Modelling and Design of Smart Net-zero Energy Solar Buildings

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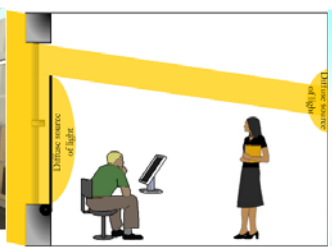
Major international trends in high performance buildings

- Adoption by ASHRAE and developed countries of net-zero energy/ zero carbon as a long term goal (eg *ASHRAE Vision 2020*);
- Measures to reduce/shift peak electricity demand from buildings, thus reducing the need to build new power plants; optimize interaction with smart grids; resilience to climate change; charging EV;
- Steps to efficiently integrate new energy technologies such as controlled shading devices and solar systems, thermal and electrical storage;
- Energy flexibility in building used to optimize performance and interaction with smart grids; predictive control.

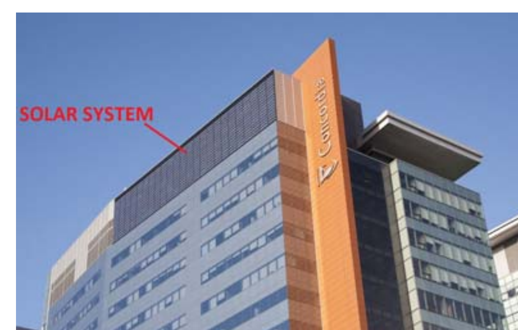
NREL RSF



Bottom-up shades

STPV

EcoTerra **BIPV/T**

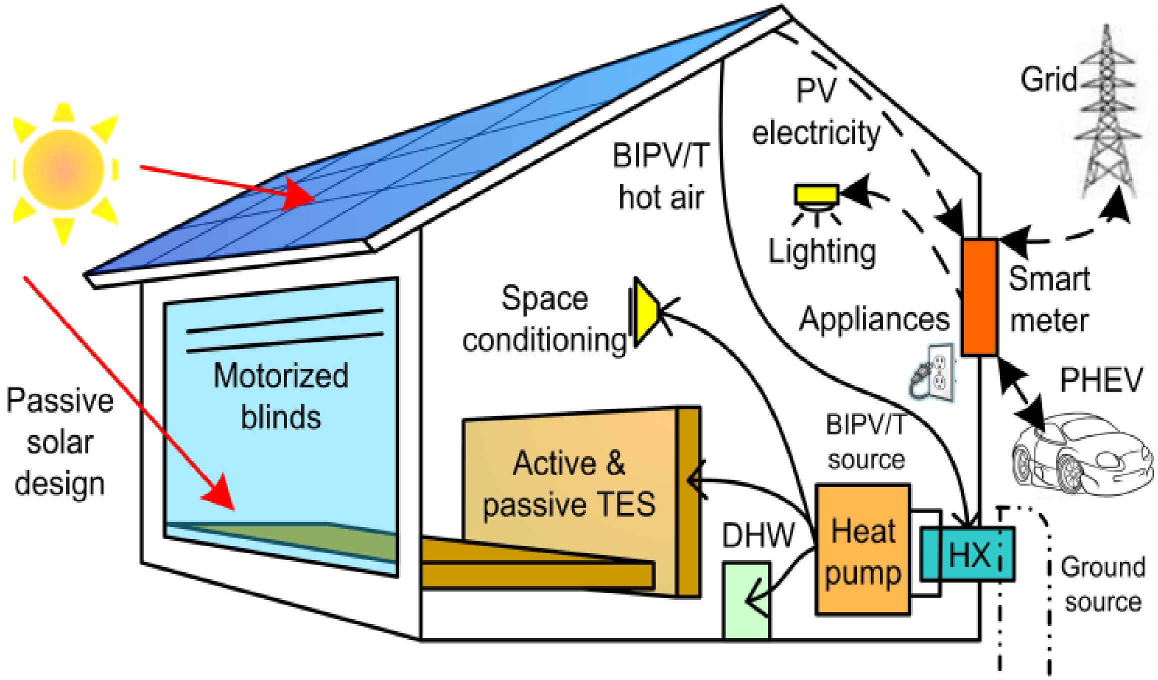


Concordia JMSB

Smart Solar Building concept – towards resilience

Optimal combination of solar and energy efficiency technologies and techniques provides **different pathways to high performance and an annual net-zero energy balance**

Solar energy: electricity + daylight + heat



Integrated approach to **energy efficiency and passive design**

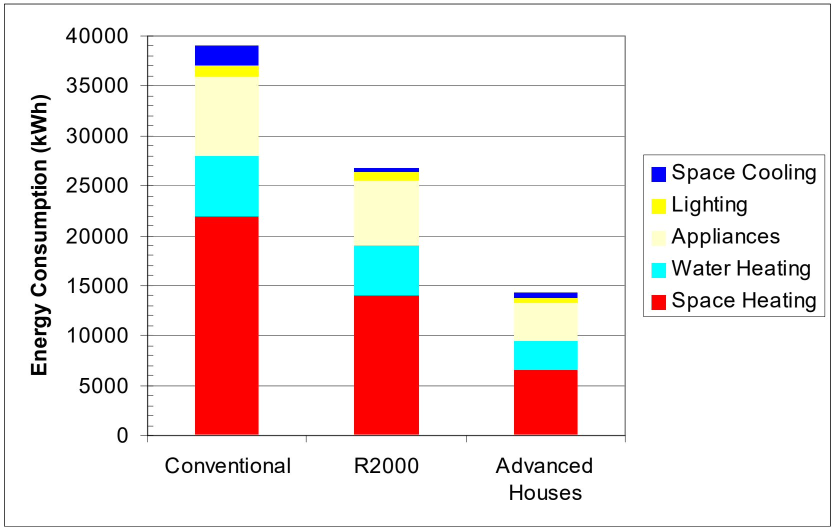
Integrated design & operation

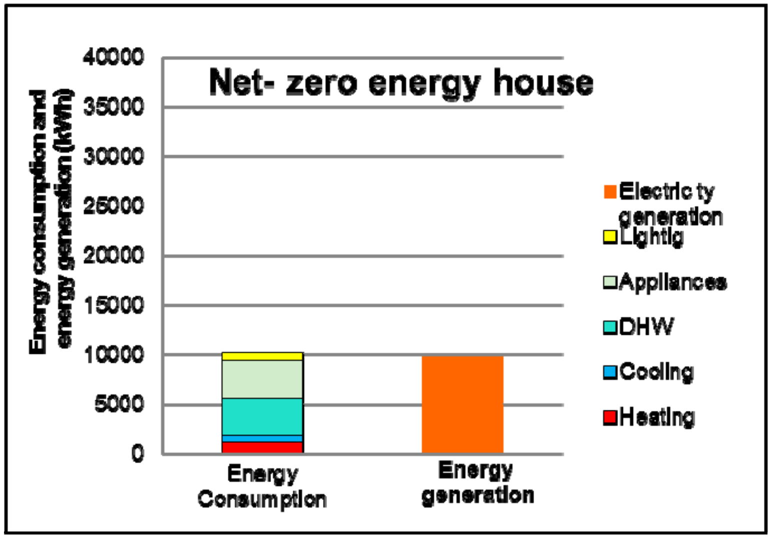
Solar optimization: requires **optimal design of building form**

Key design variables: **geometry – solar potential, thermal insulation, windows, BIPV, energy storage**

Residential energy use in Canada

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

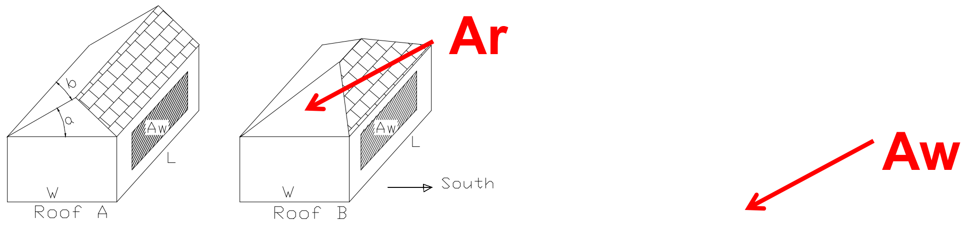




Source: NRCan

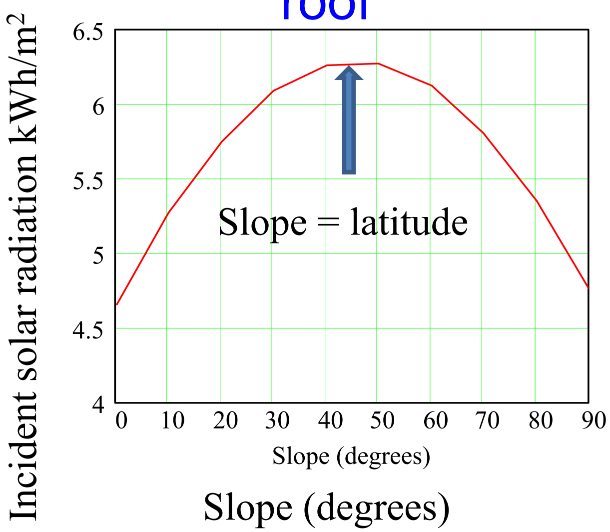
A net-zero energy house produces from on-site renewables as much energy as it consumes in a year

Optimization of buildings for solar collection



Two roof forms for the same floor plan

Solar energy on roof



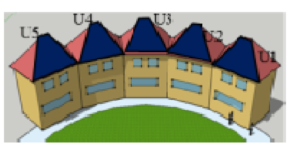
Important design variables:
Roof slope and aspect ratio L/W
Also window area

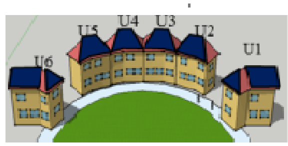
Slopes 40-50 degrees desirable
Aspect ratio higher than 1; around 1.3

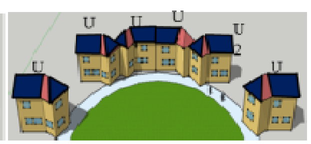
Optimize surfaces Ar and façade Aw simultaneously

Smart Net-Zero Energy Solar Buildings (NZEBs)

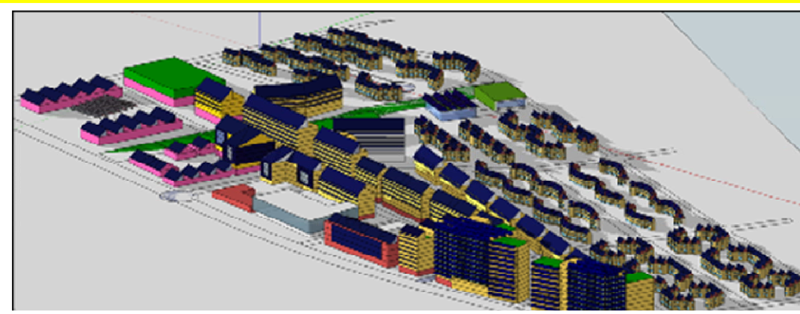
- Net-zero annual energy balance: many possible definitions depending on boundary: House? Community? Net-zero energy cost?
- Net-zero is an objective target that promotes an integrated approach to energy efficiency and renewables; **path to net-zero is important**
- Why smart? NZEBs must be comfortable and optimally interact with a smart grid
- NSERC **S**mart **N**et-zero **E**nergy **B**uildings Strategic **R**esearch **N**etwork (SNEBRN) builds on the previous NSERC Solar Buildings Research Network (SBRN) – now under renewal - Smart solar buildings and communities



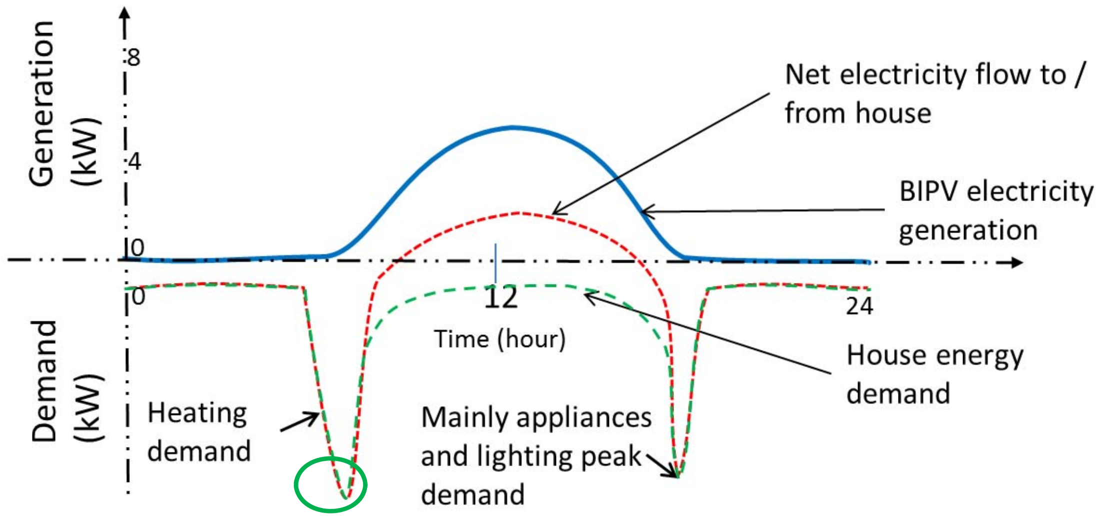




Smart solar community, S2e London Ontario



Electricity demand and generation in solar house with BIPV
typical profile for NZEB on cold clear day



Peak heating demand can be reduced through predictive control

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

NZEBs need to be designed to ensure a predictable impact on the grid and to reduce and shift peak demand

Commercial/Institutional Buildings: some trends

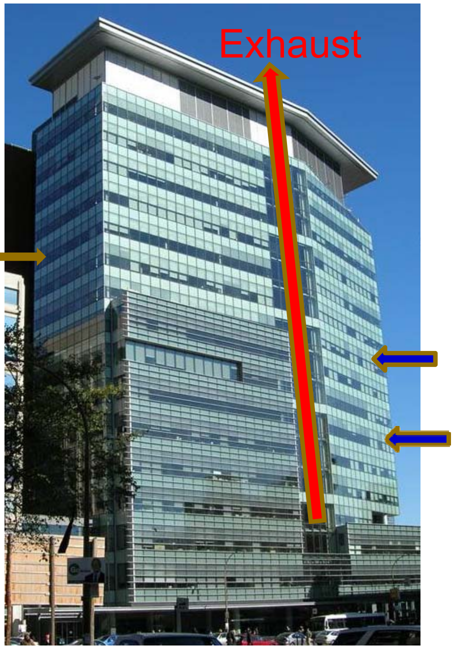
- Electric lighting: transformation in building design that moved towards **smaller window areas until the 1950s;**

- Followed by evolution to air-conditioned "glass towers" with **large window areas**: more daylight – but higher cooling and heating requirements; now LED lighting;

- Currently: renewed interest in daylighting and natural/hybrid ventilation; eg **hybrid ventilation system** at Concordia EV building & predictive control (NSERC/HQ IRC);

- **Building-integrated photovoltaics (BIPV)**, possibly with heat recovery (BIPV/T) or semitransparent PV windows (STPV).

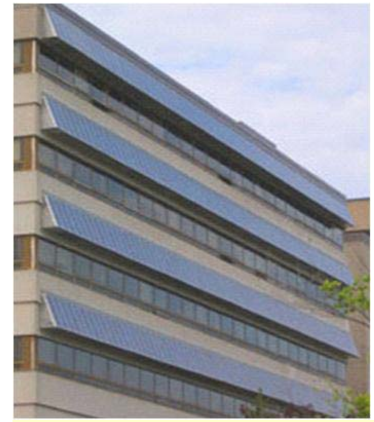
- PV modules have dropped in price by 90% in last 10 years! Can be used as building envelope element!



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 (BIPV/T), and transmit daylight in semitransparent PV (STPV).

Not just adding solar technologies on buildings



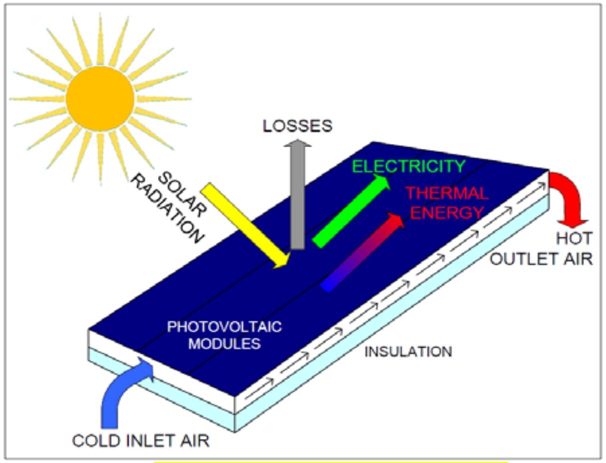
*PV overhangs Queen's University (**retrofit**)*

Athienitis house (BIPV/T)

BIPV/thermal – 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

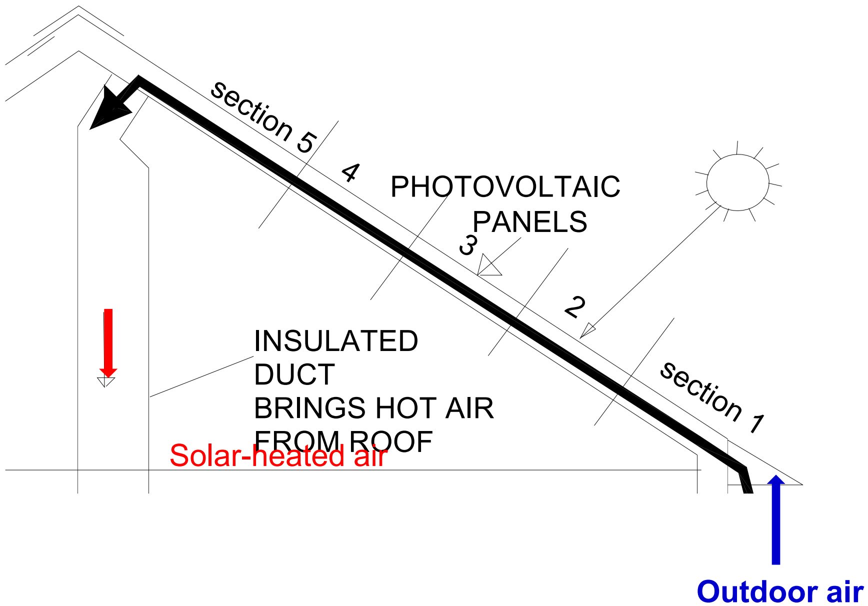
EcoTerra™

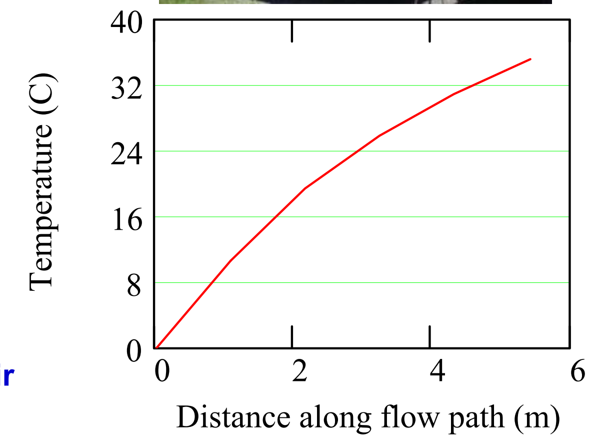


Open loop air BIPV/T

SOLAR BUILDINGS RESEARCH NETWORK
RÉSEAU DE RECHERCHE SUR LES BÂTIMENTS SOLAIRES

BIPV/T roof in 5 sections for analysis - Energy model (2D Finite Difference – explicit)





An open loop air system is utilized for the BIPV/T system as opposed to a closed loop to avoid overheating the photovoltaic panels
Electrical and thermal models are linked since electrical efficiency of PV is a function of temperature (increases with lower temperatures of PV)

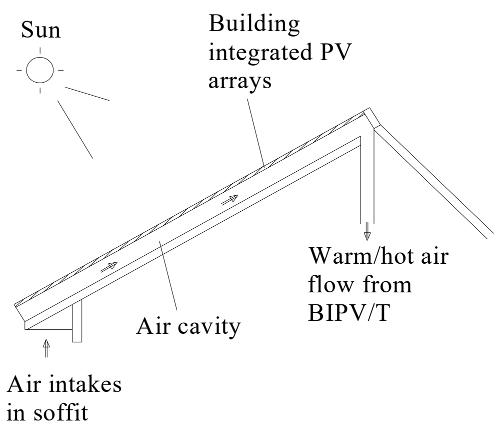
EcoTerra™ EQuilibrium™ House (Alouette Homes)
an SBRN-led demo project (2007)

2.84 kW Building-integrated photovoltaic-thermal system

Passive solar design: Optimized triple glazed windows and mass

Ground-source heat pump

BIPV/T roof construction in a home builder factory as one system – a major Canadian innovation under the NSERC Solar Buildings Research Network (2005 – 2010)



Based on research and simulation models developed and BIPV/T prototypes tested outdoors

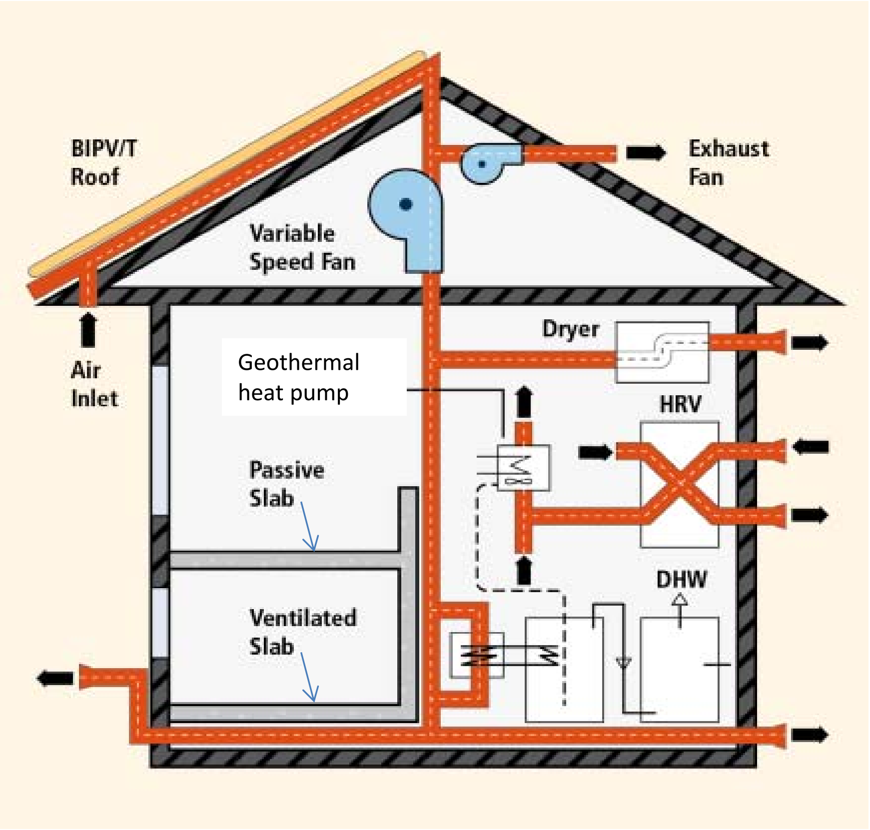
Partnership included university researchers and students, prefabricated home builder, utility and government lab

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

Assembly of House Modules (in about 5 hours)

Prefabrication (pre-engineered) of homes can reduce cost of BIPV through integration
Quality of installation is enhanced

Resilience: Note snow melting from BIPV/T roof

Integration

Note difference in south facing window areas

Athienitis house, Domus award finalist

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

Private project

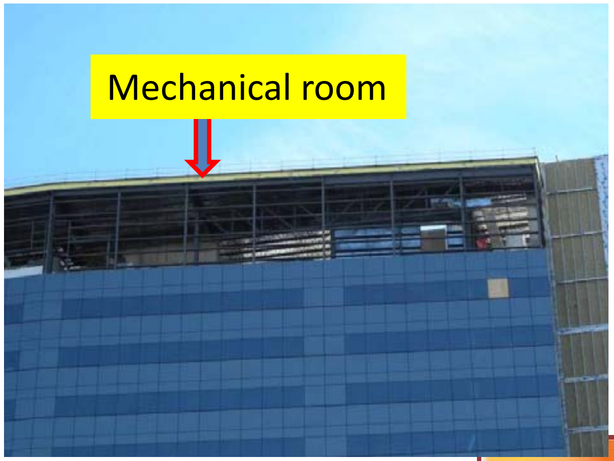
Athienitis House (2006)
Domus award finalist

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

JMSB BIPV/T SYSTEM (Concordia University 2009)

- Building surface ~ area 288 m^2 generates both solar electricity (up to 25 kilowatts) and solar heat (up to about 75 kW of ventilation air heating);
- **BIPV/T system** forms the exterior wall layer of the building; it is not an add-on;
- Mechanical room is directly behind the BIPV/T façade – easy to connect with HVAC
- Total peak efficiency about 55%;
- New system developed recently that simplifies design and has inlets in PV frames.



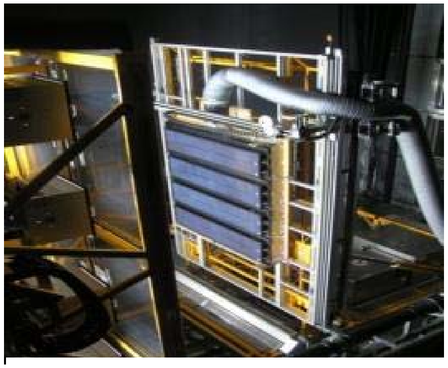
Occupant behavior:

Note shade positions

IoT with smart sensors can *facilitate automation of shades*

More R&D needed to make design of such systems routine; develop systems for retrofit

Development of BIPV/T systems
Solar Simulator - Environmental Chamber (SSEC)



BIPV/T prototype tested
in vertical position;

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

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

2-storey high
environmental chamber
with solar simulator

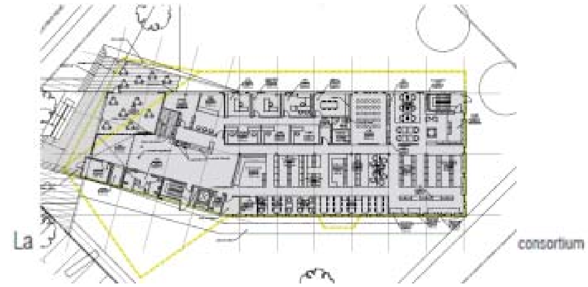
Concordia solar simulator
testing BIPV/T system
Roof system

New Varennes Municipal Library (2016) – Solar NZEB

South elevation – before final

Official opening:
May 16, 2016

2017 sq.m. NZEB



First public institutional designed solar NZEB in Canada
110 kW BIPV (part BIPV/T), Geothermal
Radiant heating/cooling, passive solar

Our team provided advice: **choice and integration of technologies and early stage building form**
Design required several iterations - e.g. **final choice of BIPV system required minor changes in roof** design for full coverage. **Roof slope close to 40 degrees to reduce snow accumulation.**

PRESENTLY MONITORING PERFORMANCE & OPTIMIZING OPERATION

Varennes Library – Canada's first institutional solar NZEB

Officially opened May 2016

- 110 kW BIPV system (part BIPV/T)
- Geothermal system (30 ton)
- Radiant floor slab heating/cooling
- EV car charging
- Building received major awards (e.g. **Canadian Consulting Engineering Award of excellence**)

Market is ready for such projects provided standardized BIPV products are developed
Now modelling and optimizing operation and grid interaction under a NSERC Hydro Quebec Chair

We guided the energy design of the building

Varennes Library: living lab

Multi-Functional Library
First Public Canadian Solar NZEB

Rendering just before final design; note skylights

EV charging

Building has become **a living lab**:
photo from class visit

At a Glance

- Net Floor Area: 2100 m^2
- BIPV/T Roof: 110.5 kWp
- Solar Heat Recovery: 1142 L/s (pre-heated fresh air)

Thermal Storage

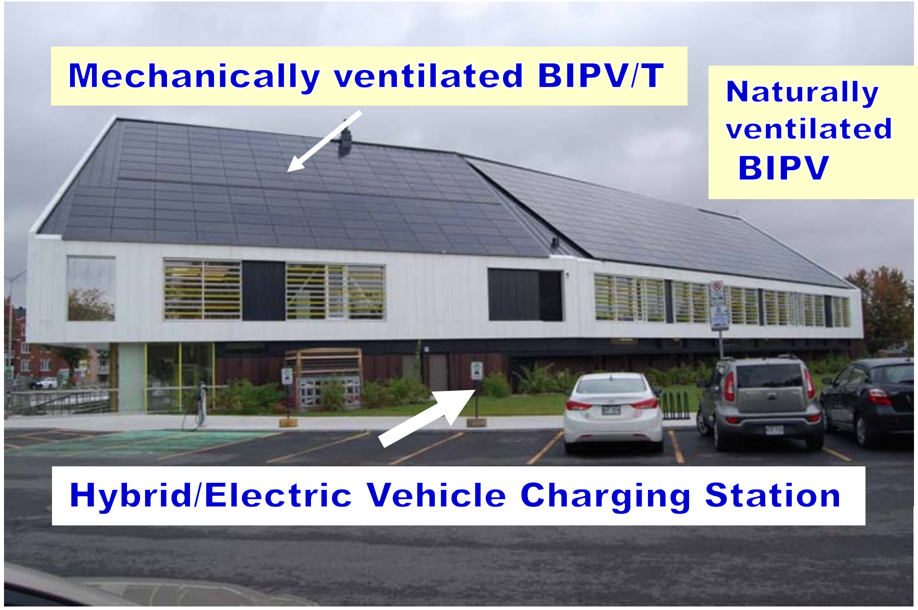
- **8x 150m geothermal boreholes**
- **Concrete slab, hydronic radiant**

Other Passive Solar Design Features

- Natural cross-ventilation
- Exterior fixed solar shading

Window to wall ratios

- North: 10%
- South: 30%
- East: 20%
- West: 30%

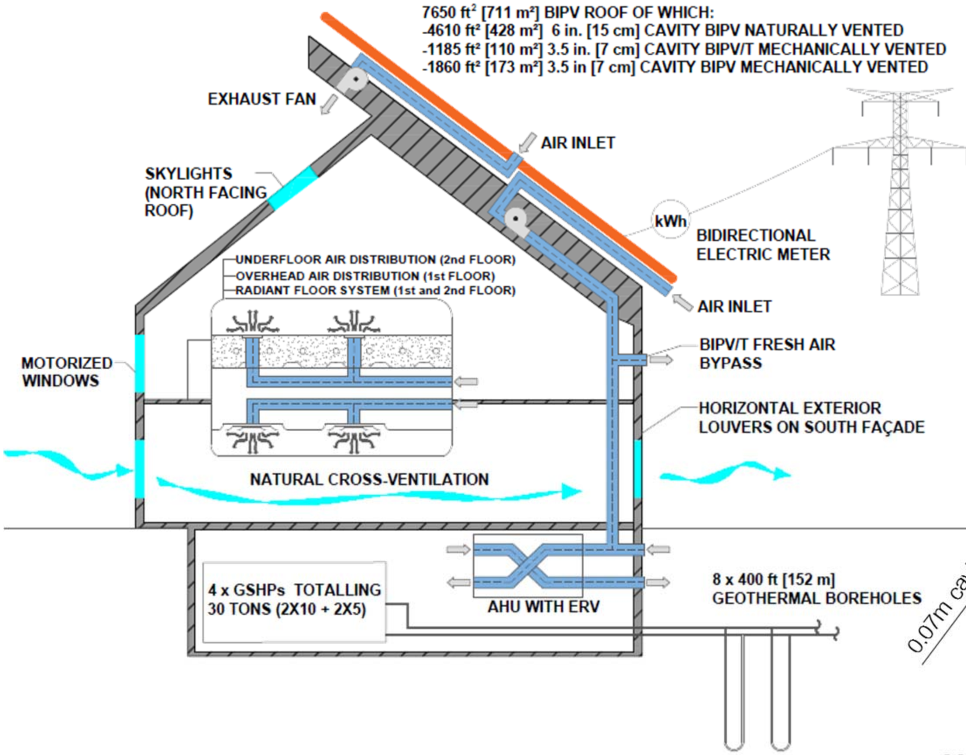


110 kWe BIPV (part BIPV/T)
Heat recovered on part of the array to supplement fresh air heating
38° slope, oriented South to South-East

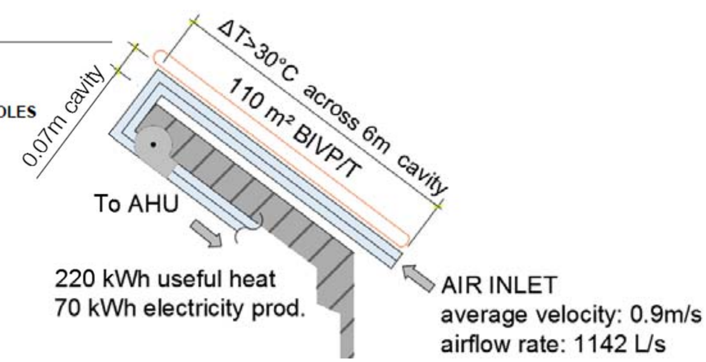

Skylights
Vegetation
Screen
(Growing)
Smaller triple glazed windows on
North Side


Fixed solar shading
on South side
Geothermal Wells (8)

Library Systems BIPV/T (part of roof)

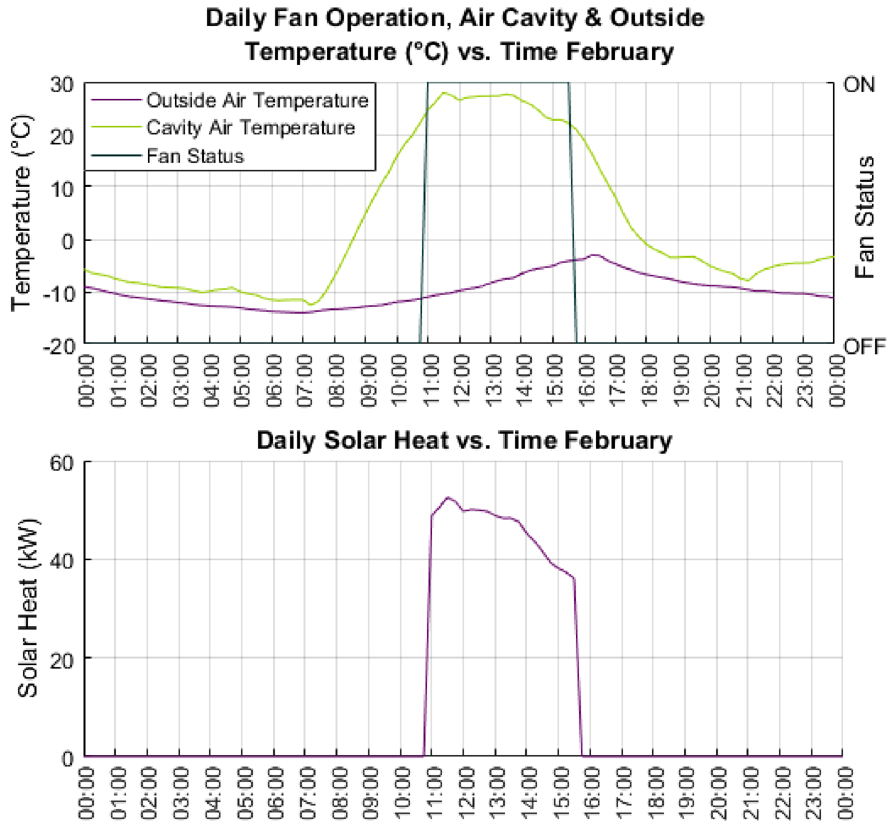


- Custom BIPV/T, one inlet
- Fan activated for outlet air temperature >25°C
- Rated electrical efficiency: 15.9% STC
- **Combined efficiency up to ~60% (thermal + electrical)**



For such systems to become low-cost and routine, **prefabricated roof sections** must be built in a factory (similar to curtain wall systems) and assembled by crane

BIPV/T System (winter clear day performance)



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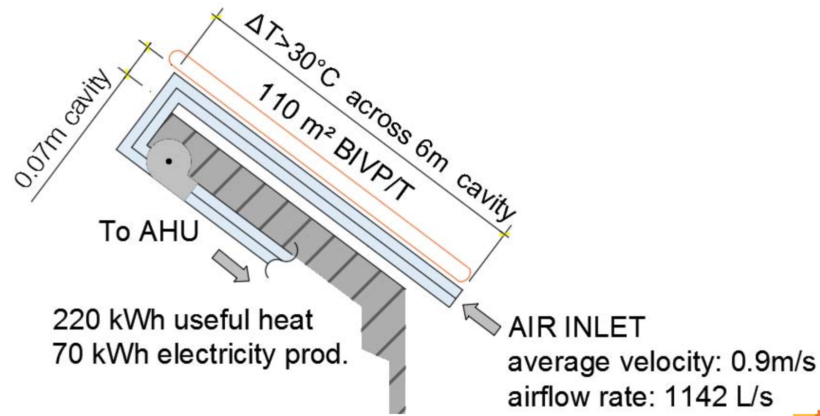
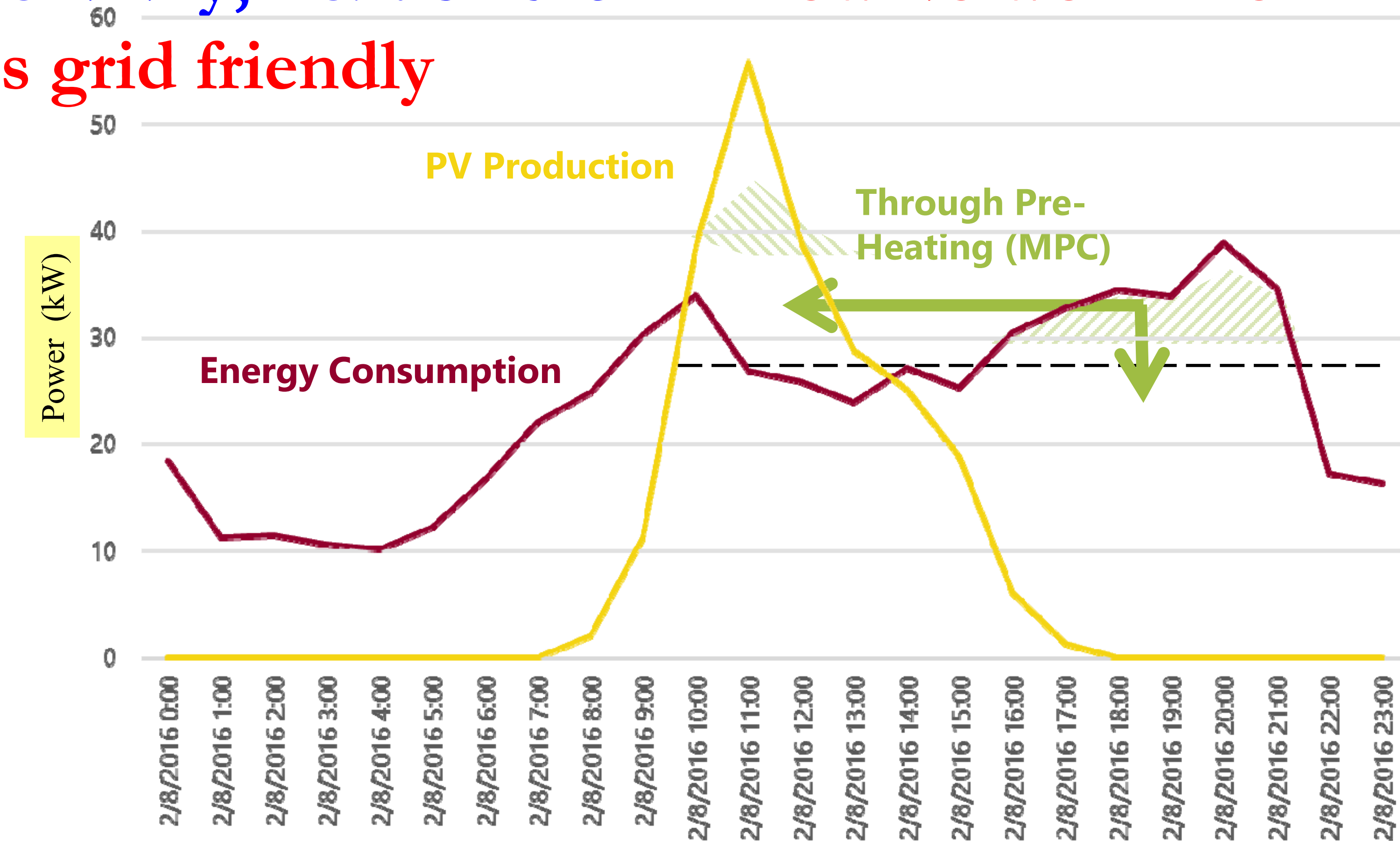


Production and Consumption Mismatch
Clear cold day, Feb. 8 2016 - how do we make NZEBs grid friendly



Model Predictive Control (MPC) is being developed to reduce peaks due to heating demand and optimally export electricity to the grid; 6 hours to 1 day prediction horizon

Solar Decathlon China 2018 – our team TeamMTL

House

Two-story row house

Automated off-site prefabrication

Total heated space: 200 m²

HVAC

BIPV/T and BIPV

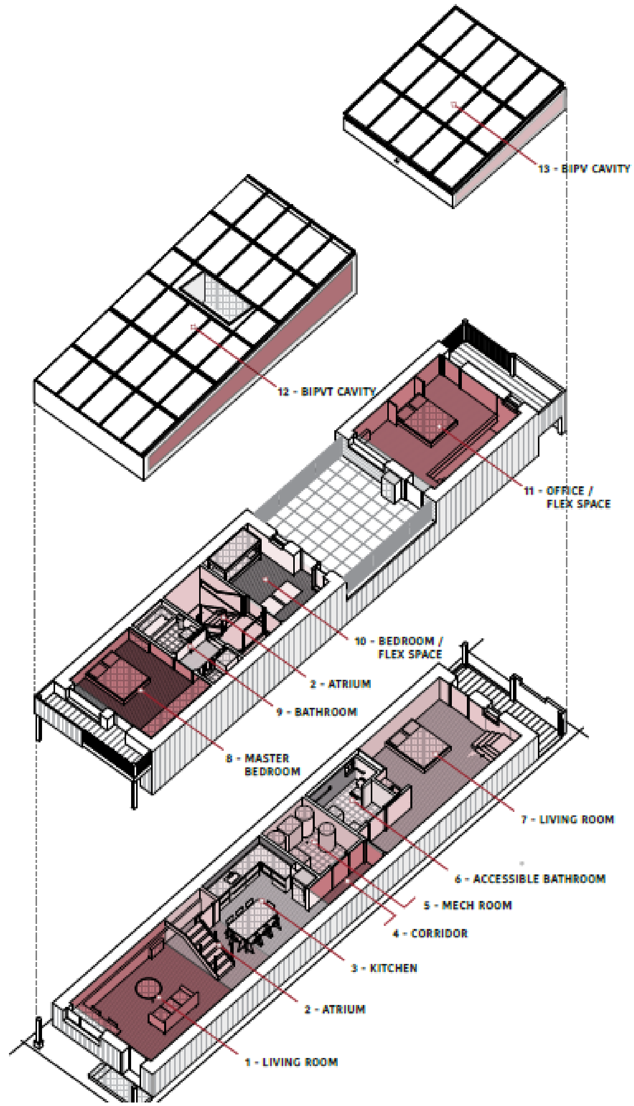
Water-to-water heat pump

Two thermal storage tanks

Energy Recovery Ventilator (ERV)

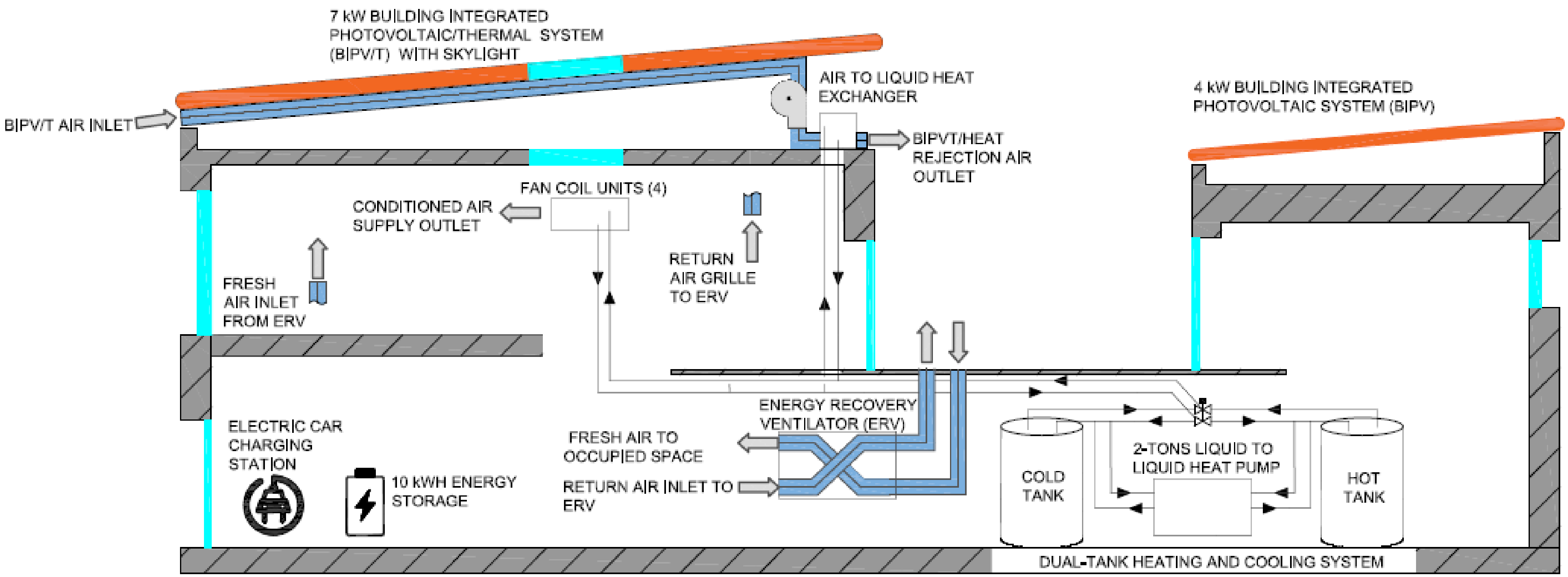
Modeling

TRNSYS (13 thermal zones)



House in China
Picture from above

Energy System for TeamMTL Solar Decathlon

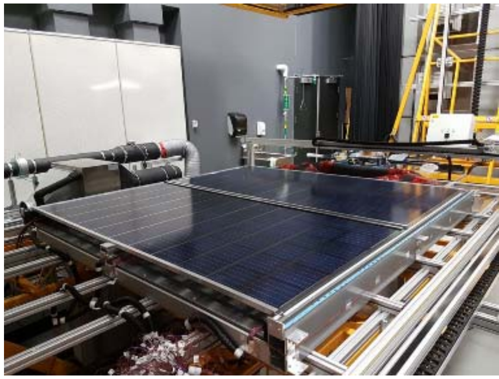


Energy flows between house and grid can be optimized based on grid state and price signal
Based on house load/generation flexibility

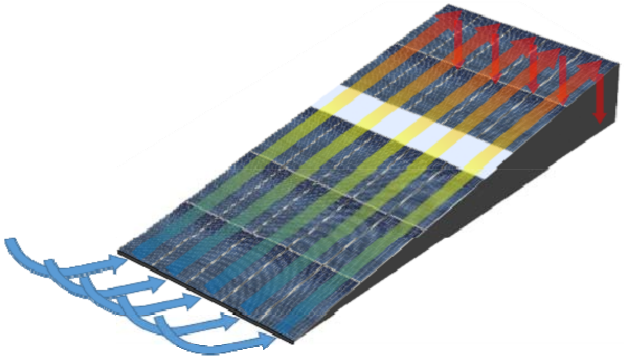
BIPV/T, BIPV design and Solar Decathlon China 2018

TeamMTL

Concordia-McGill



Grid interaction Strategies for Energy flexibility
Collaboration with Hydro Quebec

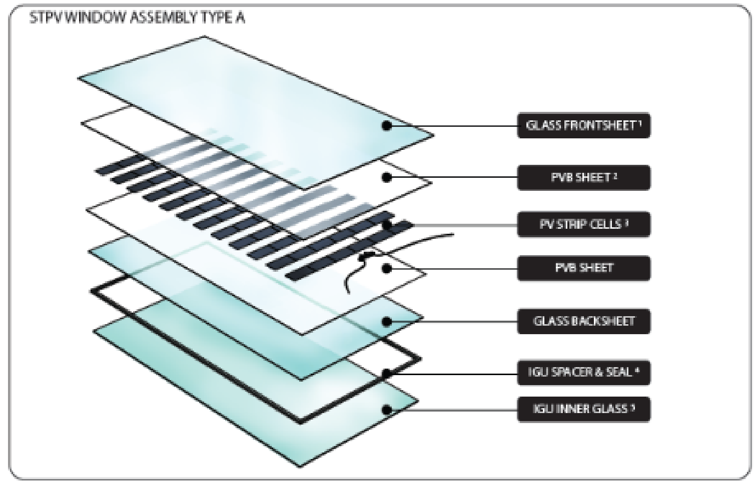


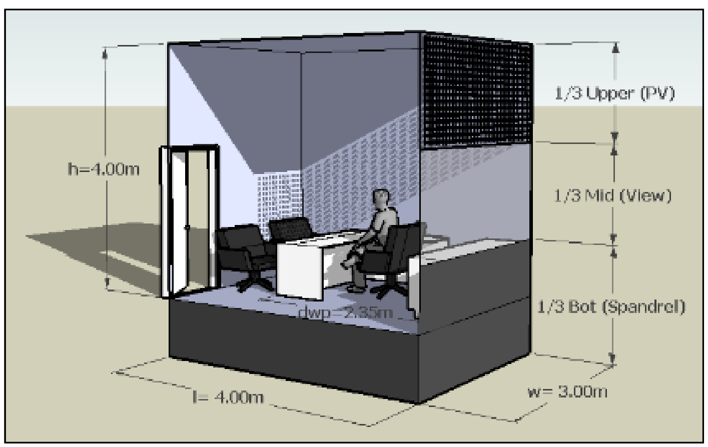
Awards in
Architecture
Engineering
Innovation …

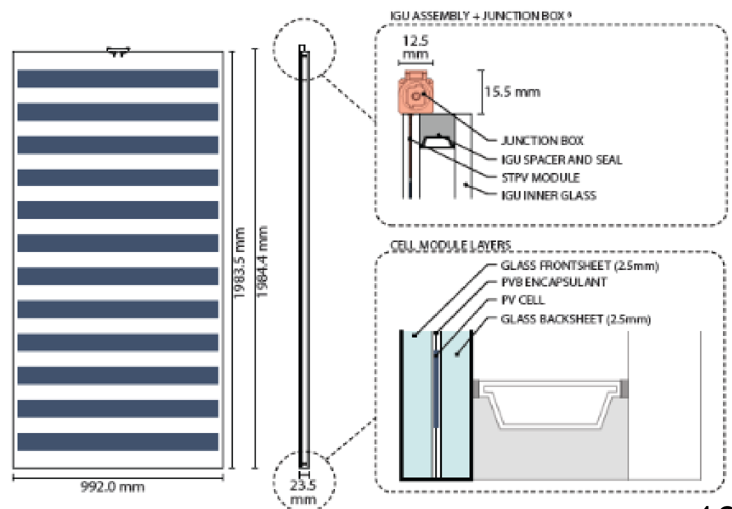
BIPV/T roof
Modular design
Developed at Concordia (CZEBS)
In Solar Simulator lab

Semi Transparent Photovoltaic (STPV) Window development

- Turn Building Envelope to Solar Power Plant
- Offset Electric Lighting Loads by Daylight Transmission
- Reduce Heat Losses in Winter & Heat Gains in Summer
- Integrated with Structural, Functional & Aesthetic Properties
- Reduce GHG Emissions in the Lifecycle Building Performance

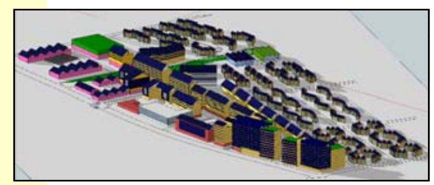






Towards smart netzero solar buildings and communities

BUILDING SYSTEMS	CURRENT BUILDINGS	FUTURE SMART NET-ZERO SOLAR BUILDINGS
Building fabric	Passive, not designed as an energy system	Optimized for passive design and integration of active solar systems
Heating & Cooling	Large oversized systems	Small systems optimally controlled; integrated with solar, CHP; *Communities: seasonal storage and district energy; smart microgrid, EVs*
Solar systems	No systematic integration – an after thought	Fully integrated: daylighting, solar thermal, PV, hybrid solar, geothermal systems, biofuels
Building operation and	Building automation systems not used effectively.	Predictive control to optimize comfort and energy/cost performance; online demand prediction; grid-friendly.
Integration with design	**Operating strategies not optimized with design.**	**Integrated design that considers optimized operation; optimize form and basic features in early design**



Smart community