Synergy Zones for provision of technical services to small urban areas

Abstract

This document outlines a systems model for the development or redevelopment of small urban zones to maximize operational efficiencies within these zones by optimising supply, demand and storage functions of energy, potable water, greywater, materials and local transportation systems associated with multiple buildings and community services.

A. Introduction

In the developed world, communities are facing massive costs to renew aging infrastructure under conditions of a weak economy, while a large portion of communities in the developing world are seeing rapid growth outpacing their ability to expand using traditional infrastructure models. At the same time communities in both the developed and developing world are under increasing pressure to become much more sustainable and competitive in an increasingly globalized economy. The research and development program outlined in this paper will help developers, planners, governments, and utilities to address these multiple issues more effectively and at a lower cost while improving the quality of life in the communities they serve.

The technical genesis of this proposal is based on the R&D work being carried out in many jurisdictions on Smart Grids, which is focused on the concept of optimization of supply and demand of electrical power at a regional level, through control and storage systems at consumer locations.

Our program is based on the observation that there are many other building services beyond electrical power that could create new levels of efficiency and reduction of waste from the optimization of supply and demand. If the Smart Grid concept were to be developed at a smaller scale it would be possible to deal with the interaction of a wider range of issues and more in depth. Such an integrated approach at a local scale might more logically be called a Synergy Zone.

Some of the neighborhood-scale (zone) systems that could benefit from optimization of storage, supply and demand, and a reduction in wasted energy and material flows include:

- Thermal energy for space heating or cooling;
- Domestic hot water;
- Grey water;
- DC power at the zone and building level;
- Solid waste generated by building operations;

Each of these urban sub-systems could benefit from appropriate storage systems, controls and algorithms for optimization of supply and demand, and distribution networks.

Optimising supply and demand of parking spaces, and the provision of local public transport systems are separate but related issues. The development and implementation of these concepts will require a pattern of property control and management that facilitates the integration of individual building systems and operation into the larger local zone.

Such an approach would provide an appropriate framework for neighborhood infill and renovation initiatives that aim for very high levels of performance.

B. System overview

The **Synergy Zone** initiative, as we define it, would include the following elements within a small urban neighborhood (here referred to as a Zone for convenience).

1. The starting point in a new development is to maximize the passive solar performance potential of the buildings in the Zone, individually and collectively. At the level of individual buildings in new zones, this means that the solar access of buildings should be impaired as little as possible, and that the orientation and configuration of each building should maximize its passive performance. Even a zone containing buildings that are sub-optimal in terms of passive solar potential may have a high level of passive performance as a whole if inter-building spaces are tight enough to maintain a high level of density and if they are strategically oriented. These arguments obviously do not apply to existing zones.

2. The Smart Grid proposals we have seen are silent on the topic of **space heating or cooling,** and the possibility of **thermal generation** in the zone (GSHP, CHP or bio-mass), as well as **thermal storage** in the zone to serve such thermal sources. This is especially logical in the context of some buildings producing a heat surplus (captured through heat-recovery ventilation systems), while others could benefit economically 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. We therefore see 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.

3. **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.

4. Many modern buildings make provision for **rainwater capture** and grey water use, but some (e.g. highrise) have relatively minimal opportunities for rainwater capture, while low-rise buildings 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.

5. A similar case can be made for a zone-wide system for **solid waste capture and storage** for all buildings in the zone, such as provided by central vacuum systems. Such a system could be linked to a local zone **bio-generation plant.**

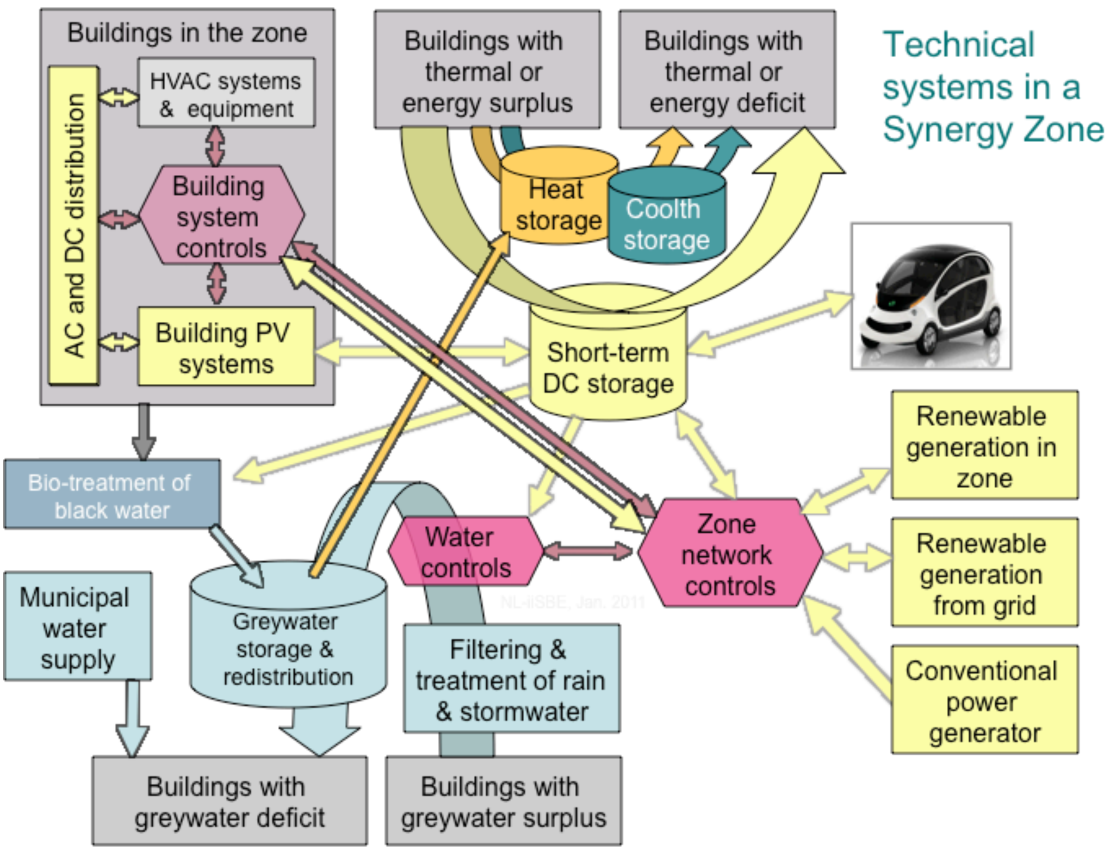
6. The role of **DC power generation** is dealt with in some Smart Grid proposals, but usually in relation to power contributions by regional renewable energy sources and with respect to use by plug-in electric vehicles. **Sources of DC power** include that produced from CHP, PV, wind power, bio-mass or other common renewable source 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. **DC storage** will be a more important issue for local synergy zones compared to regional smart grids, because of the increased possibility of direct use of the DC power in the zone, without having to convert to AC for transportation, then back again to DC at the point of use.

   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. Of course, as in Smart Grid projects, excess DC power could be converted to AC and exported back to the grid. This study will not involve detailed studies of the best mode of DC storage.

We also propose to explore the installation of **DC power systems in commercial buildings** in the zone, operating in parallel with conventional AC systems to directly provide power to low-voltage DC equipment. Such direct use of DC would increase operating efficiencies by reducing conversion losses. 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 buildings, such as electronic light ballasts and computer equipment. A major Japanese company is reportedly ready to produce a parallel AC/DC distribution system for buildings. Such parallel systems would represent a major shift in systems thinking, and would also require that parallel lines of electronic equipment be developed. Another use if DC power for the **re-charging of electric vehicles** in the zone.

7. 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, 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.

Figure 1: Schematic representation of a Synergy Zone



C. Efficiency and Performance

Although we cannot yet identify the scale of energy, emissions and materials savings that may accrue from the introduction of Synergy Zones, we do have some credible estimates related to he implementation of smart grids at a national scale in the U.S.A.

The U.S. Department of Energy has sponsored a report (Pratt et al. 2011), published in January 2010, aiming at estimating both the energy and CO_2 benefits that the implementation of a smart grid at the U.S. national scale could provide. The robust methodology used in this report takes into account both direct reductions (savings in the end-use energy consumption or reduction in the generation requirements) and indirect reductions (cost savings produced by smart grid functions and reinvested in energy efficiency and renewable resources). By 2030, expected reductions in CO_2 emissions associated to the reductions in the electricity consumption directly due to a U.S. national scale implementation are expected to be up to around 12%, and 6% indirectly. These reductions are very significant, but are not sufficient in the urgent context of climate change mitigation.

Table 1: Potential Reductions in US Electricity and CO_2 Emissions in 2030 attributable to smart grid technologies, assuming 100% penetration (adapted from Pratt et al. 2010).

	Reductions in Electricity Sector CO_2 Emissions	
Mechanism	Direct (%)	Indirect (%)
Conservation Effect of Consumer Information and Feedback Systems	3	-
Joint Marketing of Energy Efficiency and Demand Response Programs	-	0
Deployment of Diagnostics in Residential and Small/Medium Commercial Buildings	3	-
Measurement & Verification for Energy Efficiency Programs	1	0.5
Shifting Load to More Efficient Generation	<0.1	-
Support Additional Electric Vehicles and Plug-In Electric Vehicles	3	-
Conservation Voltage Reduction and Advanced Voltage Control	2	-
Support Penetration of Renewable Wind and Solar Generation	<0.1	5
Total Reduction	**12**	**6**

Going Further: Thermal Considerations

We have already outlined the benefits that are awaited from the introduction of smart grids on the electricity side. We see Synergy Zones as adding additional energy and environmental benefits from the integration of other systems, beyond what is currently planned. The Rotterdam Hart van Zuid case study provides an estimation of what could be achieved for the building energy consumption by a smart and synergetic approach of thermal flows. Beyond gains in efficiency and emission reductions, gains in resiliency and quality of service could be expected. More detailed theoretical and practical work though is needed to test this hypothesis. Further investigation has also to be made in order to quantify the gains that could be associated with such a synergetic approach applied to waste water and waste material flows.

The Rotterdam Hart van Zuid Case Study

In the Rotterdam Hart Van Zuid case study, Tillie et al. (Tillie et al. 2009b) apply the REAP method to a whole district, by optimizing 4 clusters (neighborhood scale): Zuidplein cluster, Ikazia cluster, Motorstraat cluster and Ahoy cluster. For each cluster, the method aims at reducing the overall energy needs of the cluster, using a stepped strategy. The first step consists in inventorying the energy consumption at the cluster scale. It also aims at adding new functions (shops, supermarkets, leisure infrastructures…) in order to balance the heat:cold ratio. A building office for instance requires cooling most of the time. But to cool a given amount of air, any air conditioning system produces an equivalent amount of hot air. This heat is currently wasted in most of the buildings, whereas it could be reused by other buildings that require heating instead of cooling (housing for instance).

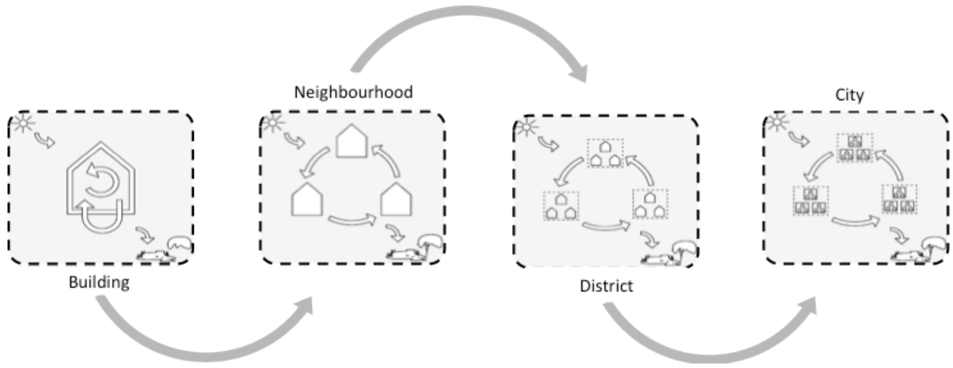


Figure 2: Knotting the flows at every scale, adapted from Tillie et al. (2009b)

Tillie et al. inventory a wide range of buildings, with different cooling/heating needs patterns: housings, offices, shops, supermarkets, ice rinks, swimming pools, etc. The need for cooling or heating of these buildings changes throughout the day and the year. With an adapted mix of buildings (a heat : cold ratio close to one) and heat/cold storage infrastructures, the heat/cold waste streams could be reused. With a perfect mix (heat:cold ratio equals one) and appropriate heat/cold storage systems, this process could theoretically lead to a 50% reduction in energy consumption for heating and cooling: as all the heat usually wasted by cooling systems is reused, heating is “free”.

Tillie et al.’s detailed case study proves that significant reductions (up to 44%) could be achieved just by an appropriate mix of buildings, heating/cooling requirements, and heat/cold storage facilities at the neighborhood scale. Further investigations though have to be made to analyze the dynamic of such heat transfers, and the possibilities of heat and cold storage, to confirm the potentialities of such an approach.

Tillie et al. (2009a) present a stepped strategy at the building scale aiming at reducing energy consumption at the building scale. The first step consists in making the building more passive, smart and bioclimatic in order to reduce energy consumption. Secondly, all the waste energy streams, such as waste heat, water and materials, are reused and recycled. Eventually, renewable energy production satisfies the remaining demand.

The further interest of this strategy is that it could be applied at all the city scales: building, neighborhood, district and city. At each and every scale, the same stepped strategy can be implemented: reduction of energy consumption, reuse and exchange of waste energy streams and renewable energy production. At every scale, the implementation of such a scheme leads to further energy and emission reduction opportunities. Scaling up from the building scale to the neighborhood or zone scale means determining whether energy can be exchanged, stored or cascaded between buildings in the considered neighborhood. In other words, if at individual building level all the waste heat has been recycled, the remaining demand for heating or cooling can probably be solved by surrounding buildings with a different pattern of energy, buildings with an excess of the required energy requirements, with a heat or a cold surplus.

According to Tillie et al., this strategy could lead to far bigger reductions in carbon emissions in the building sector, compared to the 12% of direct reduction expected with smart grids. They even go one step further with the Rotterdam Energy Approach and Planning (REAP) (Tillie et al. 2009a) by providing an extremely detailed case study aiming at quantifying the gains associated with a synergetic approach of thermal flows at the urban neighborhood scale. The Rotterdam Hart van Zuid district study indicates that REAP could be successfully used to develop plans for energy-neutral existing urban areas.

Tillie and his colleagues apply this method to the four clusters of the Hard Van Zuid district. For the Zuidplein cluster, the heat:cold ratio could reach 1:0.8, assuming heat and cold storage: 1 m² of supermarket operations could heat 7 m² of housing. This would theoretically lead to a 44% drop in the energy consumption for heating and cooling. For the Ikazia cluster, a hospital cluster, consuming energy seven days a week, the possibilities to create and use a heat-cold balance are reduced, as the heat-cold ratio is only 1:0.24, leading to a 19% drop in energy consumption for heating and cooling. For the third cluster, Motorstraat cluster, the authors propose to redevelop the street and create a balanced, multi-functional cluster, by combining housing, offices and leisure buildings (swimming pool and a new ice rink). This building diversity also means a diversity in the heat/cold requirements, leading to a good 1:0.8 heat:cold ratio.

Scenarios for mixes of occupancy and configuration types within Synergy zones and clusters

It is obvious from the nature of Synergy Zones and also from the analysis of Tilley et al, that the mix of occupancy and building configuration (low-rise, high-rise, fat, thin shapes etc.) will greatly affect the maximum level of efficiencies possible. The issues are complicated further when the concept is applied to existing zones, which have a greater diversity of configuration and technical characteristics than new construction. Finally, when the interaction of technical systems at these various scales is considered, the picture becomes still more complex.

The total performance gains are likely to vary with the type of zone;

- The location of the zone with respect to wind regimes will affect the viability of wind power generation within the zone, while the potential for geothermal-based heating or cooling will be affected by aquifers and geology;
- Open space uses (green areas, playgrounds, parking lots) will be good collectors of rain and storm water and may be sites for solar energy systems, but are obviously irrelevant with respect to thermal exchanges;
- Heterogeneity of building configurations will affect potential. For example, a combination of some low-rise and medium to high rise will enhance potential for solar renewable generation and greywater exchanges because of greater roof area in low-rise and more demand with less roof area in higher buildings.
- Residential and non-residential occupancies will be another factor in performance potential, since residential occupancies have heavy demand for DHW and space heating, while commercial uses typically generate excess internal heat gains;

In many cases, older urban neighborhoods may have the best conditions, while areas from 1950 to 1990 may be too homogeneous to be good prospects.

Figure 3 below illustrates that the various elements (electric power, greywater and thermal sub-zones) may be of considerably different areas within a Synergy Zone.

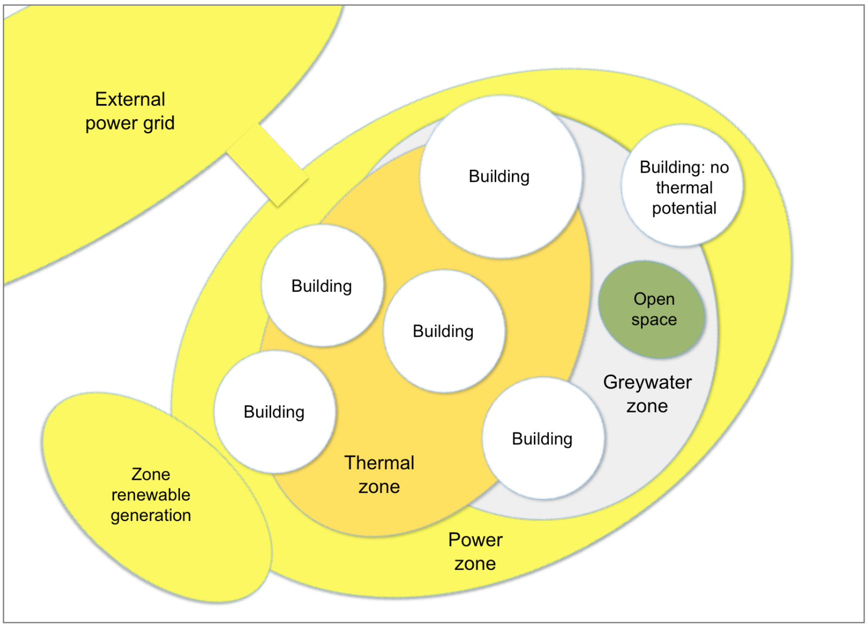


Figure 3: Schematic representation of possible differences in sub-zone areas in a Synergy Zone

Figure 4 provides more system-specific detail on the relationships between systems, occupancy types and zone areas.

Figure 4: Relationship of technical systems, various occupancy types and scales

Synergy systems at various scales	Residential Buildings	Commercial or Public Buildings	Building cluster (min. 50,000 m2)	Zone (min. 200,000 m2)
Distribution and Disposal systems				
Telecom / internet distribution	Building telecom / internet distribution	Building telecom / internet distribution	Telecom / internet secondary distribution	Telecom / internet primary distribution
AC power distribution	Building AC distribution	Building AC distribution	Transformers and cluster distribution	High-voltage transformers and zone distribution
DC power distribution		Building DC distribution	DC distribution to cluster equipment	DC distribution to zone equipment
Ventilation, heat/cool	Building ventilation, heat / cool distribution	Building ventilation, heat / cool distribution		
Hydronic distribution	Building hydronic distribution	Building hydronic distribution		
DHW / service hot water distribution	Building DHW distribution	Building service HW distribution		
Potable water distribution	Building potable water distribution	Building potable water distribution	Cluster site potable water distribution	
Greywater distribution	Building distribution to toilets and landscaping	Building distribution to toilets and landscaping	Building distribution to landscaping	Building distribution to landscaping
Hydronic return for low-temp. storage	Building hydronic return for low-temp. storage	Building hydronic return for low-temp. storage		
Blackwater disposal to treatment	Building blackwater disposal to treatment	Building blackwater disposal to treatment		
Solid waste disposal to recycling	Short-term storage per floor and building	Short-term storage per floor and building	Public solid waste disposal to recycling	Public solid waste disposal to recycling
Organic waste disposal to compost	Short-term storage per floor and building		Public organic waste disposal to compost	Public organic waste disposal to compost

	Synergy systems at various scales	Residential Buildings	Commercial or Public Buildings	Building cluster (min. 50,000 m2)	Zone (min. 200,000 m2)
	Storage and Control systems				
13	DC storage		Building DC storage and control	Cluster DC storage and control	Zone DC storage and control
14	High-temp thermal diurnal storage			High-temp thermal diurnal storage and control	
15	Waste heat low-temp. thermal storage			Low-temp thermal diurnal storage and control	Low-temp thermal diurnal storage and control
16	DHW / service hot water storage	Building / dwelling DHW storage and control	Building service HW storage and control	Cluster HW storage and control	
17	Grey water storage			Cluster greywater storage	
	Recovery and Treatment systems				
18	Hydronic heat recovery	Building hydronic heat recovery	Building hydronic heat recovery	Cluster recovery to low-temperature storage	
19	Air heat recovery	Building or dwelling HRV	Building HRV		
20	Black to greywater treatment			Black to greywater preliminary treatment	Black to greywater secondary treatment
21	Greywater to potable treatment			Greywater to potable preliminary treatment	Greywater to potable secondary treatment
22	Organic waste composting			Cluster site organic waste composting	Zone central organic waste composting
	Power, Thermal and Water generation systems				
23	Thermal cooling systems	Building or dwelling chillers / AC units	Building chiller systems	Cluster chiller systems	
24	Thermal heating systems	Building or dwelling boilers or furnaces	Building boilers		
25	PV power generation	BIPV or rooftop if low- or mid-rise	BIPV or rooftop if low- or mid-rise	Cluster free-standing PV collectors	Zone free-standing PV collectors
26	Solar DHW thermal generation	Rooftop, if low- or mid-rise	Rooftop, if low- or mid-rise	Cluster free-standing DHW solar collectors	Zone free-standing DHW solar collectors
27	Ground source heat pump thermal generation			Cluster GSHP thermal generation system	Zone GSHP thermal generation system
28	Wind power generation		Rooftop wind turbines	Cluster free-standing wind turbines	Zone free-standing wind turbines
29	CHP power generation			Cluster CHP system	Zone CHP system
30	Biomass power generation			Cluster CHP system	Zone CHP system
31	Stormwater collection			Cluster site stormwater collection	Zone site stormwater collection
32	Rainwater collection	Rooftop rainwater collection, if low- or mid-rise	Rooftop rainwater collection, if low- or mid-rise		
	Regional supply and treatment systems				
33	Potable water supply				Municipal potable water supply
34	Sanitary waste treatment				Municipal sanitary waste treatment
35	AC power supply				Regional AC power supply

A next step will be to establish more specific projections, such as potential energy, emissions, water and material reductions, and specific technical issues and solutions, for various situations of area size and occupancy types. This will require the development of a generalized model.

D. Further planned development

The following specific studies will be carried out within the context of several pilot projects.

1 Identify case studies that approximate at least some of the concepts being studied, and study aspects that were successful and others that were not;

2 Identify potential urban zones for the implementation of pilot projects ;

3 Identify special issues that are related to new v. existing neighborhoods;

4 Identify special implementation issues in existing neighborhoods, specifically regarding the linkage of technical systems to existing buildings;

5 Develop approaches to deal with management structure, occupant input needed for operations and likely occupant behaviour;

6 Prepare estimates of energy, emissions, water and cost performance gains that can be made in a synergy zone relative to a building- by-building and occupancy-by-occupancy approach;

7 Obtain data on operating cost and income, and develop generalised models;

8 Identify costs and benefits v. scale of implementation for PV, solar thermal, thermal storage, DC storage;

9 Identify technical issues that exist in the operation of parallel AC-DC distribution systems;

10 Develop control and allocation strategies for potable, grey, storm and black water;

11. Identify regulatory issues related to DC power and greywater use;

12. Develop strategies for user charges, income, fees etc. for individual users.

E. Anticipated benefits

We have already outlined the benefits that are awaited from the introduction of Smart Grids. We see Synergy Zones as adding additional energy and environmental benefits from the integration of other systems, beyond what is currently planned. Perhaps most important are gains in resiliency, efficiency and quality of service. More detailed theoretical and practical work is needed to test this hypothesis.

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