Neglected Issues in Building Performance

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ABSTRACT: The paper outlines a number of potentially very useful building performance concepts that have been ignored, forgotten or only partially adopted. The idea explored in this paper is that, despite many significant advances in specialized fields, there are also many issues that remain outside the mainstream of building research, guidelines or conventional wisdom. Some of these are technically challenging to integrate into current body of knowledge, but others remain "outside the tent" for reasons that are difficult to justify.

The review of neglected issues in building performance includes the Integrated Design Process (IDP) and Predicted v. Actual performance, which are both recognized as being important but are not fully implemented. The differences between Source, Primary and Delivered energy are well recognized by energy specialists, but not by many professionals. There is a major misconception about Zero or Nearly Zero definitions amongst some professionals and almost all professional publications, or perhaps such groups are choosing to disregard the importance of embodied energy and emissions in the lifecycle environmental impacts of buildings. The differentials between Predicted and Actual performance are beginning to become recognized as being important, but need more visibility. An issue related to metrics, occupant density and annual person-hours, is something that is generally ignored but should not be, since it places energy and emission results in a much more realistic context. Weighting in rating systems is another metric-related issue which must be resolved if rating results are going to have any meaning beyond marketing value. The prospect of Synergy Zones offers the possibility of improved performance within small urban areas, but the problems posed by management complexity will be difficult to overcome. Finally, going "off the grid" with large buildings is clearly a bad idea.

Keywords *design process, integrated design process, IDP, source energy, primary energy, delivered energy, zero energy, nearly zero energy, predicted performance, actual performance, occupancy patterns, rating systems, weighting, Synergy Zones, off the grid*

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1. NEGLECTED ISSUES

1.1 The importance of the design process

One source of support for the idea that the structure of design process can have a major impact on the resulting performance of the building is the experience gained from a small Canadian demonstration program for high-performance buildings, the C2000 program, which was developed and managed by Natural Resources Canada (NRCan), with the author as developer of the requirements and manager of the process (Larsson, 2009).

One feature of the program was the provision of funding to cover what were expected to be significant incremental costs for high-performance systems necessary to reach the challenging performance goals of the program. Another important aspect was that efforts were made to have the client, architects, engineers and specialists to work as a team. This aspect proved to be very successful and resulted in most performance goals being reached at significantly lower costs. The design support process used in the C-2000 program came to be referred to as the *Integrated Design Process* (IDP), and all project interventions in the program came to be focused on providing advice on the design process at the very early stage of design.

The work at NRCan led iiSBE to develop an IDP tool (Larsson 2000-2009) allows the design team leader to easily identify which of the key actors in the process should be involved at each step of the process. In parallel with the development of IDP concepts in the C-2000 Program, the International Energy Agency (IEA) launched a working group called Task 23, which focused on the same ideas, but on a more theoretical plane. The work of Task 23 led to a guideline (Löhnert, Dalkowski and Sutter, 2003).

IDP may be thought of as a process that, at the minimum, helps clients and designers to avoid bad decisions and at best, supports a search for optimal performance. Another key aspect of IDP is that small errors made early in the process tend to spread their influence in a major way as the design progresses.

The use of IDP is especially important in early phases of the process. At this stage, architects and engineers almost never question the client's initial space and performance requirements, as expressed in the functional program, and their focus is on developing a design that implements the client's requirements. This approach overlooks the fact that bad decisions, including unnecessary facilities or excess space requirements, are often to be found in the functional program and spread their influence through all the later stages in the process.

If the goal is to produce a high-performance building, this excess must be challenged and this can be done by including the client in frank discussions about the functional program requirements at the very beginning of the design process. The figure below shows a simplified graphic of major steps in the IDP process:

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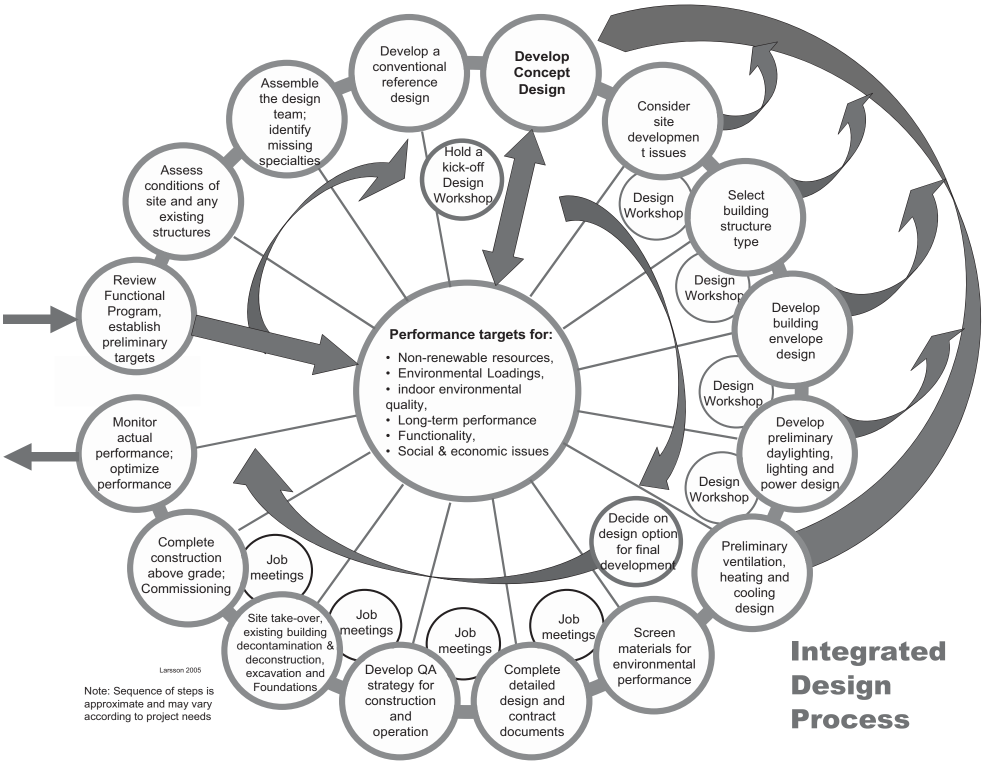

Figure 1. A simplified graphic representation of the IDP process (Larsson, 2008)

IDP is now generally recognized to be important in supporting high performance, but it is still not standard practice, and some elements of the design process, especially the development of the functional program, is still not considered.

1.2 Source, Primary and Delivered energy

There is widespread confusion, except within narrow specialist circles, of the differences between Source, Primary and Delivered energy. Most professionals are content to describe energy performance in terms of the sum of annual metered electricity plus the energy content of fuels (gas, oil) used on site to produce heat. These are actually not comparable quantities, since the fuel used to provide heat undergoes efficiency losses in combustion processes, even if combustion equipment is highly efficient.

A further complication is that the delivered electricity is the end result of a series of efficiency losses, starting with efficiency losses at the remote power plant in the generation of power from raw fuels. For example, the International Energy Agency estimates (Petersen, Torcellini and Grant, National Institute of Building Sciences, 2015) that electricity that is produced in a coal-fired boiler may lose about 60% of its potential energy in the combustion process, and that is before accounting for distance-related transmission losses in the grid.

Delivered energy is easier to deal with in the calculations used to assess energy efficiency, but in view of the factors outlined above, it can be very misleading. These issues become especially important as we focus on Greenhouse Gas (GHG) emissions, since the same amount of energy produced by coal in Warsaw or by hydro-electricity in Oslo will have source emissions that may differ by a factor of about 3.

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1.3 Zero energy or nearly zero buildings

Zero Energy or Nearly Zero Energy buildings have recently become very popular at policy, program and project levels. For example, the introduction to the European Commission web page on Energy states that:

> *Nearly zero-energy buildings have very high energy performance. The low amount of energy that these buildings require comes mostly from renewable sources.*
>
> *The Energy Performance of Buildings Directive requires all new buildings to be nearly zero-energy by the end of 2020. All new public buildings must be nearly zero-energy by 2018.*

A recent publication by the U.S. government (NIBS, Sep. 2015) provides a somewhat different definition:

> *A Zero Energy Building (ZEB) is an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.*

The NIBS definition clearly states that we are referring to the operating phase of the building's life cycle, but even this very useful paper does not discuss the relationship between energy consumption during the construction and operating phases. This would be reasonable if there was no connection between energy used to construct the building, but that is not the case. Ten or more years ago, a rule of thumb often used was that initial embodied energy was equivalent to a few years of operating energy, but recent improvements in operating performance (which reduces operating energy) is strongly related to the use of better and/or more materials (which increases initial embodied energy). For example, the greater initial embodied energy related to more thermal mass and the more frequent use of use of triple glazing constitutes a partial trade-off with better operating performance.

This relationship leads to the conclusion that a more logical metric than operating energy would be life-cycle energy, blending embodied and operating energy values into a unified *life-cycle energy* measure. Although a desirable goal, some problems immediately come to mind: to place initial embodied energy on the same footing as operating energy, we need to amortize the embodied energy over the building's life span to provide an annual figure, and this is somewhat difficult to predict. A second problem is that as soon as the building's life span (say 60 or 75 years) is considered, we must also factor in recurring embodied energy resulting from the replacement of building envelope elements, mechanical equipment and indoor fit-up components. Finally, a practical problem is the difficulty of tracking down the embodied energy values of diverse building elements, and then there is the question of identifying the manufacturers' source energy and emission values. Clearly, integrating embodied energy and emissions into a life-cycle measure is a very complex matter.

Nevertheless, life-cycle emissions is the only factor that is relevant to the environment and climate change and therefore we must attempt to deal with it, even if the difficulties mentioned will make it impossible to be exact. Therefore we must be very clear as to not mislead the industry into thinking that zero operating energy is a total solution.

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1.4 Predicted v. actual performance

Most designers concern themselves with the potential performance of the building as predicted at the time of design by means of their experience with similar designs or by using simulations Building operators and managers are more concerned with the actual performance during operations, usually assessed at least two years after construction in order to reduce the variability that occurs as new systems are managed by new operators.

Predicted and Actual energy performance values can be quite different, as iiSBE Canada's experience in Post-Occupancy Evaluations in 2013-14 showed (Bartlett, K; et al, October 2014). Nine buildings were assessed by a team of researchers from 3 Canadian universities, with their predicted and actual performance, in categories of energy, emissions, water and indoor environment performance being compared with reference performance benchmarks. The energy use intensity results show a wide variation between the three sets of data, as shown in Fig. 2.

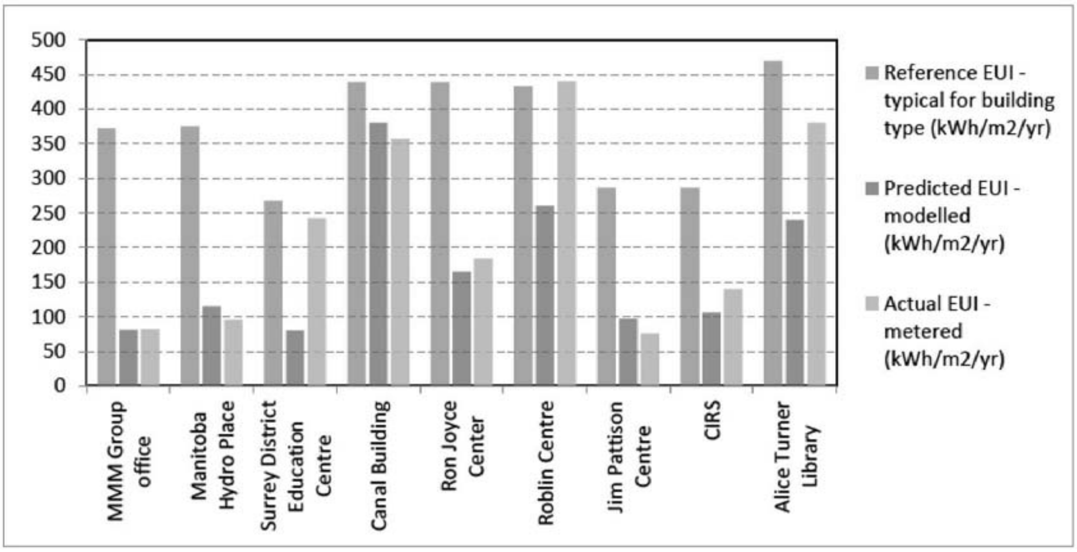

Figure 2. Comparison of building EUI predicted, actual and reference in Canadian POE study

Two of the study's conclusions are germane to this discussion:

1. Actual building occupancy (i.e., hours of operation and occupant load) can be very difficult to determine if not monitored and recorded on an ongoing basis;

2. Building occupancy often changes significantly from the original design assumptions, which can have significant impact on actual energy and water use.

1.5 Occupants and their occupancy patterns

The number of occupants is a useful factor to relate to energy or water consumption, but the simplicity of the metric is deceptive. During the design phase, most predictions about energy, emissions or water performance are normalized according to the building area (e.g. kilowatt hours per gross or net m2 or kWh/m2*yr.) or, in the case of water consumption, by the number of occupants (e.g. litres per person per year, or LPP*yr).

When a building is in its operational phase, however, the number of occupants at any given time may be quite different from the original assumptions. This can be a result of

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one or several of the following factors:

- The building is not fully rented, therefore one or more floors are empty or partly occupied;
- Uses have been located in the building have uses that are different from the original assumptions, such as a ground-floor café with high energy usage due to kitchen equipment.
- Operating hours may have changed. It will readily be seen that an office that shifts from a regular 35- or 40-hour week to a more intense pattern will increase energy and water consumption. This need not be a shift that applies to all occupants; it could be floors that are partly occupied on weekends or nights.

The Canadian study previously cited provides an example of this kind of issue:

> *This multi-use academic building is home to a university department, housing students, faculty, and support staff. The building has a main floor cafeteria, computer lab, and lecture hall .... The fourth floor is currently unfinished, though it is partially conditioned. The building hosts special events on many evening and weekends, an expected occupancy load of the building, but one that is difficult to measure accurately.*

This example shows that some building types, such as academic buildings, have occupancy patterns that are more difficult to predict than others. In such circumstances, reporting performance results to two decimal places is definitely unwarranted.

The question of what metric is most suitable to report operating performance remains. In the iiSBE SBTool system, most performance results are normalized in order to account for both the number of occupants and their hours of attendance. SBTool provides results normalized both by area or per person, and also by million annual person hours (maph).

1.6 Weighting in rating systems

All commercial rating systems have some form of mechanism to weigh the relative importance of the performance criteria, and several are trying to make these weights increasingly science-based. However, if we look at some major commercial systems, the weighting is only done within major issue areas, such as Energy, Indoor Environment etc. All these systems provide overall integrated scores, and they produce the weighting between issue areas by having expert panels produce weights for these major categories. For example, LEED v4 allocates weights to impact categories as follows:

35%	Climate change;	20%	Health & well-being;
15%	Water resources;	10%	Biodiversity;
5%	Green economy;	5%	Social equity, community health;
10%	Natural resources.		

This kind of weighting scheme is simple to apply, but its main problem is that it is based on a consensus by an expert panel, and it is applied at the level of impact categories, not at individual criteria levels. The case of LEED poses a more severe problem because of its widespread use, which means that standard weights are allocated to hugely different regional conditions. For example, if a 15% weight for Water Resources is appropriate for a location with average rainfall and aquifer conditions, how can it also be appropriate for the States of Nevada (24 cm annual rainfall) and for Hawaii (179 cm)?

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Weightings for the German DGNB rating system are also based on the work of expert panels, and have similarly dubious credibility. Site quality is not weighted. The DGNB weighting schema has a clean and simple structure, but the basis of these allocations is not credible. The DGNB weights are:

22.5%	Environmental quality;	22.5%	Economic quality;
22.5%	Sociocultural & functional quality;	22.5%	Technical quality;
10%	Process quality.		

The HK BEAM case is also based on expert consensus, but it is at least grounded in the experience of one physical location, which presumably explains the high weight for Site. HK-BEAM allocates weights as follows:

25%	Site;	8%	Materials;
35%	Energy use;	12%	Water use;
20%	Indoor environmental quality.		

SBTool provides an algorithm that allocates percent weights based on type of criterion, its estimated impact, duration and extent, with a modification for local conditions. While far from being perfect, this approach is a vast improvement on existing systems. The SBTool weighting algorithm is structured as follows, and applies to each low-level criterion.

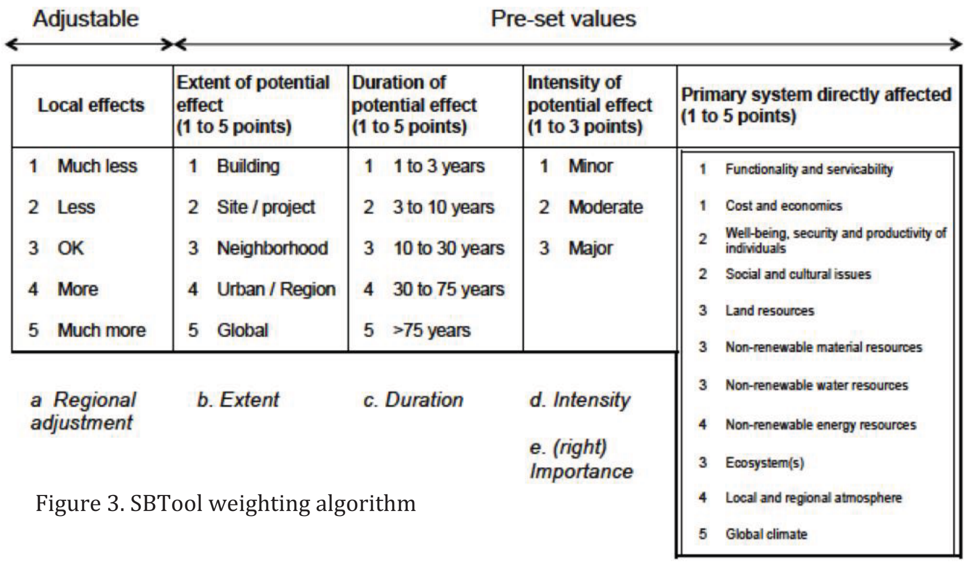

Figure 3. SBTool weighting algorithm

1.7 Small urban areas and Synergy Zones

We have gone very far in improving the performance of new single buildings. One most important area for future work is to explore the performance synergies within groups of buildings. Such synergies can include balancing supply and demand of thermal energy, domestic hot water, and greywater slated for reuse. The possibility of using DC power generated from PV systems on the site without having conversion losses also arises if DC distribution systems are installed in commercial buildings.

A Synergy Zone initiative, as we define it, would consist of a small urban zone or cluster that contains buildings with a variety of configurations and occupancies. Variation is important, because the concept is based on balancing supply and demand, and buildings

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with different uses and configurations (height, footprint) are usually in either a deficit or surplus situation with respect to thermal energy and water.

The storage and exchange of thermal energy is an important priority, logical in the context of some buildings producing a heat surplus (captured through heat-recovery ventilation systems), while others could benefit from zone-supplied heat. On the cooling side, some building operators may find it more economical to draw on a chilled thermal source supplied from the zone. This implies a need for thermal mid-term storage of thermal generation sources and a re-distribution system of low-temperature heating systems of buildings in the zone that have thermal deficits. Optimization controls and software are essential to optimize such a system.

Domestic hot water systems are another candidate for optimisation of supply and demand, given that some occupancies (residential, hotels, restaurants) have high demand, while commercial or public occupancies have little demand, but offer the possibility of DHW production through waste heat produced in combined heat and power (CHP) systems or (for DHW pre-heating) recapture of thermal energy from HRVs.

Many modern buildings make provision for rainwater capture and grey water use, but some (e.g. high-rise) have relatively minimal opportunities for rainwater capture, while low-rise buildings (e.g. schools) can produce large amounts. There is therefore logic in exploring a zone-wide greywater treatment, storage and redistribution system for all buildings in the zone. Such a system would filter and treat grey and black-water within the zone before storage. Again, optimization controls and software are essential to optimize such a system.

The role of DC power often focuses on generation of DC power from PV panels, conversion to AC through power inverters and uploading to the grid, in the context of feed-in tariff arrangements. Such discussions, however, almost always consider such systems in the context of a single building. In the case of small urban areas, the source of DC power may include that produced from CHP, PV, wind power, bio-mass sources in the zone. Power can also be produced on buildings in the zone that have orientations or configurations suited for solar, which would ensure diversity of supply.

The storage of DC power will be an important feature of a Synergy Zone approach, to store power generated in the zone as well as off-peak power from outside sources, for redistribution to other buildings in the zone with a DC deficit. The ability to use DC power in the zone would minimize conversion losses to AC for transmission and then back to DC again through rectifiers at the point of use.

A more radical approach, but one with much potential, is to explore the installation of DC power distribution systems in commercial buildings in the zone, operating in parallel with conventional AC systems to directly provide power to low-voltage DC equipment. The proposal for use of direct DC building systems reflects the greater availability of DC power sources and also the increasing prevalence of DC-powered systems in and around buildings, such as electronic light ballasts, computer equipment and re-charging of electric vehicles. The issue of jurisdiction and management is of critical importance in cases where a zone is not under single ownership. Coordinated system implementation and operation within a zone under multiple ownership could easily fail at the beginning unless there are contracts and agreements in place that allow a common management body to build,

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operate and charge for the required systems. In such cases, the physical implementation of systems, their operation and the revenue and cost sharing will require a new form of cooperative zone management to be successful.

The Synergy Zone concept has been promoted by iiSBE since 2009 (Larsson 2009), without any success in finding partners to implement the proposal. A conservative estimate is that the total operating energy reductions compared to very efficient individual buildings would be in the order of 20%. Figure 4 below provides a schematic of how a synergy zone might be structured.

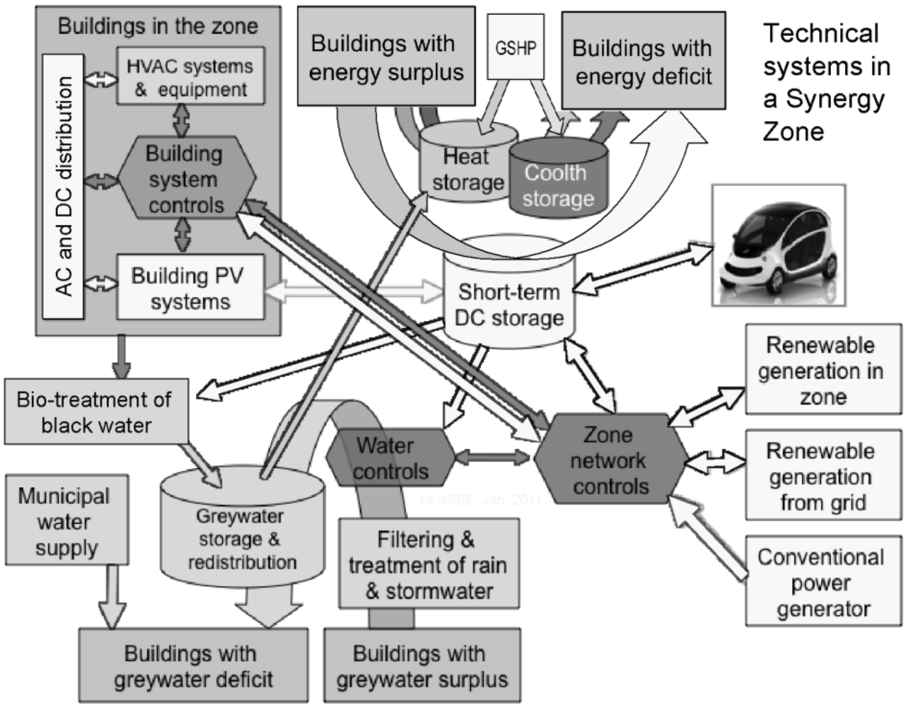

Figure 4. Technical systems in a Synergy Zone

1.8 Going off the grid

Many investors, researchers and designers are very interested in reducing and even eliminating the dependence of houses and buildings on existing public infrastructure systems. This is based both on costs and a change in design philosophy.

Many of the very early initiatives were based on the need to solve the problem of houses located in low-density rural areas with no existing public electrical, water or waste systems, and often populated by low-income people. In such areas, the water and waste issues could be solved relatively easily by means of traditional wells and septic fields, electrical power could only be provided by means of very expensive power lines or generator units. Social changes over the last 50+ years made the idea of living away from urban areas and closer to nature more attractive, and middle-class people were in a better position to pay for such an option. The situation was made more tractable with the advent of wind or solar systems that could generate DC power, despite high capital costs and even if variable wind or solar conditions made such systems only partly reliable.

A few designers of large buildings have tried to adopt the same philosophy, but larger buildings are almost always located in urban areas where a full range of public services is

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almost always available at reasonable cost. The implication of going off the grid with larger buildings in urban areas is that costs will be high and, much worse, if many buildings follow this approach, existing public services will become uneconomic, resulting in rates for other users being increased. This could be a death spiral for utilities.

2. CONCLUSIONS

This review of overlooked issues in building performance includes the Integrated Design Process (IDP) and Predicted v. Actual performance, which are both recognized as being important but are not fully implemented. The differences between Source, Primary and Delivered energy are well recognized by energy specialists, but not by many professionals who should be aware of these crucial differences. There is a major misconception about Zero or Nearly Zero definitions amongst some professionals and almost all professional publications, or perhaps such groups are choosing to disregard the importance of embodied energy and emissions in the lifecycle environmental impacts of buildings. The differentials between Predicted and Actual performance are beginning to become recognized as being important, but need more visibility. An issue related to metrics, occupant density and annual person-hours, is something that is generally ignored but should not be, since it places energy and emission results in a much more realistic context. Weighting in rating systems is another metric-related issue which must be resolved if rating results are going to have any meaning beyond marketing value. The prospect of Synergy Zones offers the possibility of improved performance within small urban areas, but the problems posed by management complexity will be difficult to overcome. Finally, going "off the grid" with large buildings is clearly a bad idea.

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