Design, Construction, and Actual Performance of Prefabricated Wooden Houses

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UNIVERSITY OF
ALBERTA
"uplifting the whole people"
— HENRY MARSHALL TORY, FOUNDING PRESIDENT, 1908
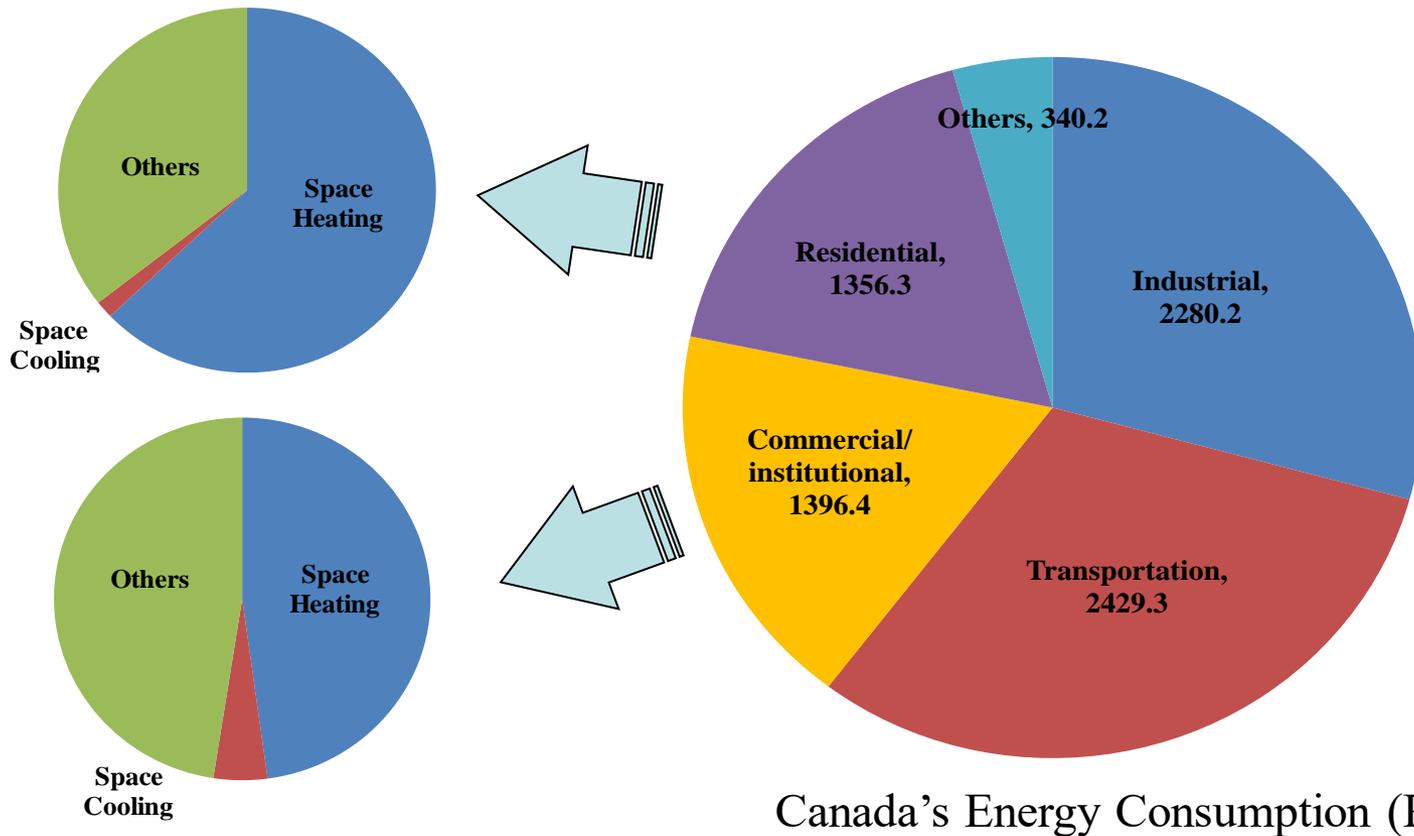
February 12, 2024

Outline

- Introduction

- Design & construction
  - House, energy & mechanical systems

- Monitored performance
  - Thermal performance
  - Energy analysis

- Mass-Timber-Panel Basement

- Conclusion

Introduction
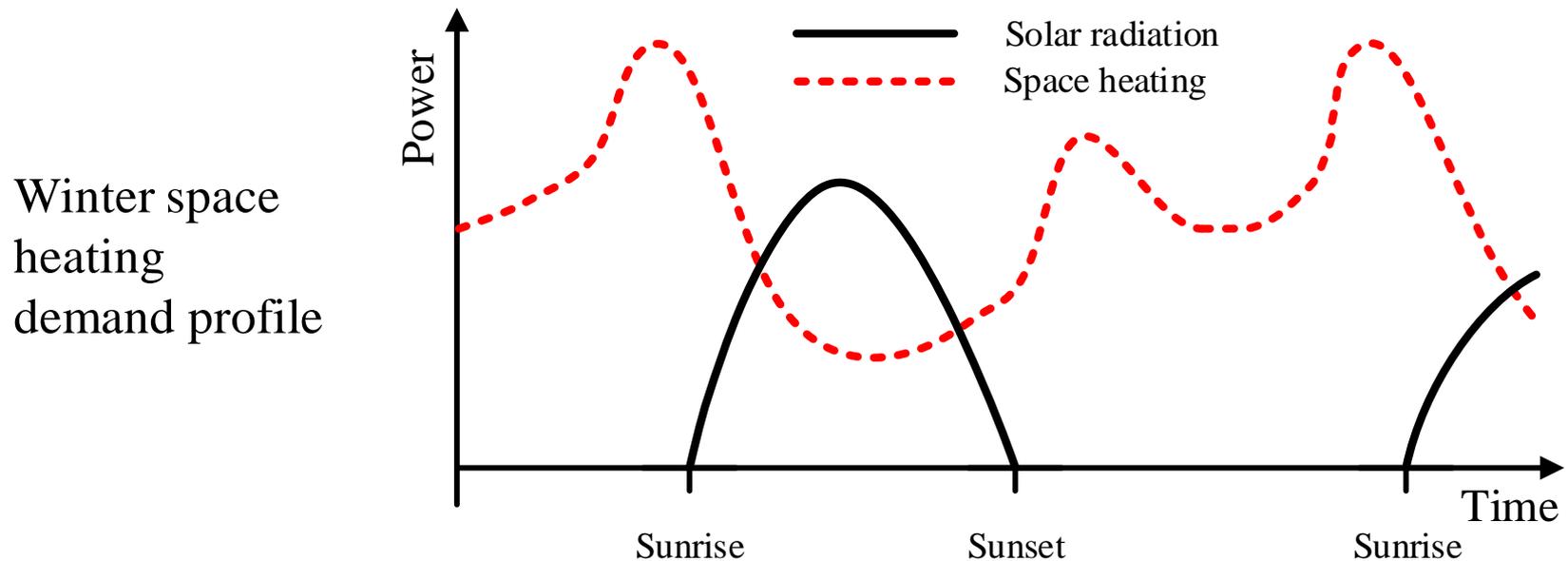
- Energy consumption for space heating/cooling
  - > 21% of the national energy consumption

Canada's Energy Consumption (PJ*)

* PJ = 2.8E8 kWh

Introduction

- Peak electricity demand

Winter space heating demand profile

(Legend: Solar radiation — Space heating)

Axes: Power (vertical), Time (horizontal). Markers along Time axis: Sunrise, Sunset, Sunrise.
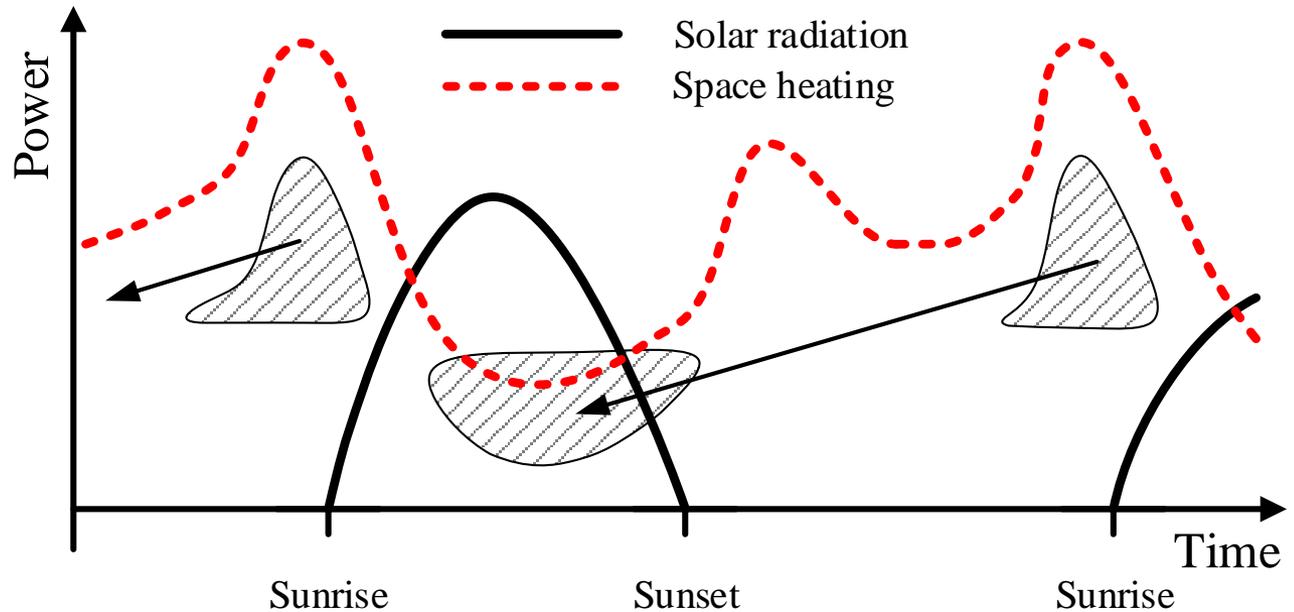
- Demand and supply mismatch (amount, time)

Introduction

- Improved load profile
    - Low energy consumption
        - Energy efficiency measures
    - Reduce and shift peak demand
        - Active thermal energy storage (TES)

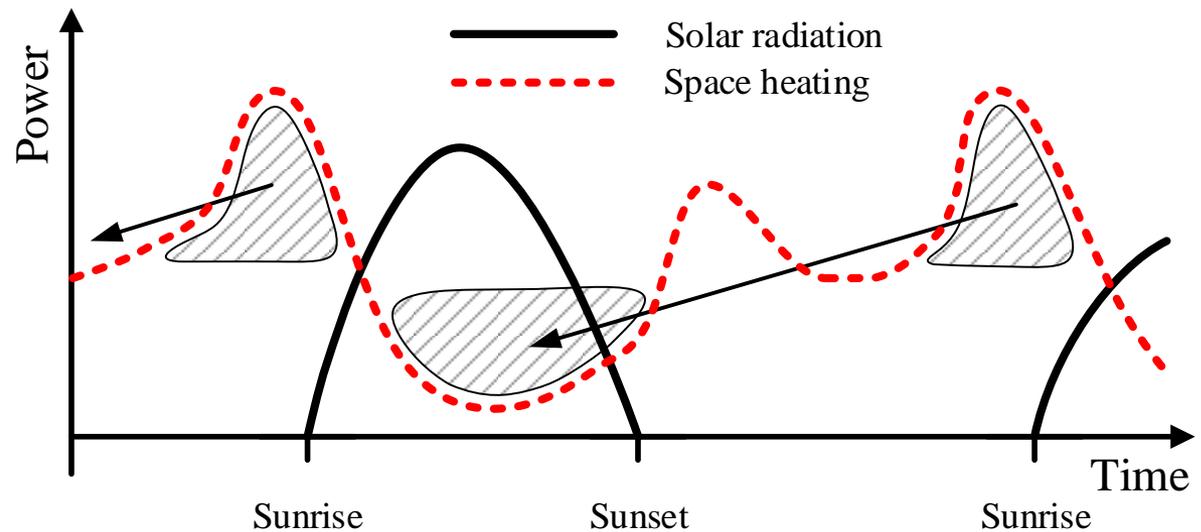Winter space heating demand profile

Introduction

■ Utilization of ambient renewable energy

   ■ Solar energy

      ■ Passive solar heating

      ■ Solar thermal collector & PV

   ■ Geothermal

Introduction

- Building Integrated Photovoltaic/Thermal (BIPV/T) system
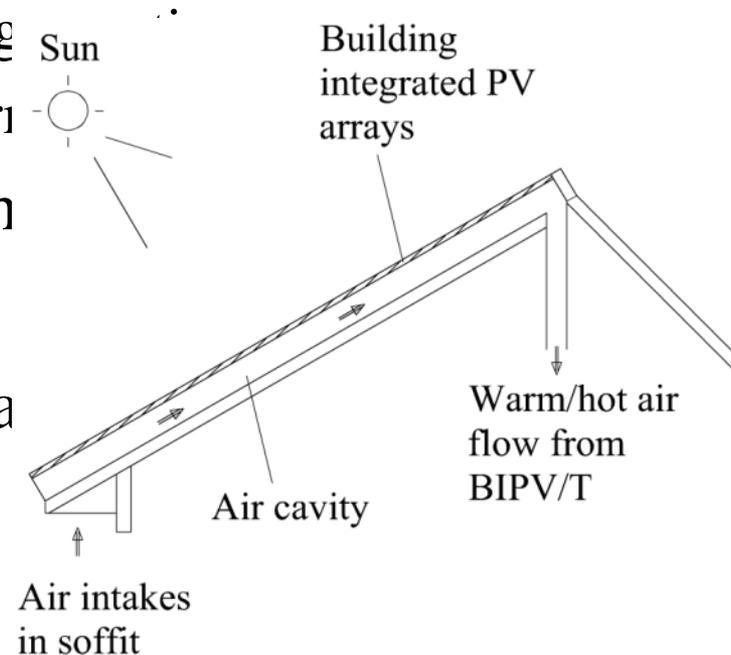 - Significantly increase overall efficiency
    - Higher efficiency of electricity g
    - Collect then
  - Enhance arch appealing
  - Reduce overa

Sun

Building integrated PV arrays

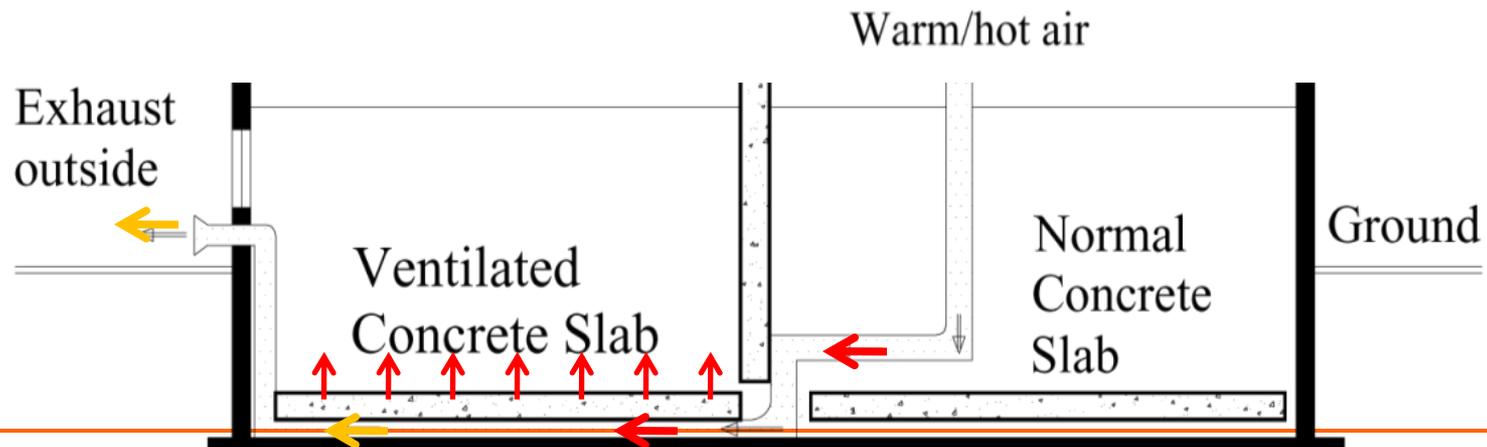Warm/hot air flow from BIPV/T

Air cavity

Air intakes in soffit

Introduction

- Ventilated Concrete Slab (VCS)
  - Thermal energy storage
    - Suitable thermophysical properties
    - Active thermal mass
    - Large quantity
  - Assist space heating/cooling

Background

- CMHC* EQuilibrium (2006 ~ 2010)
  - One of the winning projects nationally
- Single family, detached house in Eastman, Quebec, Canada
  - 210 m^2 (two-story with a semi-basement)
- Construction finished in Nov. 2007
- Occupied since August 2009
- Important research project of several groups
  - SNEBRN, Hydro Québec, NRCan, CMHC, IEA
  - Case study of IEA task 40 "nZEB"
- Demonstration & public education

Design
&
Construction

Key Design Features

■ High performance envelope

  ■ Thermal insulation: Walls: RSI 6.4 (R 36);

                          Roof: RSI 9.3 to 10.9 (53 to 62)

    – Structure integrity and acoustic insulation

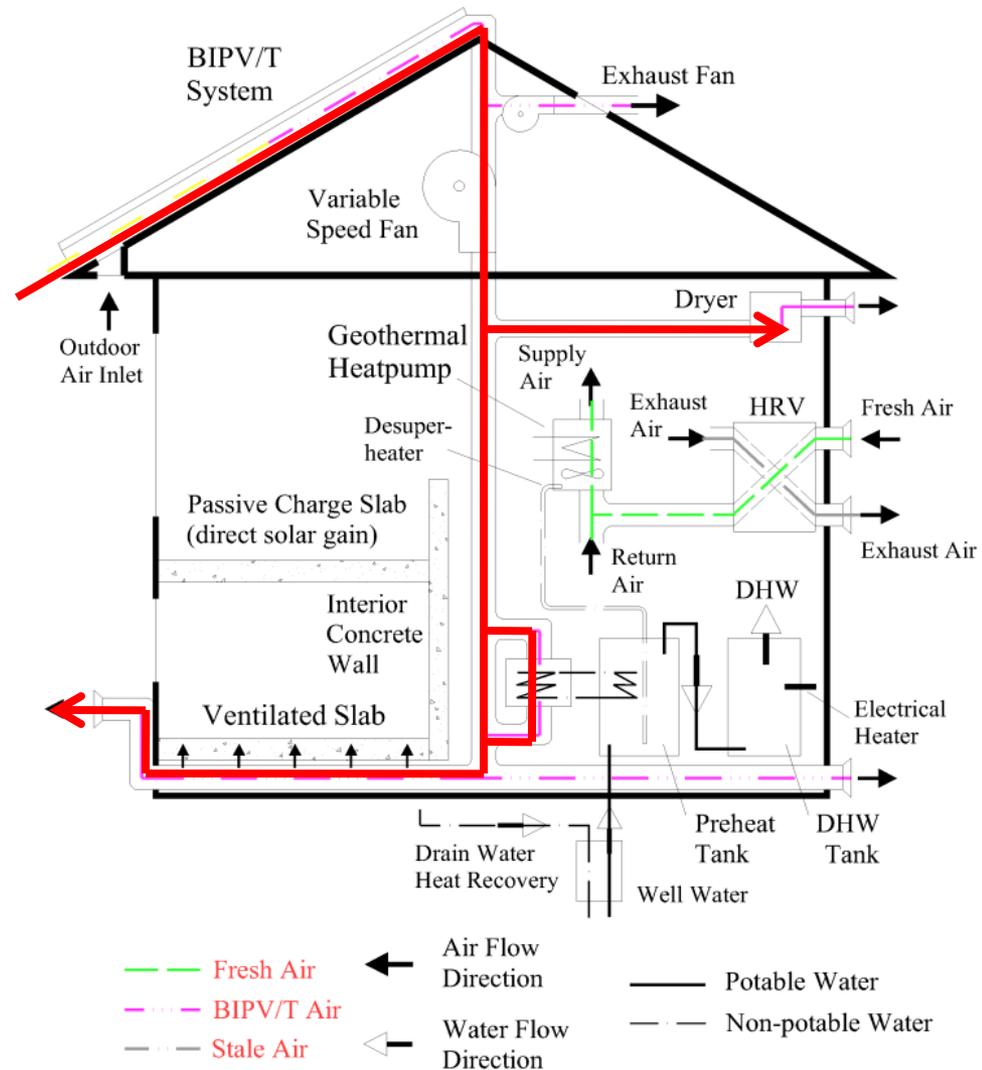 ■ Air-tightness: < 0.1 air change per hour

Key Design Features

- ## Building-integrated photovoltaic & thermal system (BIPV/T)
  - Electricity generation
  - Thermal energy collection
  - DHW heating
  - Drying clothes

- ## Ventilated concrete slab
  - Active thermal energy storage
    - Assist space cooling/heating

  ~ 30 m², 5 m³, 3 kWh/K
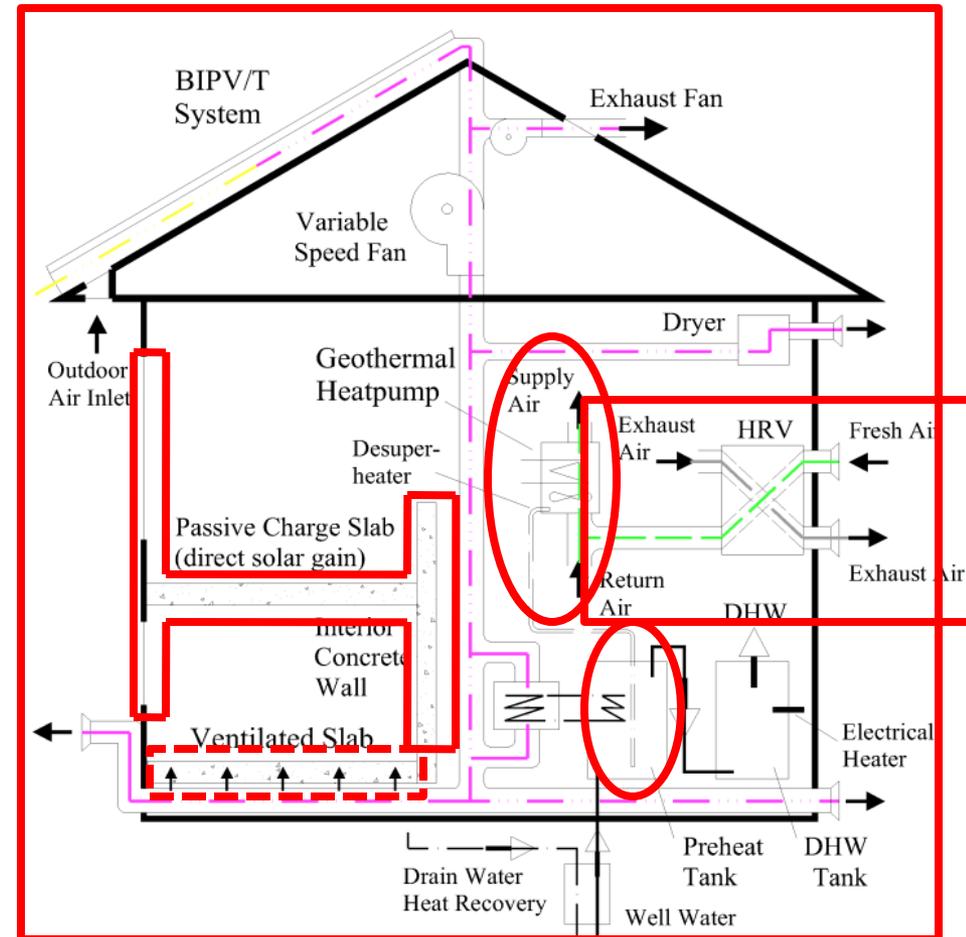
Key Design Features

- **Passive Solar Heating**
  - Large south-facing windows
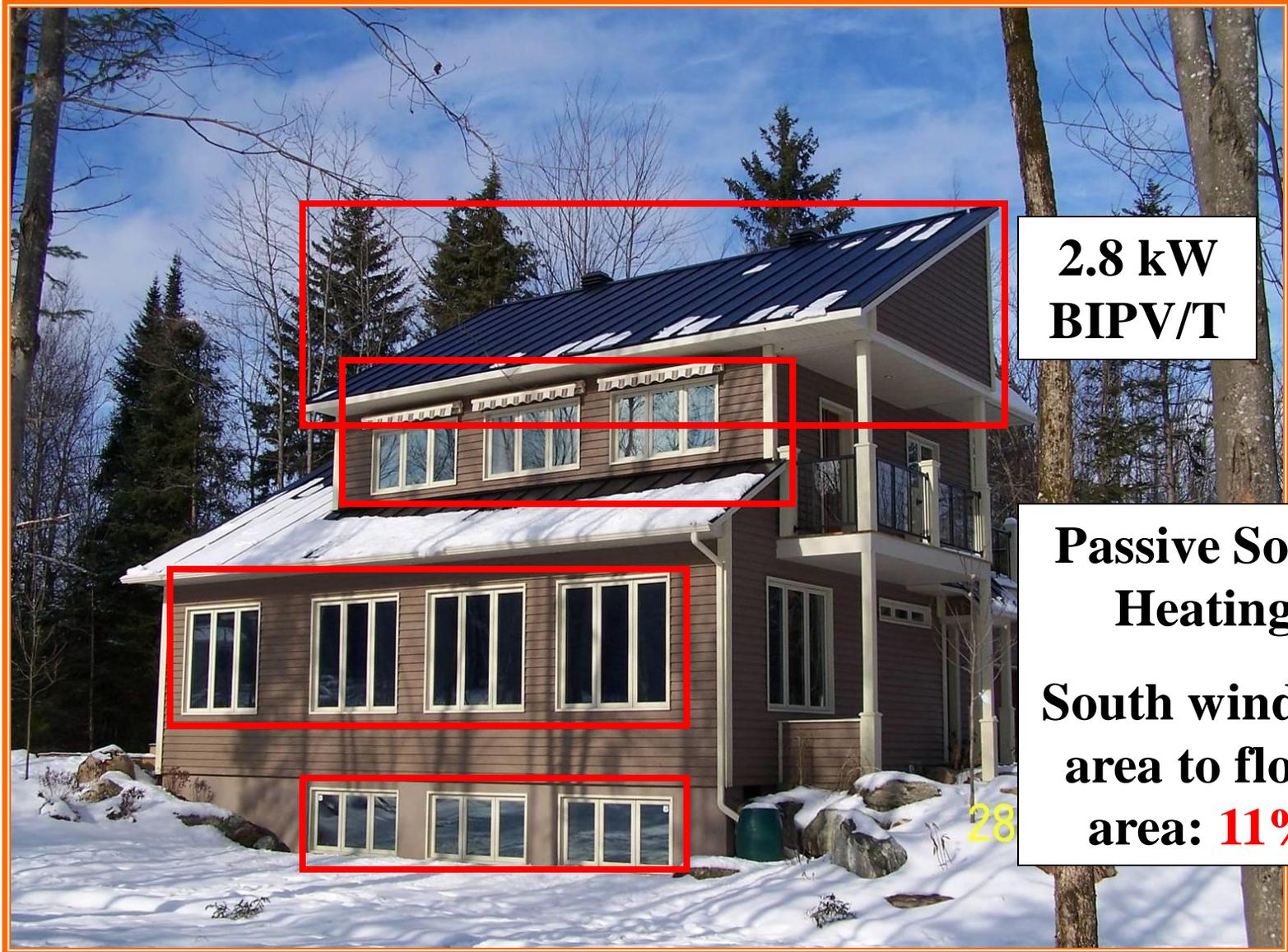 - Significant thermal mass (concrete slab & walls)
  - Motorized blinds
- **Geothermal HP**
  - Heating/Cooling
  - Partial DHW heating
- **Heat recovery ventilation**
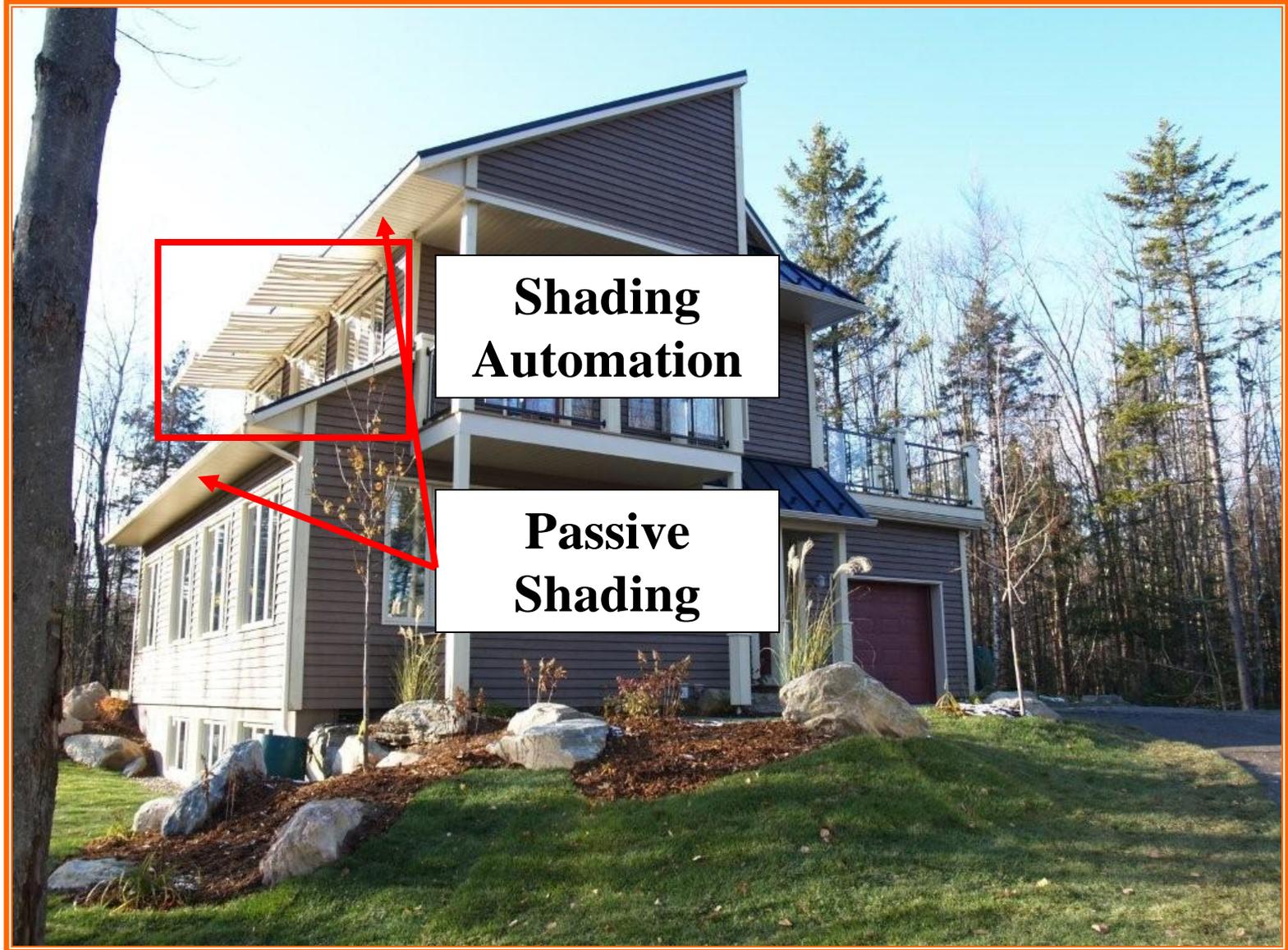- **Automation system**
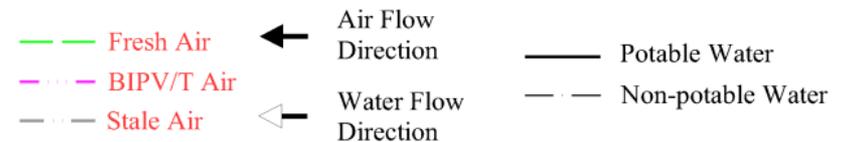
Key Design Features

2.8 kW BIPV/T
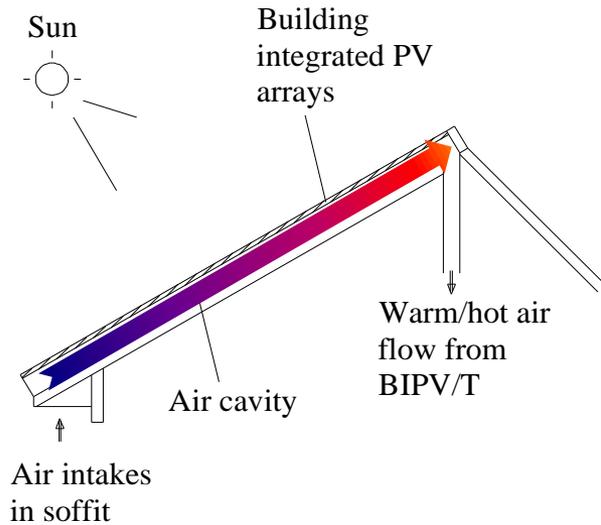
Passive Solar Heating

South window area to floor area: **11%**

Key Design Features

Shading Automation

Passive Shading

Building-Integrated Photovoltaic & Thermal (BIPV/T) System

Sun

Building integrated PV arrays

Warm/hot air flow from BIPV/T

Air cavity

Air intakes in soffit

ÉcoTerra

- Thermal insulation
  - Two types/layers of insulation for the envelope

Basement

Above grade

ÉcoTerra

Pre-fabrication
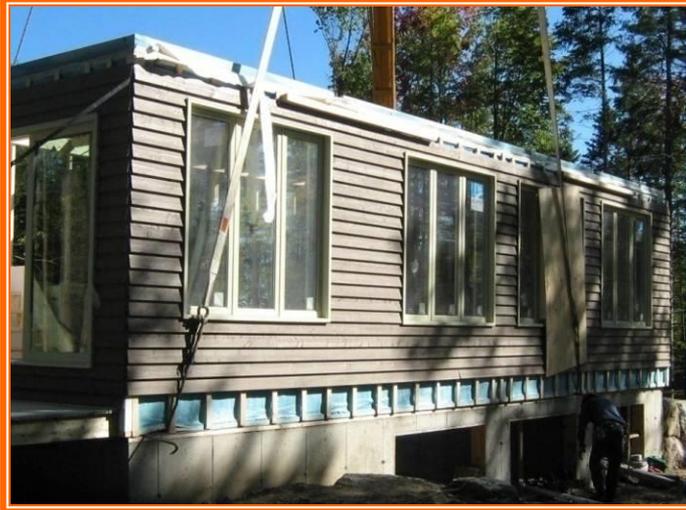
Floor

+

Ducting

Walls and
Partitions

One
Module

Spray
Insulations

ÉcoTerra

■ On-site assembly of modules

ÉcoTerra

Built Environment

Family Room
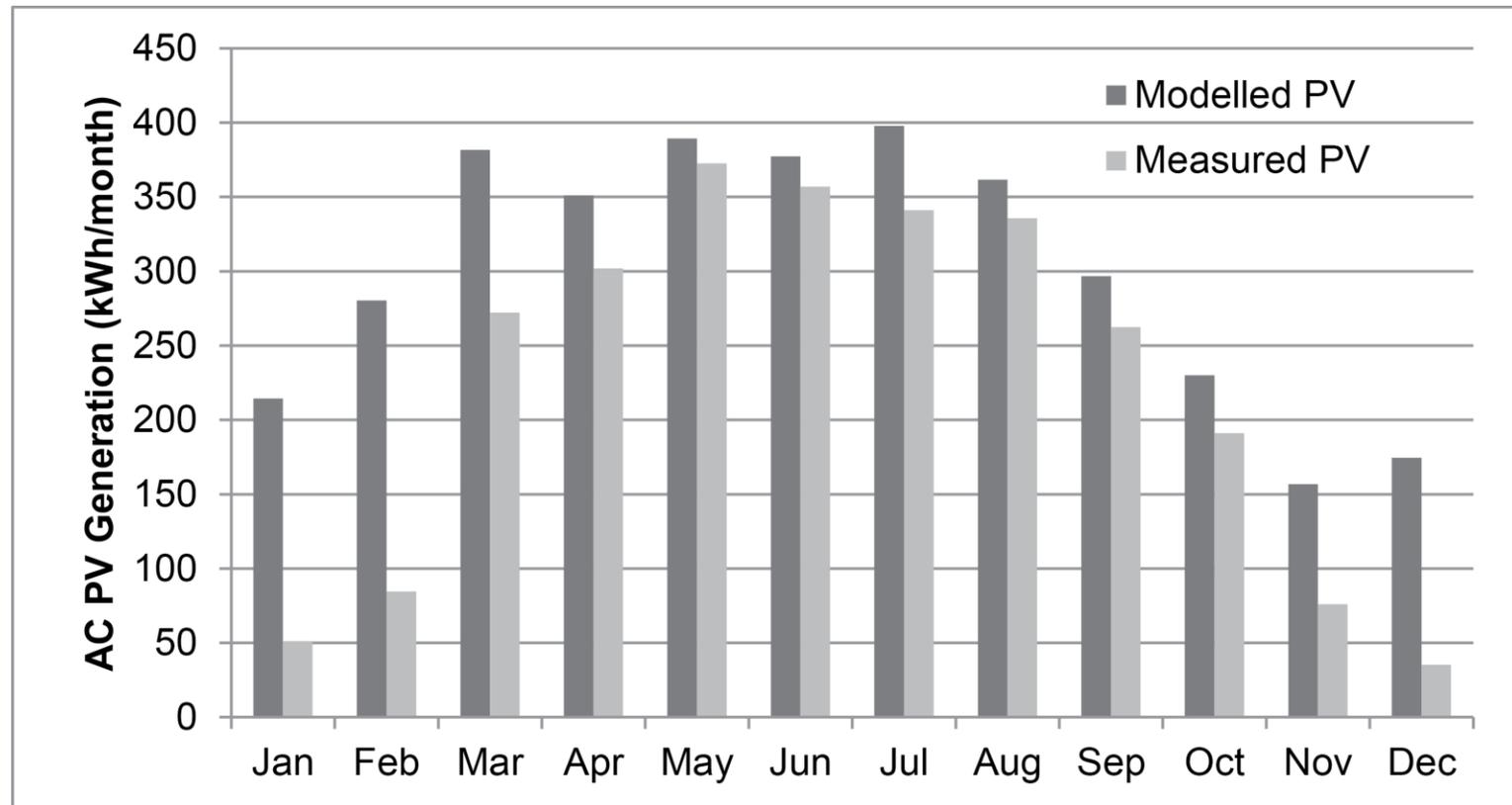
Study Room & Basement (VCS)

Mechanical System

Monitoring

Thermal and Energy Performance

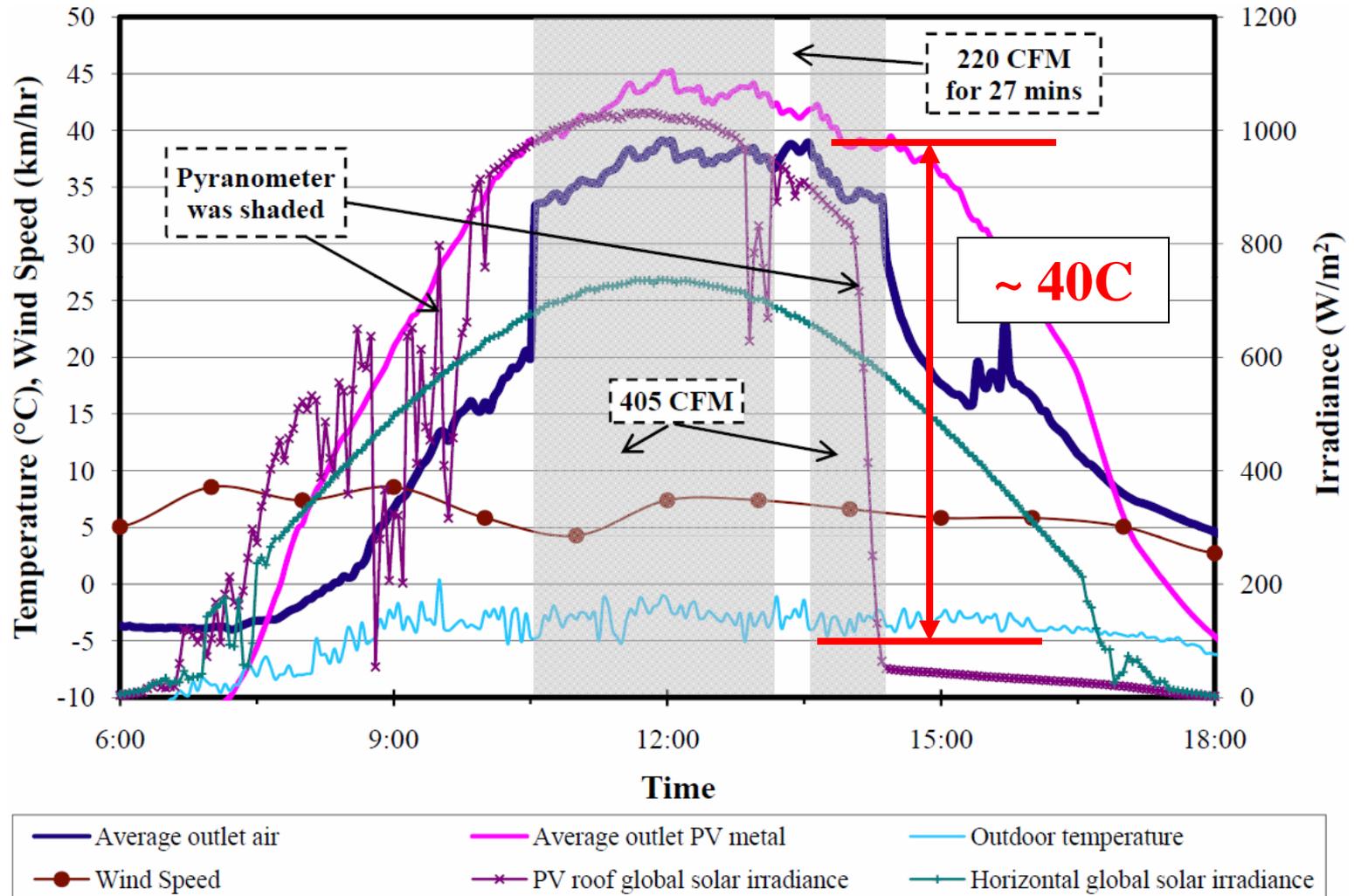# PV Electrical Performance

- Modeled: 3265 kWh/yr
- Monitored: 2570 kWh/yr
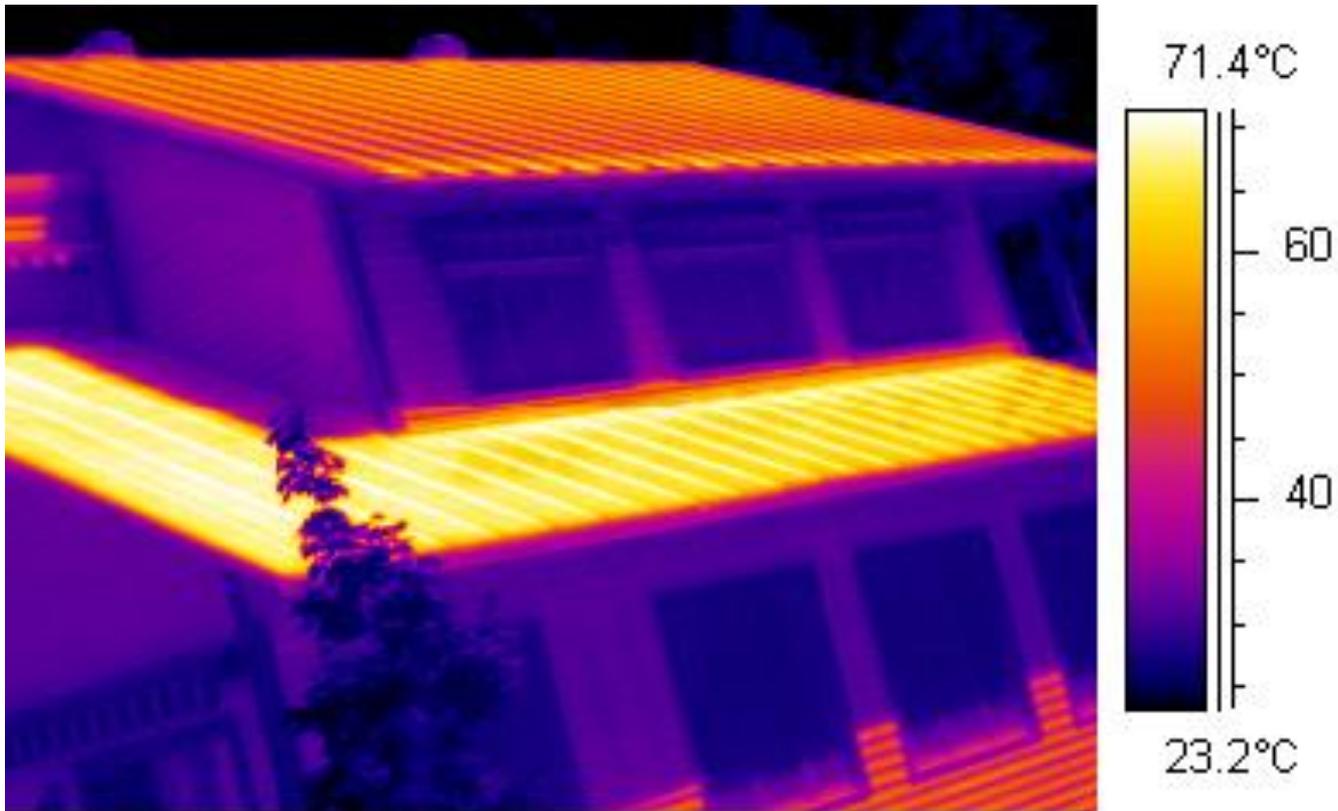 - Winter snow accumulation effect

BIPV/T - cold sunny day

■ Thermal energy collected: 9.5 kW @ 12:00
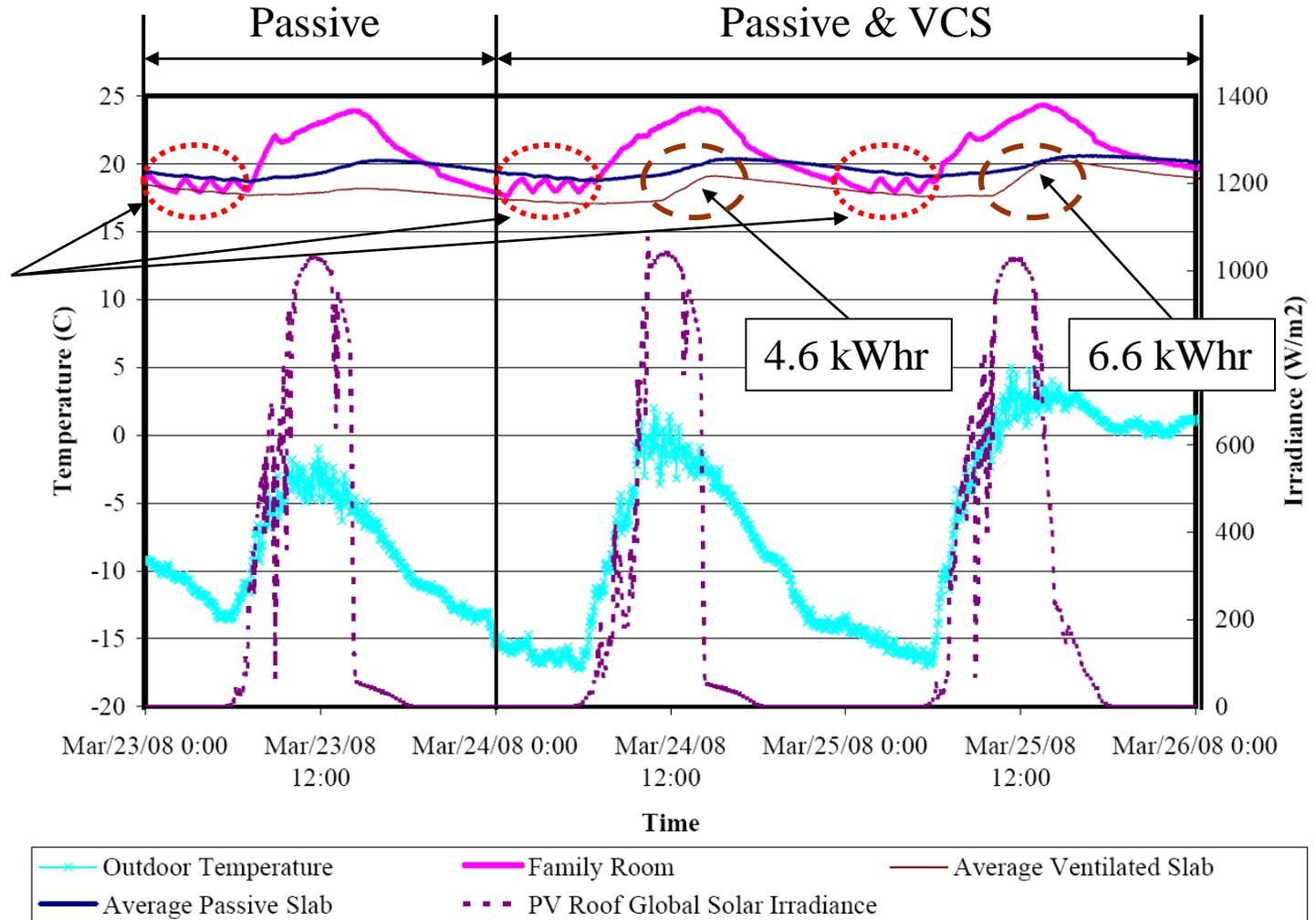
BIPV/T

Hot summer days (infrared image)
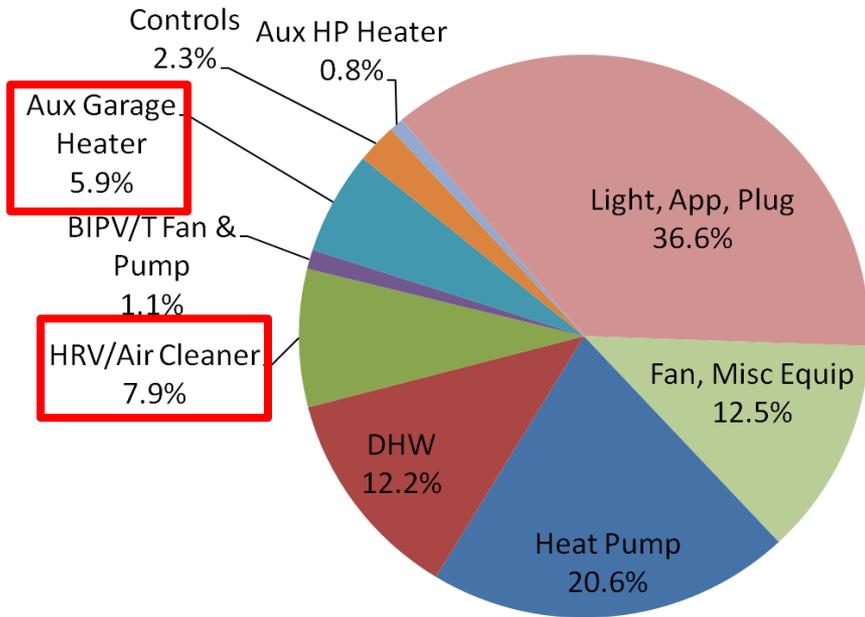

June 22th, 2008

House and VCS

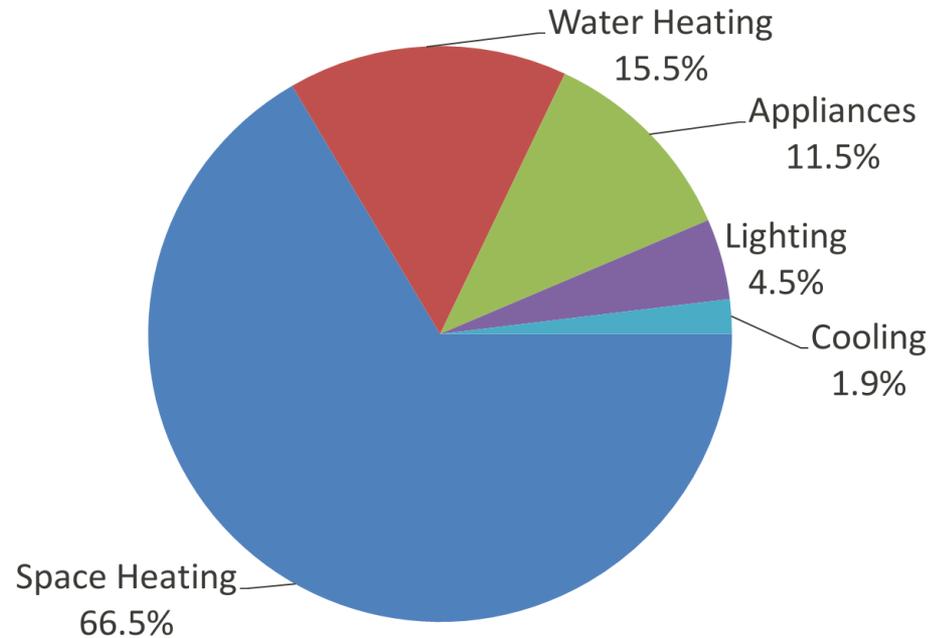■ Passive solar heating & VCS (cold sunny day)

Energy performance

Annual Consumption by End-Use

ÉcoTerra

10,318 kWh/year

49 kWh/m²/yr (156 kWh/m²/yr for Québec)

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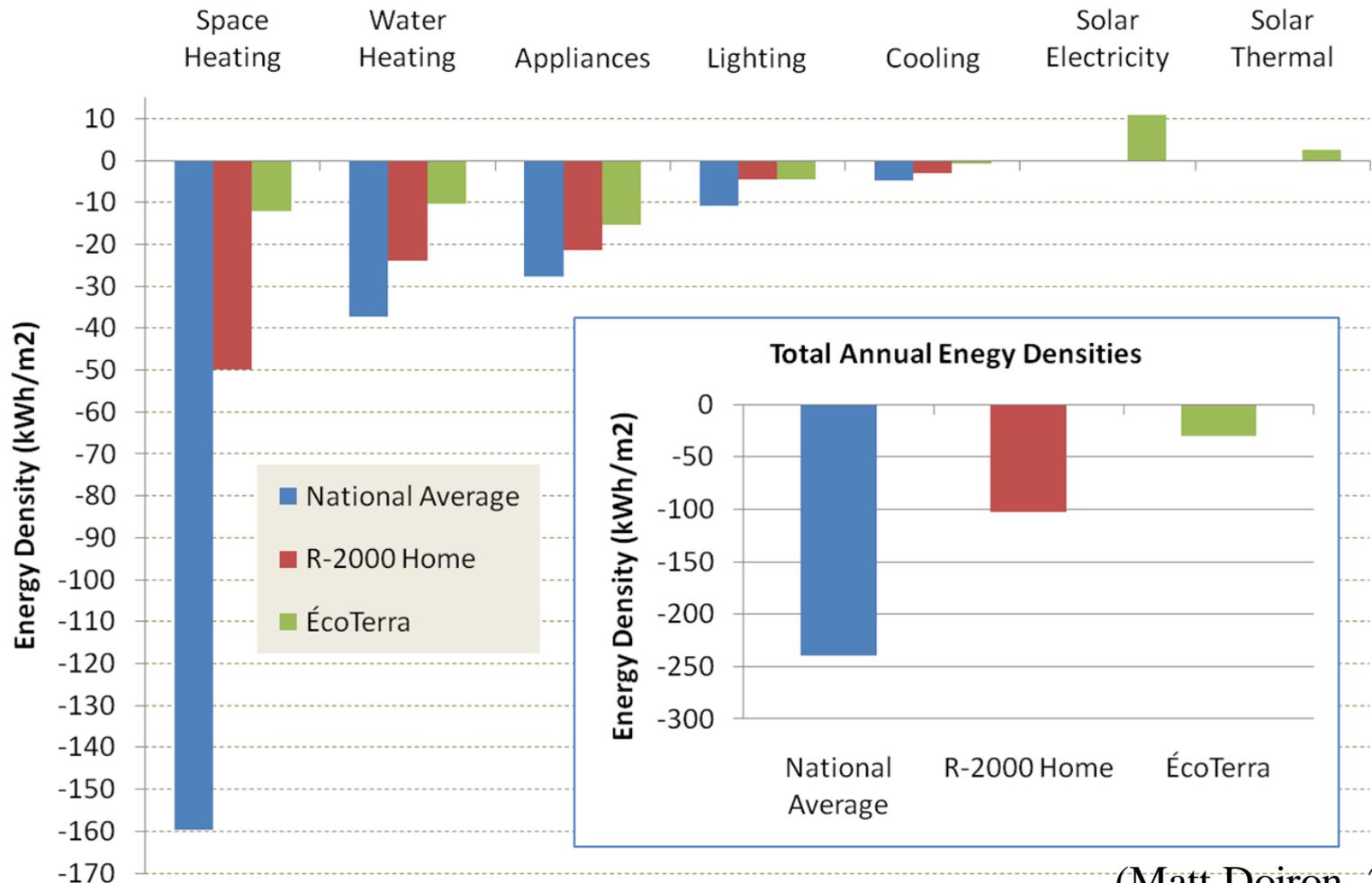
38,389 kWh/year

(Matt Doiron, 2011)

Design vs. Actual

(a) Before occupied

(b) Occupied
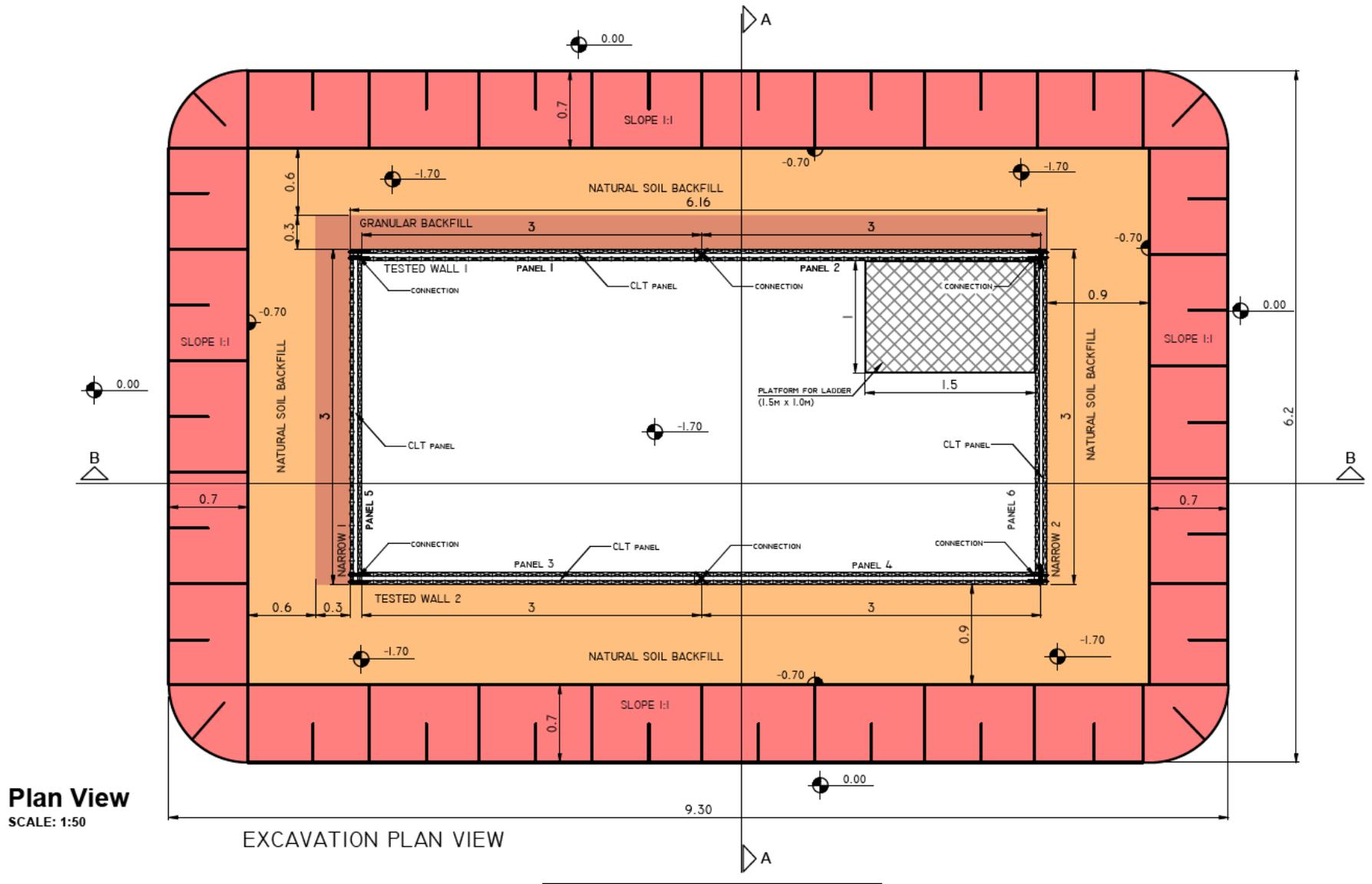
Energy Performance

Annual Consumption by End-Use

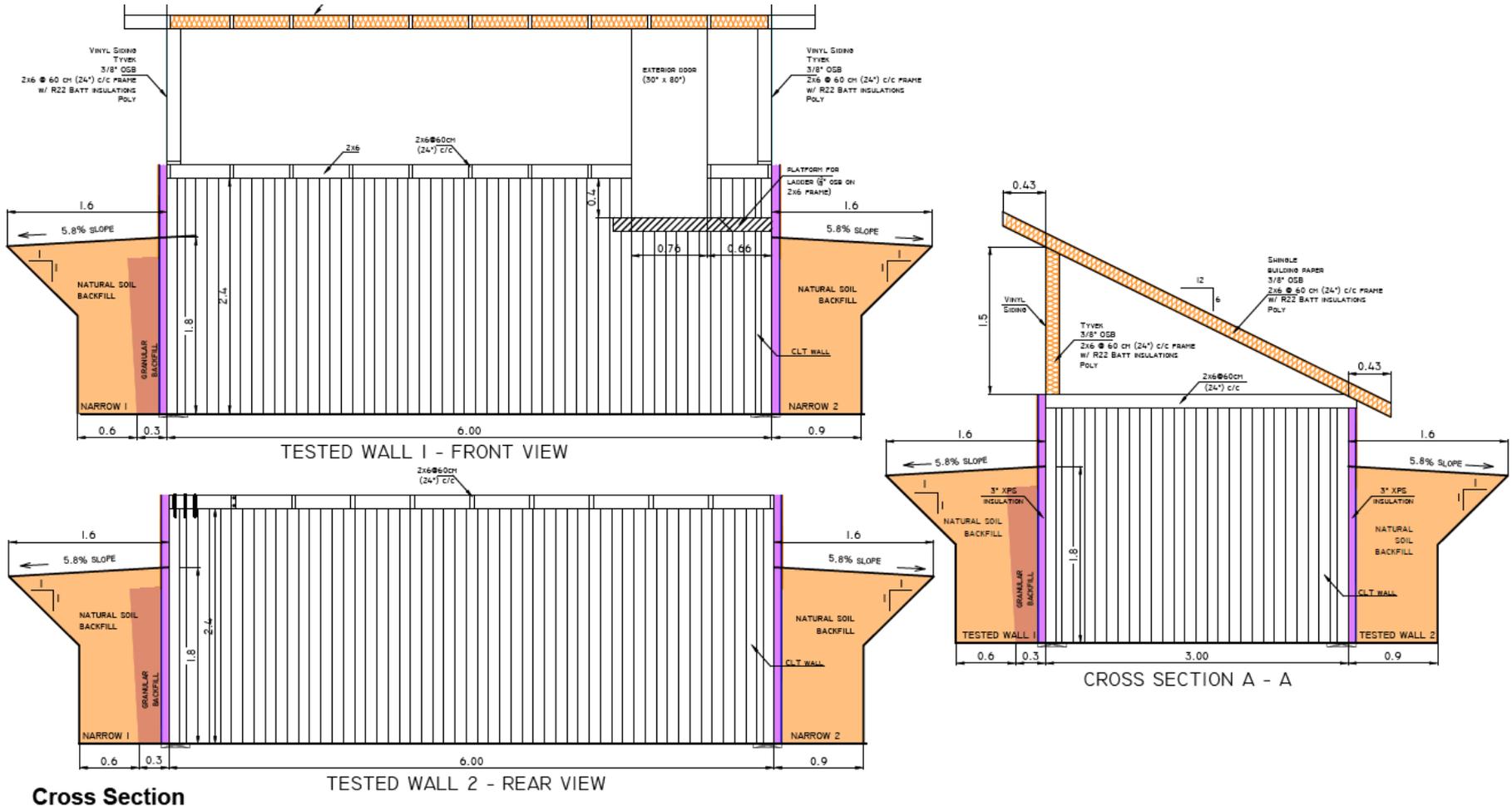(Matt Doiron, 2011)

Cross-Laminate Timber (CLT) Basement Walls

Cross-Laminate Timber (CLT) Basement Walls


Plan View
SCALE: 1:50

EXCAVATION PLAN VIEW

Cross-Laminate Timber (CLT) Basement Walls

TESTED WALL 1 - FRONT VIEW

TESTED WALL 2 - REAR VIEW

Cross Section

CROSS SECTION A - A
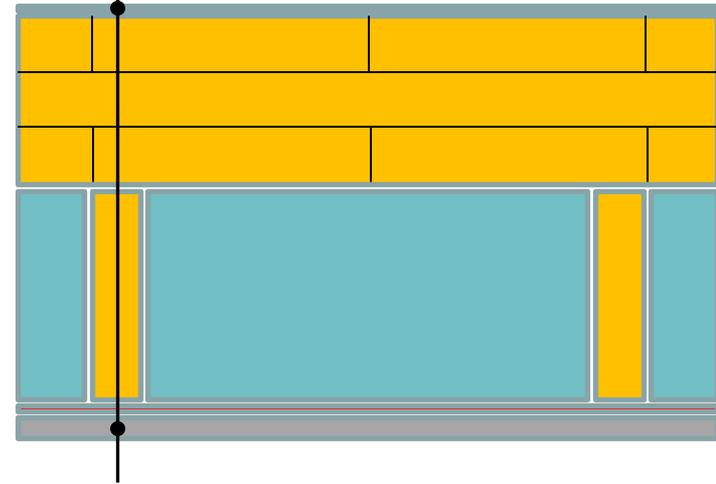
Cross-Laminate Timber (CLT) Basement Walls

Effective thermal resistances

Exterior water proof membrane
3/4" XPS continuous insulation
3-ply CLT panel
2x4@16" stud with cavity thermal insulation
Cavity insulation
Vapor barrier
Interior gypsum board and paint

Exterior water proof membrane
3-ply CLT panel
2x6@16" stud with cavity thermal insulation
Cavity insulation
Vapor barrier
Interior gypsum board and paint
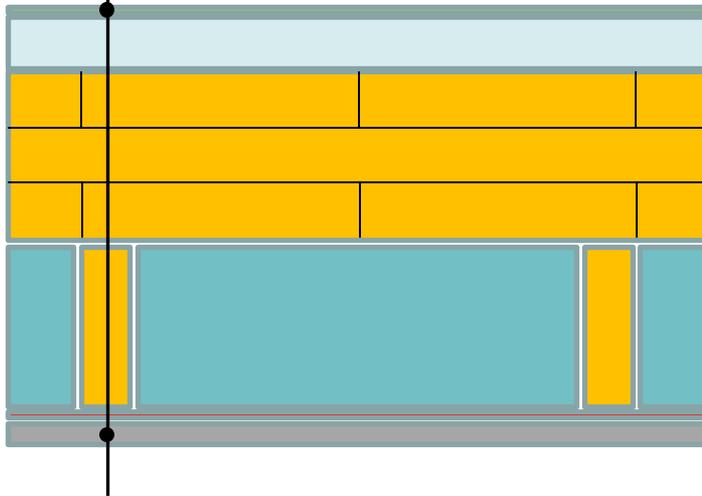
Nominal RSI is 3.7, effective RSI is about 3.3 (R 18.9).

Nominal RSI is 4.5, effective RSI is about 3.9 (R 22).

Code requirement: RSI 2.98 (R 17.5). Both configurations pass condensation tests.
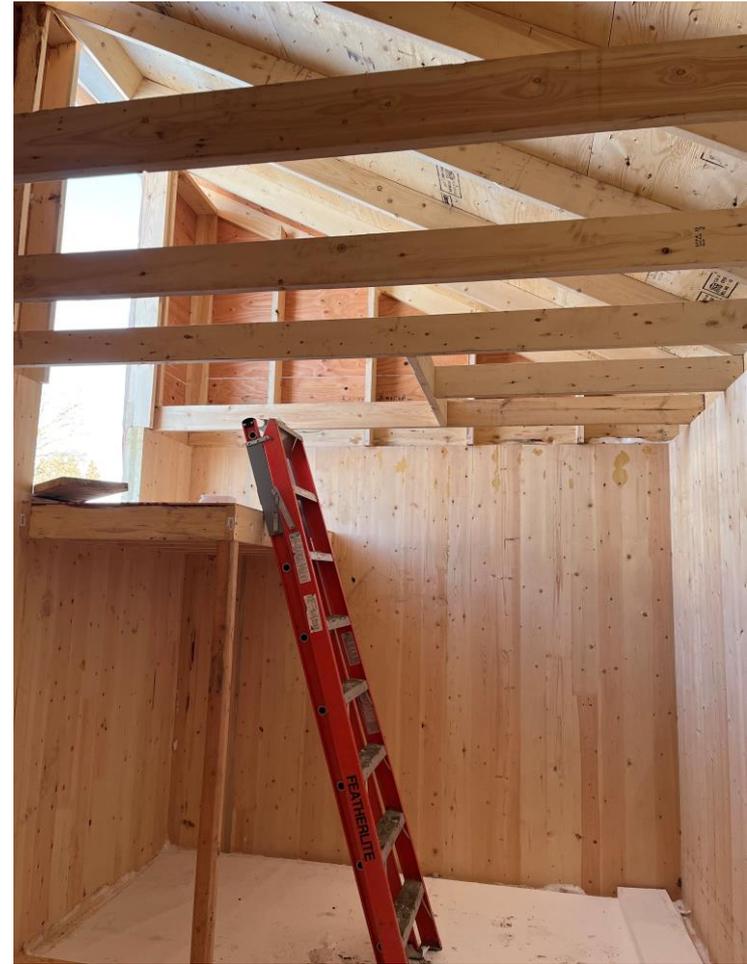
Cross-Laminate Timber (CLT) Basement Walls
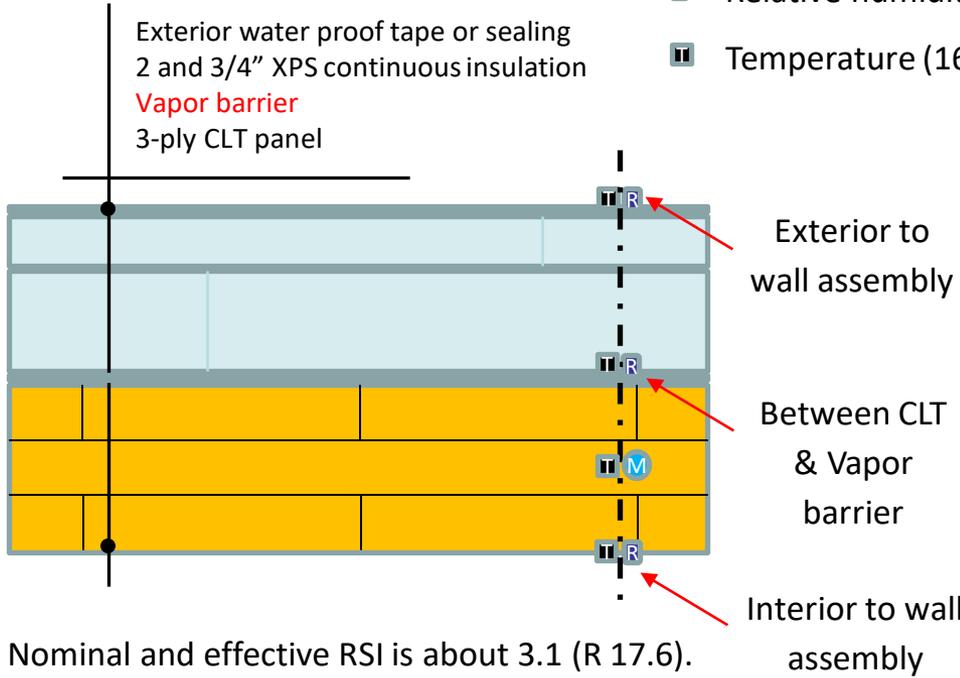
Cross-Laminate Timber (CLT) Basement Walls
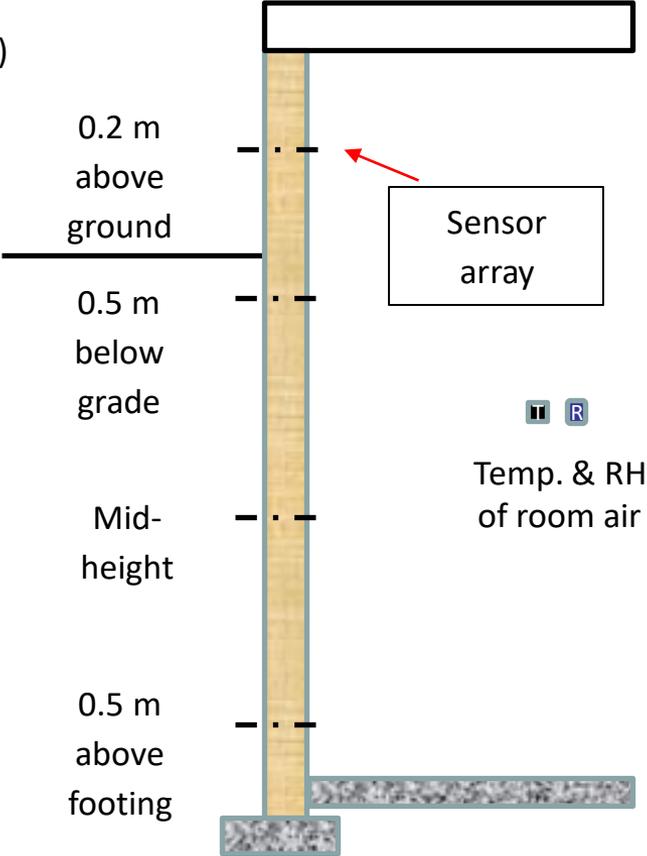
Cross-Laminate Timber (CLT) Basement Walls

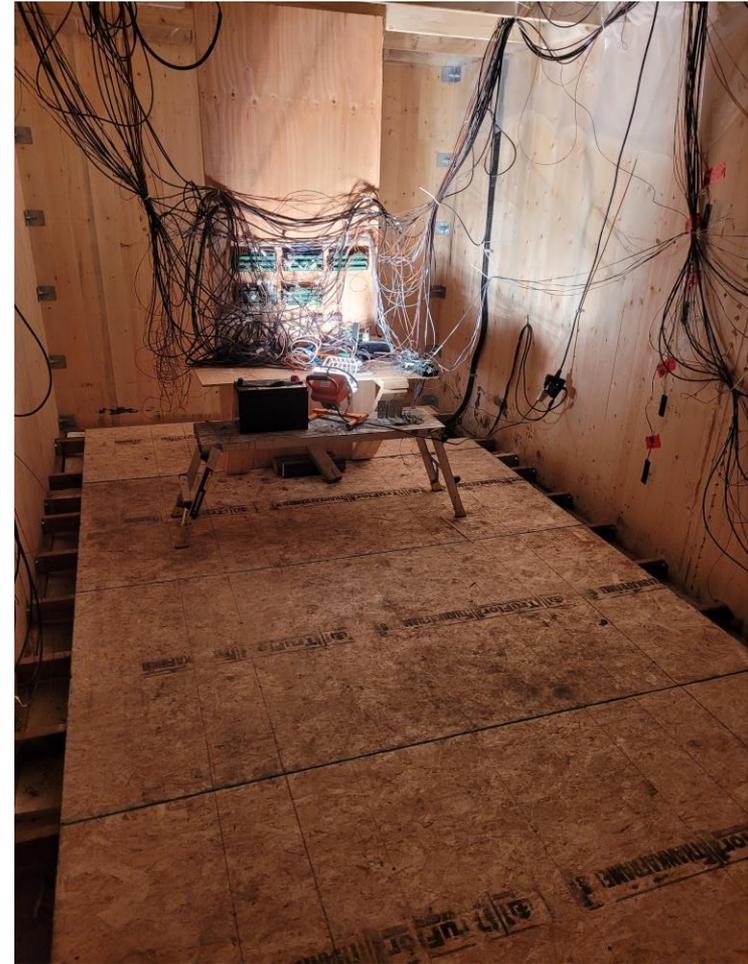# Cross-Laminate Timber (CLT) Basement Walls

Effective thermal resistances

M Moisture content (4)
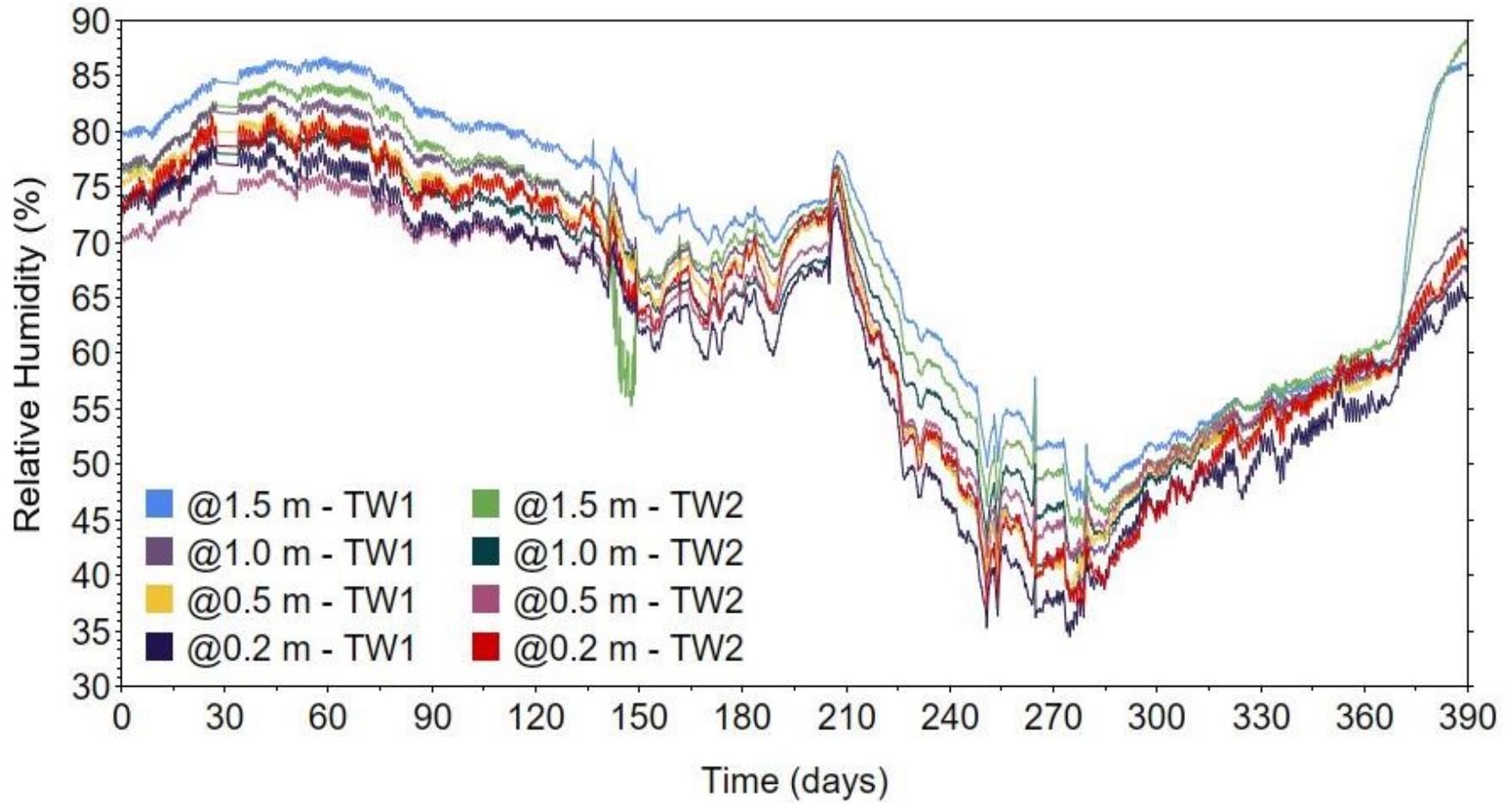
R Relative humidity (12+1)

T Temperature (16+1)

Exterior water proof tape or sealing
2 and 3/4" XPS continuous insulation
Vapor barrier
3-ply CLT panel

Exterior to wall assembly

Between CLT & Vapor barrier

Interior to wall assembly

Nominal and effective RSI is about 3.1 (R 17.6).

Code requirement: RSI 2.98 (R 17.5). This configuration passes a condensation test.

0.2 m above ground

0.5 m below grade

Mid-height

0.5 m above footing

Sensor array

Temp. & RH of room air

Cross-Laminate Timber (CLT) Basement Walls

Relative Humidity

Conclusions

- A low-energy solar home is designed, built, and assessed.
  - It integrates innovative and conventional systems
  - The energy consumption is 25% of the national average, but with potential of less than 20%.

- Low-energy design enhances energy efficiency

- Occupant factors

Questions / comments ?