording or publication. As a last step, it is recommended that the federal government maintain a massive (numerous not complex) data base (of these indices) on the energy performance of buildings in both the public and private sector.

1. Btu/sq.ft.yr
2. Btu/sq.ft.HDD (var. bases)
3. Btu/sq.ft.CDD (var. bases)
4. MMBtu
5. MMBtu/HDD
6. MMBtu.CDD
7. KWH/yr
8. GJ/yr
9. $/yr
10. $/sq.ft.yr
11. Simple Payback (years)
12. Life Cycle Payback (years)
13. UA Building
14. UA Conduction — BTUH/°F
15. UA Infiltration
16. Air Changes Per Hour
17. Heating Load Ratio (Loose/Tight Construction)
18. Office Energy Index
19. Home Energy Index
20. % of HUD Average
21. % Heating Energy Saved
22. Thermal Index Point for Envelopes (U-points)
23. Heat Flux w/m^2
24. Heat Flow w
25. Building Thermal Resistance — BTR
26. Daily Load vs. Daily Average Temperature — DLDT
27. Peak Load — kw
28. Power Consumption
29. COP
30. Equipment Size
31. Partial Load Ratio
32. Equivalent Full Load Hours
33. Seasonal Performance Factors for HVAC
34. Time Constant of the Building (In hours or days)
35. Thermal Capacitance of the Building (BTU/°F)
36. Moisture/Mass Balance (net moisture flux)
37. Balance Point Temperatures (°F)
38. Solar Savings Fraction
39. Solar Load Ratio
40. Solar Utilization Factor
41. Percent Daylight
42. Watts/sq.ft. Lighting Load
43. Lumens/Watt Lighting Efficiency
44. Percent Glass
45. Aspect Ratio
46. Surface to Volume Ratio
47. Comfort Index
48. Indoor Air Quality Index
49. Thermal Performance Degradation Factor (%)
50. Load Profile Histograms
51. Thermographic Profiles (Scales for relating thermography to heat loss)

Figure 1. List of indices

	Value of Index				have used extensively	needs research or stdization	data for no. of bldgs.
	envelope load dominatd		internal load dominatd				
	l	h	l	h			
BTU/ft^2 year	3	9	1	10			200
BTU/ft^2 × DD heating	5	7	6	3			20
BTU/ft^2 × DD cooling	6	2	6	2			—
UA Building	3	10	5	3			45
Time Constant of the Bldg	4	7	2	3			15
Peak Load	2	8	1	9			10
Power Consumption	2	7	2	6			10
Thermal Capacitance — Bldg	5	5	3	4			25
Balance Point Temperature	2	5	3	5			30
Solar Savings Fraction	7	2	5	0			20
Building Energy Index	3	2	2	3			10
Load Profile Histograms	5	3	2	4			30
Thermographic Profiles	6	2	8	0			20
Thermal Perf. Degradation Factor	7	1	5	2			—
BTU/ft^2 × occupancy, hours	9	0	5	1			10
UA Conduction	4	8	5	4			15
UA Infiltration	5	7	5	2			20
Air Changes/Hour	0	10	2	4			30
Equipment Size	4	4	2	7			10
Equivalent Full Load Hours	2	4	3	5			10
Aspect Ratio	5	4	6	4			
Surface to Volume Ratio	3	5	4	5			
Percent Glass	2	9	3	9			10
Solar Load Ratio	3	2	4	2			
Percent Daylight	5	2	3	5			
Watts/ft^2 Lighting Load	4	3	0	7			20
Lumens/Watt Ltg. Efficiency	7	1	3	5			
Comfort Index	2	7	2	8			10
Indoor Air Quality Index	4	5	4	7			10
$/ft^2 Operating Energy	1	4	0	5			30
Investment Payback in Years	2	4	2	5			20

Figure 2. Summary of responses to survey list of indices

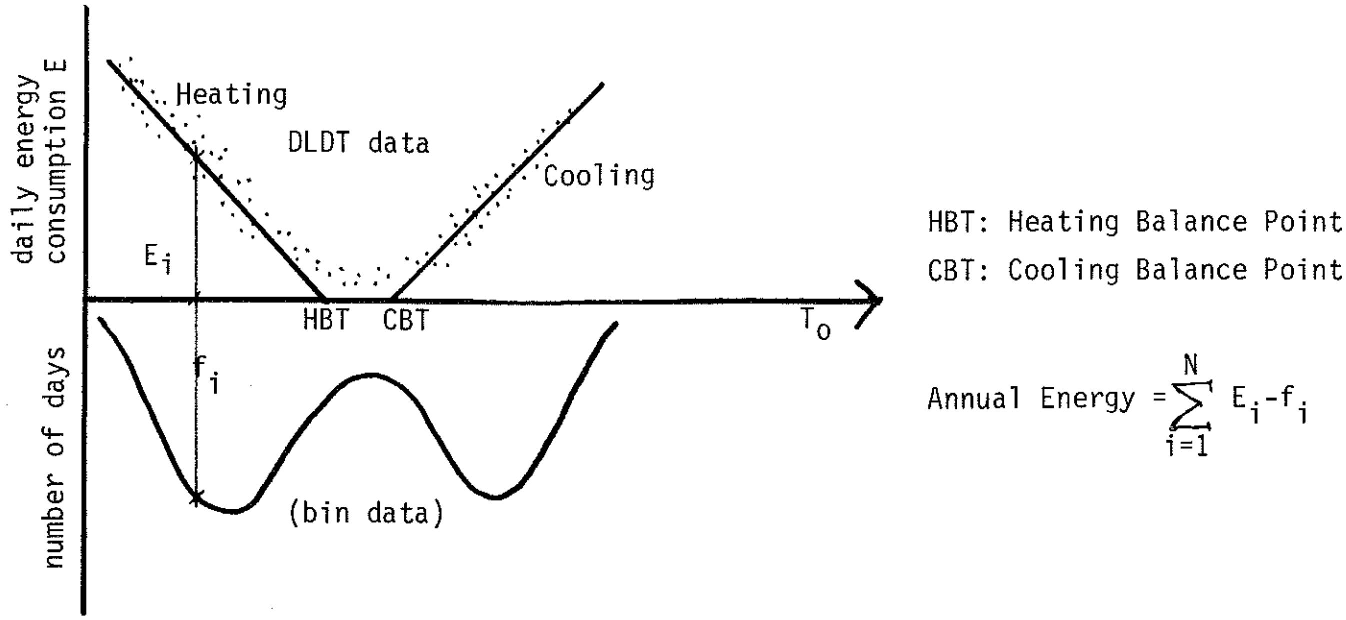

Figure 3. Daily load vs. daily average outdoor temperature

	Envelope Load Dominated Buildings				Internally Load Dominated Buildings					
GOALS FOR REFINING INDICES:	Btu/sq.ft.yr.	Percent of Glass	Air Changes/hr.	UA Total	Btu/sq.ft.yr.	Peak Load	Watts/sq.ft.	Equipment Size	Percent of Glass	Dollars/sq.ft. Operating
Improving Thermal Performance for Occupancies			●	●						
Saving Energy Over Long Term	●	●	●	●	●		●			●
Saving Money in Operation	●		●	●	●	●	●			●
Saving Material Resources										
Improving Cost Effectiveness Argument	●				●	●				●
Establishing Goals for Upgrading Buildings	●		●		●	●	●	●		●
Promoting Quality Control			●		●	●	●			●
Developing Comparative Communication Tool	●	●	●	●	●	●	●	●	●	●
Speeding Data Base Development	●	●			●		●			●

Figure 4. Evaluating preferred indices