



Research paper

Measuring ecological characteristics of environmental building performance: Suggestion of an information-network model and indices to quantify complexity, power, and sustainability of energetic organization



Hwang Yi^{a,*}, William W. Braham^b, David R. Tilley^c, Ravi Srinivasan^d

^a Paul L. Cejas School of Architecture, Florida International University, 11200 SW 8th Street, Miami, FL 33199, United States

^b Department of Architecture, School of Design, University of Pennsylvania, 210 South 34th Street, Philadelphia, PA 19104, United States

^c Department of Environmental Science and Technology, University of Maryland, 8127 Regents Drive, College Park, MD 20742, United States

^d M.E. Rinker, Sr. School of Construction Management, University of Florida, 573 Newell Drive Box 115703, Gainesville, FL 32603, United States

ARTICLE INFO

Keywords:

Average mutual information
Building energy network
Building performance
Complexity
Maximum power

ABSTRACT

The authors present preliminary study in pursuance of developing a flow network-based methodology of building performance evaluation, as current efficiency-centered methods do not fully account for the complex building performance in which nature, economy, and humans are inseparably involved. Based on the principle of entropy, this study defines building as a thermodynamic system that networks useful resources—energy, material and information—through close interconnection with the global environment. Measures of information content in energy-flow networking and ecological performance indicators from Shannon's information theory, Ulanowicz's ascendancy principle, and Odum's maximum empower principle are discussed and integratively applied to developing a generic building performance evaluation model. For the holistic indication of building sustainability, this work attempts to reconcile Ulanowicz's and Odum's statements about ecosystem development and also integrates *emergy* (spelled with an “m”) and information metrics. Environmental behaviour of the building model was tested with simulation to validate consistency with system-level principles. Results reveal that network complexity corresponds to system power and resilience (*L*) and fitness (*F*) tend to peak at an intermediate level of efficiency. This finding demonstrates applicability of Odum's maximum power principle to building study, suggesting that increasing complexity (and power) of energy-flow networking be a fundamental characteristic of sustainable building performance.

1. Introduction

Contemporary buildings are complex environmental systems. They increasingly embrace various scales of dynamic energetic phenomena in which economy, nature, and human dwelling are inseparably involved in direct or indirect ways. Despite their multidimensionality in energy and resource use, performance in current building codes and rating systems is simply described in term of the fixed quantities of energy (Joules, Watts, or Btu) and efficiency (%). Although energy-saving construction and operation are important to achieve building sustainability, quantity-based performance indication conceals intricate interaction among different types of energy use and complex material processes through a building, overlooking its broader environmental impact to global sustainability. Improving efficiency of high-tech air-conditioning systems, for example, blinds enormously complicated production processes exploiting expensive materials. We also usually discount that renewable equipment (e.g., solar panels) requires a great

deal of nonrenewable energy and human inputs to concentrate dilute natural power (Yi et al., 2017). So-called high-efficient buildings, moreover, often end up inefficient, like Jevons paradox, because their high standard of living promotes extra consumption of high-quality energy (McDonald, 2017).

The reason behind the dominance of efficiency-oriented description on building sustainability, in spite of mixed signals, is that we regard a building as a machine or a static object mechanically assembled. Buildings are machines; we build them purposefully, and they create artificial environments by design. Once a building sits on a site, however, it is “open” to the biosphere as well as ambient settings. All the physical phenomena during its life time, e.g., keeping the indoor comfortable (by either occupants or some equipment) or the weathering of building structures and materials, draw energy in, whether big or small, from the external worlds, and disperse it to the outside. Thermodynamically, indeed, a building is not a stand-alone machine, but a very communicative one.

* Corresponding author.

E-mail addresses: hyi@fiu.edu (H. Yi), brahamw@design.upenn.edu (W.W. Braham), dtilley@umd.edu (D.R. Tilley), sravi@ufl.edu (R. Srinivasan).

We can find an identical energetic feature in living organisms. They obtain energy from the environment and use it to live, adapting themselves through metabolic processes. As Schrödinger (1945) states, if we admit that this is the most fundamental characteristic of life, buildings (including occupants and surroundings) can be understood as the living in such a way that living and non-living things undergo the same physical process – energy dispersion (Sampson, 2007; Hosey, 2012). In this context, buildings can be likened to living systems, although, technically, buildings are neither alive nor purely organic.

The analogy between building and life, in effect, is not new. Buildings are compared quite often to living organisms. One employs it as a metaphor of formal representation, or some others highlight functional resemblance (Steadman, 2008). In the study of building performance, however, the thermodynamic analogy has been elucidated by few (Salingaros, 1997; Fernández-Galiano, 2000; Braham, 2015), and not developed to a concrete methodology based on physical science. Though some recently attempted to model a building with biological accounts (Gamage and Hyde, 2012), misunderstanding of the analogy is widespread in the green building industry. Even in the most rigorous sustainable building standard – The Living Building Challenge (LBC), it says, “ideal built environment should function as cleanly and efficiently as a flower (International Living Future Institute).” The photosynthesis efficiency of a flower is, in fact, less than 6%, while the efficiency of a photovoltaic panel ranges from 10 to 20%. This metaphoric agenda hides the fact that upper-class organisms in a trophic chain have greater transfer efficiency.

To integrate different approaches into a larger whole, accordingly, building performance should be evaluated based on a systematic approach that builds on a holistic thermodynamic understanding of nature and artificial systems. Everything-as-a-thermodynamic-process dwells on the flow-specific aspect of energy, *i.e.*, transfer and conversion between different energy forms, and, thus, thermodynamic interpretation of environmental phenomena enables to integrate the living and non-living in energy streams, thereby characterizing a building as an energy-channeling component within a whole environmental life cycle.

Therefore, it is important to find a methodology to describe, analyze, and measure building performance by incorporating dynamic networking of all kinds of energies and resources exchanged, both internally and externally, all the way through global ecosystems. To this end, this study introduces a new measure to building study, *information* (or *information entropy*), and seeks to incorporate it into performance indices. A modern concept of information was suggested by Wiener (1948) to suggest study of system feedback and responsive machine control in cybernetics. Shannon (1948) provided a mathematical definition of information through logarithmic uncertainty in a communication channel so that it quantifies signal transport attributes in a non-deterministic way.

Information has gained wide popularity in various areas—statistics, mechanics, social science, and biology. Meadows and Wright (2008) states that any system incessantly processes information by self-organizing matter and energy, and information content has an enormous effect on how systems operate. Furthermore, Kelly (2011) argues that the performance of contemporary goods and technologies should be evaluated by their information capacity, rather than materialistic values of their carriers. Thus, information is a measure of the ‘quality’ of energetic performance. In biology, Koestler (1967) asserts that energy particles (called ‘*holons*’) tend to develop a hierarchical organization in biotic systems and information of this hierarchy is the inherent hallmark of all living systems.

This approach does not negate the importance of energy efficiency, but calls for a comprehensive paradigm of building energy study, because pursuing greater efficiency (or vice versa) is not aimless, yet owes to system dynamics of a larger whole. To develop a specific method, whether or not thermodynamic accounts are immediately applicable needs to be validated first, and also, it is necessary to identify that an individual building develops a specific internal configuration of energy

transfer pathways and how to network energies between the global environment and local building components. Then, building performance can be diagnosed by monitoring the topologies of network patterns. To find answers of these queries from R.E. Ulanowicz and H.T. Odum, this research intends to (i) prove the consistency of eco-systemic characteristics and building performance and (ii) establish a model for generic building sustainability analysis. Furthermore, this work attempts to illustrate, with thermodynamic accounts, how building performance incorporates informational aspects of ecosystems.

Section 2, following, explores system-level principles that are applicable to ecological indications of building sustainability. It shows that thermodynamic principles justify the physical-biological system analogy. Sections 2.1 and 2.2 discuss the relevance and discrepancy between the law of entropy and maximum power principle that characterize ecosystem developmental behaviour. Section 2.2 introduces mathematical measures of information content and definitions of informational ecosystem indices suggested by Shannon (1948) and Ulanowicz (1986). In Section 3, principles and system measures from Section 2 are validated for their applications to buildings. This step is critical to defining the scope of modelling as well as demonstrating the consistency of the maximum empower principle and information-based indications of system development. Section 4 presents a schematic building network model and pilot simulation with informational indices, confirming the applicability of ecosystem principles. Findings from this test provide a rationale for the use of information as a new building sustainability indicator.

2. System-level principles of energy transport and measures of performance

2.1. Thermodynamic principles of living system analysis

The second law of thermodynamics (SLT; *i.e.*, the law of entropy) is a universal principle applicable to the entire physical/non-physical energy processes. According to the SLT, if energy in a system is depleted and becomes wasteful (low quality energy; *e.g.*, heat), the system will perish, and, conversely, if it gains useful energy (high-quality energy), it survives. Since work indispensably involves an entropy increase as it discounts the potential energy of a source, it is reasonable to postulate that production of entropy is a dominant indicator of all biological metabolisms.

On the largest system scale—the universe, the SLT is axiomatic, for the universe is assumed to be a closed system. Nevertheless, it does not immediately clarify an internal logic of open (living) systems driving them to keep persisting against the death (*e.g.*, why a highly-ordered system is naturally selected, survives in competition, and eventually well-fitted to the environment.), as the systems continuously moving towards a non-equilibrium state are not always subject to the overall increase in entropy of the universe. This contradiction was noticed by Lotka (1922) and Schrödinger (1945). They state that the ‘course of events in a physical system’ did not strictly follow the SLT, and mentioned ‘freedom of choice’ in the course of system processing of energy transformation is the main method of maintaining an ordered equilibrium (Lotka, 1922). Thus, a more immediate principle is needed.

2.1.1. Theorems of entropy production

As any form of nutritional substance on the earth is present in a form of energy (Odum and Odum, 1976), the vitality of all physical, non-physical systems needs energy that always produces entropy. The theorem of minimum entropy production (MinEP) suggested by Prigogine (1945) states that a stationary or near-equilibrium system tends to maintain the lowest entropy production rate. The MinEP’s general mathematical derivation proves that an orderly stable state must produce lower entropy, which is consistent with the SLT. Nevertheless, the MinEP explains local system states with strict linear conditions and a state of very slow, purely diffusive transfer (Nicolis and Prigogine, 1977;

Download English Version:

<https://daneshyari.com/en/article/5741491>

Download Persian Version:

<https://daneshyari.com/article/5741491>

[Daneshyari.com](https://daneshyari.com)