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Exposing lifestyles : transactive solar architecture

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EXPOSING LIFESTYLES:
TRANSACTIVE SOLAR ARCHITECTURE

by

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Abstract

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Architecture is capable of increasing the energy consciousness of its occupants through the development of spaces that promote active participation with solar energy systems. Current architectural practice maximizes neither the availability of solar energy nor the potential of solar technologies, failing to recognize critical social elements of renewable energy and address an increasing disconnect between individual energy use and energy source. Through an architectural response, this thesis explores the role of active solar technologies in mediating between occupants, internal and external environments, and energy consumption patterns. The development of an interactive, energy gathering, animated facade, challenges the perceived 'value' of energy, forcing occupants to measure consumption choices against desires for daylight, views, and the ability to generate income. A transactive environment that makes occupants' lifestyles explicit on a building's façade ensure individuals achieve a heightened sense of energy awareness requiring them to engage their architecture and question everyday energy decisions.

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Michael

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Introduction

The world is facing an energy crisis. Decades of cheap energy have fuelled a society of consumption and ecological devastation whose full effects are only now being realized. Concern for the world's energy supply, and the detrimental manner in which demand is being met, place an increasing emphasis on the world's urban centres and cities; their responses will play a dramatic role in the changes required to divert further economical, social, and ecological catastrophes. As individuals have become increasingly disconnected from their energy sources, the consequences of their consumptive behaviours have become blurred, or made invisible altogether. Architecture can, and must, play a crucial role in reestablishing this lost link between consumer and consequence.

This thesis aims to ignite discussion and debate on present-day energy consumption patterns by demonstrating, and proposing, a manner in which architecture can mediate and inform citizens of the effects of their energy choices. Furthermore, by engaging pressing issues of environmental stability and global warming, providing appropriate solutions through the use of solar technologies, facilitating solar architecture in cool climates, educating as to the viability and potential of architecturally integrated solar technologies in urban environments, and visualizing, through the design-research process, an architectural response, this thesis strives to promote a heightened level of energy consciousness. By making decisions regarding energy use and consumption architecturally explicit, individuals are better situated to understand the implications of their actions and habits, empowering them to make more responsible energy choices.

It is widely known now with constant media attention and international conferences that the planet is on the brink of an ecological crisis. Global warming and climate change due to the continual burning of fossil fuels, combined with growing urban centres and increasingly energy dependent societies are no longer issues that can be ignored. By taking a lead in environmental initiatives and the pursuit of renewable technologies, countries, cities, groups, and individuals can position themselves to not only succeed, but become international leaders in the changing energy economy and the fight against climate change. In considering the architect's role, the implementation of solar technologies extends beyond the additive application of photovoltaics on roofs and facades – the realm of the architect is beyond the skin of the building as he or she is responsible for the entire built environment, *and* the social and behavioural influences that their contributions may have on the public(s). It is of utmost importance that solar technologies stop being considered as something that is 'applied' as an afterthought, but rather as another component on the architect's palette; too often in architecture are buildings and solar technologies seen as two separate components. The integration of solar technologies and their consideration from the beginning of the design process will only improve the quality of solar architecture produced – the possibilities of which grow with every new technological and design innovation. Furthermore, with emphasis so often placed on efficiency, there is a common belief that solar technologies must always be used to their maximum efficiency and if unattainable should not be used. This manner of thinking is not applied to other architectural components/materials such as stone, steel, or brick, so why should it apply to solar technologies? A spirit of efficiency and environmentally conscious building should undeniably apply to all methods of construction and material choices, not just solar.

Solar energy is of particular importance in the realization of a post-fossil fuel future: not only are there numerous historical connections between human civilization and the sun, but there also exist underlying connections to nature as scientists attempt to replicate natural phenomena such as photosynthesis in the development of solar energy technologies. Though often criticized as being inefficient, expensive, and unlikely to work in cold northern climates, countries such as Germany, renowned for its cloudy skies and receiving on average less solar radiation than most Canadian cities, have managed to position themselves as world leaders in solar energy and solar architecture. In regards to efficiency and cost, solar is typically compared to the burning of fossil fuels – a comparison that not only fails to take into account the numerous stages involved in the processing of fossil fuels (i.e. extraction and transportation), but fails to consider any environmental efficiencies – the collection of solar energy produces no waste! The first of four sections that discuss and present a multitude of views and opinions, as well as establishing a collection of current research pertaining to the issues presented within this thesis, *The Case for Solar & the Current State of Energy Demand*, examines present conditions and the reliance on fossil fuels, illustrating a need for a solar based future.

As important as the use and adoption of renewable resources, such as solar, is the manner in which such technologies are utilized and integrated. Through their embracement of the decentralized energy model, active solar technologies offer the greatest benefits and potential in urban environments with their ability to function and integrate at an infinite number of scales. The integration of solar energy technologies enables cities to not only limit and minimize their energy needs, but drastically reduce the energy resources that must be imported across municipal boundaries, improving not only the economical viability of a city, but the energy conservation and ecological consciousness of its citizens. If people are more closely connected to the environment and the source of their energy, they are better situated to understand the effects of their consumption habits. *Application and Accessibility: A case for Integrated, Visual Energy Sources* explores the pertinent issues regarding solar technologies and the built environment, arguing that the manner in which solar technologies are implemented is not only important in terms of operating efficiency and energy generation, but that the visibility and accessibility of such technologies have far reaching effects on both the physical and social societal realms that alter and inform an individual's energy consciousness. The positive effects that the visibility and engagement of renewable energy systems has on the energy consciousness of the public must be maximized and understood in order to shape not only the built environment, but the manner in which the public operates and lives within it.

Departing from the benefits of visible renewable technologies, the third section, *From Observer to Participant: Engaging Energy, Engaging Architecture*, expands from the purely visual to explore the manner in which people and architecture may interact with each other. By examining and understanding research that looks at design, psychological, and societal issues of interactive architecture, human behavior awareness, and responsive architecture, architects may make full benefit of the additional social and emotional benefits of enabling energy and environmental engagement. By enabling users to engage and interact with their environment, architects may empower individuals and facilitate an environment in which they are better suited to control their energy demanding lifestyles; awareness is achieved through empowerment, and empowerment is achieved through awareness.

The final section, *Transactive Solar Architecture*, presents an architectural design exploration: a transactive photovoltaic system that solidifies and makes manifest through an animated façade the relationship between individuals, the greater public, and their energy needs and consumption. In an attempt to architecturally visualize the energy consciousness of its occupants, the proposed project engages both the public and individuals by demanding they reevaluate energy and consider the manner in which they position themselves in their collective environs. Thus far, architects have struggled in expressing architectural techniques of sustainability, but by engaging interactive and transactive systems, and including the occupant as a participant, it is possible that architecture not only express ideals of sustainability and energy generation, but the lifestyles and energy consciousness of those within.

In addition to the aforementioned goals, the work of this thesis is being completed in parallel to the International Energy Agency's (IEA) *Task 41: Solar Energy and Architecture* – an ongoing international collaboration of researchers and practitioners from 14 countries with the aim to instigate the successful integration of solar technology in architecture. As a deliverable for Task 41, Subtask C (Communication Guidelines), a number of North American projects have been collected and analyzed in regards to their use and integration of solar energy technologies, and were presented at the IEA Task 41, 3rd Annual Experts' Meeting in Bolzano, Italy in March, 2010. These case studies may be found in their present state of development in Appendix B. This thesis research is situated under the larger project of Task 41, attempting to tackle issues and questions regarding the role of photovoltaics in architectural projects.

Definition of Terms

Despite being heavily rooted in scientific disciplines, many terms associated with the use and study of solar technologies are either loosely defined or often used interchangeably in a variety of syntaxes.

Energy

Although it carries a clear definition, the use of the word energy is also disputed as it is often used to describe oil, gas, coal, and electricity by many writers. Patterson (2007), however, emphasizes that this usage of the word 'energy' is wrong and actively misleading. Citing the First Law of Thermodynamics, he reminds us that energy can never be produced or consumed (energy is often referred to as 'consumed' in many readings and discussions on the topic), but that the amount of energy in the universe always remains the same (ibid). He stresses that because energy is a constant it demonstrates why it is such an important concept to understand how the world works; "We don't have to conserve energy. Nature does it for us" (ibid, p. 6). When energy consumption, production, and conservation, is discussed, what is really being referred to is the concept of 'energy carriers' such as fuels and electricity. The fact that electricity is simply an 'energy carrier' leads to the important distinction between energy and electricity in that the production of electricity is a major consumer of primary energy, i.e. coal, nuclear, hydroelectric, and natural gas when it is used for electricity generation (Evans, 2007). As such, Patterson makes the critical distinction that we can use energy better, as opposed to consuming or producing it, as that's what we do with energy – we use it, not consume it (2007).

Ambient Energy and Fuel

Patterson (ibid) is specific in explaining the differences between ambient energy and fuel: ambient energy, such as solar energy, is all around us regardless of whether we want to use it, whereas fuel is a material containing energy that we can release on purpose and on demand. The important corollary he notes is that fuel energy is reasonably easy to measure and quantify, and because it can be stored, it can be possessed, that is own it, buy it, and sell it. Ambient energy, however, cannot be bought or sold – nobody owns it (at least not yet), and this is a very important distinction (ibid).

Renewable Energy

Renewable energy sources are defined by Evans as being "primarily those which are inexhaustible in nature, and which are ultimately derived from the radiant energy of the sun reaching the earth" (2007, p. 68). This includes solar, wind, hydro, landfill, sewage, small scale CHP (combined heat and power), and biomass, which are often referred to as 'embedded' generators since they are local and not run by the large energy operators and corporations that run the traditional electricity grid (Ritchie & Thomas, 2009b). Renewable energy sources however, are also typically characterized by having a low 'energy density' (the energy generated per unit cross-sectional area, or surface area) when compared to fossil fuel sources, and are also prone to regional variables such as weather (Evans, 2007; Kalogirou, 2009). Nuclear energy is often placed in a 'grey area' of sustainability; though it does not contribute to the atmospheric concentration of greenhouse gases, it does however follow the traditional fossil fuel chain from extraction through to nuclear waste (ibid).

Solar Energy

In the scope of this thesis, the term 'solar energy' refers to direct solar active and passive systems, not inclusive of wind, biomass and other renewables that are often included under the umbrella of 'solar' (Ritchie & Thomas, 2009; Scheer, 2002). When they use the term 'solar society', for example, Ritchie and Thomas use solar "in the broad sense of renewable resources including wind and biomass which are effectively derived from solar energy" (ibid, p. 56). Solar energy is used as a source of thermal energy as either for space heating and/or cooling, or to generate electricity (Evans, 2007). Passive solar heating "refers to architectural design techniques which enable the building structure to absorb as much solar energy as possible during daylight hours in the winter months" so that the energy can be released to replace heat normally provided by traditional fuel fired or electric heating apparatuses (ibid, p. 88). Active solar heating uses the sun's energy, through the use of solar collectors for example, to heat water or another fluid and then circulate it through the building or used for hot water generation, while active solar electricity generation (the focus of this thesis) uses photovoltaics (PVs) or concentrated solar collectors to create usable power (ibid).

Energy Consciousness

The term 'energy consciousness,' as used in this thesis, is a manner of evaluating the awareness and sensibilities of either individuals or groups when examining/discussing their energy use. An individual with a high energy consciousness, for example, would demonstrate a greater understanding of the effects that their energy choices have on their surrounding environment; this is not limited to the ecological, but rather extends to the social, political, and economical as well.

1 The Case for Solar & the Current State of Energy Demand

It is of no surprise that the world is facing an ecological and energy crisis. The manner in which the human race has systematically consumed this planet's resources is cause for concern, and demands the close attention of all disciplines, including, but not limited to, architecture. Globalization has accelerated the depletion of earth's natural resources while at the same time increasing the detachment between energy use and energy source. The global collective must abandon the priorities set by fossil fuel based systems (economic, socio-political, etc.) that define present day societies, and look towards alternatives that promote a more sustainable, more ecologically conscious way of living. Humans did not always operate with such disconnect between energy source and use; before pelicans were drowning in oil, humans understood, and cherished, their relationship with the sun – a relationship that if reestablished demonstrates great potential in weathering this storm.

Figure 1.1: BP Oil Spill - Louisiana Coast; (The Big Picture, 2010)

1.1 Human Relationship to the Sun

As long as humans have inhabited the earth they have depended on, utilized, captured, and profited from the sun's energy. The sun is not only essential for sustaining human life, but is responsible for sustaining all living things and existence as a whole on this planet – it is the oldest energy source ever used. All forms of energy in the world are of solar origin, and sunlight is the primary energy source to hit the surface of the earth, whereby it is harnessed via a variety of natural and synthetic processes – the most important of which is photosynthesis used by plants to capture and transform the sun's energy into a chemical form (Kalogirou, 2009).

The relationship between humans and the sun has forever extended to the environments, dwellings, and structures that they have inhabited. The relationship between architecture and the sun is not a new area of exploration; Socrates (470-399 BCE) taught the correct orientation of buildings/dwellings in order to have houses that were cool in summer and warm in winter (Kalogirou, 2009). Heschong (1979) discusses how buildings, both old and new, modify the landscape by creating different microclimates on all sides and surfaces of a building – different solar and thermal zones whose characteristics must all be understood. As for active systems, the photovoltaic phenomenon was discovered in 1839 by Antoine Becquerel as a low-polluting, established, reliable technology (Ritchie & Thomas, 2009b). Solar furnaces and solar collectors had also been researched and experimented with by the end of the 19th century as shown in Figure 1.2 and Figure 1.3 (Kalogirou, 2009).

Historically, humans have recognized the sun as the power behind all natural phenomena – a reason why many historic tribes and civilizations considered the sun a god (ibid). Early uses of the sun's energy were to dry and preserve food and evaporate water to provide salt (ibid). In another important evolutionary example, Patterson (2007) explains humans' use of clothing and shelter to reduce energy flows, reducing the loss of heat energy from one's body and reducing energy flows from inside to out to increase comfort respectively – clothing and shelter manage energy for with no measurement or payment required (Patterson, 2007). Although shelter and clothing are not typically considered 'energy technologies', Patterson believes that understanding the relationships of energy to our environments is important if we are to address our failing uses of energy. He posits that it was not until the invention and widespread adoption of the steam engine that we lost our connection with ambient energy – the convenience of being able to store, stockpile, and transport won us over. He describes how we are all "immersed in natural energy systems of astonishing complexity and variety" (p. 6) of which we take for granted – our surroundings remain habitable because of the sun, plants store solar energy which we eventually eat, and they release the oxygen we breathe in order to process food (ibid.). And unlike other energy sources, the sun's energy is plentiful, clean, and free.

Understanding the role that solar energy has played in the development of modern cultures is of key importance in understanding the role that solar energy can play in redefining the urban environment and the manner in which societies presently maintain themselves. Maximizing the use of solar energy provides a natural 're-evolution' of energy use and human-energy relationships.

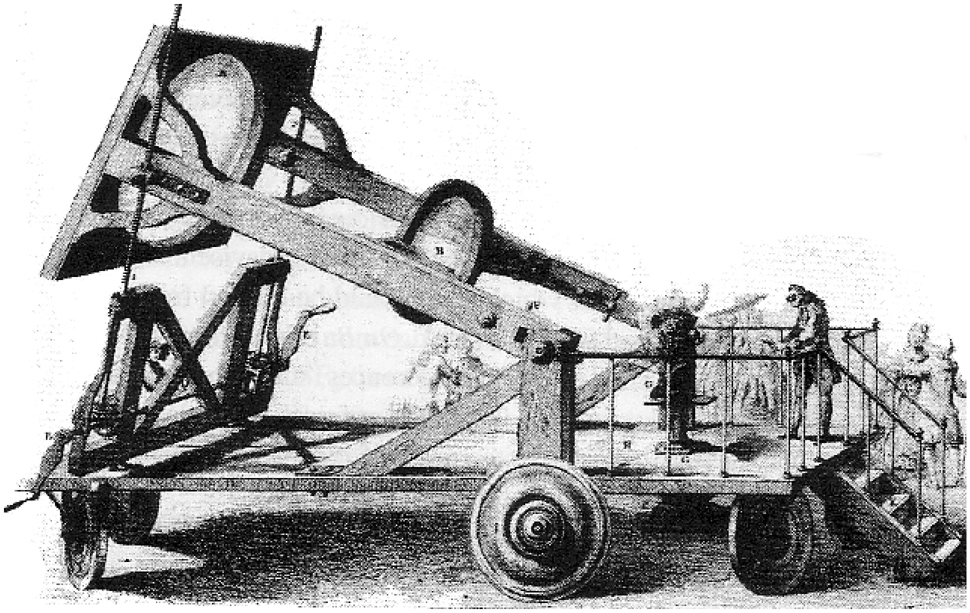


Figure 1.2: Lovoiser's Solar Furnace, 1774; (Kalogirou, 2009)

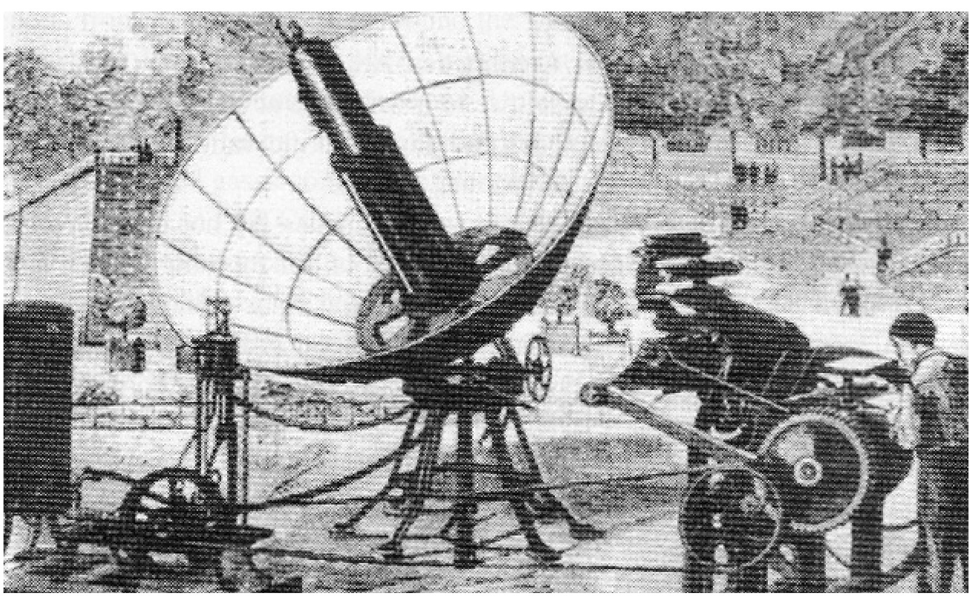


Figure 1.3: Parabolic Collector Printing Press, 1878 Paris Exposition; (Kalogirou, 2009)

1.2 Solar as Ecological Design

Although the bulk of literature surrounding the use of solar technologies is both scientific and technical in its basis, the relationship between the sun, the built context, and human inhabitation has been discussed by many theorists who suggest an inherent link between human and natural systems. In addition to the importance of environmentally conscious design, ecological relationships are of key interest when dealing with solar, for at their basic level, solar energy systems are a technological attempt at recreating natural systems such as photosynthesis.

The link between design and ecology is not a new area of research; Sim van der Ryn and Sterling Bunnell, whose work dates back to the 60s, for example, identify the concept of 'Integral Design' that suggests by studying the biology of natural systems designers will be better situated to design environments for people (2007). As noted, civilizations have used the power of the sun and integrated ecologies for generations, yet throughout recent years many modern cities have lost or ignored this connection. In *Integral Design* (1997) the authors pose the following question: "Why emulate natural design; what is there about the behavior of natural systems that we should pay attention to in designing our cities, towns, and houses?" (p. 136). They state the simple fact that the source of all life energy is the sun, and that without the numerous complex natural systems used to transform energy, life and civilization would cease to exist (ibid). The use of active solar technologies to emulate naturally occurring systems is an obvious choice, even before the present day calamities that have made renewable technologies a necessity are considered.

Van der Ryn and Bunnell also discuss the evolution of natural systems to counteract entropy (the loss of energy in a system) into negentropic (the opposite of entropy) systems – opposing concepts that both draw strong parallels with the case for sustainable energy systems such as solar energy technologies: capturing and generating heat and electricity from the sun's energy that would otherwise be lost (1997).

In his text, Orr uses the term 'ecological design' as not necessarily an environmentally sustainable approach, but as a means to describe "the ensemble of technologies and strategies by which societies use the natural world to construct culture and meet their needs" (2007, p. 16). He states that there is no one correct design strategy, but that there are rather numerous strategies, and each must be determined as to whether it works ecologically and whether it can be sustained within the regenerative capacity of the ecosystem. He states that current ecological design, with an ever expanding human population and technology base, has become a problem, and the manner in which we address the ecological design problem will have drastic effects on all aspects of our culture and civilization including ethnic conflicts, economics, hunger, political stability, health, and, perhaps most importantly, human happiness (ibid).

Orr (ibid) discusses two different approaches to solving the imminent ecological problem. He challenges and disregards Lewis' (2002) proposition of 'Promethean environmentalism', which he claims aims to protect nature by keeping us away from as much of it as possible. Lewis himself says "human society should strive to separate itself as much as possible from the natural world" (p. 16). He (ibid) disparages so-called eco-radicals and places his faith in advanced technologies, such as solar technologies and their respective advancements, to both remedy and substitute nature for us, whereas Orr (2007) believes that Lewis refuses to acknowledge that we are capable of becoming stewards of the environment, or that we are ecologically competent. Orr argues that it was in fact our very efforts to disconnect ourselves from nature that created the ecological mess we are now experiencing in the first place – a disconnection that may hopefully be restored through the reintegration of natural energy systems into the built environment. He favours, instead, Sim van der Ryn's (2007) view that design adapt and integrate itself with nature's processes, along with a smart use of resources coupled with a rethinking of our uses of technology as presented by Lovins, Lovins, & Hawken (2000) and Benyus (1997).

Benyus (ibid) makes a strong case for *learning* from nature as opposed to *extracting* from nature. Citing the high efficiencies of natural systems, she believes that the study of biomimics will pave the way to our successful inhabitation of this planet by discovering what works in the natural world, and how nature accomplishes complicated tasks in seemingly simple ways with little energy and no waste. She states in her introduction: "the more our world looks and functions like this natural world, the more likely we are to be accepted on this home that is ours, but not ours alone" (ibid, p. 3). 'Functioning like the natural world' implies that we draw our energy from the sun, as plants do in photosynthesis, although comparisons between solar technologies and the complex organic chemistries that make up photosynthesis show that the efficiencies of PVs fail in comparison. Benyus (ibid) sees hope in the role that nature can play in developing, and implementing, new solutions based off of lessons learned in nature. She is also clear to point out that even our fossil fuels are the result of photosynthesis – 600 million years worth of compressed plants and animals who owe their very existence to the sun (ibid).

1.3 Global Warming, Climate Change, and the Fossil Fuel Problem

Although the debate on global warming and climate change continues, the scientific community largely shares the belief that our continued consumption of fossil fuels since the industrial revolution is changing the global environment; a change whose dramatic effects are still to be fully realized and understood. In 1995, the United Nations Intergovernmental Panel on Climate Change (IPCC) concluded that "the balance of evidence suggests a discernible human influence on global climate," and, in the 2001 IPCC report, that "there is new and stronger evidence that most of the warming observed over the past 50 years is attributable to human activities" (as cited in Evans, 2007, p. 34). Underlying climactic concerns is the human race's reliance on fossil fuels and the difficulties in identifying and switching to a different, environmentally friendly, and economically beneficial energy system. Currently the world's energy sources are dominated by fossil fuels, with 80 per cent of the world's energy demand derived from crude oil, natural gas, and coal, with a further seven per cent derived from nuclear power sources (Evans, 2007). The problem of fossil fuels, as stated by Goswani (2007), is both as much environmental as it is social and economical, and is an issue that must be addressed immediately. It is widely assumed that 75% of the world's natural gas reserves and 90% of oil reserves have already been discovered. It is estimated that peak oil will be reached within the next five to ten years (some believe that we have already passed the peak), while by 2025 natural gas production is expected to peak, and by 2030, two-thirds of available uranium will have been extracted for nuclear energy use. Coal, the most polluting of the fossil fuels is expected to last for 180 years, peaking between 2050 and 2060 (ibid). Oil and natural gas reserves are only expected to be able to meet demand for 41 and 67 years respectively (Kalogirou, 2009). The speed at which fossil fuels are being extracted has only been increasing with advances in technology and the rapid development of emerging economies; between 1980 and 2000 global energy demand increased by 40 per cent (Evans, 2007; Goswani, 2007). Some researchers, however, see a silver lining in the arrival of peak oil, believing that the permanently higher energy prices that follow will prioritize energy efficiency and environmental accountability. Goswani states that "higher energy prices must be seen as a necessary precondition for the transition to a sustainable energy future. In the long run, high energy prices are not the problem but the first step towards a solution" (2007, p. 36). Such a mentality, however, is worrisome as although high energy prices may be beneficial in the long run, it relies on a "let's wait and see" attitude that lacks real initiative and urgency.

The solutions and freedoms to be found in a societal shift from fossil fuel dependency to renewable energy are far from near, only 0.5% of the world's power is generated from wind, solar, and geothermal power (Evans, 2007). If hydro power is included in this mix, all renewable energy sources combined account for only 17.6% of electricity production in the world. There are those, however, who believe the future lies not in traditional renewable energies (i.e. solar, wind, tidal, etc.) but in a move to natural gas economy that would eventually phase into a hydrogen one (Vaitheeswaran, 2003). This, however, replaces one fossil fuel with another, alongside faith placed on a still unproven technology, as opposed to an immediate shift from fossil fuels to proven, renewable, and reliable technologies such as solar power.

An additional problem with the current global fossil fuel model is that it is just that: 'global'. Although coal reserves are fairly reasonably distributed, oil and natural gas, for example, are very unevenly distributed with large concentrations in the Middle East and Russia for example (Evans, 2007). As depleting resources increase the price of fossil fuels, countries must import resources at far greater expenses, or, as has been done in Canada, extracted from non-conventional reserves with even greater ecologically damaging processes, such as the oil sands in Alberta (ibid). Viewed by some as a national tragedy, the closure of the Alberta tar sands would emphasize Canada's ecological priorities and responsibilities, as well as result in both social and political gains despite economical difficulties during transitioning.

For a number of years, the global community has responded to the fears of climate change through a series of intergovernmental strategies, numerous conferences, expert panels, and political initiatives. Scheer (2002), however, notes that conferences, such as the Kyoto Protocol, and panels, such as the Intergovernmental Panel on Climate Change (IPCC), are unsuccessful and counterproductive as they give governments excuses to prolong change until all countries ratify agreements and treaties. Scheer (ibid) believes that global conferences are fixated on win-win solutions that protect the interests of fossil fuel companies. He believes that the Kyoto Protocol, among other agreements, is fundamentally flawed as it is founded in the idea that existing energy infrastructures need only be made more efficient and can be retained – thereby protecting the investments and structure of the existing centralized energy industry. Participating Kyoto countries are depending on more efficient fossil fuel energy systems, rather than a move to renewable energy systems to meet their targets (ibid). In more recent news, member countries (Canada included) attending the November 2009 Asia Pacific Economic Cooperation (APEC) summit failed again to agree on a climate change deal as many countries felt their economies would suffer (Schiller, 2009). Scheer argues that "there is no point in constructing a global strategy for climate change if renewable energy is seen as a secondary issue" (2002, p. xiv), and that "national governments are incapable of moving on from their traditional role as the protectors of the energy industry" (p. xi), that is, moving beyond the status quo. It may be suggested then that an energy revolution occur on smaller, more manageable scales: cities, neighbourhoods, nodes, and individuals. Such a change will involve, as suggested by most researchers, a 'sustainable energy supply mix' – one that involves not just a single renewable energy source, but maximizes the advantages of multiple renewable energy sources in order to escape from the grasp of a fossil fuel economy. Of this mix, this thesis will focus on how active solar energy technologies can be utilized, applied, and integrated at the more manageable, immediate scale of the individual/group.

1.4 International and Canadian Energy Predictions

The International Energy Agency (IEA), in addition to establishing and overseeing *Task 41: Solar Energy and Architecture*, is the organization primarily responsible for documenting and publishing reports on global energy consumption, the proliferation of solar energy technologies, and current energy trends, as well as mapping future energy consumption. *Renewables in Global Energy Supply* (IEA, 2007), for example, predicts a growth of 6000% in solar electricity generation by the year 2030 and, based off of current and projected costing, alongside continuous research and development, it is predicted that the solar energy market will be fully competitive with traditional energy sources by 2020. Goswani (2007) states that the growth rate of solar has been almost 40% over the last few years, and that the adoption of solar technologies will only increase over time with rising energy prices. Furthermore, it is predicted that the renewable energy sector will generate new jobs and industries with the demand for installation, production, and distribution of solar technologies for example (Kalogirou, 2009).

Providing a strictly Canadian perspective on energy consumption and the use of solar technologies in Canada, CanmetENERGY (Natural Resources Canada's clean energy research and technology development division) forecasts similar predictions to the IEA and identifies solar as an alternative energy source essential in achieving Canada's social, economic, and environmental goals (CanmetENERGY, 2009). CanmetENERGY has done much work on both building and community energy consumption and efficiency, including the examination of net-zero housing and renewable energy implementation. Their *Urban Archetypes Project* is currently developing energy profiles of average households in 31 neighbourhoods within eight communities across Canada, yet despite the inclusion of large urban communities such as Calgary and Ottawa, the neighbourhoods studied primarily represent low-density residential suburban developments with little information or consideration given to mid- to high-density urban centres. Similarly, Dignard-Bailey and Johnson's associated work, *Implementation Strategies for Solar Communities* (2008), avoids looking at dense urban areas, yet provides a good framework for the study of suburban neighbourhoods, as well as providing comparative analyses between Canadian and European solar communities that prove solar energy technologies are capable of drastically reducing the ecological footprint of the modern built environment. Since cities are responsible for 80 per cent of the world's greenhouse gases (Doucet, 2007) it is essential that research in the areas of solar communities and ecological urbanism is undertaken. The manner and success in which solar energy technologies are integrated into the built environment will ultimately determine the success of any future solar architecture.

1.5 Feasibility and the Energy Supply Chain

The feasibility of solar energy technologies is a complex issue that has been extensively explored. There are three main standpoints on the issue: those who believe solar is not financially viable, those who believe it is, and, the view shared by the author, those who believe the potential environmental costs outweigh any financial costs that might be incurred in implementing a solar future.

Typically, counter arguments to a solar future cite the relatively low efficiency of photovoltaics compared to large power plants where more than 50 percent of the fuel consumed for generation is transformed into electricity (Swan, 2007). Both Scheer (2002) and Swan (2007) claim that this is a misleading comparison as it examines segments of the supply chain in isolation – neglecting to disclose the costs associated with extraction of fuels and the transmission of electricity. There are dramatic costs and measures involved from extraction, through transportation, processing, final consumption, and eventually wastes that are typically ignored when comparing solar energy to fossil fuels (Scheer, 2002). Swan claims the distribution system loses about 60% of power in transmission, not taking into account the power then lost by consumers, and that the process from extraction to delivery of energy extracted from fossil fuels can consume 75-90% of the energy value of the fuel (ibid). Evans (2007) shares this point of view, declaring that we must take a 'well-to-wheels' approach, taking into account the full energy conversion chain tracking energy supply from source to use (Figure 1.4 shows energy conversions in the traditional fossil fuel chain).

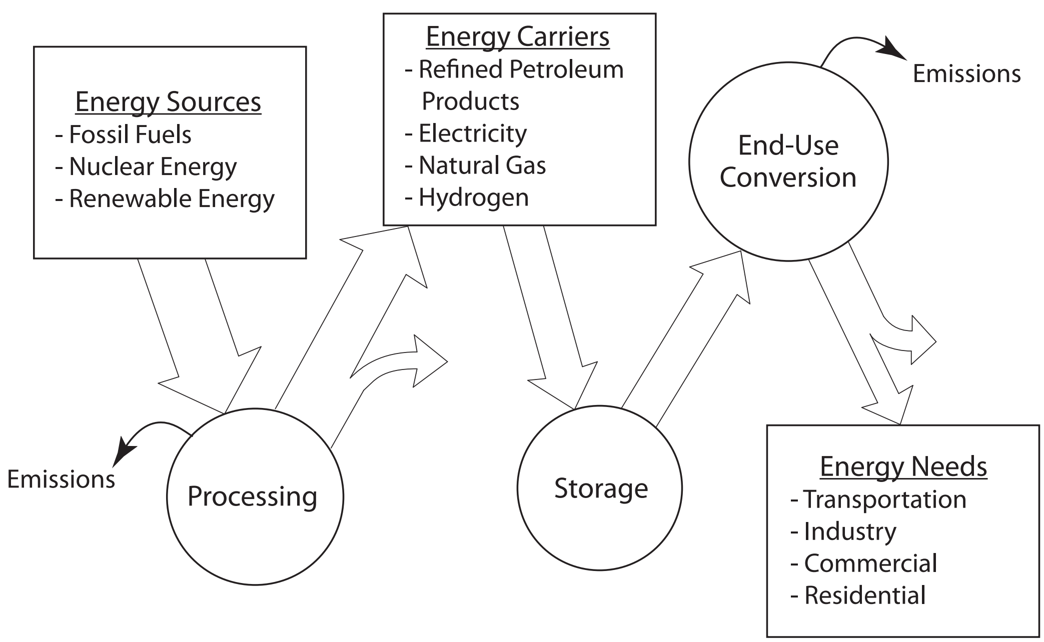


Figure 1.4: The Energy Conversion Chain; (redrawn from Evans, 2007)

Swan (2007) notes that although most photovoltaics achieve 15% efficiency, new photovoltaics achieve 18% and some have been tested in development to reach 25% efficiency, demonstrating that they can be equally efficient when compared to the fossil fuel chain – plus there is no shortage of sunlight and it is available where it's needed. Concentrating PVs have reached efficiencies of 40% and solar thermal systems can operate in the range of 40-60% efficient (Kalogirou, 2009).

Van der Ryn and Bunnell suggest that the traditional linear systems, such as the fossil fuel supply chain, represented in much of our built world and characterized by linear energy flows, high entropy, closed systems, high waste, uniformity, and surges in energy flow, must be set aside in favour of the closed integral loop fundamental to living systems – i.e. low entropy, open systems, little waste, self regulating, and steady energy flows (1997). Some suggest that if the entire fossil fuel chain is analyzed and taxed accordingly, while removing the $300 billion plus subsidies that fossil fuel companies receive from national governments every year, consumers would be aware of the full cost of energy derived from fossil fuels (Kalogirou, 2009; Scheer, 2002). The supply chains of renewables, for example, are much shorter, or in some instances, such as photovoltaic and solar hot water systems, non-existent due to onsite harnessing and generation (ibid). The shorter supply chains of renewables also severely reduce the costs that would traditionally be sent 'off site' or extracted at each 'link' in the traditional chain. Toronto, for example, spent over $4.45 billion dollars a year on energy in 2005, of which barely any stays in the local economy (City of Toronto, 2007). Even if only a small percentage of energy was produced within the city's boundaries via integrated solar systems, an immediate economic benefit to the city would be seen. Additionally, it should also be noted that a 'solar city' would further reduce its energy costs by drastically decreasing the amount of energy lost through the transmission of power over great distances (Scheer, 2002).

Scheer (ibid) also notes that compared to fossil fuel energy chains, renewable energy is only exposed to concentration and monopoly in one sector: manufacturing and construction (the production of solar collectors and photovoltaics for example). He states that the problem fossil fuel companies have with solar technologies is that "sunlight and wind cannot be patented and sold under license" (ibid, p. 86), although this can hardly be seen as a problem for the consumer/energy user.

This fundamental idea of shortened or looped systems has become increasingly relevant and mirrored in the ongoing sustainable revolution with low energy buildings and net-zero projects that attempt to achieve as closed a loop as possible. Drawing on renewable energy maintains and feeds this cyclical systemic structure as opposed to linear, open ended, high waste fossil fuel systems. Hassan Fathy notes that the architect must be aware of such systems and the climate in which he/she builds, drawing on historical comparisons, noting that "before the advent of the industrial era and mechanization, man depended on natural sources of energy and available local materials in forming his habitat according to physiological needs" (1997, p. 144). Fathy, recognizing that the use of new forms and materials is inevitable, does not intend that we imitate the pre-industrial design era, but rather suggests that architects measure the appropriateness of their decisions relative to both the natural environment as well as to the local vernacular that likely originated with natural methods.

Examining the immediate cost effectiveness of solar technologies, Morris (2006) posits that the actual cost of solar generated power is much less than typically stated as great savings can be achieved when photovoltaic systems, for example, replace traditional facades (savings can be found in the cost of the metal, glass, and/or stone that might have otherwise been used as cladding, as well as potential gains in floor area due to thinner wall sections). Additionally, because most solar energy equipment is small, it can benefit from a faster pace of development due to modern manufacturing techniques, thereby facilitating further cost reductions (Kalogirou, 2009).

In regards to economic pressures and energy security, Scheer (2002) believes that the traditional economies of scale do not apply to renewable energy, and that a 'solar resource base' will lead to the de-monopolization and re-regionalization of the traditional fossil energy industry, although this concept of decentralization is discussed in greater depth in the next subsection.

It is important to note however, that the feasibility of solar energy technologies should not only concern economics, but rather take into account the environmental, social and/or sustainable feasibility of any solution. Feasibility cannot, and must not, simply be measured on economical terms when so much is at stake. Kalogirou (2009) acknowledges the following benefits of renewable energy systems such as solar: social and economic development, land restoration, reduced air pollution, the abatement of global warming, increased fuel supply diversity, the reduced requirement for transmission lines within the electricity grid, employment opportunities, the diversification and increased security of energy supplies, and increased regional and national energy independence through decentralization and 'on-site' energy collection.

1.6 Decentralization of the Energy Supply System

A transition to renewable energy sources such as solar dictates not only a change in the energy source, but drastic changes in the way the energy supply system operates.

Currently, the fossil fuel system operates in a centralized manner whereby useable energy is generated / produced in one or more high-capacity central locations (such as power plants), from where it is then transmitted (often over long distances) and dispersed into the larger network of end users. A decentralized (or distributed) energy system, on the other hand, can use the same interconnected network, though the fundamental difference is that useable energy is captured at many individual small scales (through photovoltaic panels for example) widely dispersed across the network (see Figure 1.5).

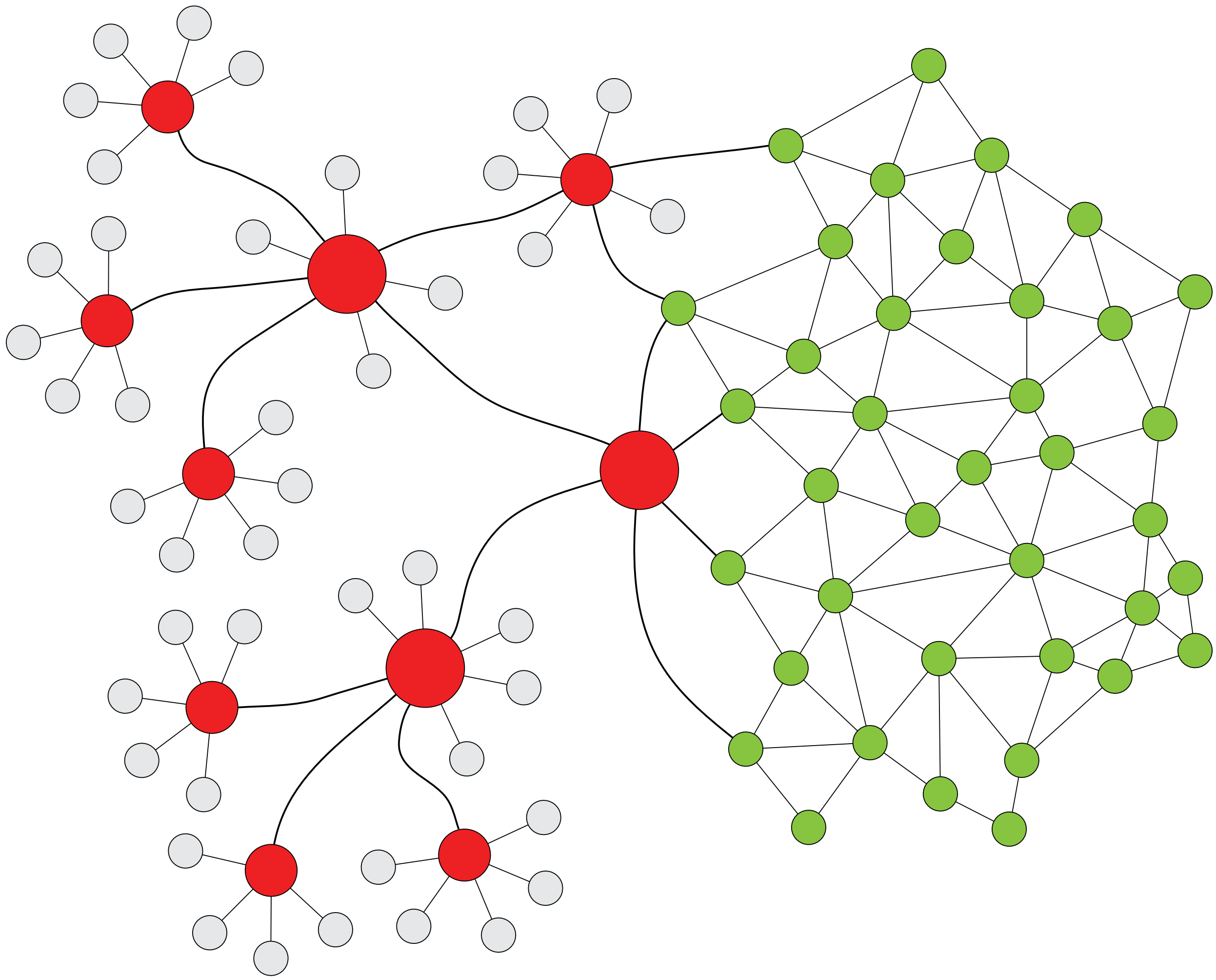


Figure 1.5: Centralized/Traditional System (Left) versus Decentralized System (Right)

Some argue that support of centralized systems and the opposition to the decentralized application of PVs is rooted in a 19th century vision of power plants where electricity must be made in a factory (Swan, 2007). Scheer (2002) is equally concerned however, that people have become accustomed to large centralized energy systems, and are skeptical and fear the idea of guaranteed energy from renewable sources through large numbers of local microplants that would be required in a future solar city. Swan poses the following question: "Which is more efficient, a system that consumes more than half the energy it generates in machinery stretched out over the landscape, or a system that consumes a tiny quantity of steel and silicon to produce electricity from a roof only feet from the toaster?" (2007, p. 63). *A Natural Capitalism* (Lovins, Lovins, & Hawkens, 2000) proposes a world with improved energy and resource efficiency and, as projected by Orr (1997), would be powered by "efficient small-scale renewable energy technologies distributed close to the end point of use" (p. 22), while at the same time protecting natural biological systems through an economy designed to fit ecological systems using measures such as taxing pollution as opposed to income – ideas widely discussed and supported by the likes of Scheer (2002) and Patterson (2007). Lewis (2002) however, disagrees with this idea of decentralization, suggesting, and hoping, that a solar future will be delivered through a corporate centralized system.

Suggesting that the future is not the 'global city', but rather the 'solar city', Scheer (2002) believes that decentralization will not only solve energy needs of cities, but would cause a much needed change in social urban growth patterns. He believes that megacities and their growth are only sustainable at present time due to their heavy reliance on the fossil fuels that are doing them so much harm, but unfortunately, provides few specifics as to how urban growth will actually change in a post-fossil economy. He states that architects must give thought to optimal solar gain, exploitation of ambient heat as a secondary source, natural ventilation, selecting building materials according to insulating properties and energy manufacturing costs, internal air circulation, and intelligent buildings that are built for the climate they are situated in (ibid). In a decentralized solar model, "buildings do not just consume energy: in future they must also be seen as systems for collecting and harvesting solar energy" (ibid, p. 197).

Scheer (ibid) continues with discussions of a future solar information society, believing that information technology (IT) can make solar smarter, ensuring smoother transitions from national energy grids to micro grids. The deployment of power from state to individual can be viewed with the same sort of liberalization experienced with the advent of IT and internet - the big players decline, while the smaller, independent players grow more powerful.

Another key benefit to a decentralized system is increased energy security and reliability. Should one of the few large power plants in a centralized system become nonoperational, its ability to provide a significant percentage of either heat or electricity, are largely felt, whereas a failure of a microplant in a decentralized network would largely go unnoticed. The vulnerability of centralized systems is clearly seen in the increasingly common black- and brown-outs; the resiliency of a decentralized system is incomparable to that of a centralized one. Nuclear reactors, for example, are typically offline 40% of their life span for either maintenance or repairs (Swan, 2007), and in Canada, 98% of power outages originate in the transmission/distribution grid (City of Toronto, 2007).

In *Keeping the Lights On*, Walt Patterson (2007) notes that the decentralization of energy sources through the use of solar energy technologies will not only benefit western urban centres through lower costs, increased security, and less environmental impact, but that the successful implementation of solar technologies in developed nations "will greatly improve the likelihood that they will also be adopted elsewhere" – he is keen to point out that traditional electricity has failed to reach two billion people through the traditional fossil fuel model (p. 121). Orr, who shares this view, states that "given our inability to meet the basic needs of one-third of the present population there are good reasons to doubt that we will be able to do better with the far larger population now in prospect" (2007, p. 18).

1.7 Climate

Solar energy technology is often marred with skepticism when its usage is discussed in cooler, northern climates such as Canada. In their text, *Solar Architecture in Cool Climates*, Porteous and MacGregor (2005) address common misconceptions and skepticisms regarding the viability of solar architecture in northern climates by examining various case studies and the role that active and passive

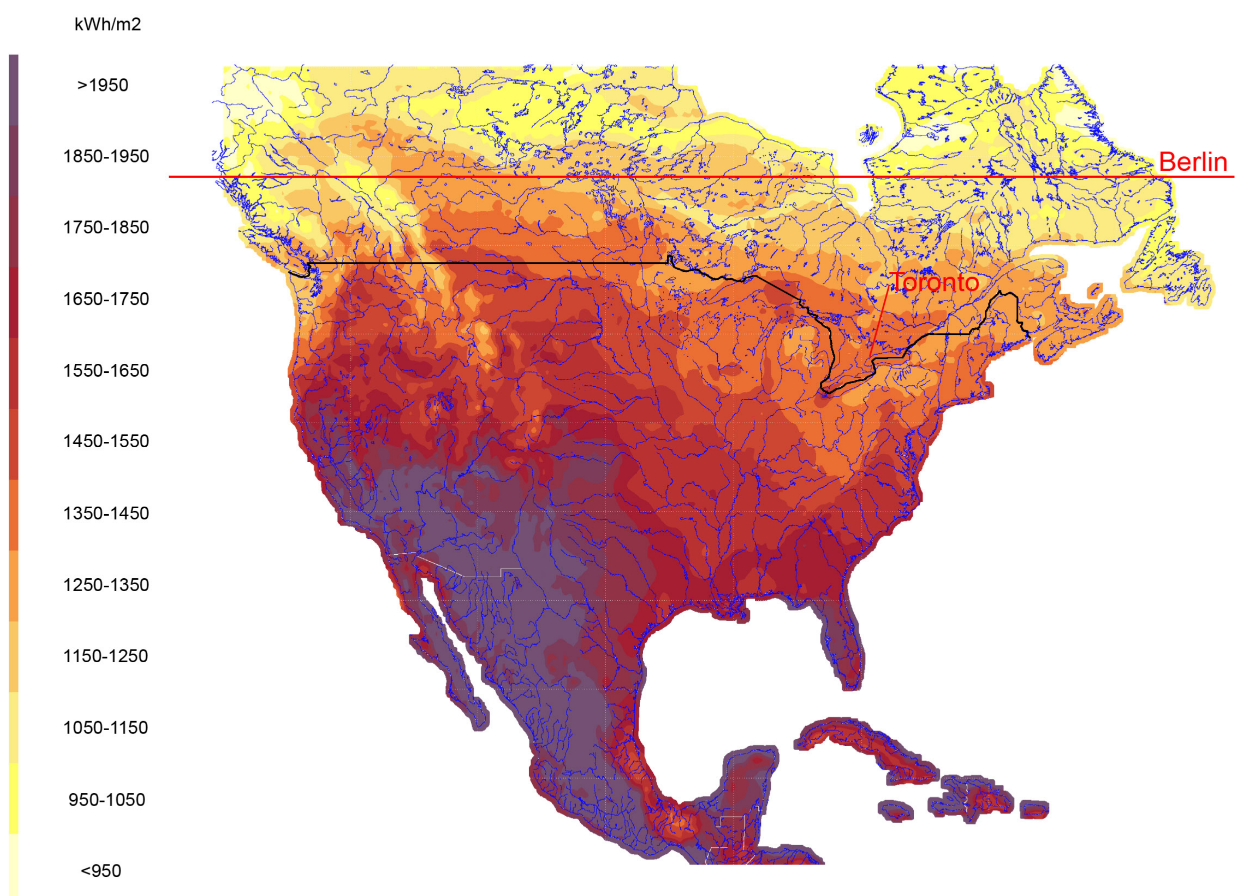


Figure 1.6: North America Solar Radiation, Annual Mean 1981 – 2000; (Meteonorm, 2000)

solar systems have in cool climates. In the latitudinal zones of cities such as Toronto and Chicago, solar supply and demand are well aligned, and more consistent in fact, than many 'hotter' climates commonly expected to yield greater solar gains (ibid). Although more southern regions typically have greater solar insolation levels, their demands are typically higher in the summer when cooling is required as opposed to high heating demands in winter as typical in northern climates. The length of the heating season therefore also becomes critical – a well insulated house for example will have a shorter, less intense heating season than a poorly insulated one, which, according to Porteous and MacGregor, indicates that passive solar design is as important as energy efficiency and heat conservation (2005).

It is important to note that Germany, the world leader in solar renewable technology with more than 1000 times the installed solar energy capacity than that of Canada, has an average yearly solar irradiance level lower than most Canadian major cities (Johnson, 2009; Meteonorm, 2000). Toronto, for example, receives over 35% more solar radiation per unit of surface area than Berlin, receiving similar levels to cities like Milan, yet Toronto's installed photovoltaic capacity per capita is roughly

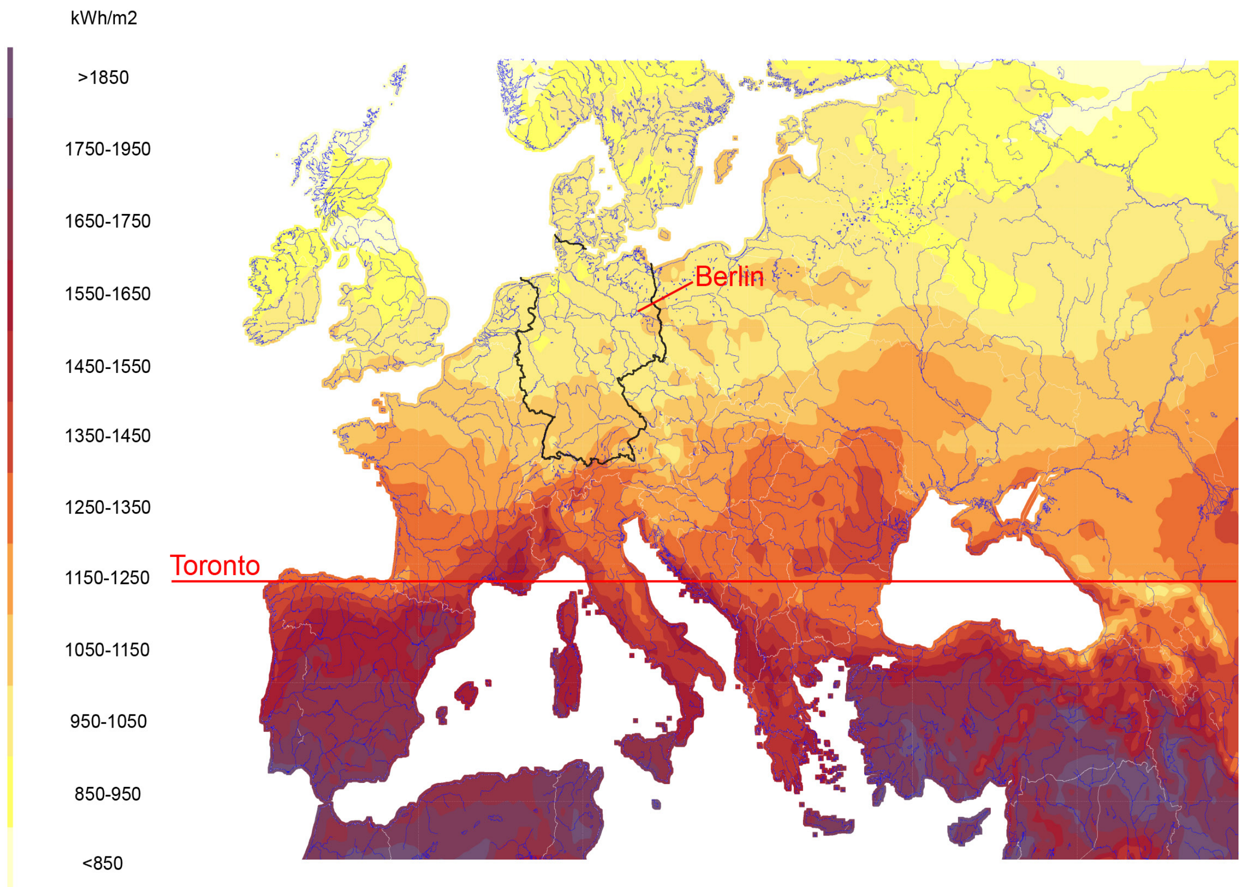


Figure 1.7: Europe Solar Radiation, Annual Mean 1981 - 2000; (Meteonorm, 2000)

three per cent that of Germany's (City of Toronto, 2007; Natural Resources Canada [NRCan], 2009). Figure 1.6 and Figure 1.7 compare the solar radiation levels between North America and Europe respectively.

In an examination between countries of similar climates, Porteous and MacGregor (2005), attempt to explain the widespread adoption of solar technologies in Northern European countries such as Germany, Denmark, Sweden, and the Netherlands as opposed to its limited use in countries such as Canada, Scotland, Norway, and Finland. They note that strong government subsidies, ambitious energy plans, marketing strategies, cooperation between various levels of governments, fiscal taxation policies, and large investments in research and development have placed the northern European countries at the forefront of both solar thermal and photovoltaic installations (ibid). Although the authors give credit to Canadian architects such as Peter Busby and Martin Liefhebber for using passive and active solar technologies in their projects in British Columbia and Toronto respectively, Porteous and MacGregor (2005) are quick to point out that a more widespread adoption of solar technologies in Canada is vastly limited. One reason for these trends is that Canada is such a large, sparsely populated country, making it difficult to achieve the critical mass achieved in small, densely populated countries such as the Netherlands (ibid). It should also be noted that the cost of energy derived from traditional energy sources is much cheaper than the above mentioned countries (Figure 1.8), therefore providing little economic incentive for Canadians to make the switch to renewable energy sources, which in turn have longer payback periods due to the low costs (City of Toronto, 2007).

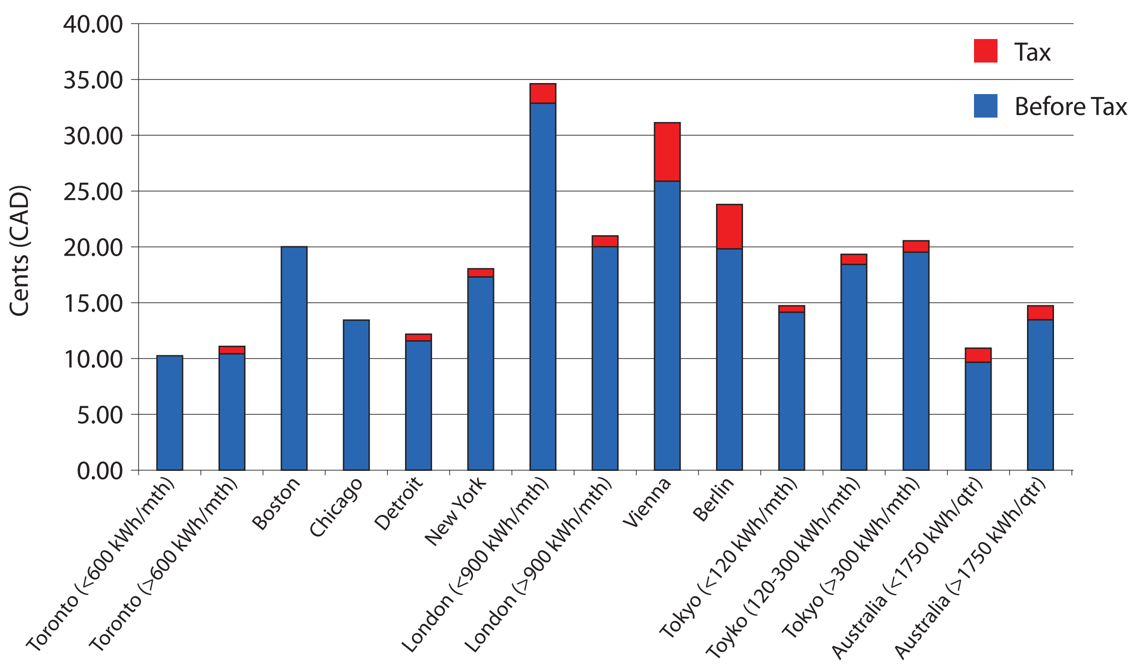


Figure 1.8: Electricity Price Comparison; (redrawn from City of Toronto, 2007)

If achieving critical mass is important to the widespread adoption of solar technologies (ibid) and if increased distances in transportation and transmission of electricity in a centralized system increase costs and decrease energy efficiency and conservation (Scheer, 2002; Patterson, 2007; Evans, 2007), a dense Canadian urban environment, such as Toronto, would be suitable for both the study, and widespread application, of active solar systems such as photovoltaics. Many of the European strategies noted by Porteous and MacGregor previously (such as government subsidies, fiscal policies, investment in research and development, etc.) are policy related, and should therefore, in theory, alongside successful architectural integration, be easily adaptable strategies that may be implemented in Canada – providing, of course, that the social and political impetus is there to push things forward.

2 Application and Accessibility: A Case for Integrated, Visual Energy Sources

If the use of solar energy is to be adopted as a partial solution to the world`s energy problems, the manner in which it is used and implemented is of key importance. The possibilities presented by embracing the decentralized energy model would see themselves played out at a variety of scales of solar technology implementation; each yielding a different result environmentally, ecologically, and architecturally. In addition to appearance, functionality, and aesthetic, the successful integration of renewable energy systems is proven to positively reinforce the energy consciousness and energy awareness of those who experience and engage with it. This section discusses different approaches and scales of integration, and the ecological, economical, and social effects that would accompany a future dependency on urban solar energy technologies.

2.1 Electric Infrastructure

The decentralization of the energy supply system, and the resulting effect on cities, would in essence create an electric infrastructure contained within the city scale. This concept, however, is not an unfamiliar one. In his study of the decline of Canadian and American urban centres, Clive Doucet (2007) draws on the example of electric streetcars as a sustainable electric infrastructure. He suggests, however, that electric streetcars were 'too cheap', and were forced to give way to the development and economic powerhouse of the automobile and its associated economic sectors (e.g. road construction, repairs, etc.). In a view shared by Scheer (2002), Ritchie and Thomas (2009c), and Patterson (2007), Doucet reinforces the notion that cities should not, and cannot, depend entirely on outside resources, stating that "all good things cannot flow to the city" (2007, p. 130). He believes that an equilibrium must exist between city and countryside, whereby the city cannot "be allowed to suck the countryside dry" (ibid, p. 130). Although he calls for healthier, more sustainable, urban environments, Doucet believes that it is impossible for modern day cities to be entirely self-sufficient using Rome and other early European cities that required vast resources to be imported into their borders as an example. He states that as 80 per cent of Canada's population now lives in cities, "human life has again become city life" (p. 133), but expresses concern as to the ecological state of our cities, noting the many smog advisory days in Toronto in the summertime that only a few years ago were practically unheard of (ibid).

Believing that the electrical supply is becoming more vulnerable, citing the effects that increasingly common brownouts have on the functioning of the city, Doucet (ibid) is clear in emphasizing that modern cities are unmanageable without heat or electricity. He claims that the major blackout that knocked out half of North America, leaving 50 million people in the dark (*Toronto Star*, 2009), in 2003 was "made possible by the desire of the 'energy industry' to move electricity around the continent like a commodity in order to be able to sell to the highest bidder" (p. 134). Such a system he claims has no flexibility and no independence (2007) – qualities that are inherently lacking in a centralized system yet may be found in a decentralized solar city. As cities grow and energy demand increases, the reliability and capacity of energy supply grids is continuously pushed beyond its limits resulting in brownouts, power loss, and rotating black outs in some cities. Most recently, one third of Brazil's citizens and all of Paraguay lost power due to problems on the transmission lines leaving 70 million people without electricity and 7 million without water (*Toronto Star*, 2009).

A city responsible for its own energy supply through the successful widespread integration of solar energy technologies minimizes risks and literally brings power and responsibility back into the hands of its citizens, empowering the populace to live a fuller, more ecologically conscious future.

2.2 Maximizing Solar Potential

In considering the application and integration of solar technologies, it is important to distinguish between the different ways in which solar energy may be used. Kaiser (2008) identifies three different ways: individual use, technical use, and social use. Individual use relates to the quality of daylight, views, and the integration of sunny areas into planning and design in order to increase feelings of well-being and comfort. Technical use includes the physical and/or biological utilization of solar energy to convert it into useable energy, as well as using it to minimize the strain on the environment (this includes daylighting, heat recovery, solar thermal, and photovoltaic systems in regards to buildings). Finally, the social use of solar energy includes the creation and preservation of outdoor areas receiving plenty of sunlight in order to create pleasant areas for occupying and stimulating plant growth (ibid). An additional use, not stated by Kaiser, would be a second social use or 'informative use', whereby the use and application of solar technologies visually informs the public. As visions of a smog-spewing coal plant provide a negative image that deters excessive energy use, the capturing of solar energy through active solar systems promotes a positive image of environmental responsibility and energy awareness. Ideally, any urban integration of solar technologies will culminate in the successful combination of all of the abovementioned uses.

In maximizing solar potential, Ritchie & Thomas (2009a) outline four main principles: daylighting, passive solar gain, solar thermal panels, and solar electric photovoltaic panels (PVs). Unlike active systems, daylighting is not a new concern in architecture, but has rather been an underlying principle of design as old as the profession itself. It has now however become of much more prominent interest as developments and research in city planning have linked daylighting to better health, increased senses of well-being, and the enlivenment of architectural spaces (ibid) – further emphasizing the importance of the human relationship to the sun (refer to section 1.1). In regards to design, higher floor-to-ceiling heights and narrower floor plans usually ensure occupants are closer to windows and therefore natural light. Modern architects have also used technical requirements in regards to daylighting as generators for aesthetics – the authors cite the need for larger windows on lower levels to maintain the same daylighting levels as higher floor, for example (ibid).

Passive solar gain takes advantage of the solar radiation falling on the various building surfaces of a structure including roofs, walls, and windows. Basic principles such as letting the sun in during the winter to reduce heating loads and minimizing sun in the summer to reduce cooling loads are the most standard and traditional passive strategies (Kalogirou, 2009; Ritchie & Thomas, 2009a). Active strategies also take advantage of the solar radiation on surfaces, but utilize solar thermal panels that collect solar energy and transfer it to a fluid (ibid), or solar photovoltaics to convert solar energy directly into electricity. It is important to note, however, that building surfaces are far from the only surfaces to which such technologies can be applied, and/or integrated. Urban environments present a multitude of spaces and locations within cities that may be suitable for solar energy technologies.

2.3 The Urban Environment

In his description of the "rise and fall of the fossil city" (2002, p. 121), Scheer states that for megacities' growth (referring to population, economy, *and* quality of life) to continue successfully, "energy sources must find their way back into the city," claiming that the 'solar city' will strengthen "the economy of the city by the quantity of renewable energy it produces" (ibid, p. 127). Orr (2007) points out that the problems presented by population growth and technology are not new and are a result of human evolution, and that our ecological damage has increased with the level of civilization and scales of technology. He notes how early hunters gathered food using little energy, and then how with the increased efficiency of capturing sunlight through agriculture, the growth and development of cities became possible. Hunter-gatherers, however, drove many species into extinction, farmers became guilty of deforestation and land degradation, and cities themselves have continued to evolve into increasingly unsustainable entities of their own. Orr predicts that we "face an imminent collision between a growing population with rising material expectations and ecological capacity" (pg. 17) – one that architects must face and propose solutions to. Scheer (2002) describes how pre-industrial cities needed an area of fields and woodlands between 40 and 100 times the size of the city to sustain its energy needs (ibid). To put this into a local, regionalized, perspective, the average person in Toronto requires an area of 5.2 hectares per person, while the accepted ecological benchmark for global sustainability is 1.7 hectares per person (City of Toronto, 2007). Applying Toronto's footprint per capita to its current population results in an ecological footprint of 132,673km – an area 207 times the size of Toronto; engulfing much of southwestern Ontario as if other neighbouring cities did not exist! (See Figure 2.1) Although this footprint takes into account all the energy needs of the city, not just electricity, the successful integration of active solar systems into the built environment would go a long way in minimizing the dramatic footprint the city currently occupies.

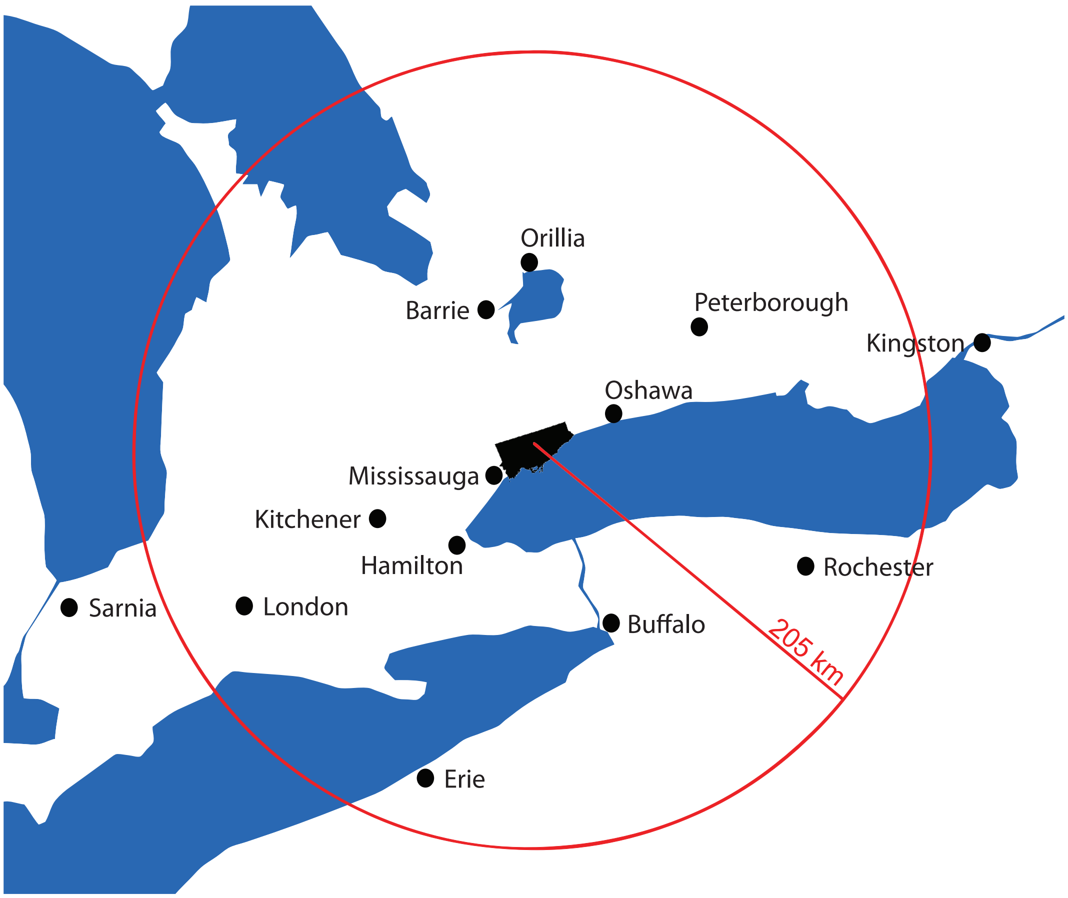


Figure 2.1: Toronto's Ecological Footprint

Furthermore, Toronto's electricity use per capita, although lower than Canada's as a whole, is far greater than that of many other western countries and cities as shown in Figure 2.2 and Figure 2.3 (City of Toronto, 2007). This pattern of ecological degradation and excessive consumption must not, and cannot, continue; solar energy technologies and ecologically sensitive urban developments will be of critical importance in Toronto, or any city for that matter, in solving these pertinent issues.

The appropriateness of renewable technologies such as solar in urban environments is further elaborated on by Douglas Farr (2008) who believes that creating a high-performance building in a greenfield or automobile dependent context is counterproductive and is considered a half-measure. He places emphasis on walkable, mixed-use neighbourhoods that achieve their means with careful resource

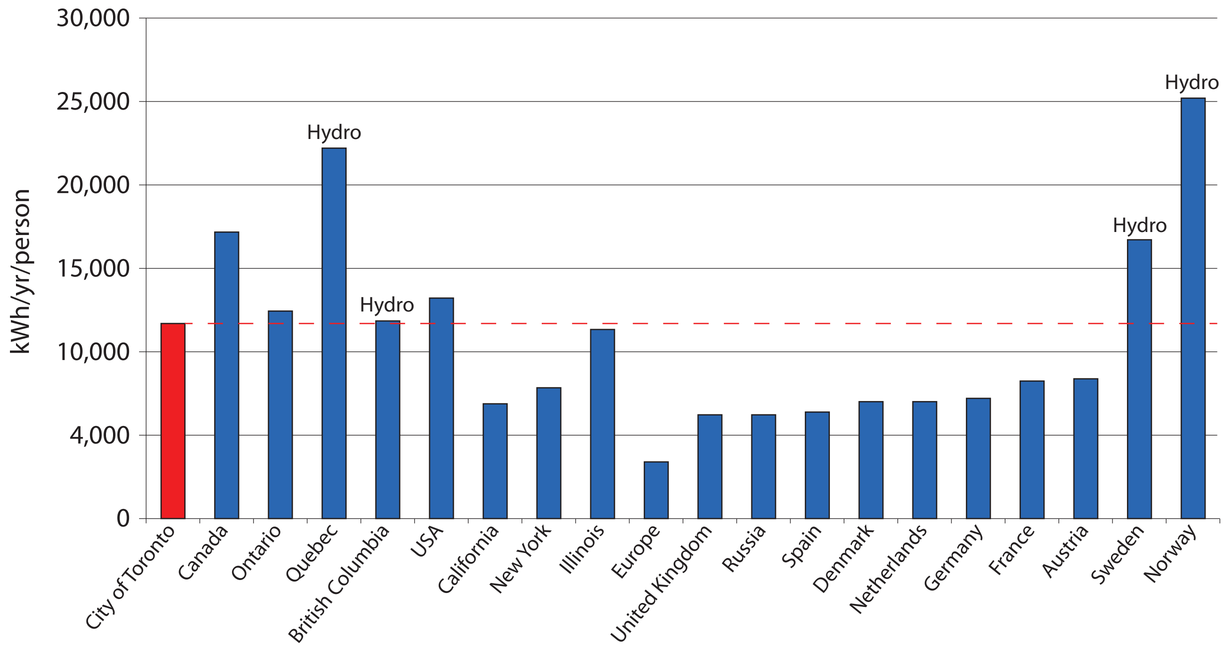


Figure 2.2: 2006 Electricity Use Per Capita Around the World; (redrawn from City of Toronto, 2007)

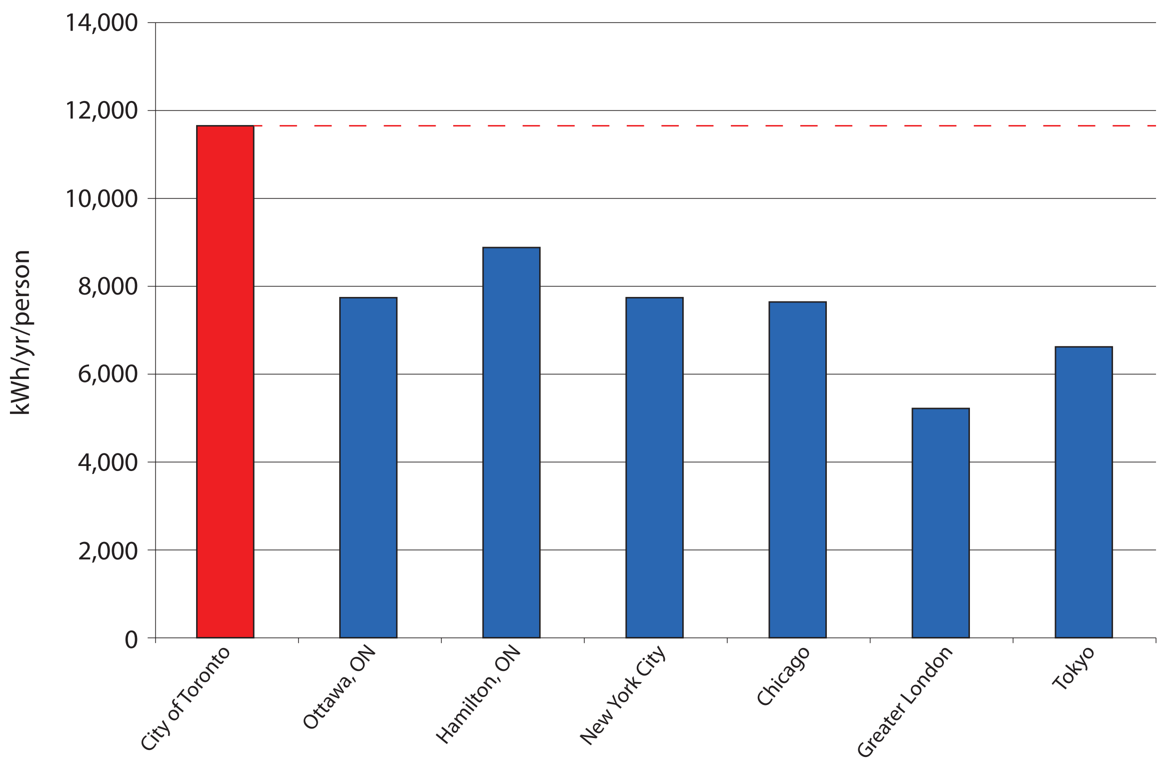


Figure 2.3: 2006 Electricity Use Per Capita in Selected Cities; (redrawn from City of Toronto, 2007)

management. He clearly defines 'sustainable urbanism' as "walkable and transit-served urbanism integrated with high-performance buildings and high-performance infrastructure" (ibid, p. 42), and that the core values of sustainable urbanism are compactness and biophilia. By compactness he refers to sustainable density and by biophilia he implies the importance of human access and associations to nature. In sharing the opinions of Orr (2007), Farr (2008) believes in humans' intrinsic relationship with nature, and that the importance of this relationship is often hidden in urban environments. He believes that our ability to see and experience where resources are produced (e.g. power generation) will strengthen our understanding and connection with natural systems, and aid in altering our wasteful consumption habits (ibid). While promoting ecologically sensitive and sustainable architecture, Orr argues that "architecture and design are fundamentally pedagogical" in that "architecture and landscapes are a kind of crystallized pedagogy that informs well or badly, but never fails to inform" (2007, p. 15). Here he makes the case that the ultimate object of design and architecture is the human mind, and that architecture inherently informs us about our relationships to nature and people, and as such, determines, or at least contributes, to the public ecological competence and ecological consciousness. Orr states that "renewable energy technologies become a source of energy as well as insight about the flows of energy in ecosystems," and that "ecological design becomes a way to expand our awareness of nature and our ecological competence" (ibid, p. 30). A visible solar economy within Toronto therefore has the potential to not only reduce the city's energy imports, but actively and visually engage its citizens in energy conservation and ecological prioritization.

In their book, *Sustainable Urbanism*, Ritchie and Thomas discuss the role that cities must play in minimizing the impact that cities will have on the global climate, how their environmental footprints will change, and how sustainable technologies and initiatives can be incorporated into urban design (2009c). Key to their discussion on urban sustainability is site analysis: they stress that any integration of solar technologies must take into account the many aspects of site, and the manner in which solar geometries are affected by the built environment (ibid), i.e. taking into account both the existing and future built context. The authors are keen to note, however, that other principle items such as wind, air quality, noise, temperature, etc., must also be considered, and that in order to create a sustainable urban environment, all aspects must be thoroughly integrated. In addition to integrating various urban design strategies, the manner in which "sustainability is introduced into people's daily routine will be the key to the success of our cities" (ibid, p. 10), a view strongly shared by Scheer (2002). The 'manner' in which this would unfold in regards to solar energy should be through the visible use of solar technologies as suggested by Farr above (2008). Furthermore, it is believed that a combination of legislation, economy, fashion, and a desire to 'stay modern' all impact public attitudes in regards to sustainability and energy self-sufficiency (Ritchie & Thomas, 2009c). A survey carried out by the National Consumer Council (2006) suggested that home energy generation engages residents emotionally with the issue of energy use and that microgeneration (as described in the decentralized energy model) created "a sheer pleasure of creation and of self-sufficiency" (as cited in, Ritchie & Thomas, 2009c, p. 10).

In urban environments, solar potential depends much on density, orientation, and obstruction heights. In regards to increased density, it is noted that more compact developments tend to have reduced heat losses due to less exterior surface area, more shared wall space, and increased heat island effect (Ritchie & Thomas, 2009a). Increases in density, however, also see decreases in natural ventilation, passive solar gain, and daylight (ibid). Considerations and comparisons between energy and density can be seen in Figure 2.4.

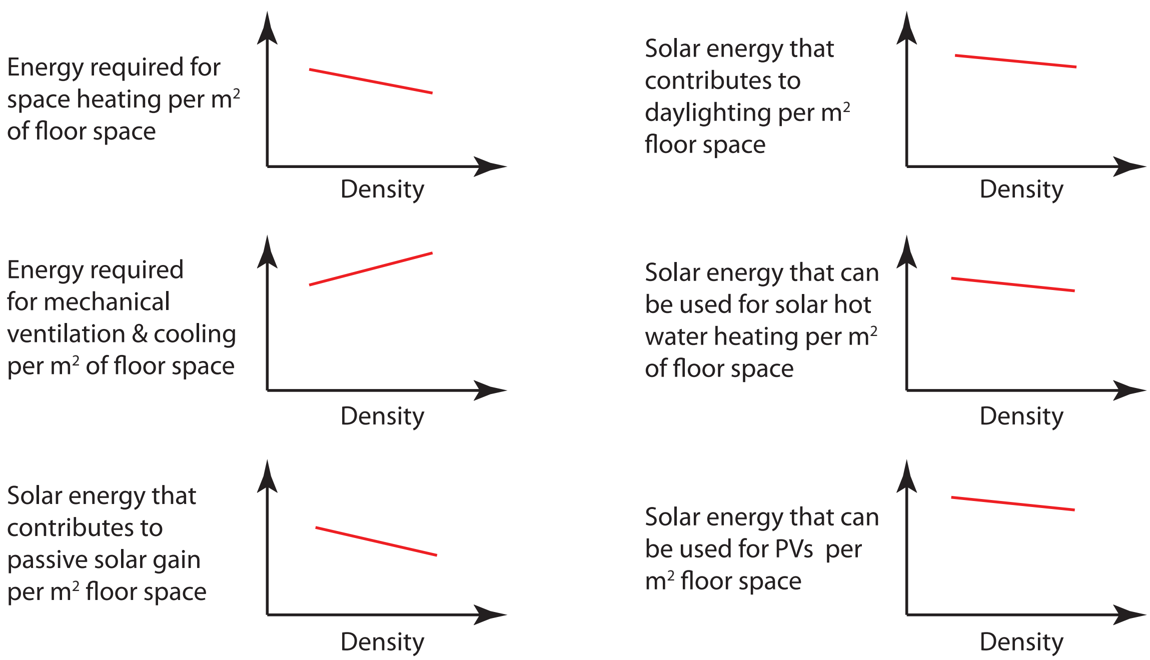


Figure 2.4: Energy and Density Considerations; (redrawn from Ritchie & Patterson, 2009a)

The potential disadvantages of increased density do not indicate that a dense urban fabric is bad or that it should be avoided, it simply emphasizes the importance that planning and developments be thought through carefully to determine their suitability in providing enclosures for high numbers of people, while still achieving high levels of sustainability. With increased compactness and density, the integration of photovoltaics becomes more difficult due to potential shadowing from surrounding buildings, with PV installations in urban areas usually being limited to rooftops, and therefore failing to maximize the solar potential of additional building surfaces. As an urban site planning strategy, having taller buildings on the north side is the simplest way of preserving solar potential to surrounding buildings in the same development (ibid). Ritchie and Patterson (2009a) believe that the potential of solar radiation is the most important development currently under way and that, until recently, roofscapes have been the 'forgotten fifth façade' (p. 48). Steemers (2000) meanwhile suggests that densities of up to 200 dwellings per hectare are possible before negative energy impacts are significant – based on an average obstruction angle of 30 degrees (as cited in Ritchie & Thomas, 2009a, p.48). On the other hand , Ritchie and Thomas (2009a), do point an advantage of increased densities: community heating and district power plants become more feasible, as does combined heat and power (CHP) projects. Higher densities also imply shorter travel distances, and therefore have lower transmission losses (ibid) – a resulting positive effect of centralized energy systems, as previously noted (Evans, 2007; Patterson, 2007; Scheer, 2002).

The work of Ritchie and Thomas (2009a), as well as many others, however, only addresses the exterior skins of buildings in urban environments without examining or exploring other possibilities for solar technologies in the urban environment. If a new solar economy is to be fully adopted in the coming future, all aspects of the city must be considered. (This area of thought led to the exploration and mapping of a variety of unconventional areas in Toronto whereby solar technologies could be integrated to create a cohesive solar city. These mappings and diagrams may be found in Appendix A).

In drawing comparisons between nature and the manner in which the modern city operates and draws from beyond its borders, Benyus uses the following urban analogy: "Nature, on the other hand, cannot afford to follow this strategy. Life can't put its factory on the edge of town; it has to live where it works" (1997, p. 97). If the principles of nature, and learning from nature are adhered to, a city that "looks and functions like the real world" (ibid, p. 3) would in turn then draw its resources from within its own borders – energy or otherwise. By reestablishing cities' connection to the sun and the ecological environment, it is possible then that, if the urban form adapt to allow the integration of solar energy technologies, an urban environment more closely integrated with nature will be realized. The city must work where it lives!

2.4 Urban Integration

The concept of locally generated electricity and hot and cold water in urban areas has traditionally most typically achieved through the use and implementation of district energy systems. District energy systems utilize a central plant powered by a combination of renewable resources such as municipal solid waste, landfill gas, wastewater facility methane, biomass, geothermal, lake or ocean water, and solar energy to distribute energy through wires and pipes to local buildings in the system (Newman & Thornton, 2008). Some authors also discuss the numerous benefits that such systems have on their surrounding environments and inhabitations: improving local economies by increasing energy reliability, stabilizing energy costs, increased property values, and "recirculating energy dollars in the local economy through capital investment and jobs in construction, operation, and maintenance" (Newman & Thornton, 2008, pg. 199). It must be noted however that district energy systems are most suitable for new developments, as the bulk of construction costs lay in the construction of the underground piping network – a process only feasible in existing urban sites if significant vertical densities exist to support the system (ibid). They point out that district energy systems are most viable in master-planned communities and one-owner districts (i.e. colleges and university campuses), as the need for built density, old mechanical equipment, and a high level of building owner cooperation in existing areas can prove difficult (ibid). Individual energy and thermal production and dramatically smaller scale operations are therefore more feasible and practical in certain types of projects such as urban infill and retrofittings/renovations. Local district energy projects include Toronto's Enwave system that utilizes the cool water from Lake Ontario to reduce cooling loads in many downtown office buildings, and the proposed new district energy plant by Norman Foster in the Lower West Donlands redevelopment. This district energy plant, however, is powered by natural gas, thereby shifting dependence from one fossil fuel to another as opposed to renewable resources – a move that would undoubtedly result in a different urban and architectural solution. Although district energy plants fit well into the idea of a decentralized energy society, they must adhere and progress towards the larger goals of a fossil fuel free city.

Active solar technologies, however, are capable of working at yet an even smaller scale, from an individual photovoltaic panel, to larger solar arrays that occupy entire rooftops. They function much like district energy systems in their enhanced resilience and immediacy, yet rather than representing an entire district from a single building with a single purpose, each active solar installation may contribute to, meet, or exceed the demands of their respective user(s) while occupying no more of the urban environment than is already required by the existing or proposed building with which they are integrated.

In their discussion of a solar society (which includes a multitude of renewable energy systems in this case), Ritchie & Thomas try to frame the idea in an architectural and visual context by posing the question: "What form might a solar society take and what might be the time-scale?" (2009b, p. 56). They briefly provide four potential solar scenarios for cities:

(i) a national grid network distributing electricity to cities from renewable energy sources outside the city,

(ii) a renewable national grid network whereby electricity is used to split water into hydrogen and oxygen, which would then be transmitted through a pipe network to cities (also known as a hydrogen economy)

(iii) a situation where solar energy is being produced within the area itself, and

(iv) a scenario that is a combination of 'on-site' generation and 'off-site' supply via the grid system – a combination of scenarios one and two (Ritchie & Thomas, 2009b).

The last scenario is the one predicted most likely to be enacted as it is the most pragmatic and adaptable of the four scenarios. It benefits from reducing transmission losses by on site generation and an increase in visibility to influence and educate the population about their energy use habits, while still drawing additional energy as required from beyond the city in order to meet demand (ibid).

Farr (2008) echoes this call for integrated design, considering architecture and buildings as entire systems that integrate human and natural systems together. The ultimate goal of design integration according to Farr is when efficiencies allow for entire systems to be eliminated, whereby the benefits of "integrating high-performance transport, water, sewer, lighting, and power systems with high-performance buildings that consume few to no resources and produce little to no waste" become evident (ibid, p. 52). Brenda and Robert Vale (1991) emphasize holism as a building principle, in that all green building principles should be used simultaneously in approaching architecture and the built environment. In a renewable future, solar integration will play a large part in achieving this design goal, while the elimination of entire systems draws heavily on the concept of decentralization and the minimization of the energy supply chain.

Lewis (2002) also comments on the future of cities, and how they will be redefined in a more ecologically sensitive future. He maintains a traditionalist view however, that cities must, and will, continue to draw demands from the countryside, establishing the position that cities are meant for economics and trade, whereby other needs can be met by importing across city borders. Although he believes that cities can dramatically reduce their energy footprint through the implementation of newer, more efficient technologies and passive solar design, his only consideration to active solar technologies is that of large scale PV electricity generation (ibid.). Lewis fails to recognize the potential of integrated solar technologies within the city, as the large scale generation he discusses requires huge amounts of land that cannot be supplied in the dense urban centres he so vehemently supports. The application of solar technologies within the city must then be done through architectural integration, considered early on in the design process.

Of key importance to the integration of solar energy systems in urban environments is the need, and possibility, to reduce space heating demands and hot water requirements through heat recovery, good/green building practices, and well insulated buildings – solar integration should not be viewed as the only solution, but as one key component of a much larger sustainable initiative. Additionally, the manner in which such systems are integrated depends not only on technical requirements, but aesthetic, formal, and visual considerations as well. Kalogirou, for example, cites 'visual intrusion' as a potential negative impact of solar systems (2009), though this can be avoided if solar energy systems are not thought of as technology that is simply applied, but rather as a 'material' capable of creative integration.

The output of photovoltaics in urban environments can be significantly reduced by overshadowing, so they are primarily best suited on rooftops unless south facing walls are un-obscured for the most part, e.g. tall buildings (ibid). The benefit of PV systems, however, is that they can be connected to the city grid to provide electricity to other users as opposed to storing it in batteries or other energy storing devices. Feed-in tariff programs, for example, ensure that utility companies purchase excess electricity from PV installations at a higher rate than the going electrical purchase price, not only promoting the use and installation of PV systems, but reducing the payback periods, making solar technologies much more price competitive. In Ontario, homeowners currently receive 80.2 ¢/kWh for electricity generated from rooftop solar sources delivered to the grid, almost 14 times the 5.8 ¢/kWh homeowners currently pay for electricity bought from the grid (Ontario Energy Board [OEB], 2009; Ontario Power Authority [OPA], 2010).

As for what designers and architects should do to prepare for future urban solar scenarios, Ritchie & Thomas (2009b) suggest that they should design for flexibility, allowing for a change in energy-supply systems in the future, whether it be the laying out of services and allowing space in the urban form, or individualized solutions per building project, or simply providing riser space for top-down servicing from photovoltaics and solar thermal systems. Regardless, architects must be prepared for the advancing solar revolution. This is "a field of enormous potential, which is likely to affect urban form in that PV-generated electricity could be used where required and, to a large extent, when required" (ibid, p. 72). This potential however, is presented with certain hurdles inherent with the use of solar energy. 'Right-to-light' for example will be an increasing concern, especially in growing urban environments, where it would be counter-productive if future developments were to overshadow solar installations (ibid). Although Canada had "right to ancient light" legislation in the 1800s when British Common Law was adopted, these laws were rescinded in the 1900s in response to urban planning needs (City of Toronto, 2009). Presently, Canada is the only industrialized nation that has not addressed the rights of property owners to the solar energy falling on their property (ibid).

Similarly, as Scheer (2002) has in regards to decentralizing the energy system , Ritchie & Thomas (2009b) also stress the importance that Information Technology will have in creating a sustainable city – most notably in two areas: the control of systems and components, and the provision of information to users. IT can, for example, control building engineering systems, allow for solar energy installations to track the sun, and find its way into new materials and components that respond to environmental conditions (responsive skins for example). IT also plays a role in the design stage, by allowing designers to make smart choices and predictions about urban forms, materials selection, as well as eventually monitoring performance (ibid). This will enable the public to participate in the process, keeping them informed of the status of the system, energy, and consumption, and create a greater understanding and communal awareness of the environment and what must be done to improve and sustain it.

While writers and researchers such as Scheer and Patterson have stressed the importance of a fully integrated solar city, Farr, Orr, and Ritchie & Thomas, have stressed the importance of a visual connection and interaction between individuals and their energy sources, and that local and immediate energy generation engages residents directly. Meanwhile, Kalogirou has cited visual intrusion as a roadblock to visually integrated solar systems. Architecturally, the problem then becomes: 'how can active solar technologies be successfully integrated into the urban fabric, *while*, still maintaining the visibility of such systems in order to increase the energy consciousness and awareness of its citizens?' Three existing projects of varying degrees of architectural and ecological quality are explored over the next few pages in order to better understand how architects and planners have thus far responded to the urban integration of active solar technologies.

Case Study: Drake Landing Solar Community

Location: Okotoks, Alberta, Canada

Date: 2007

Architects / Designers: SAIC Canada and Sterling Homes

Design Strategy / Goals: Lauded as North America's first solar community, with ninety percent of each home's heating requirements derived from solar thermal heating. Operating in temperatures as low as -33 °C in the winter, the 800 solar thermal energy panels cover all south facing roofs of the garages, as well as small portions of each residence.

Observations: Unfortunately Drake Landing Solar Community represents the kind of green project that has been celebrated in North America. The designers of this project have simply taken the stereotypical Canadian suburb and 'greenwashed' it. The architecture fails to respond in any way to the energy demands of the occupants, and does not attempt to work creatively with the solar technologies used. Instead, the solar thermal panels have been applied additively, resulting in the appearance of an afterthought. Unfortunately, if solar technologies continue to be applied in this manner (as 'visual intrusions' as described by Kalogirou (2009)), people will be unwilling to implement visible solar technologies rather than embracing them. Although this project has greatly minimized the heating demands of the community on the electrical and natural gas grids, it has done very little, if nothing, to promote ecologically conscious choices from its residents – this is further emphasized in the car dependent community that it operates within.

Figure 2.5: Aerial view of Drake Landing Solar Community (DLSC, 2009)

Case Study: Solar City Linz

Location: Linz, Austria

Date: 1995 - 2008

Architects / Designers: Although the numerous buildings in Linz were completed by a variety of architectural firms, the initial concept, masterplan, and energy strategy was developed by a consortium of architects and designers including: Foster and Partners, Herzog + Partner, Richard Rogers Partnership, Jan Kaplicky, Latz + Partner, and Renzo Piano Building Workshop

Design Strategy / Goals: Solar City Linz is a master-planned satellite town on the outskirts of Linz designed as a 'model' for future sustainable growth. The design team identified solar energy, and its integration, of central importance in both architecture and town planning, and as such, one of the goals of this project was to integrate solar energy into the architectural composition. It was intended that the consumption and supply of energy be harmonized in the development through a variety of renewable technologies; primarily a natural gas district energy plant, and the secondary source of solar.

Observations: Although 'solar' was intended to be the driving force in the development, the manner in which solar technologies have been integrated into the numerous buildings appears, for the most part, an afterthought. While passive solar design considerations may have been taken into account and widely implemented, the architectural language of the development is one that ignores the integration of active systems in their composition. Rack and rooftop mounted solar arrays, as opposed to building integrated solar systems for example, leave the impression that the implementation of solar technologies was not considered from the beginning of the architectural design process. The positioning of residential blocks so that they do not shade the facades of the buildings to their north demonstrates good urban solar planning practices. The manner in which solar technologies have been integrated in this project, however, emphasizes the need to consider solar through all stages of design, – it also demonstrates what should be avoided.

The residential units of Solar City Linz are not unlike many other European housing projects in their appearance and arrangement, leaving the impression that this project could have just as easily been an exercise in renovations and/or retrofits – the solar technologies used have simply been applied, as opposed to architecturally integrated. Furthermore, by locating all the photovoltaic cells on rooftops, the designers have failed to take advantage of the social and behavioural benefits of visible solar technologies. Despite the large use of photovoltaics, the residents in the units are still disconnected from their energy sources, so that while the net energy demands of the development as a whole are reduced, the photovoltaics fail to engage the residents on a visual and responsive nature. Although this satellite town is considered to be a sustainable development, the resulting product is far from a 'true' solar city.

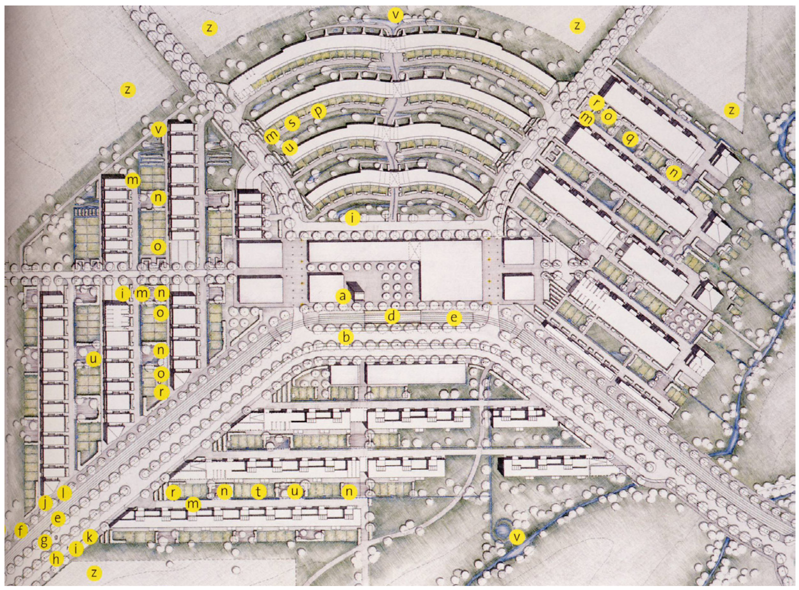


Figure 2.6: Solar City Linz Masterplan; (Kaiser, 2008)

Figure 2.7: Solar City Linz Housing; (Kaiser, 2008)

Case Study: Bo01 – The City of Tomorrow

Location: Malmö, Sweden

Date: Ongoing; begun for the 2001 Swedish Housing Exposition

Architects / Designers: Masterplan by Klas Tham in collaboration with the City of Malmö Planning Office

Design Strategy / Goals: Similarly to Solar City Linz, Bo01 was an exercise/experiment in sustainable community building. An entirely new, 22 hectare ecological district, Bo01, also known as the City of Tomorrow, houses 1,908 inhabitants in 1,303 apartments with a zero-carbon footprint. Situated by the ocean on what was once a former industrial complex, the City of Tomorrow attempted not only to revitalize contaminated land, but to demonstrate that it is possible to create environmentally sustainable densities of approximately 60 dwellings per hectare – 100 per cent of the district's energy comes from a combination of solar, wind, and biomass. In addition to numerous photovoltaic arrays, the district includes 1,400m2 of solar-thermal collectors to provide a large portion of the heating energy required. Even though the City of Tomorrow generates all the heat and electricity it requires on-site, the new power grid and heating networks are linked to the existing city infrastructure so that excess energy is not wasted and a balance between supply and demand may be achieved. Through the extensive use of solar and renewable technologies, Malmö, Sweden has become one of the unofficial world 'solar cities'.

Observations: The varied use of solar technologies (evacuated tubes, photovoltaics, etc) has, for the most part, been considered in some of the architectural projects through all phases of design. There are still some buildings though where it appears solar technologies were applied afterwards, as opposed to integrated, and the potential for further solar integration into public spaces still exists – unlike Solar City Linz, however, the use of solar technologies was not an explicit mandate in this project.

In one or two instances the photovoltaics and evacuated tubes are used as expressive elements on the buildings contributing to the streetscape, a positive sign that in some locations of the development the connection between human habitation and energy is reinforced. The locations where this occurs however are minimal, and for the most part much of the potential for the visible integration of solar technologies in the facades of the buildings went underutilized, and while in their units, residents are visually unaware of their energy sources.

This project is of importance as it demonstrates successful sustainable urban planning strategies in a climate very similar to Canada's. The City of Tomorrow shows that it is possible to integrate solar technologies in dense, mid-rise urban environments as part of a larger renewable energy strategy, though more consideration and emphasis on the visual connection between energy and public would have strengthened this project considerably.

Figure 2.8: 'City of Tomorrow' Aerial View; (Ritchie & Thomas, 2009c)

3 From Observer to Participant: Engaging Energy, Engaging Architecture

If, as argued in the previous section, the visibility of energy sources plays a significant role in shaping and determining an individual or group's energy consciousness and consumption habits, there will, and must be, changes to the manner in which architectural environments are conceived and function. If architecture transcends the boundaries between observer and participant so that people may actually physically engage with their surroundings, then so can the boundaries between energy used within a building, and energy captured by a building. Fox and Kemp reiterate this notion of interactive environments with the following: "Perhaps the most important goal of an interactive system today should be to act as a moderator responding to change between human needs and external environmental conditions" (2009, p. 113).

This section presents a number of concepts that examine the interactive relationship between individuals and their environments, the role that architecture can play in mediating between the two, and alludes to the possibilities by which occupants can physically engage their energy sources through the medium of architecture.

3.1 Interactive Environments

If the lifestyle of an individual can be simply affected by the visibility of a collection of solar arrays, for example, how then does the built environment respond to the heightened energy consciousness of the individual? This back and forth dialogue between individual and environment describes, in essence, an interactive architecture. According to Usman Haque, interactive systems should be viewed as circular, whereby "one enters into a conversation: a continual and constructive information exchange," for if the information exchange occurs in a purely linear fashion, then the system, or individual, is only 'reacting' not 'interacting' (as cited in, Fox & Kemp, 2009, p. 13). Perhaps the most definitive characteristic of interactive architecture is when the occupant transcends from the role of 'user' to the role of 'participant' – the same ideal could just as easily be applied to energy.

Much of the work in the field of interactive environments sprung from the rapid development of computation technologies in the 1980s and 1990s, at which point theorists contemplated the notion of 'smart environments' through the integration of computational systems with architecture (Fox & Kemp, 2009). These proposals typically utilized a central control system for a building, which are common place in architecture today through the use of automated building systems that control everything from the interior climate of a building to controlling shading systems that minimize the amount of direct light and heat gain into a space. Rather than relying purely on traditional methods of information gathering through sensors and detectors, adaptive controls, coupled with a basic artificial intelligence are able to monitor and control the energy use in a building by learning from and responding to the trends and actions of the occupants, lending to various degrees of home automation (ibid) and emphasizing the importance of a two-way (or interactive) dialogue with the environment. Now with the internet, mobile devices, and the emergence of ubiquitous computing, the ability of individuals to interact, and control, their environments has increased dramatically. Mobile technologies, for example, empower the user to communicate externally with a given environment, providing them with the ability to alter it from a remote location. With such developments, the integration of decentralized energy systems conceived as interactive systems become not only manageable, but desirable as occupants are now better equipped to manage their energy supply and shape their architectural environments to suit their energy demands and lifestyles.

As previously quoted, Orr states that architecture and design "never fail to inform" (2007, p. 15), and as such, it is important to consider how an interactive environment may inform the occupant and alters his or her manner of living. In examining solar technologies and the built environment, a level of interactivity, if the connection between energy use and energy source is to be reestablished, is expected between the occupant and exterior solar technologies and environment. In their discussion of living environments Fox and Kemp touch upon this subject, suggesting that if an interactive environment is responsible for mediating the needs of a user and the external environment, that communication must be facilitated through the architecture or physical space itself (2009). In other words, the interior and/or exterior spaces and volumes must adapt and adjust in response to the ever-changing relationship between occupant and external environment, or in this case, the occupant's energy habits and the source of the energy (the sun). The concept of environmental cognizance, for example, strives to make inhabitants more aware of exterior conditions, with the capability of educating and informing them of current conditions and changing environmental states (ibid). Returning to the pedagogical nature of architecture, Fox and Kemp note that "children seem happy to accept learning if it has an entertaining interactive component; they are engaged through the aspect of controlling the narrative" (2009, p. 103). If the ability to engage and control heightens the ability to learn, and the ability to see and experience energy sources increases energy awareness, an interactive solar system has great potential in heightening and improving the energy consciousness of its users.

This desire is echoed by Fox and Kemp in their belief that technology is both influencing and changing the manner in which humans interact with their environment, further noting that "today's intensification of social and urban change, coupled with concern for issues of sustainability, amplifies the demand for interactive architectural solutions" (ibid, p. 18). The following case study, Solar Collector, explores how wireless computational technologies, solar energy systems, the public, and expressive art forms can be melded together to create dramatic results:

Case Study: Solar Collector

Location: Cambridge, Ontario, Canada

Date: 2008

Architects / Designers: Gorbet Design Inc.

Design Strategy / Goals: Solar Collector is an interactive installation that allows users, via the internet, to pre-program a series of illuminating lights. Each shaft is positioned relative to the natural movements of the sun and contains small integrated photovoltaic panels that store energy throughout the day in batteries located in each rod. Come evening, the various 'light shows' remotely programmed by individuals are displayed as one continuous performance of solar possibilities.

Observations: This sculptural installation achieves two key objectives in promoting the successful adoption of active solar technologies. First, the whimsical playfulness of the installation and clean assembly demonstrate the potential aesthetic qualities of photovoltaic installations, and secondly, as an installation in a public area engages people visually, this project further presses individuals with issues of renewable energy in that it is interactive, responding to the human input and desires. This interactivity reinforces an important collaboration between the community and the sun, and, through the medium of a light show, further draws upon intrinsic desires to control, create, and perform.

Figure 3.1: Solar Collector during evening show; (Gorbet Design, 2008)

3.2 Architecture Informing Occupant, Occupant Informing Architecture

If an interactive environment is to have positive and determined results on those who experience it, and if it is accepted that interactive environments have the ability to alter and shape experiences, then it is critical to understand the social, psychological, behavioural, and physical effects that occur as a result of such experiences.

Human behaviour awareness describes the capacity of an interactive environment to understand the lifestyle of its occupants, and more importantly, its ability to inform them of their own behaviours (Fox & Kemp, 2009). A self-realization of one's actions, and a better understanding of the implication of such actions would strengthen the connection between occupant and energy use. Operating in parallel, architectural awareness describes an occupant's understanding that they are in conversation with their environment, and that their actions and behaviours affect their surroundings (ibid). Fox and Kemp explain that "while the architecture can adapt and learn from our actions and adjust itself accordingly, it also has the capacity to teach us how to live and how to work," and that "when the building responds to our actions, we are confronted with a new level of awareness and choices" (ibid, p. 142). They are also keen to note that in order for an occupant to become 'aware', there must be both a learning component and a 'dialogue of compromise' between the occupant and interactive environment (ibid). The ability of an interactive architecture to inform as well as be informed is extremely important in making explicit the behaviours of the occupants, and teaching users how to better respond to the mediating environmental conditions.

Marcus Novak describes this two-way relationship between user and architecture as transactive intelligence (Ludovico, 2001). While active intelligence describes autonomous behaviour and interactive intelligence responds directly with a user, transactive intelligence "implies intelligence that not only interacts, but that transacts and transforms both the user and itself" (ibid). Transactive architecture, therefore, would be an architecture that not only responds to the actions and behaviours of the user, but would attempt to alter and change the user directly – "sometimes we would persuade them to do as we wish; sometimes they would persuade us" (ibid). Fox and Kemp believe that such control of space enhances an emotional attachment between the user and his or her environment, thereby enhancing the spatial experience (2009).

The potential of interactive and transactive spaces to empower individuals and promote active participation with their environments will play a large role in increasing the energy consciousness of its inhabitants – a successful solar architecture will maximize the benefits of such spaces.

4 Transactive Solar Architecture

Architecture is capable of increasing the energy consciousness of its occupants through the development of spaces that promote active participation with solar energy systems. The marriage of transactive architecture and active solar technologies presents numerous possibilities and allows architects to approach issues of energy consumption and energy generation from a new vantage point. This section presents one such approach, exploring the role of solar technologies in mediating between the behaviour of occupants and their internal and external environments. By enabling users to engage and interact with the spaces they occupy, the users become empowered to control their environment, reign in consumptive habits, and better understand the implications of everyday energy based decisions.

4.1 Contextual Analysis

In order to provide a built context in which to operate, and to provide a basis for the analysis of climactic data, Toronto was chosen as the area in which the design proposal would be situated. Toronto is best suited for exploration in the use of solar technology as its energy consumption per capita far exceeds that of other major cities; currently spending enormous amounts of financial resources to import electricity from surrounding fossil fuel plants outside the city's borders. As Canada's most populous city, Toronto has the dense urban fabric required for exploration, is home to a large consumer base to achieve a critical mass for the widespread adoption of solar technologies, and has the ability to reach the largest number of people with the visible benefits enabled through the use of embedded active solar systems. The successful integration of solar technologies within Toronto would demonstrate the feasibility and possibilities achievable through the urban integration of active solar systems – strategies that could then be adopted in other Canadian, North American, and global cities.

In 2006 Toronto used over 72,000,000,000 ekWh (equivalent kilowatt hours) from all sources including electricity and natural gas, of which a pathetic one per cent is from renewable resources (City of Toronto, 2007). Toronto's current energy plan would only see five per cent of the city's energy collected from renewable resources (largely through the construction of wind turbines near, or in, Lake Ontario) by the year 2030 (ibid). This is unacceptable – additional and alternative strategies must be conceived, explored, and considered. As the city's population grows, so does its energy demands; if Toronto desires to position itself for the future and become a world energy leader it must encourage and promote an energy plan that takes dramatic and bold strides, that uses renewable energy sources as its primary source of energy, and that takes advantage of the entire gamut of renewable energy possibilities rather than fossil fuels.

If Toronto were to depend solely on photovoltaics for its energy needs it would require an area of Photovoltaics as large as the city itself[1] (Figure 4.1). Although, for many obvious reasons, such a scenario is both unfeasible and unrealistic, it illustrates the level of excess that the city currently operates within, and emphasizes the importance of not only limiting the city's energy demands, but altering the dramatic consumptive behaviour of its citizens. While the focus of this thesis is on the use and integration of active solar systems, this illustration visualizes the importance and need that solar be used in conjunction with, and alongside, all other renewable energy sources. It is important to note, however, that Toronto is not an anomaly among cities, but that this type of excess in consumption is unfortunately typical of Western and developing cities, particularly North American metropolises.

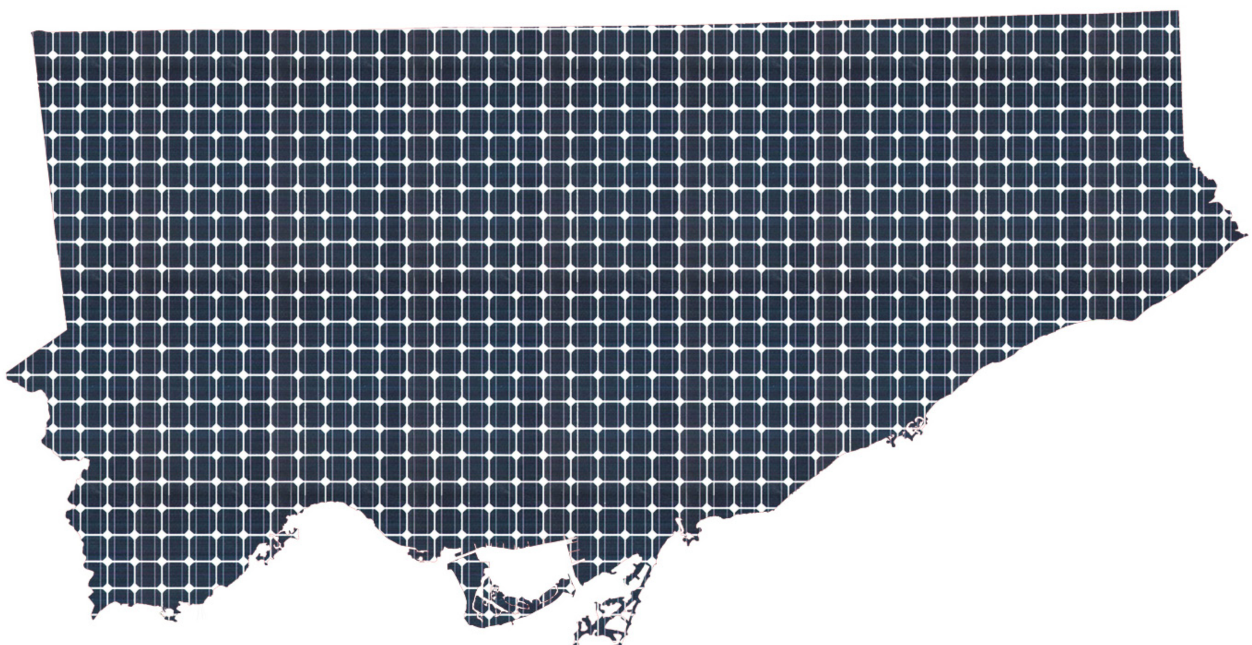


Figure 4.1: Solar City Toronto

The widespread blanketing of photovoltaics illustrated above, although generating electricity at point of use, fails to capitalize on one of the primary benefits of the decentralized energy model described by Scheer (2002) and Swan (2007): that the integration of energy collection can occur at a multitude of scales, with the greatest benefits seen at the smallest. Many individual energy sources ensure a system that is economically and functionally efficient, resilient, and immediate. Through the use of individual energy collectors such as photovoltaics, three varying scales of the city were explored to

[1] Based off Toronto's average solar radiation of 1100 kWh/m2 (CanmetENERGY, 2009), and a conservative 10% photovoltaic efficiency rate

determine the level of dissemination and engagement through which a design proposal would operate and engage the urban environment.

The Street (Figure 4.2)

Toronto's orthogonal urban grid provides an abundance of east-west arterial streets, of which many are characterized by mid-density, three to five storey buildings that run continuously along the street edge. This abundant building stock on the north side of the street is rarely covered in shadow and has great potential for the integration of solar technologies. This scale, however, falls more into the realm of urban planning and large scale massing rather than the more detailed architectural solutions with which this thesis is concerned. Research and design at the street scale is able to capitalize on a broad, public audience, but fails to address individual concerns and individual energy lifestyle choices.

The Building (Figure 4.3)

Examination at the scale of the building allows further elaboration as to the use of the south facing façades along the streets identified above. Working with photovoltaics at this scale requires that both the façades and roof plane of a building be considered, as both surfaces are exposed to direct sunlight for large periods of time. Although a common location of active solar systems, examination of the 'forgotten fifth façade' (the roof) as demonstrated in the Solar City Linz and Drake Landing case studies, would minimize exploration into the immediate interaction possible between user and energy source. In a solar city, each building would engage the public though both architecture *and* energy generation. Although the use of photovoltaics on façades would visibly engage those on the street with energy collection, examination at an even smaller scale is required to understand how individual occupants of the building may be affected by immediate active solar systems.

The Unit (Figure 4.4)

The smallest scale, and the one most decidedly appropriate, is the unit. As the scales of building and street fail to focus on the immediate relationship between occupant and energy source, an approach from the scale of the unit enables close study of the manner in which an active solar system can interact with the occupant. By considering the façade as a mediating plane between occupant, exterior environment, and energy generation, the interior spatial conditions affecting the occupant can be explored as well as the effect of design choices on the exterior. Concentrating on the unit, nevertheless, ultimately affects both the building and street, with design decisions made at one scale permeating upwards throughout all scales.

Figure 4.2: Issues of Scale - The Street

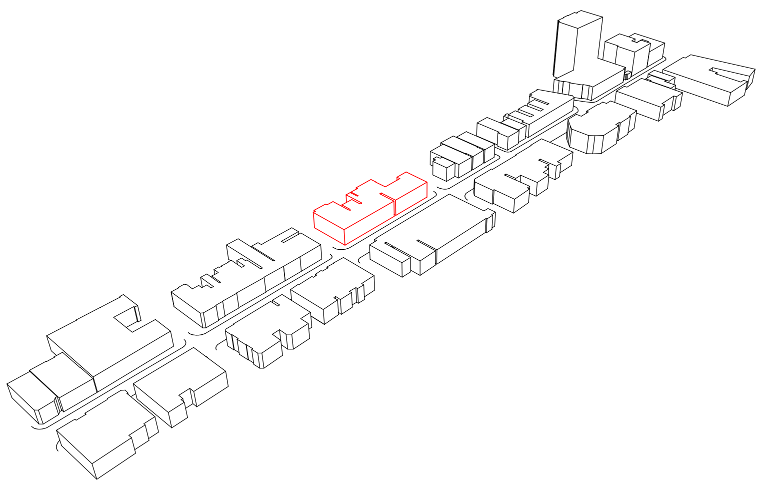


Figure 4.3: Issues of Scale - The Building

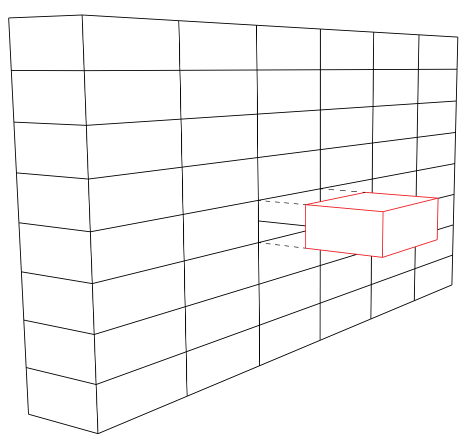


Figure 4.4: Issues of Scale - The Dwelling Unit

4.2 Design Framework and Unit Typologies

As discussed in previous sections, the use of photovoltaics, and the desired social engagement that results from careful implementation, requires the understanding and use of numerous principles and conditions. In order to organize and better understand the multitude of concepts and requirements that the development of a transactive solar architecture requires, a framework diagram was developed to map out the various criteria, inputs, outputs, and effects that such a potential system would have. This process retains concepts from all of the previous sections, attempting to visually represent the complex relationships between different, yet heavily overlapping, areas of research.

The beginnings of the framework centres around the apartment unit as the organizing element, fed by what are considered the two major 'inputs': the occupant/user, and the active photovoltaic system (see Figure 4.5). The occupant component covers the behavioural aspects, while the active system deals with a variety of more tangible, measurable factors. The eventual goal is not that these two 'inputs' compete with each other for control of the unit, but rather that they coexist as two parts of a greater architectural whole.

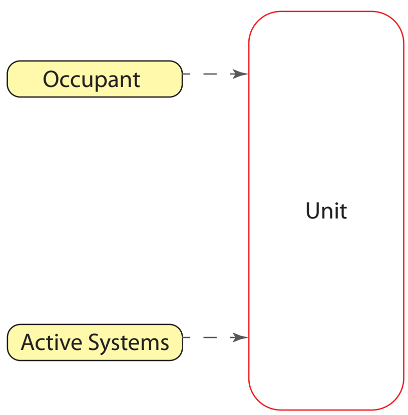


Figure 4.5: Framework Diagram - Inputs

Completing the first half of the framework, that is one side of an interactive architecture, the two major inputs ('occupant' and 'active system') are expanded to include a number of elements and pre-determinants that affect them and the unit directly (Figure 4.6). The actions of the occupant are determined by embedded behavioural patterns and choices, as well as the existing consumption patterns that define his or her current lifestyle and the manner in which he/she uses, and lives in, the unit. The active photovoltaic system has obvious physical requirements that include access to direct sunlight, which is achieved by positioning the photovoltaic array on the south façade of the unit, and a surface area large enough to generate enough electricity to meet the needs of the occupants. For the purposes of this study, the average consumption per apartment unit in Ontario is used, as are other pre-determinants such as the floor area of the average unit[1].

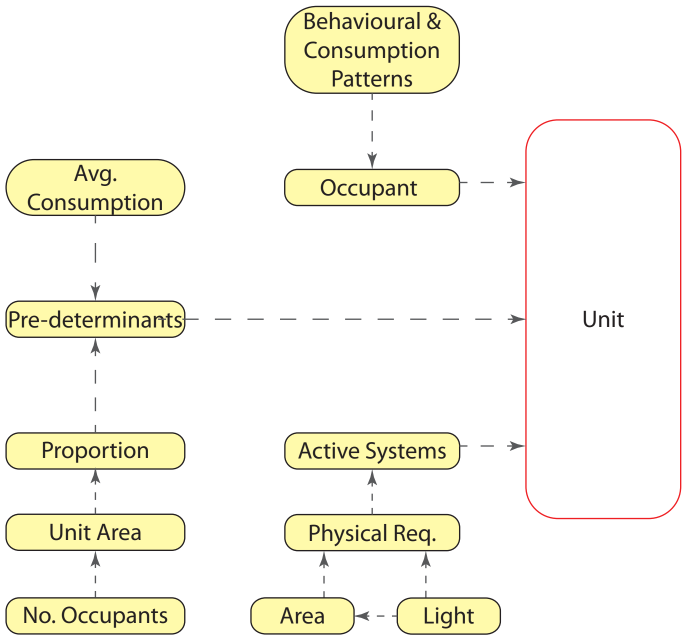


Figure 4.6: Partial Framework Diagram

As shown in Figure 4.7 on the opposite page, a number of these items are interconnected; the size of the apartment and its proportions will have effects on the amount of surface area available for electrical generation by the photovoltaic system, for example. It is also critical to note the two-way dialogue that begins to develop between the occupant and the photovoltaic system – an important indication of a developing interactive relationship between user, energy source, and, ultimately, the dwelling unit.

To shed light on to the form and arrangement of the units, further visualization of the relationships established between the active photovoltaic system and the various pre-determinants is required. To reiterate the importance of careful integration, if the dialogue between occupant and active solar system is to be successful, it must be visible, immediate, and open to engagement. Many traditional unit typologies and arrangements do not allow for such a system, as units are distributed among multiple sides of a building, either providing some units with access to direct sunlight and others with none, or disproportionately distributing external building faces that are capable of capturing direct solar energy

[1] The average annual electrical consumption per apartment unit in Ontario is 5023kWh and the average floor area of an apartment unit in Ontario is 78.5 m2 (Natural Resources Canada, 2007).

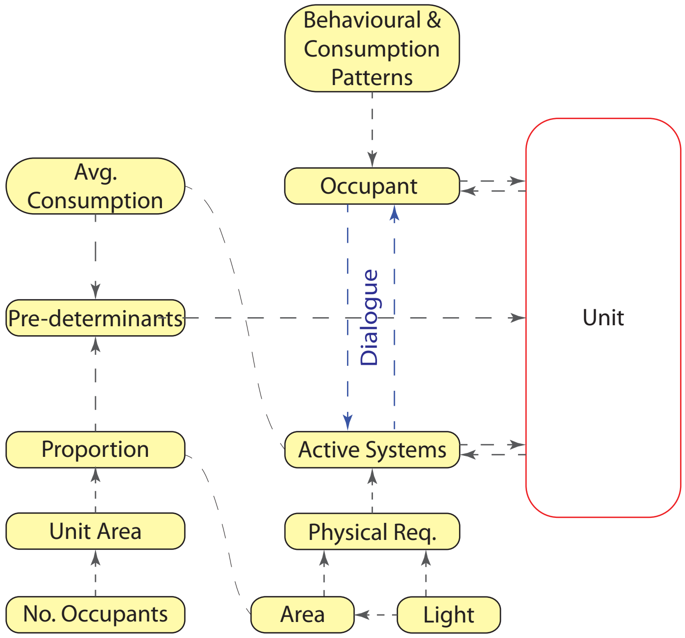


Figure 4.7: Partial Framework Diagram

between units. Figure 4.8 explores a variety of traditional apartment typological arrangements that might occur along a typical east-west Toronto arterial street to clearly illustrate how a simple requirement, such as direct access to light, can dramatically shape the manner in which units and formed, sized, and arranged. In these low- to mid-rise buildings that characterize an existing and developing fabric of Toronto's, the relationships between unit size, active surface area, and proportion are affected by the desire to generate electricity from an active photovoltaic façade.

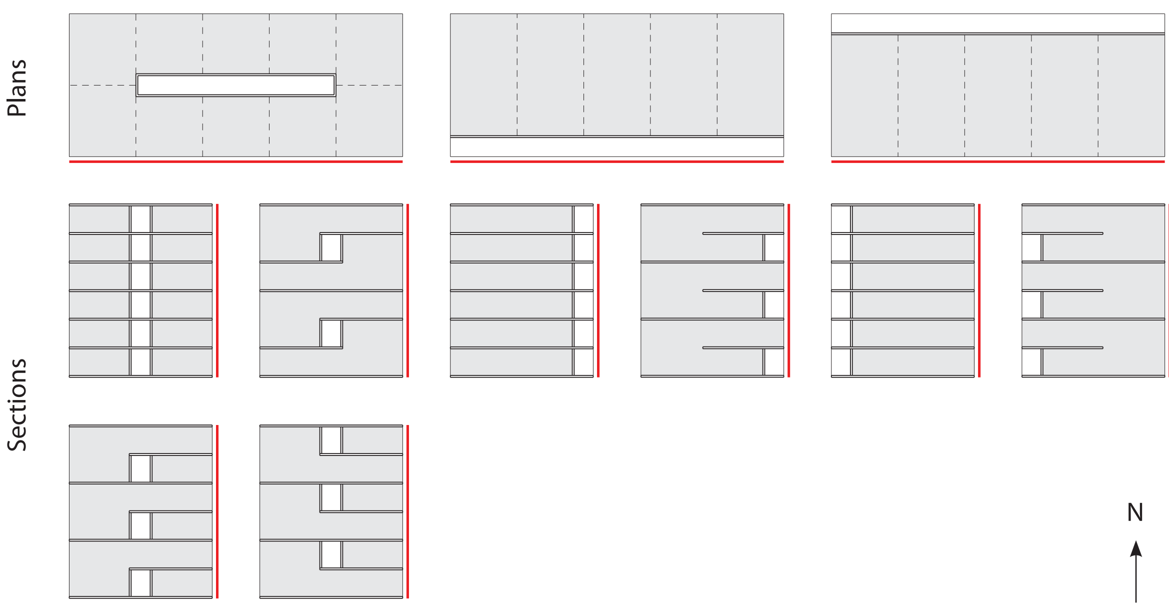


Figure 4.8: Corridor Typology Arrangements

Divided into centre, south, and north corridor configurations, two important assumptions are made: that the entire south façade will be used for electricity generation and that each unit is capable of generating an amount of electricity equal to, or more than, the amount that it uses (photovoltaic systems on the south façades are indicated by a red line). Analyzing the three configurations, the centre corridor arrangement, for example, results in units on the north side that are either denied the ability to capture their own energy, or such ability is unfairly and unevenly distributed. Although the typologies using the south corridor arrangement are each given an equal amount of façade surface area from which to capture energy, the location of the corridor denies and/or minimizes the immediate visual connection between occupant and photovoltaic system, therefore reducing the level of interactivity that may occur between the two. The third scenario, the north corridor arrangement, however, ensures that both requirements are achievable: each unit may generate its own electricity, and each unit can immediately *see* their electricity being generated, all while maintaining uniformity consistency between units in both criteria.

Although this thesis is decidedly looking at Toronto's east-west arterial streets, it is important to consider for a moment how the application of a photovoltaic façade would work on the remaining portion of the street grid; that is the north-south street. In this scenario, the typological arrangements that begin to look most favourable are the centre corridor arrangements as they allow units on both sides of the building to benefit from immediate solar energy systems (see Figure 4.9).

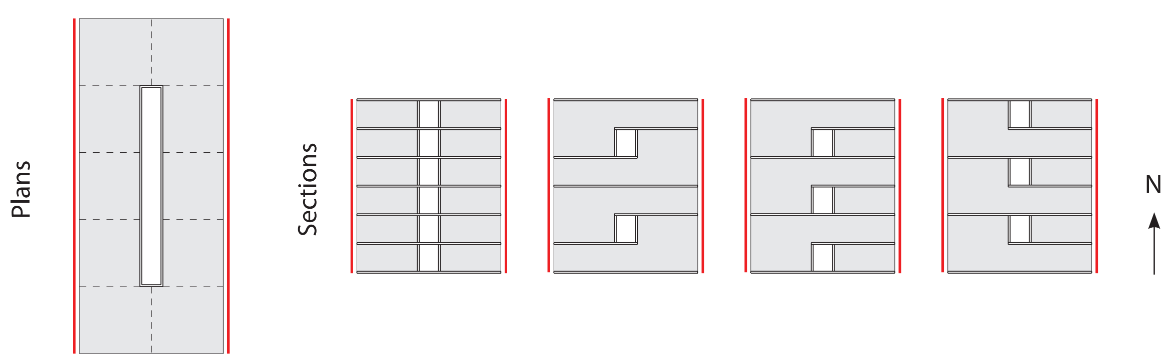


Figure 4.9: Centre Corridor Arrangement, North-South Street

In addition to the linear corridor arrangements discussed above, another common building typology that must be addressed in Toronto is the point tower. Despite the recent proliferation of point towers, because they are able to achieve very high densities with minimal services and corridor spaces at minimal cost, their inherent nature of units being spread around a service core result in similar issues as the south and centre corridor arrangements discussed: access to an active façade and direct sunlight is disproportionate, and in some cases, not achievable at all (Figure 4.10). Although Toronto's angled grid, and the freedom of building tall, provides the potential for point towers to orient themselves off of the Cartesian grid, it is still not possible to gather a substantial amount of natural light on all surfaces (indicated by the dashed red line on the rotated plan).

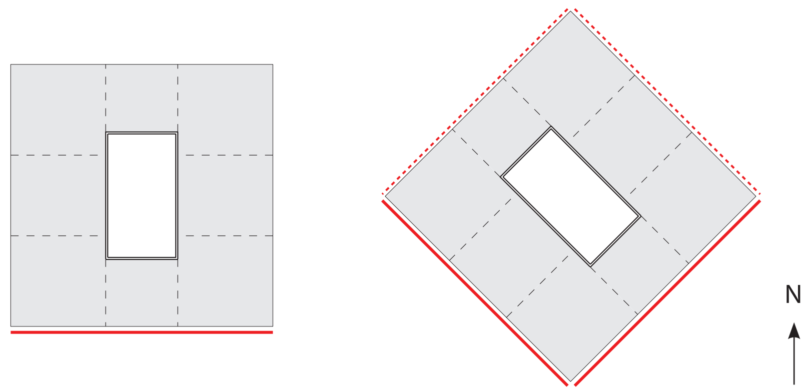


Figure 4.10: Tower Typology

Proceeding with the north corridor location of the mid-rise building typology (previously illustrated in Figure 4.8), the proportion and sizing of the units must be examined to obtain a better comprehension of the correlation between unit proportion and façade surface area available for the application and integration of photovoltaics. Maintaining the average apartment size in Ontario, and the average electrical consumption of an apartment as previously noted, the manipulation of units demonstrates the changes required in both proportion and volume to generate 100, 150, and 200 percent of the unit's electrical demand (Figure 4.11). In all the examples depicted, the units maintain the same floor area, although the floor-to-floor heights and geometry of the units change considerably. If a unit's depth remains constant, for example, the floor to floor heights must increase dramatically in order to obtain the required external surface area for the integration of photovoltaics, and inversely, if the floor to floor heights remain the same, the units must increase in length in order to create an equal amount of façade surface area. Ideally, and realistically, a hybrid between the two scenarios that proposes characteristically narrower, longer units with increased floor to floor heights, capable of generating more electricity than the unit demands would be used. This enables such a development to maintain comparable characteristics and densities of the existing urban fabric, analogous in floor to floor heights, while avoiding extremely long units off of single loaded corridors. It is important to note, however, that if the goals of this thesis are realized, the ratio of electricity generated to electricity used will rise as the energy consciousness of the unit's occupant(s) increases through immediate exposure to energy collection.

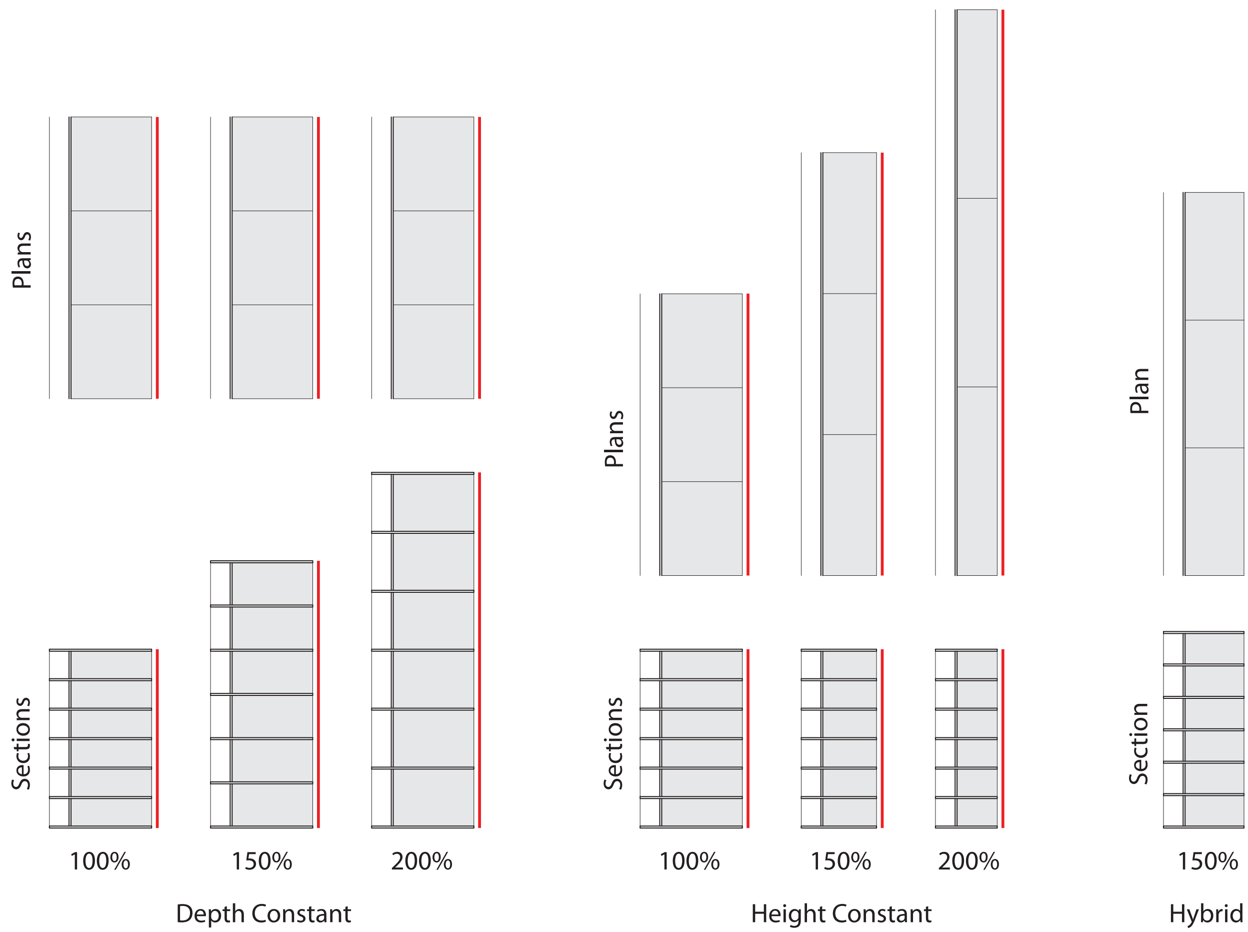


Figure 4.11: Unit Proportional Study

These proposals and typologies thus far maintain and uphold a key tenet that the south façade – the mediating plane between the interior of the unit and the exterior – is shrouded entirely with photovoltaic arrays. If this is the reality of their architecture, what then do occupants do for natural light and views? How do they interface with both the medium of electricity generation and the outside world? The next section continues this exploration in design and energy, and attempts to visualize a response to these two pertinent questions.

4.3 A Transactive Façade

The previous typological studies demonstrated the possibilities, through the careful arrangement and manipulation of units, coupled with an expansive active solar façade, of an apartment unit's capability to produce as much, if not more, electricity than it consumes. Up to this point, the design studies have concentrated primarily on measurable, quantitative aspects and parameters of the space, with little consideration given to the qualitative certainties of any spatial inhabitation. The objective of merging occupants and energy into one architectural realization has thus far been achieved at the expense of views and natural light for the occupants. This demands that the mediating façade be examined in greater depth, and developed to a greater level of detail to accommodate the realities of living and spatial occupation.

Returning to the framework diagram started in the previous section, but now examining the second half, the unit is liable at this point for two critical outputs: 'visual expression' and 'interior conditions' (Figure 4.12).

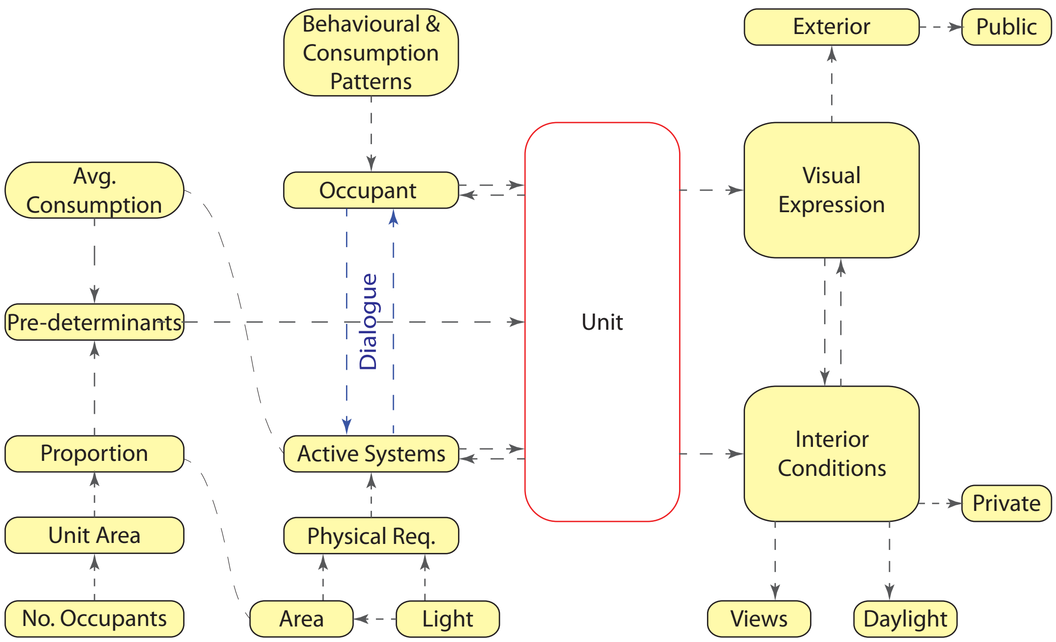


Figure 4.12: Expanded Framework Diagram

'Visual expression' addresses the manner in which the façade appears on the exterior while 'interior conditions' speaks to the nature of the occupant's experiences within the space. In order for the façade, which has been illustrated so far as a solid plane, to accommodate for variables that directly affect interior conditions, such as views and daylight, it demands an interactive solution that will have far reaching effects. The ability of the occupants to engage with and manipulate his or her space will on one hand meet their personal and private needs and desires, while concurrently express the changing visual nature of the façade on the exterior to a wider, public audience. Fox and Kemp discuss the possibilities of engaging an audience when they mention the following: "Architectural space can take advantage of an audience locally, regionally, and globally by re-conceptualizing the role that the physical environment plays in shaping the viewer's experience" (2009, p. 138), suggesting that through an interactive medium (an active solar façade in this case), the changing spatial environment of the unit may be experienced by both the occupant on the interior and the public on the exterior. It is possible then that the changing behavioural dynamics of the user and the changing spatial characteristics of the space blur the lines of private and public, redefining the notions of interior and exterior engagement.

An interactive façade capable of generating the quantity of electricity required, *and* capable of permeating natural light into the unit, led to the design of a series of operable photovoltaic louvers independently controlled by each unit alongside changing solar requirements. To manage the constantly changing parameters, and to generate multiple variations of each unit's façade, a functioning digital script was developed to manage the numerous and varying inputs; notably those illustrated in the developing framework diagram. This script had the ability to instantly adjust and modify parameters such as unit width and height, the number of vertical and horizontal divisions of the photovoltaic surface, and the percentage of louvers that are either 'active' (generating electricity from solar sources) or 'inactive.' Figure 4.13 (as shown opposite) illustrates some of the early results generated from the graphical algorithm editor and generative modeler, Grasshopper. By using a platform with which multiple variables could be modified at the behest of the operator, the working methodology of the design proposal mirrored closely the desired interactive role between occupant and unit. The left column illustrates modifications in the percentage of 'active' modules, with the results randomized as to which louvers are turned on, or off. The diagrams in the right hand column demonstrate varying changes in the size of the photovoltaic louvers, and the visual effects that different divisions of the unit's façade might have.

Transforming the two-dimensional visualizations into a three-dimensional solar façade yielded two visually similar, yet dramatically different in their effects, design proposals. Both façade proposals consist of photovoltaic louver systems that respond to the external solar conditions, as well as the energy demands and habits of the occupant, and both dictate a level of visual interactivity. Figure 4.14 demonstrates the first proposal, consisting of a series of identical, individual, operable louvers. As illustrated, the louvers can all be opened/rotated varying amounts, and the patterning and number of louvers affected varies as well. Reacting to the energy choices of the occupant, the louver system generates more or less electricity as needed. Similarly, the occupant has varying degrees of control, in that he or she has the ability to open or close louvers at the expense of electrical generation. The resulting effect, however, despite the interesting patterning, does not achieve the drama and implications desired – regardless of the occupant's actions and energy consciousness, the louvers continue to generate electricity whether open or closed. The desire for views and the availability of natural light is not necessarily affected by this proposal, nor does it provide the occupant any immediate incentive to manage their energy choices; notwithstanding the financial benefits of renewable energy at home.

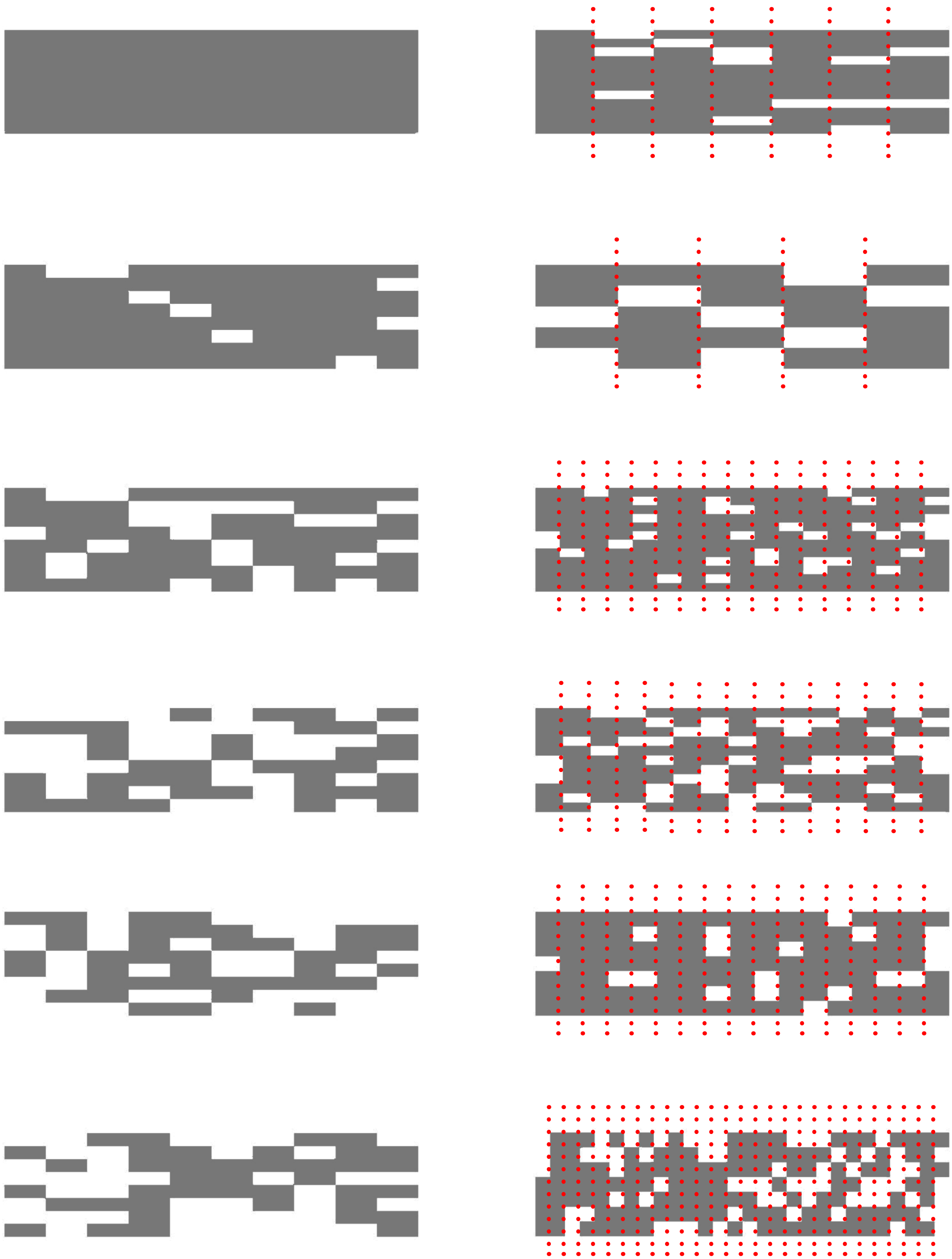


Figure 4.13: Early Scripting Results

The second design proposal which builds off of the first, introduces a folding component, whereby two photovoltaic surfaces are built into one individual louver with the capability of retracting upon itself (Figure 4.15). Again, this diagram illustrates how the louvers can open varying amounts, the randomized activation of louvers, and the randomized rotation of each louver. The implications of this second scenario are immediately clear – when any one louver is folded open, the lower portion of the louver is shaded by the portion above and its individual capacity to generate electricity is immediately cut in half. With each individual louver thought of as an energy source that can be turned on and off, and as part of a larger system and network that generates electricity at point of use, the façade becomes a literal, architectural representation of the concept of energy decentralization. Furthermore, as a mediating element between interior and exterior, the façade brings into fruition the benefits of visible energy sources discussed previously.

The repercussions of excessive energy use on the part of the occupant now have far greater implications on the interior conditions as the activation of any one louver has dramatic effects on the permeability of the façade. The occupant is now immediately aware of his/her energy choices as desires for views and natural light are challenged by the very environment in which he or she resides. Through the visualization of behaviours, choices, and lifestyle, the analogous relationship between energy use and energy source are made explicitly clear to the occupant. They do, however, remain in control – in control of their environment, in control of their external appearance, and most importantly, in control of their energy.

An environment that forces the occupant to confront their desires and question their choices represents an architecture that not only informs, but influences the occupant – an architecture that has evolved from interactive to transactive!

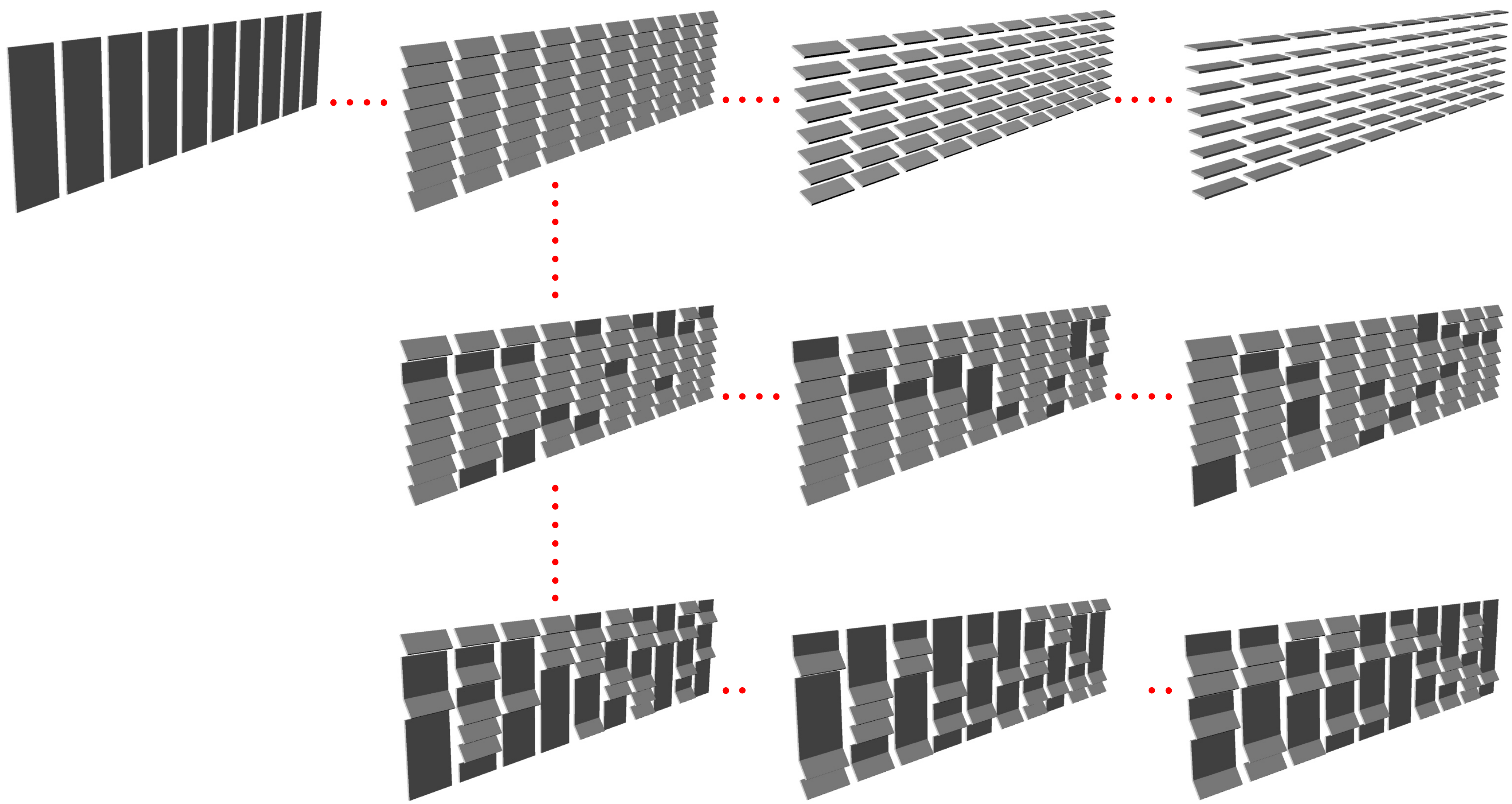


Figure 4.14: Photovoltaic Transactive Facade 1

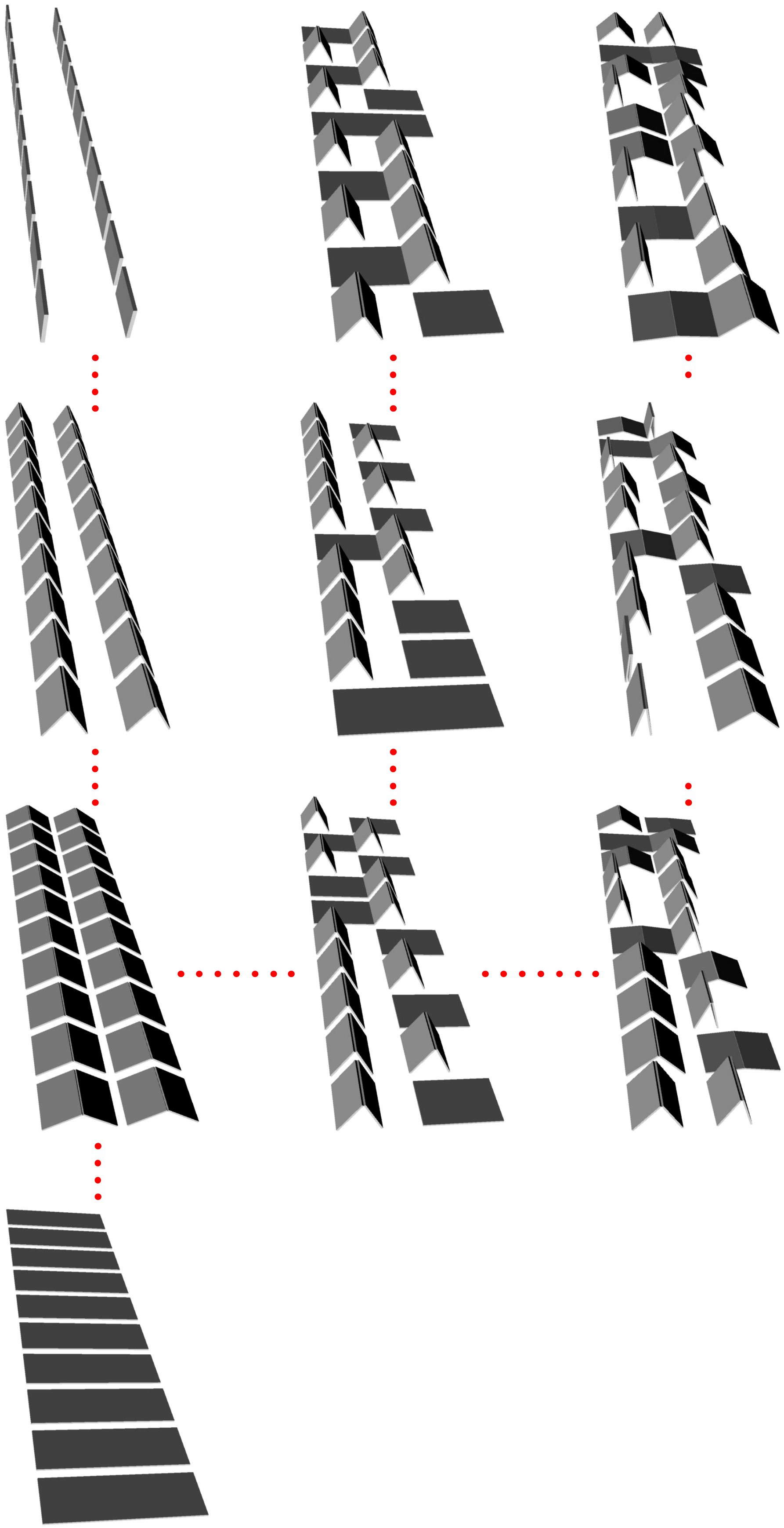


Figure 4.15: Photovoltaic Transactive Facade 2

4.4 Understanding a Transactive Solar Architecture

Through the architecture's ability to respond to actions and confront the occupant with a new level of energy consciousness, the process returns 'full circle' (similar to the closed loop, self regulating systems described by Van der Ryn and Bunnell (1997) and discussed in the first section) emphasizing the transactive qualities of the system. Influencing the behavioural and consumption patterns of the occupant, the completion of the framework sees a plethora of relationships unfold; some visual, some social, some tangible, yet regardless of physicality and consistency, all play important dynamic roles in achieving a transactive solar solution (Figure 4.16). The dialogue made possible between public and private by the expressive façade informs both groups of the consequences of their energy use, heightening their energy consciousness, and ultimately affecting their behavioural choices, consumption patterns, and the overall average consumption of all concerned.

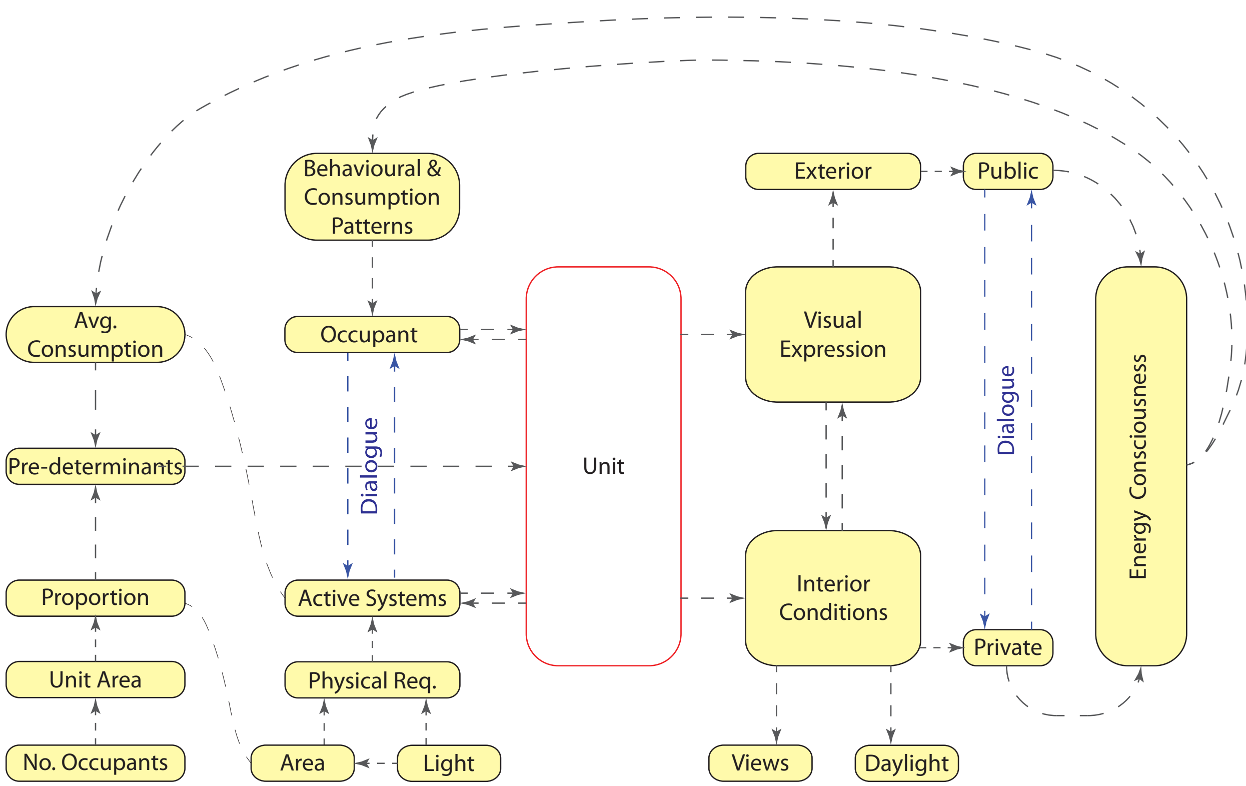
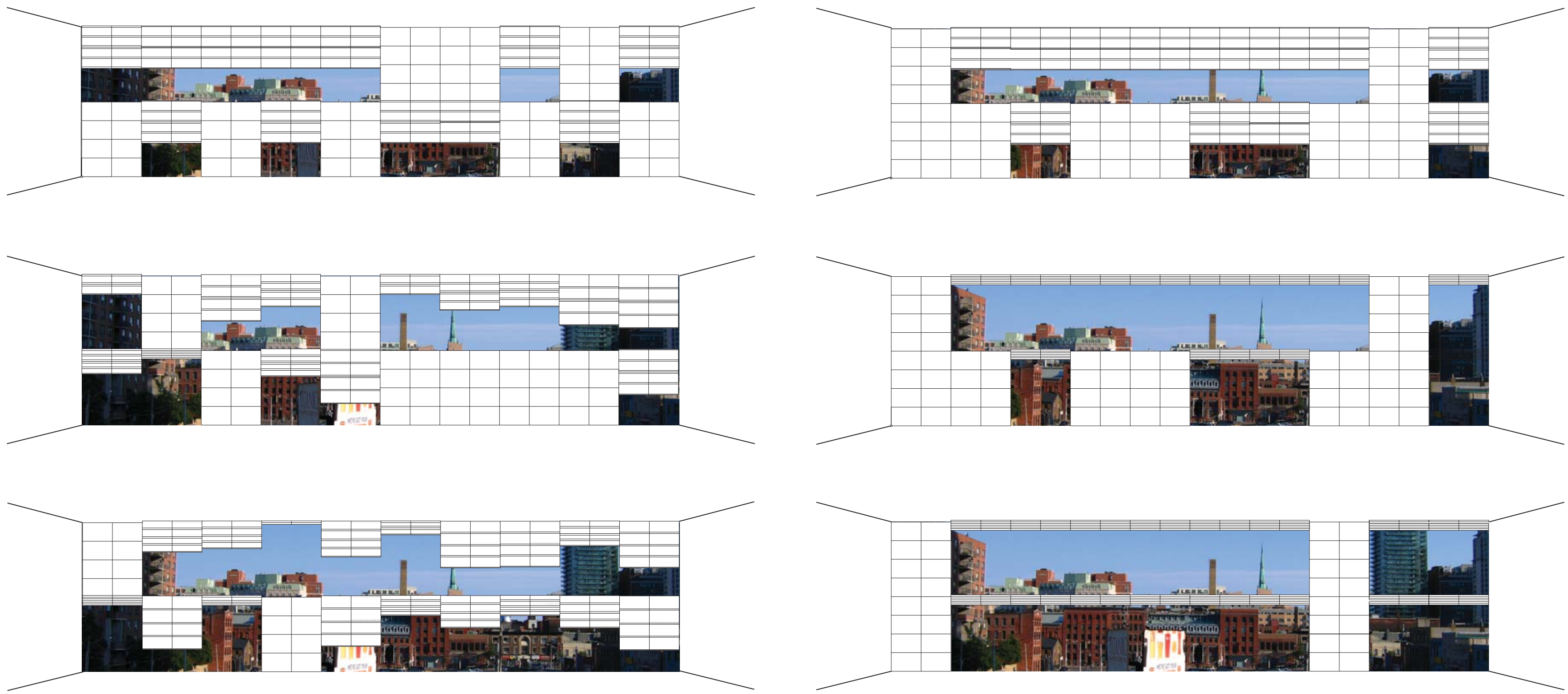


Figure 4.16: Completed Transactive Framework Diagram

To better understand the implications on both the individual occupant and the outside public, both interior and exterior conditions must be explored in more detail. In a transactive architecture, the occupant is a participant of a larger system, yet still capable of exerting control to a certain degree. Beyond energy choices, the occupant plays a participatory role in his or her dwelling to consciously



Randomized

Occupant Controlled

Figure 4.17: Framing Views

choose the appearance and patterning of the façade, or, if desired, allow the transactive system to rein control and generate an image of its own accord. Figure 4.17 demonstrates this give and take relationship by comparing the different interior experiences offered through a randomized, system-controlled output, and a user-defined, occupant controlled output. With the capability of the occupant to frame specific views, comes the ability of the occupant to become a performer, choosing the manner in which he or she is displayed and exposed on the exterior. The transactive solar façade becomes more than an electricity generating surface; it becomes a canvas for expression. The positioning of the system as a plane between interior and exterior ensures the occupant is continually connected through sight with the source of their energy. When looking from within the unit to the exterior, the occupant is as much aware of the urban landscape that they are framing, as the frame itself – the photovoltaic louvers that power their unit and enable their lifestyle.

A heightened sense of spatial and behavioural awareness is not limited to the part of the occupant however; the public is actively engaged through the changing façade. Fox and Kemp note that "as users have the ability to manipulate space, they also have the ability to create new types of connections with each other" (2009, p. 156). Figure 4.18 examines the manner in which individual units could be viewed and experienced from the street, and the different types of connections that could be made.

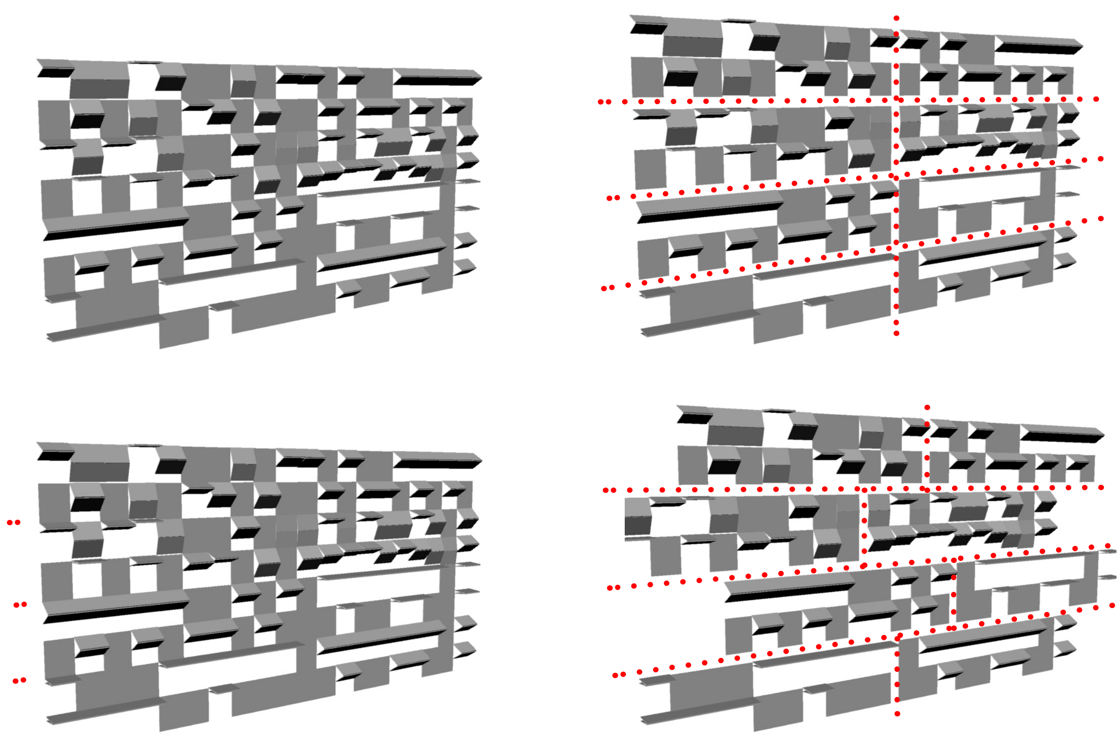


Figure 4.18: Exterior Arrangements & Relationships

Beginning with the left two examples, if units are not individually emphasized and separated, the public on the street are unable to distinguish between the expressed overall ecological consciousness of the building and that of each unit. By emphasizing the uniqueness of each occupant, by spreading the units apart as demonstrated on the top right, the units may be measured against one another, visually expressing the value that each occupant has placed on energy and the choices that the individuals within have made. Staggering the units along the façade, as illustrated in the lower right image of Figure 4.18, accommodates the opportunity for different sized units (one bedroom versus two bedroom for example) and creates an additional sense of playfulness along the streetscape, further advancing the building as a conversation piece. The distinctiveness of each unit is critical in emphasizing the individual responsibilities that everyone must bear in the pursuit of a more ecologically sensitive future.

Furthermore, with the introduction of a lighting channel that surrounds each unit, an additional reading of the occupants is achieved at dusk. If an individual has generated more energy throughout the day than he or she has used, the unit is framed in a light of green, while units that have done the opposite, units whose occupants' consumption habits are more wasteful, result in a frame of red light for an hour or so after sunset (Figure 4.19).

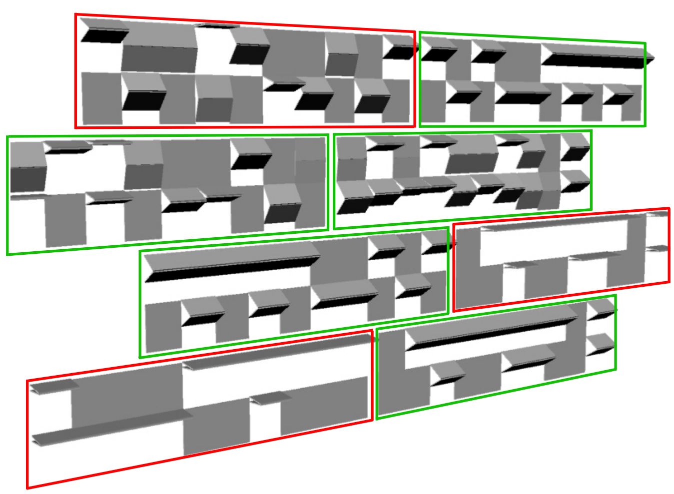


Figure 4.19: Illuminated Units

This subtle addition to the façade further advances the architecture and occupant as a performance piece, while perceptibly measuring the concerns and lifestyle of one occupant against another. Behavioural awareness is no longer simply achieved on an occupant by occupant basis, but allows for one resident to become aware of another's behaviour through experiences of mutual interactivity.

4.5 Engaging a Transactive Solar Architecture

Important to note is the previously unexplored connection between 'unit' and 'grid' (Figure 4.20). With the potential for generating more electricity than used, occupants are given the opportunity to use their façades as an additional source of income – creating a two-way relationship with the energy grid as opposed to the one-way relationship typical of other buildings.

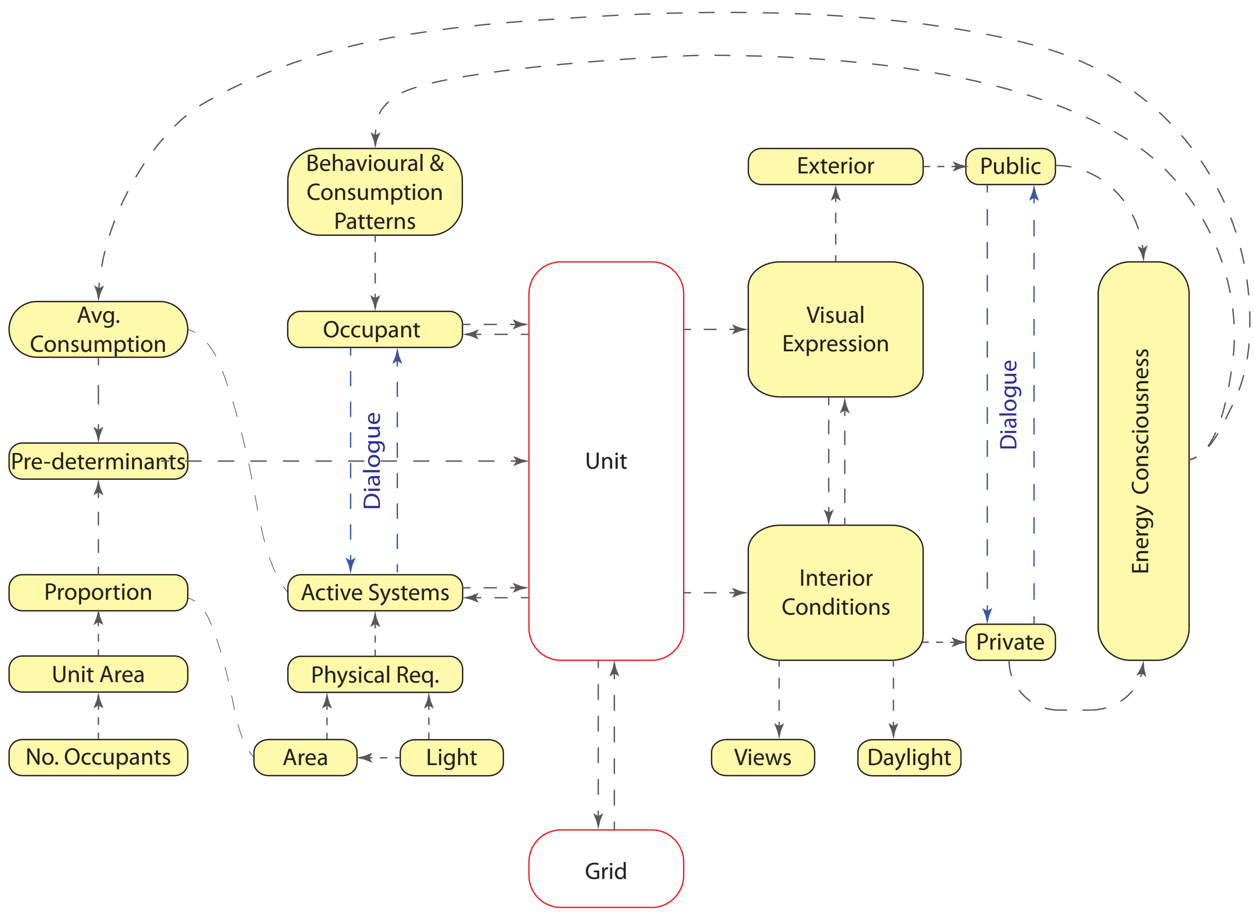


Figure 4.20: Framework Diagram - Unit to Grid Relationship

With Ontario's feed-in-tariff (FIT) program, the utility is required to pay homeowners who generate electricity from photovoltaics and other renewable sources a rate far above the current market rate. The Ontario Power Authority currently pays 80.2 ¢/kWh for rooftop and building integrated photovoltaic systems, compared to the time of use (TOU) rates of 5.3, 8.0, and 9.9 ¢/kWh range that residential consumers pay for electricity, rewarding consumers that consciously shift their demand to off peak hours (OPA, 2010; Toronto Hydro, 2010). The FIT program benefits the consumer as it provides an additional source of income for those who embrace solar technologies, while lowering the demand and increasing the capacity of the province's energy grid, reducing the need for new, fossil fuel based power plants. As an additional incentive to architecturally integrate solar technologies, the rate offered for building integrated photovoltaics is higher than the 64.2 ¢/kWh paid for electricity generated from ground-mounted photovoltaic arrays (OPA, 2010), which are often constructed at the behest of valuable farm land and open green space. Furthermore, feed-in-tariffs have always been geared towards residential single family home owners and small commercial and industrial businesses. With an interactive solar façade used at the scale of the apartment, the capacity to generate income and relieve an already strained energy grid is shared by an entirely new group of consumers currently unable to take advantage of such incentive programs.

By using photovoltaics as the energy collecting medium in the units, the peak generating times align with the peak consuming times – during the day in the summer, when the sun is strongest and photovoltaics work at their best, is the time at which the utility sells electricity at the highest rate for example. During these hours, occupants can sell much more electricity to the grid at a very high rate, and then purchase back the electricity required in the mid- and low-peak times in the afternoons and evenings when electricity prices are lower. In winter, however, when consumers require heat rather than air conditioning, peak usage rates occur in the evenings, rather than during the day. Although not as well aligned, electricity generated during the day still occurs at the mid-range level of both price and grid demand, and the price paid by the utility for electricity is still far more than the occupant would pay otherwise. It is critical to understand then, that energy consciousness is not just *how* energy is used, but *when* energy is used – it emphasizes a holistic approach to all aspects of energy consumption and conservation.

To examine the actual economic implications and benefits of a solar façade, the average annual electrical consumption per apartment in Ontario (5023kWh), the average price of 6.5 ¢/kWh paid in Toronto Hydro's time of use program, and the 80.2 ¢/kWh paid to the consumer for integrated photovoltaics through the FIT program are used to calculate the potential income generated by an occupant. If an occupant with strong ecological consciousness and careful management of his/her energy use is able to generate 100 percent of the electricity used in the unit throughout the year, he/she would profit $3701.95 a year![1] Even if the occupant produces only 50% of the electricity consumed he/she would still see an additional income of $1850.98. The benefit of a transactive system that strives to change the habits of the occupant, is that this amount will increase over time as the occupant become increasingly aware and cognizant of the environment he/she is operating within.

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[1] (price paid by utility to occupant for electricity generated) – (cost of electricity paid to utility) =
(5023kWh x 80.2 ¢/kWh) – (5023kWh x 6.5 ¢/kWh) = $3701.95

It should be noted, that although the current feed-in-tariff program is based on 20 year contract terms (ibid), such high rates will not be paid for electricity forever. The purpose of such programs is to provide incentives for early adopters of solar technologies, even if, judging by the state of the environment and the depletion of natural resources, it is not early enough. The only certainty, however, is that energy prices will continue to rise, ensuring that point-of-use energy generation technologies will always have a certain degree of economic benefits. Even without such benefits, the state of the environment, and the consumptive lifestyles that define present day society, ensures that we *can't* afford not to integrate and engage solar energy systems.

Furthermore, considering the lifestyle of the occupants, the average resident is likely at work during the peak energy hours of the day. This increases the efficiency of the solar façade as during these times, when the sun is strongest, the occupant is likely either away from his or her unit, or requires the shading that closed louvers provide, allowing the system to function, in terms of electricity and income generation, at its best. With the advent of ubiquitous computing and the proliferation of mobile devices, occupants may still be connected to the source of their energy, and the transactive solar façade at home, even if they are not (Figure 4.21).

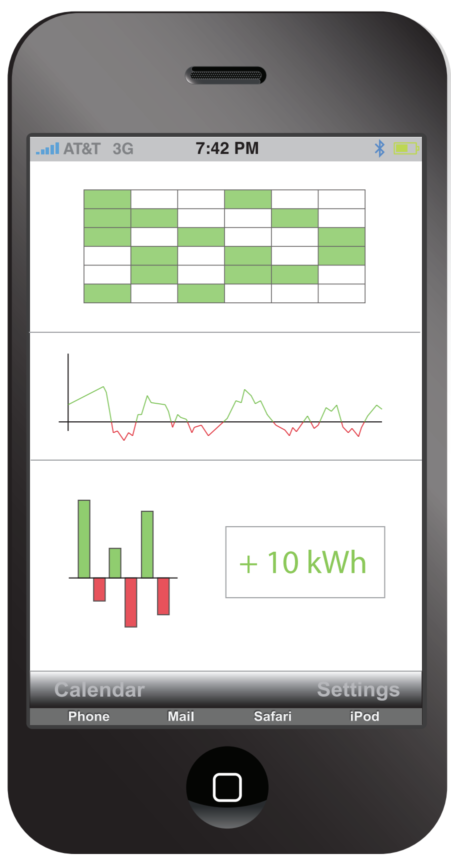

Figure 4.21: Mobile Control

Advances in communication and information technologies facilitate levels of engagement with both architecture and energy, previously not possible. Figure 4.22 illustrates how the transactive system expands beyond the confines of physical space, permitting the occupant to interact with their home environment through either a mobile device or internet connection, or through a touch-screen interface in the actual unit, and how these technological mediums communicate with both the façade and the energy grid. By making it easy for occupants to engage energy use and conservation, residents have little reason to resist conversations with their façades.

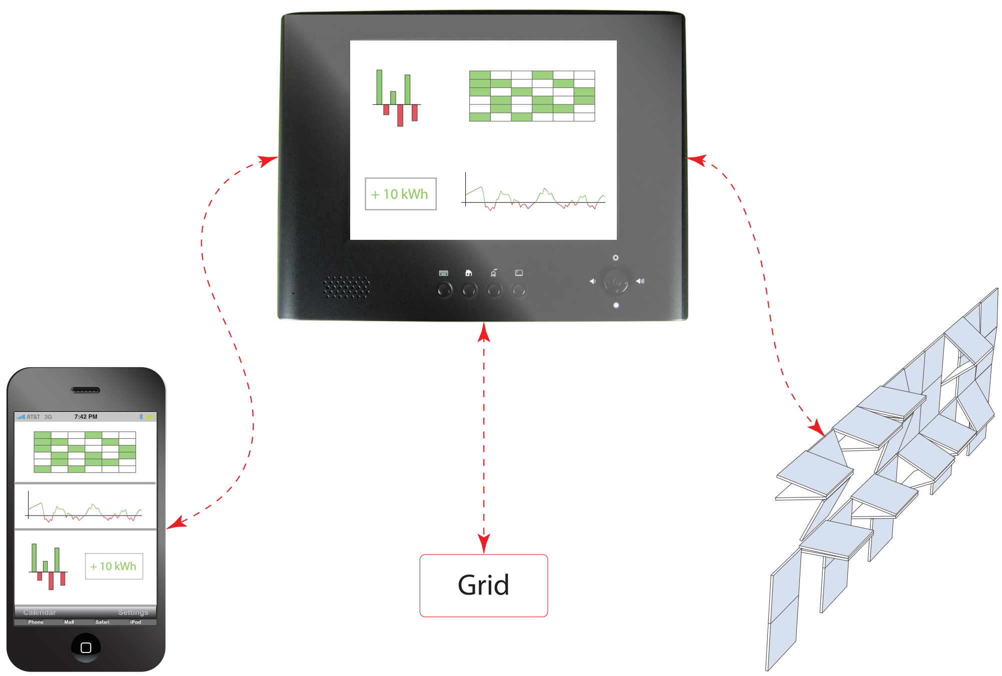

Figure 4.22: Occupant Interfaces

The interactive user interface allows the occupant to directly communicate with the intelligent system, determine which louvers are 'active' or 'inactive', view the real-time output of the system, compare consumption to previous days, weeks, months, or years, view any monetary changes, and most importantly, become physically and visually engaged with energy. The wall-mounted user interface is shown on the exploded axonometric (Figure 4.23) alongside a visual summary of the other physical elements that make up the built system: the glazing system that provides elemental protection from the exterior, the lighting channel that highlights through colour the behaviour of the occupant(s), and the louver system which enables the transactive relationship between occupant, energy, and observer. Repeated for individual units across the building's façade, each occupant's lifestyle is exposed; performed as a dance across a continually changing transactive solar façade (Figures 4.24 to 4.26)

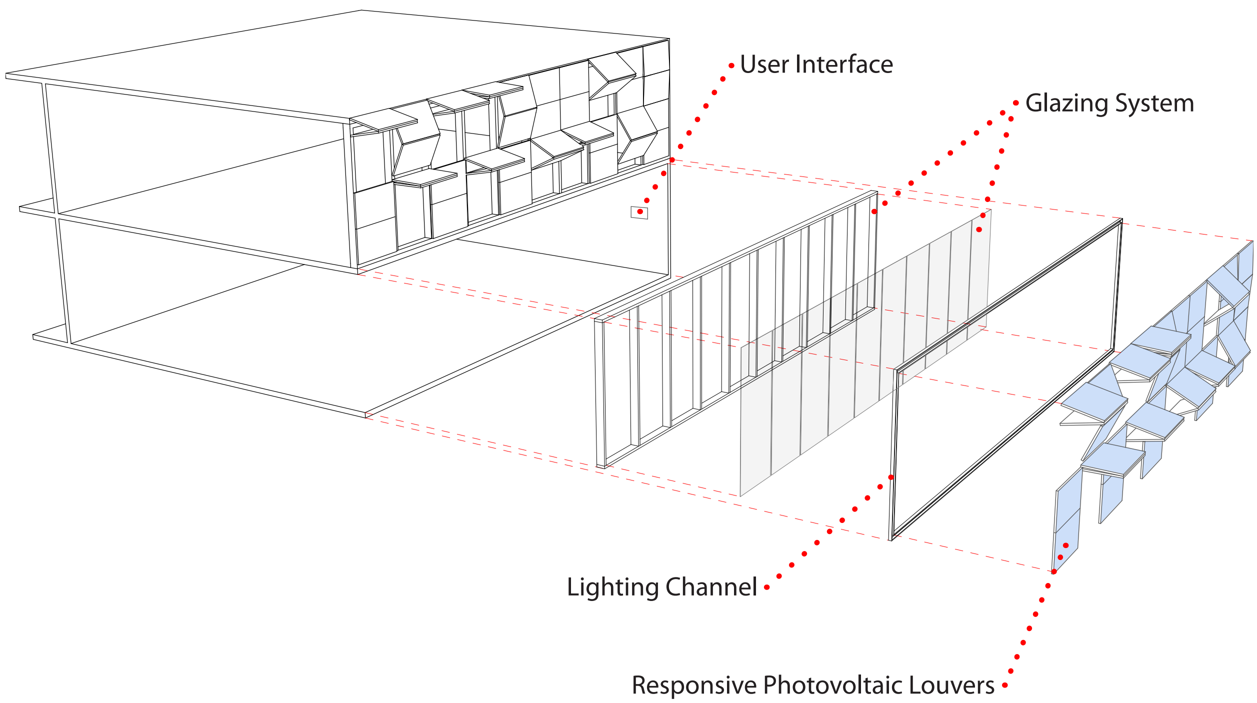

Figure 4.23: Exploded Axonometric

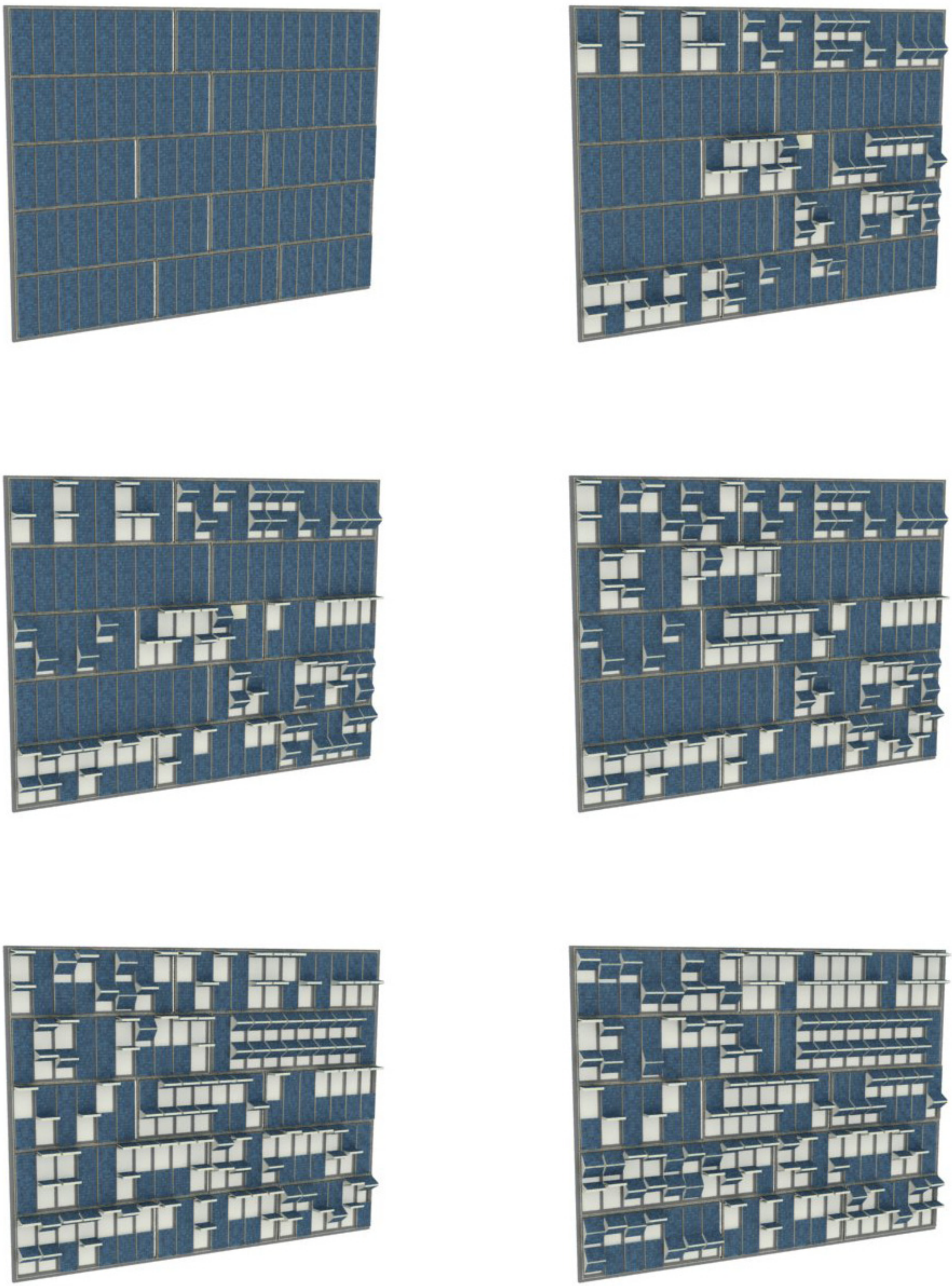

Figure 4.24: Transactive Façade Sequence 1-6

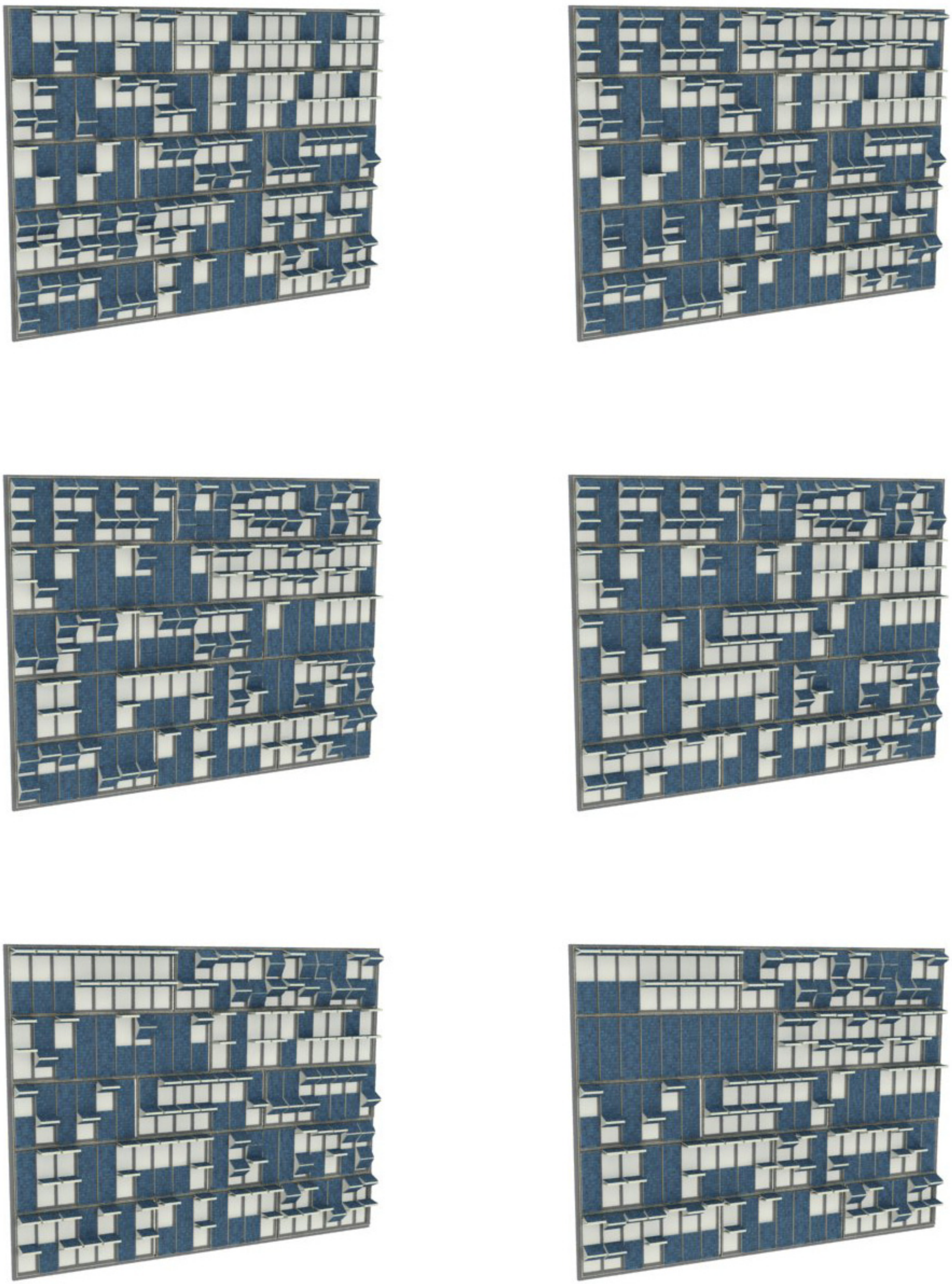

Figure 4.25: Transactive Façade Sequence 7-12

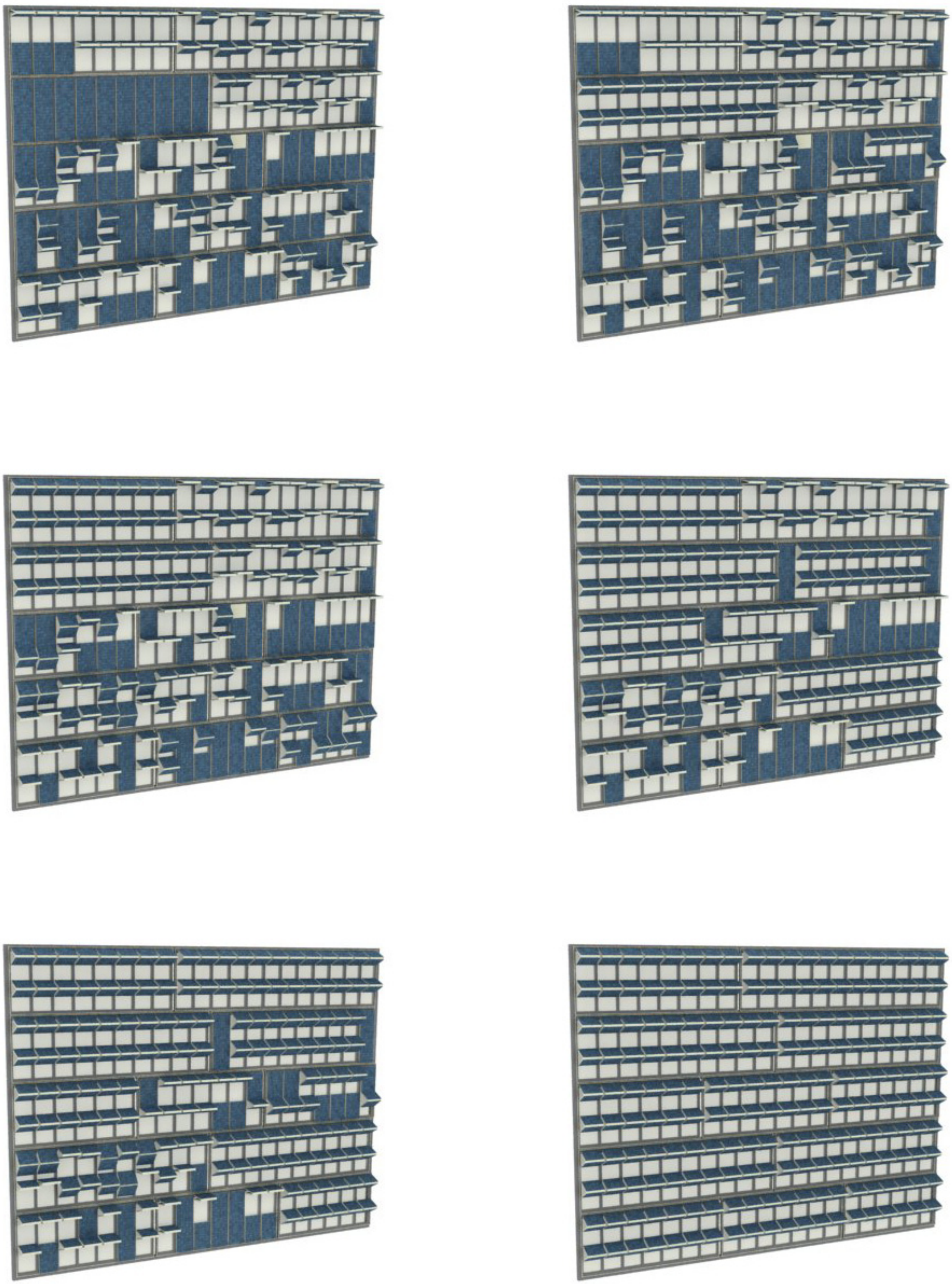

Figure 4.26: Transactive Façade Sequence 13-18

The use of the façade as a mediating element allows individuals to not only participate with the generation of their resources but to promote that interaction simultaneously with a larger public. Unfolded before their eyes, viewers on the street become an audience to the occupant – a visual representation of a lifestyle within, made manifest through the expressive use of a solar architecture determined by the behaviours, priorities, and thoughtfulness of the performer within. This continually changing environment creates a heightened sense of architectural awareness in that the occupants become cognizant of their environment and begin to understand that they are in dialogue with their architecture. Through such a system, the perceived 'value' of energy is challenged, as consumption choices are measured against the occupant's desire for daylight, views, and the ability to generate income. The continued visibility and engagement of a transactive solar architecture ensures a heightened ecological consciousness and a more responsible means of living.

To a certain extent, our behaviours are nothing but learned intuitions growing out of our experiences in the world. We learn early how to operate our buildings, opening doors, windows, and shades ourselves, but when the building responds to our actions, we are confronted with a new level of awareness and choices.

– Fox & Kemp, 2009, p. 148

Figure 4.27: Transactive Solar Street Presence

Conclusions

Architecture is capable of increasing the energy consciousness of its occupants through the development of spaces that promote active participation with solar energy systems.

This paper examines the relationships between solar energy, energy supply systems, the urban environment, and both human and environmental ecologies, identifying the vital role that active solar technologies, and the ability to view and engage with them, can, and must, play in cities' move towards environmental accountability. Humans and cities have traditionally relied on and been connected to the sun – a relationship that must be reestablished and exploited to avoid the economic and environmental degradation associated with continued fossil fuel use. Within this strategy, a shift towards renewable energy sources such as solar will facilitate the decentralization of the traditional energy system, reducing the energy supply chain and positioning energy sources closer to their uses.

Despite its northern climate, solar energy is not only feasible and practical in Canada, but has the potential to play a pivotal role in the growth and development of major cities such as Toronto by reducing cities' energy imports and demands. By reestablishing its connection to natural ecologies and energy systems, Toronto can both actively and visually engage its citizens in matters of energy conservation and ecological preservation.

In a transactive solar architecture the occupant becomes actively engaged in the architecture, becoming a participant as opposed to mere observer, while similarly, the observers on the street become participants in a dialogue of consumption made manifest through expressive architectural techniques of sustainability. The increased visibility of energy sources has a direct, positive impact on people's energy and consumption decisions, with a heightened human behaviour awareness achieved through the development of interactive and transactive environments that connect with, and transform, both the user and themselves.

A solar architecture that can actively engage, and be engaged by, its occupants promotes a sense of urgency and understanding, and empowers individuals to become part of the solution as opposed to part of the problem. As intelligent environments learn from the behaviours of the inhabitants through observation, a transactive solar architecture may in turn inform and influence those within – favourable behaviours may be facilitated and rewarded, while damaging and consumptive behaviours denied. In the scenario presented, occupants must weigh the value of energy, daylight, views, and income in every energy related decision they make.

An architecture that informs, educates, promotes, and shapes the eco- and energy consciousness of both its occupants and the greater societal whole, is an architecture that gives hope in realizing a more ecological, more environmental, more understanding future.

Appendix A: Alternate Explorations

This section documents a portion of work that did not end up being included in the final design project. It includes different trains of thought, varying ideas, sketches, mappings, case studies, and diagrams that arose out of the creative design-research process. Representing various branches of exploration, the following collection is presented loosely with an emphasis on alternate ways in which solar technologies might be implemented into the city, and what implications they would have on the built form.

Urban Analysis

The beginnings of this thesis began by identifying a lack of research into the urban integration of active solar technologies. Although much work has been done in integrating various solar elements into buildings, the urban landscape presents a multitude of possibliites for exploration. As architects are responsible for both the built and unbuilt environment, there are few, if any, areas of the city that are beyond the potential realm of solar architecture. Imposed on top of Superstudio`s Continuous Monument - an urban planning project that was to extend endlessly - a vision that defines a dependency on solar technologies and the importance of solar integration is shown in Figure A.1.

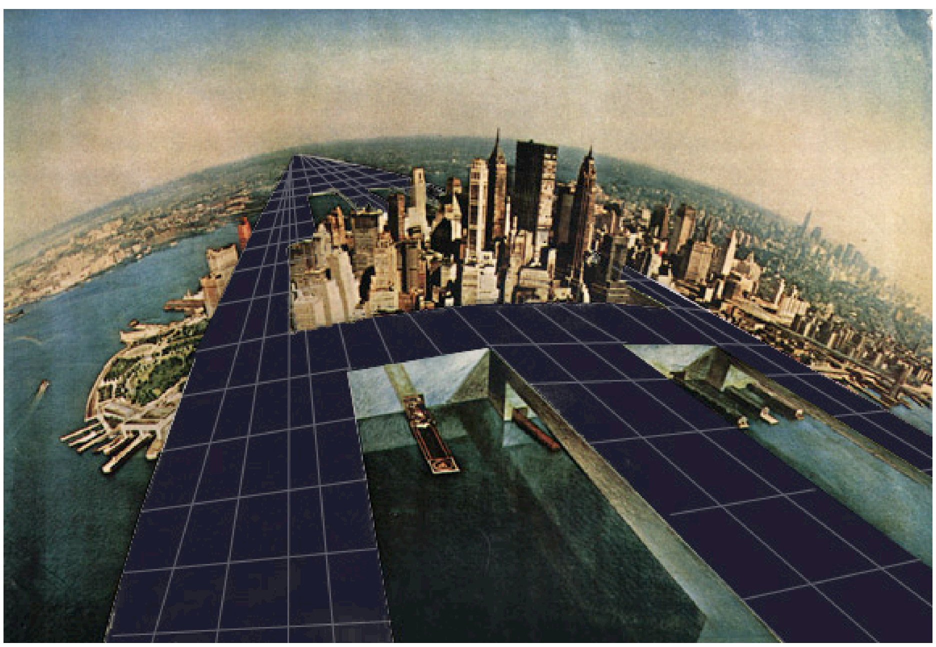

Figure A.1: Continuous Solar; (base image from MW Architecture, 2009)

Although unrealistic and sensational, the above image illustrates a need to think outside the box and entertain scenarios peviously not thought possible or worth of study. Working within Toronto, an early exercise was undertaken to identify and map out a number of pre-existing urban spaces and typologies within which solar technologies could be implemented at a later stage. These areas included laneways, rail corridors, hydro corridors, and major highway arteries (Figures A.2 - A.5 respectively).

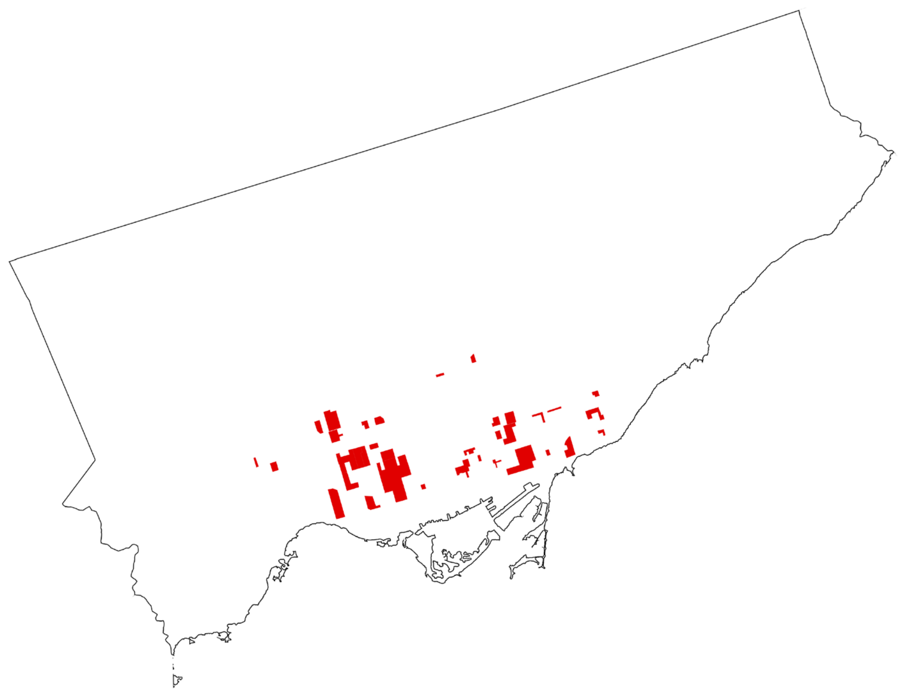

Figure A.2: Residential Toronto Blocks Serviced by Laneways

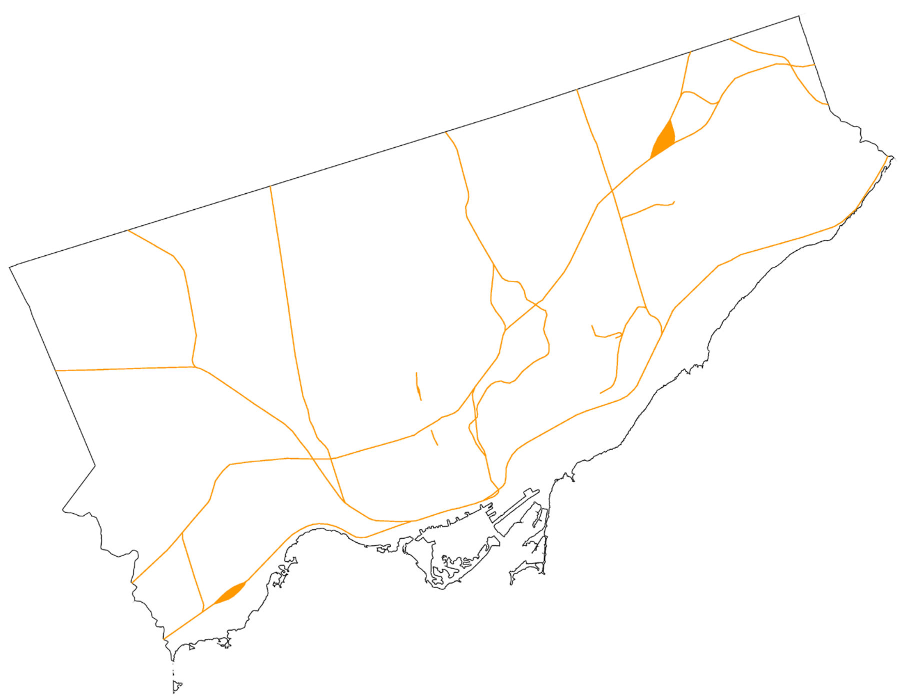

Figure A.3: Toronto Railway Corridors

Figure A.4: Toronto Hydro Right of Ways

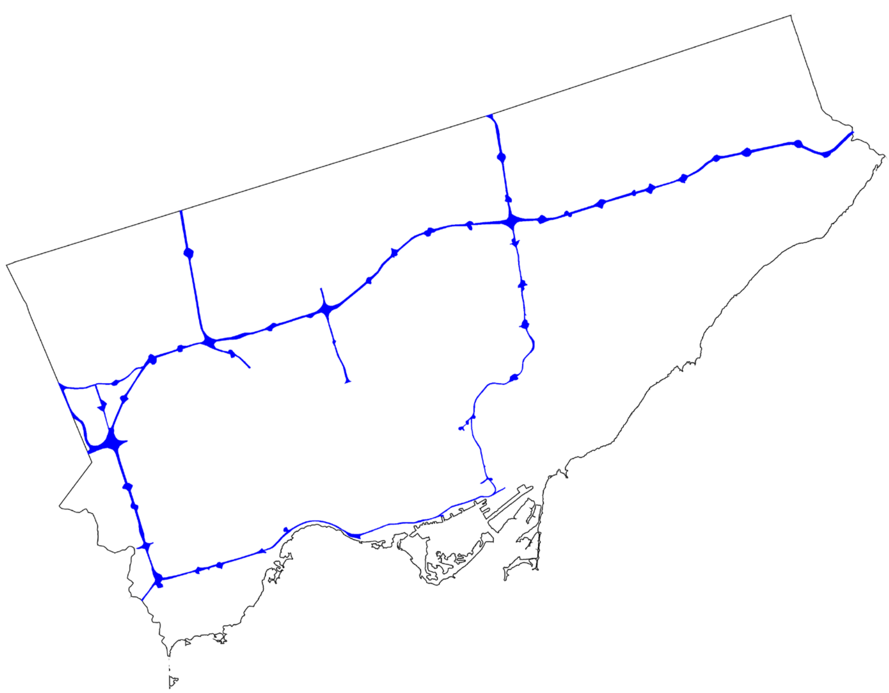

Figure A.5: Major Toronto Highways and Interchanges

Laneways have been identified by the City of Toronto as areas for intensification and urban growth; alongside which the implementation of solar technologies should be explored. Rail corridors currently only serve as a 'single level' piece of infrastructure (they only accommodate rail transport), and existing hydro Right of Ways (ROWs) currently act as the arteries by which the city's electricity is imported into the city. According to the City of Toronto, hydro and railway corridors combined account for 2.3 per cent of the city's area, totaling 337 km in length. ROWs are drastically underutilized, and due to their function are not well suited for residential development. Their limited uses, along with their tradition as energy arteries, make solar a suitable area of consideration and exploration for design. Highways and their associated interchanges are largely untapped in their energy potential. Presently acting as crucial transport arteries for the city, any solar design exploration would likely consider the potential to build alongside or above to increase the potential/efficiency of the major arteries. Toronto is contained by highways on all four sides with each one providing very different experiences and design potentials. The Gardiner Expressway, for example, is positioned directly adjacent to the dense downtown core, whereas the Don Valley Parkway runs through the natural ecological system that is the Don River Ravine.

When the mappings are overlaid one atop the other, potential urban solar infrastructural networks begin to appear, and the level of potential integration within these underused spaces looks promising (Figure A.6). This 'infrastructural' approach, whereby 'ribbons' of solar energy systems weave throughout the city would make solar energy systems not only visible throughout the city of Toronto, but integral parts of the urban fabric. Corridors of transport, whether it be people, goods, or electricity, now become more productive corridors of generation. A solar energy intervention would make such corridors more productive by building on existing infrastructural systems.

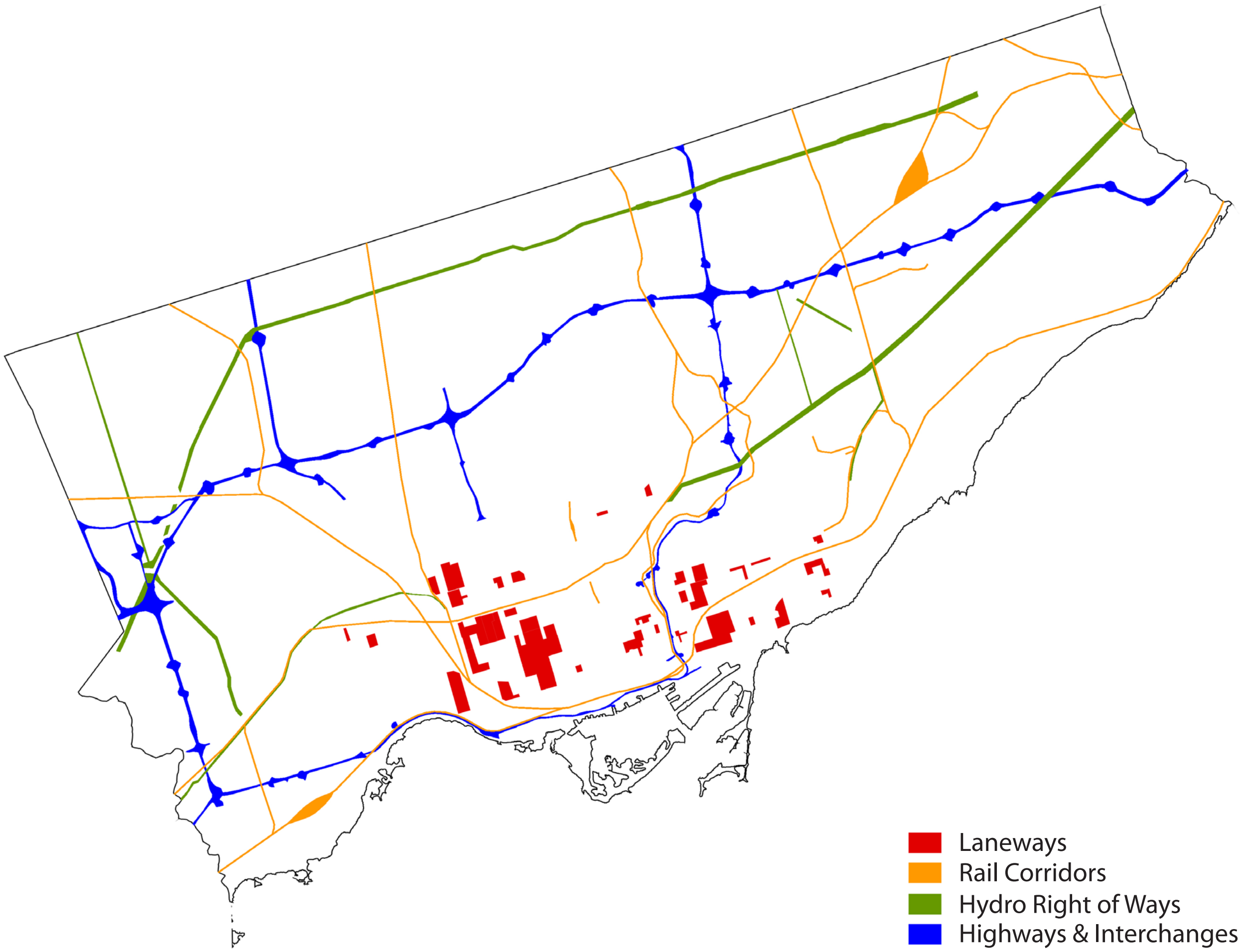

Figure A.6: Composite Map of Toronto's Alternative Solar Possibilities

Case Study: Lilies

Location: River Clyde, Glasgow

Date: 2007

Architects / Designers: Peter Richardson, ZMarchitecture

Design Strategy / Goals: This ideas project attempted to stimulate river activity and change through the use of large scale solar power generation. Lilies is a design project largely based in, and inspired by, nature, focused on the idea that large lilypads are optimized for efficient photosynthesis. As they are simply tethered to the riverbed, the solar photovoltaic lilies may be moved individually as needed, and are equipped with motors so that they rotate to maximize solar gain.

Observations: This project provides an interesting response to questions of ecological sensitivity and sustainability, and is successful in that it pushes boundaries in its unconventional approach to minimize the carbon footprint of Glasgow. Lilies, like the mapping exercises, attempts to use existing infrastructural networks (a natural river system in this case) to make manifest issues of active solar energy generation. It reimagines traditional notions of nature and technology and demonstrates the potential in bringing the two together through architecture.

Figure A.7: Inspired by Nature; (ZM Architecture, 2010)

Figure A.8: Aerial View of Solar Lilies; (ZM Architecture, 2010)

The Built Form

Another area of exploration that was not incorporated into the final design component, although also looking at Toronto's east-west arterial streets, was the manner in which the physical forms of the city and street, and their ability to act as surfaces for active solar systems, are affected by growth and development. Figure A.9 demonstrates the consistency, scale, and fabric typical of Toronto's developing east-west arterial streets. As noted in the main body of this thesis, the abundance of these arteries demands attention in the pursuit of a solar based future.

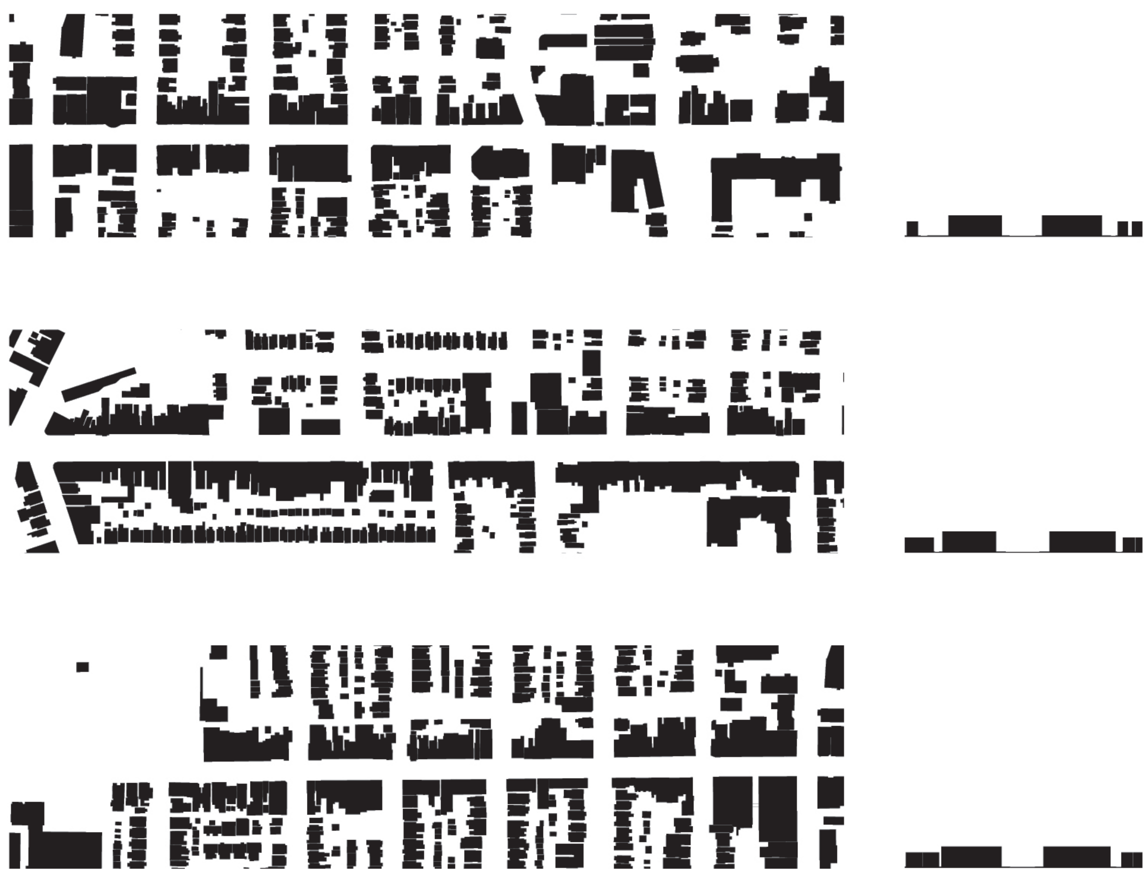

Figure A.9: Toronto's East-West Arterial Streets

Using computer modeling and solar analysis tools, a typical arterial street was slowly manipulated to examine the resulting effects on available solar radiation. Figure A.10 and Figure A.11 illustrate how the north side of the street is affected by developments on the south. This type of analysis would be essential in determining a set of 'solar by-laws' that would govern an urban development that promotes good solar policy and enables the successful urban integration of solar technologies.

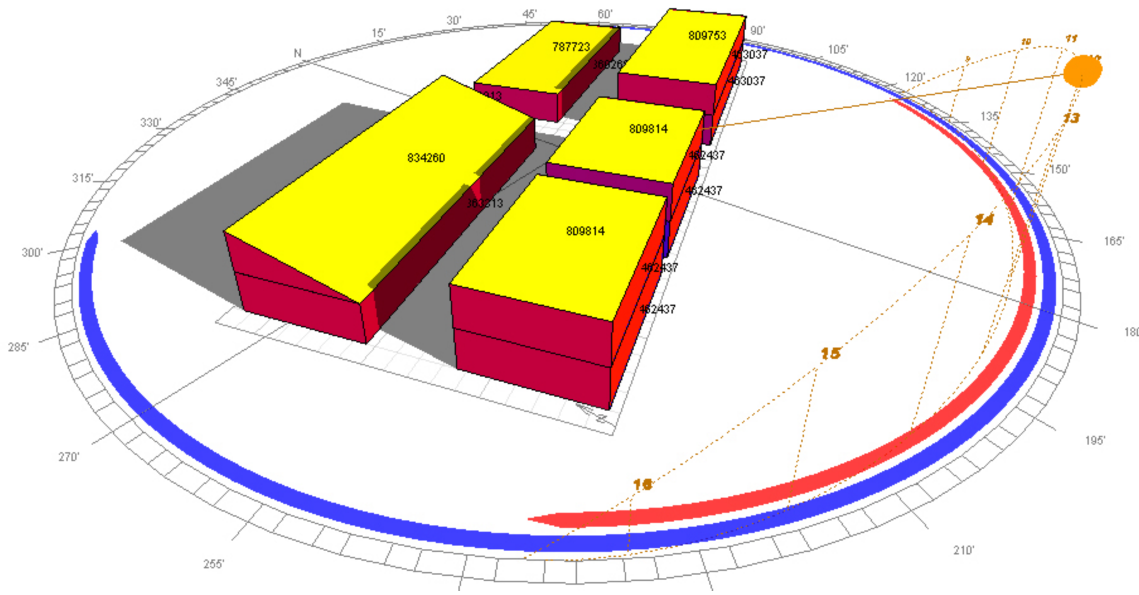

Figure A.10: Digital Solar Radiation Analysis

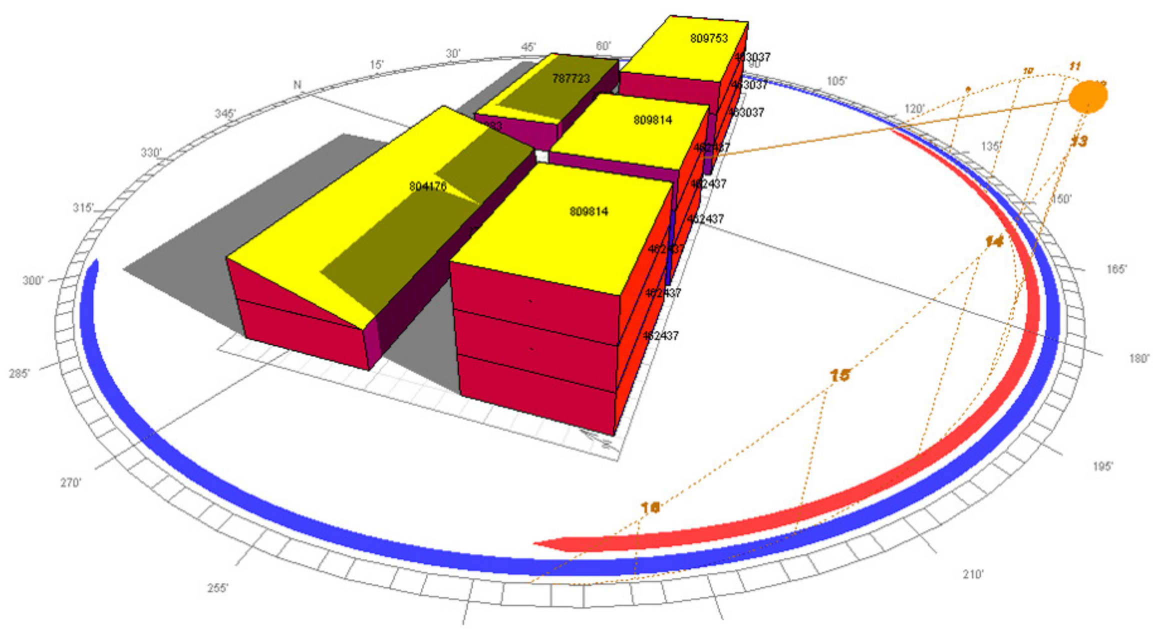

Figure A.11: Digital Solar Radiation Analysis, Increased Height

Proceeding one step further, individual façades were explored to obtain more detailed outputs regarding incident solar radiation. Breaking the surface into a grid, Figure A.12 illustrates the changes that occur across the south face of a building on the north side of an east-west street as the buildings on the south increase in height (1 storey, 2 stories, and 3 stories). Brighter areas indicate large amounts of solar radiation hitting the surface, while darker areas indicate little solar radiation hitting that area. Again, this information would be useful in managing urban solar growth, while also enabling designers and architects to successfully integrate solar technologies on any surface.

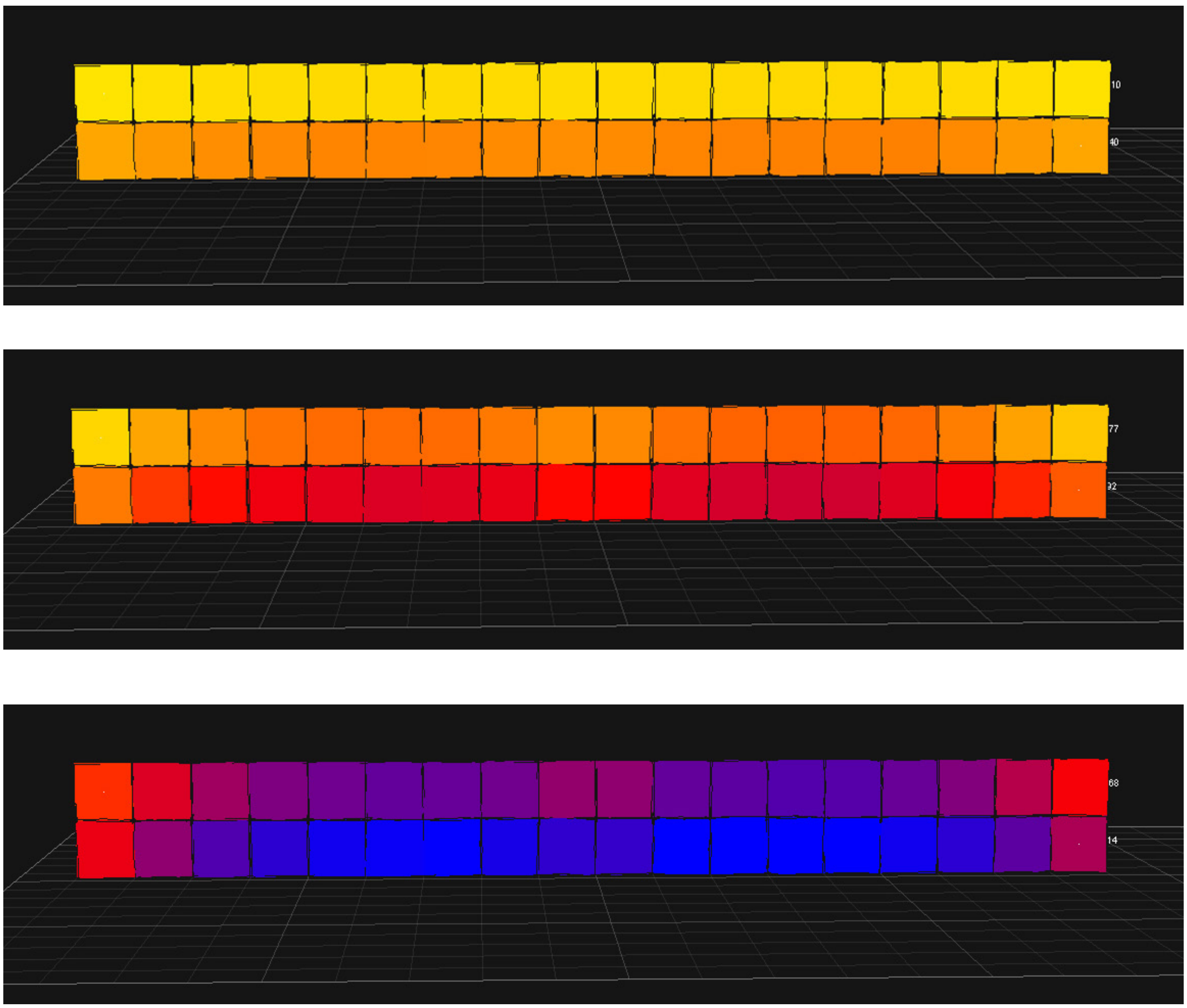

Figure A.12: Solar Availability as Affected by Urban Growth

Appendix B: IEA *Task 41: Solar Energy in Architecture*, Subtask C – Case Studies

As part of the International Energy Agency's *Task 41: Solar Energy and Architecture*, *Subtask C*, a series of case studies that demonstrate the use of solar technologies in North American architecture have been collected. The objective of these case studies, and of Subtask C, is to compile a database of significant architectural projects from all participating countries for disseminated to, and use by architects, engineers, designers, and professionals. A number of the collected case studies were presented at the 3rd experts' meeting in Bolzano, Italy in March 2010; a selection of these case studies may be found over the following pages.

For more information on *Task 41: Solar Energy and Architecture*, and the efforts and publications of its contributing members, please visit: http://www.iea-shc.org/task41/index.html.

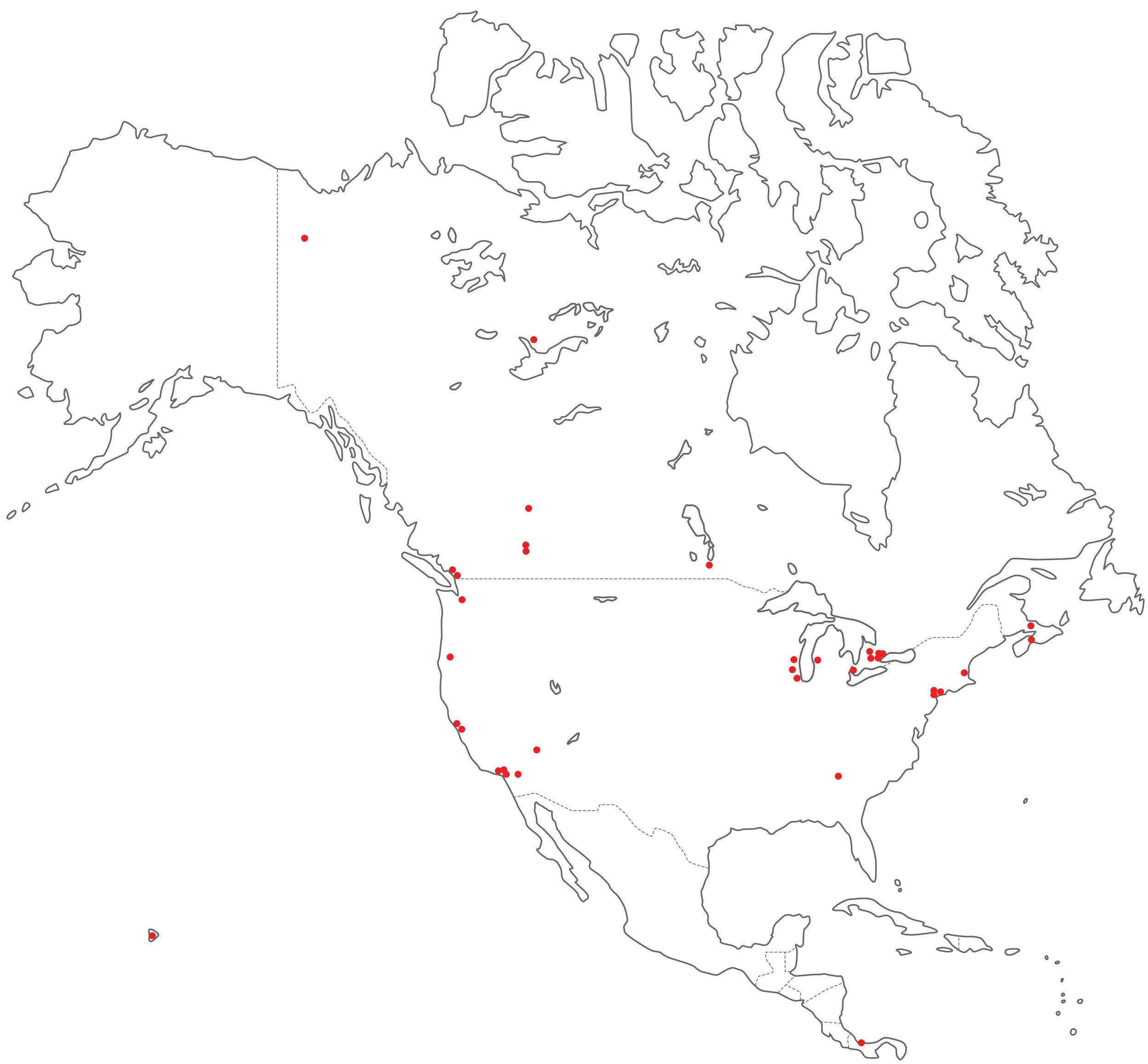

Figure B.1: Map of Identified North American Case Studies

IEA-SHC Task 41 ARCHITECTURAL EVALUATION OF SOLAR ARCHITECTURE


Photo 1


Photo 2

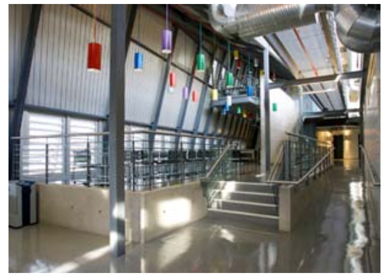
Photo 3

PROJECT TITLE | Training facility with solar wall

LOCATION

Name of building/housing	Fire and Emergency Training Services Institute
Address	2025 Courtneypark Drive East, Mississauga, Ontario
Country	Canada
Google map link	2025 Coutneypark Drive East, Mississauga, Ontario

CONTACTS

	Firm name	Website (or email)
Owner	Greater Toronto Airport Authority	http://gtaa.com
Architect	Kleinfeldt Mychajlowycz Architects Inc.	http://www.kma.to
Energy consultant	Caneta Research Inc.	http://www.canetaenergy.com

BUILDING

Completion year	2007	building	2007	solar energy		
Category	x	new building		renovation		
Function		residential		office	x	institution, sport, school

LOCATION SOLAR ENERGY

Facade		applied	x	integrated		balcony parapet
Roof		applied		integrated		on rack
PV integrated in glass		facade		roof		solar shading
Passive solar		double facade		solar chimney	x	solar wall
Orientation of the system	x	west	x	south		east

SPECIFICATION

Photovoltaic		crystalline		thin film		other:
Solar thermal collectors	x	flat plate		vacuum tube		other:

ATTATCHED IMAGES

	Title/motive	Photographer
Photo-1	Front entrance with view of solar wall	Richard Fitoussi, Witness Photographic
Photo-2	Angled solar wall	Conserval Engineering
Photo-3	Interior: Cafeteria area behind solar wall	Richard Fitoussi, Witness Photographic

ADDITIONAL INFORMATION (if possible)

Literature	
Links	
Attached pdf	

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
As part of the ongoing expansion of Pearson International Airport, the new Fire and Emergency Services Training Institute (FESTI) came with a mandate to pursue high sustainability practices. Taking full advantage of the site, the double-angled, south-west facing, 240m^2 solar wall heats the air that is then used to condition the interior spaces. By combining the use of the solar wall with the thermal mass of hollow core concrete slabs, heat captured from the sun's energy can be stored and released on demand, while eliminating much of the bulky mechanical equipment traditionally needed to condition interior spaces.
As one of the primary expressive elements of the building, solar wall compliments and works with the architecture rather than competing against it.

A: assessment

1	2	3	4	5	6	7	8	9	10
								x	

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
On the angled south-west facade black, perforated corrugated metal makes up the solar wall. Additional non-perforated metal panels are used behind the solar wall on the tower to harmoniously bring together the various elements of the project. The bold colour and large surface of the solar wall highlights this facade as being significant to the project without compromising the architectural language of the project. The successful integration of the solar thermal energy system, and the layering of materials adds to the visual aesthetic and modern appearance of the facility.

B: assessment

1	2	3	4	5	6	7	8	9	10
								x	

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
The double angle of the solar wall enhances the dynamics of the interior spaces, creating distinct volumes that contain the cafeteria eating/seating areas. Punctuated by louvered windows, the solar wall allows daylight to reach these spaces as well as the main circulation space.

C: assessment

1	2	3	4	5	6	7	8	9	10
							x		

EVALUATION FORM COMPLETED BY
This must be the person who can be contacted for further information, even if more people has contributed to the answer

Name	Michael Clesle
Organisation	Ryerson Univeristy
Email	mclesle@ryerson.ca

Upload this form and 2-3 images (jpg or tiff) + other possible materials (pdf)
If there are questions or comments to completing this questionnaire send a mail to: kakapp@tmf.kk.dk

Assessment overall:

1	2	3	4	5	6	7	8	9	10
								x	

IEA-SHC Task 41 ARCHITECTURAL EVALUATION OF SOLAR ARCHITECTURE

Photo 1

Photo 2

Photo 3

PROJECT TITLE — **College with building integrated photovoltaics**

LOCATION

Name of building/housing	Red River College, Princess Street Campus
Address	160 Princess Street, Winnipeg, Manitoba
Country	Canada
Google map link	160 Princess Street, Winnipeg, Manitoba

CONTACTS

	Firm name	Website (or email)
Owner	Red River College	http://www.rrc.mb.ca/
Architect	Cibinel Architects Ltd.	http://www.cibinel.com/
Energy consultant	Daniel Lyzun + Associates Ltd.	http://www.daniel-lyzun-associates.com

BUILDING

Completion year	2004	building	2004	solar energy		
Category	x	new building		renovation		
Function		residential		office	x	institution, sport, school

LOCATION SOLAR ENERGY

Facade		applied	x	integrated		balcony parapet
Roof		applied		integrated		on rack
PV integrated in glass	x	facade		roof		solar shading
Passive solar		double facade		solar chimney		solar wall
Orientation of the system		west	x	south		east

SPECIFICATION

Photovoltaic	x	crystalline		thin film		other:
Solar thermal collectors		flat plate		vacuum tube		other:

ATTATCHED IMAGES

	Title/motive	Photographer
Photo-1	South facade with BIPV	Cibinel Architects Ltd.
Photo-2	Classroom Interior showing BIPV	Cibinel Architects Ltd.
Photo-3	Detail of BIPV	Terri Meyer Boake

ADDITIONAL INFORMATION (if possible)

Literature	
Links	
Attached pdf	

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
Located on a former brownfield site, sustainability and green technologies were at the forefront of this project from its outset. The new building connects to a renovated one on the west, and maintains the facades of five neglected heritage structures on the east. Building integrated photovoltaics are included on a portion of the south facade on the upper half of the building. The area used for solar energy gain contributes to the overall composition of the building, emphasizing the upper volume at night; during the day, the BIPVs blend into the glazed facade, working well with the building's transparent aesthetic.

A: assessment

1	2	3	4	5	6	7	8	9	10
								x	

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
Construction details of the photovoltaics are hidden as the solar cells are seamlessly integrated into the double glazed facade. Working seamlessly with the established architectural aesthetic of the building, the colours of the photovoltaics blend together quite well with the remainder curtain wall glazing.

B: assessment

1	2	3	4	5	6	7	8	9	10
							x		

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
The building integrated photovoltaics add depth to the glazed curtain wall panels, creating a mosaic effect that enhances the interior qualities of the classrooms on the south end of the building. Their effect is further amplified as the BIPVs bypass the floor slabs resulting in a 'floor to ceiling' appearance. The proportions of the individual solar cells are similar to the proportions of the curtain wall mullions, resulting in a pleasing geometrical relationship from both the outside and from within.

C: assessment

1	2	3	4	5	6	7	8	9	10
								x	

EVALUATION FORM COMPLETED BY
This must be the person who can be contacted for further information, even if more people has contributed to the answer

Name	Michael Clesle
Organisation	Ryerson University
Email	mclesle@ryerson.ca

Upload this form and 2-3 images (jpg or tiff) + other possible materials (pdf)
If there are questions or comments to completing this questionnaire send a mail to: kakapp@tmf.kk.dk

Assessment overall:

1	2	3	4	5	6	7	8	9	10
								x	

IEA-SHC Task 41 ARCHITECTURAL EVALUATION OF SOLAR ARCHITECTURE


Photo 1


Photo 2


Photo 3

PROJECT TITLE	**Cultural centre above the Arctic Circle with PVs**

LOCATION

Name of building/housing	John Tizya Cultural Centre
Address	Old Crow, Yukon Territory
Country	Canada
Google map link	Old Crow, Yukon Territory

CONTACTS	**Firm name**	**Website (or email)**
Owner	Vuntut Gwitchin Government	http://www.vgfn.ca
Architect	Kobayashi + Zedda Architects	http://www.kza.yk.ca
Energy consultant	Howell-Mayhew Engineering	http://www.hme.ca

BUILDING

Completion year	2008	building	2008	solar energy		
Category	x	new building		renovation		
Function		residential		office	x	institution, sport, school

LOCATION SOLAR ENERGY

Facade	x	applied		integrated		balcony parapet
Roof		applied		integrated		on rack
PV integrated in glass		facade		roof		solar shading
Passive solar		double facade		solar chimney		solar wall
Orientation of the system		west	x	south		east

SPECIFICATION

Photovoltaic	x	crystalline		thin film		other:
Solar thermal collectors		flat plate		vacuum tube		other:

ATTATCHED IMAGES	**Title/motive**	**Photographer**
Photo-1	View of south elevation in context	Kobayashi + Zedda
Photo-2	Close-up of PVs and shading devices	Kobayashi + Zedda
Photo-3	Small prop plane that delivered all materials	Kobayashi + Zedda

ADDITIONAL INFORMATION	(if possible)
Literature	
Links	
Attached pdf	

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
Located in some of the world's most extreme climates, at 67 degrees north latitude (above the arctic circle), and temperature fluctuations from -59 C in winter to +30 C in summer, this cultural centre is an unlikely place for solar energy technology. Accessible only by air, all building components (solar modules included) had to fit through the 1.2 metre door of a propeller airplane – challenging the architects and engineers to design a year-round community space that could be easily put together in modules.
The photovoltaic array assists in off-setting diesel generated electricity which runs at an extremely high cost of approximately $3.25 per litre (over three times the national average). Although not operational in the winter, the photovoltaics are capable of generating surplus electricity in the spring, summer, and autumn during which Old Crow experiences up to 24 hours of daylight.

A: assessment

1	2	3	4	5	6	7	8	9	10
							x		

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
With a population of approximately 250 in the community of Old Crow, the installation and details had to be simplified and the PV modules prepared for installation prior to delivery due to a lack of skilled labour in the area.
The solar panels fit well with the corrugated metal siding of the building, although they still maintain a fairly functional appearance – details are simplified due to the cost of transport and size restrictions as mentioned.

B: assessment

1	2	3	4	5	6	7	8	9	10
						x			

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
The only contribution that the photovoltaics make to the architectural quality of the interior is by providing some shading on the upper windows adjacent to each panel.

C: assessment

1	2	3	4	5	6	7	8	9	10
			x						

EVALUATION FORM COMPLETED BY
This must be the person who can be contacted for further information, even if more people has contributed to the answer

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Upload this form and 2-3 images (jpg or tiff) + other possible materials (pdf)
If there are questions or comments to completing this questionnaire send a mail to: kakapp@tmf.kk.dk

Assessment overall:

1	2	3	4	5	6	7	8	9	10
						x			

IEA-SHC Task 41 ARCHITECTURAL EVALUATION OF SOLAR ARCHITECTURE


Photo 1


Photo 2


Photo 3

PROJECT TITLE	**Northern government building with building integrated photovoltaics**

LOCATION

Name of building/housing	Greenstone Government of Canada Building
Address	5105 50th Avenue, Yellownife, Northwest Territories
Country	Canada
Google map link	[5150 50th Avenue, Yellowknife, Northwest Territories, Canada]

CONTACTS

	Firm name	Website (or email)
Owner	Public Works & Government Services Canada	http://www.pwgsc.gc.ca
Architect	Manasc Isaac	http://www.miarch.com
Energy consultant	GF Shymko & Associates	-

BUILDING

Completion year	2005	building	2005	solar energy		
Category	x	new building		renovation		
Function		residential	x	office		institution, sport, school

LOCATION SOLAR ENERGY

Facade		applied	x	integrated		balcony parapet
Roof		applied		integrated		on rack
PV integrated in glass	x	facade		roof		solar shading
Passive solar		double facade		solar chimney		solar wall
Orientation of the system		west	x	south		east

SPECIFICATION

Photovoltaic	x	crystalline		thin film		other:
Solar thermal collectors		flat plate		vacuum tube		other:

ATTATCHED IMAGES

	Title/motive	Photographer
Photo-1	View of south elevation	Manasc Isaac
Photo-2	Close- up of BIPV system	Manasc Isaac
Photo-3	Interior atrium behind glazed BIPV system	Manasc Isaac

ADDITIONAL INFORMATION (if possible)

Literature	
Links	
Attached pdf	1 – ”Greenstone Post Occupancy Evaluation”

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
Located in the Canadian North, the Greenstone Government building had the task of achieving a highly sustainable building capable of operating successfully throughout huge temperature fluctuations dropping to -50 C in the winter. Although not conceived at the outset of the project, an integrated design process enabled the installation of a building integrated photovoltaic system at no additional cost to the originally planned shading devices.
The vertical orientation of the system maximizes the availability of low winter light. Post occupancy studies show that the BIPV system generates far more electricity in the winter months (most notably February – May) when electrical demands are greatest. Additional solar gain is achieved from reflectance off of snow in the winter months. As the largest BIPV installation in Canada at the time of the building's opening, the Greenstone building avoids many of the power failures that are experienced in Yellowknife.

A: assessment

1	2	3	4	5	6	7	8	9	10
						x			

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
The BIPV system was integrated into a high performance curtain wall system comprised of triple glazed windows with fibreglass frames designed to reduce energy consumption. The blue colour of the thin film photovoltaic cells is picked up in the non-active glazing units in the curtain wall system.
It was noted however, that there were difficulties during construction using a European supplier (issues with location and climate) for the PV units due to a lack of Canadian manufacturing capacity at this time. Due to limited local labour, the BIPV units had to be shipped pre-assembled and ready to install.

B: assessment

1	2	3	4	5	6	7	8	9	10
							x		

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
The BIPV system allows for significant shading in the large four storey atrium space, thereby eliminating the need for externally mounted shading devices. The south-facing facade creates a 'winter room' for the community, and the photovoltaic cells provide dynamic lighting patterns on the interior.

C: assessment

1	2	3	4	5	6	7	8	9	10
							x		

EVALUATION FORM COMPLETED BY
This must be the person who can be contacted for further information, even if more people has contributed to the answer

Name	Michael Clesle
Organisation	Ryerson University
Email	mclesle@ryerson.ca

Upload this form and 2-3 images (jpg or tiff) + other possible materials (pdf)
If there are questions or comments to completing this questionnaire send a mail to: kakapp@tmf.kk.dk

Assessment overall:

1	2	3	4	5	6	7	8	9	10
						x			

IEA-SHC Task 41 ARCHITECTURAL EVALUATION OF SOLAR ARCHITECTURE


Photo 1


Photo 2


Photo 3

PROJECT TITLE	**Energy centre with large photovoltaic array**

LOCATION

Name of building/housing	Hawaii Gateway Energy Center
Address	73-4460 Queen Kaahumanu Highway, #101, Kailua-Kona, Hawaii
Country	USA
Google map link	73-4460 Queen Kaahumanu Highway, #101, Kailua-Kona, Hawaii, USA

CONTACTS	**Firm name**	**Website (or email)**
Owner	Natural Energy Laboratory of Hawaii Authority	http://www.nelha.org
Architect	Ferraro Choi and Associates, Ltd.	http://www.ferrarochoi.com
Energy consultant	Lincolne Scott, Inc.	http://www.lincolnescott.com

BUILDING

Completion year	2005	building	2005	solar energy		
Category	x	new building		renovation		
Function		residential	x	office		institution, sport, school

LOCATION SOLAR ENERGY

Facade		applied		integrated		balcony parapet
Roof	x	applied		integrated		on rack
PV integrated in glass		facade		roof		solar shading
Passive solar		double facade		solar chimney		solar wall
Orientation of the system		west	x	south		east

SPECIFICATION

Photovoltaic	x	crystalline		thin film		other:
Solar thermal collectors		flat plate		vacuum tube		other:

ATTATCHED IMAGES	**Title/motive**	**Photographer**
Photo-1	South elevation	Ferraro Choi
Photo-2	West elevation	Ferraro Choi
Photo-3	Rear view of photovoltaic array	Ferraro Choi

ADDITIONAL INFORMATION	(if possible)
Literature	
Links	
Attached pdf	

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
As a zero-net-energy building, this project attempts to demonstrate the environmental mission of the Natural Energy Laboratory of Hawaii Authority (NELHA). An integrated design process ensured that architects and consultants worked together from the beginning in order to achieve the desired energy goals. The large photovoltaic arrays that produce more electricity than the building uses are the focal points of the project, supported on large structural supports that emphasize the importance of the solar arrays.
The photovoltaic arrays are cantilevered off the building to limit the laboratory's footprint on the eco-sensitive terrain. Photovoltaics were not placed on the roof of the structure itself as that surface is covered in copper roofing designed to heat up a plenum beneath to act as a thermal chimney.

A: assessment

1	2	3	4	5	6	7	8	9	10
						x			

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
The large white steel structure supporting the photovoltaic arrays make a bold move contrasting heavily against the otherwise subtle, concrete building. The photovoltaics themselves contrast against the white steel, allowing the structure to seemingly blend into the background and disappear from a distance.

B: assessment

1	2	3	4	5	6	7	8	9	10
						x			

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
The large photovoltaic array does not affect the interior of the space as it is organized as an additive element in this project. It does however create dramatic covered spaces on the exterior of the building. The PV array is positioned such that it does not shade all sun from the interior – during the day, the building is entirely lit by natural light.

C: assessment

1	2	3	4	5	6	7	8	9	10
				x					

EVALUATION FORM COMPLETED BY
This must be the person who can be contacted for further information, even if more people has contributed to the answer

Name	Michael Clesle
Organisation	Ryerson University
Email	mclesle@ryerson.ca

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1	2	3	4	5	6	7	8	9	10
					x				

IEA-SHC Task 41 ARCHITECTURAL EVALUATION OF SOLAR ARCHITECTURE


Photo 1


Photo 2


Photo 3

PROJECT TITLE	Tennis club with thin film photovoltaics

LOCATION

Name of building/housing	Challengers Tennis Club
Address	5029 South Vermont Avenue, Los Angeles, CA
Country	USA
Google map link	[5029 South Vermont Avenue, Los Angeles, CA]

CONTACTS	**Firm name**	**Website (or email)**
Owner	Whittier Foundation	
Architect	Killefer Flammang Architects	http://www.kfarchitects.com
Energy consultant	Helios International, Inc.	

BUILDING						
Completion year	2002	building	2002	solar energy		
Category	X	new building		renovation		
Function		residential		office	x	institution, sport, school

LOCATION SOLAR ENERGY						
Facade		applied		integrated		balcony parapet
Roof	x	applied	x	integrated		on rack
PV integrated in glass		facade		roof		solar shading
Passive solar		double facade		solar chimney		solar wall
Orientation of the system	x	west		south	x	east

SPECIFICATION						
Photovoltaic		crystalline	x	thin film		other:
Solar thermal collectors		flat plate		vacuum tube		other:

ATTATCHED IMAGES	**Title/motive**	**Photographer**
Photo-1	East Elevation	Michael Arden
Photo-2	Underside of photovoltaic canopy	Michael Arden
Photo-3	View from Southeast	Michael Arden

ADDITIONAL INFORMATION	(if possible)
Literature	
Links	
Attached pdf	

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
Almost all roof surfaces have been taken advantage of to provide electricity by way of a large photovoltaic system – these areas include the roofs over the two change rooms at the north and south, as well as the large canopy structure linking the two sets of tennis courts together.
Due to the symmetrical composition of the building, three of the six photovoltaic arrays face east, while the other three face west.

A: assessment

1	2	3	4	5	6	7	8	9	10
					x				

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
The large scale usage of photovoltaics results in a very functional, industrial aesthetic that can also be seen in the hollow structural steel canopy structure. As an applied system the details are concealed within the roof surfaces while the system's blue cells blend with the two-tone exterior tiles emphasizing the use of solar energy on this project to the visiting public.

B: assessment

1	2	3	4	5	6	7	8	9	10
				x					

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
Although the photovoltaics do not directly contribute to the architectural quality of the interior, the resulting supporting structure of the primary solar arrays creates a dramatic canopy that acts as both a focal point for the project as well providing a shaded patio above the cafeteria and eating area.

C: assessment

1	2	3	4	5	6	7	8	9	10
				x					

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Assessment overall:

1	2	3	4	5	6	7	8	9	10
				x					

IEA-SHC Task 41 ARCITECTURAL EVALUATION OF SOLAR ARCHITECTURE


Photo 1


Photo 2


Photo 3

PROJECT TITLE	**Net zero house with photovoltaics and solar thermal techonologies**

LOCATION

Name of building/housing	Riverdale NetZero Project
Address	9926 87 Street, Edmonton, Alberta
Country	Canada
Google map link	9926 87 Street, Edmonton, Alberta, Canada

CONTACTS

	Firm name	Website (or email)
Owner	-	info@riverdalenetzero.ca
Architect	Habitat Studio and Workshop Ltd., and Manasc Isaac Architects Ltd.	http://www.habitat-studio.com http://miarch.com/
Energy consultant	Howell Mayhew Engineering Inc.	

BUILDING

Completion year	2008	building	2008	solar energy		
Category	x	new building		renovation		
Function	x	residential		office		institution, sport, school

LOCATION SOLAR ENERGY

Facade	x	applied		integrated		balcony parapet
Roof	x	applied		integrated		on rack
PV integrated in glass		facade		roof		solar shading
Passive solar		double facade		solar chimney	x	solar wall
Orientation of the system		west	x	south	x	east

SPECIFICATION

Photovoltaic	x	crystalline		thin film		other:
Solar thermal collectors	x	flat plate		vacuum tube		other:

ATTATCHED IMAGES

	Title/motive	Photographer
Photo-1	Facade and roof with solar systems	SABHomes Magazine
Photo-2	Front elevation with PVs and solar wall	Rachel Pressick
Photo-3	Solar wall overhang providing summer shade	Rachel Pressick

ADDITIONAL INFORMATION (if possible)

Literature	
Links	http://www.riverdalenetzero.ca
Attached pdf	1 – "Riverdale NetZero House – CMHC Project Profile"

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
As one of the winning entries in the Canada Mortgage Housing Corporations (CMHC) EQuilibrium Sustainable Housing Demonstration Initiative, the primary goals of the project are to build and demonstrate sustainable housing practices in Canada. Equipped with both solar thermal and photovoltaic panels the Riverdale Net Zero house promotes the use of both major types of solar energy collection.
The solar thermal panels are oriented at 90 degrees in response to Edmonton's optimal winter sunlight. The water-based solar thermal system feeds into a forced-air heat distribution system as well as heating water for use by both households. The photovoltaics are designed to supply more than the household energy requirements with the excess being sold back to the utility.

A: assessment

1	2	3	4	5	6	7	8	9	10
							x		

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
Both the photovoltaic and solar thermal panels are positioned prominently at the apex of the house, drawing attention to the renewable energy collected on site, while creating a contrast with the rest of the building. The roof is built up to accommodate the solar systems, with steel trusses used at the east and west ends mounted to the walk-out decks.

B: assessment

1	2	3	4	5	6	7	8	9	10
						x			

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
Neither the photovoltaic panels nor the solar thermal systems contribute to the interior quality of the residences – the angled roof that supports the solar systems contains only an attic space.

C: assessment

1	2	3	4	5	6	7	8	9	10
x									

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Assessment overall:

1	2	3	4	5	6	7	8	9	10
						x			

IEA-SHC Task 41 ARCHITECTURAL EVALUATION OF SOLAR ARCHITECTURE


Photo 1


Photo 2


Photo 3

PROJECT TITLE

City building with photovoltaics and evacuated tubes

LOCATION

Name of building/housing	City of White Rock Operations Building
Address	877 Keil Street, White Rock, British Columbia
Country	Canada
Google map link	877 Keil Street, White Rock, British Columbia, Canada

CONTACTS

	Firm name	Website (or email)
Owner	The City of White Rock	http://www.city.whiterock.bc.ca
Architect	Busby Perkins + Will	http://www.busby.ca
Energy consultant	Flagel Lewandowki (Electrical Consultant)	

BUILDING

Completion year	2003	building	2003	solar energy		
Category	x	new building		renovation		
Function		residential	x	office		institution, sport, school

LOCATION SOLAR ENERGY

Facade	x	applied		integrated		balcony parapet
Roof		applied		integrated	x	on rack
PV integrated in glass		facade		roof		solar shading
Passive solar		double facade		solar chimney		solar wall
Orientation of the system		west	x	south		east

SPECIFICATION

Photovoltaic	x	crystalline		thin film		other:
Solar thermal collectors		flat plate	x	vacuum tube		other:

ATTATCHED IMAGES

	Title/motive	Photographer
Photo-1	View of operations building from parking lot	Busby Perkins + Will
Photo-2	Detail: Solar evacuated hot water tubes	Colin Jewall – AIA website
Photo-3	Detail: PV panels mounted on trellis	Busby Perkins + Will

ADDITIONAL INFORMATION (if possible)

Literature	
Links	
Attached pdf	1 – ”White Rock Case Study – Busby”

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
Although solar energy systems only make a small contribution to the overall energy demands of the project, their integration is successful in their architectural composition. This project had many more opportunities to use solar energy technologies on a larger scale.
In addition to photovoltaics, evacuated solar tubes provide the base radiant heating for the building in combination with an in-floor heating system. The vertical lines of the evacuated tubes add to the modern aesthetic of the project.

A: assessment

1	2	3	4	5	6	7	8	9	10
					x				

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
The angled photovoltaic panels accent the locally sourced wooden canopy that runs along the west side of the building, and the solar thermal evacuated tubes work well with the general aesthetic of the project while providing some shading for the interior spaces

B: assessment

1	2	3	4	5	6	7	8	9	10
						x			

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
No effect on the interior quality whatsoever.

C: assessment

1	2	3	4	5	6	7	8	9	10
x									

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Assessment overall:

1	2	3	4	5	6	7	8	9	10
					x				

IEA-SHC Task 41 **ARCHITECTURAL EVALUATION OF SOLAR ARCHITECTURE**


Photo 1


Photo 2


Photo 2

PROJECT TITLE	**Light sculpture powered by photovoltaics**

LOCATION

Name of building/housing	Solar Collector
Address	100 Maple Grove Road, Cambridge, Ontario
Country	Canada
Google map link	100 Maple Grove Road, Cambridge, Ontario, Canada

CONTACTS	**Firm name**	**Website (or email)**
Owner	Regional Municipality of Waterloo	
Architect	Gorbet Design Inc.	http://www.gorbetdesign.com
Energy consultant	-	

BUILDING

Completion year	2008	installation	2008	solar energy		
Category	x	new building		renovation		
Function		residential		office		institution, sport, school

LOCATION SOLAR ENERGY

Facade		applied	x	integrated		balcony parapet
Roof		applied		integrated		on rack
PV integrated in glass	x	facade		roof		solar shading
Passive solar		double facade		solar chimney		solar wall
Orientation of the system		west	x	south		east

SPECIFICATION

Photovoltaic	x	crystalline		thin film		other:
Solar thermal collectors		flat plate		vacuum tube		other:

ATTATCHED IMAGES	**Title/motive**	**Photographer**
Photo-1	Sculpture Installation	Michael Clesle
Photo-2	PV and LED lights	Michael Clesle
Photo-3	Sculpture in operation at night	Gorbet Design Inc.

ADDITIONAL INFORMATION	(if possible)
Literature	
Links	http://www.solarcollector.ca/
Attached pdf	

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
The installation successfully blends engineering and art to create an interactive relationship between citizens and the sun. The positioning of the sculpture in a public place, and the ability for individuals to design their own 'light shows' via the internet, reinforces an important collaboration between the community and the sun. The positioning of each shaft relative to the natural movement of the sun, results in a whimsical, playful expression of form, reinforced at night through the varied pulsing lights.
The Solar Collector installation is a good example of how solar technologies can be integrated in pleasing, aesthetically successful manners. The playfulness of the photovoltaic integrated sculpture demonstrates the versatility and wide variety of applications made possible by PVs.

A: assessment

1	2	3	4	5	6	7	8	9	10
									x

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
The bare, natural appearance of the industrial materials used, creates a stark contrast against the natural berm in which it sits. Each shaft is constructed from recycled aluminum and the LEDs are encased in sandblasted glass prisms, arranged in sets of four around each shaft so that the evenly diffused light appears to originate from within the shafts. Visual expression of the photovoltaic cells is emphasized through their linear arrangement and contrast against the aluminum shafts.

B: assessment

1	2	3	4	5	6	7	8	9	10
								x	

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
N/A

C: assessment

1	2	3	4	5	6	7	8	9	10

EVALUATION FORM COMPLETED BY
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Assessment overall:

1	2	3	4	5	6	7	8	9	10
									x

IEA-SHC Task 41 ARCHITECTURAL EVALUATION OF SOLAR ARCHITECTURE


Photo 1


Photo 2


Photo 3

PROJECT TITLE

Tropical research station with large building-integrated photovoltaic roof

LOCATION

Name of building/housing	The Smithsonian Tropical Research Institute, Bocas del Toro Research Station
Address	Bocas del Toro
Country	Panama
Google map link	Bocas del Toro, Panama

CONTACTS

	Firm name	Website (or email)
Owner	The Smithsonian Tropical Research Institute	http://www.stri.org
Architect	Kiss + Cathcart, Architects	http://www.kisscathcart.com
Energy consultant	Arup	http://www.arup.com

BUILDING

Completion year	2003	building	2003	solar energy		
Category	x	new building		renovation		
Function		residential		office	x	institution, sport, school

LOCATION SOLAR ENERGY

Facade		applied		integrated		balcony parapet
Roof		applied	x	integrated		on rack
PV integrated in glass		facade	x	roof		solar shading
Passive solar		double facade		solar chimney		solar wall
Orientation of the system		west	x	south		east

SPECIFICATION

Photovoltaic		crystalline	x	thin film		other:
Solar thermal collectors		flat plate		vacuum tube		other:

ATTATCHED IMAGES

	Title/motive	Photographer
Photo-1	View of south elevation	Kiss + Cathcart, Architects
Photo-2	Detail of building-integrated photovoltaic roof	Kiss + Cathcart, Architects
Photo-3	Interior view of BIPV roof system	Kiss + Cathcart, Architects

ADDITIONAL INFORMATION (if possible)

Literature	
Links	
Attached pdf	

PAGE 2: Architectural evaluation

DESCRIBE how solar energy is integrated in the whole concept of the building and contributes to the architectural quality. Include considerations of design, details and material composition.
EVALUATE then on a scale from 1-10 (where 10 is best) to what extent solar energy contributes to the architectural quality in each category.

A. OVERALL IMPRESSION – COMPARED TO THE WHOLE BUILDING CONCEPT, FAÇADE AND ROOF ELEMENTS, COMPOSITION
As the grid power on the island is generated from unreliable, dirty, diesel generators, the economical and environmental benefits of building integrated photovoltaics are even greater on this project than on the mainland or elsewhere in North America.
The building's large integrated photovoltaic array acts as the major design element for the project, angled with a low pitch optimized for Panama's latitude. Additionally, the overhang of the roof is large enough to prevent the sun from directly hitting the exterior walls of the offices and education spaces, minimizing the solar gain of the building. The peak electricity generation of the partially transparent photovoltaic system occurs at similar times to the building's peak air conditioning loads.

A: assessment

1	2	3	4	5	6	7	8	9	10
							x		

B. COMPOSITION OF MATERIALS, CORRELATION OF COLOURS, DETAILS
The photovoltaic array, in addition to meeting energy needs, doubles as the rainwater collector by directing water to storage cisterns where it is then treated on site with the surplus used in other buildings on campus. The smooth profile of the thin film photovoltaic cells facilitates the rainwater collection, as well as emphasizing the sweeping form of the roof. In a few locations the BIPV roof is interspersed with clear glass panels where needed.

B: assessment

1	2	3	4	5	6	7	8	9	10
									x

C. SPATIAL EXPERIENCES – CONTRIBUTION TO THE ARCHITECTUAL QUALITY ON THE INTERIOR
The detail of the BIPV roof is best appreciated from the interior where the fusion of locally sourced wood and glazed roof blend together to create a harmonious balance. The interior volumes, shaded by the photovoltaic roof, minimize direct heat gain; an optimal amount of five percent of daylight is emitted into the interior rooms through clear portions between the photovoltaic cells.

C: assessment

1	2	3	4	5	6	7	8	9	10
								x	

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Assessment overall:

1	2	3	4	5	6	7	8	9	10
								x	

Reference List

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