Towards Smart Net-zero Energy Buildings and Communities:
Integration of Energy Efficiency and Solar Technologies

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Why Smart Net-zero?  Path to Net-zero

• Net-zero annual energy balance: many possible definitions depending on **control volume**: House? Community? Net-zero cost?

• NZEBs are becoming adopted by many countries as a long term target; **ASHRAE vision 2020**.

• **Objective target for high performance buildings promotes an integrated approach to energy efficiency and renewables** - path to net-zero.

• **Why smart?**  Because NZEBs must be comfortable and optimally interact with a smart grid.
Solar Community Design
Towards Net-zero Energy

- Heating load is not significantly affected by the layout of streets, provided solar access is respected.
- Some house shapes (e.g., L-shape) are more beneficial in a specific site layout.

Electricity generation 85%-110% of the total energy use of the neighborhood.

Design: C. Hachem
Residential energy use in Canada

**Fact:** The annual solar energy incident on a roof of a typical house far exceeds its total energy consumption.

A net-zero energy house produces from on-site renewables as much energy as it consumes in a year (ZEB A/B definition).

Source: NRCan
Commercial/Institutional Buildings

- **Electric lighting**: transformation in building design that moved towards **smaller window areas until the 1950s**

- Followed by evolution to air-conditioned “glass towers” with **large window areas**: more daylight – but higher cooling and heating requirements

- Currently: renewed interest in **daylighting and natural/hybrid ventilation**

- Need to integrate **BIPV/STPV in facades** to approach net-zero
Major international trends in high performance buildings

• Adoption by engineering societies and developed countries of net-zero energy as a long term goal (ASHRAE Vision 2020)

• Measures to reduce and shift peak electricity demand from buildings, thus reducing the need to build new power plants; integrate with smart grids

• Steps to efficiently integrate new energy technologies such as controlled shading devices and solar systems
Challenge of fast technological development
e.g. Photovoltaics (PV) declining in price

Efficiency of commercial PV modules approaching 20%

PV price has dropped by ~90% from 2000 to 2011!
Now feasible to use PV as building façade and roof element on surfaces facing East-South-West (depends on location)
# Towards net-zero energy

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Canadian Research in NZEBs
From SBRN to SNEBRN

• The NSERC Solar Buildings Research Network (SBRN) has performed research and demonstration projects on technologically advanced solar buildings (2005-2011); the first initiative of its kind.

• Main energy & buildings university initiative in Canada; over 100 graduate students were trained, over 400 publications, innovative demonstration projects linked to research projects and four conferences.

• SNEBRN (2011-2016) is a network that continues and expands the work of SBRN with focus on smart NZEBs; about 30 researchers from 15 Canadian Universities, 20 partners, 100 grad students.

• Key approach: objective driven – strategic.
Smart NZEB research and education at Concordia University, Montreal

- Leader of the SBRN and SNEBRN Networks.
- A leader in building engineering (programs at BSc, Master’s and PhD levels) in Canada.
- Established Concordia Centre for Zero Energy Building Studies (CZEBS) – 8 Professors and nearly 40 HQPs.
- Dept of Building, Civil and Environ. Engineering.
JMSB Building-integrated photovoltaic/thermal (BIPV/T) system – a world first: Generates solar electricity, heats fresh air and is fully integrated with the building and its energy system.

Network Vision: to perform the research that will facilitate widespread adoption in key regions of Canada, by 2030, of optimized Smart NZEB energy design and operation concepts suited to Canada.
**SNEBRN:** 30 researchers from 15 Universities
- Building and energy industry leaders (from solar, utilities, HVAC sectors)
- Govt labs (NRCan CanmetENERGY)

**Some important facts**
- Most of Canada is quite sunny, with cold winters
- Ground temperatures 6-10 °C in most populated areas (lat 42-53 N)

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**PV potential map of Canada with location of the 15 SNEBRN Universities**
Smart NZEB concept

Optimal combination of solar and energy efficiency technologies and techniques provides different pathways to reach net-zero

**Solar energy:** electricity + daylight + heat
Optimization of buildings for solar collection

Two roof forms for the same floor plan

Important design variables:
- Roof slope and aspect ratio \( L/W \)
- Also window area \( A_w \)

Slopes 40-50 degrees desirable
Aspect ratio higher than 1; around 1.3

Optimize surfaces \( A_r \) and façade \( A_w \) simultaneously

Solar energy on roof

Incident solar radiation kWh/m²

Incident solar radiation kWh/m² vs. Slope (degrees)
Electricity demand and generation
Typical profile for NZEB (home, electric) on cold clear day

Ontario has a summer (due to cooling) peak demand
27 GWe

Quebec has a winter peak demand
38 GWe on Jan. 24, 2011 7:30 am with To = -33 C in Montreal

Peak heating demand can be reduced through predictive control

NZEBs need to be designed based on anticipated operation so as to have a largely predictable impact on the grid; reduce and shift peak loads
Building Integration of PV

• Into roofs or facades, with energy system of building.

• Roofs need to shed water: think of PV panels doing some of the functions of roof shingles; shingles overlap hiding nails.

• Functional integration, architectural and aesthetic; recover heat, and transmit daylight in semitransparent PV.

Not just adding solar technologies on buildings
EcoTerra™ EQuilibrium™ House (Alouette Homes)

Transformative SBRN work; IEA SHC Task 40 / ECBCS Annex 52 case study

- 2.84 kW Building-integrated photovoltaic-thermal system
- Passive solar design: Optimized triple glazed windows and mass
- Ground-source heat pump

NRCan, CMHC

Hydro Quebec
BIPV – integration in EcoTerra

- **Building integration:** integration with the roof (envelope) and with HVAC

- **BIPV/T** – (photovoltaic/thermal systems): heat recovered from the PV panels, raising overall solar energy utilization efficiency

- **Heat recovery** may be open loop with outdoor air or closed loop with a circulating liquid; possibly use a heat pump

- **Open loop air system** used because it can work for a long time with little maintenance and no problems
BIPV/T roof construction in Maisons Alouettes factory as one system

Graduate students and researchers involved in design and monitoring; linked to Theme 1 projects
Assembly of House Modules (in about 4-5 hours)

Prefabricated homes can reduce cost of BIPV through integration

House now occupied: feedback from owners on operation/comfort

Owners presented at CMHC workshop along with SBRN
An open loop air system is utilized for the BIPV/T system as opposed to a closed loop to avoid overheating the photovoltaic panels.
EcoTerra: Ventilated Concrete Slab (VCS) – store heat from BIPV/T (also can be used for night cooling)
Full scale prototype and numerical model developed

- Construction

Normal Density Plain Concrete
Steel Deck (Canam P-2436, galvanized steel)
Ventilation Channel (cavity)
Metal Mesh (e > 5mm)
Rigid Insulation
Water/vapor Barrier
Gravel (earth)

Active and passive thermal storage to reduce peak electricity demand
Passive design and integration with active systems

Near net-zero house; a higher efficiency PV system covering same area would result in net-zero.

Study of occupancy factors indicated importance of controls.

IEA Task 40 case study

EcoTerra energy system
Lessons learned

- Solar house with close to net-zero energy consumption: about 10000 kWh/yr (of which 3000 kWh is due to occupant additions); i.e. **7000 kWh based on design**.

- Emphasis on integration and lowering of cost through prefabrication.

**To get to net zero**
1. Use of a more efficient BIPV system (with PV efficiency = 15%).
2. Better integration to utilize collected heat.
3. Replacement of garage electric heater with heat from BIPV/T system.
JMSB BIPV/T Solar Facade: A NSERC Solar Buildings Research Network Demonstration Project

Back façade of new building (JMSB- Concordia)

Funded by NRCan TEAM Program through CanmetENERGY Varennes
Brendan O’Neill – research engineer, Josef Ayoub - NRCan
Building Integration of PV – with HVAC and envelope: BIPV/T

- From one building surface with an area of about 288 m² generate both solar electricity (up to 25 kilowatts) and solar heat (over 75 kW of ventilation fresh air heating);
- **Total peak efficiency over 55%;**
- The system forms the exterior wall layer of the building i.e. it is NOT an add-on.
- Mechanical room is directly behind the BIPV/T façade.
Up to 15000 cfm fresh air = over 75 kW heat

Specially designed photovoltaic modules

Cold outdoor air

Un-glazed SolarWall® cladding

Insulation

Fan

Pre-Heated fresh air

Inverter

DC

AC

Air cavity

Partners: Concordia University, Conserval, Day4 Energy, NRCan, Schneider Electric (Xantrex)
Air flow paths in BIPV/T system

Special design to promote heated air behind PV to flow into transpired collector

25 kW electricity
Solar heating of up to 15000 cfm of fresh air

Control of airflow will be optimized
- Variable speed fan
Just 288 sq.m. was covered. Imagine possible generation with 3000 sq.m. BIPV/T
Note snow melting from BIPV/T roof integration.

Passive air circulation in BIPV/T melts snow in winter.

Normal roof collects snow.

Note difference in south facing window areas.

40 degrees slope.

Athienitis house, Domus award finalist.

Private project.
Integration – BIPV/T (1.9 kW$_e$)
Passive solar – **superior comfort**
Geothermal system (2-ton)
Efficient controls

Passive solar design + BIPV/T + Geothermal + efficient 2-zone controls

Book from Subtask B:

Modeling, design and optimization of NZEBS

What is the appropriate model resolution for each stage of the design?

What is the role of simple tools versus more advanced detailed simulation?

What other tool capabilities are needed to model technologies such as building fabric-integrated storage (PCMs), BIPV/T + heat pumps?

IEA SHC Task 40 / ECBCS Annex 52 Subtask B
RSF archetype - alternative design investigation

- Fixed louvers versus motorized (between glass)

![Diagram showing light entering and exiting through louvers]

**Profile angle (Degree)**

(Peng 2009)

Transmittance

- Light enters from 5° to 85°
- Light Louvers (section)
- Light reflected up to 30° towards ceiling

![Graph showing transmittance vs. profile angle]
Example SNEBRN project: Design of New Solar Communities

**Solar Neighborhood Design: optimizing solar potential**
- Develop optimal energy design of solar homes with BIPV, BIPV/T, solar thermal, and/or combinations of technologies
- Consider different building forms and layouts, and street planning
- Consider community peak energy generation and peak demand

**Renewable Energy Systems for Solar Communities**
- Explore optimal community energy system options suitable for Canada through the development of modeling and optimization tools to maximize use of solar energy
- Consider energy generation and demand diversity of NZEBs in solar community energy planning systems

**Solar Community Design and Density Effects**
- Identify density effects on solar community design; Consider clusters of six or more heterogeneous mix of solar buildings arrangements using conventional, new urbanism, fused-grid etc.
- Consider building shapes and sizes, and spaces between buildings to examine the impacts on neighbourhood energy demand and generation
Work under project 5.2a

- Solar community concepts with non-rectangular or rectangular house shapes and designs that may be employed with appropriate BIPV/roof designs while also allowing for optimal design passive solar gains.
- These designs also affect significantly the peak generation of electricity and the peak demand.
- Can shift and reduce the peak of electricity supplied to the grid, while also reducing the peak demand from the grid as well.
The average heating load is not significantly affected by the layout of streets.

If energy use / energy production is considered, some configurations are more beneficial in a specific site layout.
Development and Optimization of BIPV/T systems: Solar simulator & Environmental Chamber (Concordia)

BIPV/T prototype (JMSB) tested in vertical position;

JMSB BIPV/T: Peak efficiencies (thermal + electric) of 55% +

Accurate model development for innovative systems that was not possible with outdoor testing

Concordia solar simulator testing BIPV/T system similar to EcoTerra

2-storey high environmental chamber with solar simulator
Typical configuration of test in environmental chamber of SSEC facility with test façade and thermal storage
Smart Net-zero Energy Buildings

• Renovation of existing buildings provides the opportunity to cover facades with cladding that heats ventilation fresh air and generates solar electricity.

JMSB BIPV/T

Background
Concordia Engineering Building (hybrid ventilation schematic - original concept)

High mass building; studied in 2 PhD and 1 MASc theses

MPC potential is significant for night cooling to reduce peak demand.

Install variable speed fan.
Varennes NZEB Library final design (Montreal)

SNEBRN provided advice: **choice and integration of technologies and early design building form**

**Design required several iterations** - e.g. **final choice of BIPV system required minor changes in roof design** for full coverage; note also **skylights that allow deep penetration of daylight**. **Roof slope close to 40 degrees.**

*Design charettes organized by NRCan*
Solar source heat pump connected to BIPV/T

- The BIPV/T system can be used as the source of a heat pump to heat a water tank.
- Can utilize excess electricity and heat to charge chilled/hot storage for later use: REDUCE PEAK EXPORT OF ELECTRICITY.
The path towards Smart NZEBs and Communities – an opportunity for innovation

• Buildings undergoing a **transformation to reach net-zero**
• Opportunity for **leadership** – construction is engine of economic growth, high quality of life
• NZEBs will lead to many novel products, **exports, jobs**
• **Challenges:**
  – **fragmentation of building industry**
  – **transformative changes** to building design and operation
  – ambitious R&D programs: from basic research to full scale **demos with a research component**
  – **incentive measures with multiple benefits** such as production of renewable energy at times of peak demand
  – **training of engineers and architects**