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The development of urban renewable energy at the existential technology research center (ETRC) in Toronto, Canada

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Abstract

This paper presents new forms of urban renewable energy, in particular, the integration of solar and wind power into the industrial and commercial buildings with flat roofs which populate a city's downtown core. This combination of renewable energy passively adapts to pre-existing structures and exploits them to their full advantage. The working prototypes presented aim to introduce an element of multi-functionality to building-integrated photovoltaics (BIPV), creating systems which produce energy while meeting required needs and desirable features of urban buildings. We also explore the combination of wind energy and various energy efficiency initiatives with BIPV designs. Our energy efficiency initiatives include a new method of generating the perception of natural sunlight from artificial light and brainwave controlled lighting that dims automatically when occupants' concentration is lowered. These efforts result in an environment that celebrates the existential notion of self-empowerment through reducing energy consumption and having control over one's own energy production. Our discussion follows into market considerations of our BIPV designs and how project costs are lowered and space is conserved, assets when designing for urban locations. The test site for the development of urban renewable energy is the Existential Technology Research Center (ETRC), located in downtown Toronto, Canada.

Keywords: Building-integrated photovoltaics (BIPV); Awning; Louvre; Labspace; Flexible solar membrane; Solar sculptures

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1. Introduction

Many citizens of an urban core contribute to their city's energy consumption without heeding to the irreparable harm they cause their environment. While energy efficiency and renewable energy alternatives are continuously presented to the public, many individuals are unenthusiastic to adopt these proven innovations as consumable products (i.e. fossil fuels) are more available and affordable. This trend has lead to increases in air pollution in cities across the globe. In a recent study by Dr. Barbara Yaffe, Toronto's Acting Medical Officer of Health, it was estimated that air pollutants contribute to 1,700 premature deaths and 6,000 hospital admissions in Toronto each year [1].

The test site for the development of urban renewable energy is the Existential Technology Research Center (ETRC), located in downtown Toronto, Canada. The ETRC is a 3-story building which is used for industrial, residential, and research purposes. The objective of the ETRC is to introduce the world to urban renewable energy and solidify the vision of having control over the energy in our lives. The efforts of the ETRC are pushed forward with the underlying theme of self-reliability and independence from a centralized power grid.

The ETRC is designed to test a combination of BIPV prototypes, as well as energy efficiency initiatives and wind energy technologies. In particular, we explore novel ways of reclaiming flat rooftop space as usable space, where the photovoltaic structures serve multiple purposes. This paper focuses on a discussion of the following four BIPV prototypes installed at the ETRC:

- Solar Awnings
- Flexible Solar Membrane
- Solar Outdoor Labspace
- Solar Louvre

With the ETRC as our template, our ultimate goal is to replicate these BIPV designs in cities across the world.

2. Renewable energy resources

2.1. Description of BIPV system configuration

All BIPV prototypes were integrated and attached to the ETRC building using Alvin Industrial Sales (AIS) aluminum and steel pipe structures Size 6 (33.4 mm O.D.) aluminum pipe and size 8 (48.3 mm O.D.) galvanized steel pipe and fittings were used. The structural pipe and structural pipe fittings were assembled using a hex wrench.

The Flexible Solar Membrane and Outdoor Solar Lab Space prototypes were strategically positioned on the mechanical room (situated on the roof of the ETRC). The Solar Awning and Solar Louvre were constructed on the fourth floor balcony of the ETRC. A south facing direction was chosen for all four BIPV prototypes as this orientation optimized the sunlight exposure.

DC outlets of 12 V, in the form of 'banana jacks', were installed on all of the solar modules in the BIPV prototypes. These outlets provide occupants with direct access to the power of the solar modules, allowing the panels to be connected in series or parallel, to a voltmeter or even directly to a household appliance.

2.1.1. Solar awning

An awning is a roof-like structure which, attached as a cantilever to the building's side, provides coverage from rain, sun, hail or snow. Awnings are typically used to cover people as they sit or stand outside. The Solar Awning prototype consisted of five SPS Iridium 165 W solar modules alined horizontally in a row above the fourth floor balcony of the ETRC (Fig. 1). Each panel measured 1.23 m $\times$ 1.07 m and provided up to 18% conversion efficiency. The panels were aligned along a 45° angle, maximizing both the efficiency of solar energy conversion and overhead coverage of occupants. The awning was 0.94 m wide and 5.79 m long, providing a total coverage of 5.44 m^2.

2.1.2. Solar Louvre

A typical louvre is comprised of a series of horizontal slats through which light diffuses onto the individuals below The diffusing light (termed *soft light*) allows individuals to enjoy the sun without receiving its full intensity. The Solar Louvre prototype consisted of four BP 125 W solar modules and was located on the fourth level balcony of the ETRC, as

Fig. 1. The Solar Awning not only captures the sun's energy, but provides a shaded outdoor area for the occupants of the building.

shown in Fig. 2 The louvre frame was 3.05 m long and 1.50 m wide, providing 4.58 m^2 of soft light exposure. Each panel on the solar louvre is currently positioned at a 42° angle to the horizontal and are spaced 33 cm apart. The solar panels were built with telescoping bars, allowing their angle of inclination to be adjusted depending on the time of the year. Studies have shown that maximum solar radiation is obtained with 30–40° tilt angles from

Fig. 2. After capturing the sunlight's energy, the light is split and diffused, creating a pleasant mix of sun and shade for the occupant.

January to March, 0–20° from April to August and 40–60° from September to December [2]. The Solar Louvre has a full range of adjustability with angles of inclination varying from 0° to 60°.

2.1.3. Solar outdoor labspace

A labspace is an area where laboratory activities (i e. experiments, data collection) are performed. Labspaces are typically confined to indoor environments. The Solar Outdoor Labspace consists of three BP 125 W solar modules, each measuring 66 cm × 150 cm. The panels were positioned along a 45° angle on a cantilever frame attached to the south wall of the mechanical room (Fig. 3). The oak counter within the labspace measured 122 cm × 30 cm and provided bench top area for two students. This bench top area is reconfigurable due to the structural pipe fittings.

2.1.4. Flexible solar membrane

The Flexible Solar Membrane consisted of six Solar Save sheets, designed by Solar Roofing Systems (SRS), each sheet measuring 154 cm × 89 cm The entire Flexible Solar Membrane covered a total area of 8.21 m^2. Each Solar Save sheet consisted of a RWE Schott solar module sealed within a polyvinylchloride (PVC) envelope. The Solar Save sheet had a power output of 83 W and conversion efficiency of 12%. The Flexible Solar Membrane system had a total rated power output of 498 W (332 W for horizontal panels and 166 W for vertical panels). The PVC roofing is waterproof and weatherproof with an average life span of 20 years. Four sheets were placed horizontally, on the top of the mechanical room of the ETRC, while the remaining two sheets were placed vertically along the east facing wall of the mechanical room. A more coarse grade of the PVC material was positioned on the roof of the mechanical room, adjacent to the solar roofing,

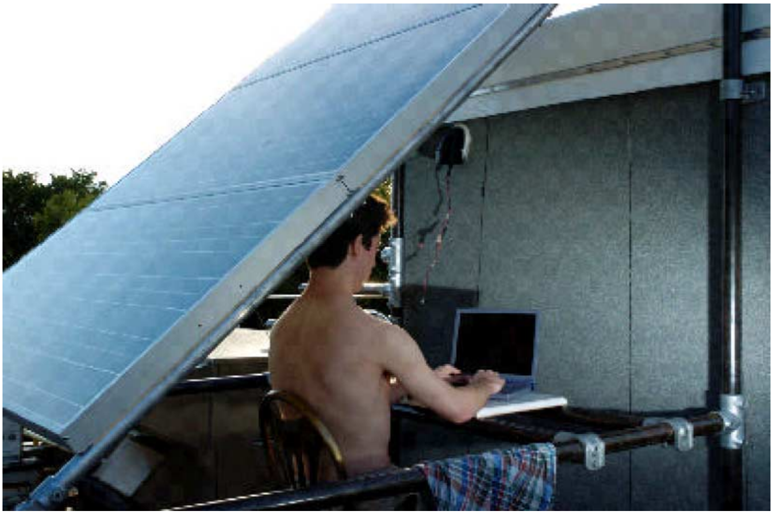

Fig. 3. Joshua Harris, project manager of the ETRC, is shown in the Solar Outdoor Labspace. The sun is directly powering the laptop computer which is connected to the solar panels by reconfigurable DC ‘banana jacks’.

Fig. 4. Agata Jaworski, a designer of the ETRC, enjoys the Flexible Solar Membrane on the roof of the mechanical room.

creating a walking/tanning area.The Solar Save sheets were heat sealed together and connected in series with all the electrical wiring channeled into the interior of the mechanical room (Fig. 4).

2.2. Evaluation of BIPV prototypes

2.2.1. Solar awning

The Solar Awning prototype presented a design which transformed a common building attribute, an awning, into an energy producing device The solar awning elegantly served a dual purpose, not only blocking the sun's rays from the occupants, but harnessing this energy for functional use The awning produced 825 W of electrical power and provided 5.44 m^2 of covered walking space, protecting occupants from sun, rain, hail and snow. The solar awning was also found to conserve rooftop space as two separate locations for an awning and a PV system have been condensed into one location.

Our research found the Solar Awning prototype to have a wide range of feasible applications when introduced to restaurants, boutiques and market food stores in downtown Toronto. In examining a restaurant with an outdoor patio, one readily sees the advantages the Solar Awning offers in a grid-tied BIPV system by greatly reducing the electrical needs from a centralized power grid. Restaurants typically use an awning to cover guests from sun or rain as they dine outside. A sunny day would allow the Solar

Awning to power various appliances within the restaurant (stoves, dishwasher, coffee makers) or build a surplus of stored energy.

2.2.2. Solar Louvre

The Solar Louvre was comprised of four BP 125 W solar modules and had a power output of 500 W The solar modules were contained within an AIS piping structure which provided the modules with varying angles of inclination. Over the course of the year the panels could be adjusted to ensure that the angle of incidence of the sun's rays with the solar panels was as close as possible to 90°.

The Solar Louvre prototype introduces the public to the field of *solar sculptures* [3], pieces of art which inspire emotion not only through aesthetics or symbolism, yet also through functionality. The Solar Louvre achieves soft light (i.e. light which has been scattered) by staggering the positions of each solar module, allowing sunlight to pass between successive panels. The staggered positioning of the panels was also found to prevent adjacent solar panels from casting shadows on each other and thus lowering solar power output.

2.2.3. Solar outdoor labspace

The solar outdoor labspace was found to meet several research needs of the ETRC, namely a site for renewable energy data acquisition and analysis The DC outlets incorporated into each solar module allowed for direct connection of data acquisition equipment (i.e. voltmeter, ammeter). The total power output of the labspace was 375 W and was capable of sustaining the electrical load of several laptop computers. The close proximity of the solar panels facilitated immediate on-site data analysis and efficient alterations of experiments conducted.

After usage of the solar outdoor labspace, the ETRC staff described the environment as an ergonomic improvement from indoor laboratories. The labspace was capable of holding two researchers and provided enough room to comfortably access the DC outlets on the solar panels. The absence of extension cords and battery packs increased bench top space while improving the safety of experiments performed. The productivity of the ETRC staff was also found to increase when using the Solar Outdoor Labspace as it provided a fresh outdoor environment to work in. Areas of study which would benefit from the Solar Outdoor Labspace include urban air quality analysis, as well as PV system and wind turbine analysis.

2.2.4. Flexible solar membrane

In the past, traditional BIPV solar roofing consisted of either ceramic PV tiles which would replace roof shingles or solar modules which require additional framing to integrate the panels into the roof [4] These novel displays of solar roofing were limited to angled roofs with construction and repair of the panels being a difficult task. The Solar Save Flexible Solar Membrane was introduced to the flat rooftop of the ETRC. The system consisted of solar modules sealed within a polyvinylchloride(PVC) roofing material.

Studies have shown that a successful BIPV roof installation must (a) not increase the level of difficulty of current roofing practices and (b) provide aesthetics similar to those of a normal roof [4]. The Solar Save Flexible Solar Membrane was found to satisfy both these conditions while eliminating the need for additional frames to house the solar modules. The PVC roofing was waterproof and weatherproof with a average life span of 20 years. PVC roofing alone has been a practice for over 25 years, ensuring that installation of Flexible Solar Membrane can be completed efficiently by experienced professionals.

The Flexible Solar Membrane was found to merge art and ergonomics into a BIPV design. An Urbeach (urban beach) environment is created with the solar panels acting as a symbolic ‘ocean of energy’ which occupants can coexist with in an enjoyable, relaxing manner. This improves the image of solar energy, increasing its market value and attracting the eye of more consumers. The Solar Save roofing provided a safe and accessible energy supply, facilitating the use of many 12 V appliances (i.e. radios, fans) from the rooftop and eliminating the need for extension cords or batteries. This form of BIPV heavily favours the urban atmosphere as the majority of buildings have unused flat rooftop space which can easily be transformed into ‘solar space’.

2.3. Wind energy

2.3.1. The urbine (urban wind turbine)

Applications of wind energy have been traditionally restricted to rural or isolated areas Currently, wind turbine farms (a group of wind turbines) are the most common application of urban environment, it was the desire of the ETRC to show the feasibility of wind energy in an wind energy Although solar energy was considered more efficient and better suited for an installation of the Lakota wind turbine. Locating the Lakota at the ETRC resulted in Canada’s first rooftop mounted urban wind turbine, named the Urbine. The Urbine was attached to the mechanical room on the roof of the ETRC using a frame of AIS size 8 galvanized steel structural pipe in a tripod design and guide wires to ground the power (Fig. 5). The frame for the Urbine also acted as a support for an outdoor shower, enhancing the occupants’ level of interaction with the prototype.

The Urbine’s light weight design (17 kg) was able to create continuous power almost silently, without disturbing the occupants of the ETRC. Unlike the safety systems in most wind turbine designs, the Urbine will not halt after reaching a predetermined level of energy production. Instead the Urbine uses a dynamic breaking system where excess energy is dumped into a 1/4 Ω, 2 kW resistor to prevent the wind turbine blades from reaching dangerous speeds and losing control. The energy dumped into the resistor can then be used in novel ways, such as heating for the mechanical room during the winter. The dynamic breaking system allows the wind turbine to produce energy upwards of 2 kW in various environments, including hostile wind storms. The installation of a wind turbine at the ETRC demonstrated that urban wind energy production is not only possible, but can be passively integrated into an urban building situated in a densely populated city core.

3. Energy efficiency initiatives

3.1. Natural artificial lighting

The Natural Artificial Lighting System consists of a series of collimated stage lights which are mounted outside the ETRC. These lights create parallelogram-shaped

Fig. 5. The Urbine: Canada's first rooftop mounted urban wind turbine. The frame of the urbine also supported the outdoor shower, cooling occupants as they relax on the Flexible Solar Membrane.

Fig. 6. The Natural Artificial Lighting System of the ETRC includes large ceiling windows to let light in and white opaque walls that trap the light once inside. This system transforms a dark, rainy evening into one which is appears bright and filled with daylight.

shadows as they pass through ceiling windows, mimicking those created by natural sunlight (Fig. 6). In creating the illusion of a sunny day, the Natural Artificial Lighting System tricks occupants into believing there is more light than actually present. This system was typically used during nighttime or overcast days. In making the interior seem daylight-bright, much less wattage of light was needed to satisfy the occupants compared to that of typical indoor lighting systems. The interior walls of the gallery were also painted completely white to enhance reflection of the light once inside the gallery.

3.2. Brainwave lighting

The Brainwave Lighting System consists of electroencephalogram (EEG) sensors which monitor a person's brainwave levels and converts this information into an output of corresponding light intensity directly proportional to an individual's brainwave activity (Fig. 7). The Brainwave Lighting System uses the concepts of biofeedback and EEG analysis derived by Daniel Chen et al. [5].

When an individual's concentration rises, there is a corresponding increase in the intensity of the surrounding lighting. The lights in the room will similarly dim when an individual becomes more relaxed and concentration levels drop. The room's lights will completely shut off once there is no brainwave activity**.** The Brainwave Lighting System, while ensuring that individuals have the proper lighting for the appropriate task, greatly reduces unnecessary energy consumption.

Fig. 7. The Brainwave Lighting System being demonstrated by Mark Post, a researcher at the ETRC.

4. Market considerations

4.1. Cost analysis of the BIPV prototypes

A cost analysis of the BIPV prototypes was desired to further assess the feasibility of urban renewable energy The Solar Awnings consisted of five SPS Iridium 165 W solar modules, each with retail value of \$9.67/W, together totaling \$7975. The Solar Outdoor Labspace and the Solar Louvre consisted of three and four BP 125 W solar modules respectively, each with a retail value of \$8.12/W, together totaling \$7,105. The Flexible Solar Membrane consisted of six RWE Schott cells (\$7.18/W), together totaling \$11,400. The roofing material for the Flexible Solar Roofing cost approximately \$1,000, increasing the prototype cost to \$12,400. The AIS piping and fittings which made up the frames of the BIPV prototypes totaled a cost of \$750. The overall project cost of the combined 2.2 kW BIPV system was \$30,230, valuing the energy produced at \$13.3/W.

As visible from Fig. 8, the Flexible Solar Membrane was the most expensive prototype. This cost difference was expected as the Flexible Solar Membrane required the most additional materials to achieve its secondary task, that of replacing normal roofing. The other three BIPV prototypes required little or no additional materials to meet the requirements of its secondary role (i.e. awning). An average solar installation consisting of 24–125 W panels (totaling 3 kW) costs approximately \$10/W (totaling \$30,000) [6]. Our PV system was found to cost \$3.3/W more in comparison with the cost of an average solar installation. This increase in cost was found to be acceptable when considering the significance of the additional tasks performed by BIPV prototypes and the individual retail values of the building enhancing structures (i.e. awning, louvre, roofing, labspace).

4.2. Reduction in the current price of PV installations

The high cost of a photovoltaic installation is currently the limiting factor in the advancement of PV industry For most citizens of developed countries this presents an unrealistic decision which, regardless of a desire to invest in renewable energy, falls to the option of fossil fuels and other non-renewable sources. Technological improvements have increased PV efficiency over the years and in turn lowered their cost, noting a 5% decrease

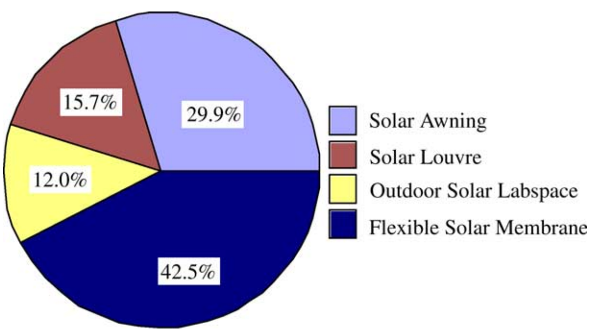

Fig. 8. The cost breakdown of the BIPV prototypes.

in 2002 [6]. These advancements, however, have been slow in their coming and have failed to result in significant cost reductions.

To lower PV costs, a broader, more innovative approach is recommended, where multi-functionality is taken as a key design factor when designing BIPV systems. The four prototypes presented in this paper illustrate this approach as they allow traditional building functions to be integrated into the PV design. In examining the Solar Awning, it is seen that all the requirements of a normal awning (covering occupants from hail, rail, snow or sun) have been met while simultaneously producing electricity from solar energy. The BP 125 W panels (used in our Solar Awning) are capable of withstanding hail at terminal velocities. This design approach allows project costs to be lowered by (a) eliminating materials needed to construct elements of the building and (b) conserving the building space used. In our Solar Awning, the frames needed for the awnings and the PV system (consisting of piping and fittings) have been combined into one structure. Studies have shown that similar approaches to combine PV systems with common building attributes have resulted in an approximately 60% decrease in project costs [7]. In lowering project costs, the cost of the PV system had consequently lowered. Utilization of the multi-functional design allows for the integration of solar energy into societies of lower economic strati to no longer be dependant on scientific or technological breakthroughs, feats which may lie many years into the future. This approach precipitates the movement of solar energy installations into our urban streets, neighborhoods and homes.

5. Conclusions

An urban downtown building was altered to utilize renewable energy for the purpose of this study. Our designs included BIPV prototypes as well as energy efficiency and wind energy initiatives. The BIPV prototypes were found to invite human interaction and enhance the building's functionality. The practicality of these prototypes became an educational tool for both the researchers at the ETRC and the public at large.

The major problem facing today's renewable energy industry is the lack of public acceptance due to the high costs of these technologies. The advancements at the ETRC closed this gap and increased the public's knowledge, and comfort level, with renewable energy products. Our installation was also a proof of concept for what is possible for all urban buildings. It is our hope that this study will compel others to complete similar projects in the future using the ETRC as a template. In investing in urban renewable energy, pollution caused by the burning of fossil fuels will be reduced, allowing the quality of life in urban centres to increase. Even though this research field is still in its infancy, urban renewable energy has the potential to grow and become the standard in all developed cities.

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