SOLAR BUILDINGS RESEARCH NETWORK — RÉSEAU DE RECHERCHE SUR LES BÂTIMENTS SOLAIRES

IEA SHC Task 40 / Annex 52 Workshop

Integrated Energy Concepts for NZEBs: Combining Passive and Active Systems

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Montreal NZESB PhD Summer Workshop Introduction

- Lectures followed by case study work; case studies and examples introduced in lectures.
- Objectives:
  - Provide common background to Task40/41 PhD students by group of international experts
  - Apply knowledge and skills to Task 40 case studies
  - Facilitate current and future collaboration between students
  - Provide initial starting point of case studies; results to be presented in Basel.

Six Case Studies

1) EcoTerra House, Eastman (near Montreal), Canada

4) Leaf House, Angeli di Rosara, Italy

5) SolarCompany, Heusden-Zolder, Belgium

6) NREL Research Support Facilities (RSF), Golden, USA

2)EnerPos , Saint-Pierre, Reunion Island, France

3) Green Tomorrow, Dongbaek, Korea

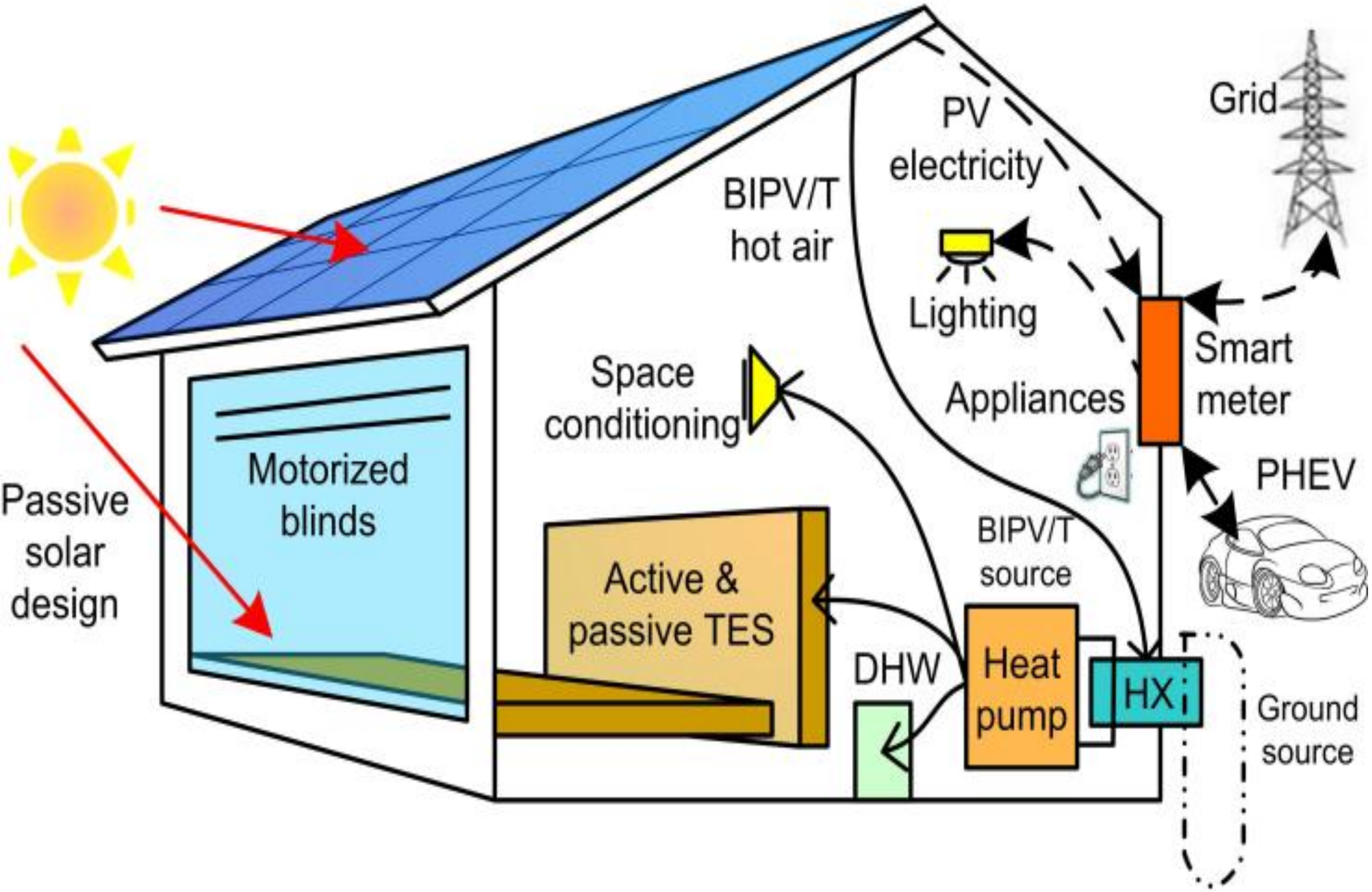
NZESB Detailed Case Studies

- **Selected STB in-depth case studies will be used to:**

1. **Document the following:**
   - **the design process**
   - **which modeling tools were used and how**
   - **notable features of each building**
   - **gaps of existing tools in designing NZESBs**
   - **building energy use and comfort**
2. **Study accuracy of modeling tools / modelling issues and use of calibrated energy models to analyze building performance**

- **Explore opportunities for cost reduction or further energy reduction using optimization tools.**

Smart NZEB concept – Combining active and passive



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

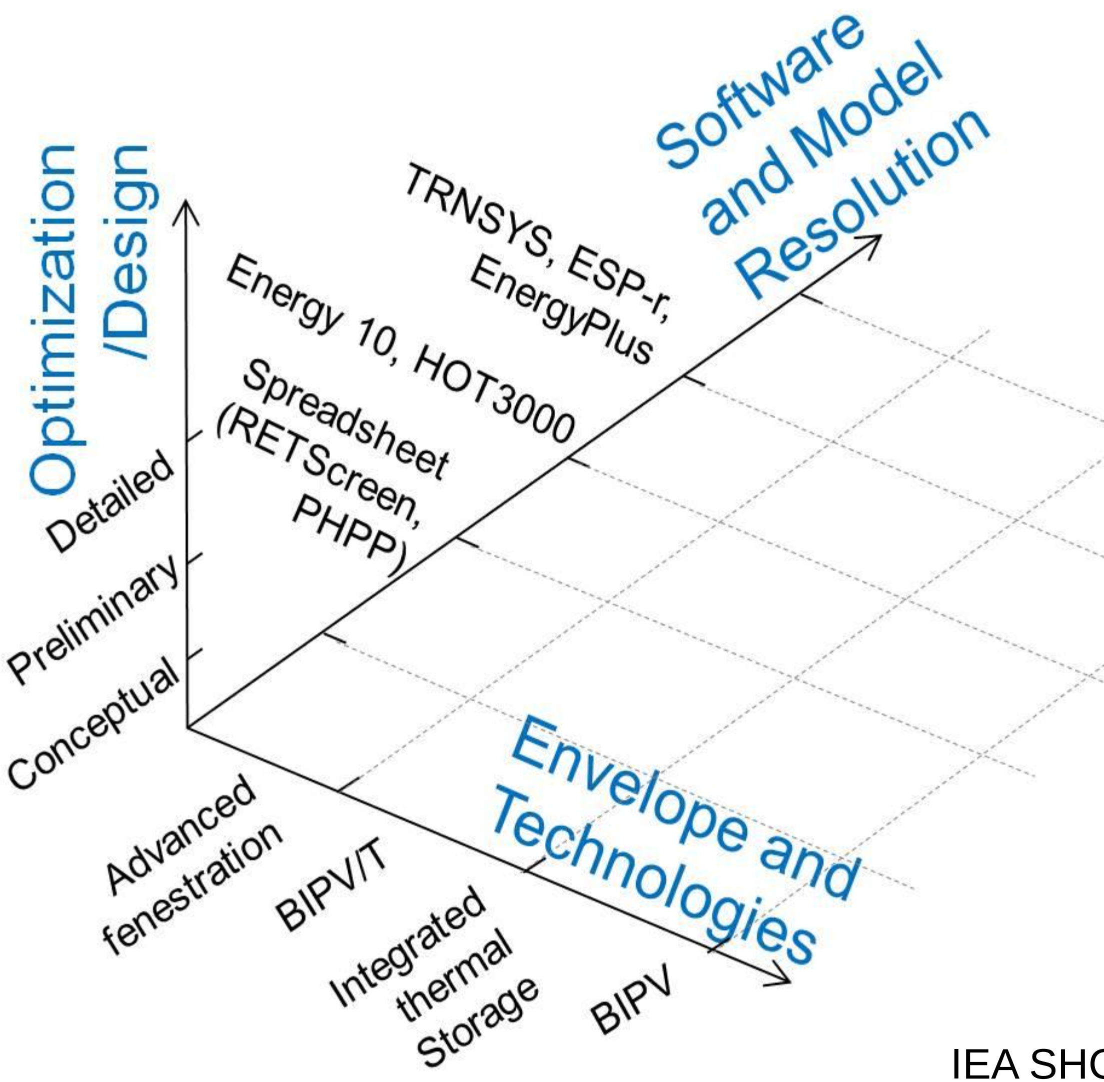
Integrated design & operation.

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

Optimal combination of technologies provides different pathways to reach net-zero

Solar electricity + Daylight + Solar heat

Modelling, design and optimization of NZEBS



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

What is **the role of simple tools** (e.g., RETScreen, PHPP) versus more advanced **detailed simulation?**

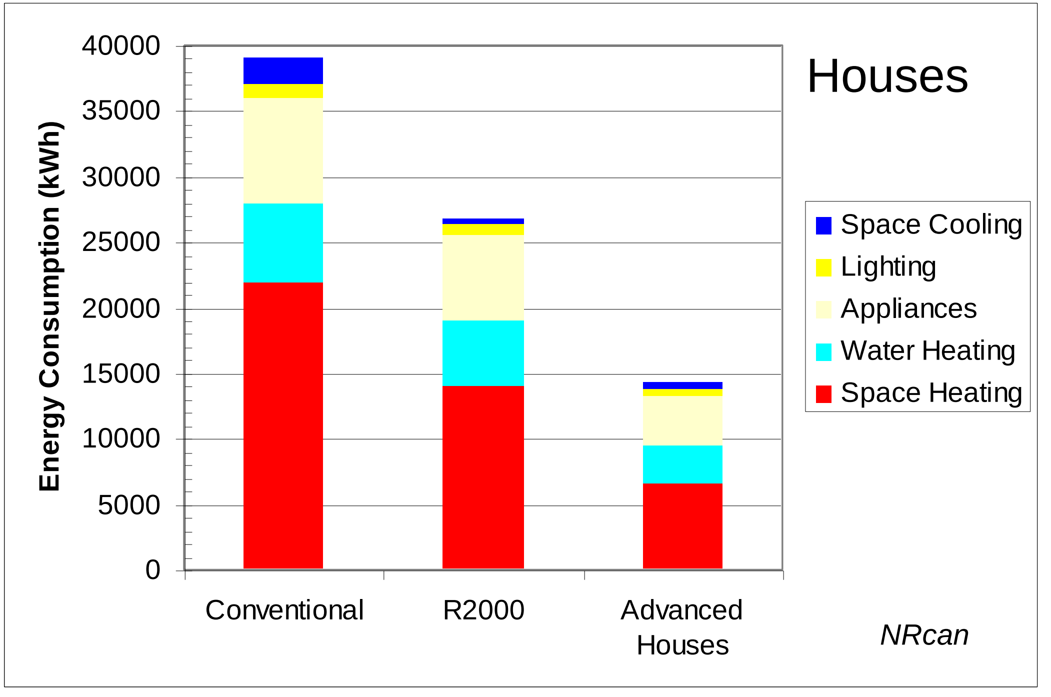
What other tool **capabilities are needed to model new technologies such as building** fabric-integrated storage (PCMs), BIPV/T?

Canadian Energy & Buildings Picture

- Buildings consume about 53% of electricity; homes mainly for heating, but commercial buildings have a high lighting and cooling load.
- Buildings - a third of GHG emissions.
- Most Canadians own single family homes.

- Energy picture changes between provinces – e.g. Quebec is mainly hydro while Ontario relies on fossil fuels/nuclear but has now introduced a generous solar power incentive program.

Building energy use in Canada



Buildings: ~30% of GHG emissions & 53% of electricity consumption

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

The average annual net energy consumption of an Advanced House (90s) was in the range **46-110 kWh per square meter of floor area**.

The Canadian situation and examples from Canada

- A highly insulated house – “advanced house” will generally have a low heating load about 6000 kWh/yr per year concentrated in 3-4 months. However most homes need around 20000 kWh/yr.

- Most have forced air systems but low interior mass.
- Natural ventilation and passive heating/cooling are important but currently underutilized.
- SBRN has developed BIPV/T and other technologies (control ..) and led several early stage demonstrations linked to research projects.

Integration of solar technologies

- Into roofs or facades.
- Roofs need to shed water: think of PV panels doing some of the functions of roof shingles; shingles overlap hiding nails.
- To integrate PV in facades, standard glazing and curtain wall technology may be employed with wires going e.g. through framing.
- **With HVAC system.**
- Functional integration, architectural and aesthetic.

PV overhangs Queen's University (retrofit)

Design of single family detached home

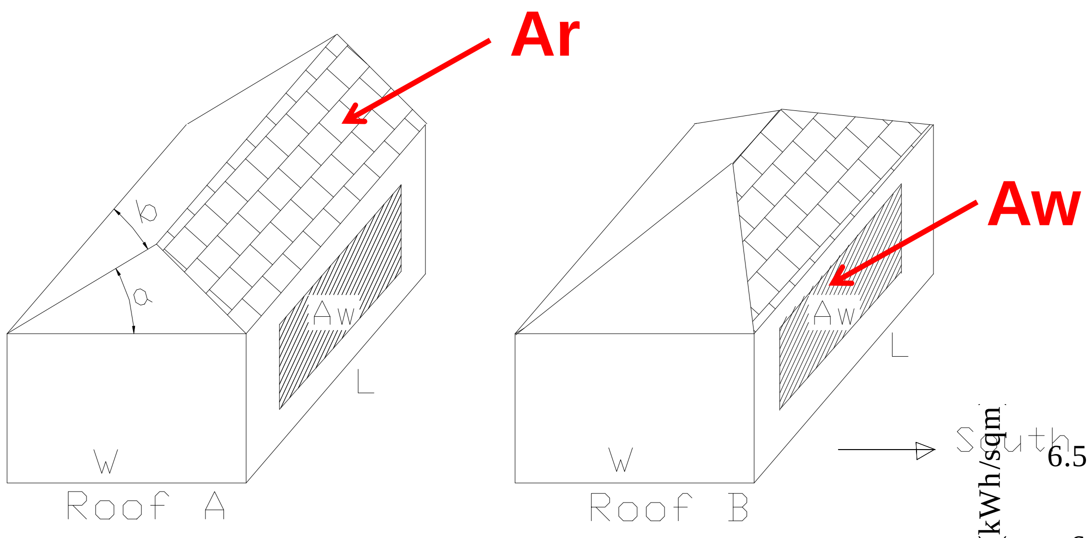
- Design of single family detached home usually starts with selection of single storey, two-storey or split design options. Two-storey option = most common.

- Two-storey option permits higher slopes that are needed to shed snow in winter (40 – 50 degrees).

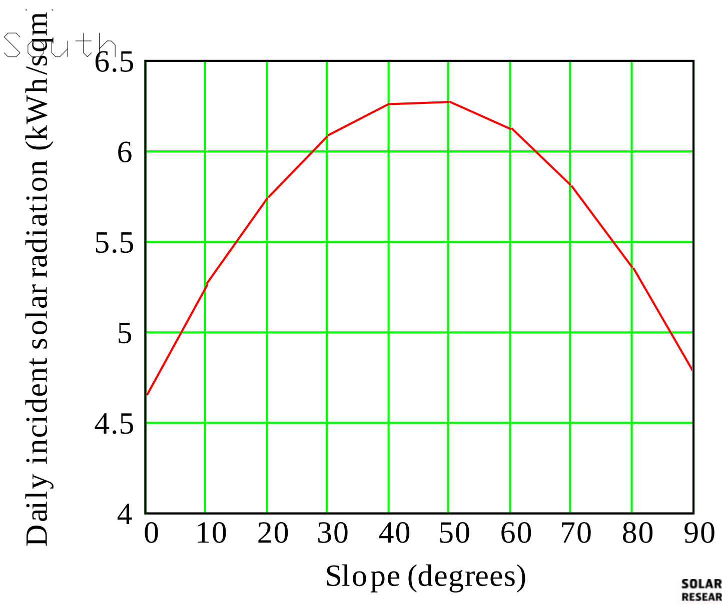
- "Boxy" design is not a necessity – Solar houses can look nice!

- Two-storey home designs more suitable for passive solar → provide a large south-facing façade, optimal roof slopes (35-50 degrees) and occupy less land.

Solar optimization of form:
Two common roof shapes



Consider, for example, **two roof forms for the same floor plan** often used with some variations in Canadian housing.



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

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Optimize roof Ar and façade Aw simultaneously

Athienitis house – Domus Award Finalist 2006

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

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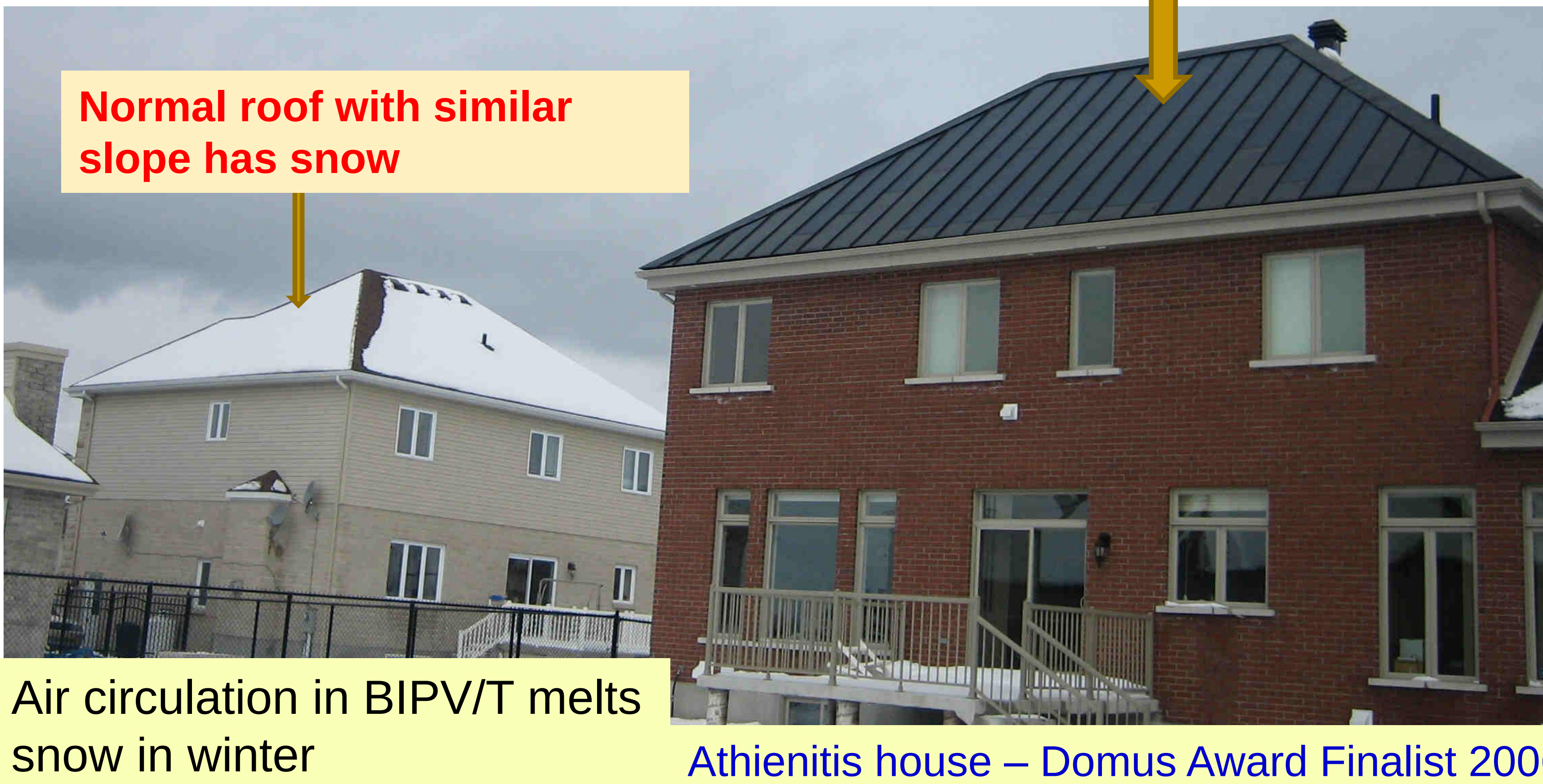
Note snow melting from BIPV/T roof

Integration



Normal roof with similar slope has snow

Air circulation in BIPV/T melts snow in winter

Athienitis house – Domus Award Finalist 2006

Design of single family detached home example: EcoTerra

- Models in RETScreen, HOT2000, EnergyPlus, Mathcad (BIPV/T, comfort).
- Using initial models perform case studies.
- Compare different design tools.
- Document gaps.
- Preparatory documents on case studies will be sent to participants before the workshop.

Objectives of Design of EcoTerra house

- Energy efficient design – airtight, optimal insulations levels.
- Passive solar design – south facing windows to reduce winter heat loads and mass to prevent overheating.
- Optimize combination of energy efficiency technologies, building-integrated solar, geothermal heat pump.
- Come as close to net-zero as possible but try to reduce costs through integration and prefabrication.

A net –zero energy house produces from on-site renewable energy sources as much energy as it consumes.

EcoTerra™ EQuilibrium™ House (Alouette Homes)

IEA SHC Task 40 / ECBCS Annex 52 : Example case study

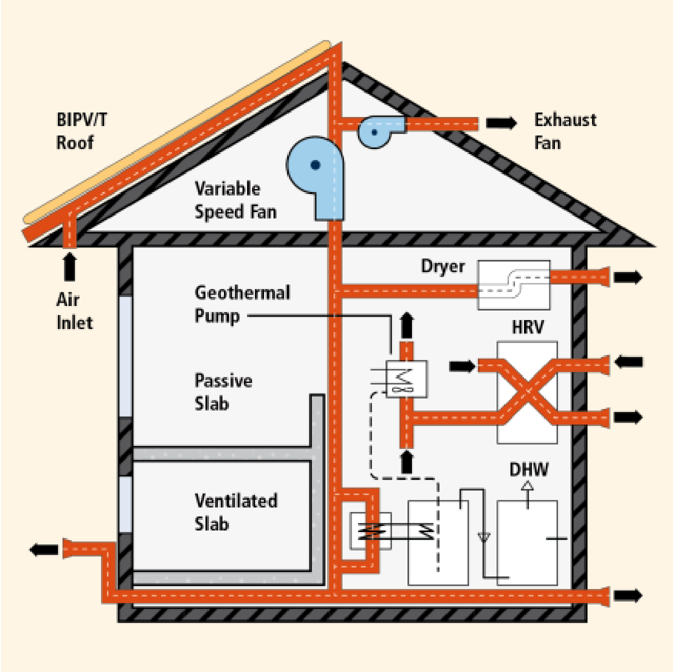
2.84 kW Building-integrated photovoltaic-thermal system

Passive solar design: Optimized triple glazed windows and mass

Ground-source heat pump

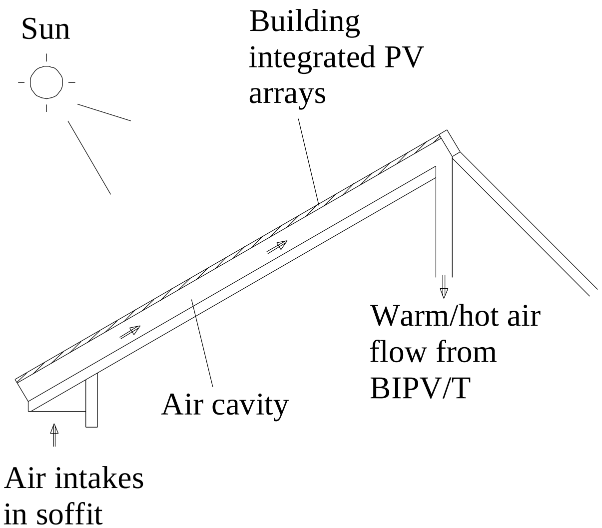
Envelope and energy system

- Two-story, single family, detached house, 230 m^2
- **Passive solar design** combines south facing triple glazed low-e argon windows with distributed internal thermal mass and a hollow core slab in the basement (active charge / passive discharge)
- Glazing area: North: 0.65m^2, South: 20.9 m^2, East: 6.67 m^2, West:5.2m^2
- **South Glazing to Floor Ratio: 9.1% (42% of south façade).**
- Air-tightness: 0.85 ACH @ 50 Pa
- Roof RSI- 9.1 Walls RSI- 6.3



Energy system combines passive design with two-stage geothermal heat pump and building-integrated photovoltaic-thermal system

BIPV/T roof construction in Maisons Alouettes factory as one system – a major SBRN innovation



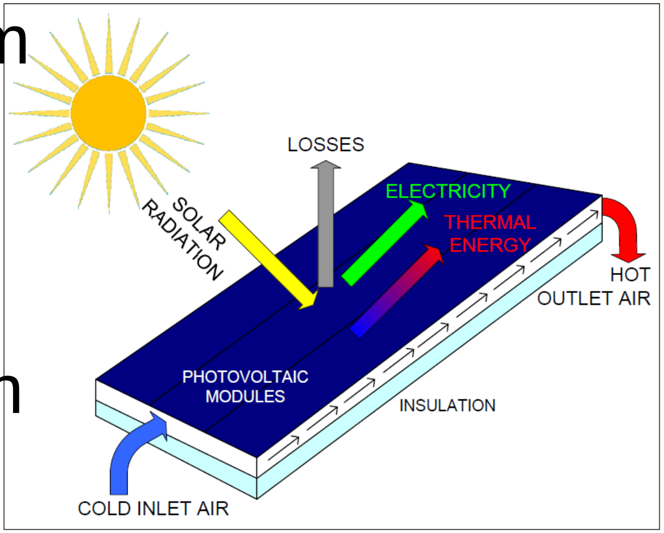
Based on research and simulation models developed at Concordia

Graduate students and researchers involved in design and monitoring

BIPV – integration

- Building integration: integration with the roof, wall, or fenestration (semitransparent PV) or as shading devices; also with HVAC system.
- BIPV/T – (photovoltaic/thermal systems): heat is also recovered from the PV panels, thus raising their overall solar energy utilization efficiency.
- Heat recovery may be open loop with outdoor air or closed loop with a circulating liquid.

EcoTerra™

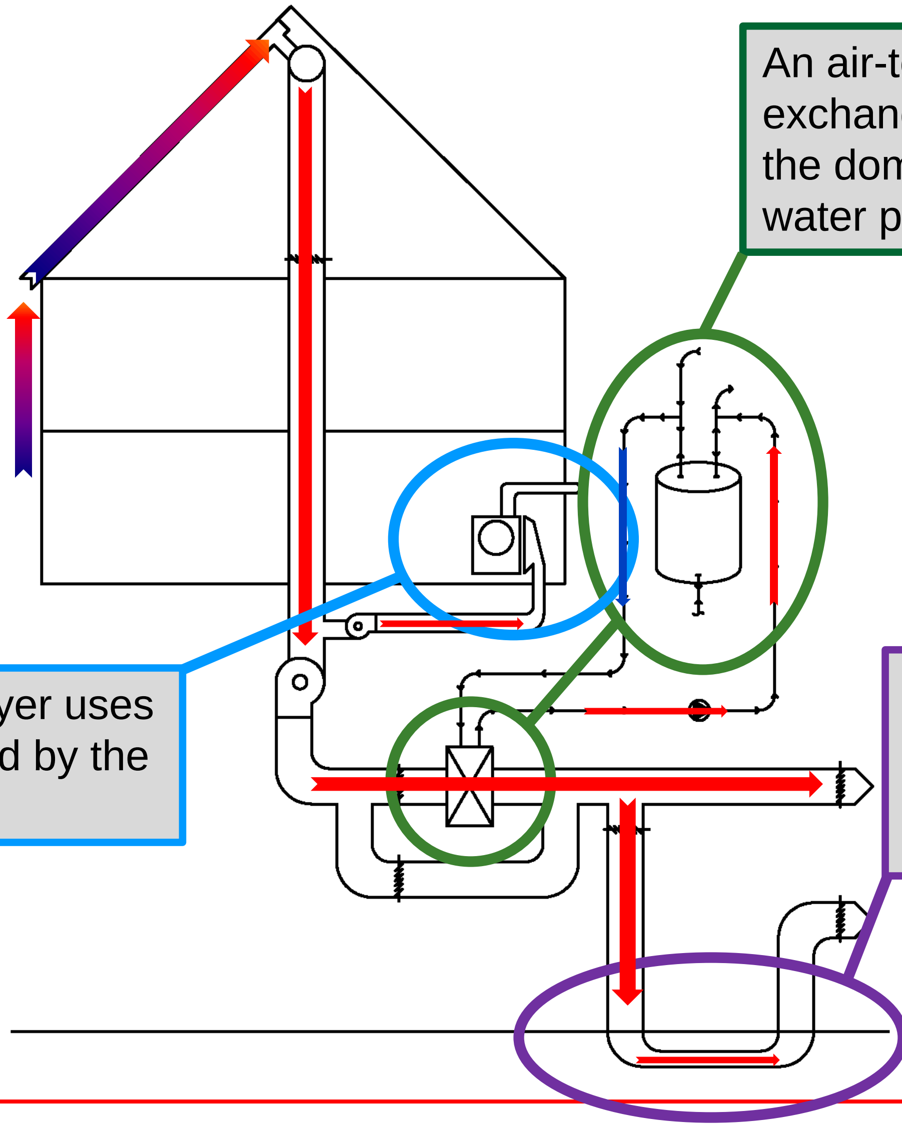


Open loop air BIPV/T

Energy System Overview

Air enters the roof at the soffits and is heated by the sun before entering the house.

An air-to-water heat exchanger charges the domestic hot water preheat tank.



A clothes dryer uses air preheated by the BIPV/T roof.

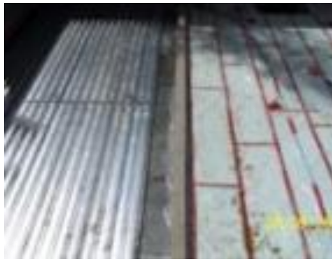
The ventilated concrete slab is charged by air from the BIPV/T roof.

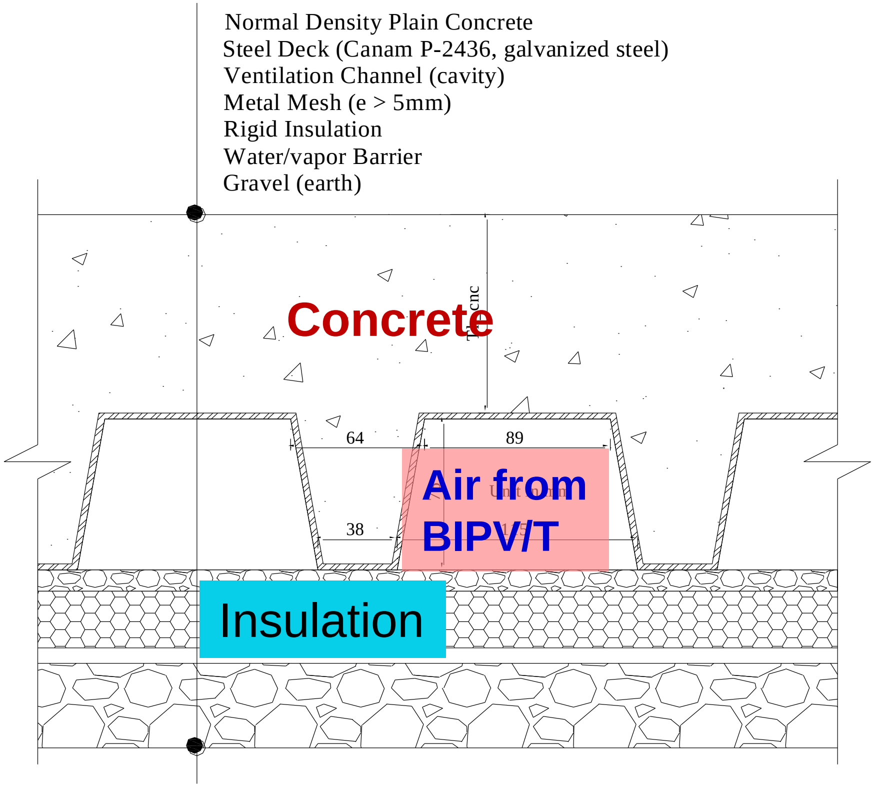
EcoTerra: Ventilated Concrete Slab (VCS) – store heat from BIPV/T (also can be used for night cooling)

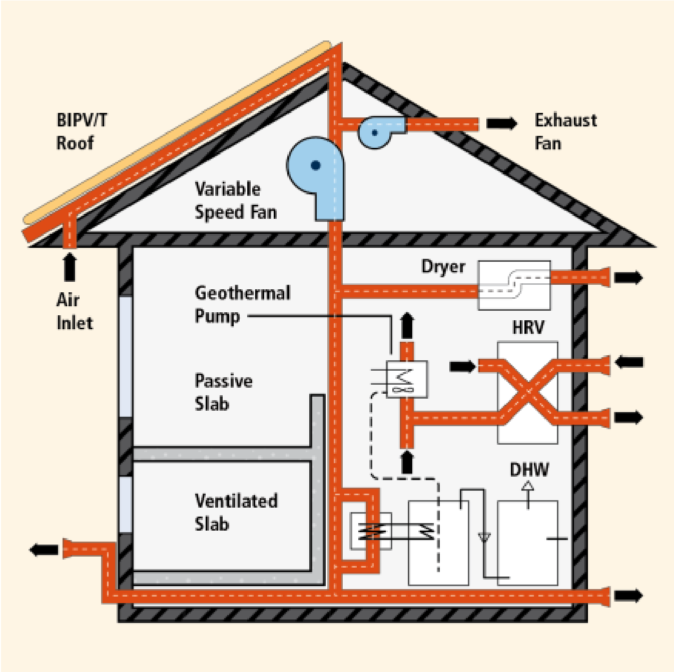
Full scale prototype and numerical model developed

- Construction



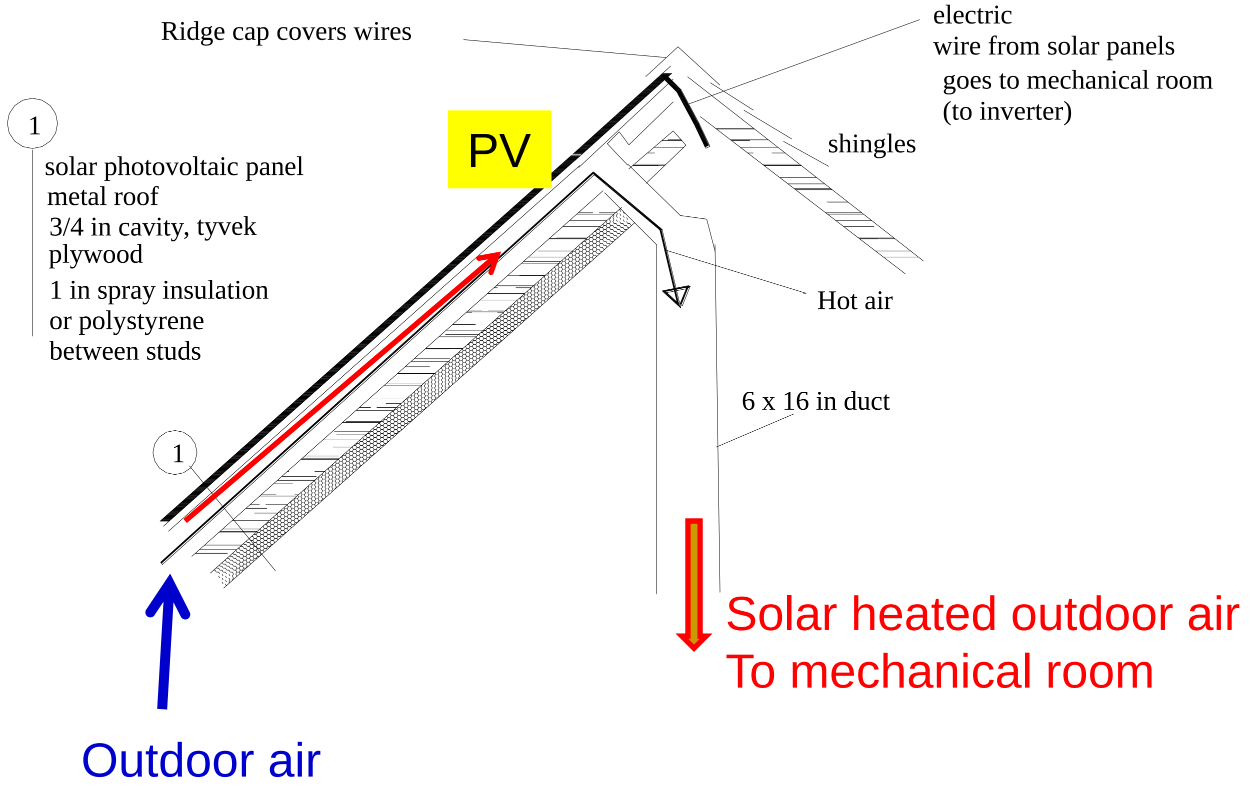




Active and passive thermal storage to reduce peak electricity demand

Building-integrated photovoltaic/thermal (BIPV/T) system principle and design

Open loop
Air system

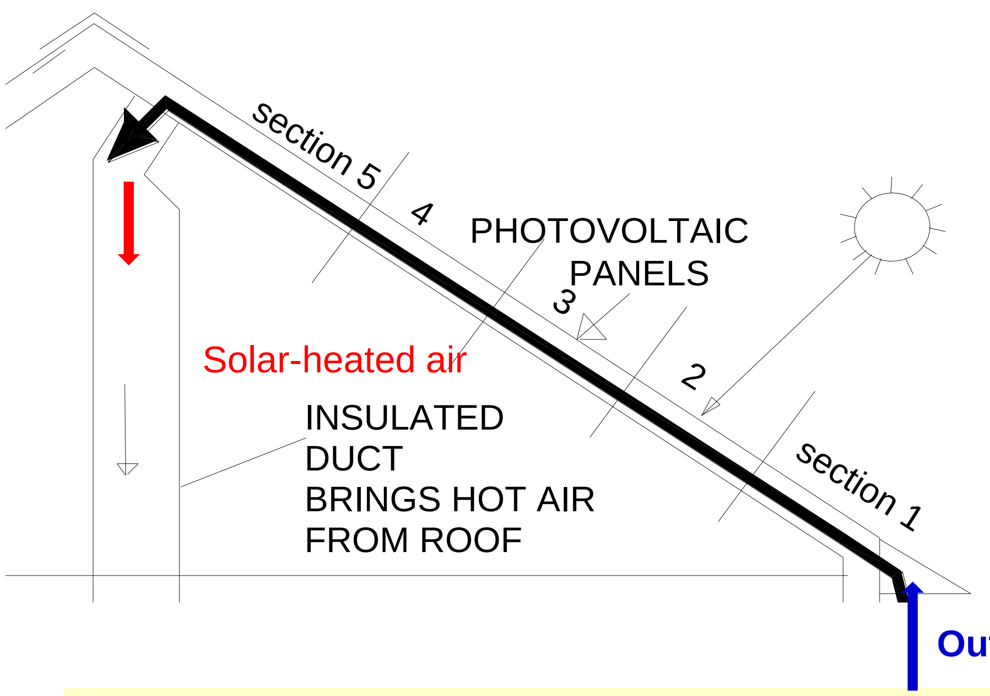


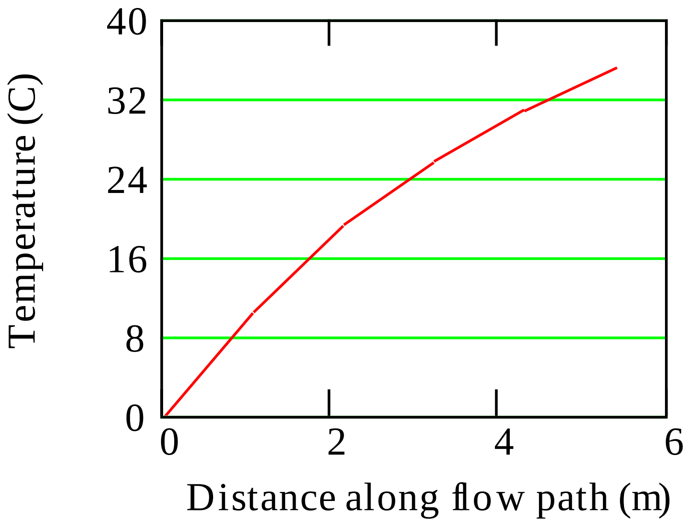
Heat recovery from PV roof raises combined solar efficiency by a factor of >= 3

Possible approaches to design

- **Yearly simulation** versus **design day** approach to compare design options on a relative basis. Both have advantages and disadvantages.
- Consideration of active and passive approaches at the early design stage (similar to combined building – HVAC simulation).
- Approximate yearly simulation with HOT2000 (it can not do thermal mass and control strategies).
- More detailed thermal analysis with our custom developed software (e.g. for BIPV/T and VCS slab) using Mathcad.

BIPV/T roof in 5 sections for analysis Energy model



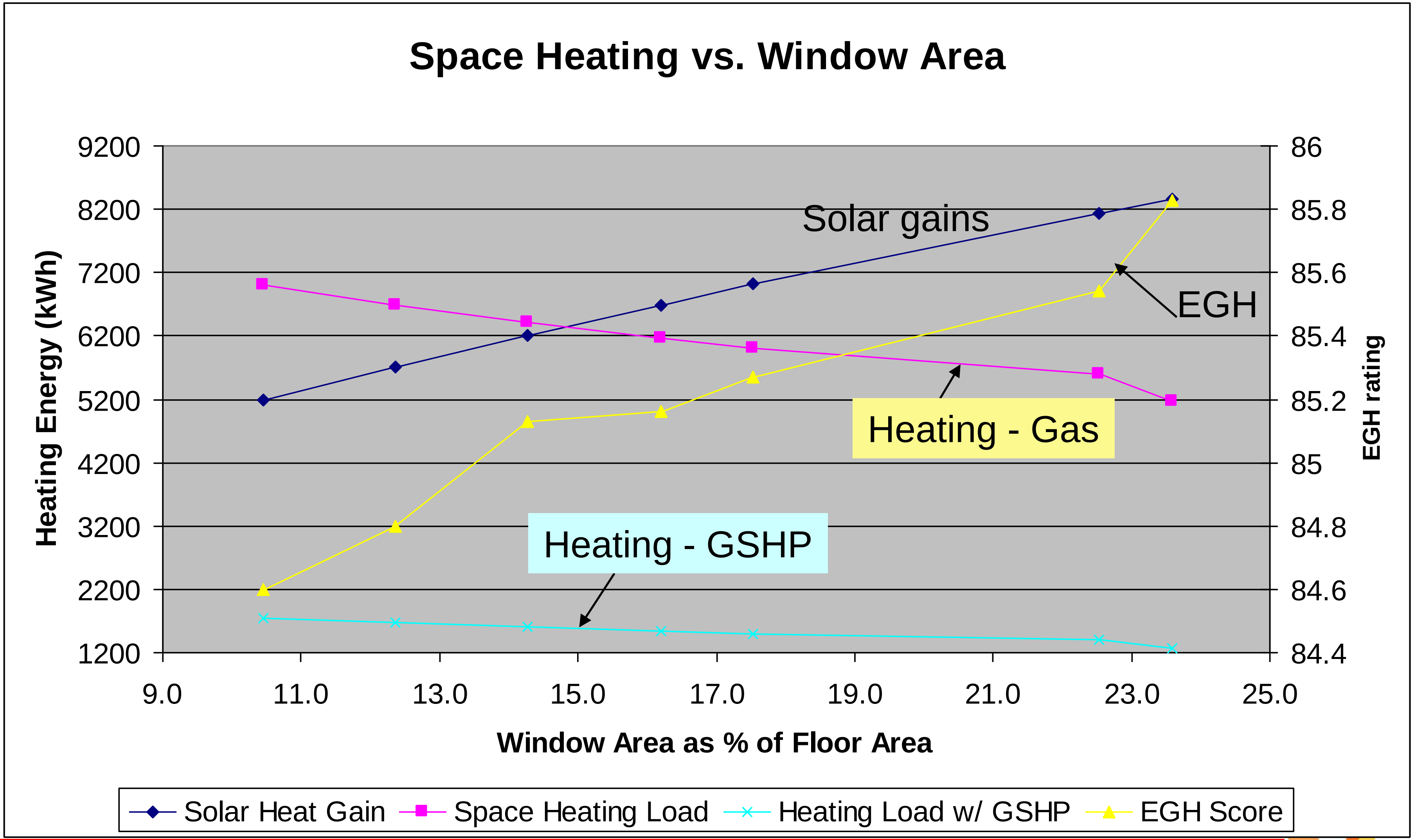


An open loop air system is utilized for the BIPV/T system as opposed to a closed loop to avoid overheating the photovoltaic panels.

Procedure for Initial Energy Analysis

- HOT 2000 simplified analysis to get approximate energy performance figures (energuide etc.) for major parameters such as **window area** (and type) and **thermal insulation.**
- Benefits of **ground source heat pump as compared to gas furnace** in reducing energy consumption for heating (e.g. for one unit of electricity produce four units of heat).

HOT 2000 Preliminary analysis



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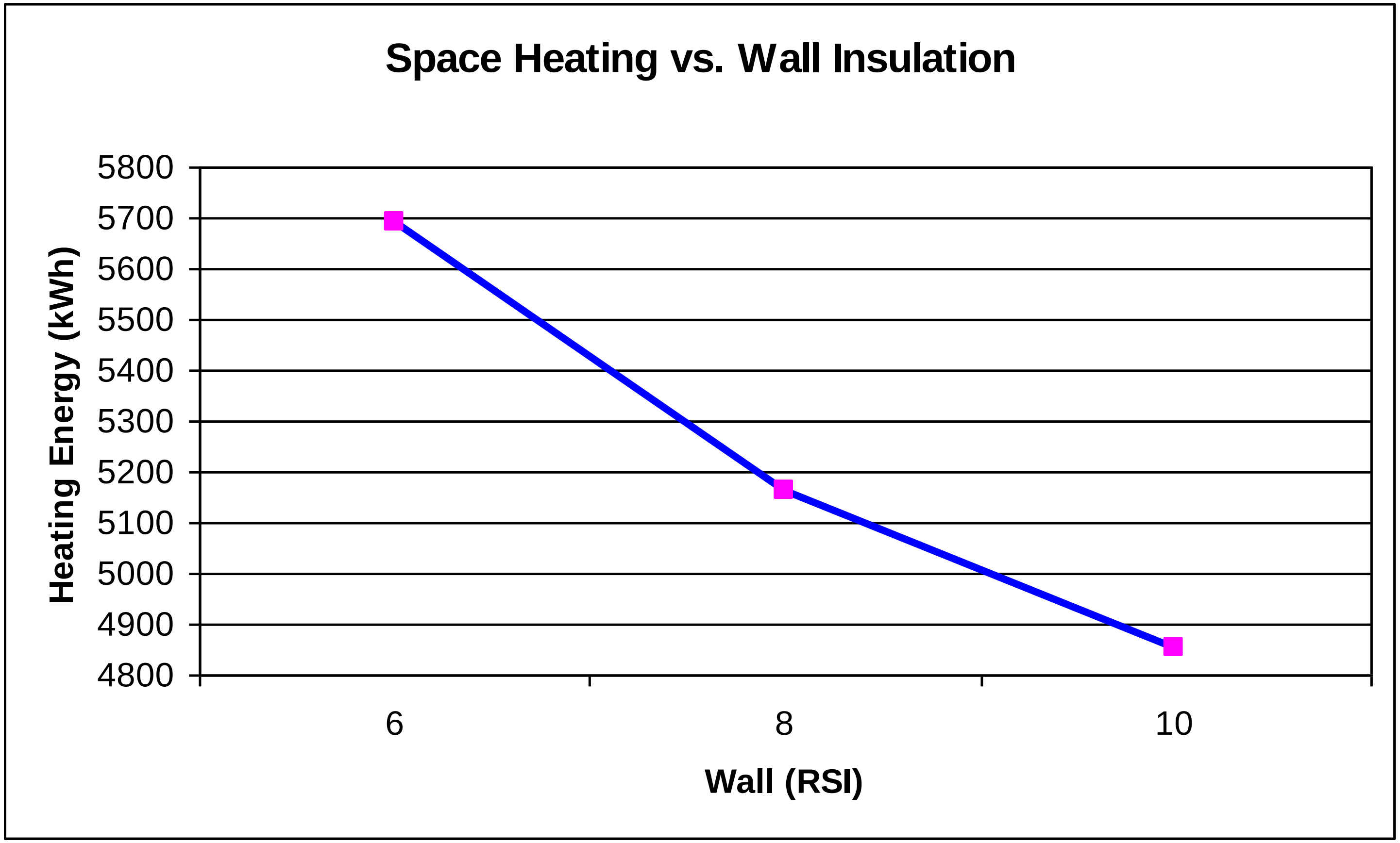
How much insulation, window type?



Note that benefit in going from 6 to 8 RSI is twice that of going from 8 to 10 RSI – but cost is higher than for photovoltaics

Double-glazed low-e argon filled windows adopted; triple glazed >> when?

Tabulated HOT2000 relative results during preliminary design

Case	South Window Area	Percentage of Window to Wall Area %	Percentage of Window to Floor Area %	Solar Gains		Space Heating Load (MJ) w/o ground source HP		Space Heating Load (MJ) w/ GSHP		EGH
				(MJ)	(kWh)	(MJ)	(kWh)	(MJ)	(kWh)	(w/o GSHP)
1	33.5	60.4	23.6	30141.1	8373	18583	5162	4542	1262	85.83
2	32	57.7	22.5	29246.5	8124	20170	5603	5043	1401	85.54
3	24.88	44.9	17.5	25313.6	7032	21631.6	6009	5408	1502	85.27
4	23	41.5	16.2	24097.3	6694	22202.4	6167	5551	1542	85.16
5	20.27	36.6	14.3	22390.4	6220	23070.2	6408	5768	1602	85.13
6	17.55	31.7	12.4	20577.8	5716	24067.5	6685	6017	1671	84.8
7	14.83	26.8	10.4	18661	5184	25192.3	6998	6298	1749	84.6

Case 1 South facing windwos equals to about 24% floor area

Wall RSI	Space Heating Load (MJ) w/o ground source HP	Space Heating Load (MJ) w/ GSHP	EGH (w/o GSHP)	kWh
6	20486	4991.1	85.48	5691
8	18583	4542	85.83	5162
10	17461	4276.2	86.04	4850

The results are intended to give relative impact of major parameters

-Need to be recalculated for final design

- Window and mass need to be fine-tuned in Mathcad

Numerical model in Mathcad

- Transient heat conduction modeled with explicit finite difference thermal network method.
- Flexibility in changing model and accounting for complex designs.
- E.g. one heat source in floor and one in air node.

$$
\begin{pmatrix} qaux_{p+1} \\ T_{1,p+1} \\ T_{2,p+1} \\ T_{3,p+1} \\ T_{4,p+1} \\ T_{5,p+1} \\ T_{6,p+1} \end{pmatrix} :=
\begin{bmatrix}
\mathrm{if}\left[K_p \cdot (Tsp - T_{2,p}) > q_{max}, q_{max}, K_p \cdot (Tsp - T_{2,p})\right] \cdot \left[(Tsp - T_{2,p}) > 3.0\right] \\
\dfrac{\dfrac{T_{2,p}}{R_{12}} + \dfrac{To_p}{R_{1o}} + \dfrac{T_{6,p}}{R_{16}} + qaux_p \cdot .4}{\left(\dfrac{1}{R_{12}} + \dfrac{1}{R_{1o}} + \dfrac{1}{R_{16}}\right)} \\
\dfrac{\dfrac{T_{3,p}}{R_{23}} + \dfrac{T_{6,p}}{R_{26}} + \dfrac{T_{1,p}}{R_{12}} + 0.7 \cdot St_p}{\left(\dfrac{1}{R_{23}} + \dfrac{1}{R_{26}} + \dfrac{1}{R_{12}}\right)} \\
\dfrac{\Delta t}{C_3} \cdot \left(\dfrac{T_{4,p} - T_{3,p}}{R_{34}} + \dfrac{T_{2,p} - T_{3,p}}{R_{23}}\right) + T_{3,p} \\
\dfrac{\Delta t}{C_4} \cdot \left(\dfrac{Tb_p - T_{4,p}}{R_o} + \dfrac{T_{3,p} - T_{4,p}}{R_{34}} + qaux_p \cdot .6\right) + T_{4,p} \\
\dfrac{\Delta t}{C_5} \cdot \left(\dfrac{T_{6,p} - T_{5,p}}{R_{56}} + \dfrac{To_p - T_{5,p}}{R_{5o}}\right) + T_{5,p} \\
\dfrac{\dfrac{T_{2,p}}{R_{26}} + \dfrac{T_{5,p}}{R_{56}} + \dfrac{T_{1,p}}{R_{16}} + 0.3 \cdot St_p}{\left(\dfrac{1}{R_{56}} + \dfrac{1}{R_{26}} + \dfrac{1}{R_{16}}\right)}
\end{bmatrix}
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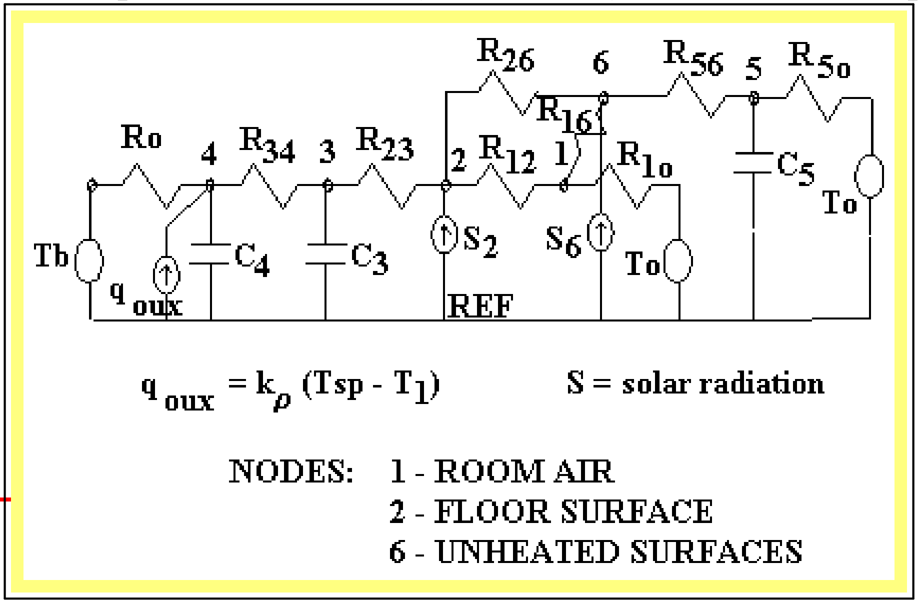


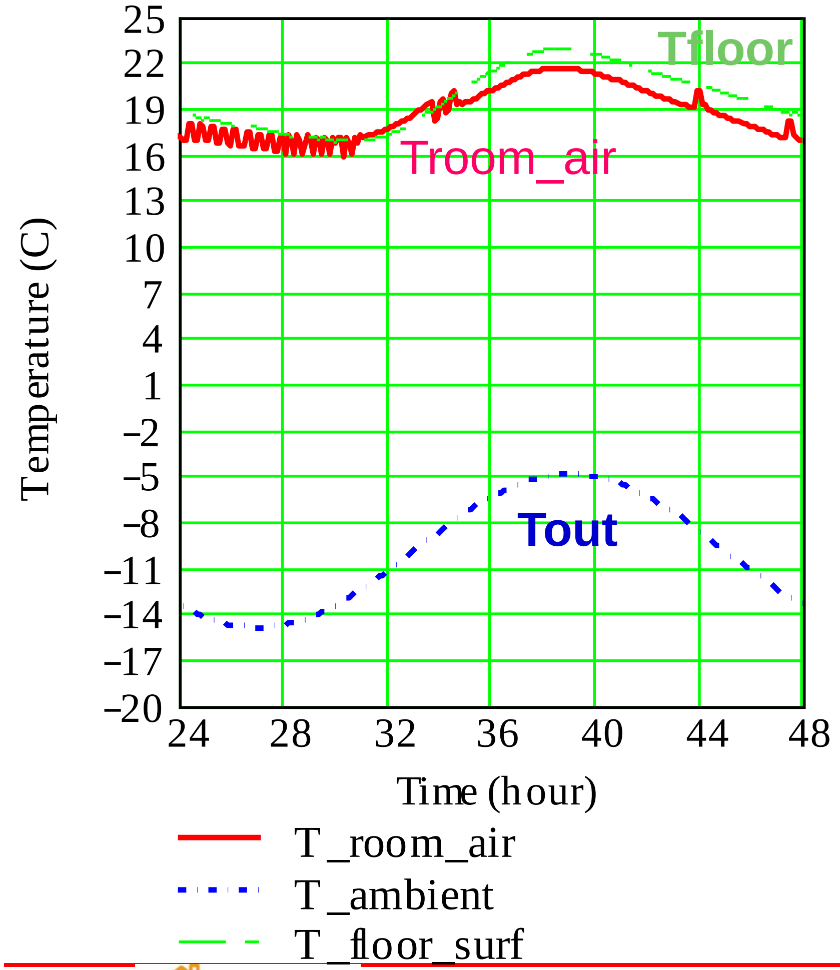
Third order network model

Example: Thermal analysis – clear winter day

Case	Window area (% of south face) and R-value	Mass (cm concrete on first floor)	Aspect Ratio	Heating Type	Energy consumption kWh	Max room temp. C
1	30 (RSI 1)	5 cm	1.3	conv	54	24
2	40 (RSI 1)	5 cm	1.3	conv	51	27
2a	40 (RSI 1)	20 cm	1.3	conv	36	25
3	40 (RSI 1)	20 cm	1	conv	39	24.5
4	50 (RSI 1)	20 cm	1.3	conv	27	28.5
5	50 (RSI 1)	20 cm	1.3	Radiant-conv.	26 (50 on avg day)	28
6	50 (RSI 0.6)	20 cm	1.3	Radiant-conv.	46 (69 on avg day)	27

Optimize window area, type and mass

Design day analysis for passive design

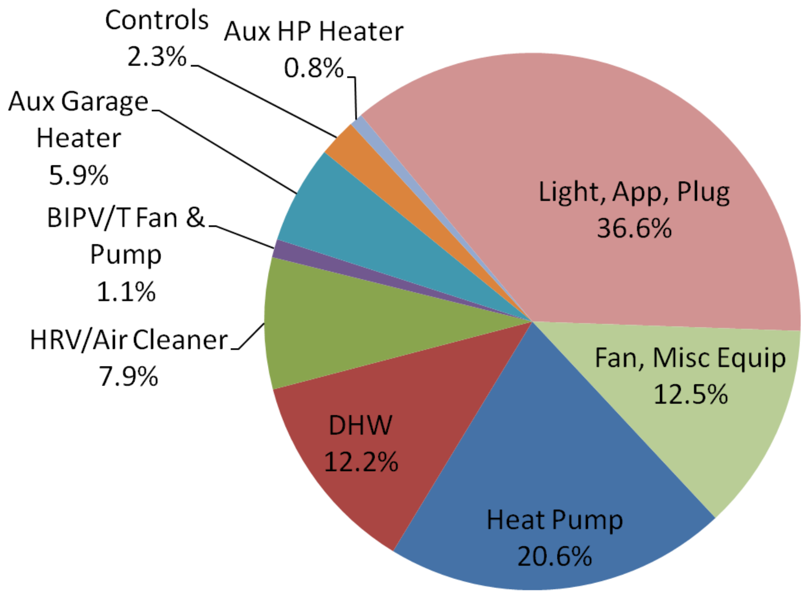


Typical temperature profiles on a cold sunny day in February

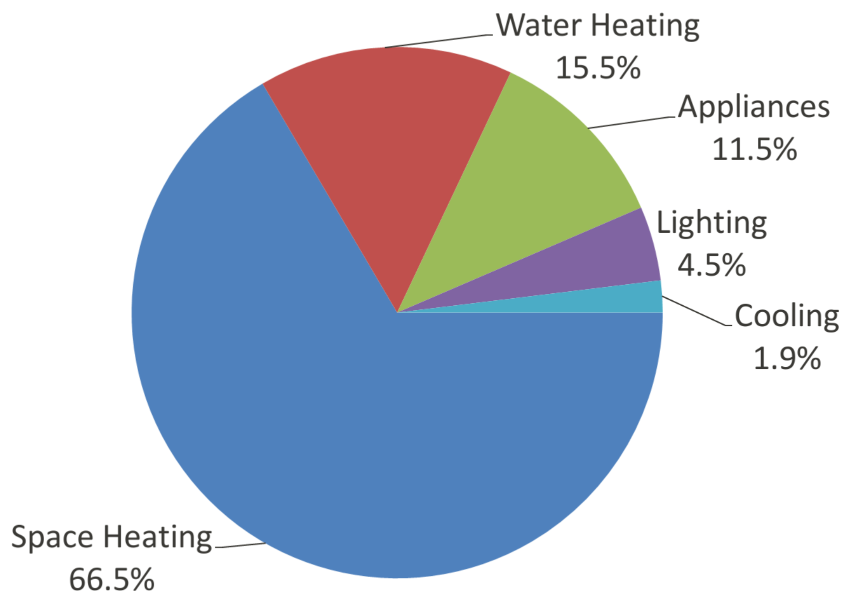
Some heating at night only.

Direct gain zone is expected to experience in general a temperature swing of 2-6°C associated with solar gains on clear days in January to March.

Annual Consumption – First year and reaching net zero



ÉcoTerra
10,318 kWh/year

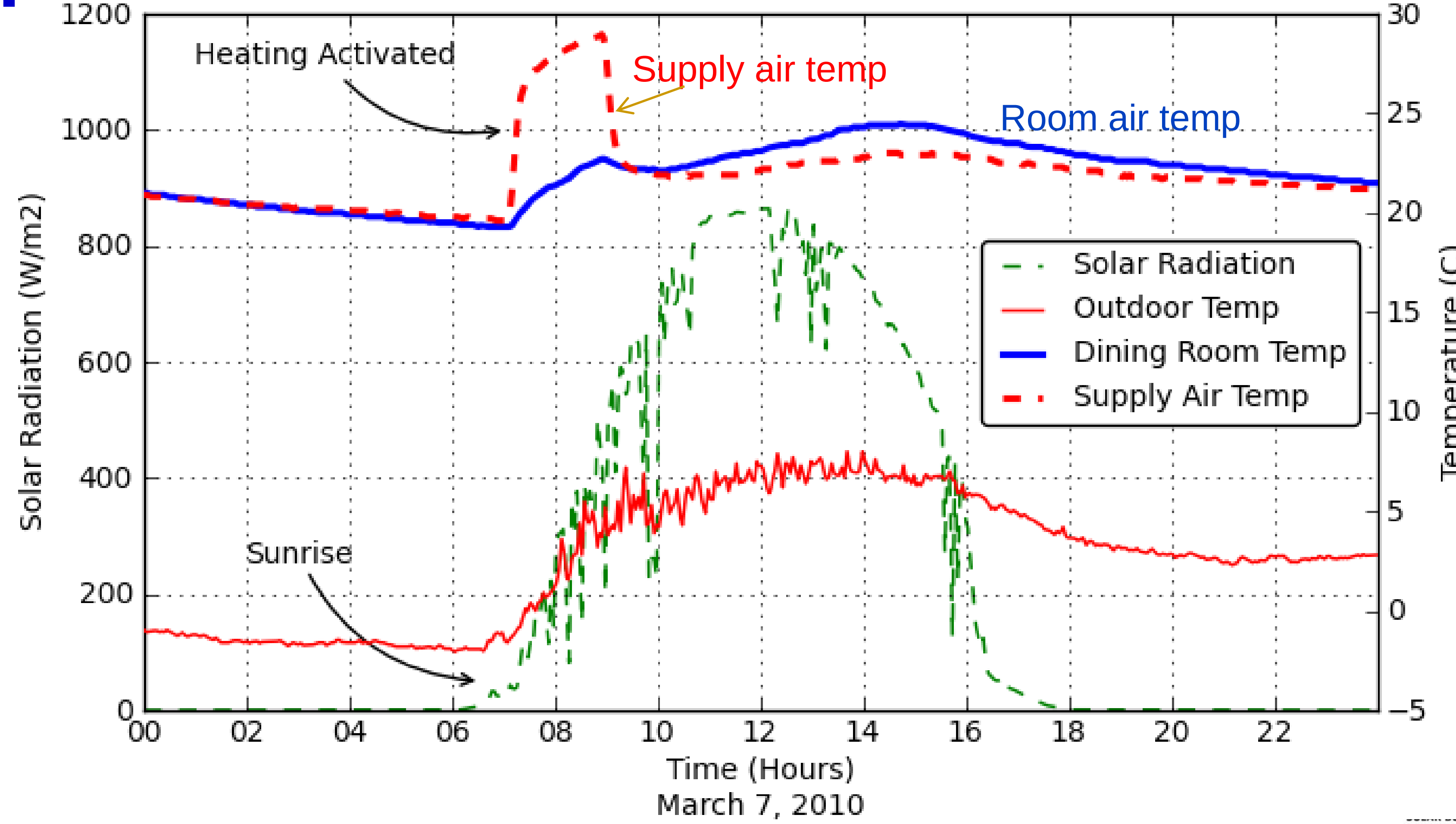


Average Single-Family Detached Home in Canada
38,389 kWh/year

About **3000 kWh** are due to additions by occupants: garage heater, added lighting, …
15% efficient BIPV system would result in net-zero; also improved use of heat

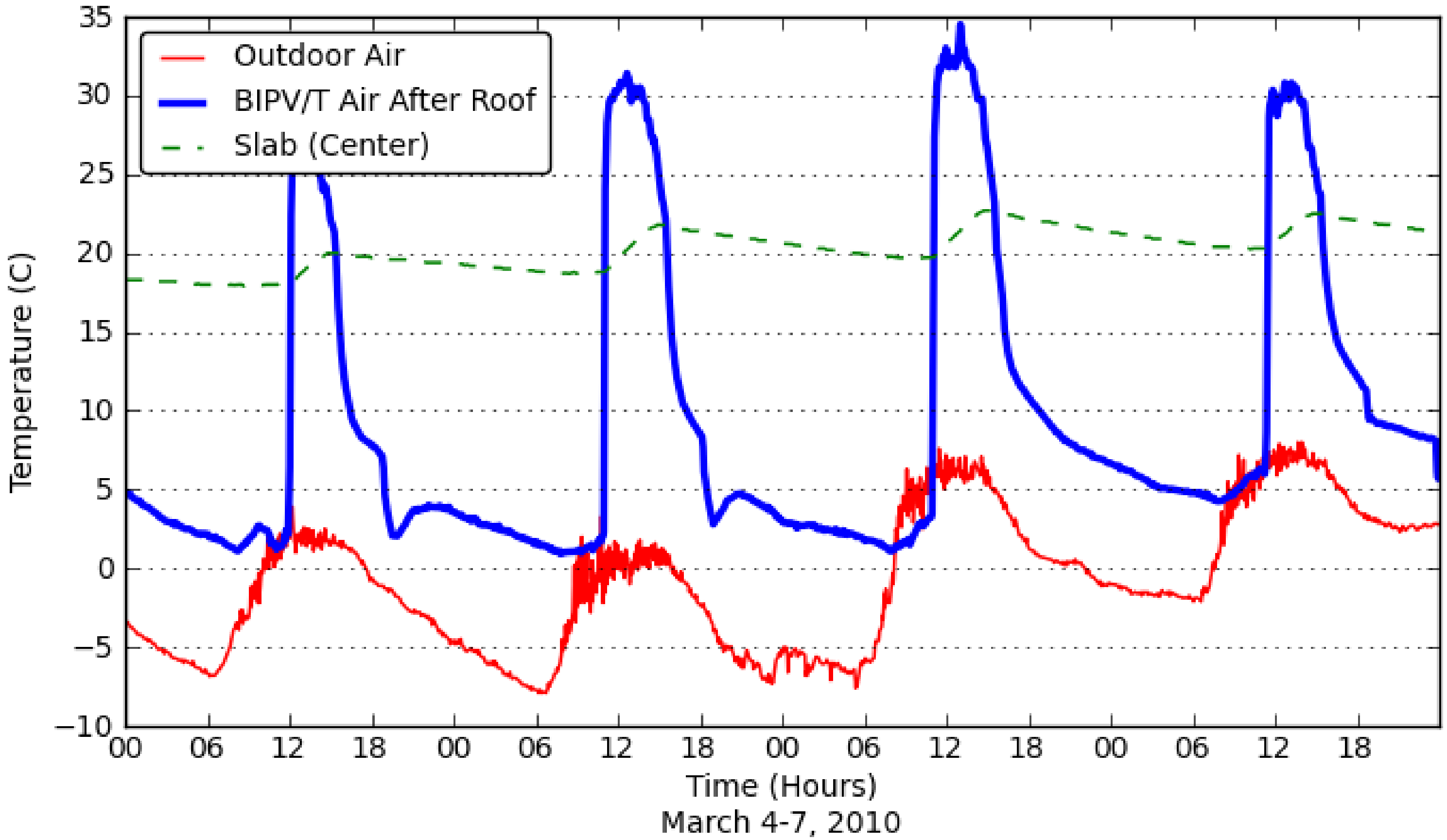
Data from: http://www.oee.rncan.gc.ca/corporate/statistics/neud/dpa/tableshandbook2/res_00_2_e_4.cfm?attr=0

Typical winter sunny day performance



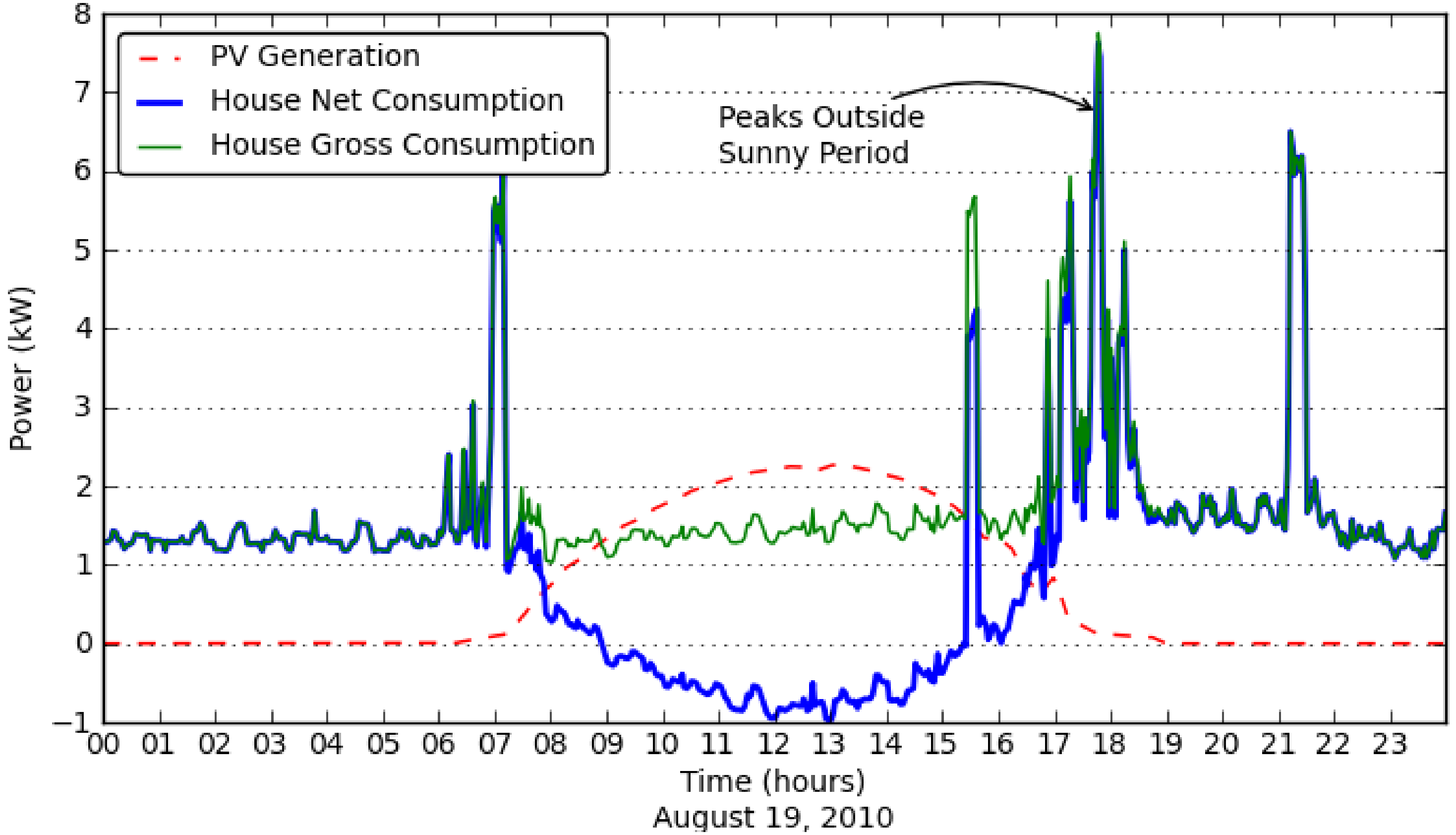
Passive solar gains result in almost no heating needed on a cold sunny day

Ventilated Concrete Slab Performance



- Slab peak temperature rises from 20˚C to 22.5˚C

Demand Reduction and Export to Grid: Example summer day



- Peak demand outside of generating hours;
- House supplies energy to grid during daytime

Alstonvale Net Zero Energy Equilibrium House

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Energy positive house – 8.4 kW BIPV   Also charges electric vehicle

Alstonvale Net Zero House (ANZH)

- A prototype of a house with a **Building Integrated Photovoltaic Thermal (BIPV/T)** roof as its main energy source.
- The ANZH designed to supply electric power for an electric vehicle /PHEV.
- **Passive solar design and SMART control strategies** are key elements in the design, incorporating together the HVAC, power production, lighting and shading systems.

8.4 kW BIPV/T linked to **air-water heat pump** that heats **4500 L storage** tank

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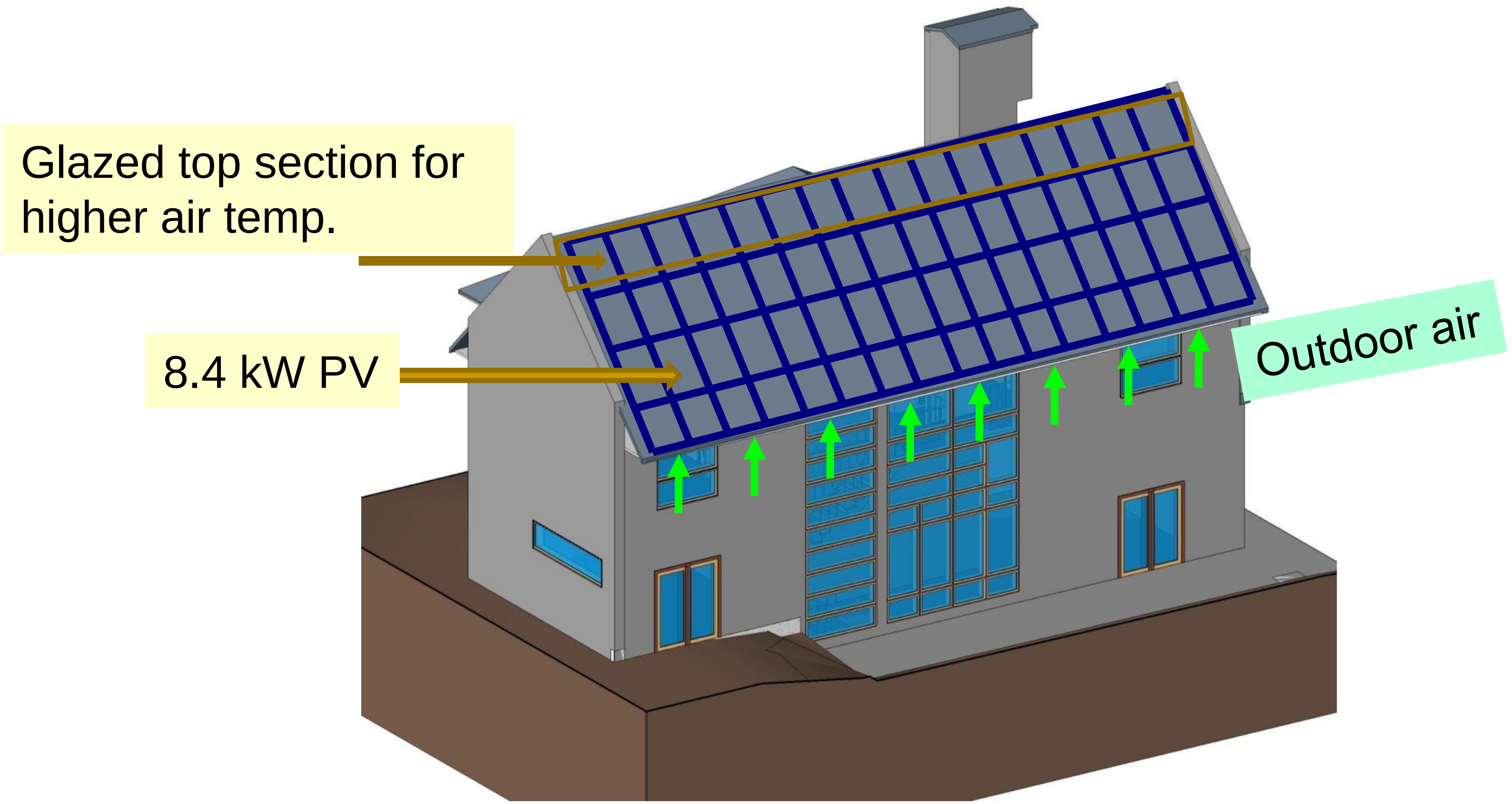
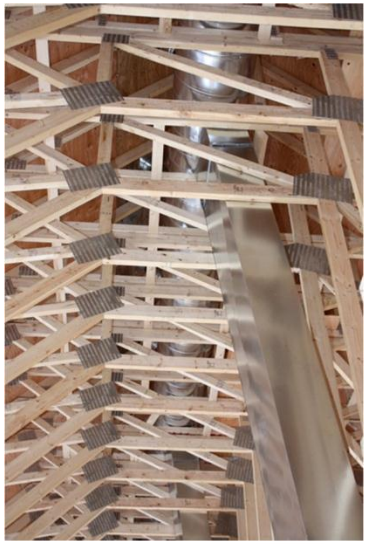
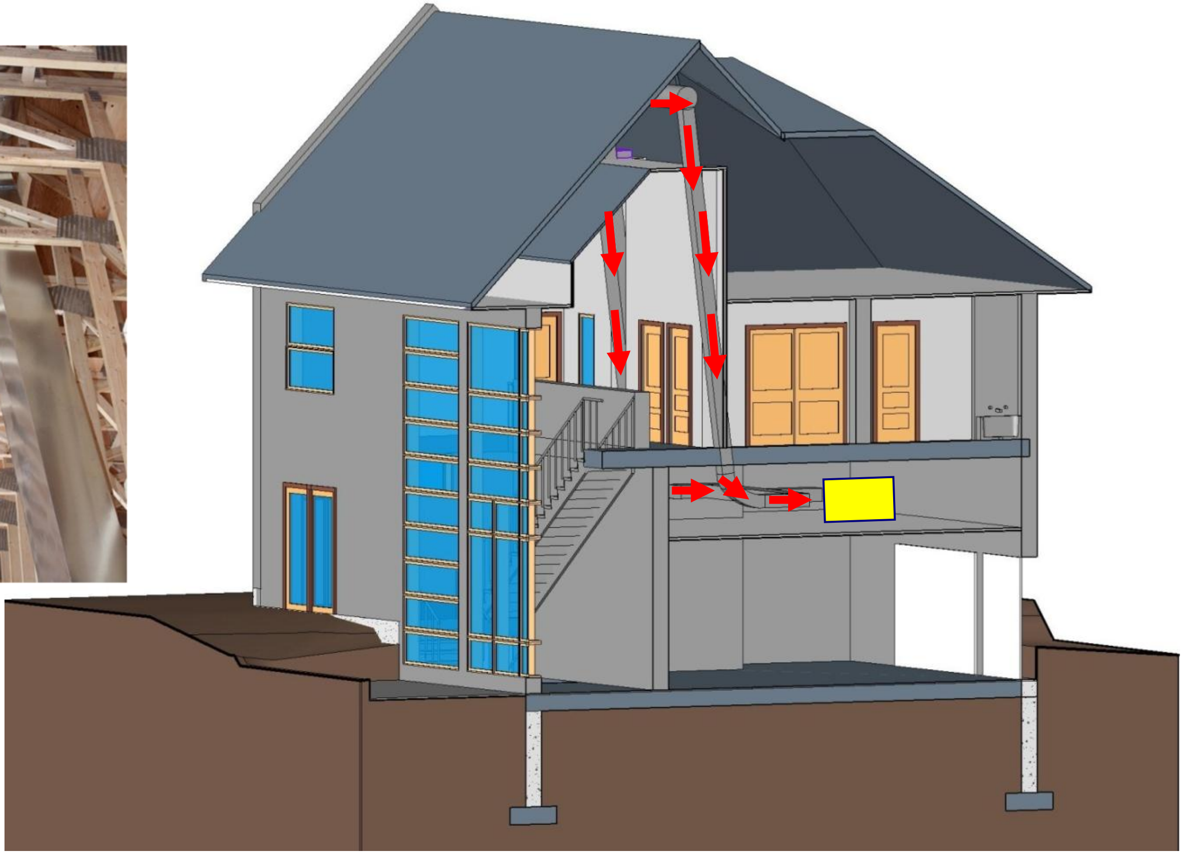
BIPV/T Roof of Alstonvale house



Solar-heated air used as source for air-to-water heat pump

BIPV/T Manifold and Duct

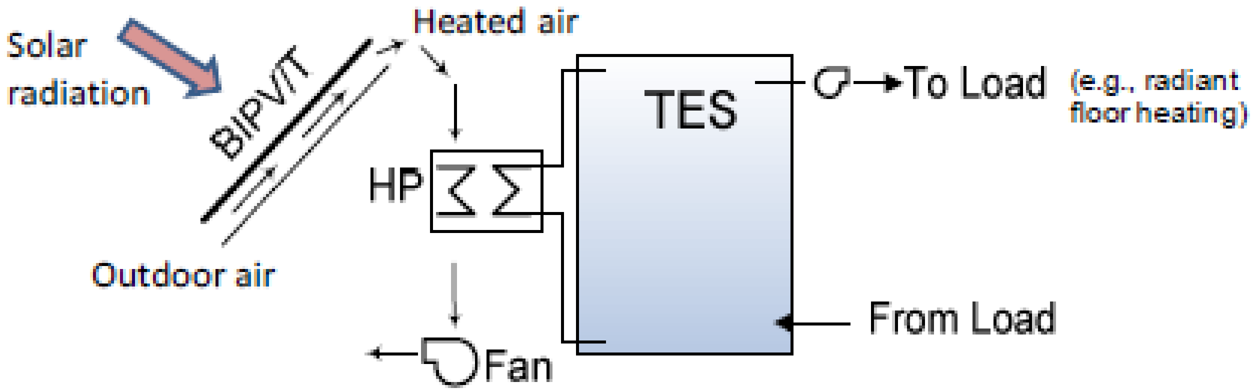




Air-to-water heat exchanger in garage ceiling

Predictive control – solar source heat pump
(J. Candanedo)

- The BIPV/T system is used as the source of a heat pump to heat a water tank.



- The problem consists of finding the **optimal set-point** for the water tank, depending on the expected load and available solar radiation.

Commercial and institutional building examples

- JMSB – new office building – focus on façade –integrated BIPV/T
- Trudeau airport – control of shading and daylighting.
- Hybrid ventilation – engineering building of Concordia.
- NREL building

JMSB BIPV/T Solar Facade: A Solar Buildings Research Network Demonstration Project

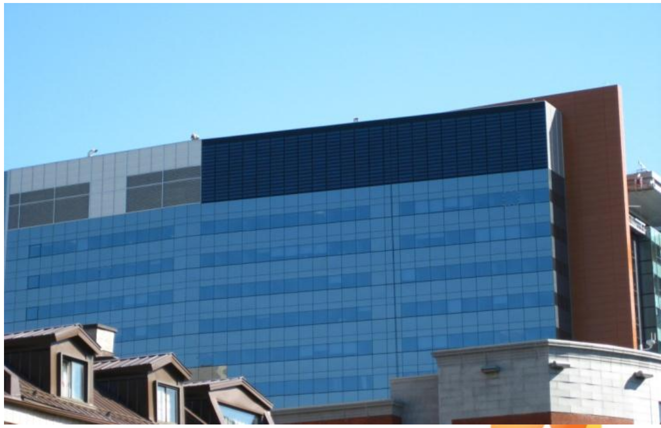
Back façade
of new building
(JMSB- Concordia)

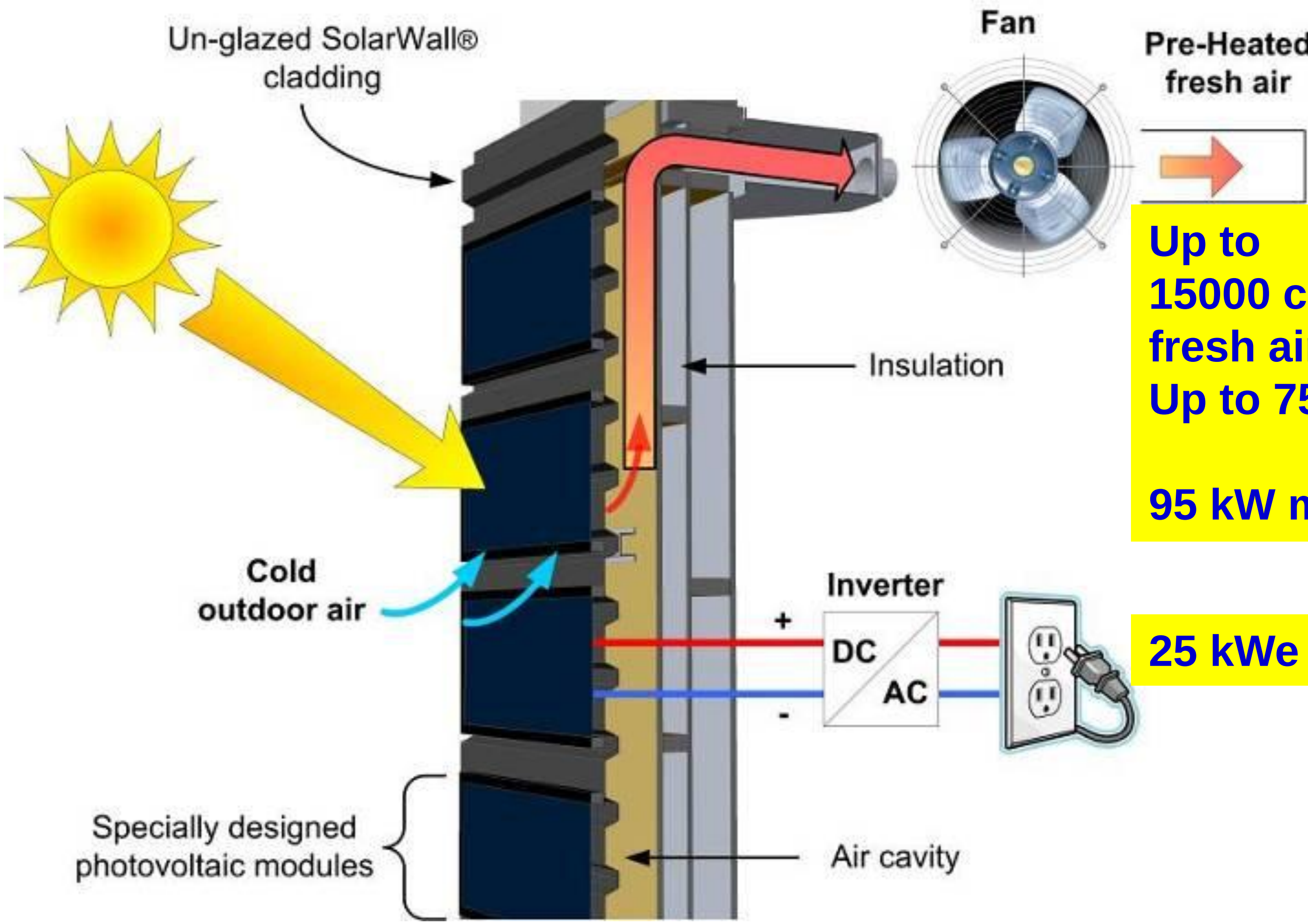
Key Features

- It consists of specially designed photovoltaic panels optimally combined with perforated wall cladding through which much of the ventilation air of the building is drawn as solar-heated fresh air.

Building Integration

- Essentially, from one building surface with an area of about 300 square metres, we generate both solar electricity (up to 25 kilowatts) and solar heat (up to 75 kW of ventilation fresh air heating).
- The system also forms the exterior wall layer of the building i.e. it is NOT an add-on, and that is why we call it building-integrated.





Up to 15000 cfm fresh air = Up to 75 kW heat

95 kW measured

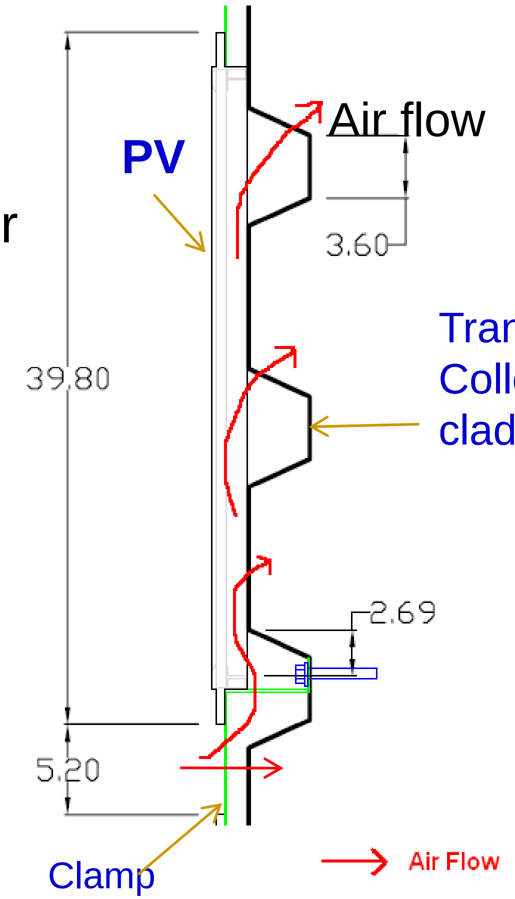
25 kWe

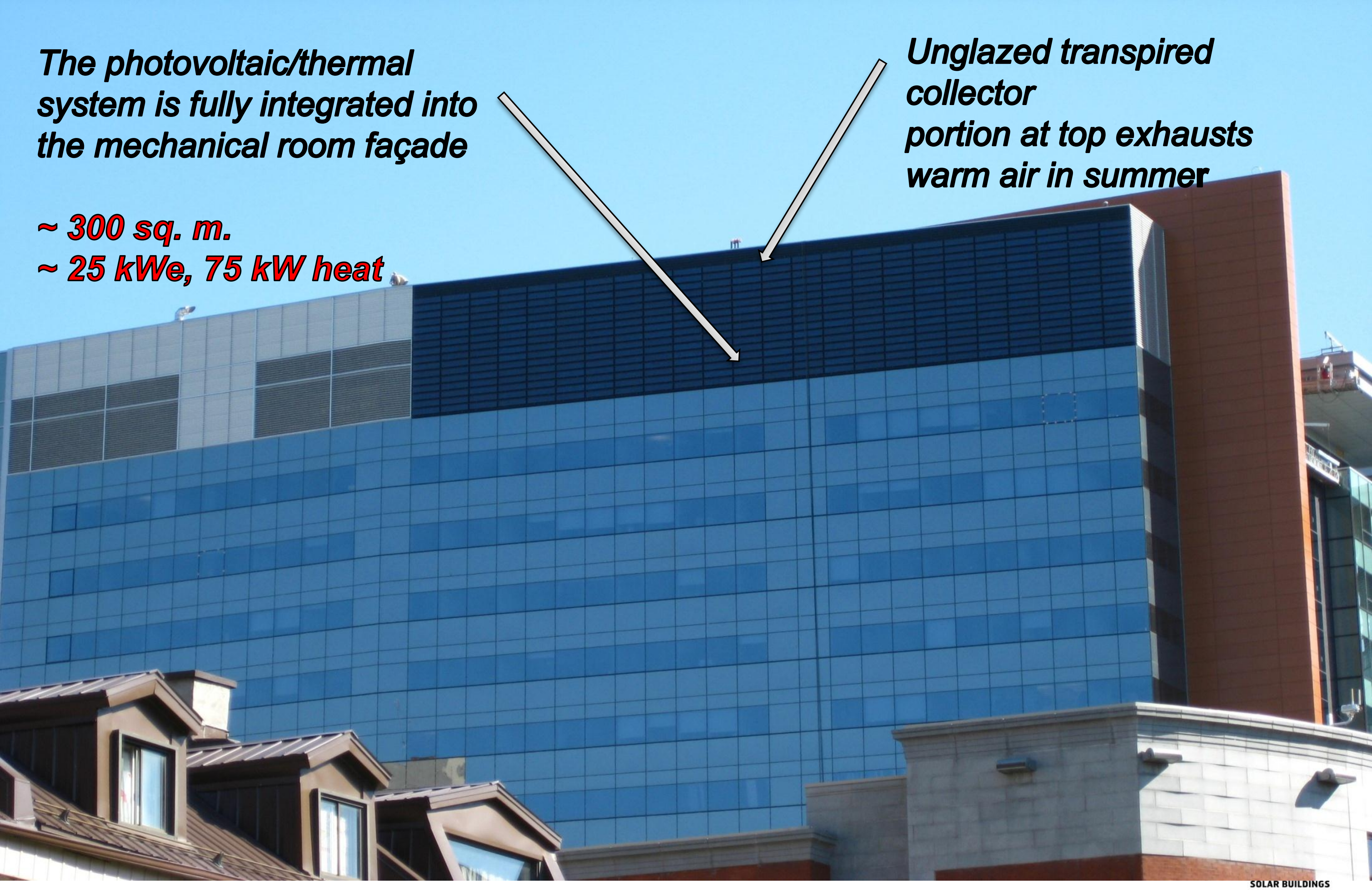
Air flow paths in BIPV/T system

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

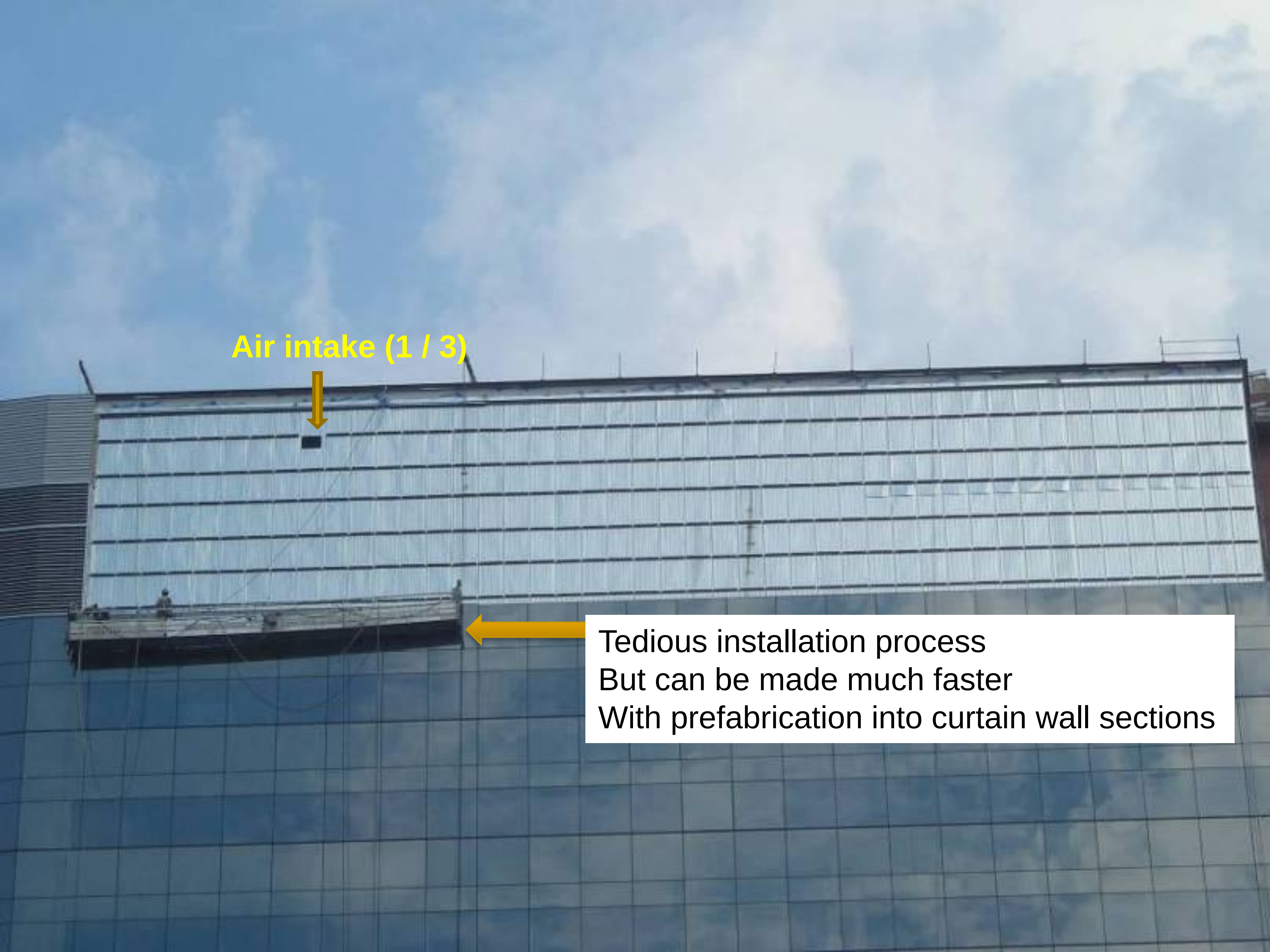




SOLAR BUILDINGS RESEARCH NETWORK

Integration: with the envelope, architectural and with HVAC (fresh air preheat)


Mechanical room

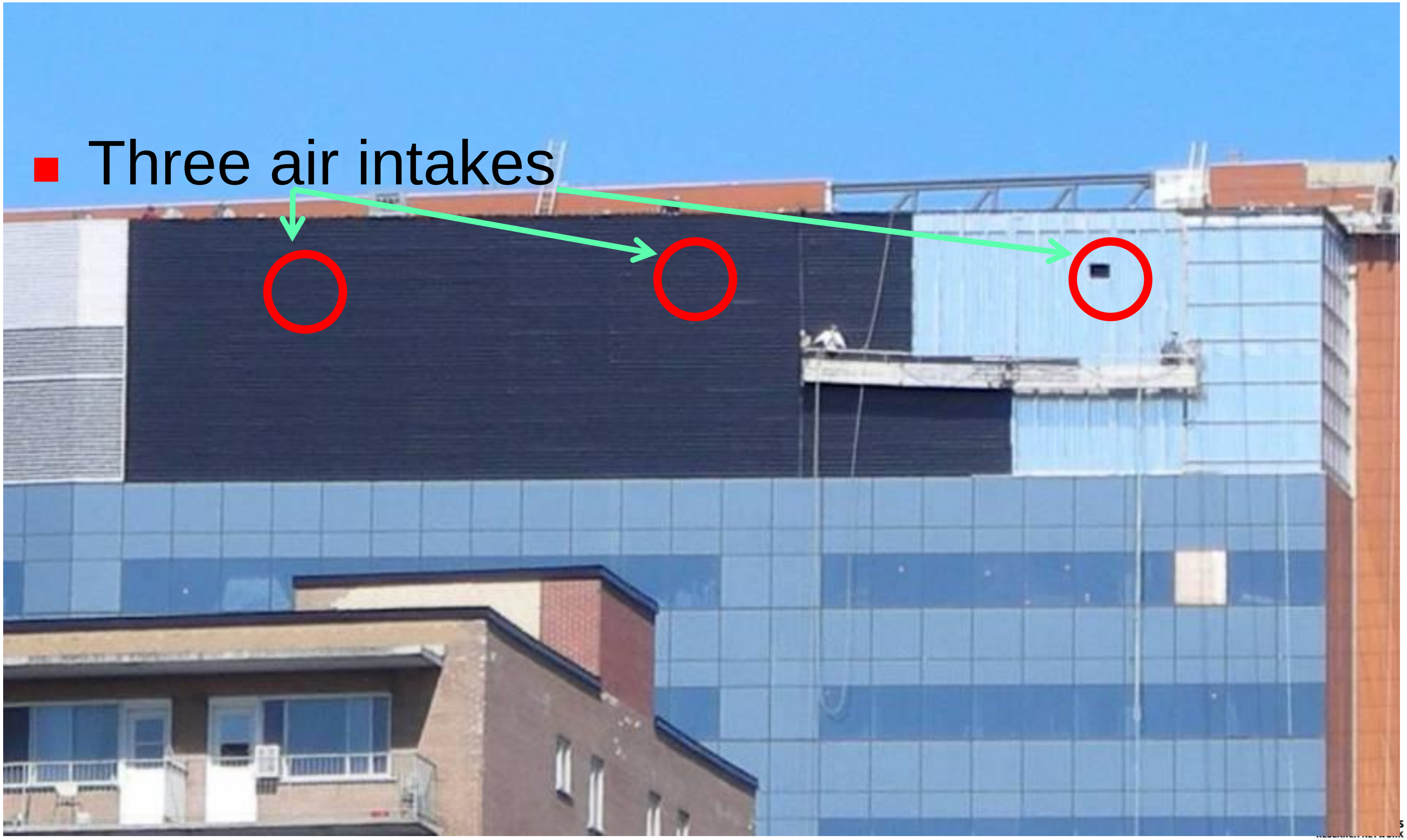

Air intake (1 / 3)
Tedious installation process
But can be made much faster
With prefabrication into curtain wall sections

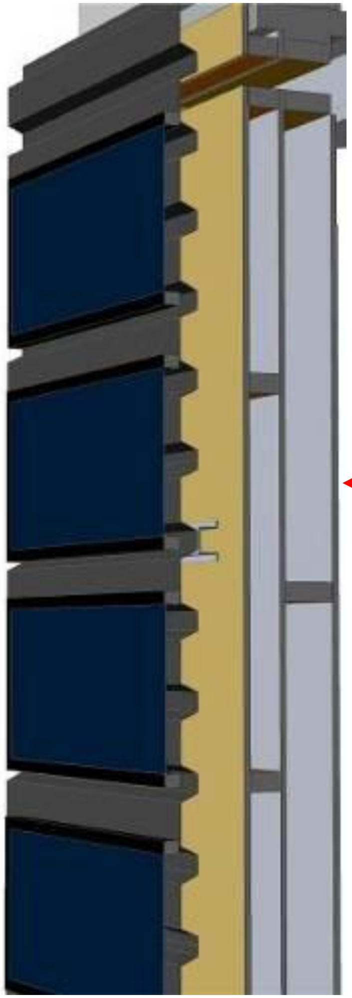

100 mm insulation
Mineral wool and
steel lining


Installation of transpired Collector cladding
Air cavity

Convenient location – mechanical room floor

- Three air intakes





Experimental prototype developed at Concordia

Transpired collector

Transpired collector with PV

Testing of two design options under the same conditions

Electricity is Typically about 4 times as valuable as heat output

Results from BIPV/T test facility (Concordia)

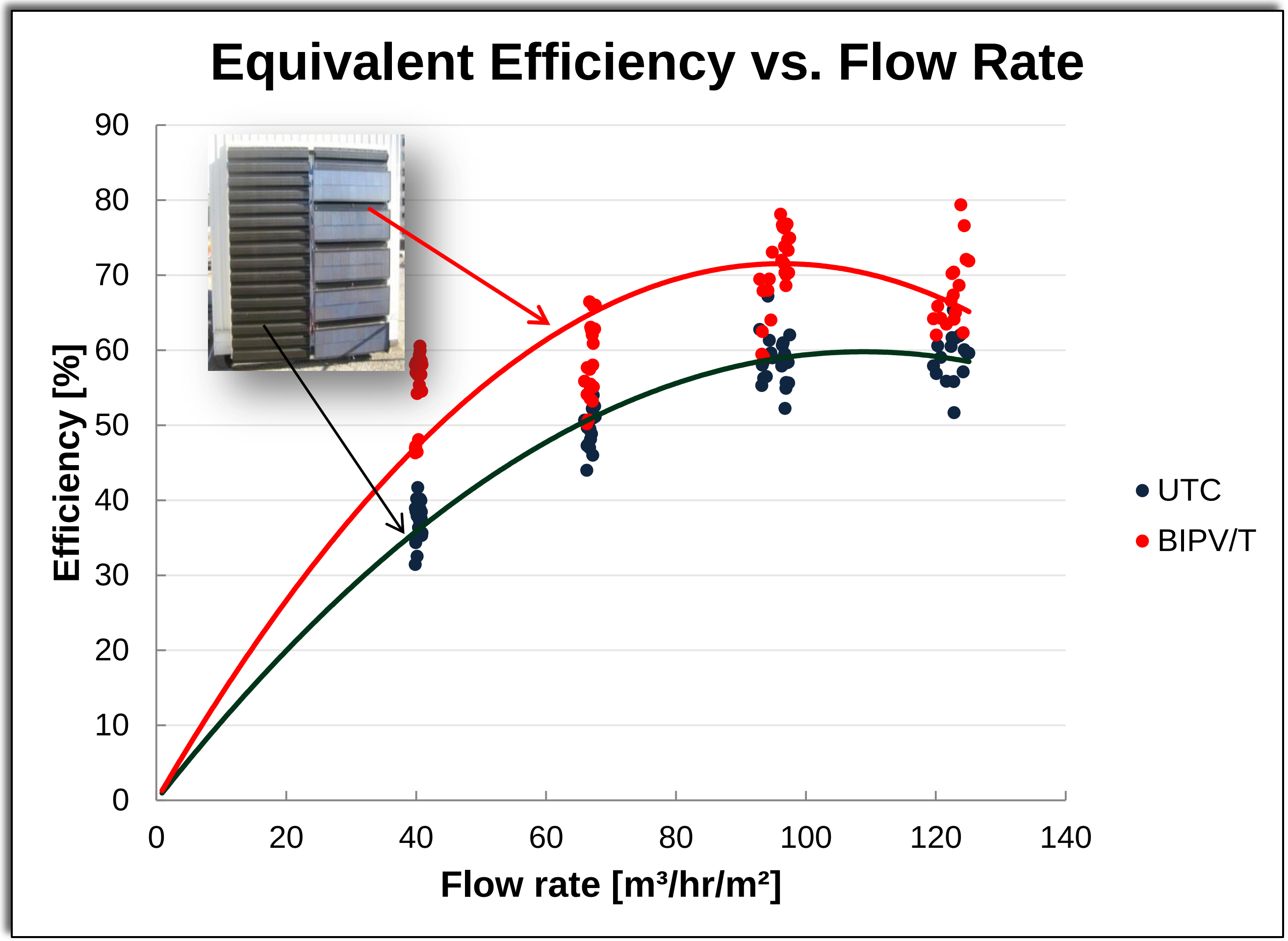
Electricity is about 4 times as valuable as heat.

Equivalent efficiency Shown for clear April day.

Promising system!

Control of airflow is Important

JMSB system is being monitored and studied.

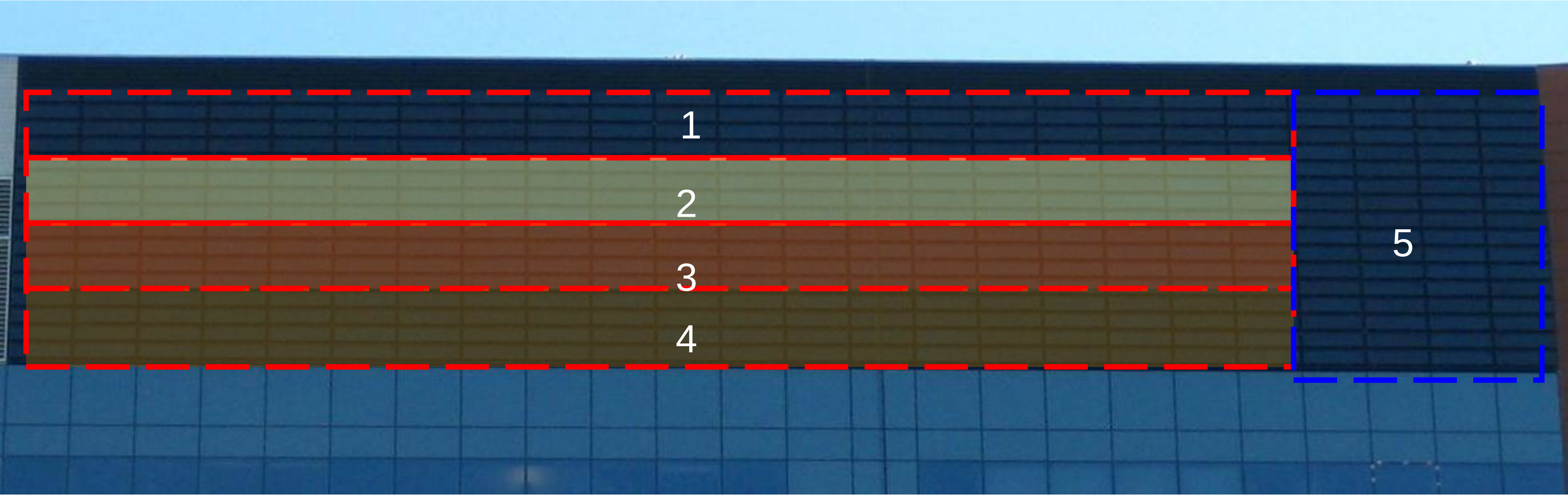


Initial results from the JMSB systems show a recovery of up to 90 kW of heat

SOLAR BUILDINGS RESEARCH NETWORK

PV Panel Layout (25 kWp)

- **5 inverters (5 kW capacity/each)**
  - Grouped in narrow strips to avoid slight temperature stratification effects
  - 5th array created to meet geometric constraints
- **383 modules @ 65 W**
- **10 modules in series (Inverters 1 – 4)**
  - 5th inverter : 9 in series



Installation process

- Engineered system – prototype.
- Special clamps designed to attach panels so as to allow airflow.
- Can be further developed to reduce installation time if solar cells can be directly integrated on transpired wall cladding.

Can use curtain wall technology to reduce installation time.

Just 300 sq.m. was covered.
Imagine possible generation with 3000 sq.m. BIPV/T

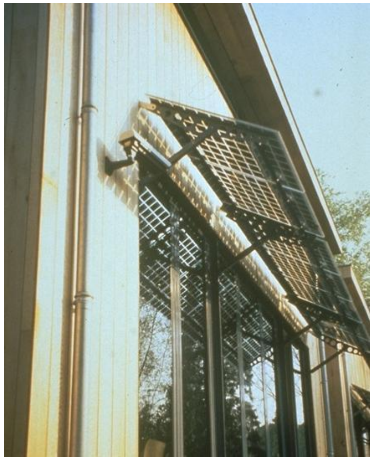
Possibilities in the design of a building like JMSB

- If the whole or larger part of near-south facing façade is covered with BIPV/T system (can be semitransparent) and roof is also covered – can potentially cover all energy needs of a well insulated building (now will cover about 5%).
- Need to be fully integrated for aesthetic and architectural appeal.

SEMITRASPARENT PV FOR FACADES

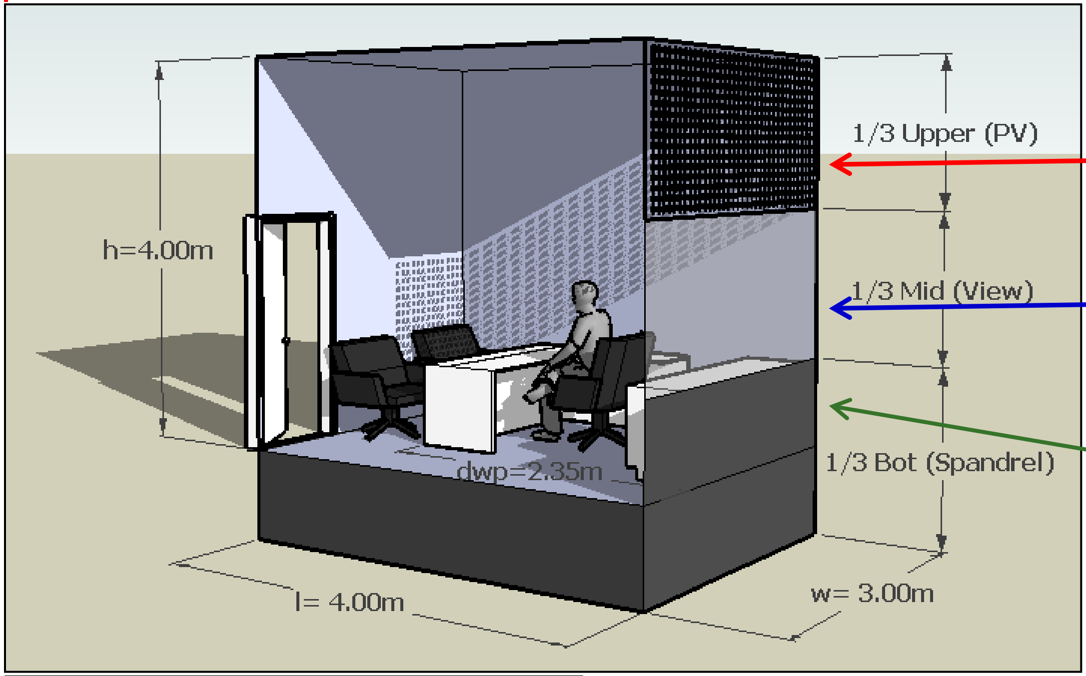
- Generate electricity and transmit daylight simultaneously → also reduce lighting and cooling energy consumption.

Artistic semitransparent PV window – Concordia Solar house



- Challenge: develop low-cost semitransparent PV windows that optimize the net energy generated while transmitting adequate daylight.

Semitransparent PV windows: **Daylight + solar electricity**

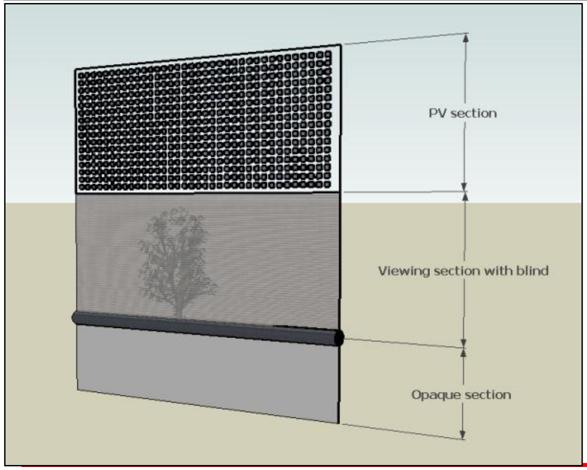


3-section façade:

1/3 Upper section with semitransparent PV

1/3 Middle viewing section with blind

1/3 Bottom opaque section below workplane



Base case –
Single office located in Montreal

Develop concepts and design methodology for façade with PV

SOLAR BUILDINGS RESEARCH NETWORK
RÉSEAU DE RECHERCHE SUR LES BÂTIMENTS SOLAIRES

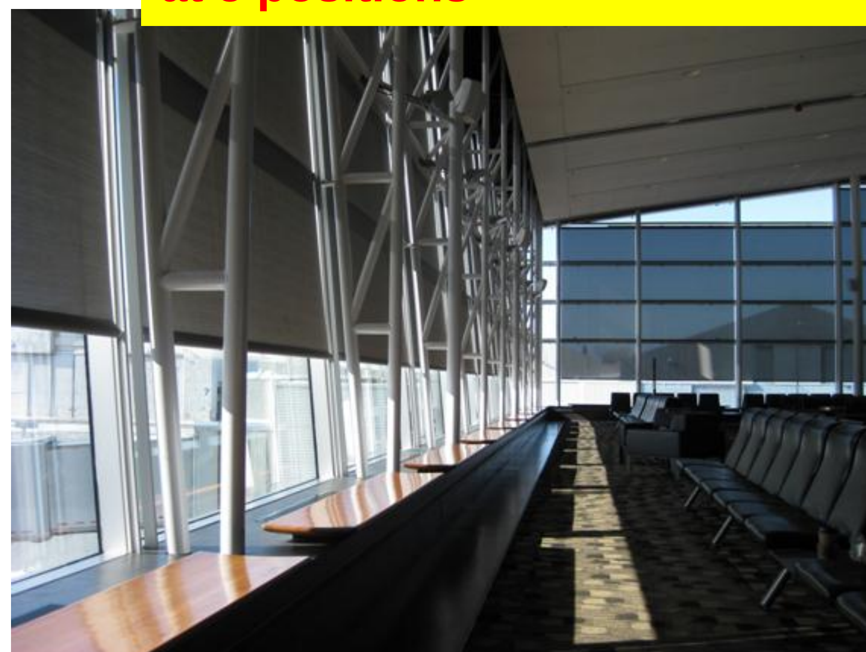
Trudeau airport: Before and after

Electric lights were on during sunny days, when daylight levels are high.
The motorized shades were open, causing discomfort near the perimeter and overheating.

Automatic control of motorized shades successfully implemented with SBRN control algorithms

Motorized shades controlled at 5 positions

No motorized shade control

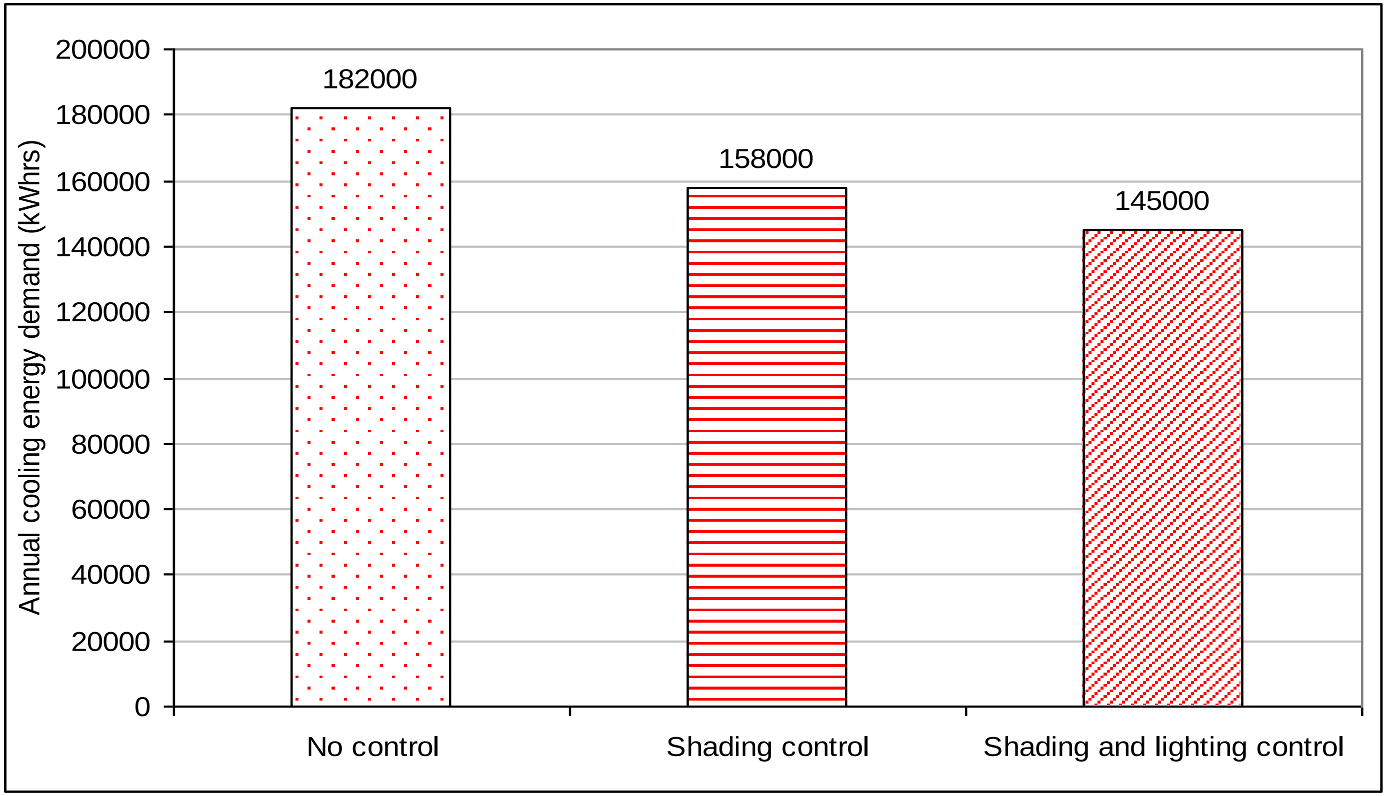


Annual energy demand for cooling is reduced by **13%** if the shades are appropriately controlled and by **20%** if the lights are simultaneously controlled.

RÉSEAU DE RECHERCHE SUR LES BÂTIMENTS SOLAIRES

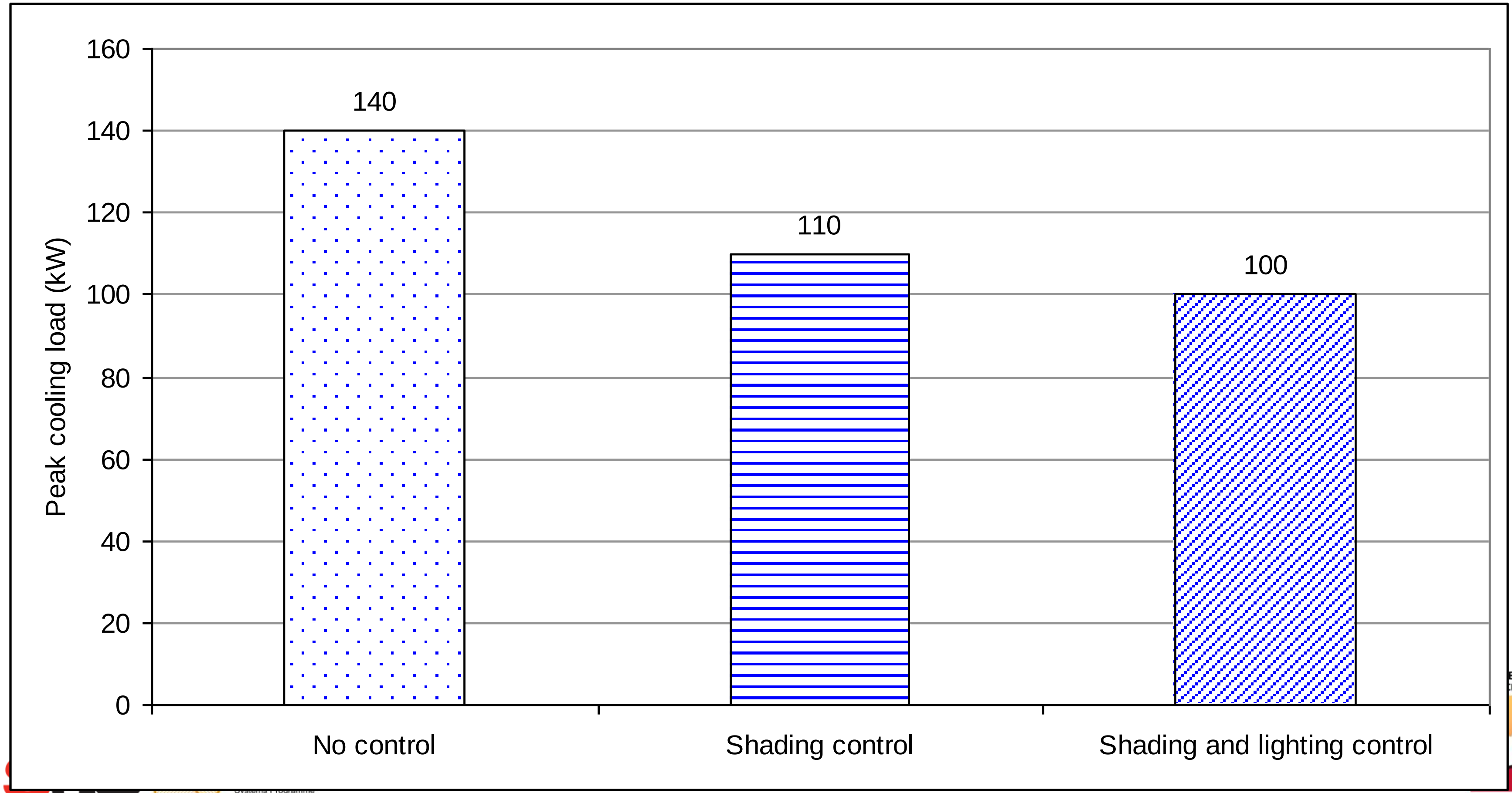
Simulation results- annual energy demand

- The annual energy demand for cooling is reduced by **13%** if the shades are appropriately controlled and by **20%** if the lights are simultaneously controlled.



Simulation results - peak load reduction

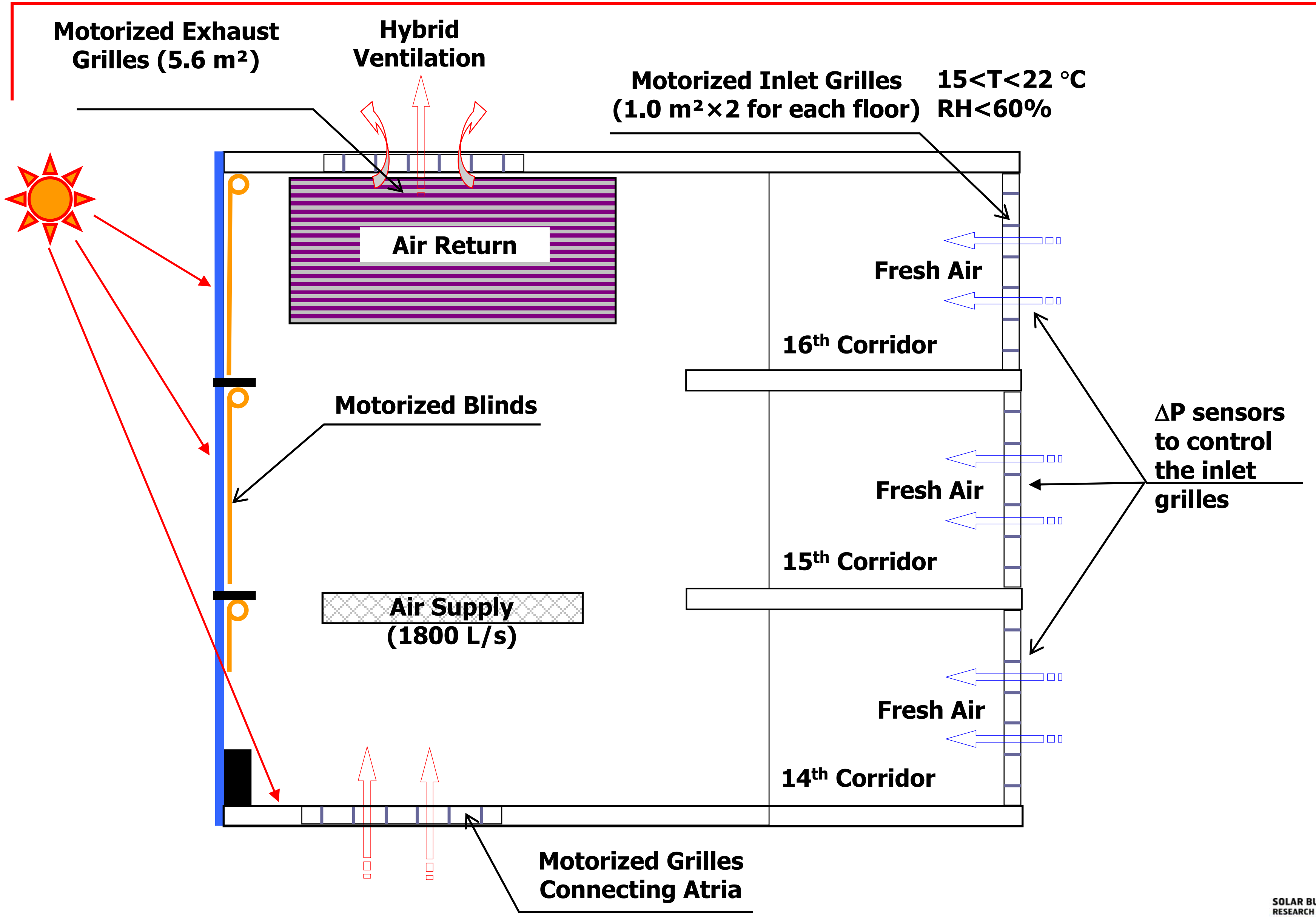
- Peak cooling load is reduced by **21%** if the shades are appropriately controlled and by **28%** if the lights are simultaneously controlled.



HYBRID VENTILATION

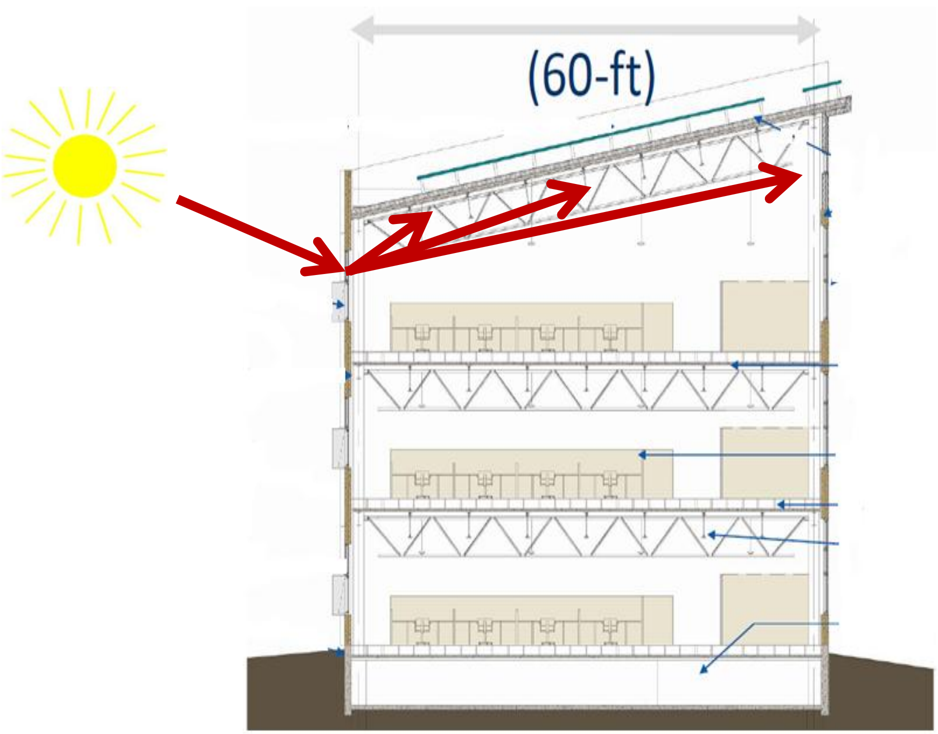
P. Karava

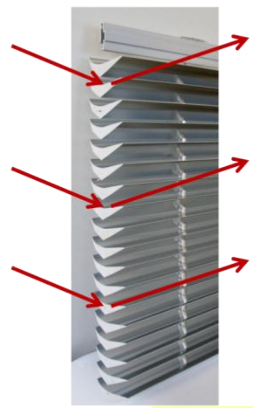
- 15 storey-atrium separated every three storeys with a floor slab; motorized blinds



40% SAVINGS IN COOLING ENERGY CONSUMPTION

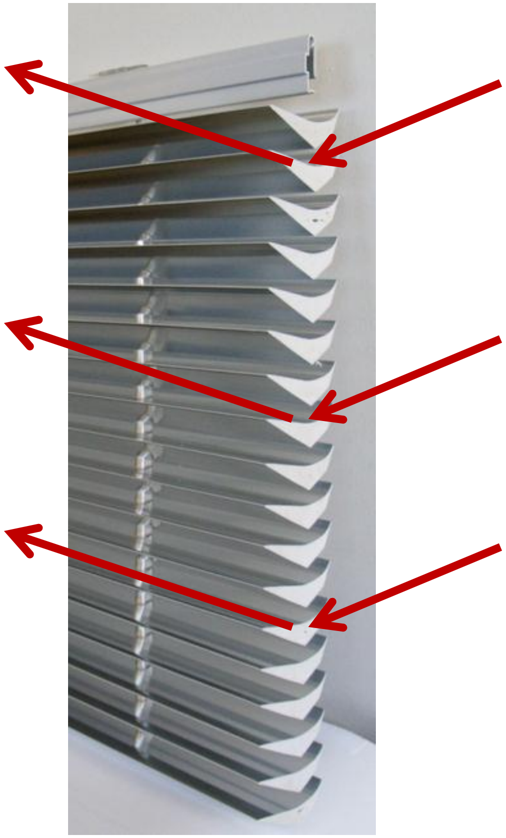
Example: NREL Building (Daylighting Strategy)





Use of fixed reflective louvers on inside of top part of south facing windows to reflect daylight towards the back of the open plan space and the ceiling

Daylighting Strategy (NREL)



A passive daylight reflection louver is use to reflect daylight towards the back of the space

Design Issues for Ventilation and Daylighting

- 20 m deep for natural ventilation (mainly at night) and optimal daylight distribution.

Figure 2: Radiance Rendering of Top Floor

Figure 3: Radiance Rendering of Typical Floor

Example of fixed reflective daylighting device used at NREL [custom made]. [Issues: dust accumulation].

Credit: NREL Building (RSF), Adam Hirch

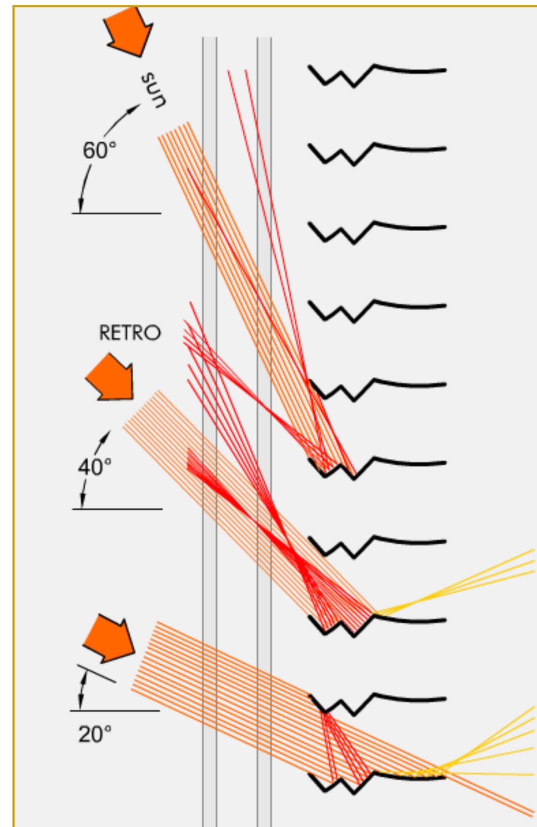
Technology options for daylight control

Mataro Library Spain

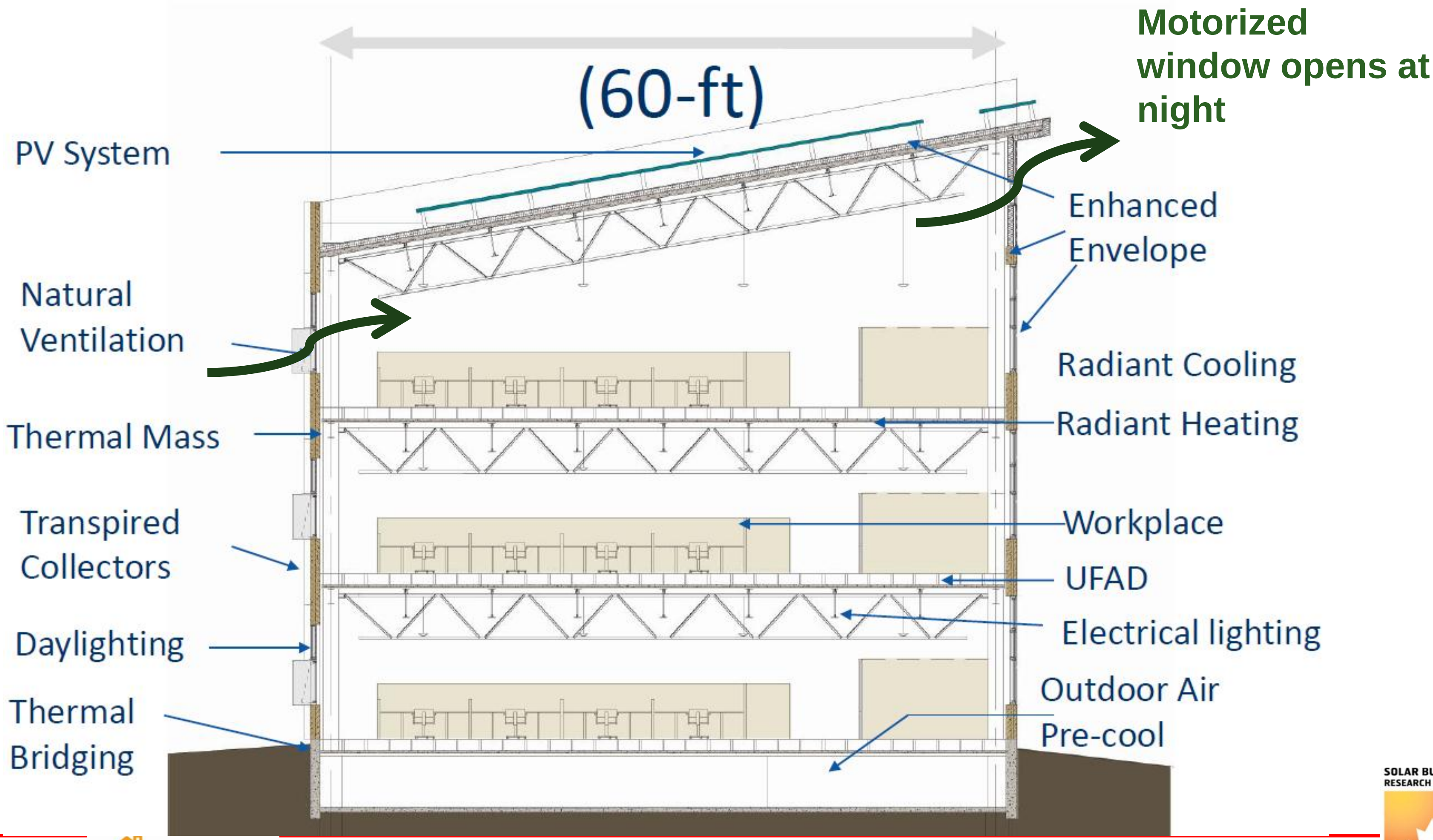
53 kW semitransparent PV facade

Motorized reflective venetian blinds
Between glazings is another option

New reflective blinds



NREL Building (cooling with Natural ventilation)



Challenges for development of cost-effective Net-zero and Low-energy homes/buildings

- Integration of solar technologies with the architecture and with the envelope.
- Integration and optimization of solar with energy efficiency technologies – must not be separate.
- Thermal storage and passive solar design – what are the obstacles.
- Integrated thermal – daylighting design; lighting control.
- Integrated control of HVAC + solar systems: reduction of peak loads, optimal comfort.
- **Education and culture of architects and engineers.**