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Published in:
ISEC 2024 – 3rd International Sustainable Energy Conference

DOI (link to publication from Publisher):
10.52825/isec.v1i.1093

Publication date:
2024

Document Version
Publisher's PDF, also known as Version of record

ISEC 2024 – 3rd International Sustainable Energy Conference
Solutions for Energy Efficiency
https://doi.org/10.52825/isec.v1i.1093

Published: 09 Apr. 2024

Integrated Energy Solutions: A Call for Inclusion of Non-Technical Factors

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Abstract. The central supposition put forward in this paper is that typical building-related energy efficiency measures do not automatically yield the looked-for large-scale environmental effects. Rather, many such measures entail two kinds of reductionism, in that they *i)* treat buildings detached from the larger system (such as the urban context), to which they belong; *ii)* concentrate on solutions, which are predominantly technological in nature. As a consequence, the complexity of the challenge may be neglected, along with other non-technical, yet potentially critical areas of concern. Such areas include, inter alia, economy, politics, policy, as well as societal and psychological circumstances. In this paper, we discuss a few typical instances of such reductionist stances to shed light on factors that impede their utility. Moreover, we highlight a few instances of systemic methods that have been suggested as having the potential to address complex problems in general, and the environmental implications of energy efficiency measures in the context of the built environment in particular.

Keywords: Energy Efficiency, Buildings, Integrated Solutions, Complexity

1. Introduction

Discussions of environmental challenges typically highlight topics such as non-renewable energy use, resource depletion, greenhouse gas emissions, air, land, and water pollution, and biological degradation. Thereby, construction, operation, and maintenance of buildings are suggested to play a major role. It is thus not surprising that the "sustainable buildings" discourse typically starts with the statement that buildings are responsible for some significant share of energy use and environmental emissions. This assertion is of course valid. However, there is a gap between the reference to the global environmental challenge on the one hand and the proposed specific solutions in the sustainable building area on the other hand. The contention is that the typical instances of "sustainable buildings" strategies do not necessarily yield the postulated major mitigation effect at the global level. Rather, a fair share of these strategies displays two types or levels of reductionism. One level pertains to the treatment of buildings in isolation from the larger system in which they are part of (e.g., settlement patterns, urban infrastructure). The second level concerns the frequent focus on technology-centric solutions. Consequently, other potential areas of intervention (related, for example, to economic, political, social, and psychological boundary conditions) may receive insufficient attention. We present illustrative instances of such mono-dimensional solutions and their limitations. Moreover, we briefly discuss the potential of selected alternative systemic strategies and tools toward building-related environmental mitigation measures.

2. Expectations versus reality: the case of energy performance gap

It is generally assumed that the thermal retrofit of existing building stock is one of the most effective means to improve the energy performance of the built environment. Respective projects are typically preceded by the estimation of the expected energy savings attributable to the retrofit measures. And such, estimations do indeed point to considerable energy efficiency improvement potential. However, in many instances, the actual post-retrofit energy performance of retrofitted buildings does not rise to the level of preceding expectations. Numerous studies with subjects such as "the rebound effect" and "the energy performance gap" have addressed this discrepancy and identified candidate factors contributing to it [1]. We cannot revisit these studies in detail here. However, it may be useful to reiterate some of their core findings. Generally speaking, the occupant-driven rebound effect, as applied to buildings, suggests that predicted energy savings may not materialize in the actual practice, because building occupants may use the gained efficiency (and its positive monetary effect) to improve their living conditions (e.g., thermal comfort). For instance, under post-retrofit conditions, the occupants may shift the heating set point temperatures upwards and/or increase natural ventilation via window operation in the cold season.

Understanding the working of the rebound effect requires thus a foray beyond technology-centric considerations. Similarly, in case of the building-related energy performance gap, the explanation of the discrepancy between predicted and actual energy use cannot be based solely on technology-centric arguments. Discrepancies between the as-designed and as-built versions of buildings' construction and their systems can of course contribute to the energy performance gap, but so can other factors, such as micro-climatic conditions and human behaviour (e.g., patterns of occupants' presence in the buildings and their interactions with buildings' indoor-environmental control systems). A large-scale review of literature on building-related energy performance gap suggested a considerable deviation of actual energy use from predicted values of about 55% (±90%) [1]. Technology-related factors may explain, depending on individual instances, some fraction of such deviations, but a deeper understanding of the underlying processes – particularly in the case of the rebound effect – requires also the consideration of psychological and social factors involved in occupants' interactions with buildings and their systems.

3. A comparative case study of technological and organizational strategies

As alluded to previously, what usually comes to mind, when thinking of energy-related issues in the design and operation of buildings, are mostly technical measures (e.g., thermal insulation of buildings' envelope, installation of more energy-efficient heating and cooling systems). However, depending on the context, technical considerations may not be the only or the most critical factor. A previous study provides a useful case in point [2]. It explored the district-level energy implications of alternative living models in Vienna (Austria). The impetus to explore such models was the fact that, due to demographic changes, an increasing number of the elderly in European cities live alone in large dwellings [3]. This results in unnecessarily high demand for not only energy, but also spatial and financial resources.

The study hypothesized that communal living models [4] offer energy-related advantages due to the higher occupancy density and the shared use of spatial resources. In the course of this study, the purported energy efficiency potential was explored via numeric simulation. Thereby, a communal living model was virtually integrated in two typical houses in a district of Vienna and compared with single-occupancy solutions. Two occupancy models were considered: The first (individual) model, which, frequently represents the current circumstances, assumes that a single occupant lives in each apartment. The second (communal) model assumes a higher occupancy via smaller individual apartments but involving shared areas. For each of these models, two sets of construction-related assumptions were considered: The first assumption denotes as-is construction features, whereas the second denotes thermally retrofitted constructions. Annual heating loads were simulated for these two buildings and four scenarios (i.e., existing and retrofitted building with individual occupancy and communal living). Hence, the energy-related benefit of communal living models could be compared with benefits of thermal retrofit measures.

The results suggested that the per occupant energy efficiency improvement potential of the communal living scenario is comparable in magnitude with full thermal retrofit. Of course, the combination of both measures would be optimal. The extrapolation of these results up to the urban scale (the city of Vienna, in the present case) revealed a significant heating load reduction potential. Aside from energy conservation, the communal living could also bring about savings in space usage. Increased occupancy in the city proper could contribute to reduction of urban sprawl, traffic, and virgin land usage. Moreover, the existing infrastructure (e.g., shops, services, transportation) could be used more efficiently.

4. Technological capacity versus urban sprawl

Countries with high Human Development Index (HDI) [5] are considered to be highly advanced in terms of well-educated work force, technological capabilities, and Gross National Product. From a theoretical standpoint, these countries are the ones with the required technical and material resources to pioneer sustainable development and transformation in the built environment. They tend to have more stringent standards governing the production of building materials and systems, as well as their application towards construction of energy efficient buildings. They also possess the means and resources to develop long-term policies for large scale retrofit projects of the existing building stock. Likewise, technologies pertaining to energy efficient operation of buildings' technical infrastructure (e.g., those required for indoor environmental controls) are arguably well-developed. In view of these advantages, a natural assumption would be that over the past years, the countries with higher HDI have become more sustainable regarding the built environment. However, the question is if this apparent technological upside translates into higher resultant efficiency.

In this context, it is interesting to consider a study of the worldwide growth of urban sprawl in a time span of 24 years (1990-2014) that points to an increase in the global urban sprawl by 95% (almost 4% per year) [6]. Urban sprawl is characterized by a spread of low-density housing on the outskirts of urban areas with low access to urban infrastructure and high dependency on individual means of transport. It leads to various environmental issues, such as air and water pollution, increased use of fossil fuels due to transportation, increased impervious surfaces, disruption of critical natural habitats, loss of open spaces, and increased risk of flooding [7]. The study revealed a strong positive correlation between HDI and the growth of urban sprawl, with Europe being the most sprawled and the most rapidly sprawling continent (by 51% since 1990). According to the results, 30% of all OECD countries are affected by high urban sprawl and 90% of these countries show a high level of sprawl per capita despite a long history of sophisticated land use planning systems to govern the growth of the built environment.

This development has been attributed to the assumed higher quality of life in the low-density suburban areas. The results of the study become even more noteworthy, when paired with the statistics of vacant dwellings in these countries. An official report commissioned by the European Union [8] estimates the average share of vacant dwellings in Europe by 18% in 2011. In view of this trend, one might question the effectiveness of stringent building codes and purely technology-centric approaches in creating more sustainable habitats, in the absence of a realistic and holistic definition of quality of life as a collective vision, and policies, which support its attainment.

5. Coping with complexity: thoughts on tools and theories

The suggestion that solely technical approaches are not sufficient to effectively address the subjects of environmental mitigation and energy efficiency is of course not new. There is in fact a body of literature that describes the use of behavioural theories to guide energy performance questions relevant to built environment at multiple levels of observation (buildings, neighbourhoods, cities) [9]. Such studies have explored the relationships between *i)* building design and operation decisions, *ii)* indoor-environmental conditions, *iii)* human behaviour, and *iv)* energy performance. However, the deployed theoretical schemes appear to be rather narrowly defined, and locally customized to fit specific sets of circumstances and limited observational data. Ultimately, these approaches hardly add up to scalable theory application instances [10] that would generally inform non-reductionist building-related mitigation efforts.

Note that the main challenges in addressing the complexity of the environmental mitigation problem may not lie in the lack of suitable formal instruments. A host of mathematical tools and methods (e.g., multi-variate analysis, multi-criteria optimization, stochastic methods, agent-based modelling) have been shown to provide formally useful means to address complex problems. But such mathematical formalisms are inherently syntactic. When applied to practical problems, they require substantial domain information (i.e., estimates of variable values) and transparent estimates of variables' relative importance (e.g., estimates of relative weights). Even more critically, syntactical formalism, when applied to behaviourally relevant applications, need to rely on theoretical guidance and associated preferably white-box type models. Note that there is nothing original about the realization that complex problems require adequate theoretical frameworks. A case in point is the work of Ludwig von Bertalanffy, a biologist who was the originator of the general system theory, developed in 1940s. The point of the general system theory was to offer an alternative to *divide et impera* approach of the reductionist attitude. General system theory is, in Bertalanffy's own words, "a general science of wholeness". He suggested that the expression: "The whole is more than the sum of its parts" simply means that a system's "constitutive characteristics are not explainable from the characteristics of the isolated parts. The characteristics of the complex, therefore, appear as new or emergent" [11]. The general system theory has been ever since further developed and applied in fields such as ecology, psychology, and sociology.

Another prominent instance of efforts to address the behaviour and evolution of complex systems is associated with the complexity theory, which views systems as networks with interacting components and explores, amongst others, system states between order and chaos [12, 13, 14]. This theory has treated phenomena such as self-organization, adaptive behaviour, equilibrium and dynamics, emergence, connectivity, and co-evolution.

Promising as theoretical endeavours may be, they seem to be, in actual application cases, subject to a kind of re-segmentation: Rather than bridging over inherently heterogeneous disciplines (e.g., engineering, climatology, behavioural sciences), they seem to evolve in separate directions. Considering, for instance, the case of the general system theory, one can observe already within one domain, that can be viewed as a sub-sub-discipline (social work) of a sub-discipline (sociology) of a discipline (human sciences), a branching of the original theory into multiple versions [15, 16, 17, 18, 19].

6. Concluding remarks

In this paper, we argued that the typical efforts toward promotion and realization of sustainable buildings often fall short of the expected levels of effectiveness in environmental mitigation. We suggested that this circumstance may be in part the result of *a)* treating buildings as isolated entities and *b)* an overtly technology-centric mindset. Failure to rectify this circumstance does not appear to be per se a consequence of missing theories and instruments for integrative and holistic problem-solving strategies. However, it seems that, in practice, theories that were originally intended to act at a general system level, frequently end up addressing problems within individual disciplinary boundaries. As many other domains of industry, service, and production, it is not likely that the mitigation of buildings' negative environmental impact can be achieved via purely technological means. Rather, it depends on adequate boundary conditions, which in turn require coordinated strategies in policy, economy, and governance areas. Formal means and instruments of integrative problem-solving are available. But they are not likely to be pervasively applied in the practice without the collective will and dedication of the responsible – both private and public – stakeholders.

Data availability statement

This contribution is not based on data beyond information entailed in the provided references.

Author contributions

Conceptualization and writing of the original draft (A. Mahdavi 50%, C. Berger 25%, N. Ghiassi 25%), other relevant CreDIT criteria: relatively comparable contributions by the co-authors.

Competing interests

The authors declare that they have no competing interests.

Disclaimer

The views expressed in this contribution are the authors' and do not necessarily represent the positions of their respective institutions.

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