Maximizing the use of solar energy to radically reduce the energy needs of housing

Ian Beausoleil-Morrison

Faculty of Engineering and Design
Carleton University
Ottawa, Canada

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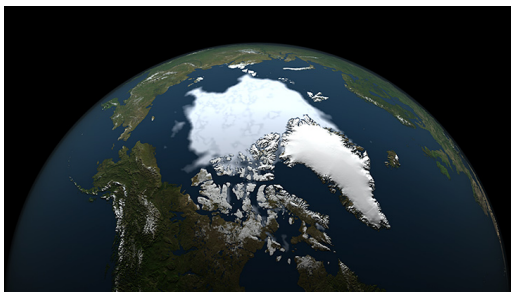
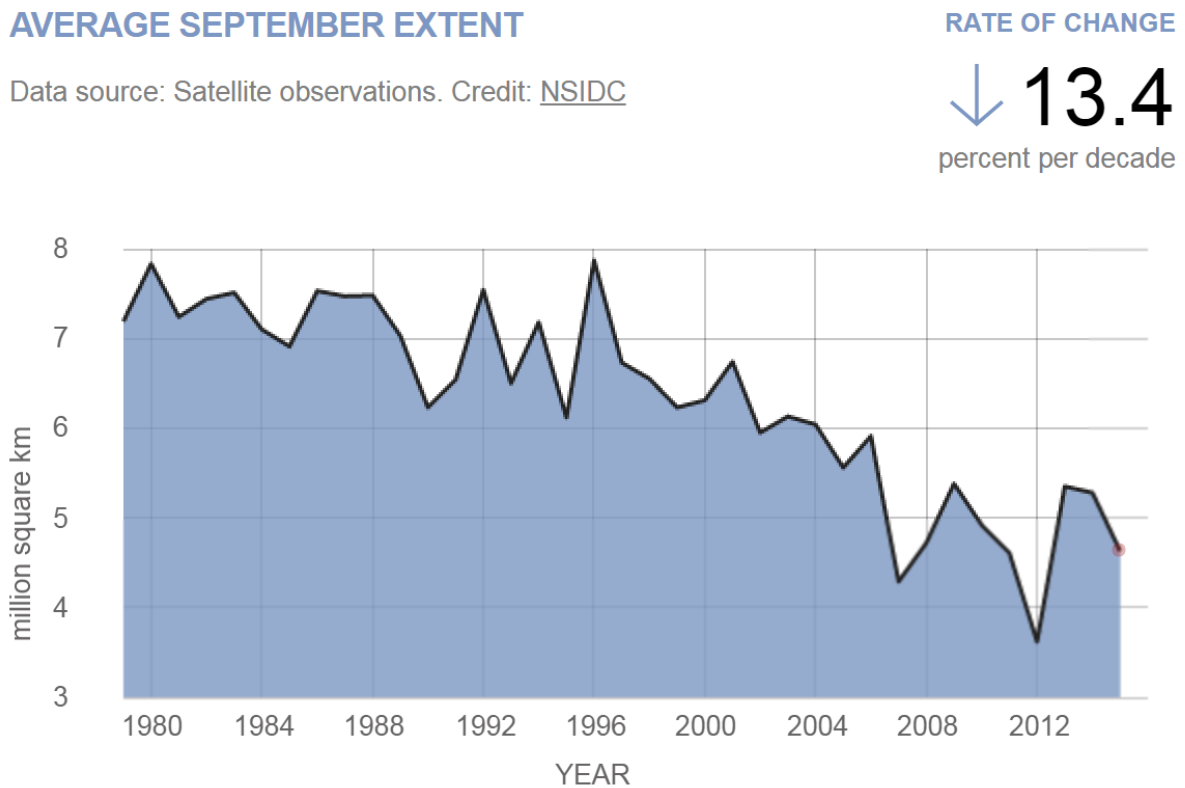
Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings
Stewart Center, Purdue University | July 11-14, 2016

Climate change

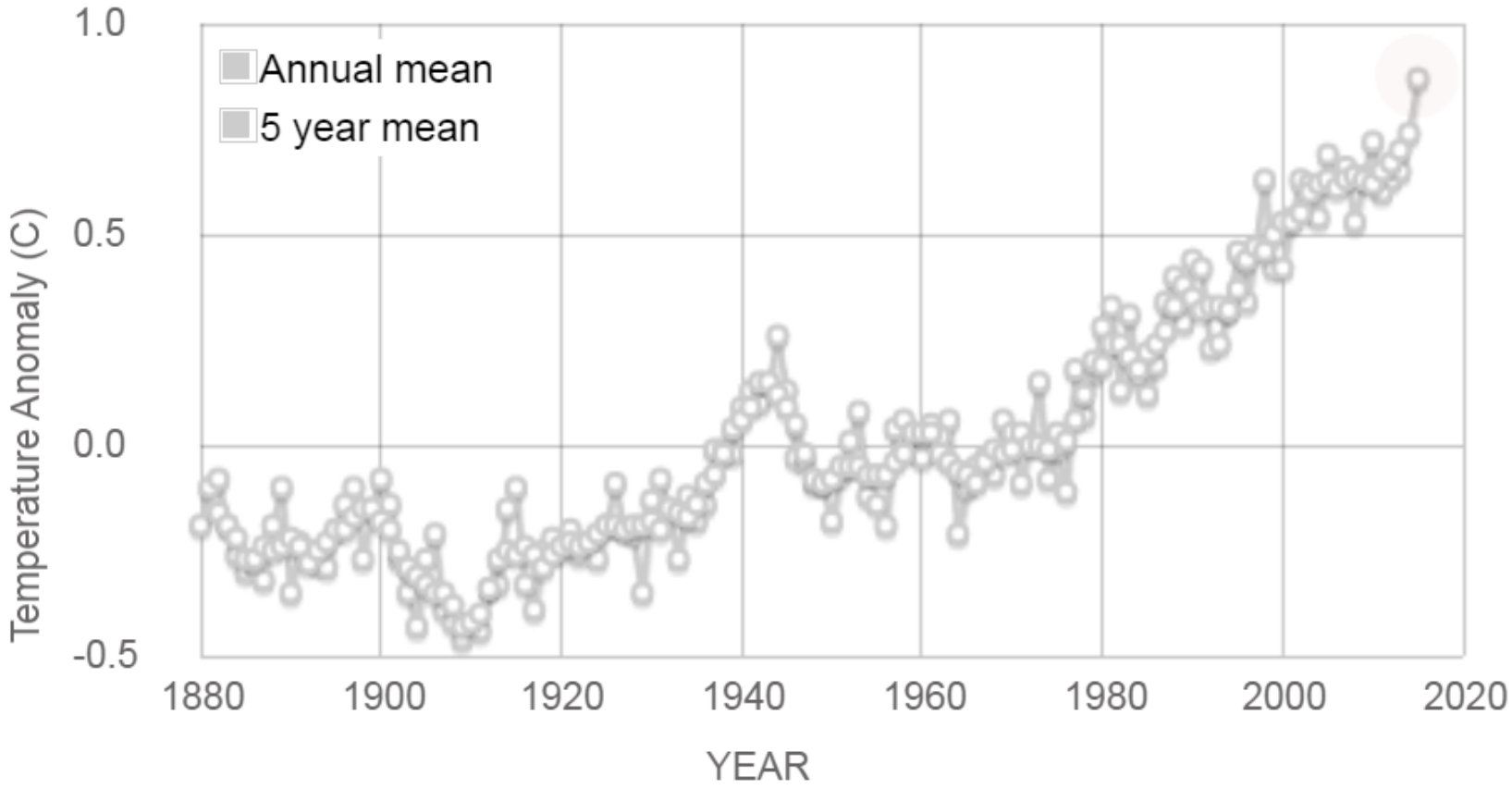




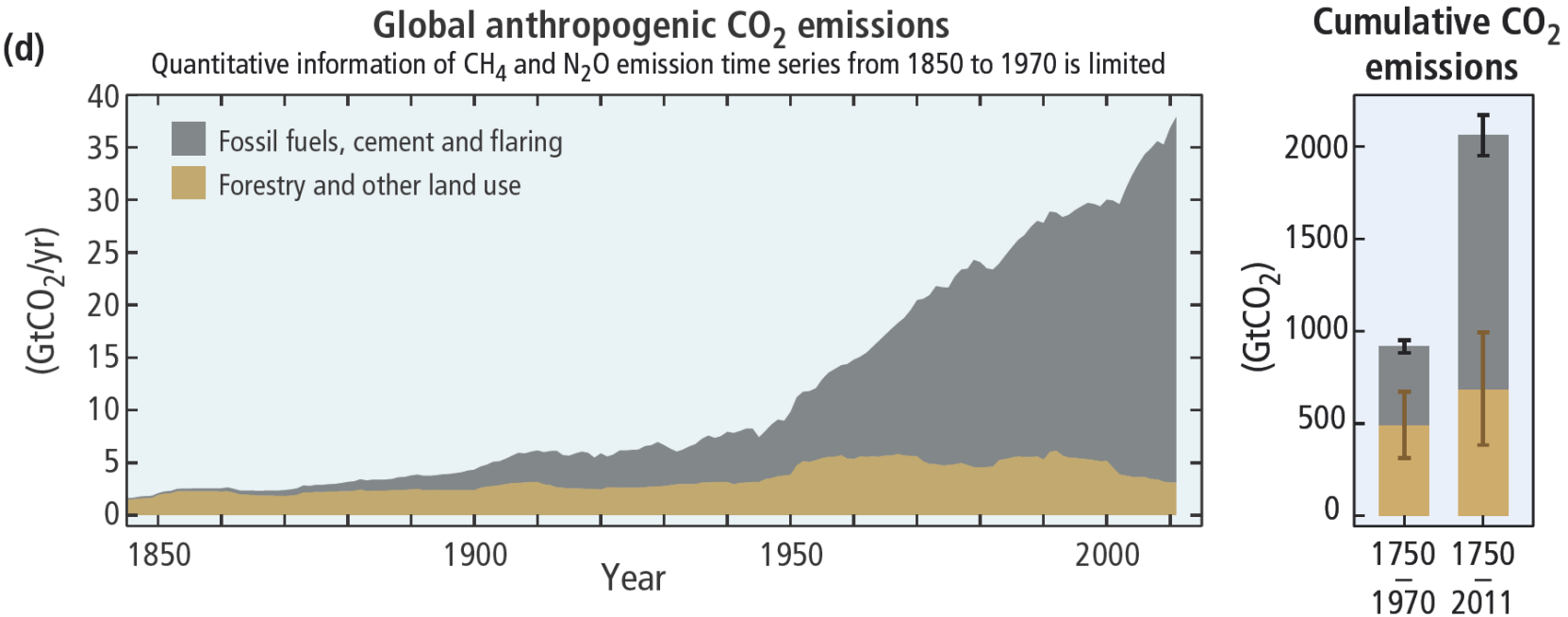
Source : NASA

Climate change

Data source: NASA's Goddard Institute for Space Studies (GISS). Credit: NASA/GISS



Energy consumption is driving climate change



Source: Climate Change 2014: Synthesis Report, AR5, Intergovernmental Panel on Climate Change, 2015.

COP21 : The "Paris Agreement"

Goal

- Limit global warming to less than 2°C above pre-industrial levels.
- Pursue efforts to limit warming to 1.5°C.

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Approach

- Each country commits to emissions reductions.
- Reach peak global GHG emissions as soon as possible.
- Balance sources by sinks by 2^{nd} half of 21^{st} century.

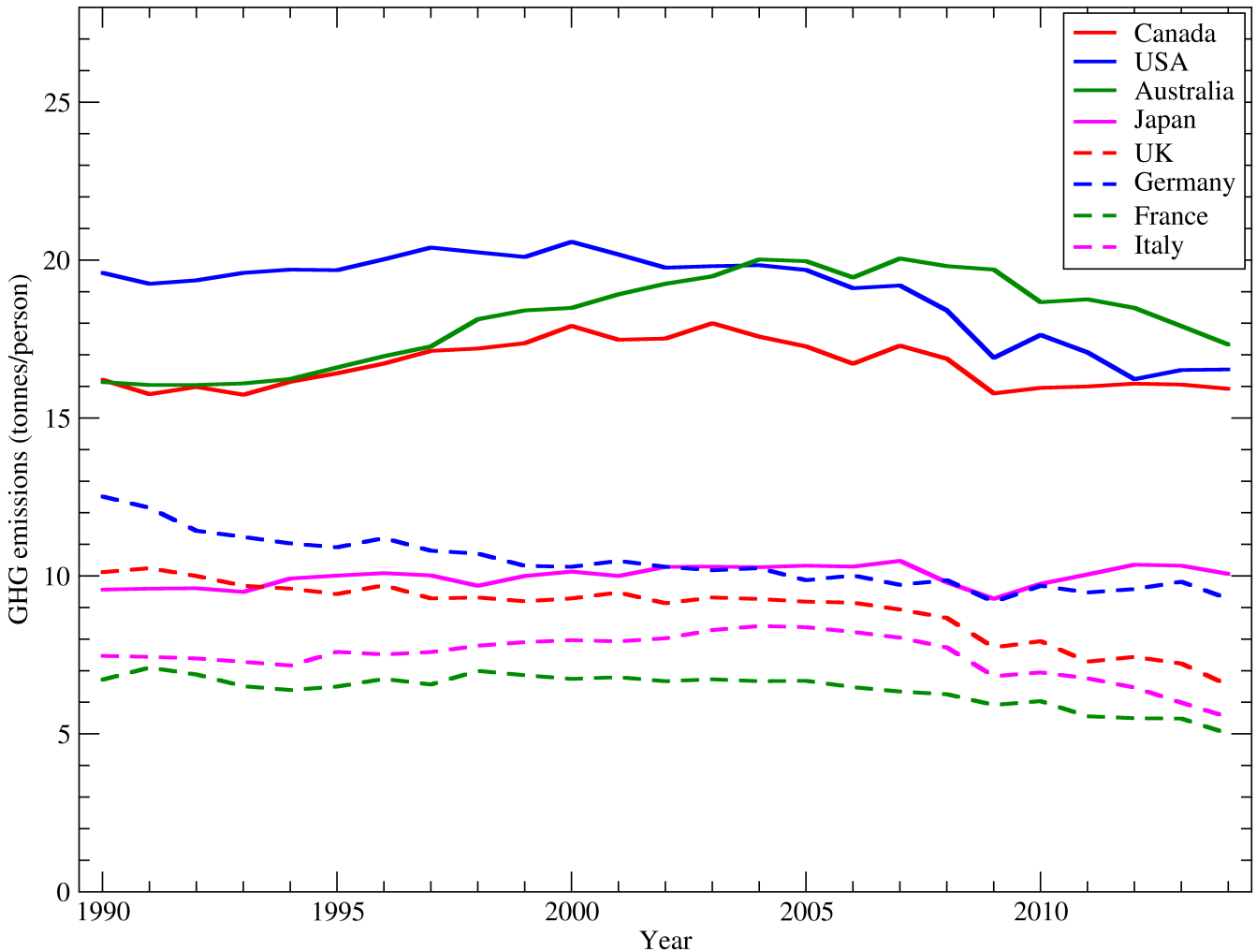
Intended Nationally Determined Contributions

- Each country makes its own commitment and plan.
- Plans to be updated every 5 years.
- Ambitions to be "enhanced" with each successive plan.

Some current INDCs:

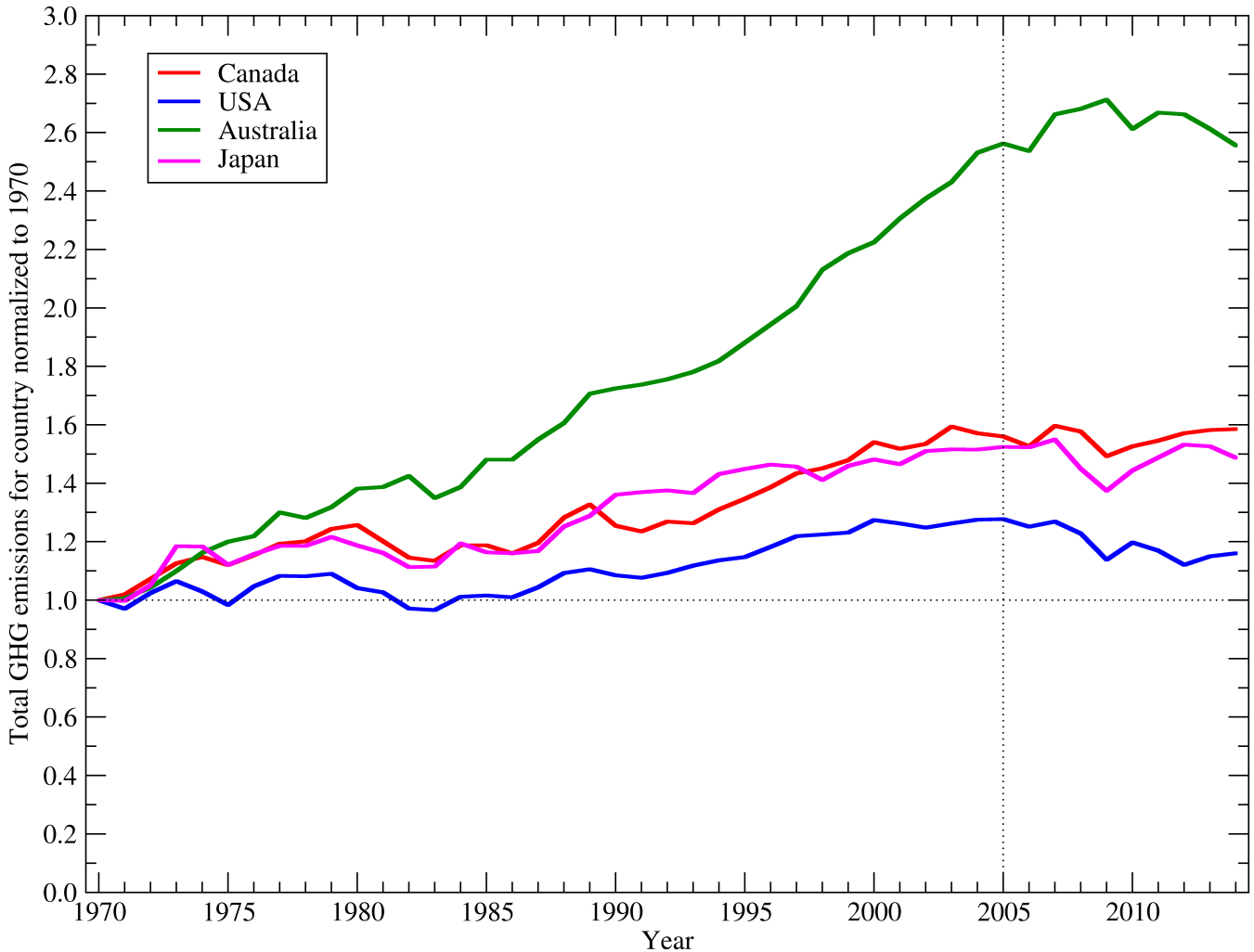
- Canada : 30% reduction from 2005-2030.
- USA : 26-28% reduction from 2005-2025.
- EU : 40% reduction from 1990-2030.
- Japan : 26% reduction from 2013-2030.
- Australia : 26-28% reduction from 2005-2030.
- India : 33-35% reduction in emissions/GDP from 2005-2030.
- China : Peak emissions by 2030.

Progress on a per capita basis



Data source : Trends in Global CO_2 Emissions, PBL Netherlands Environmental Assessment Agency, 2015

Progress on total emissions by country



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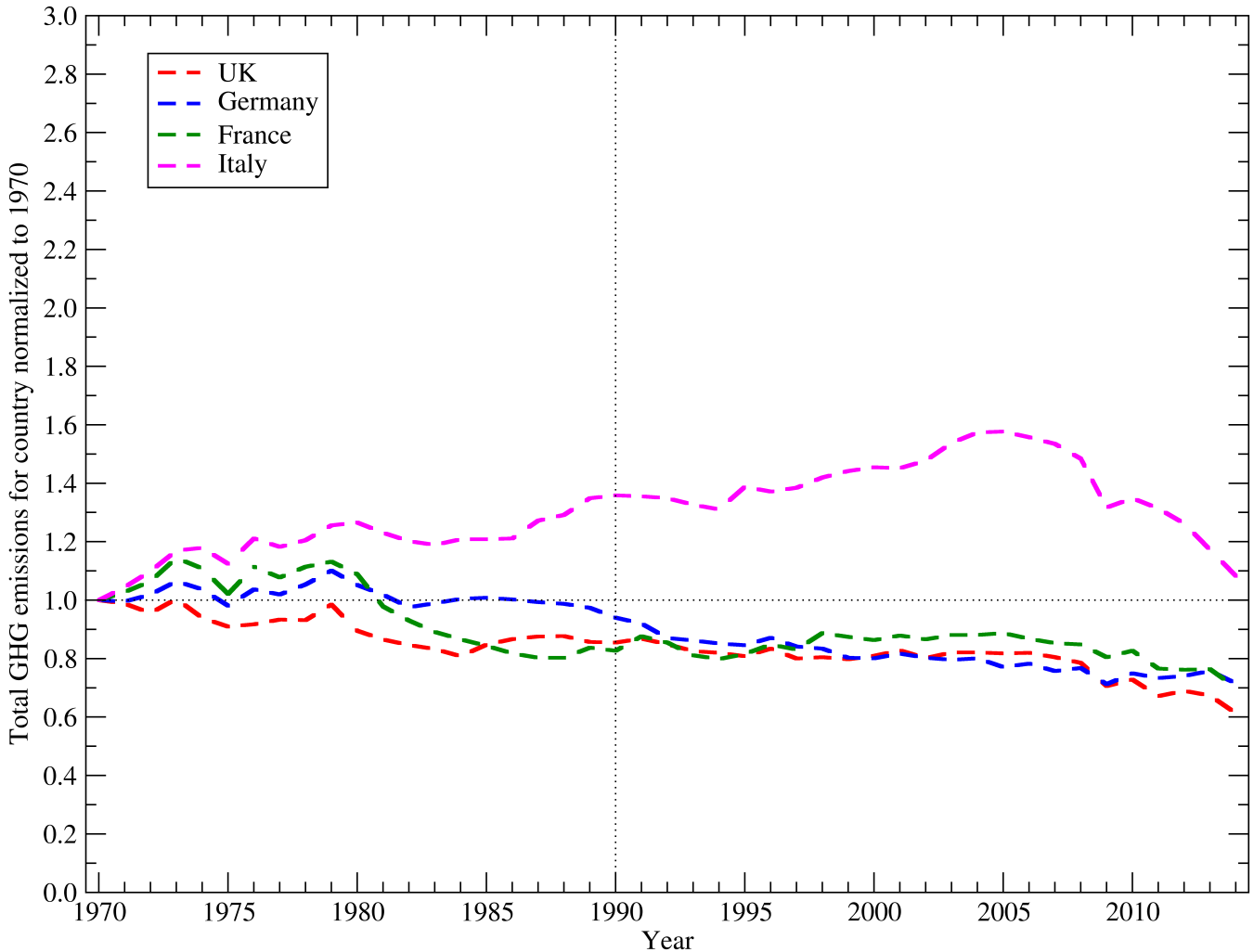

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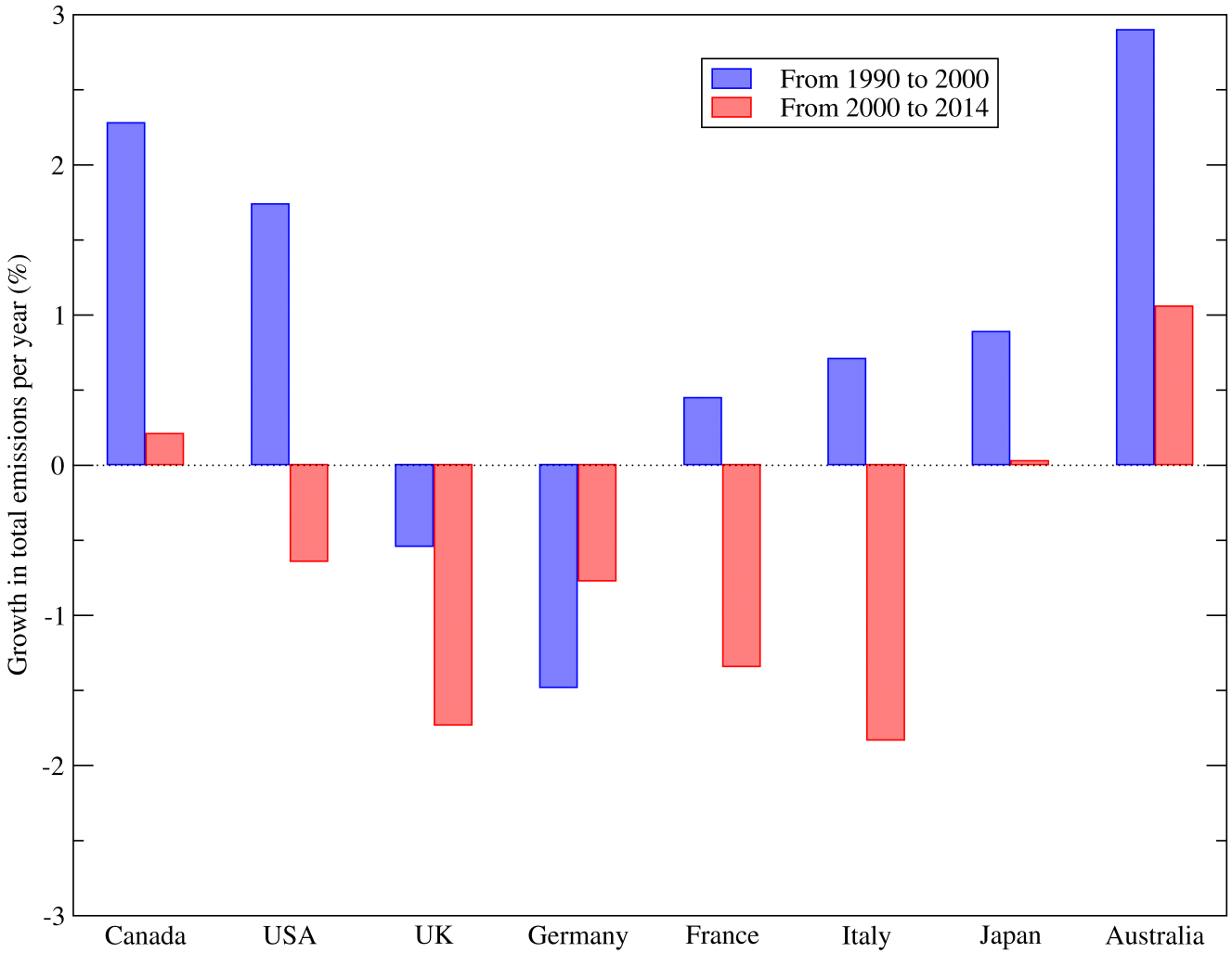
Who's on target to meet their INDCs ?



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On path to achieve Paris goal to limit warming to 2°C ?

- Many (most) countries not on trajectory to achieve targets.
- Targets set in current INDCs not sufficient[1].
- Realistic to count on balancing sources with sinks by 2nd half of 21st century ?

[1] Synthesis Report on the Aggregate Effect of the Intended Nationally Determined Contributions, UN FCCC/CP/2015/7

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- Targets set in current INDCs not sufficient[1].
- Realistic to count on balancing sources with sinks by 2nd half of 21st century ?

- More ambitious approaches required to achieve declared targets.
- And, targets must be enhanced.
- How are we going to achieve this ?

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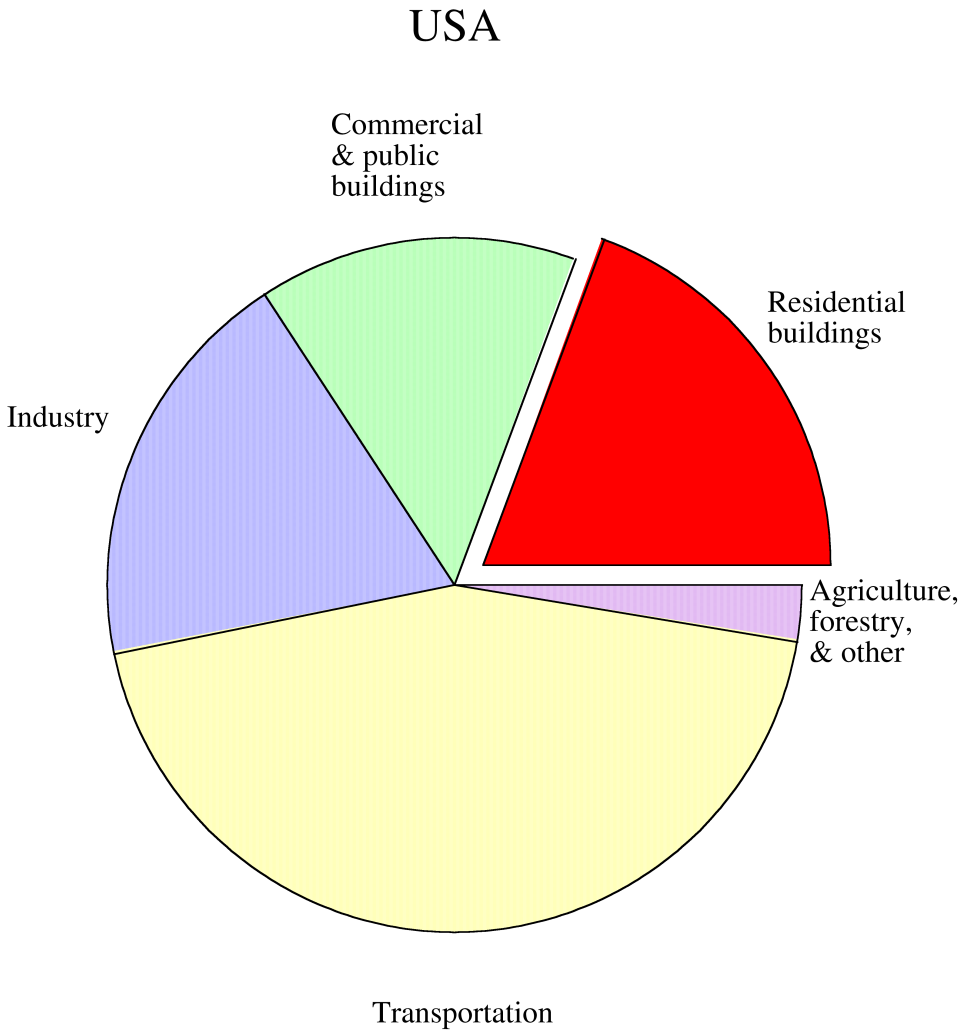
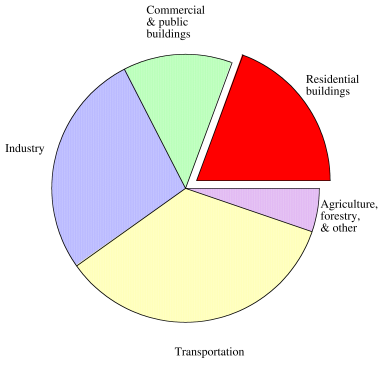
Total final consumption of energy

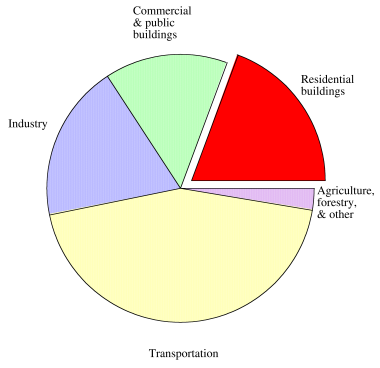


Data source : Energy Balances of OECD Countries, International Energy Agency, 2015.

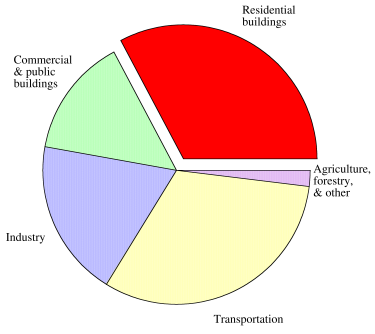
Canada



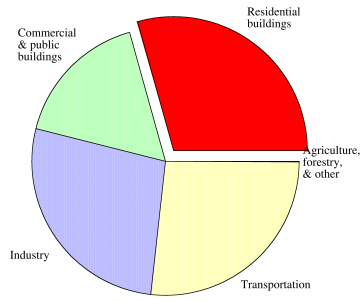
USA



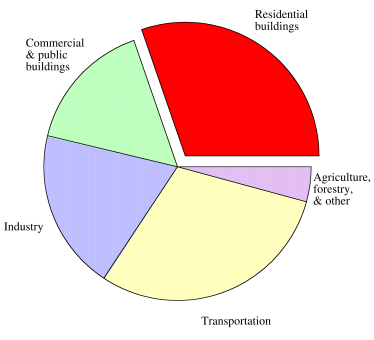
United Kingdom



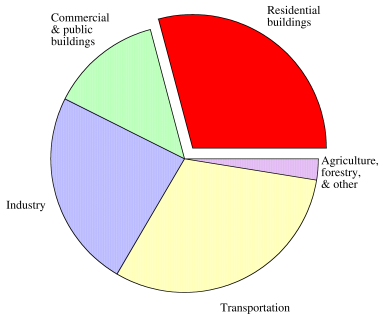
Germany



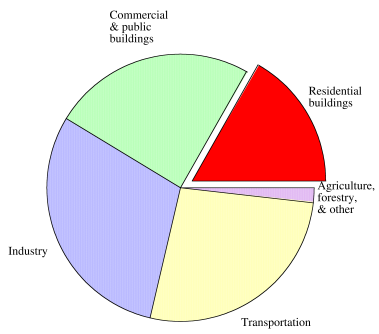
France



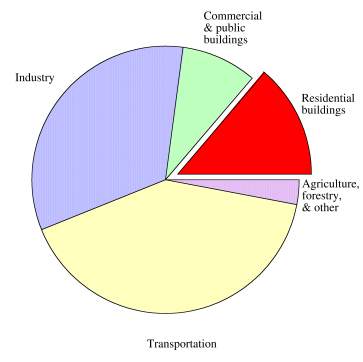
Italy



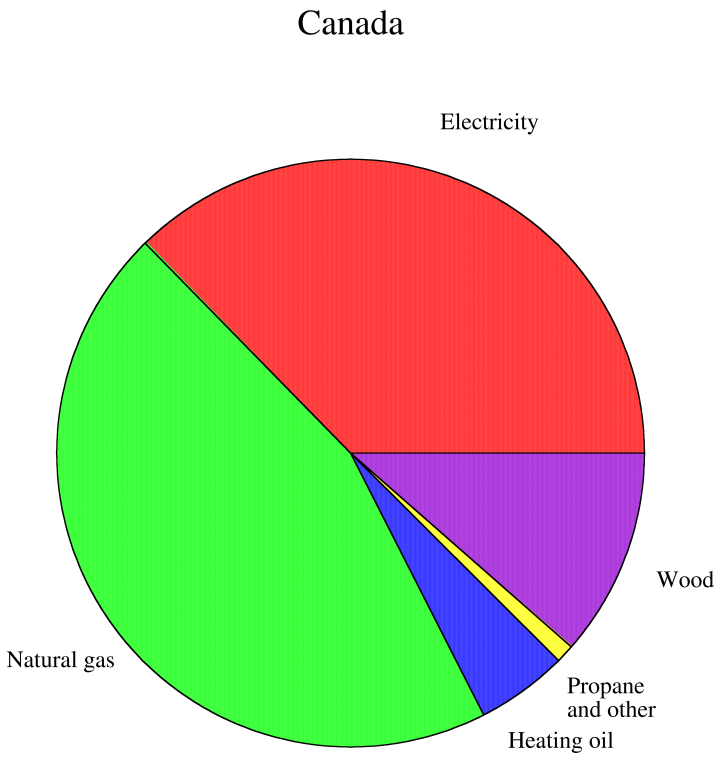
Japan

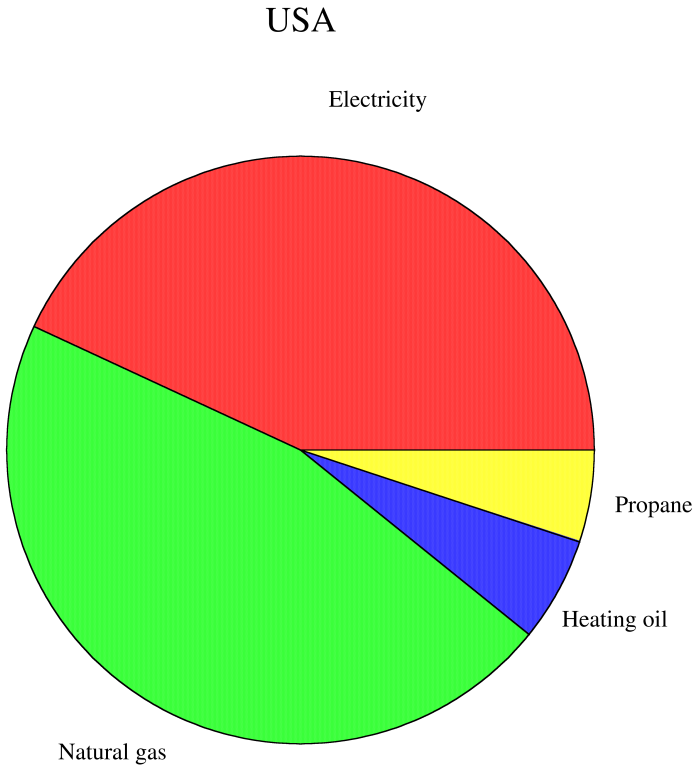


Australia



Houses predominantly use electricity and natural gas



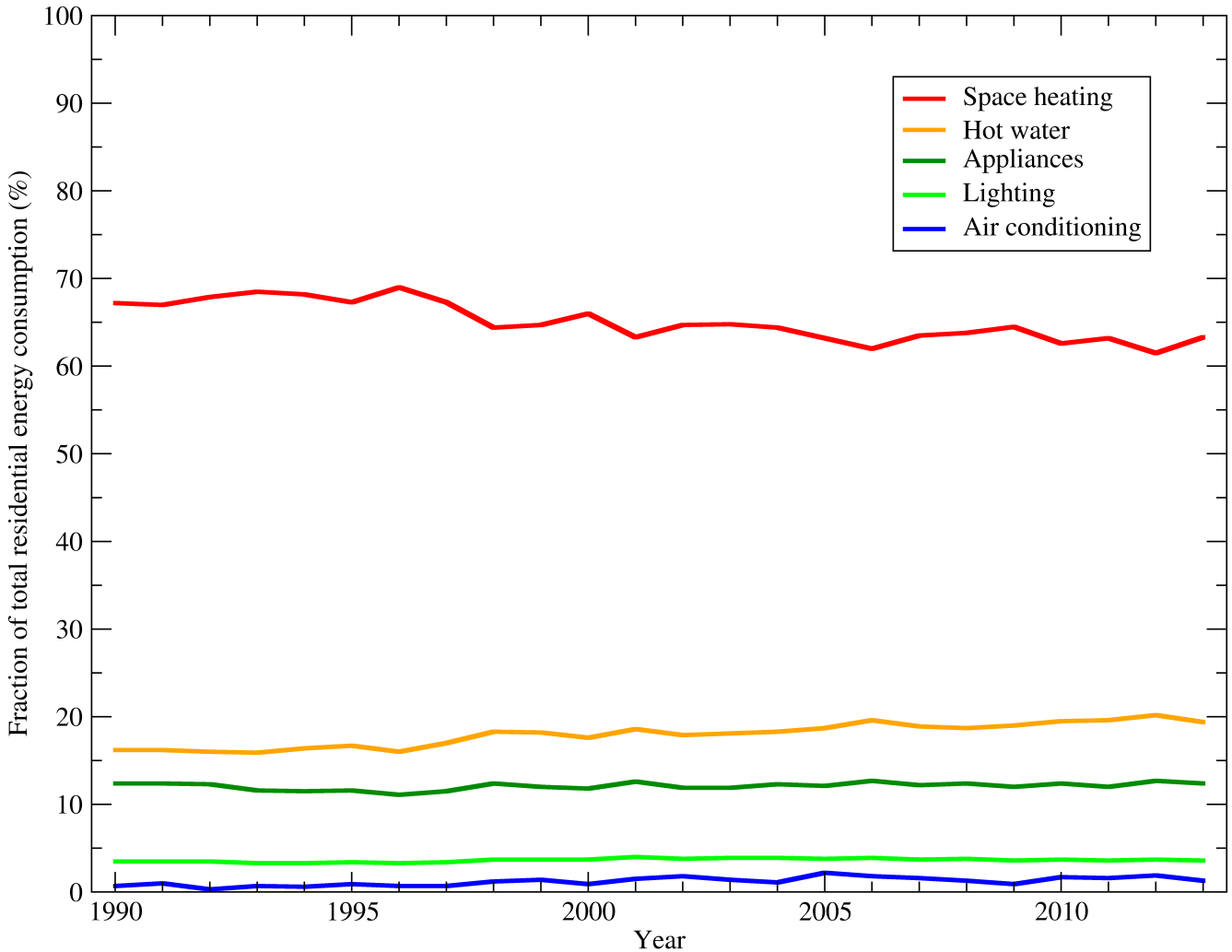


Data source : National Energy Use Database, Natural Resources Canada.

Data source : Residential Energy Consumption Survey, US Energy Information Administration.

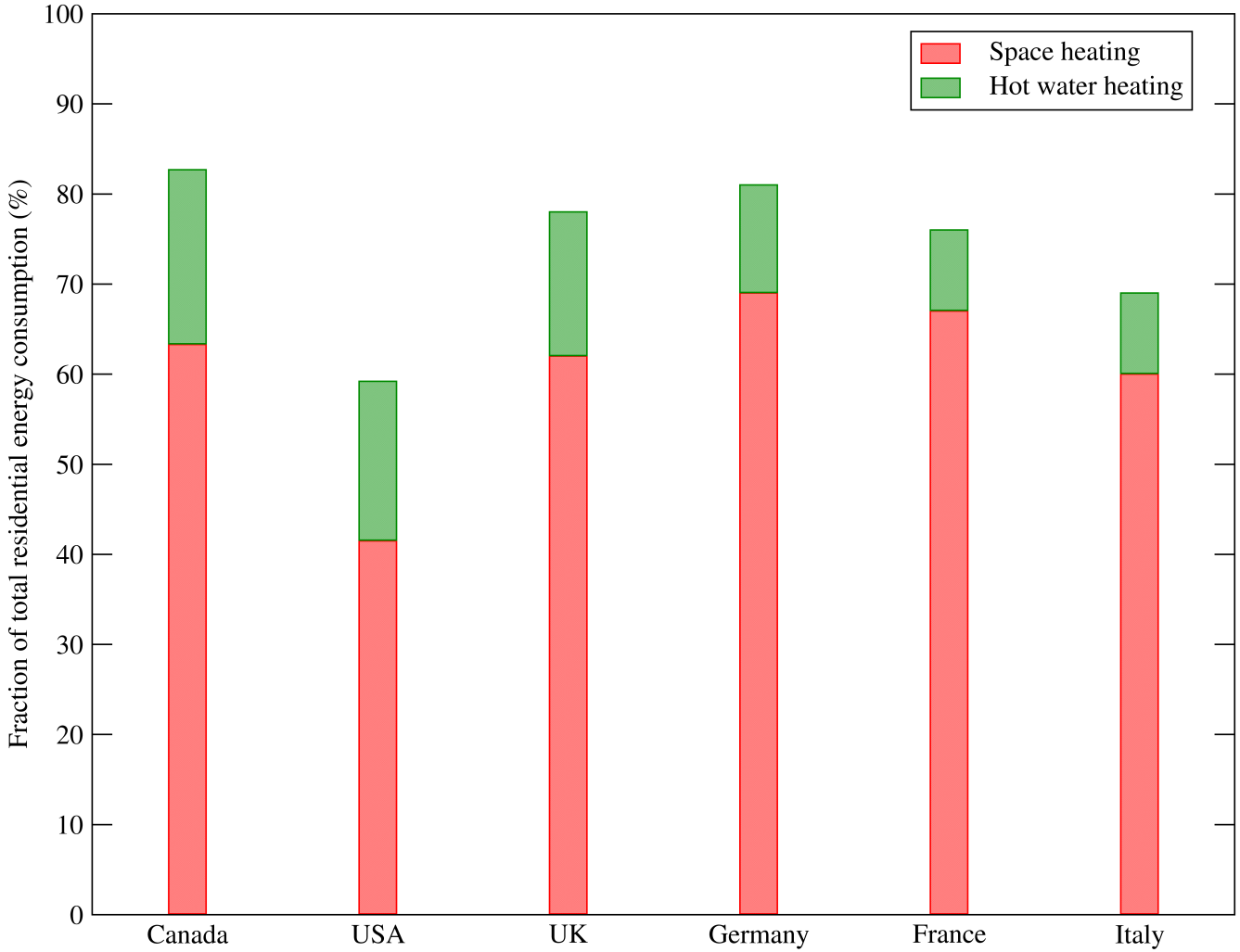
- $\sim 1/3$ of all electricity consumed in houses.
- $\sim 1/3$ of all natural gas consumed in houses.

Trends in residential energy consumption (Canada)



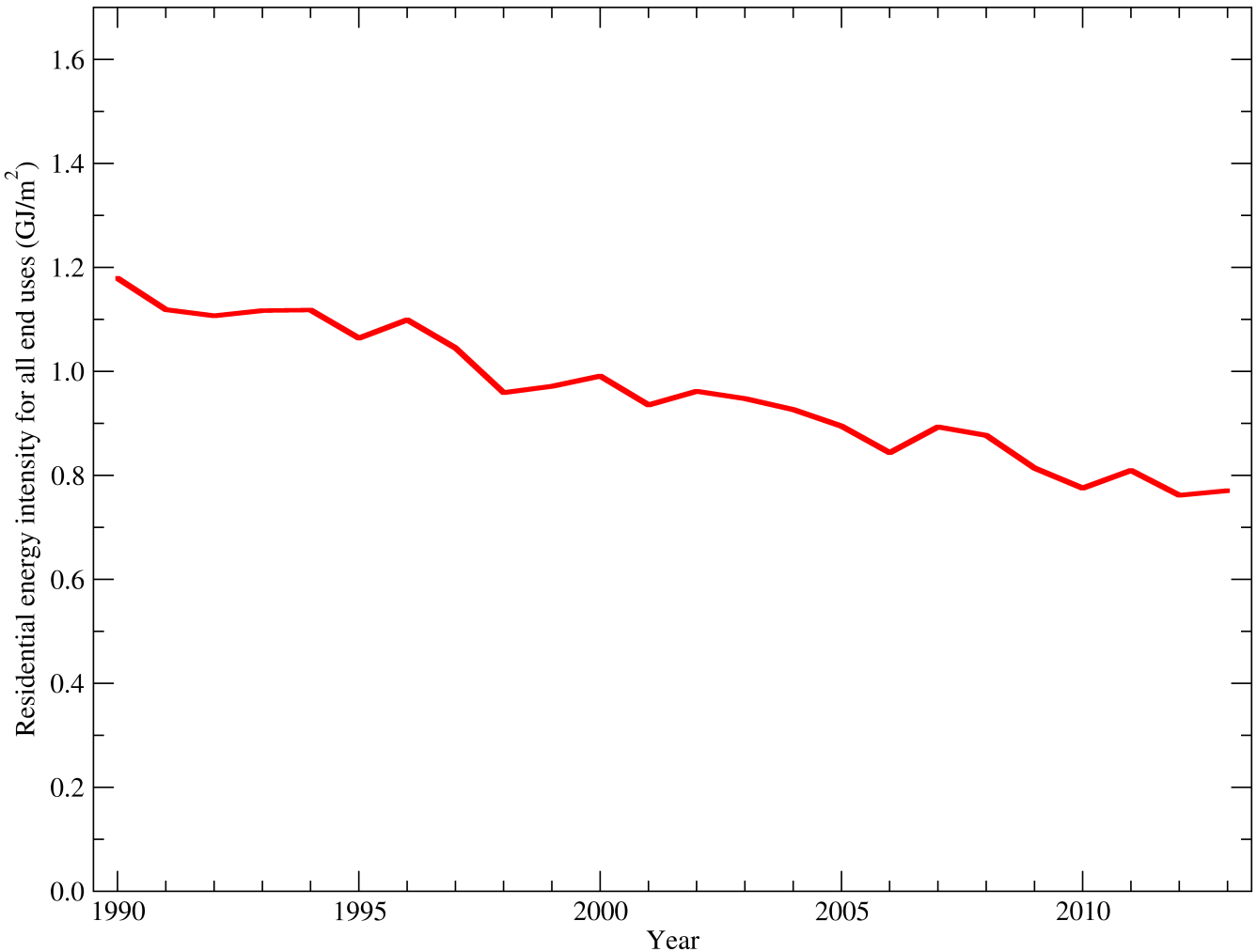
Data source : National Energy Use Database, Natural Resources Canada.

Heat demands dominant in housing



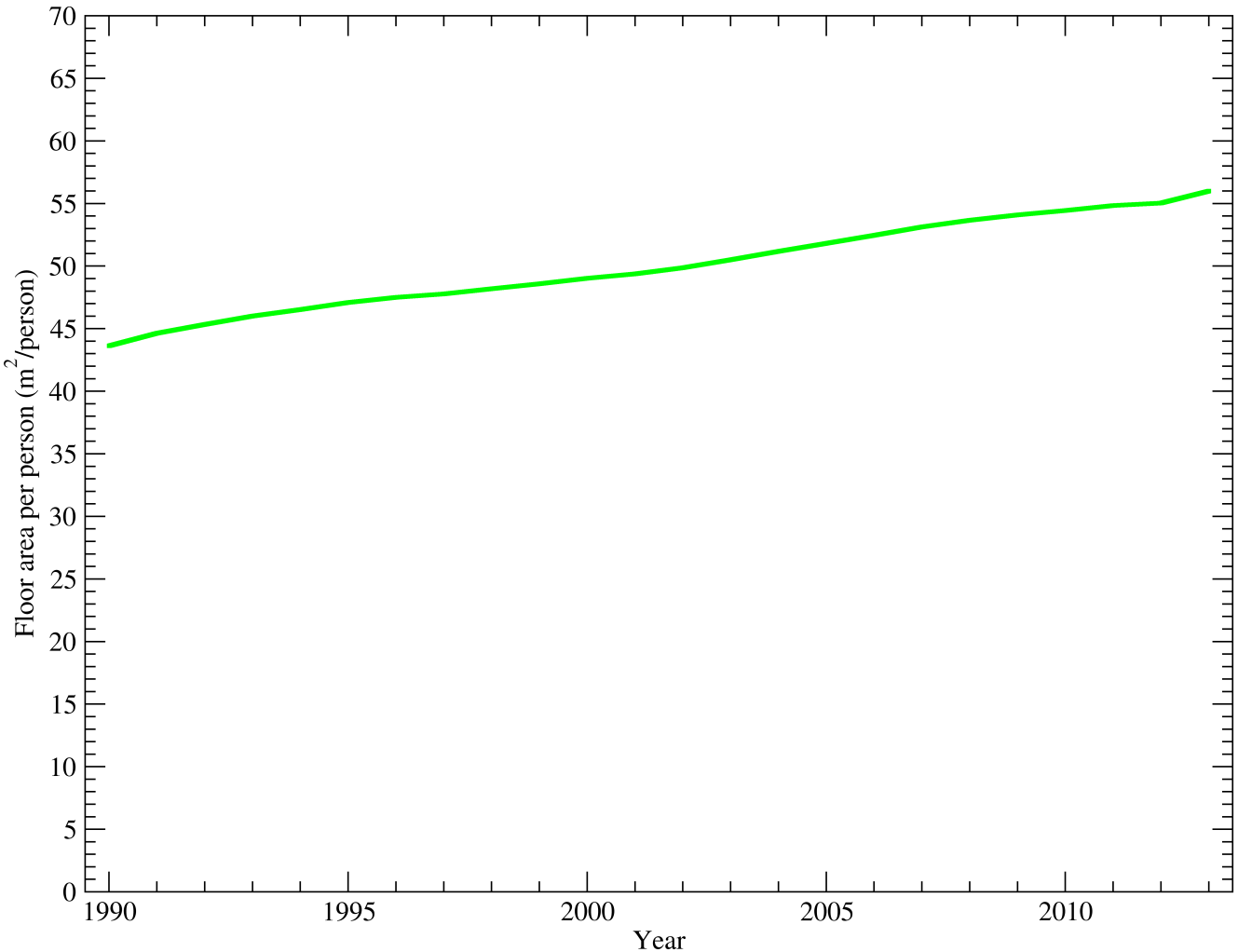
Data source : National Energy Use Database, Natural Resources Canada; Residential Energy Consumption Survey, US Energy Information Administration; Enerdata, ENTRANZE.

Canadian houses are becoming more energy efficient



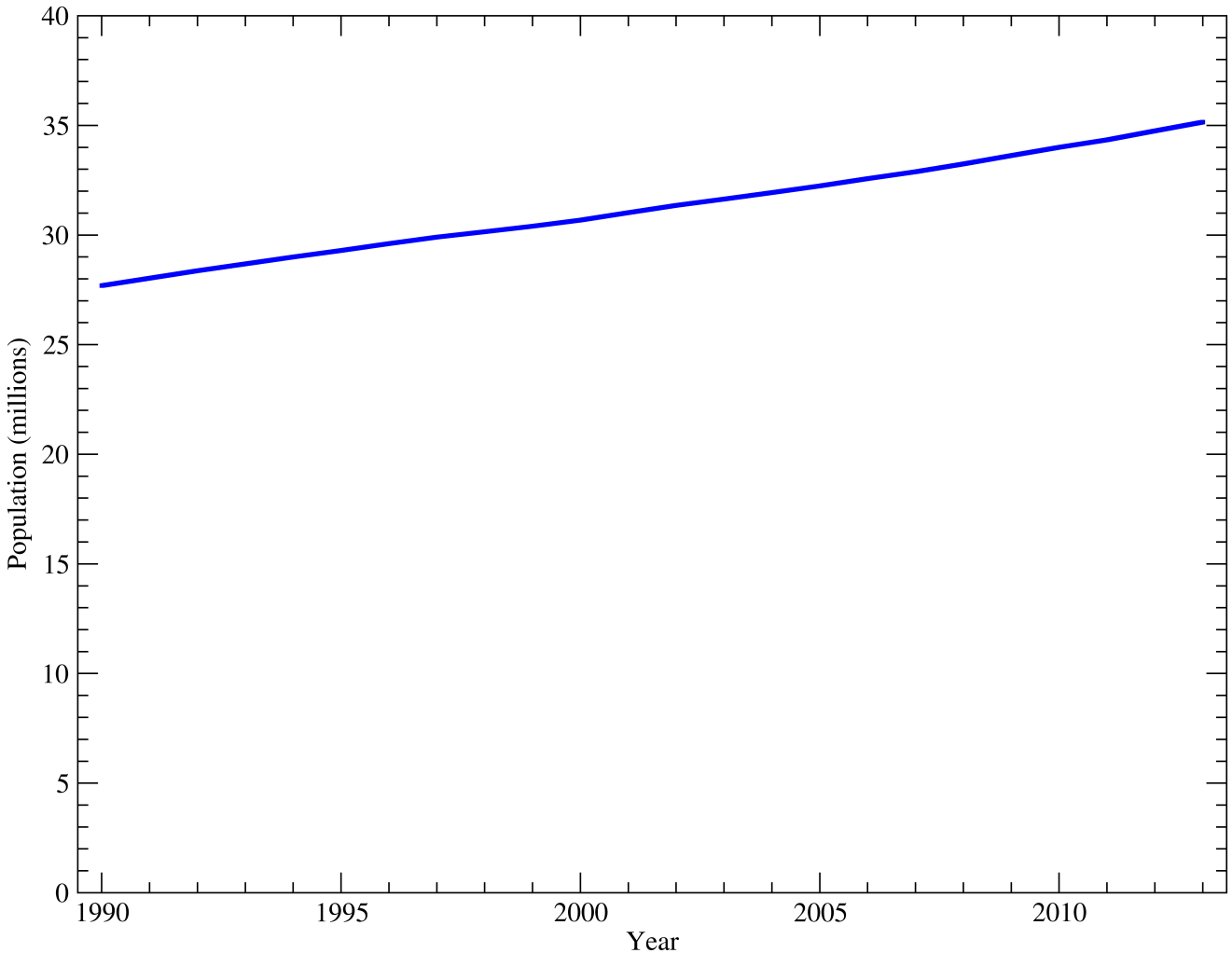
Data source : National Energy Use Database, Natural Resources Canada.

...but we are living in bigger houses



Data source : National Energy Use Database, Natural Resources Canada.

...and the population is growing



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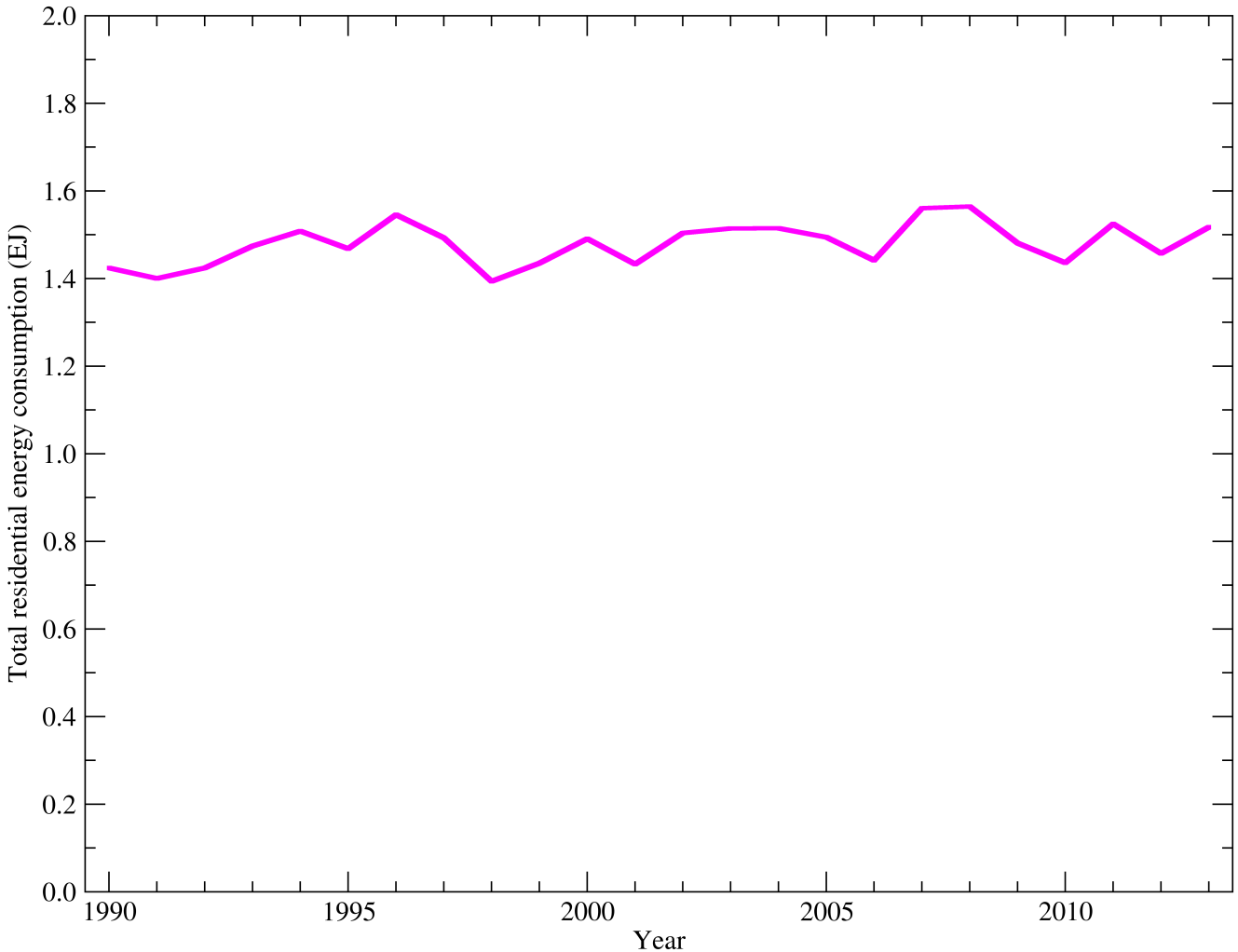
∴ Housing energy consumption still increasing



Data source : National Energy Use Database, Natural Resources Canada.

Summing up the current situation

- Energy consumption of housing sector significant.
- Important efficiency improvements have been made:
  - More stringent building codes.
  - Increased levels of insulation, more airtight envelopes, better windows.
  - More efficient electrical appliances and combustion devices.
- Efficiency gains offset by population growth and increased house size.
- Space and water heating needs still dominate.
- Electricity and natural gas principle energy sources.

Radical reduction in housing energy consumption needed—Possibilities

- Lifestyle changes :
  - Highler density living.
  - Fewer appliances.
  - Moderate thermal comfort expectations.
  - More efficient occupant behaviour.
- Enhanced efficiency :
  - More insulation, better windows, greater airtighness.
  - Improved combustion efficiencies.
  - Heat pumps to replace resistance heaters.
- Fuel switching :
  - Replace natural gas with electricity.
  - Only helpful if emissions-free generation added to grid.
- Maximize capture and use of solar energy to displace grid electricity and natural gas.

Solar options

1. Solar photovoltaics.

NIST Net Zero Energy Residential Test Facility

Solar options

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NIST Net Zero Energy Residential Test Facility

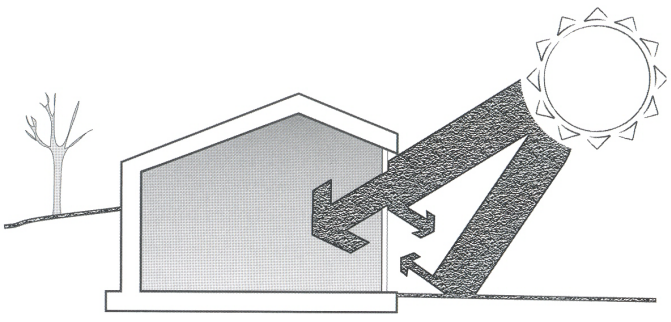
Solar options

1. Solar photovoltaics.

NIST Net Zero Energy Residential Test Facility

2. Passive solar.
3. Solar thermal.

Passive solar



Henderson and Roscoe, Solar Home Design Manual for Cool Climates, 2010.

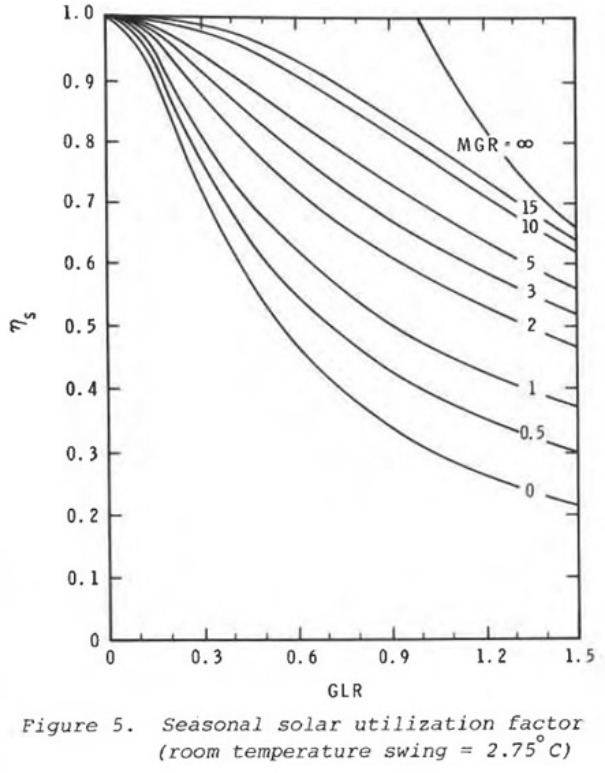
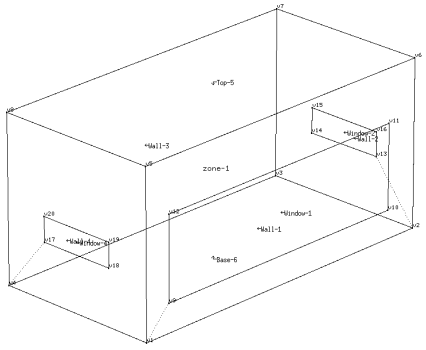


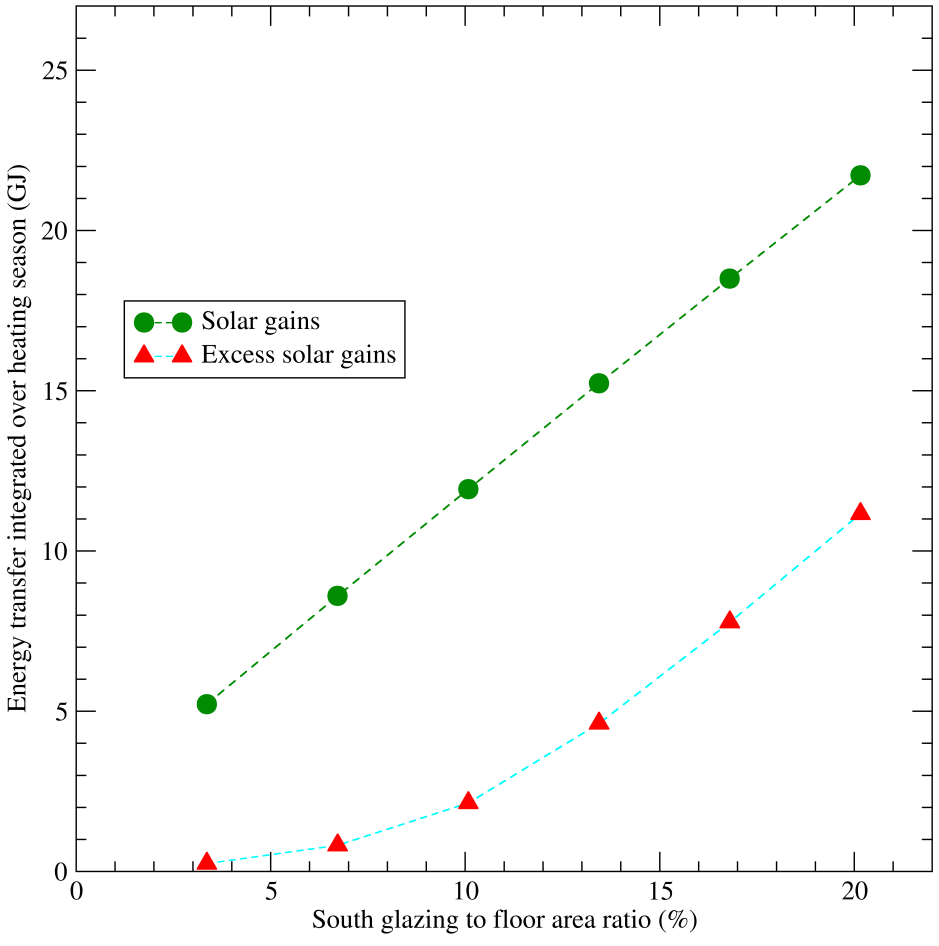
Figure 5. Seasonal solar utilization factor (room temperature swing = 2.75°C)

Sander and Barakat, Method for Estimating the Utilization of Solar Gain Through Windows, ASHRAE Transactions, 1983.

South-facing glazing area limited to protect against overheating : $\sim$ 6% of floor area.

Additional passive solar gains could be beneficial





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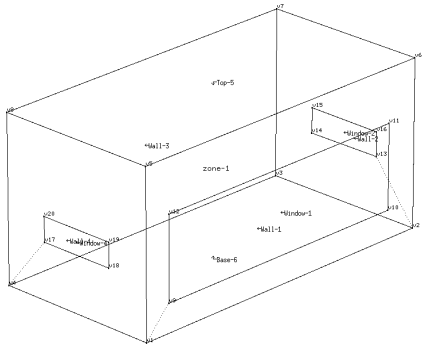
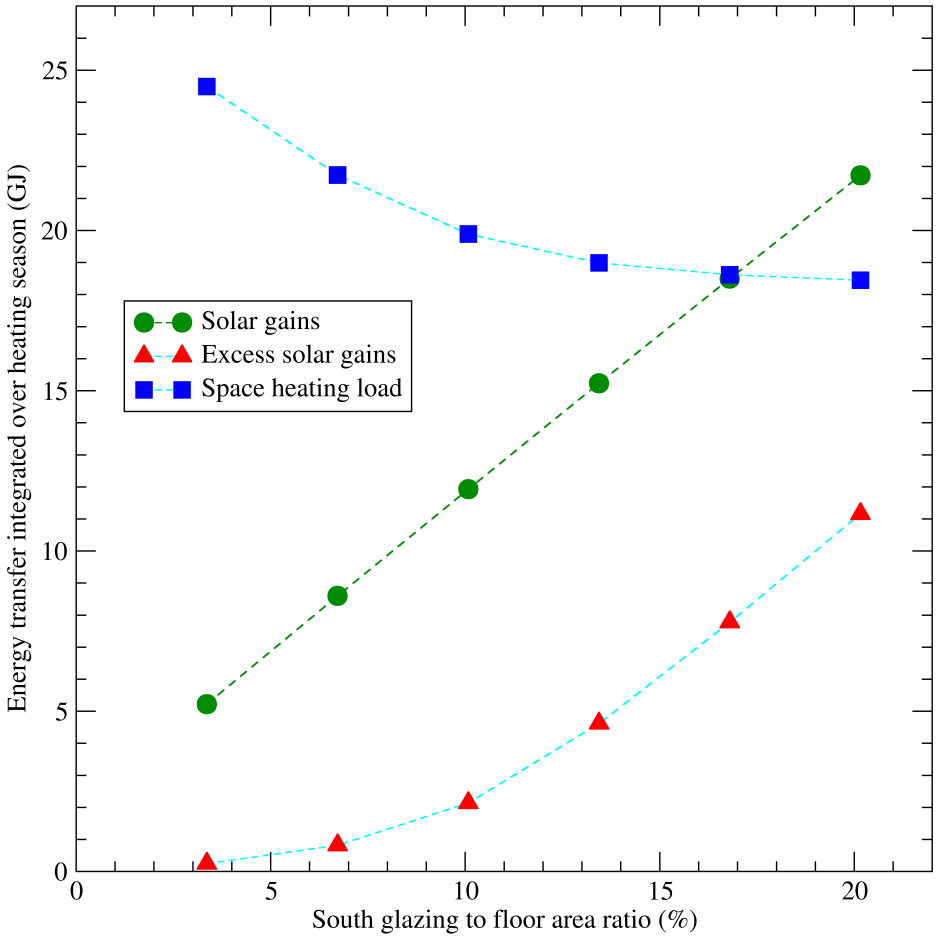
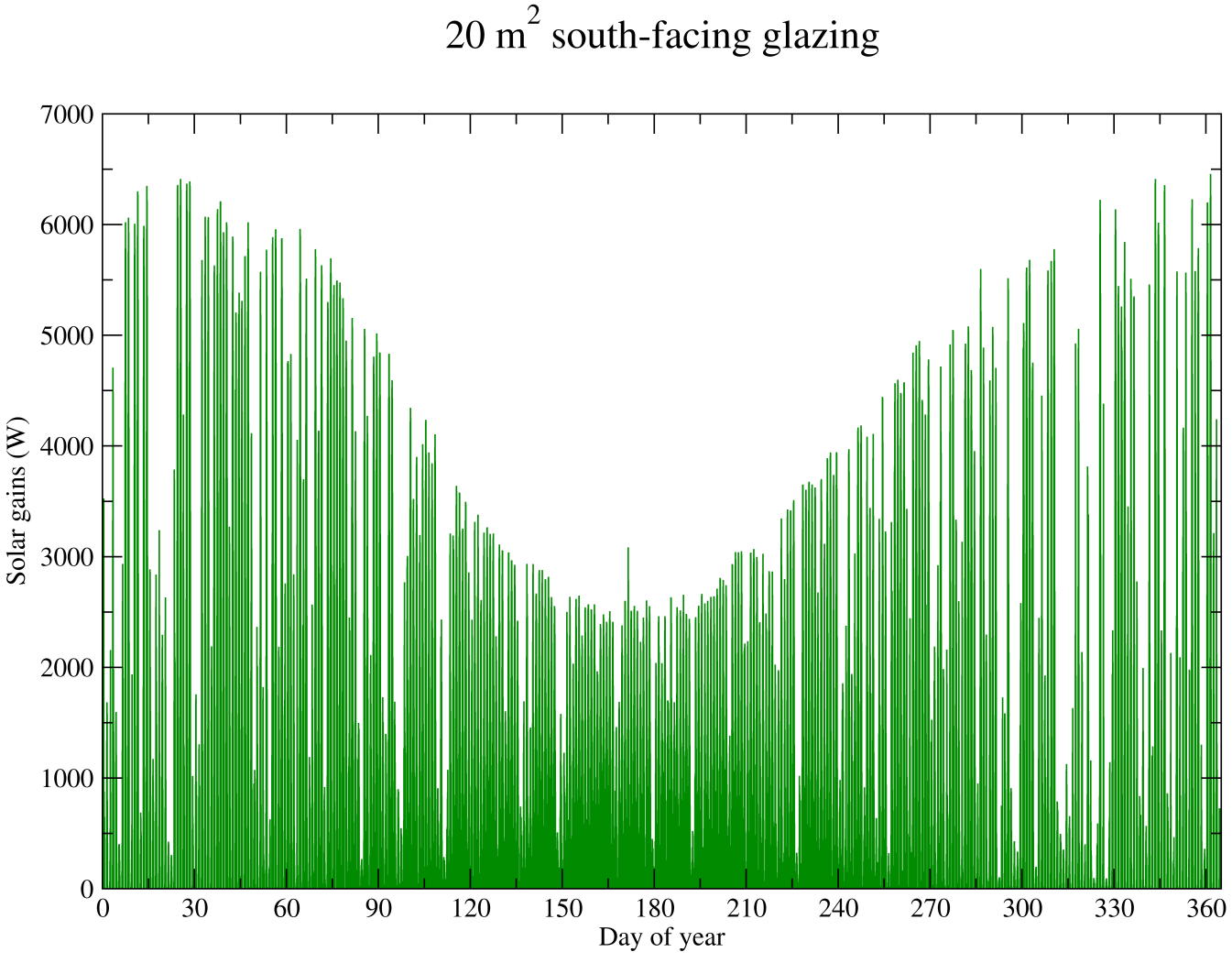




Need to manage excess passive solar gains



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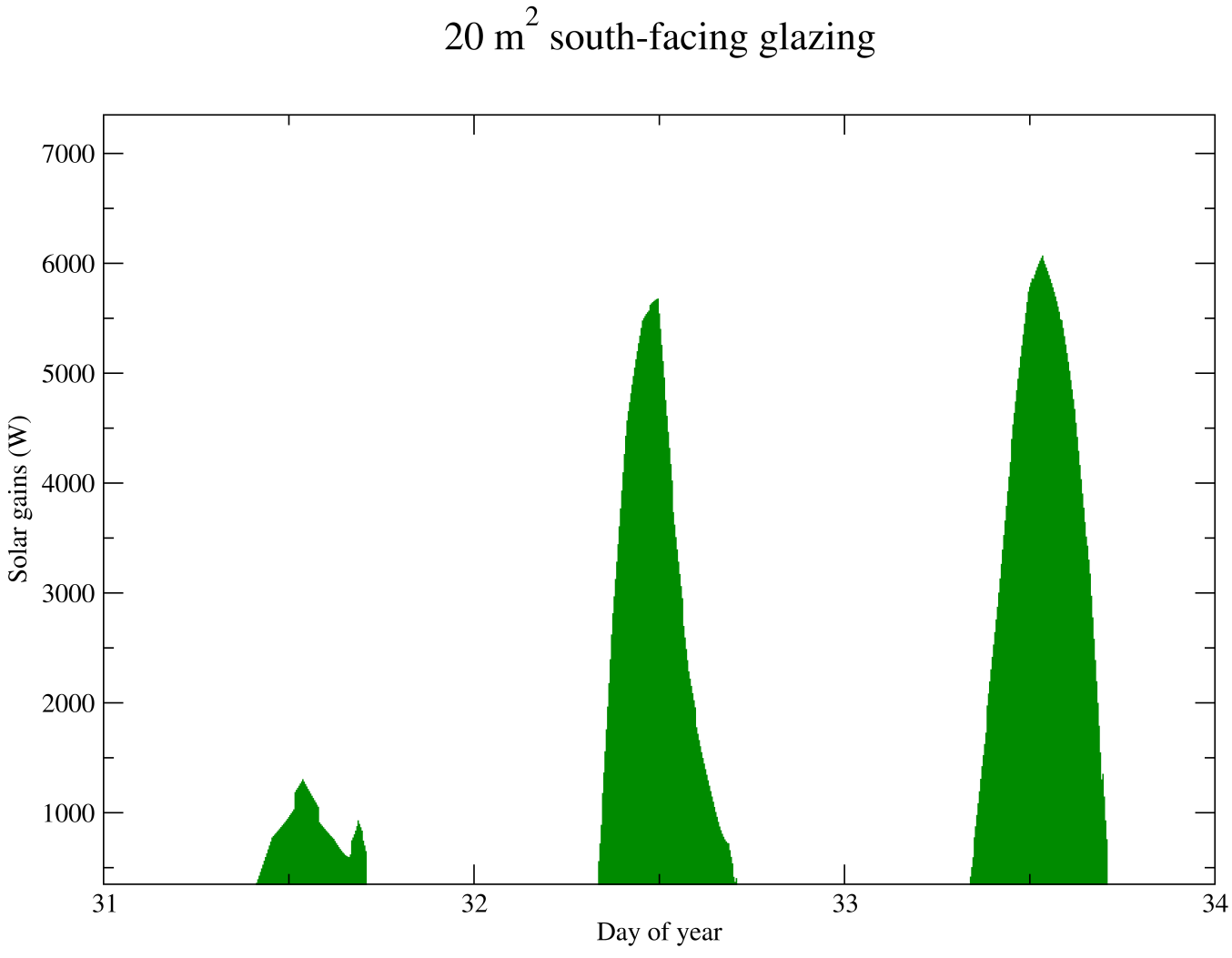
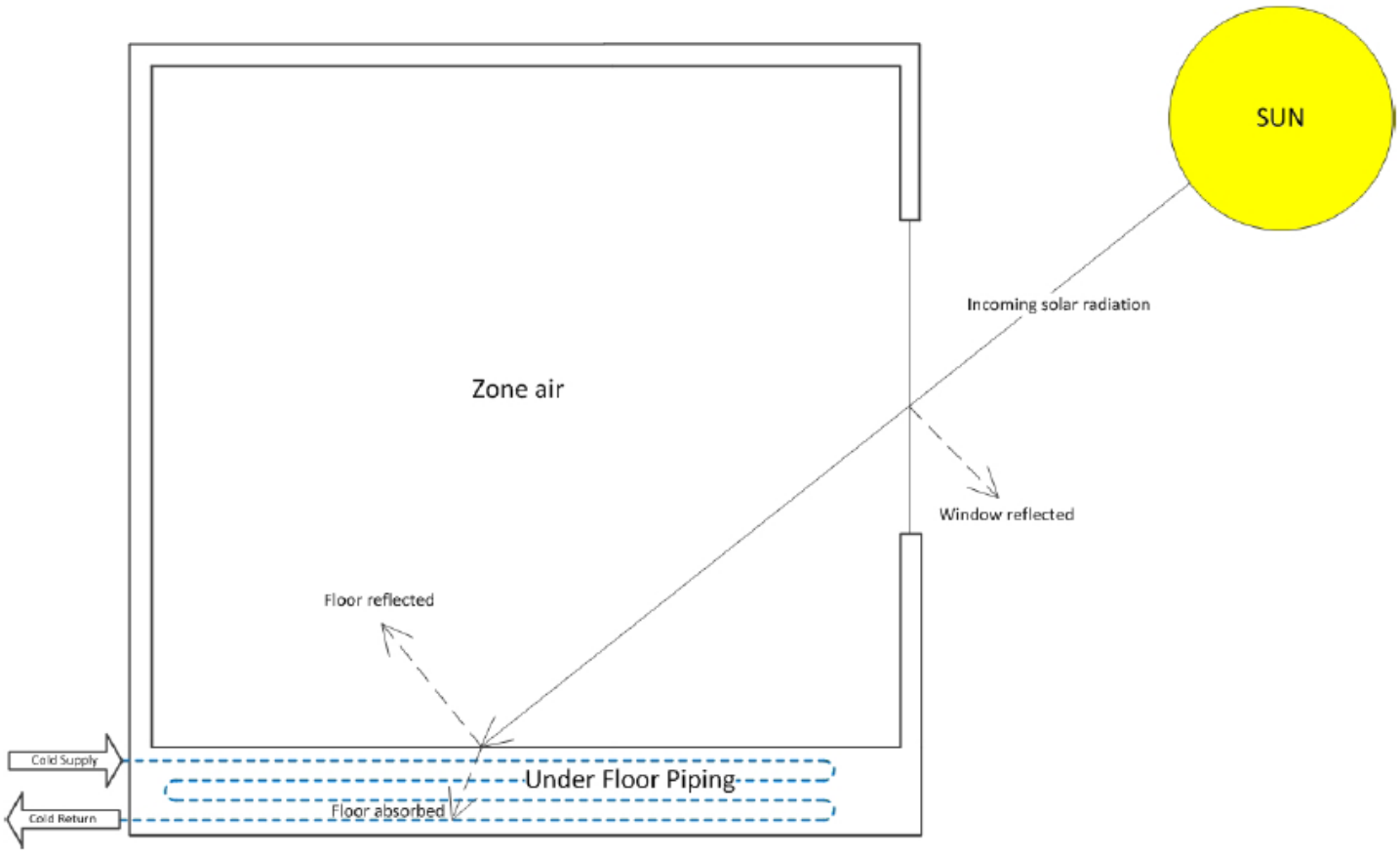
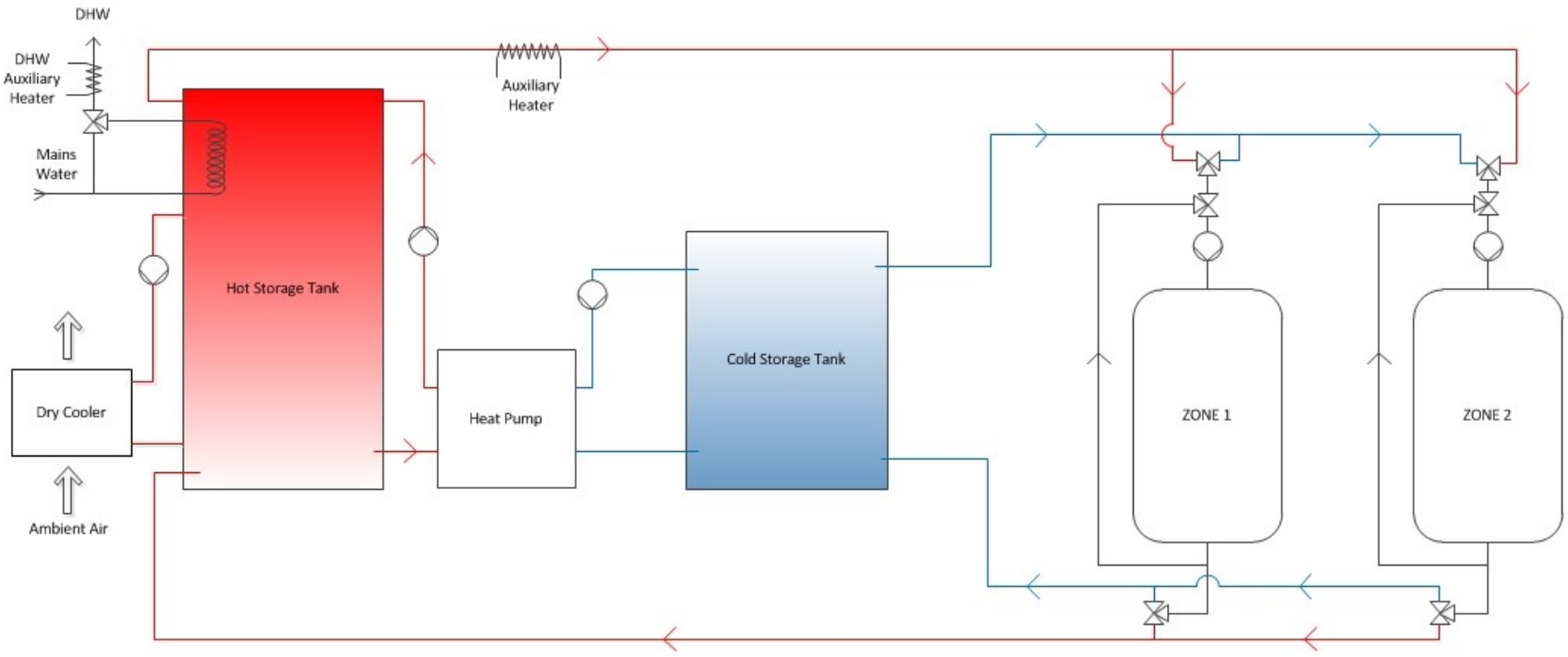


Hydronic floor as solar collector



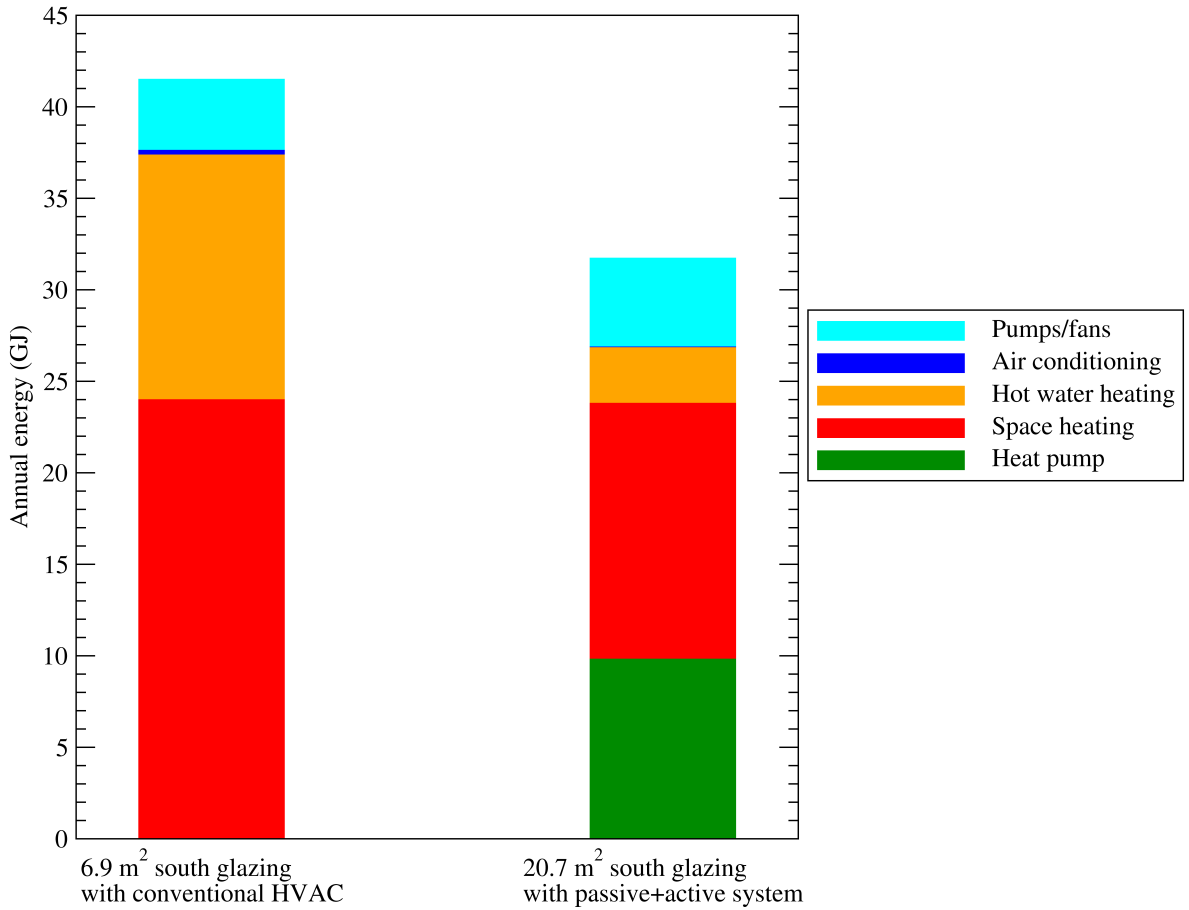
From Brideau (2016), PhD thesis, Carleton University.

Passive+active solar system



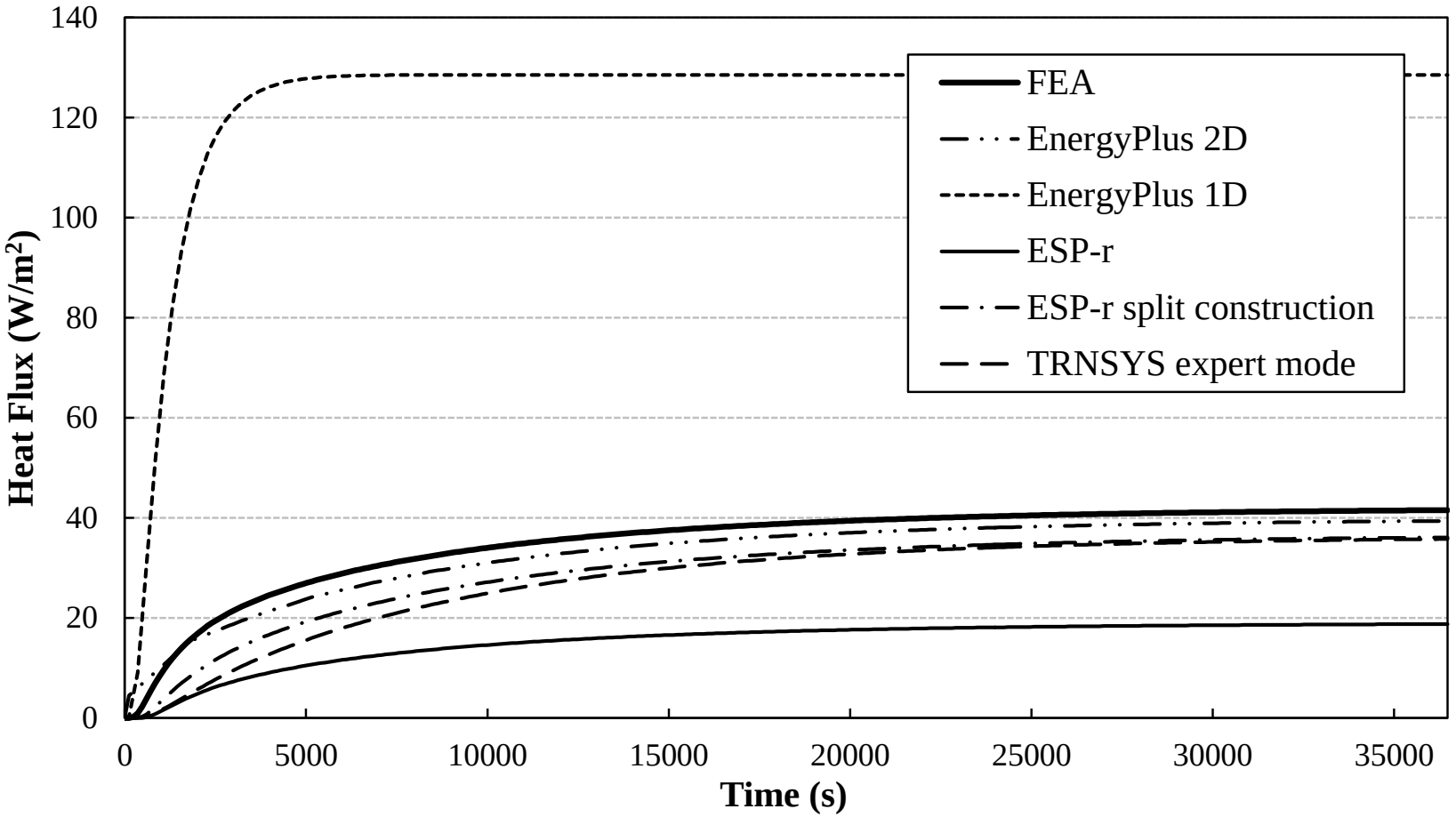
From Brideau, Beausoleil-Morrison, and Kummert (2015), Collection and storage of solar gains incident on the floor in a house during the heating season, IBPC 2015, Torino.

Potential energy savings (preliminary simulation predictions)



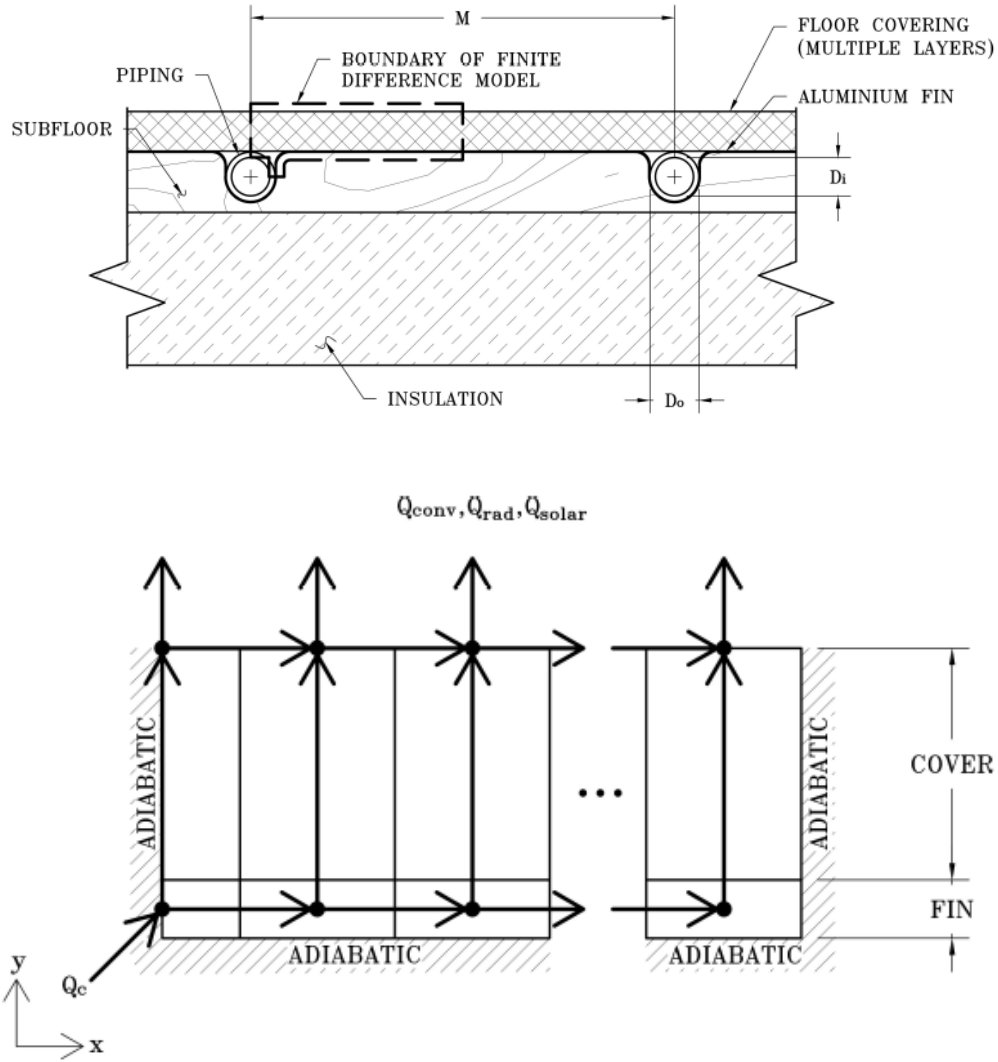
Results extracted from Brideau, Beausoleil-Morrison, and Kummert (2015), Collection and storage of solar gains incident on the floor in a house during the heating season, IBPC 2015, Torino.

Issues with existing radiant floor models in BPS tools



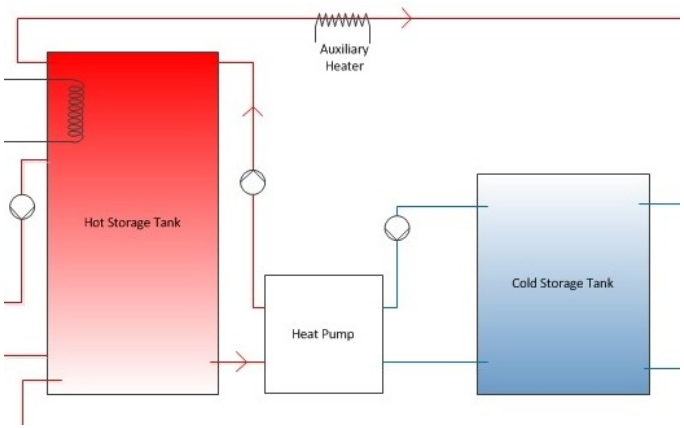
From Brideau, Beausoleil-Morrison, Kummert, Wills (2015), Inter-model comparison of embedded-tube radiant floor models in BPS tools, Journal of Building Performance Simulation.

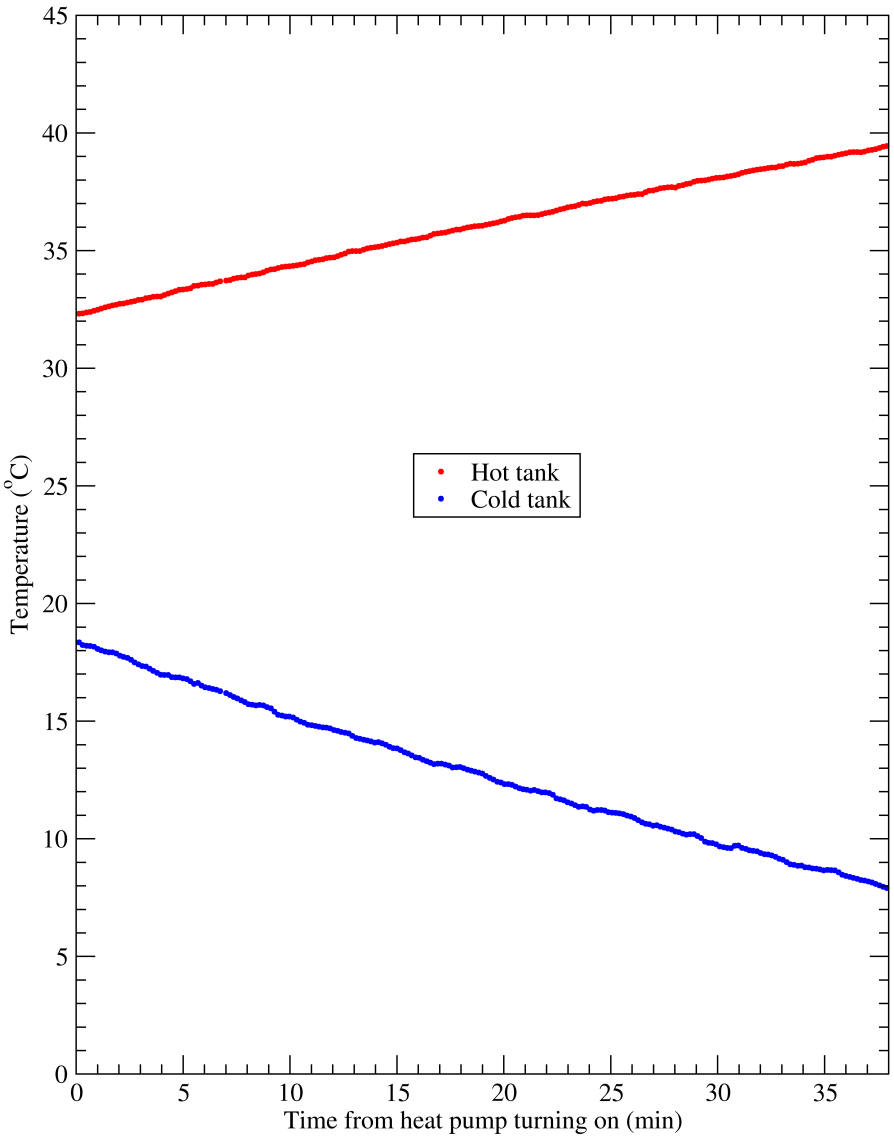
New model for above-floor tube and plate radiant floors



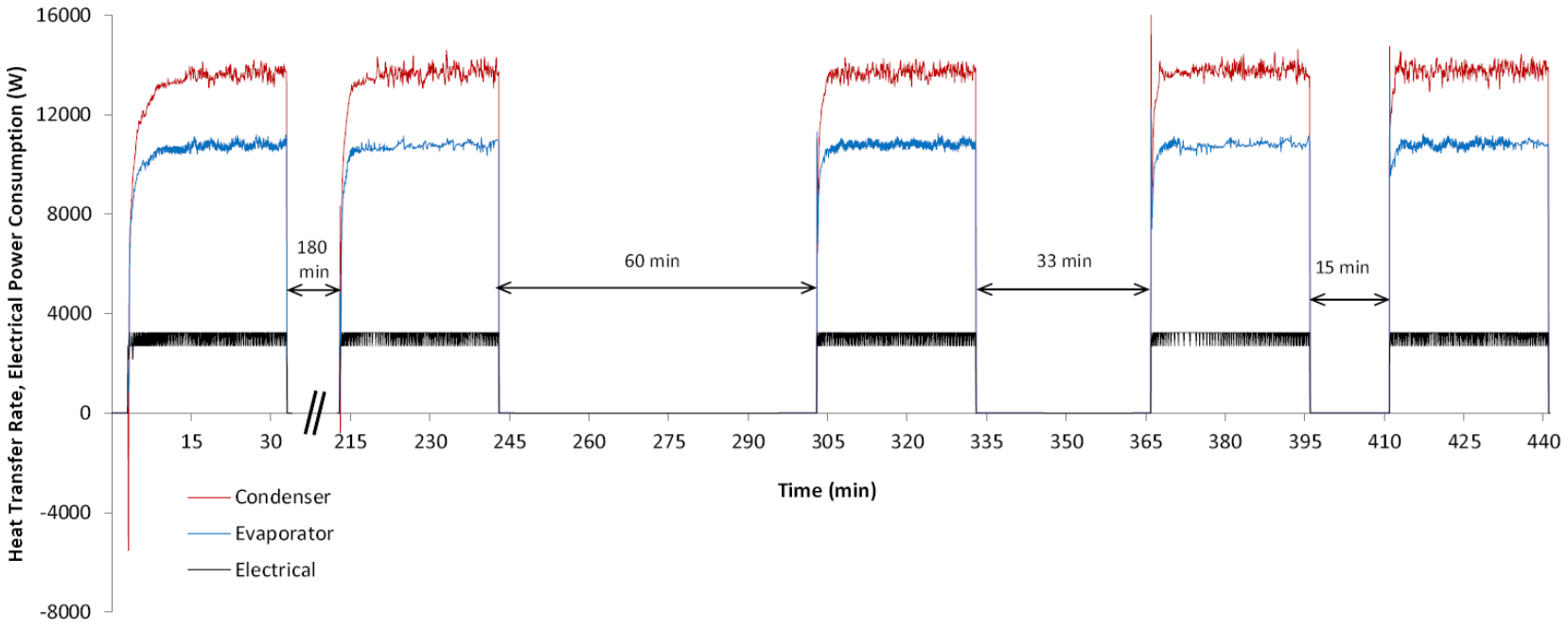
From Brideau (2016), PhD thesis, Carleton University.

Heat pump cycling times



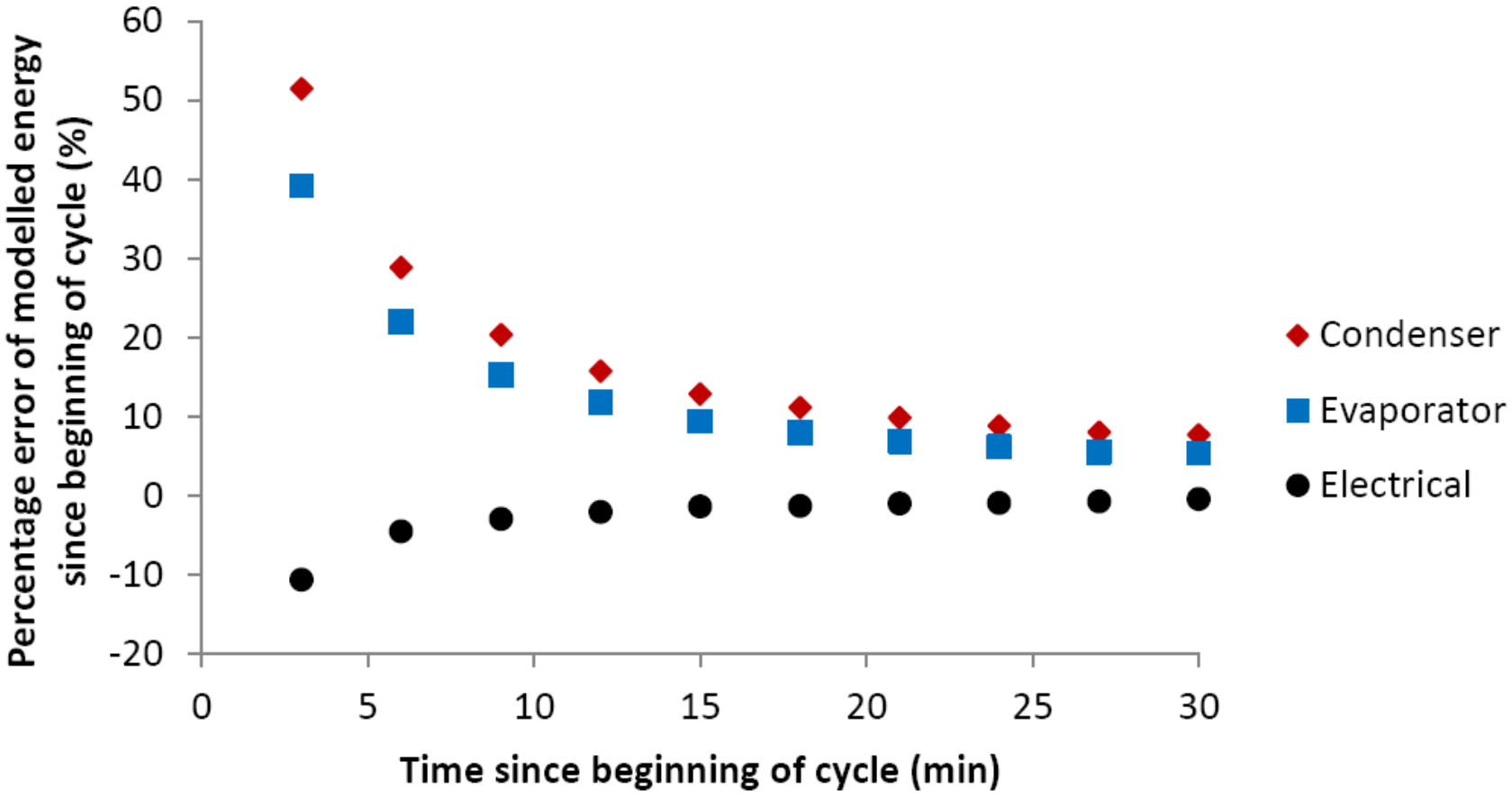


Heat pump transient effects important



From Brideau, Beausoleil-Morrison, Kummert (2016), Empirical model of a 11 kW (nominal cooling) R134a water-water heat pump, eSim 2016.

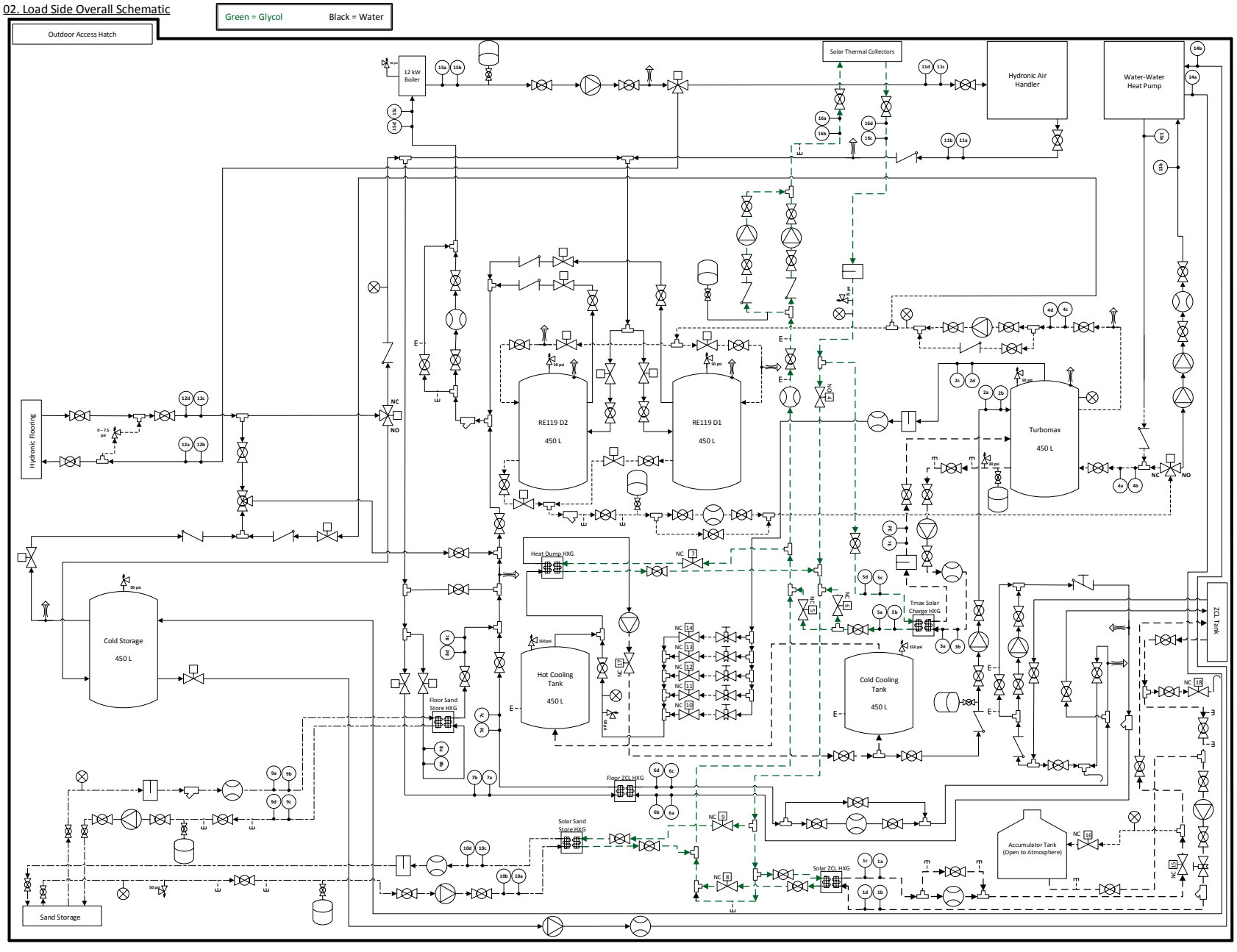
Transient heat pump model required

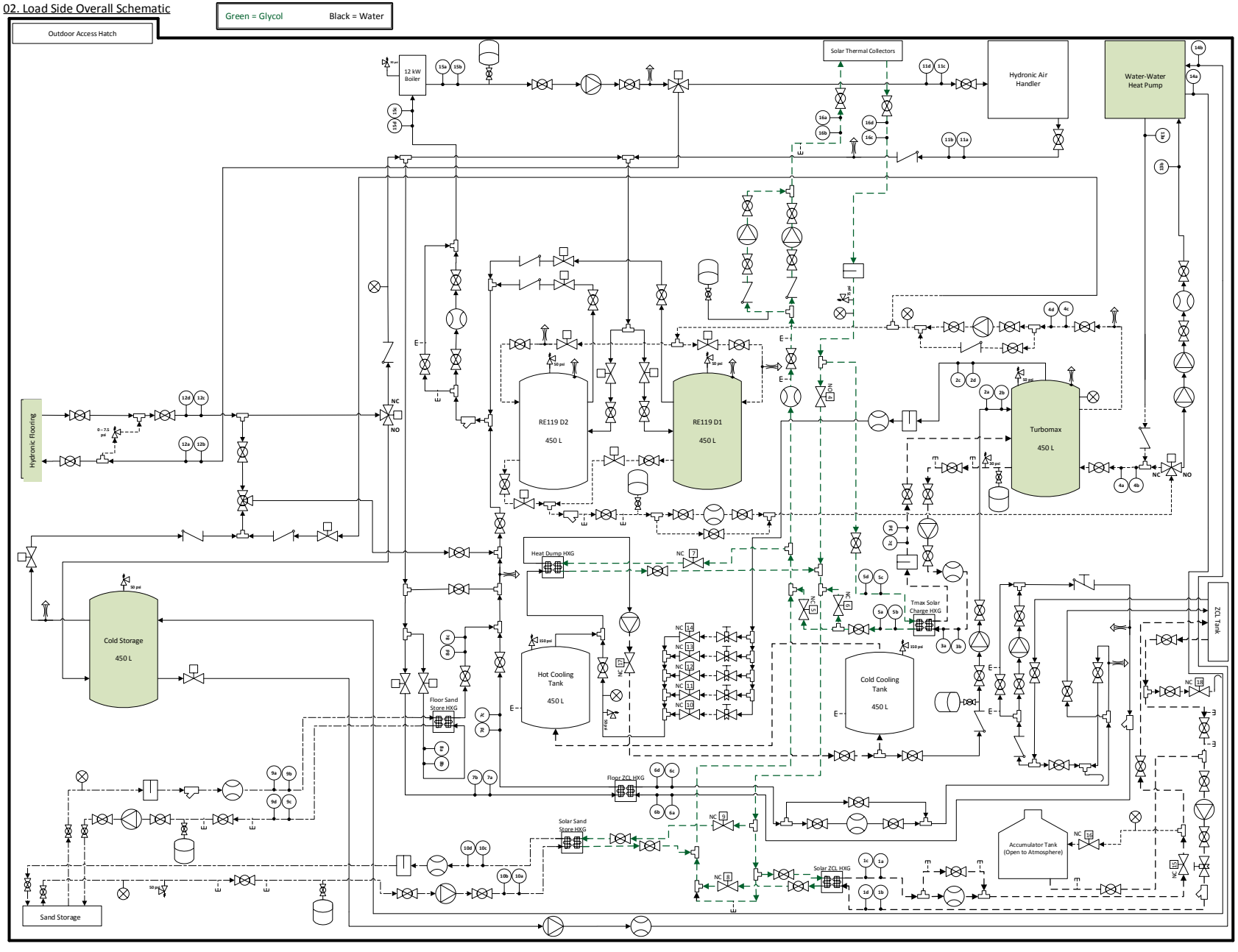


From Brideau, Beausoleil-Morrison, Kummert (2016), Empirical model of a 11 kW (nominal cooling) R134a water-water heat pump, eSim 2016.

Full-scale experiments

Above-floor tube and plate radiant floors


02. Load Side Overall Schematic
Green = Glycol
Black = Water
Outdoor Access Hatch
12 kW Boiler
Solar Thermal Collectors
Hydronic Air Handler
Water-Water Heat Pump
Hydronic Flooring
RE119 D2
450 L
RE119 D1
450 L
Turbomax
450 L
Heat Dump HXG
Cold Storage
450 L
Hot Cooling Tank
450 L
Cold Cooling Tank
450 L
Tmax Solar Charge HXG
Floor Sand Store HXG
Floor ZCL HXG
Solar Sand Store HXG
Solar ZCL HXG
Accumulator Tank (Open to Atmosphere)
ZCL Tank
Sand Storage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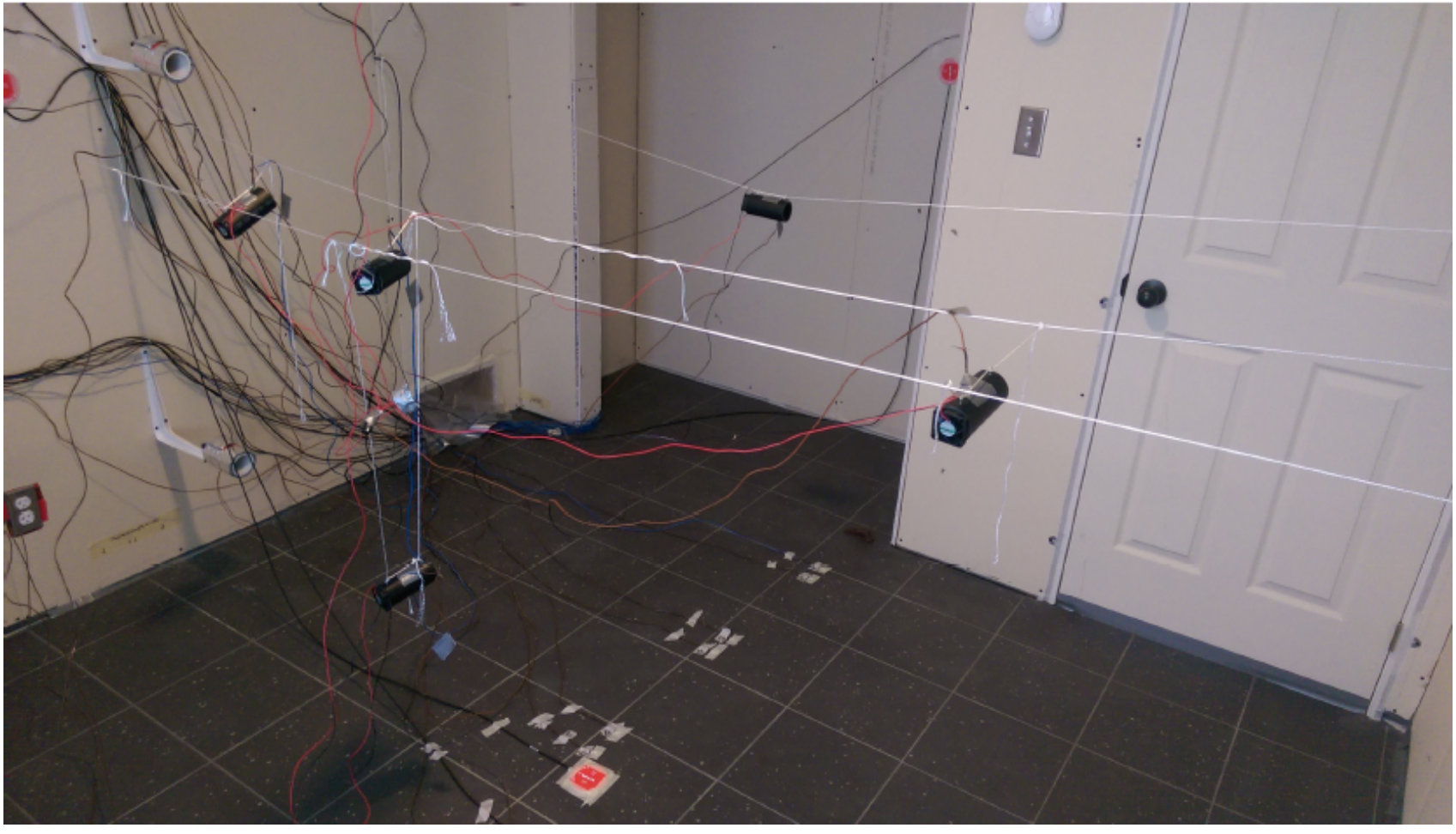
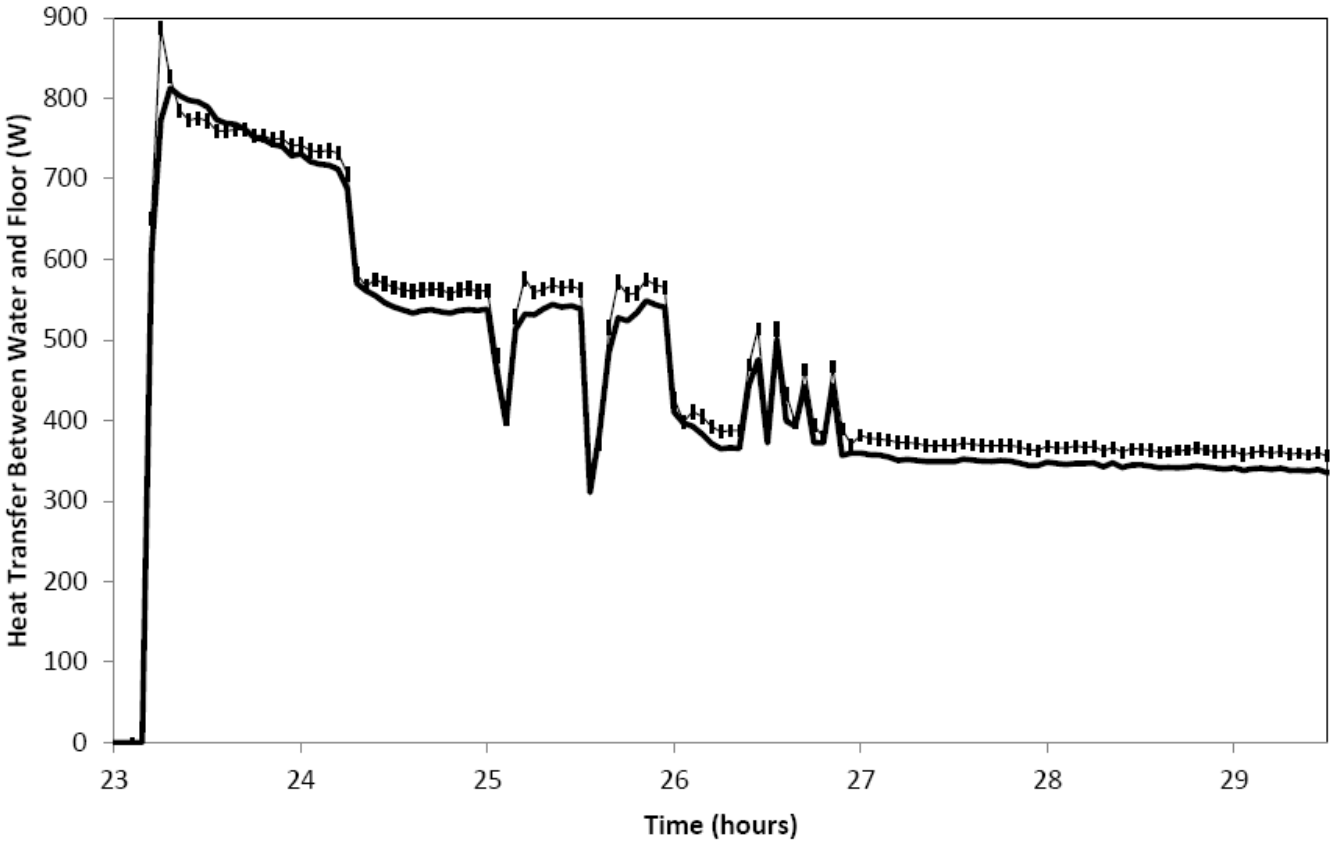
Empirical validation of radiant floor model



From Brideau (2016), PhD thesis, Carleton University.

Empirical validation of radiant floor model



From Brideau (2016), PhD thesis, Carleton University.

Research plan for passive+active system

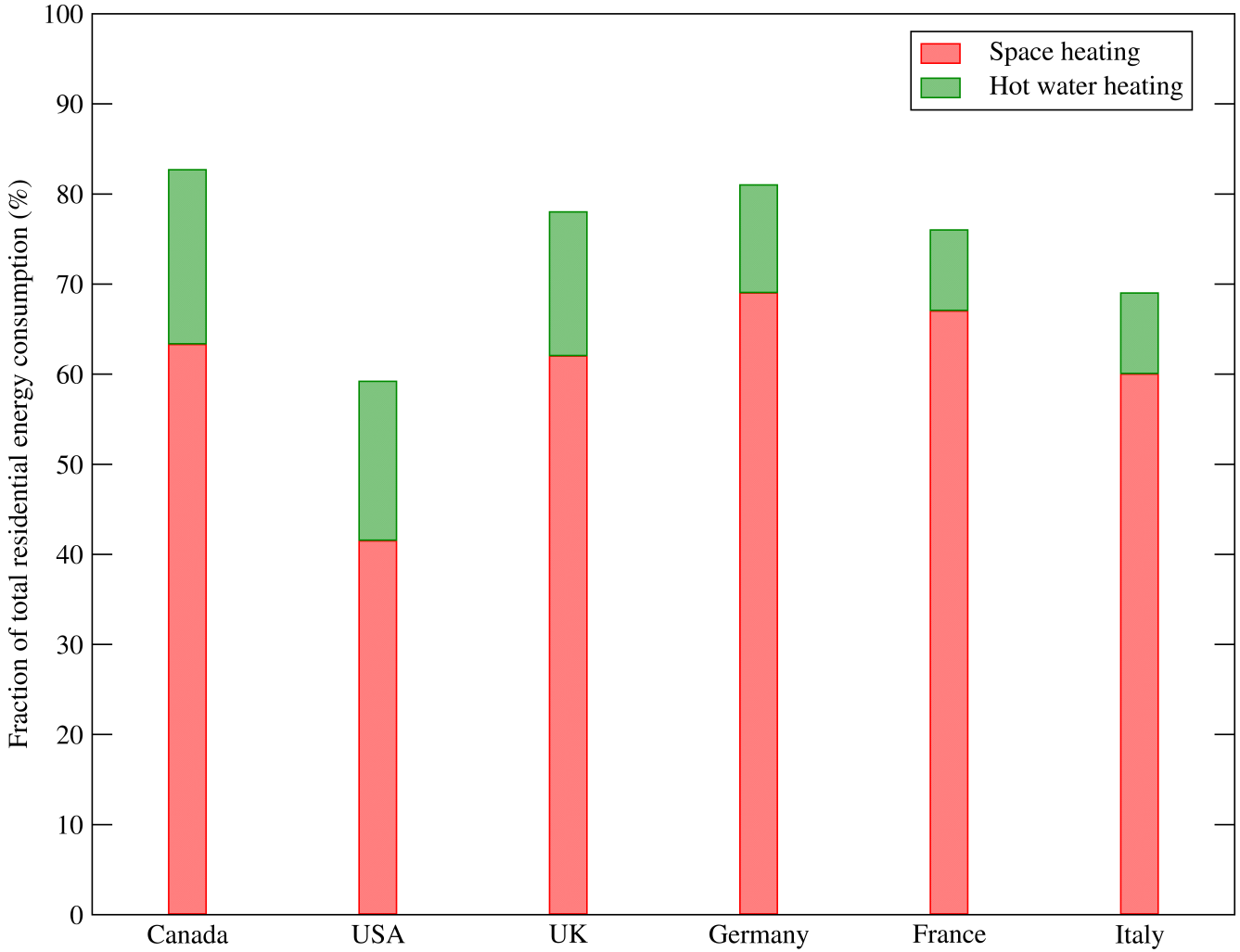
Current work

- Final commissioning tests of passive+active system underway.
- Measure impact of cold tank temperature on room heat extraction rate.
- Assess performance of complete system during summer and swing season.
- Verify component models from in-situ system performance.

Future work

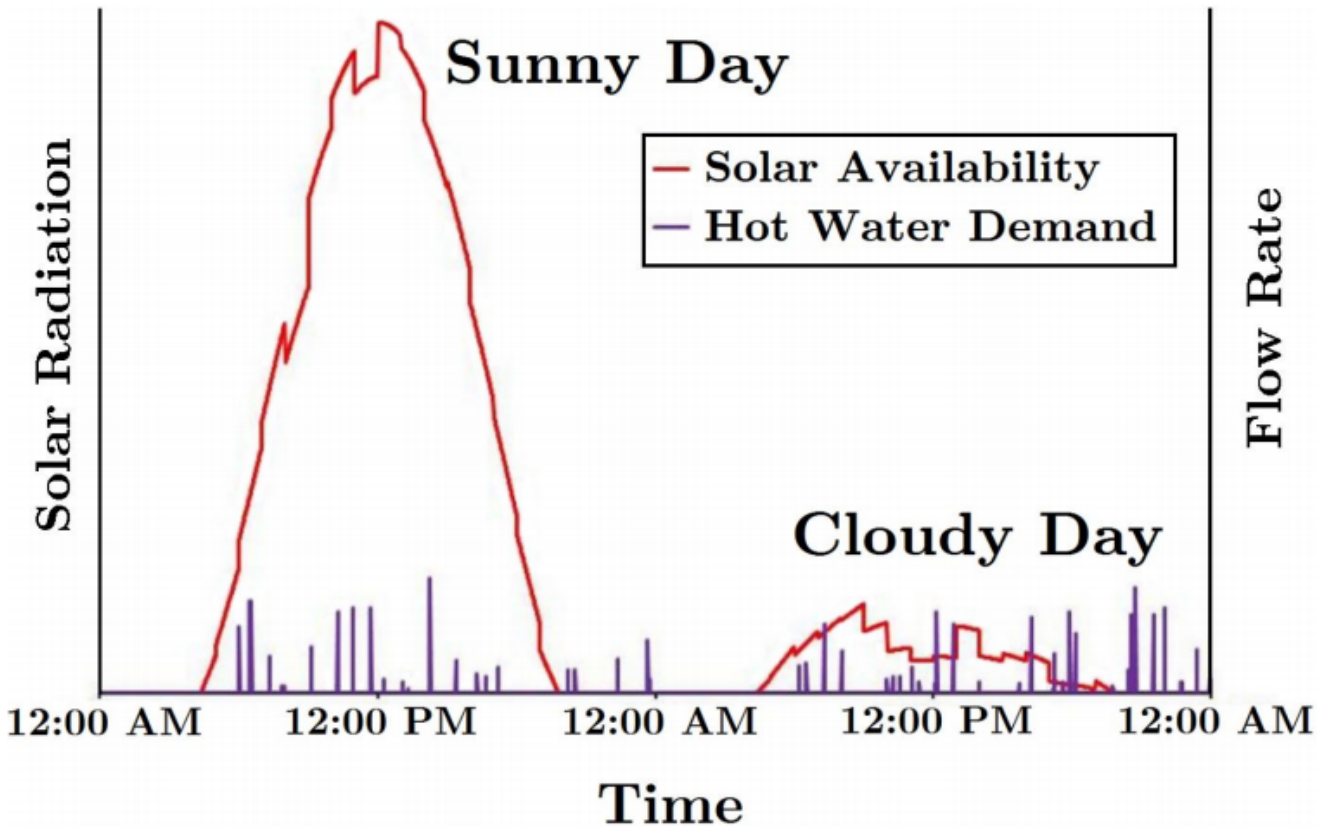
- Examine control options.
- Establish appropriate volumes for hot and cold storage.
- Refine estimates of energy savings using BPS with validated/calibrated models.

Solar thermal for space and water heating



Data source : National Energy Use Database, Natural Resources Canada; Residential Energy Consumption Survey, US Energy Information Administration; Enerdata, ENTRANZE.

Temporal mismatch between supply and demand



Source : Adam Wills (2013), Design and co-simulation of a seasonal solar thermal system for a Canadian single-family detached house, MASc thesis, Carleton University.

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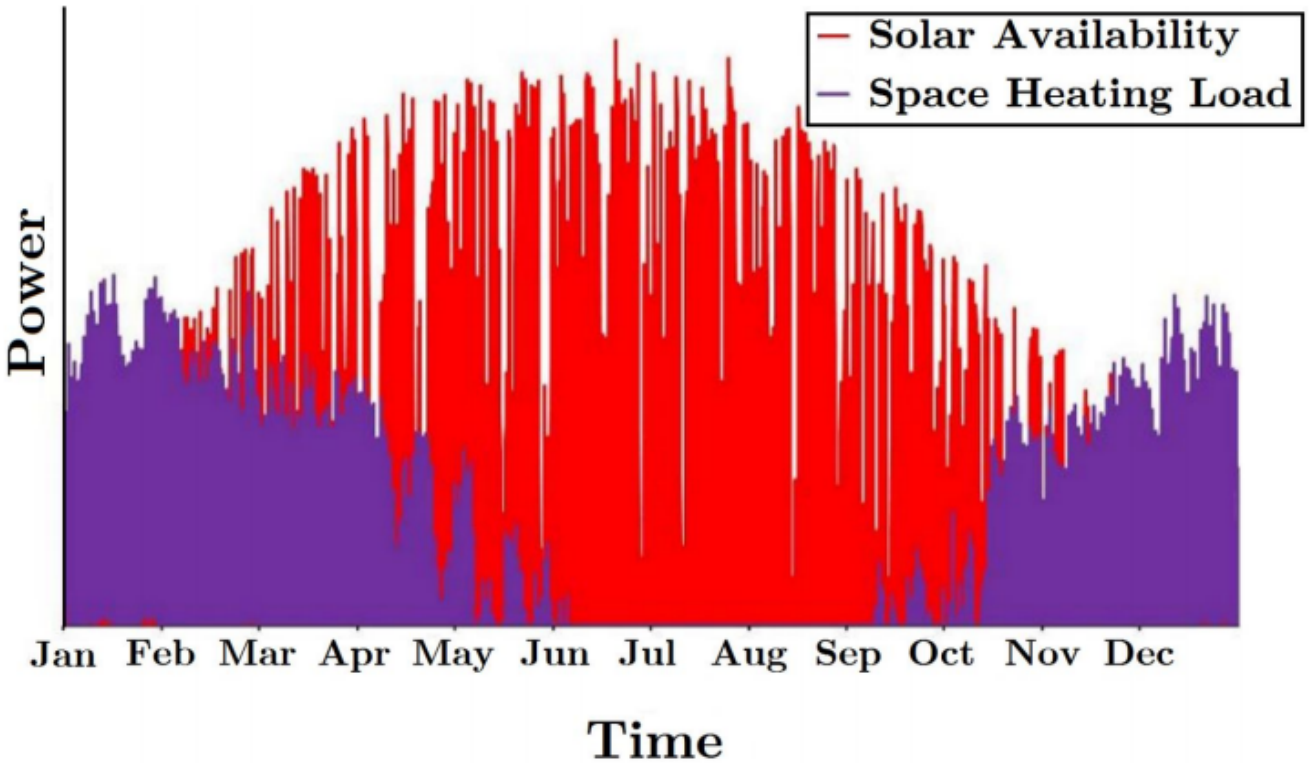

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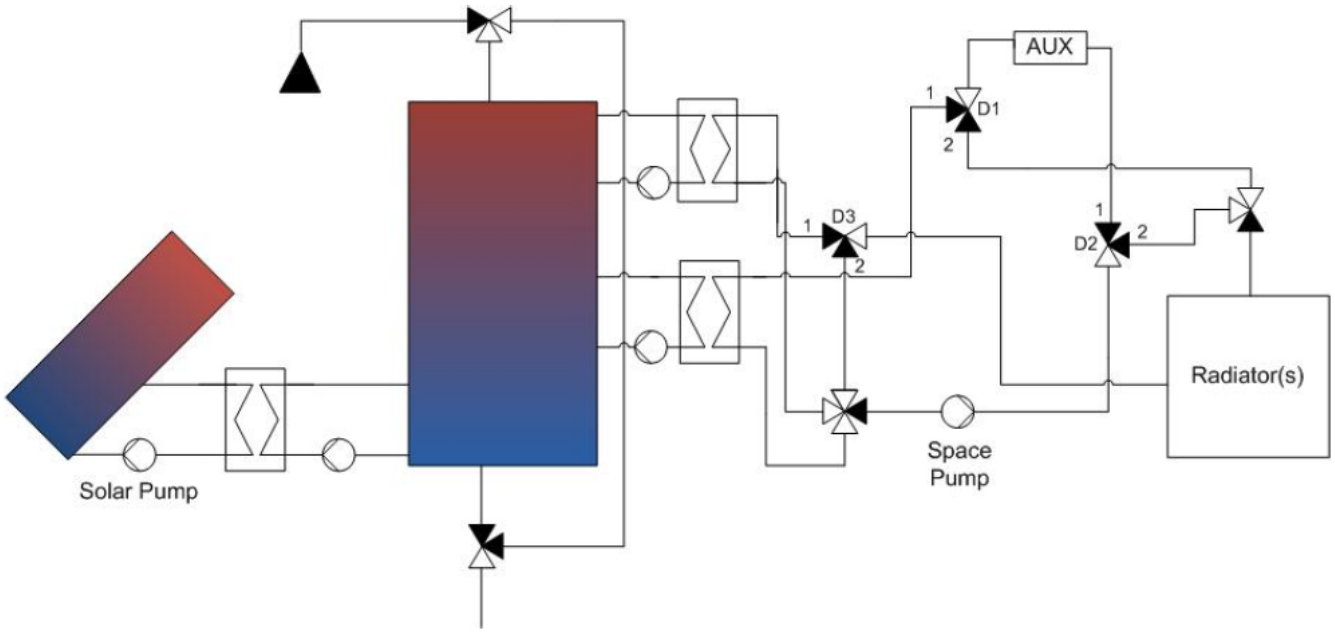
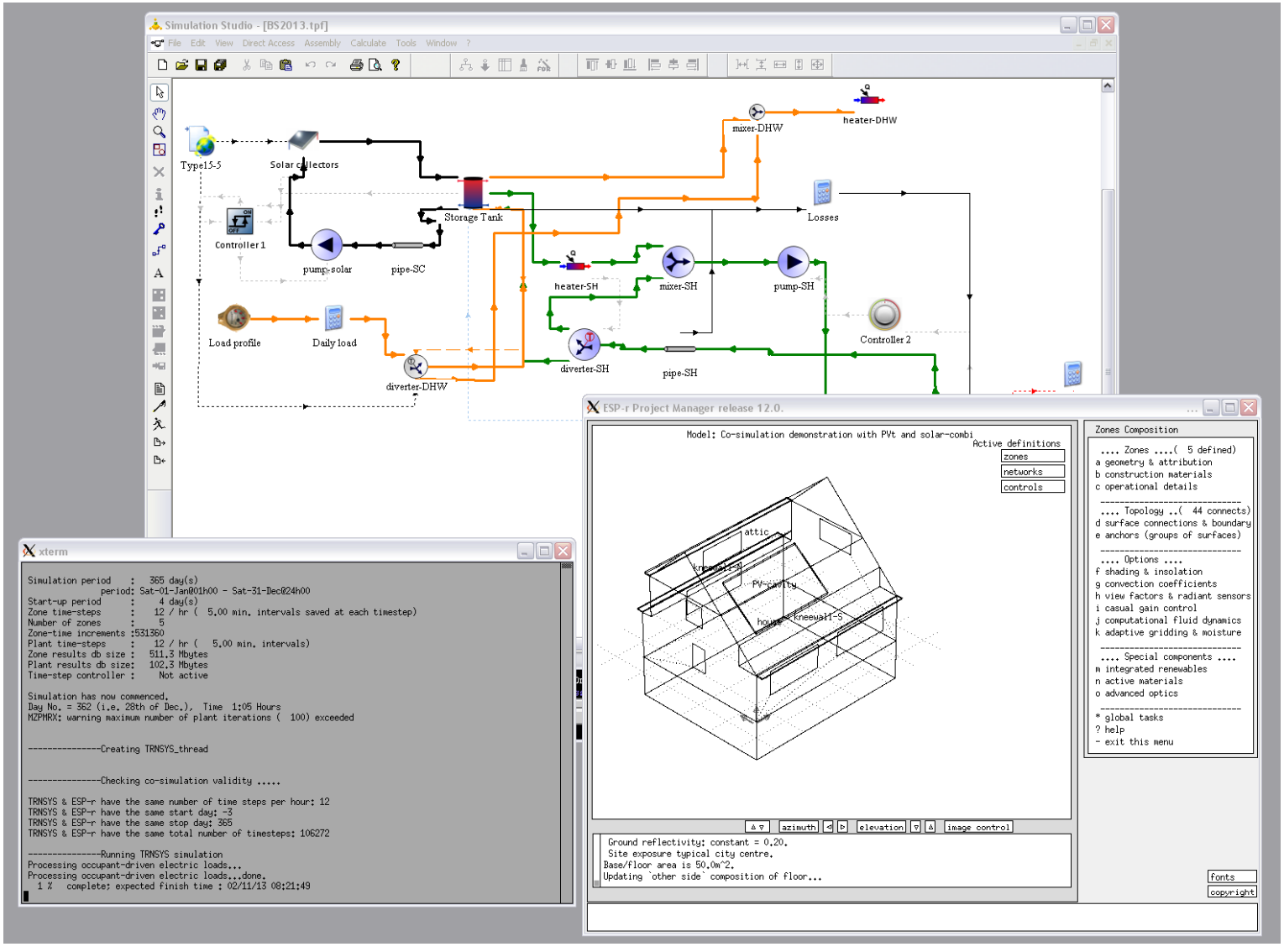
Combined solar heat and hot water heating

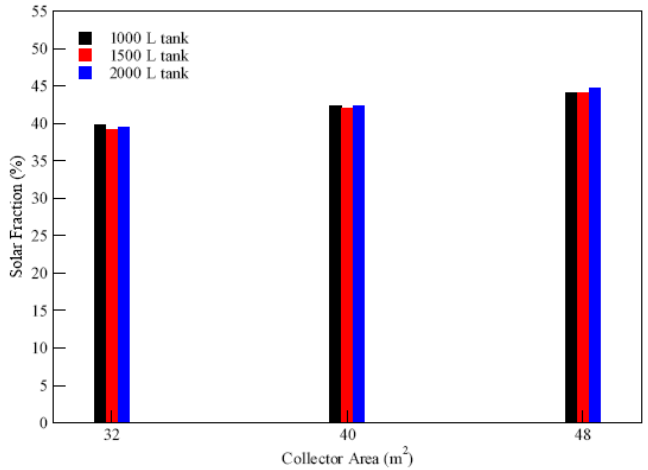


Source : Skai Edwards (2014), Sensitivity analysis of two solar combisystems using newly developed hot water draw profiles, MASc thesis, Carleton University.

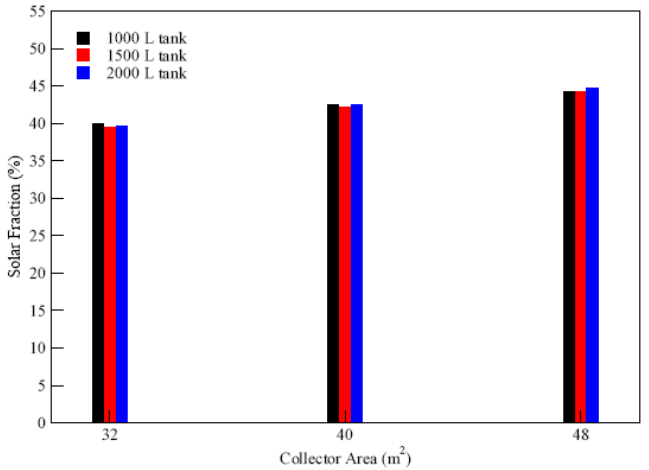
ESP-r / TRNSYS co-simulation



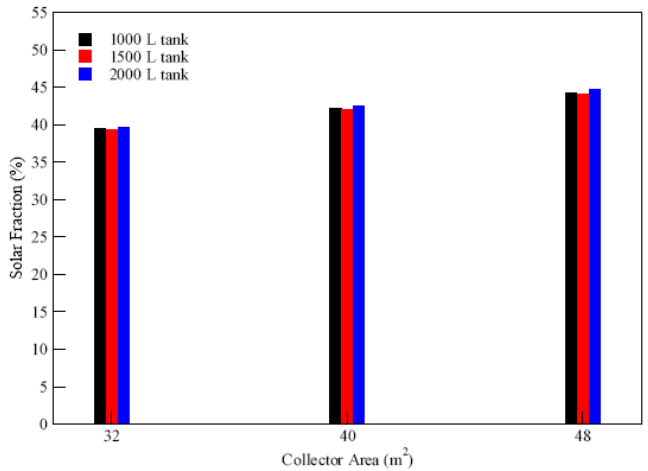
Seasonal storage required for high solar fractions



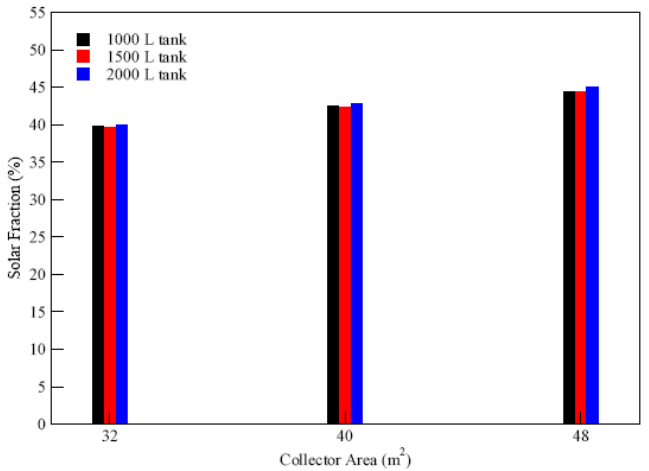
(a) Below average DHW consumer



(b) Average DHW consumer

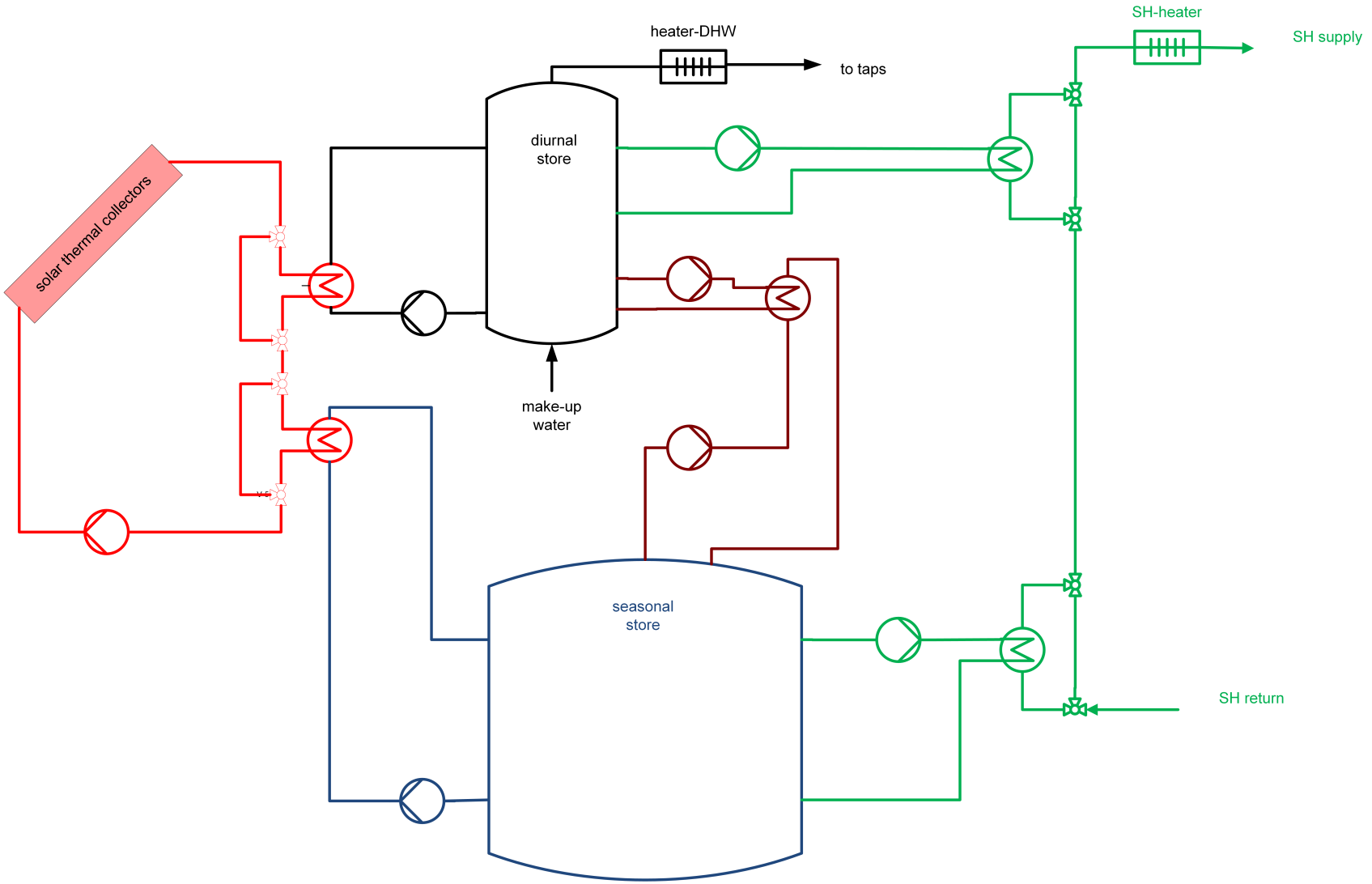


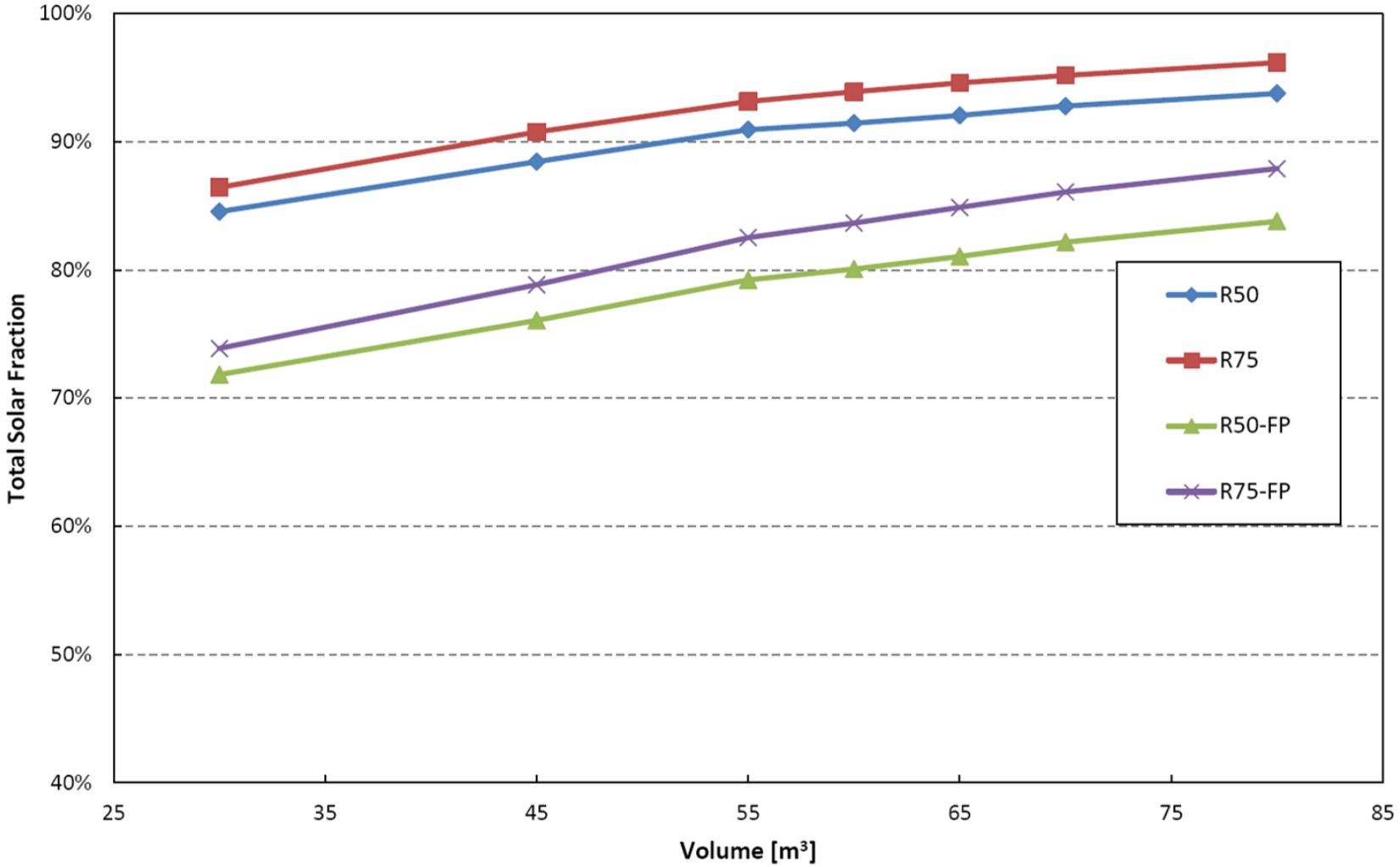
(c) Median DHW consumer



(d) Above average DHW consumer

Source : Skai Edwards (2014), Sensitivity analysis of two solar combisystems using newly developed hot water draw profiles, MASc thesis, Carleton University.


SH-heater
SH supply
heater-DHW
to taps
diurnal
store
solar thermal collectors
make-up
water
seasonal
store
SH return


100%
90%
80%
70%
60%
50%
40%
Total Solar Fraction
25
35
45
55
65
75
85
Volume [m³]
R50
R75
R50-FP
R75-FP


Urbandale Centre for
Home Energy Research
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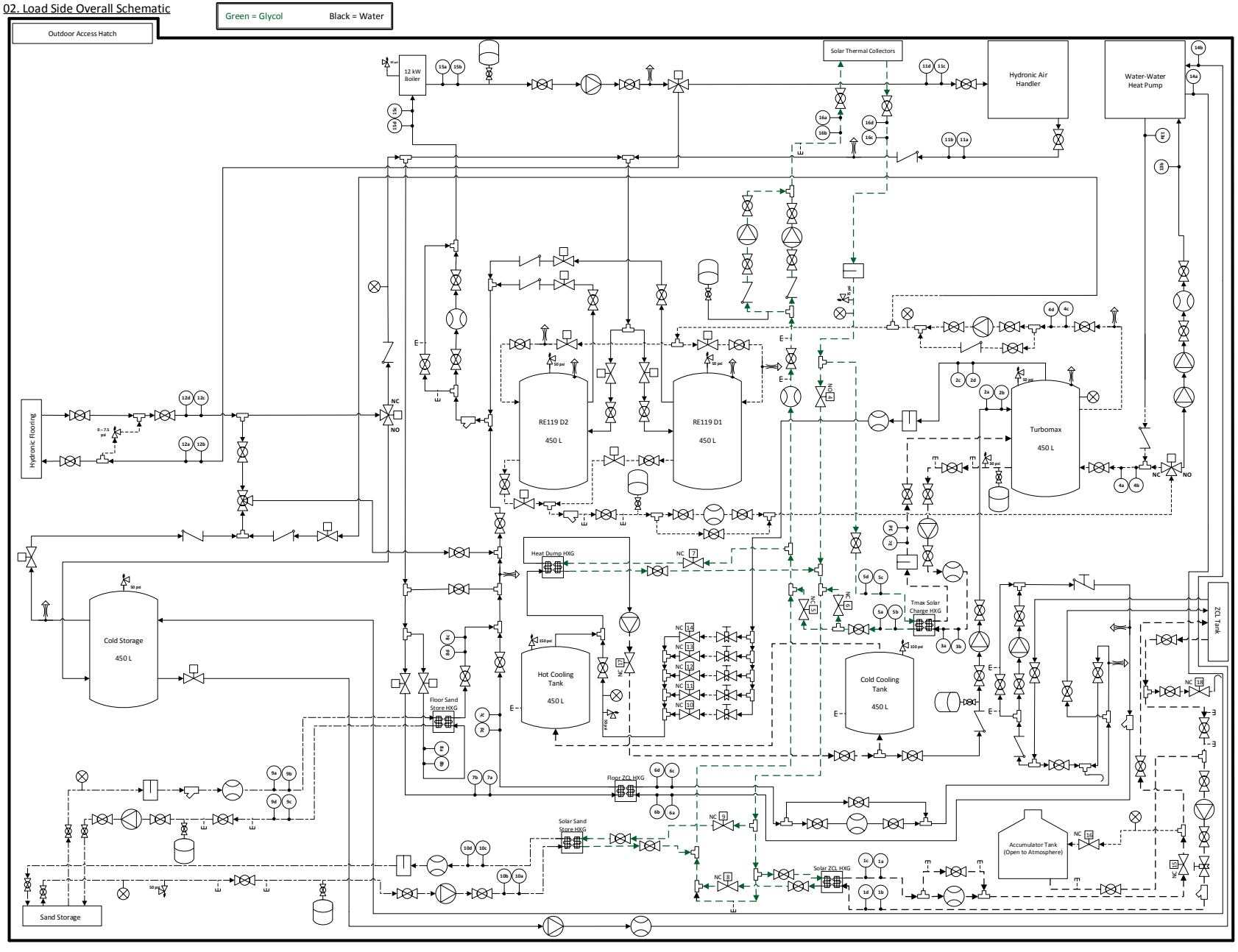
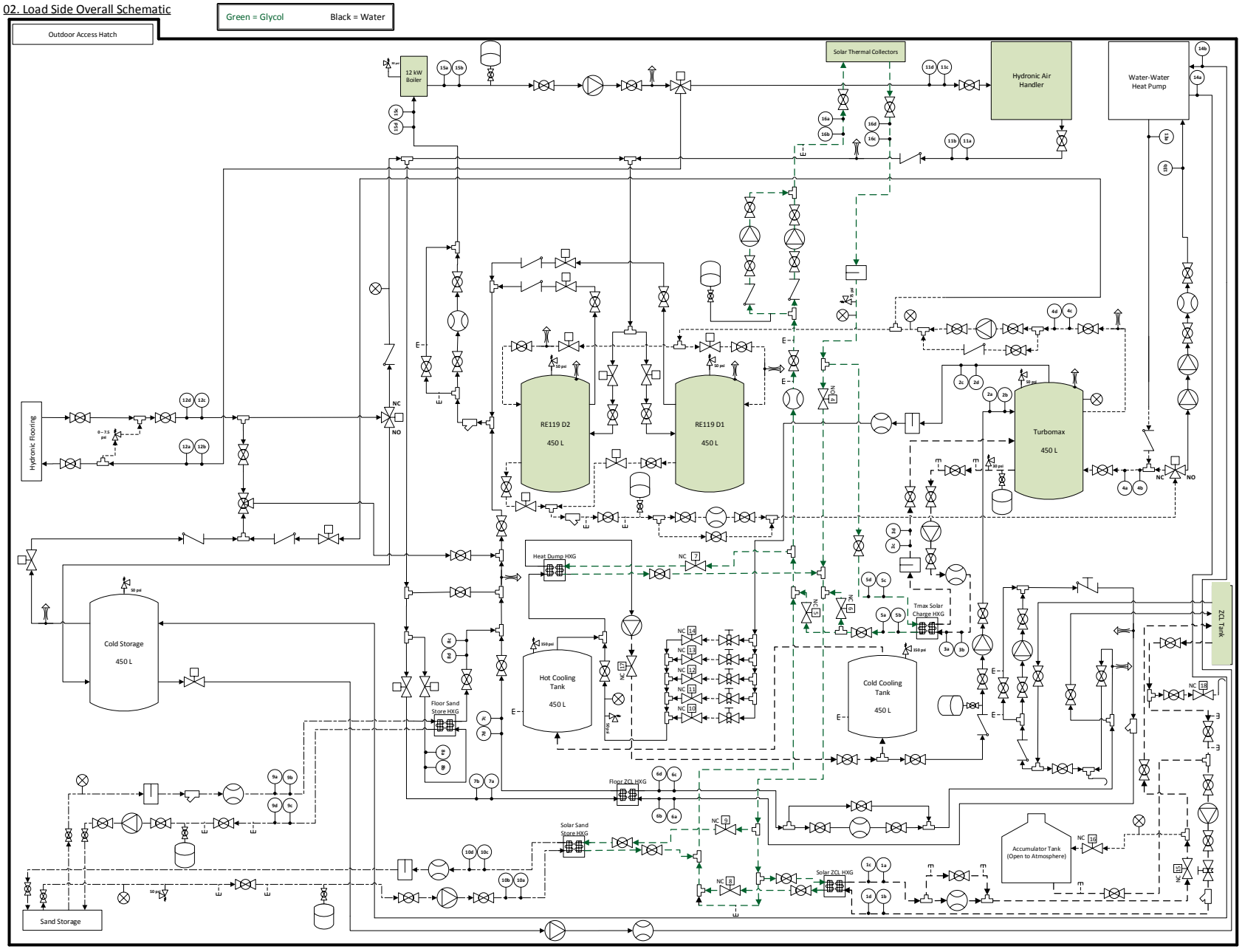
Carleton

35 m^3 burried seasonal store

Sand vs water storage


CRD


02. Load Side Overall Schematic
Green = Glycol
Black = Water
Outdoor Access Hatch
12 kW Boiler
Solar Thermal Collectors
Hydronic Air Handler
Water-Water Heat Pump
Hydronic Flooring
RE119 D2
450 L
RE119 D1
450 L
Turbomax
450 L
Heat Dump HXG
Cold Storage
450 L
Hot Cooling Tank
450 L
Cold Cooling Tank
450 L
Tmax Solar Charge HXG
Floor Sand Store HXG
Floor ZCL HXG
Solar Sand Store HXG
Solar ZCL HXG
ZCL Tank
Accumulator Tank (Open to Atmosphere)
Sand Storage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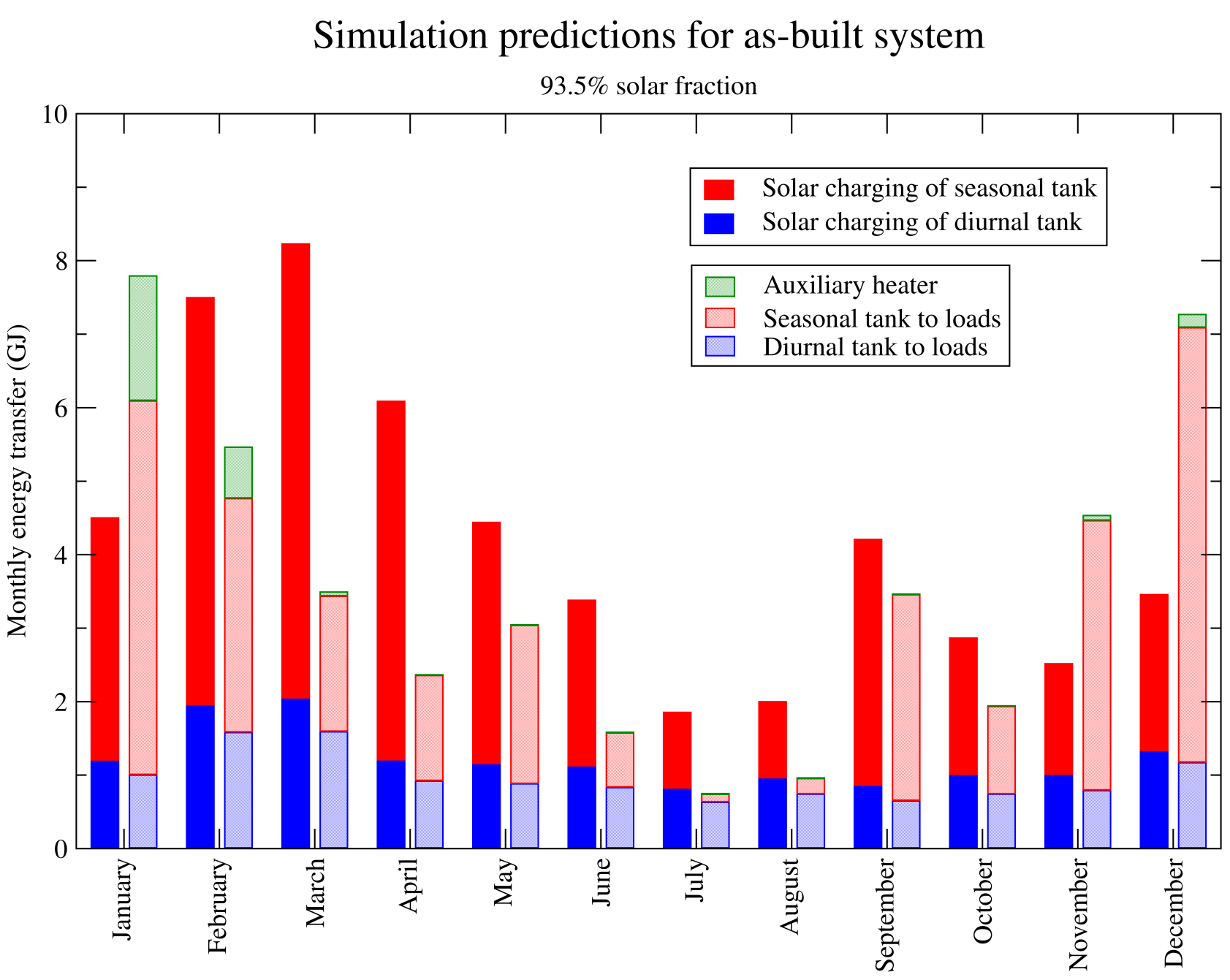
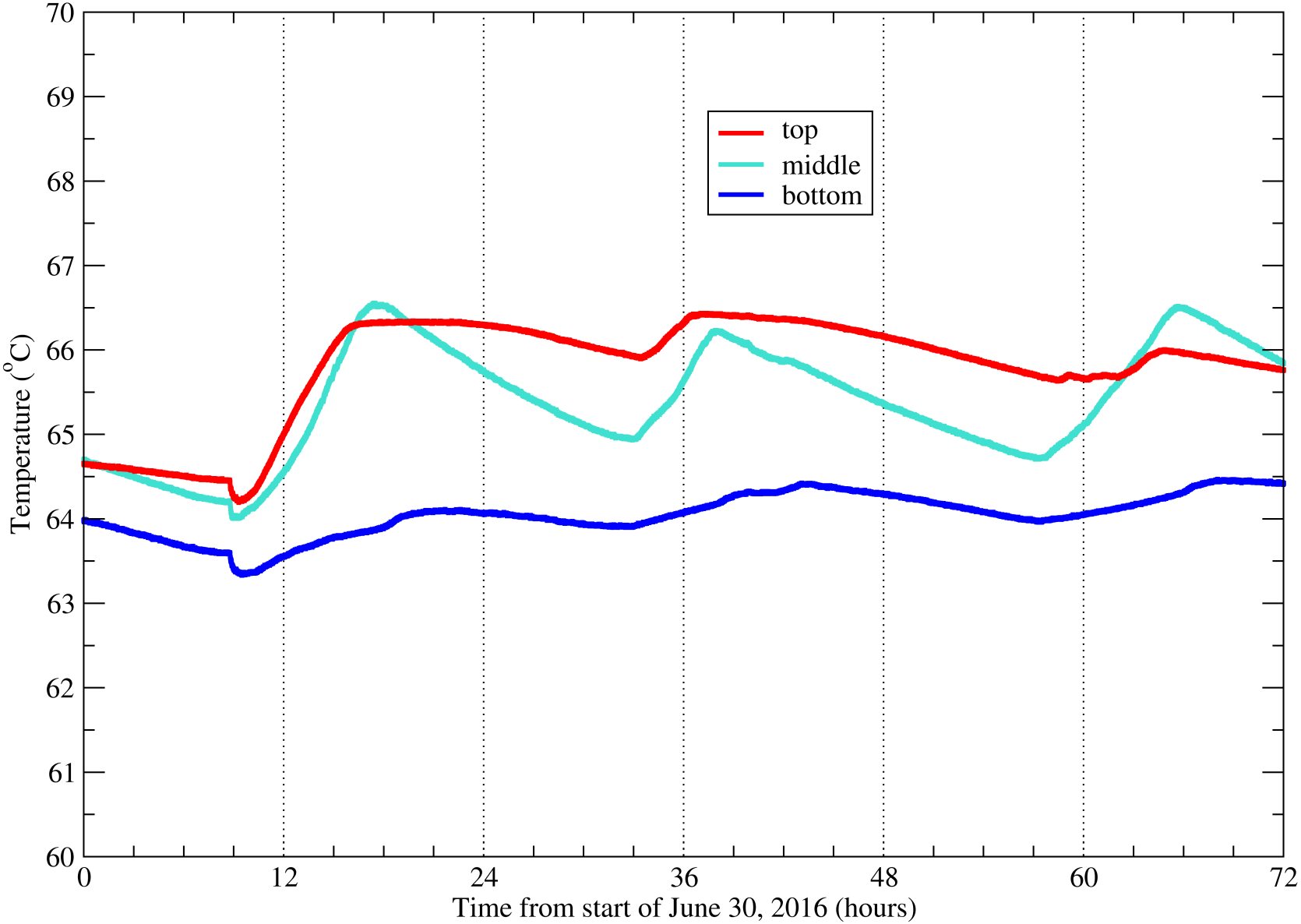

Simulation predictions for as-built system
93.5% solar fraction
Monthly energy transfer (GJ)
0
2
4
6
8
10
Solar charging of seasonal tank
Solar charging of diurnal tank
Auxiliary heater
Seasonal tank to loads
Diurnal tank to loads
January
February
March
April
May
June
July
August
September
October
November
December

Measurements of seasonal tank charging



Research plan for seasonal storage

Current work

- Final commissioning of data acquisition and control system.
- Seasonal tank cool-down tests underway.
- Heat seasonal water store to 90°C by September.
- September through May heating season test to determine solar fraction and tank stratification.

Future work

- Examine control options.
- Sand store.
- Validate component models.
- Extrapolate performance using BPS.

Concluding remarks

- Radical reductions in housing energy consumption required if we are to meet climate change goals.
- More energy efficiency is necessary, but this alone will not be enough.
- Lifestyle changes necessary. (Bold policies)
- Fuel switching from natural gas to electricity might help, but only if emissions-free generation added to grid.
- Space and water heating dominate energy requirements of housing.

Concluding remarks

- We need more solar :
  - Photovoltaics.
  - Passive solar.
  - Active solar.
- Electrical grid stability will limit PV penetration rates without significant storage.
- Opportunities for increasing contribution of passive solar gains.
- Solar thermal systems can respond to most space and water heating needs, but seasonal storage required.
- Technical solutions to radically increase solar contribution possible, but :
  - Will not be simple.
  - Will not be cheap.

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Abstracts due August 10.