Memorial University of Newfoundland
Faculty of Engineering and Applied Science

NSERC
Energy Storage
Technology Network

Design, Analysis and Control of Solar Heating System with Seasonal Thermal Energy Storage

Presented By

Md. Habibur Rahaman
M. Eng Student
MUN ID: 201890658

Thesis Supervisor:

Dr. M. Tariq Iqbal
Professor of Electrical and Computer Engineering

Presentation Overview:

Chap 1. Introduction and Literature Review

Chap. 2. Design and Analysis of Solar Water Heating System With Seasonal Storage

Chap 3. Design and Analysis of House Heating System with Storage Using Solar Electric Modules

Chap 4. Mathematical Modelling and Simulation of Solar Water Heating Systems

Chap 5. Remote control of house thermal energy storage system

Chap 6. Conclusion and Future Research

Acknowledgements

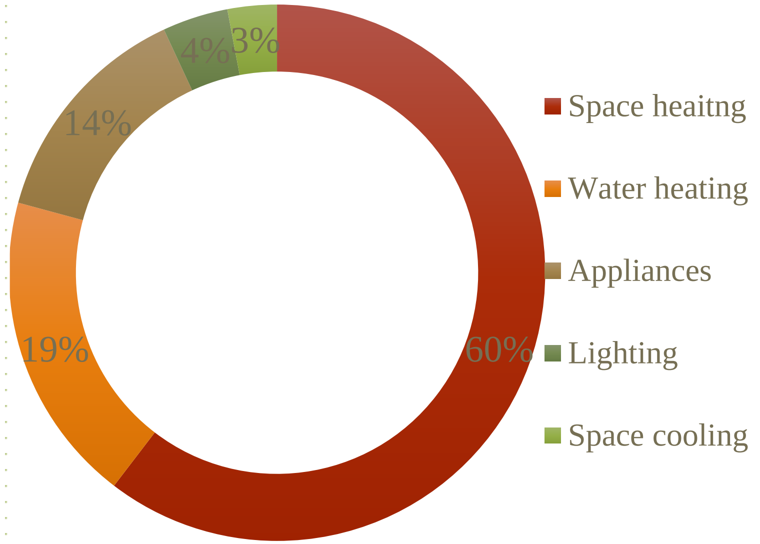
Publications and References

Questions and Answer

MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Energy consumption



Sectors	Ratios
Space Heating	67%
Appliances	15%
Water Heating	15%
Lighting	3%

Table:1 Space heating by fuel.

Fuel types	DHW	Space heating
Natural gas	68%	50%
Electricity	29%	25%
Heating oil	2%	7%
Wood	1%	17%
Other	2%	1%

Natural Resource Canada (NRCan)

6 million tons of CO_2 to Canada's GHG every year

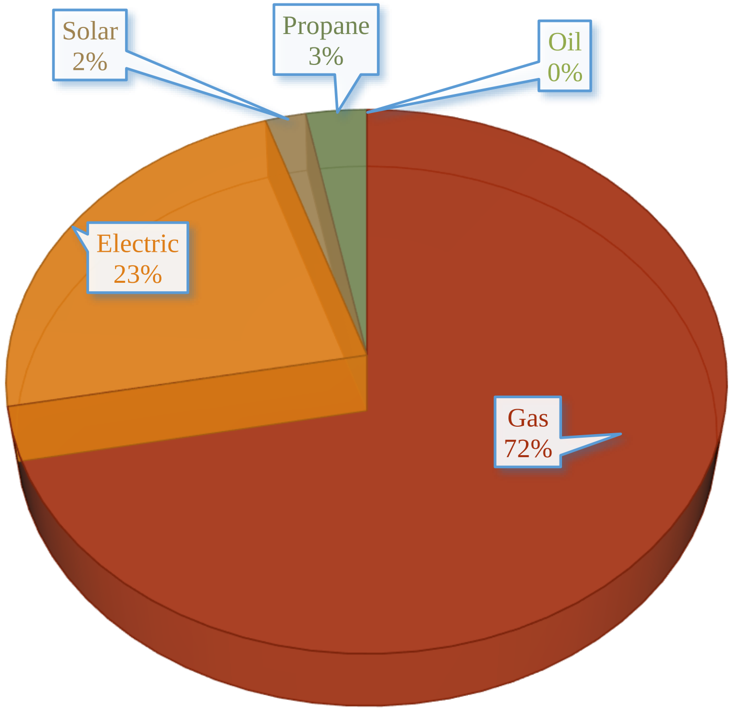
Residential consumers are consuming about 16%

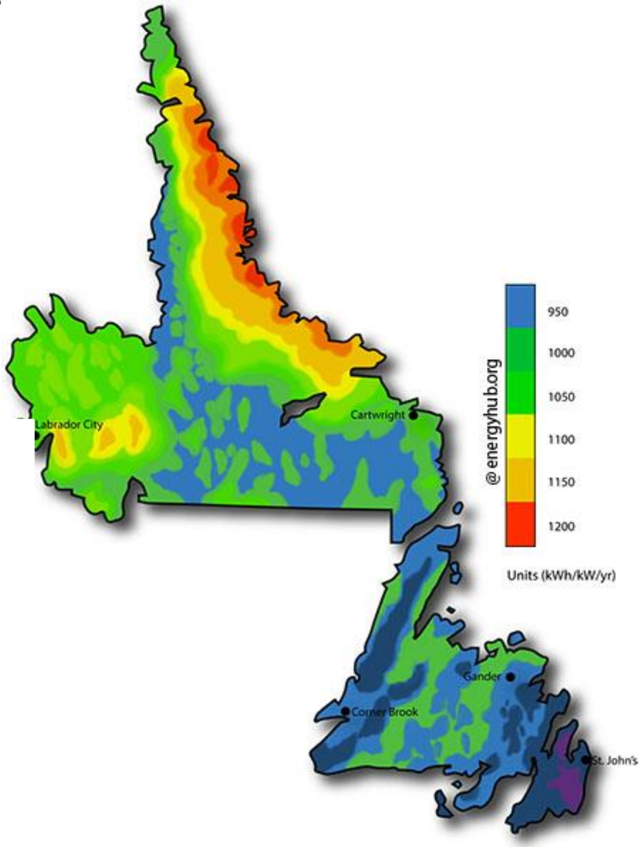
In 2020, solar electricity production is nearly 1% of the total electricity generation and almost 6300 MW.

Canada plans to reduce its GHG emissions by 30% below 2005 levels by 2030[2].

Solar Energy Resources

- In 2020, solar electricity production is nearly 1% of the total electricity generation and almost 6300 MW.
- The average annual solar irradiance in Newfoundland province is around 1000 kWh/kW/yr.
- The average per capita electricity consumption in Newfoundland province was 1294 kWh in 2019
- NL province received an F rating that means a 5 kW photovoltaic system able to produce around 4,713 kWh per year,





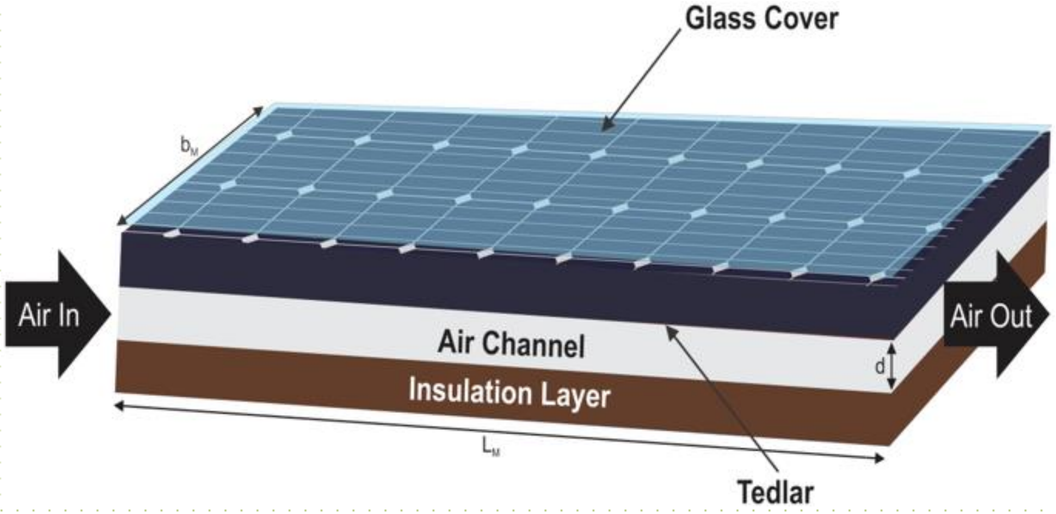
MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

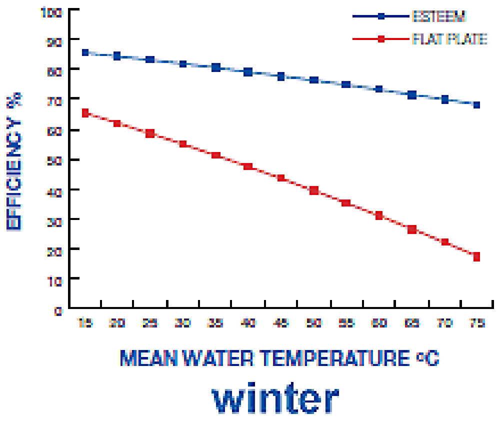
Solar Instruments

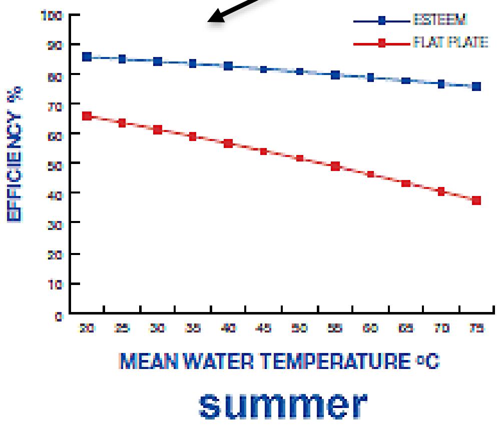
PV Array, Efficiency: 14~18%

Fig. 3 Flat plat collector (water-based)



Hybrid PVT Collector





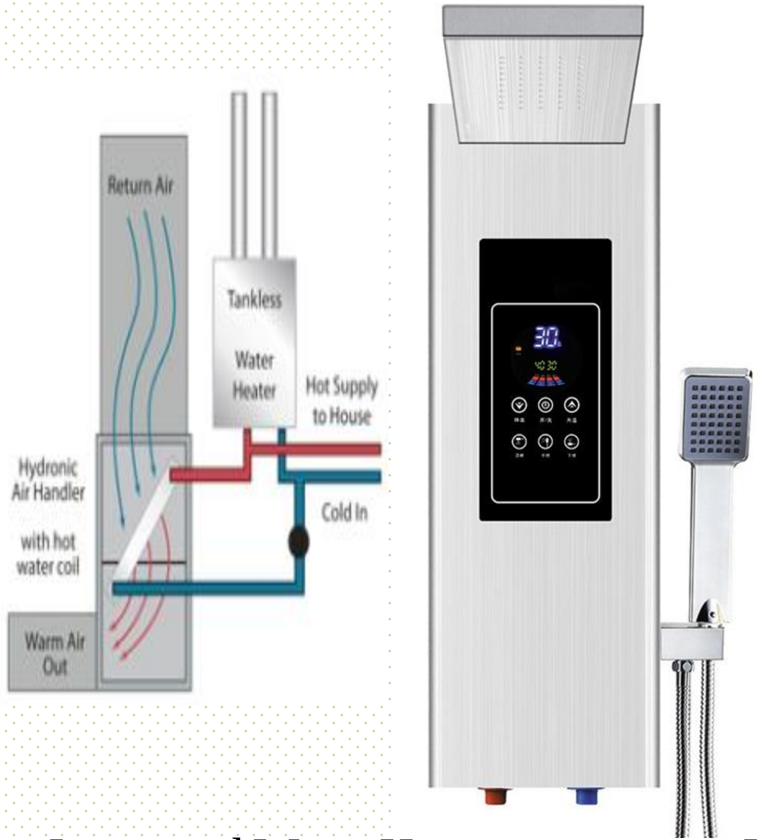
Panel type	Energy efficiency	Exergy efficiency
Unglazed PVT-air [36]	45%	10.75
Single glazed PVT-air [37]	55%	13.5%
Single glazed PVT-air [38]	55%–66%	12%–15%
Double glazed T-air [39]	—	7.4%
PVT-air [40]	33%–45%	11.3%–16%
PVT-water [41]	—	3%–15%

PVT: photovoltaic thermal; T: thermal.

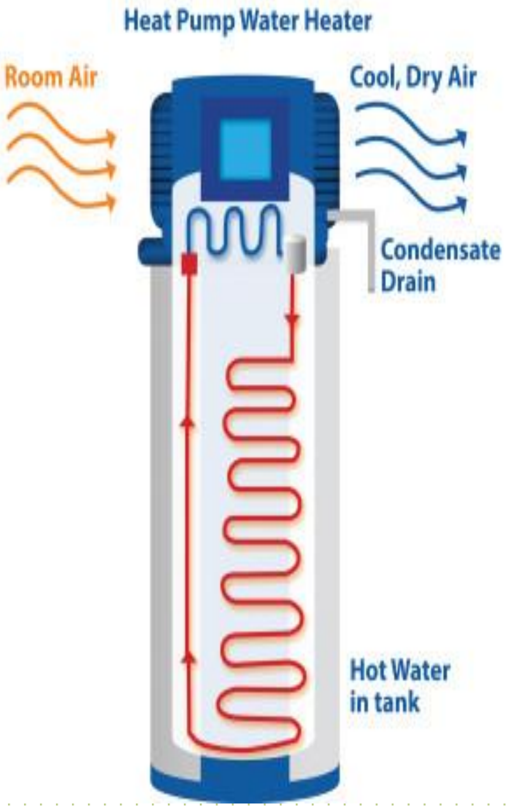
NSERC Energy Storage Technology Network

Domestic Water Heater Types

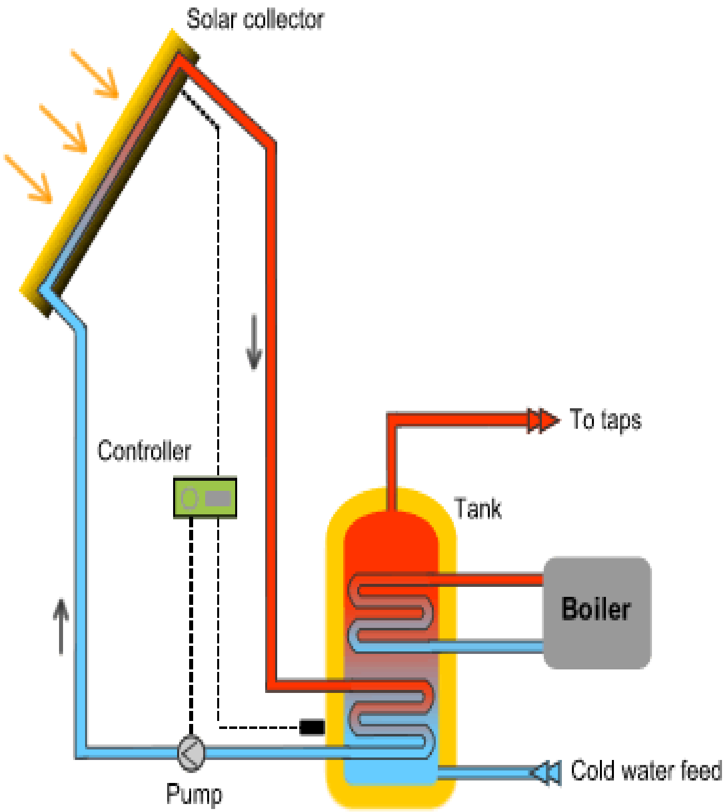
Tankless water heater



Integrated Water Heaters



Heat pump Water Heaters



Solar Water Heaters

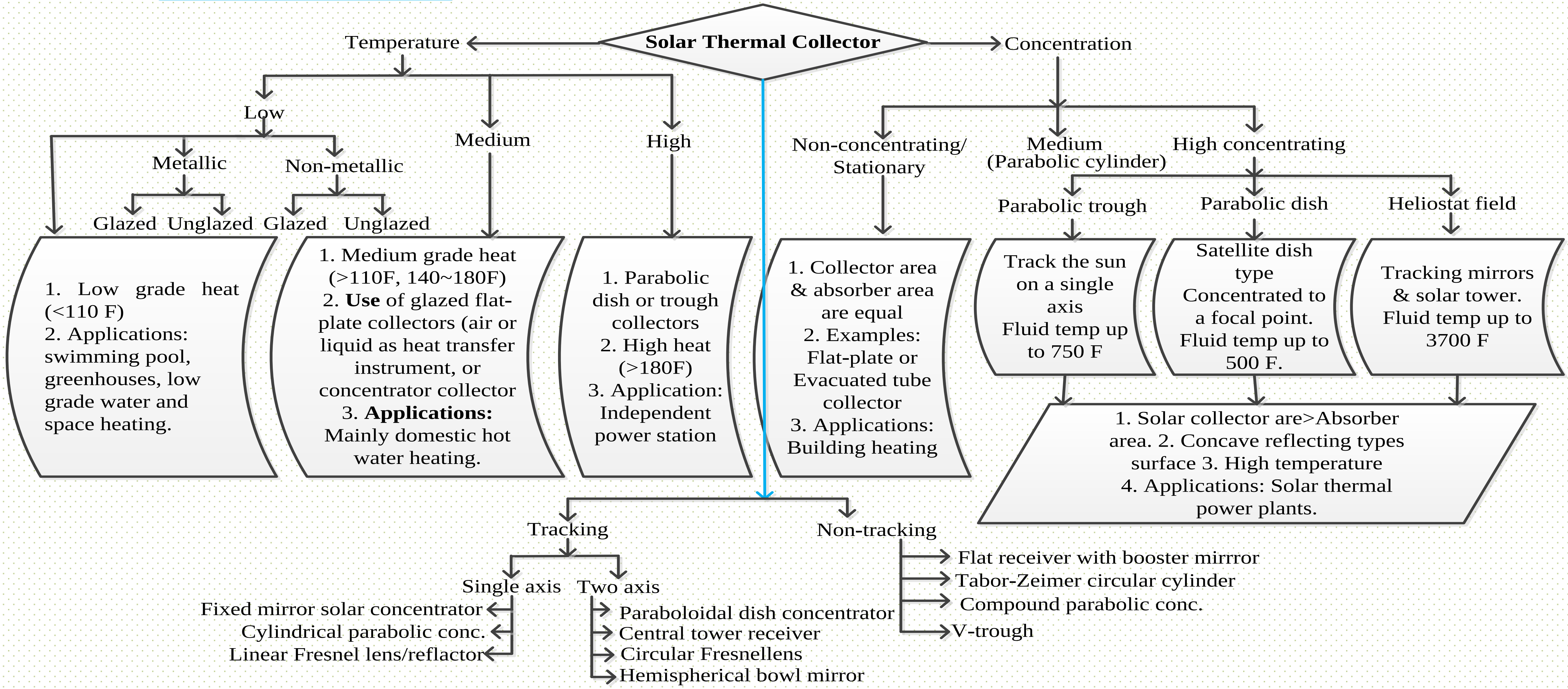
← Conventional →

TES: Thermal Energy Storage Systems
STES: Solar TES
SSTES: Sessional Solar TES

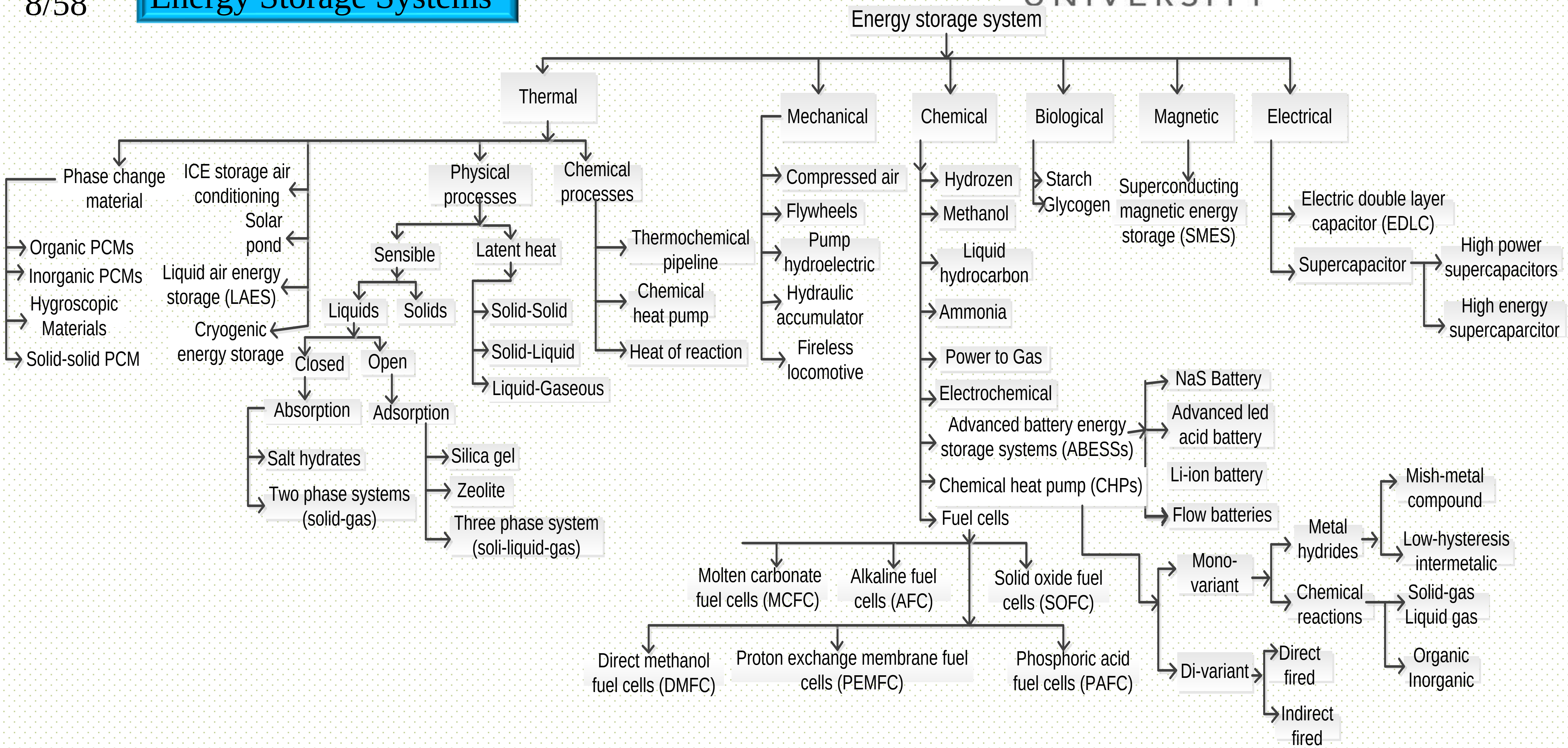
MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Thermal Collector:



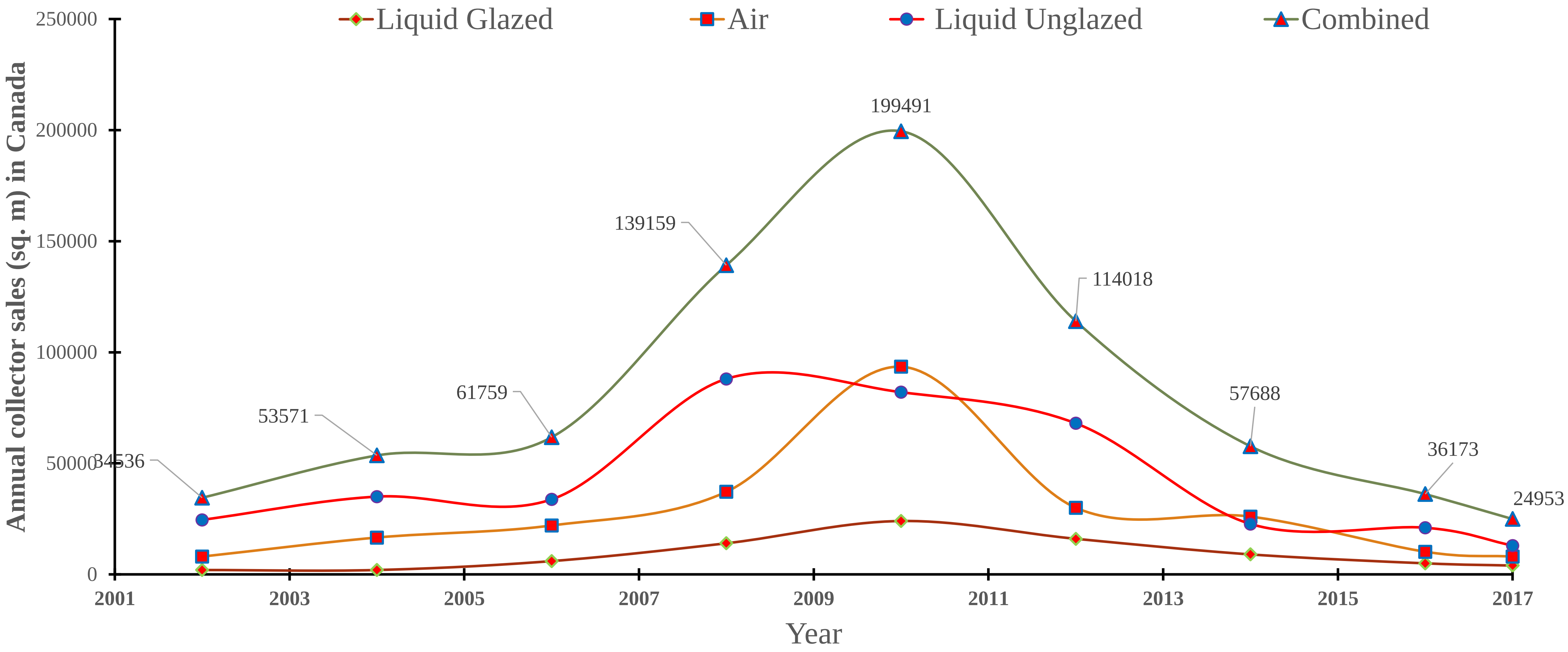
Energy Storage Systems



MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Solar Collector Market



MEMORIAL UNIVERSITY
NSERC Energy Storage Technology Network

Reference Projects

- Drack Landing project, AB in 2007.
- TES systems in BC for a fish firm.
- UOIT Developed a BTES Systems in 1990.
- Carleton University developed Low-temperature based TES.
- University of Alberta Built a BTES ES in 2015.
- Ahmed Aisa and Tariq Iqbal designed a sessional STES systems for a residential house in 2018.
- K & P contracting Ltd. built up a net-zero energy home in St. John's, Newfoundland

- Many more project around the world.

Research steps:

✓ Software Parts:

House parameters analysis using BEopt software.

» Components sizing in Mathematical calculations and Homer Software as well as weather.
» Design, simulation, and analysis of ES in PolySun software
» The TES system design and control using Matlab/Simulink software

✓ Hardware Parts:

Remote Control Implementation steps:

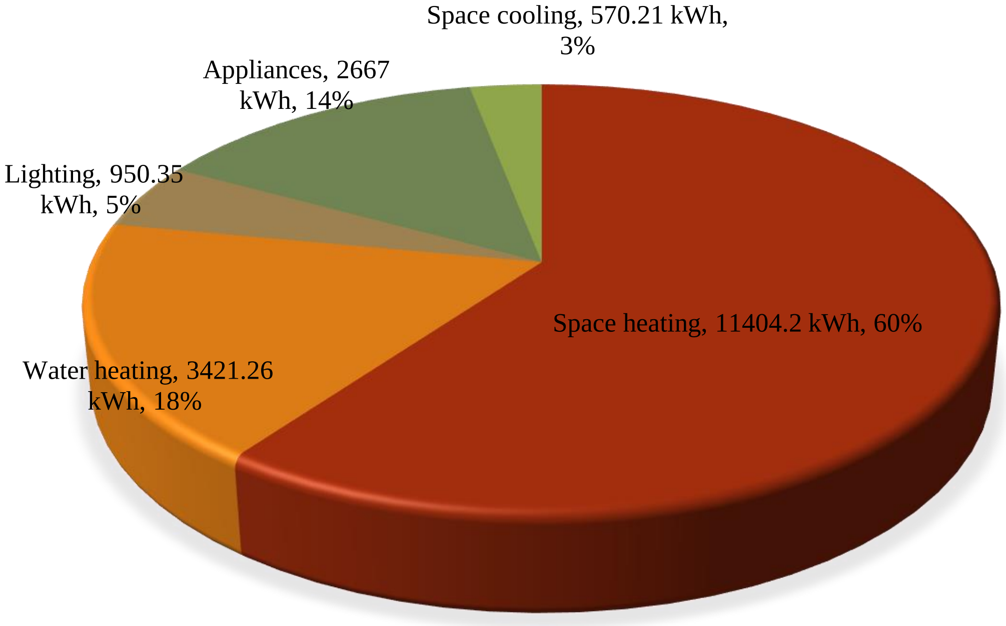
» The openHAB is used an IoT Platform (Home Server).
» Remote monitoring and control system has been developed using ESP 32Thing, MQTT and sensors.

NSERC Energy Storage Technology Network

Problem Description and Assumptions

The following assumptions are considered:

- ✓ The water flow has been considered under steady-state conditions.
- ✓ The tube flow has been assumed fully developed flow
- ✓ The collector's layer temperature has been neglected.
- ✓ All other parameters have been assumed temperature independent.
- ✓ There is no heat gain (or loss) when the water through the pumps and pipes.
- ✓ It is assumed that there is no shading and dust on the collector panel.



MEMORIAL UNIVERSITY
NSERC Energy Storage Technology Network

SSTES Components Sizing

- ✓ The required area of the solar collector 16 m^2
- ✓ The optimal volume to collector area ration should be 2 m^3/m^2
- ✓ The optimal sessional tank volume is 30 m^3
- ✓ The small tank for DWH is considered as 0.189 m^3.
- ✓ Finally, the sessional tank volume, $V = (\pi \times D^2 \times H)/4$

Where the tank height, H=3 m and the volume, V= 30 m^3. T

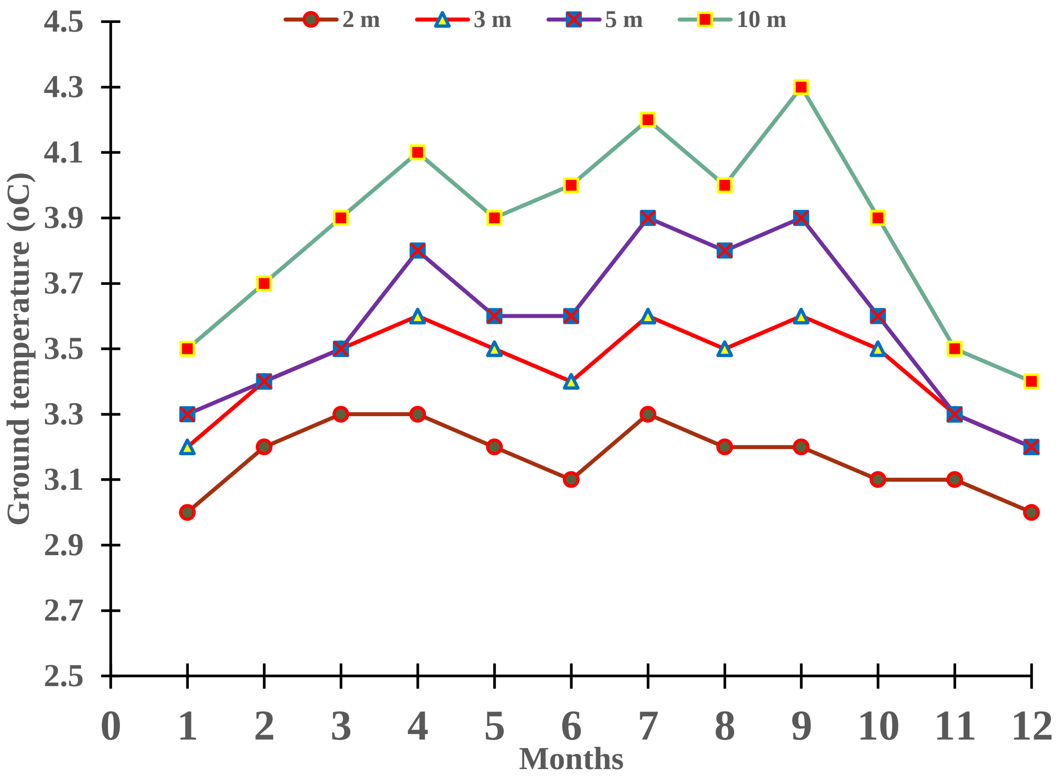
- ✓ The calculated tank diameter is, D= 3.36 m. So, H/D=3⁄3.36 =0.8

It showed a good agreement with literature.

- ✓ Heat Pump COP=$\frac{T_o}{T_o - T_i}$ =3

ASHP/GSHP?

Ground Temp: $t_o = t_d + A_d \exp\{-y[\Omega/(2a)]\} \cos\{\Omega\tau - y[\Omega/(2a)]\}$

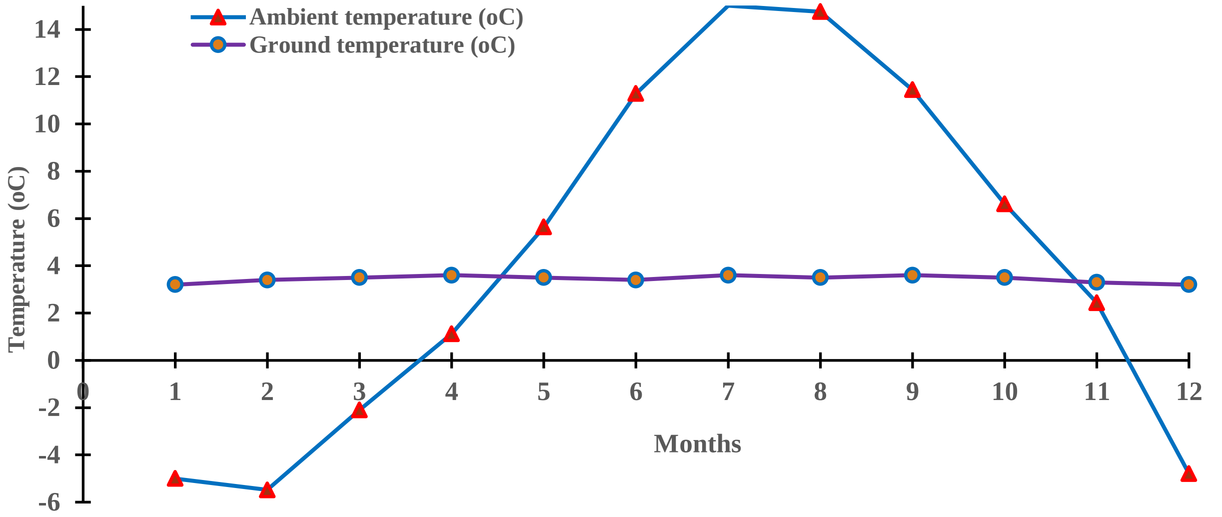


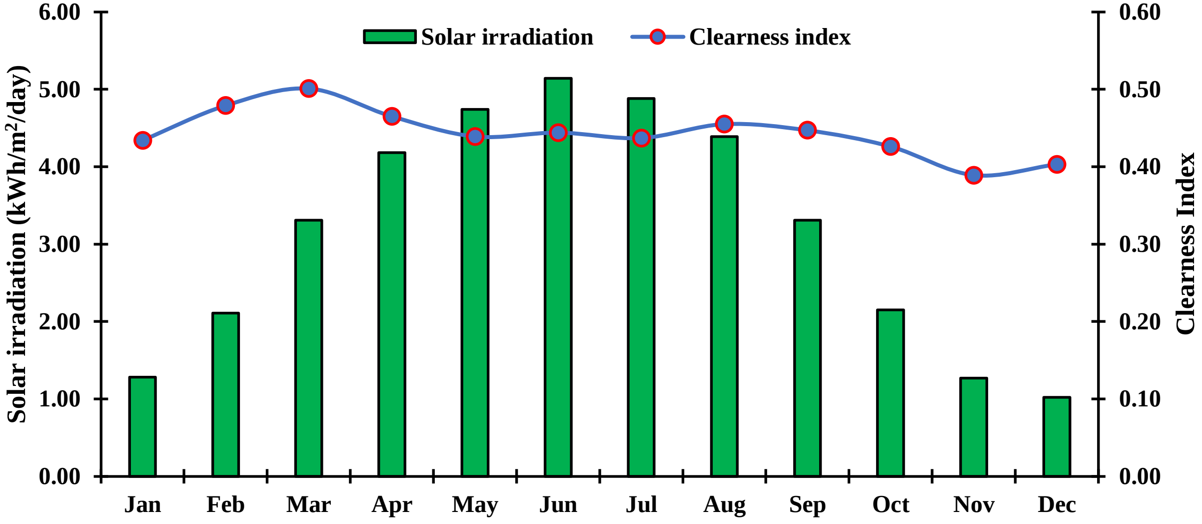
Ground Temperature

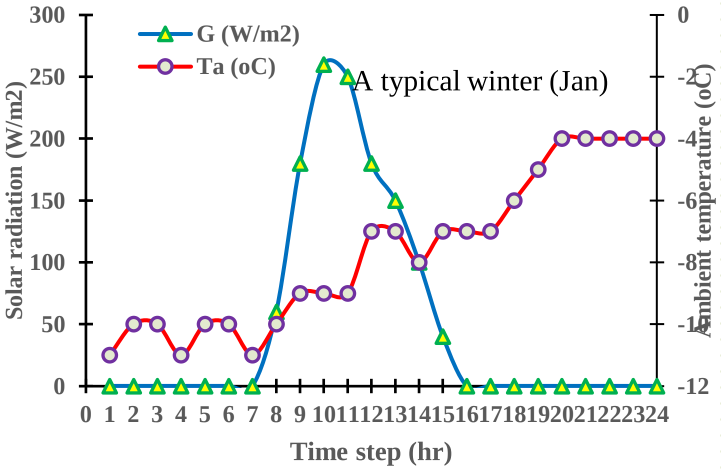
Inlet and the outlet temp difference is small so, GSHP is unsuitable

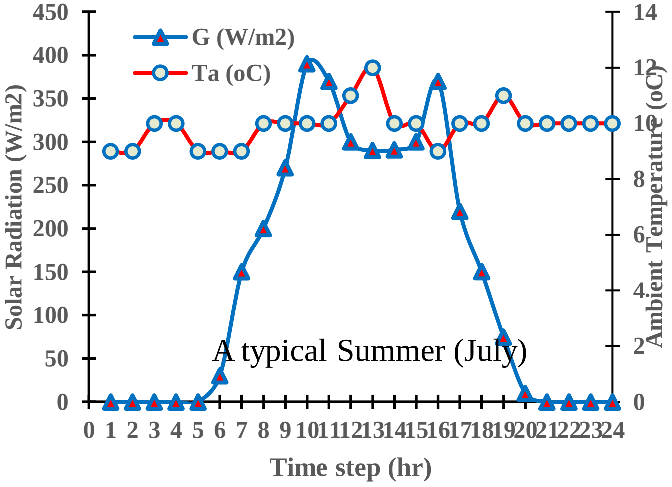
ASHP is considered.

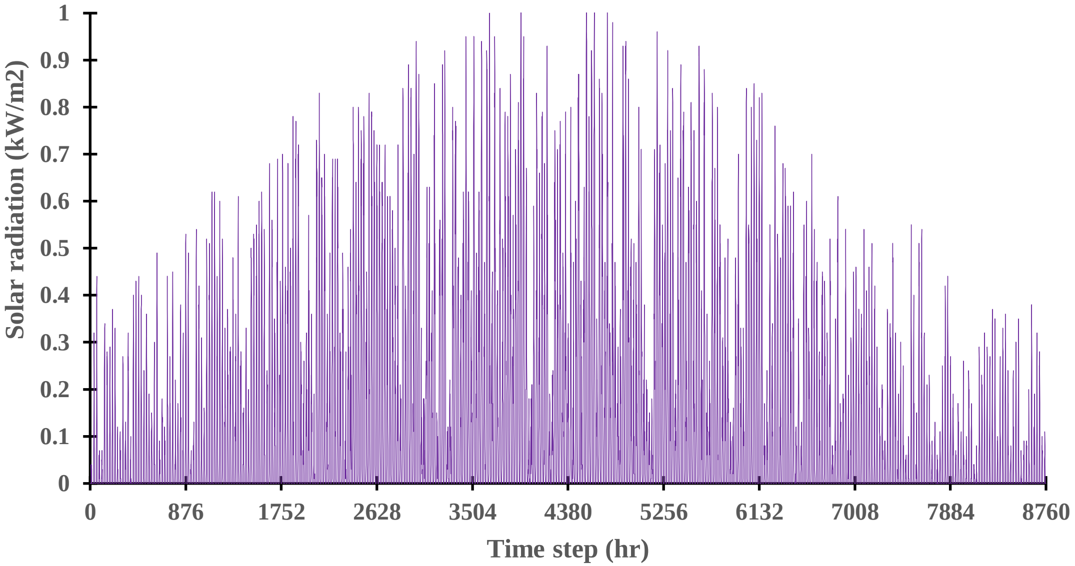
Weather Analysis







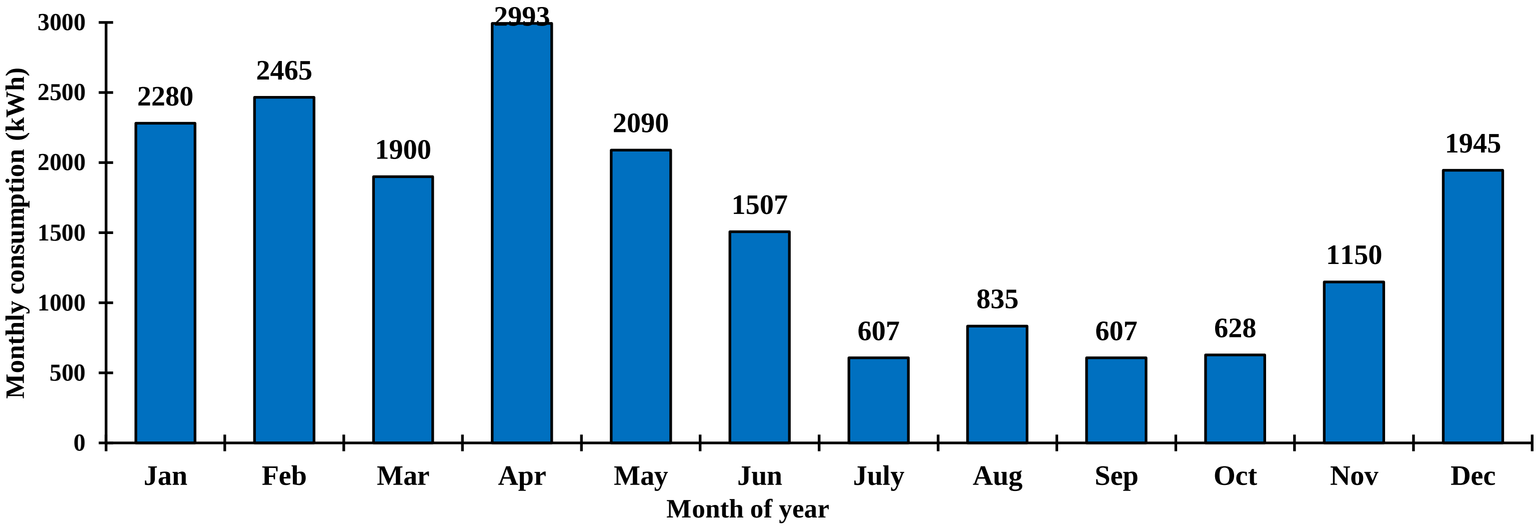


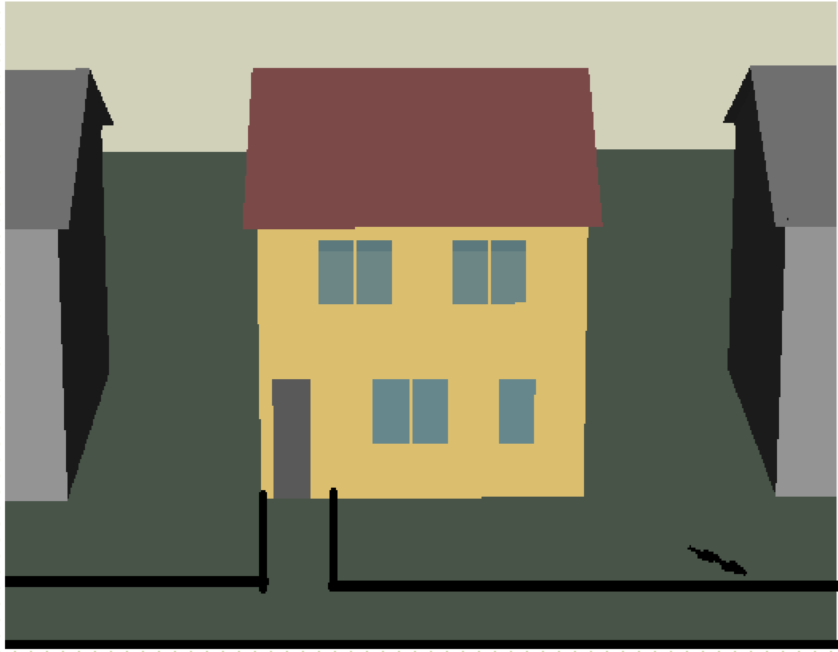


MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

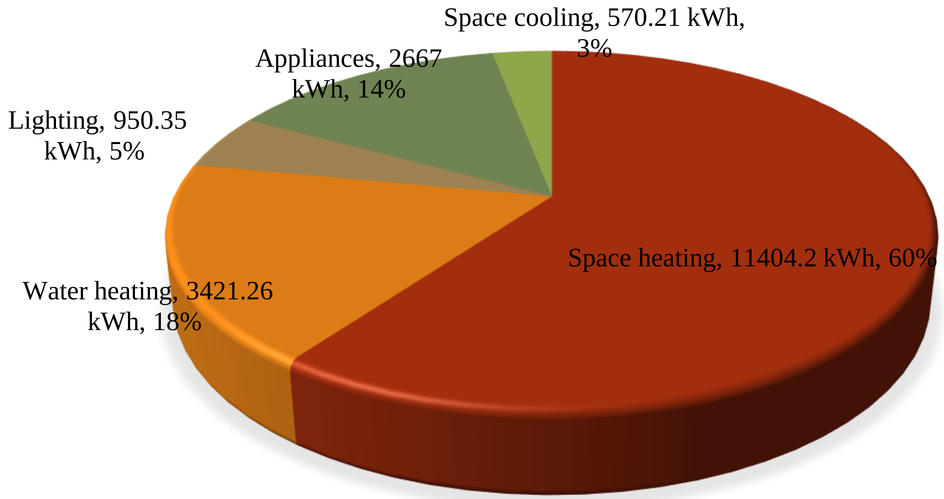
House Parameters Analysis

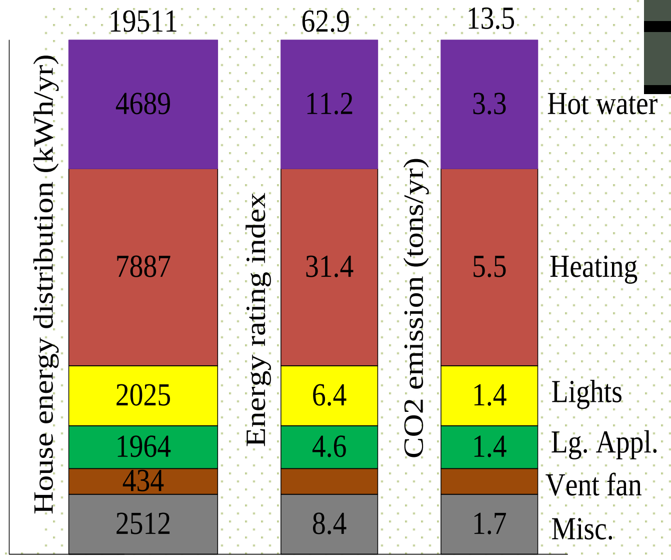




House parameters: Chap. 2, Table 1

BEopt Software is used

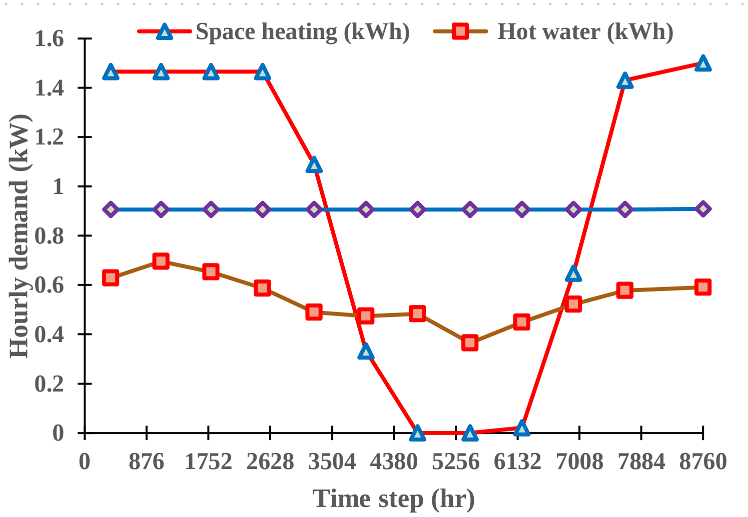


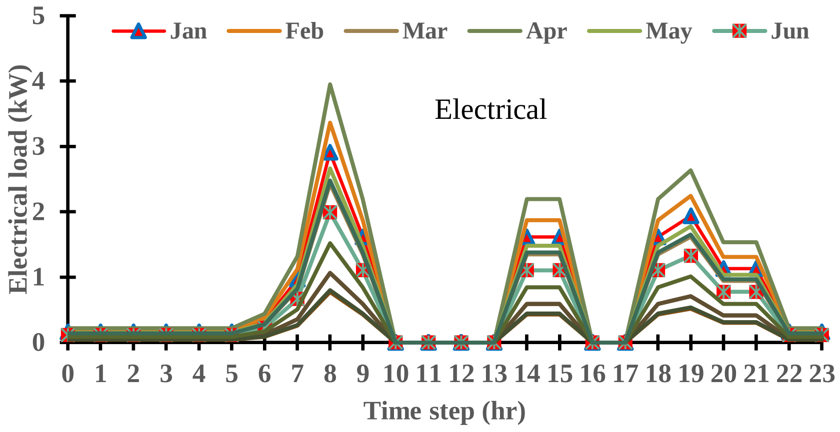


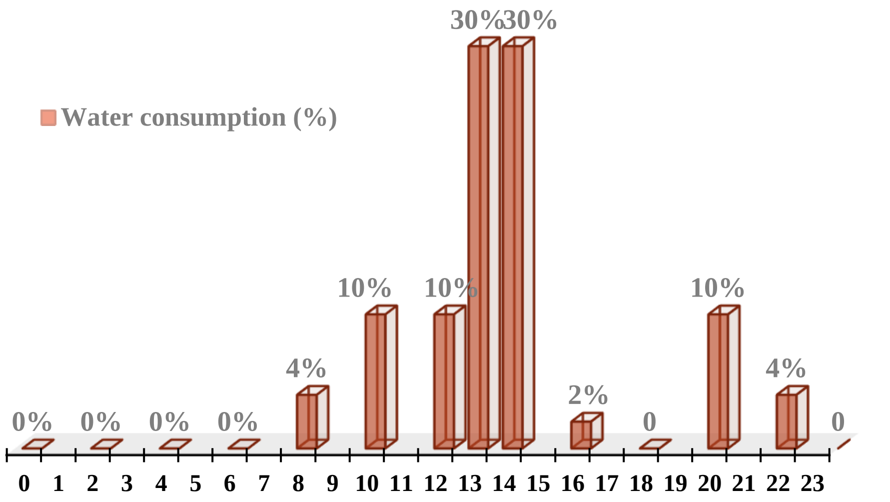
MEMORIAL UNIVERSITY

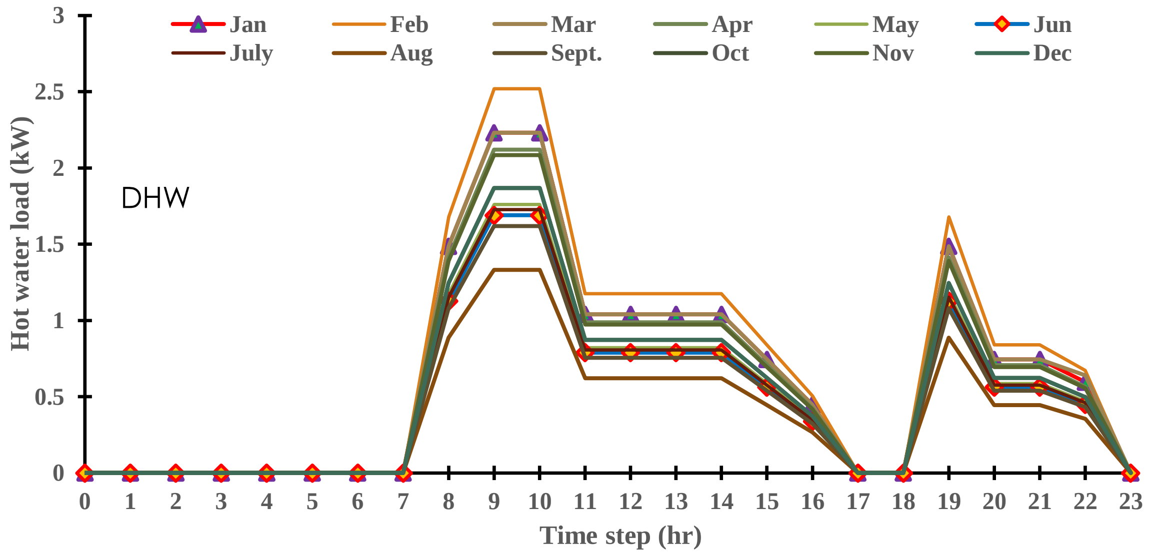
NSERC Energy Storage Technology Network

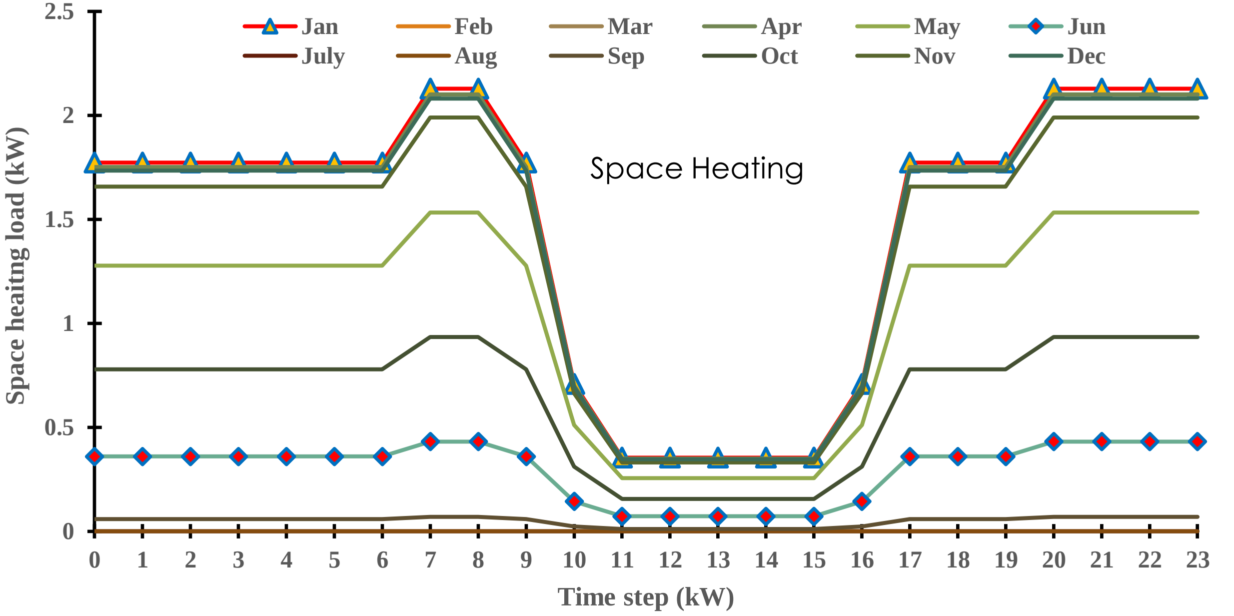
House Demand Analysis



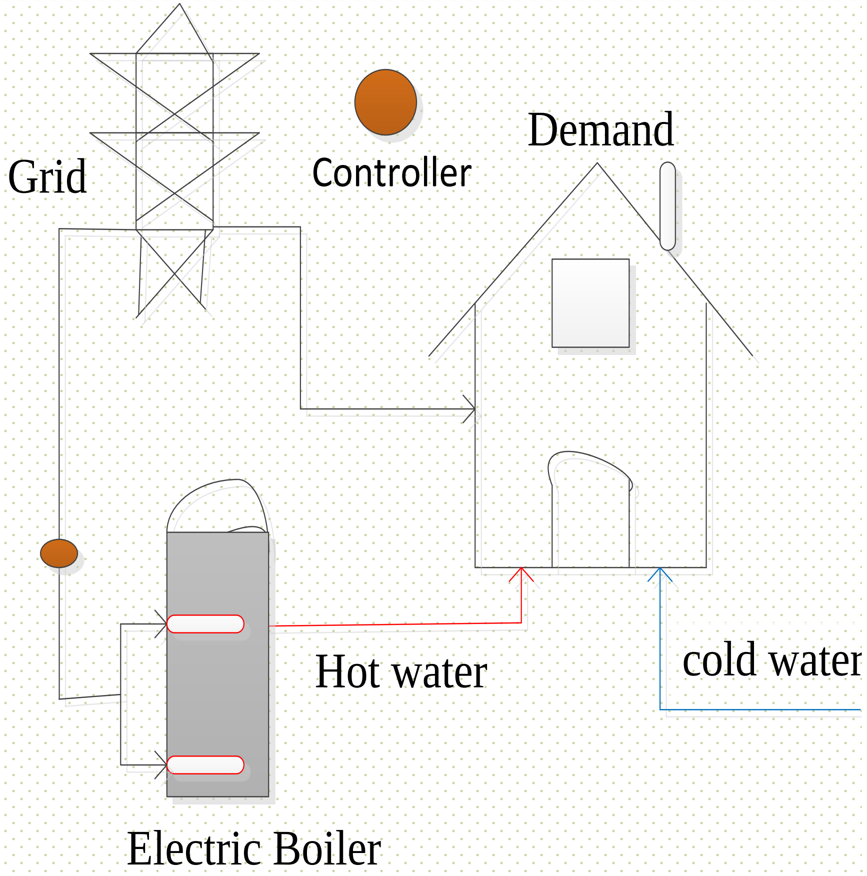


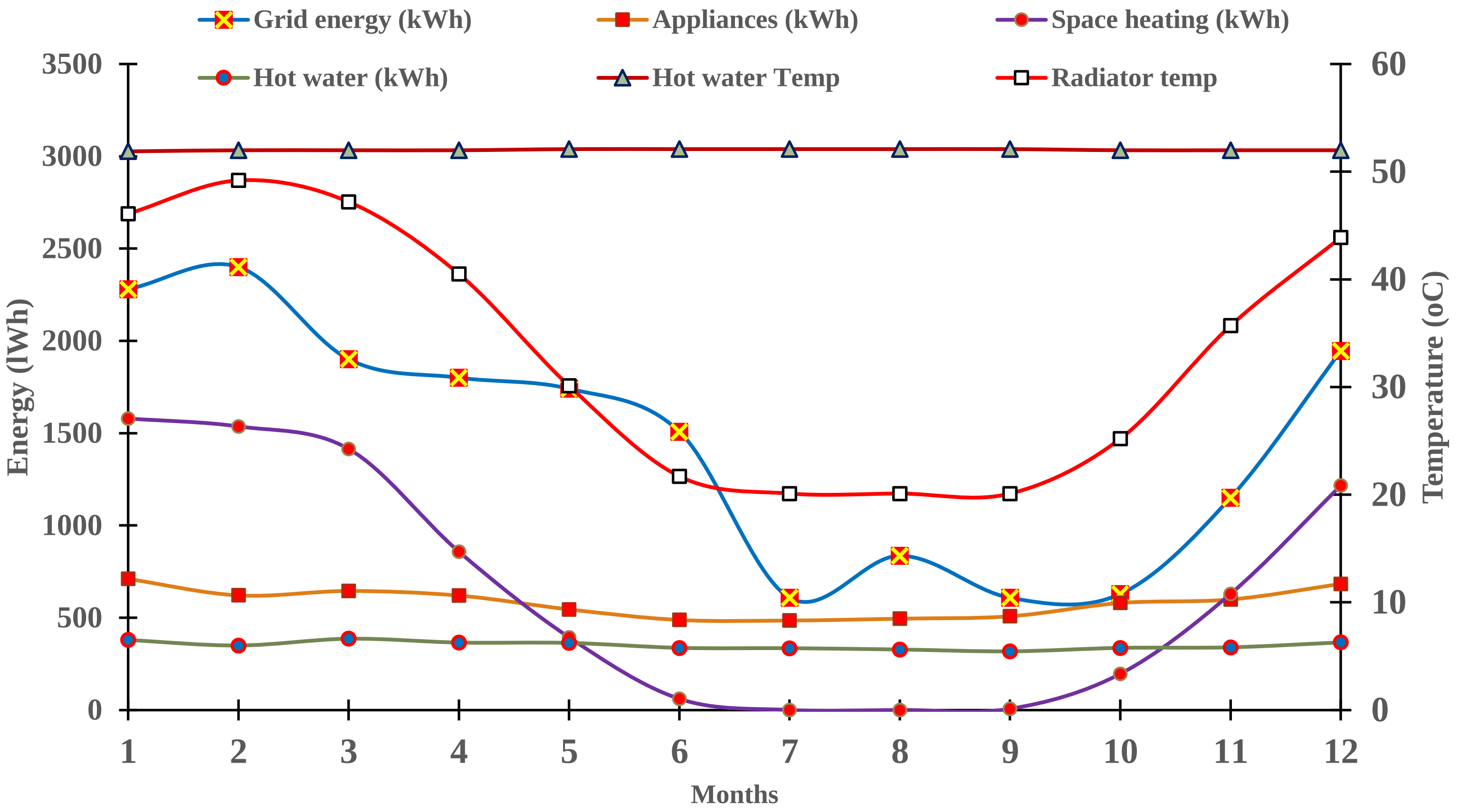






Existing House Simulation in PolySun

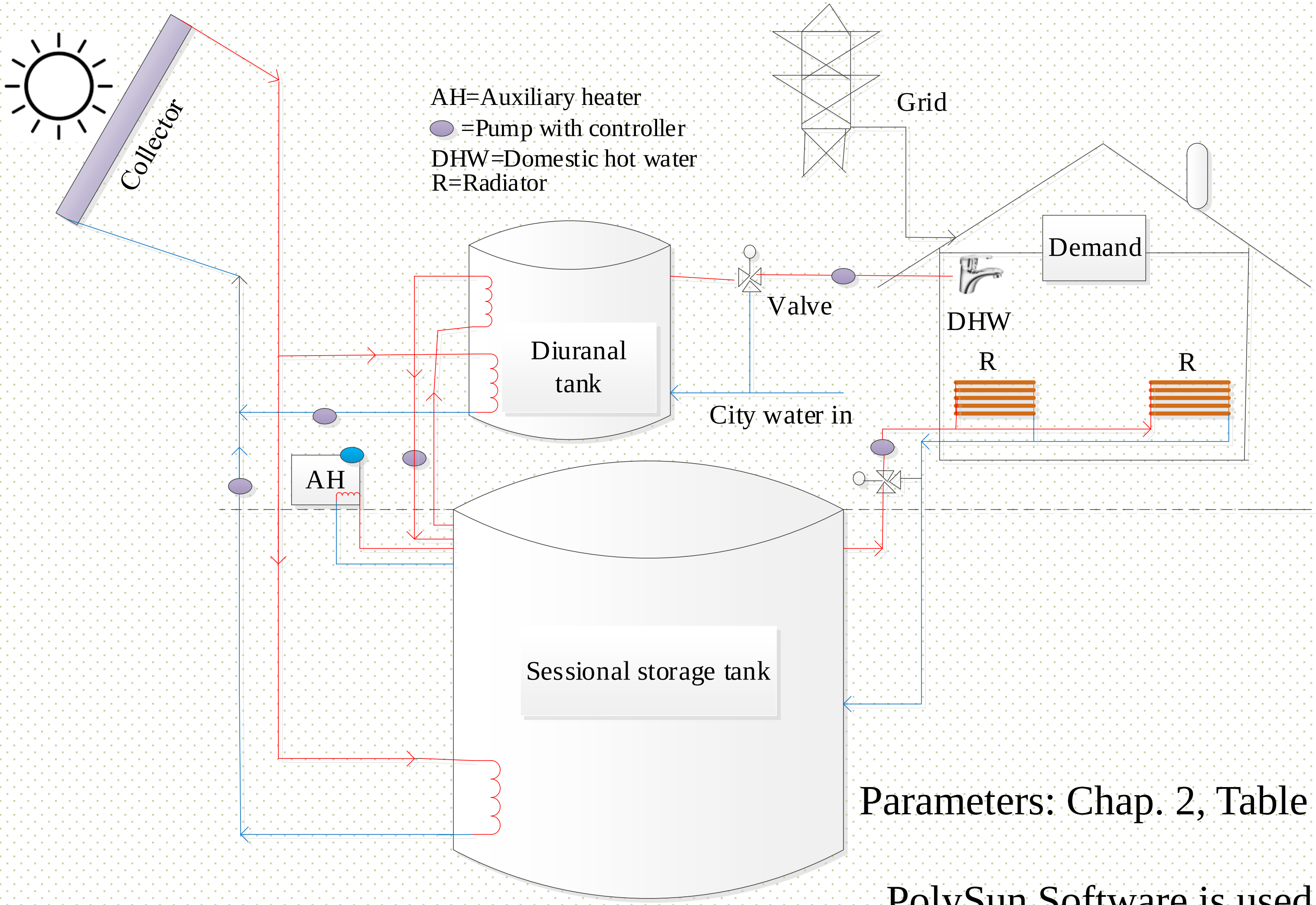




House simulation parameters: Chap. 2, Table 3

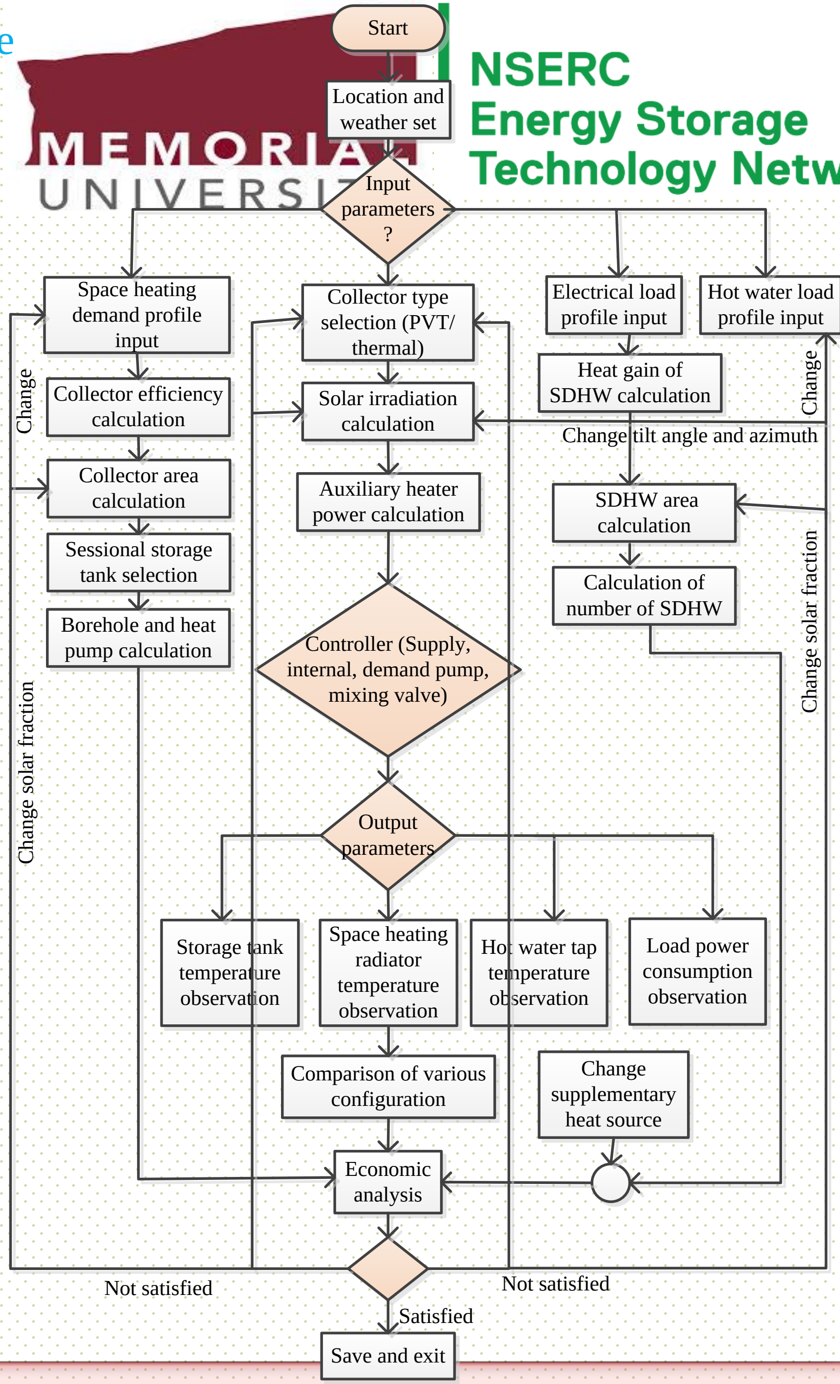
Simulation Results: Chap. 2, Table 4

SSTES Simulation & Flowchart



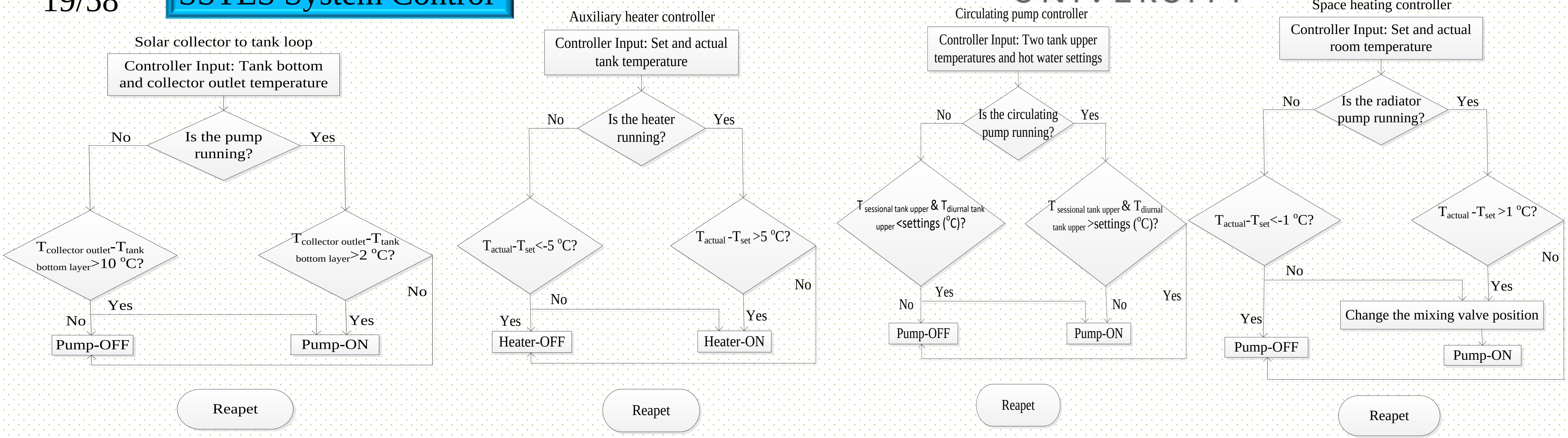
Parameters: Chap. 2, Table 6

PolySun Software is used



NSERC Energy Storage Technology Network

SSTES System Control

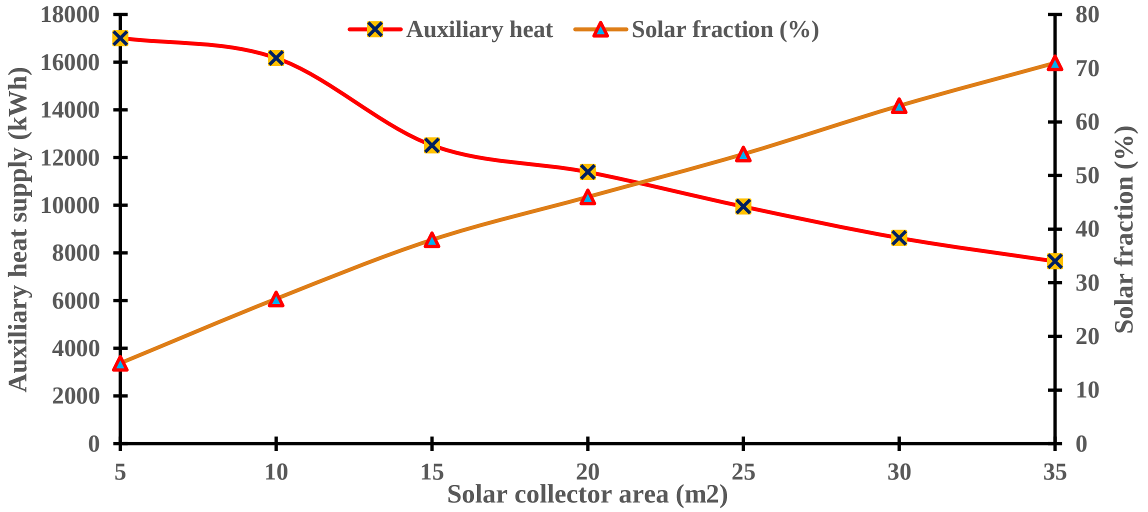


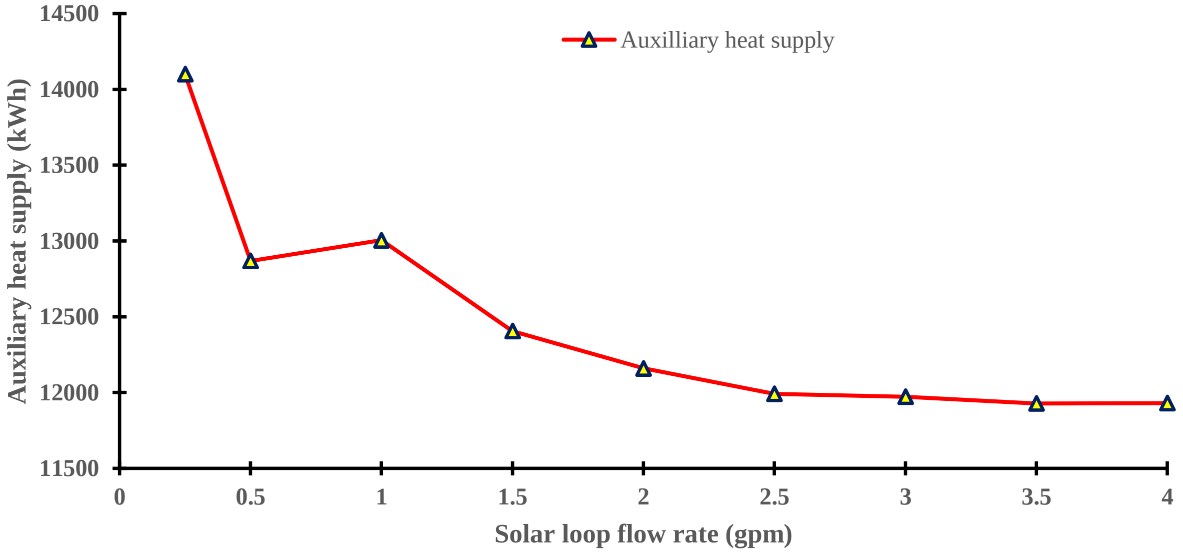
Parameters	10 m³	15 m³	20 m³	25 m³	30 m³
Fuel consumption (kWh)[HP]	4185	3621	3797	3960	4135
Eenrgy to the system (kWh)	11769	10217	10721	11132	11685
Energy saving solar thermal (kWh)	4861	6791	6860	6904	6921
CO_2 savings solar thermal (kg)	2608	3643	3680	3703	3712
Sessional storage tank heat loss (kWh)	2426	2839	3378	3809	4357
Tank top layer temperature (°C)	70.2	69.9	69.8	68.5	68.2
Tank top layer temperature (°C)	43.5	47.2	47	46.9	46.4

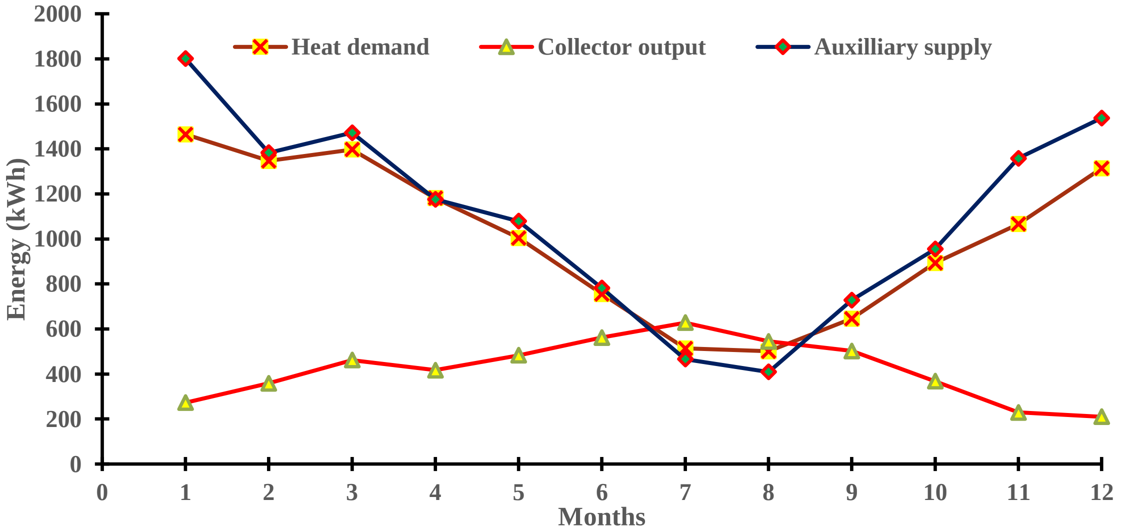
MEMORIAL UNIVERSITY

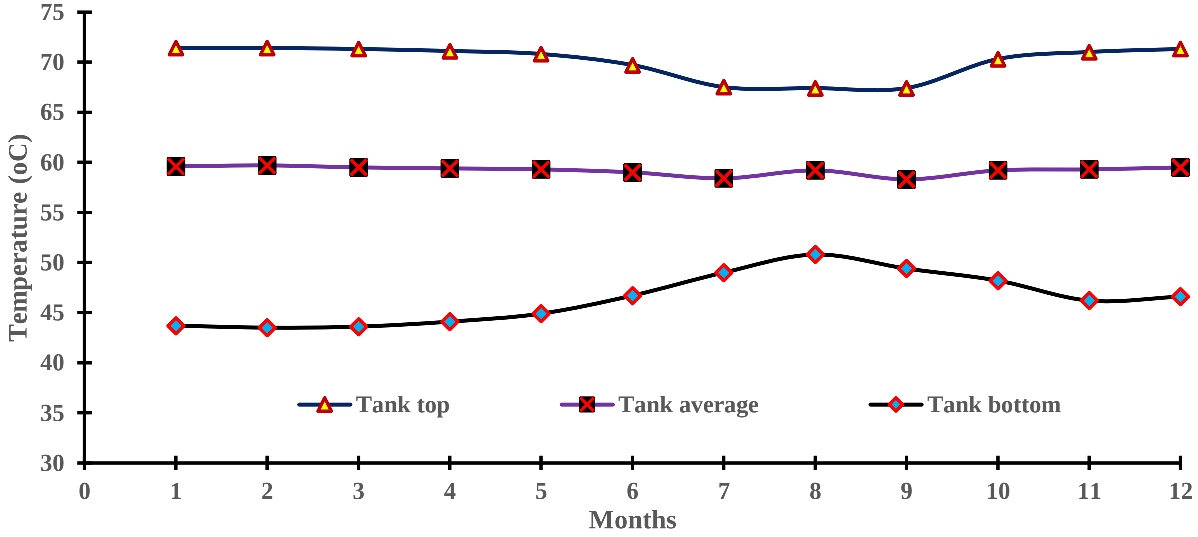
NSERC Energy Storage Technology Network

SSTES Simulation Results





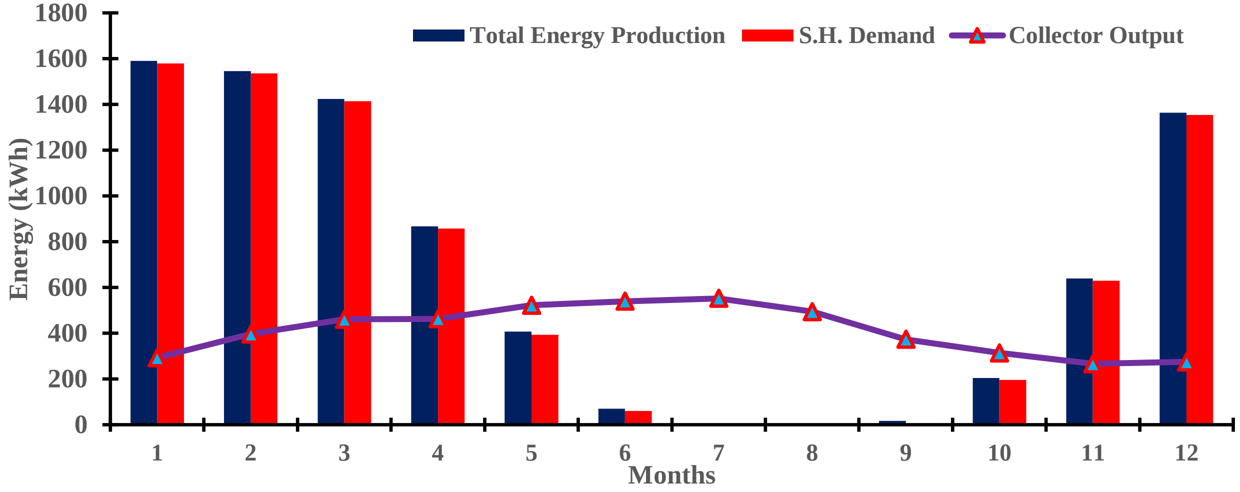


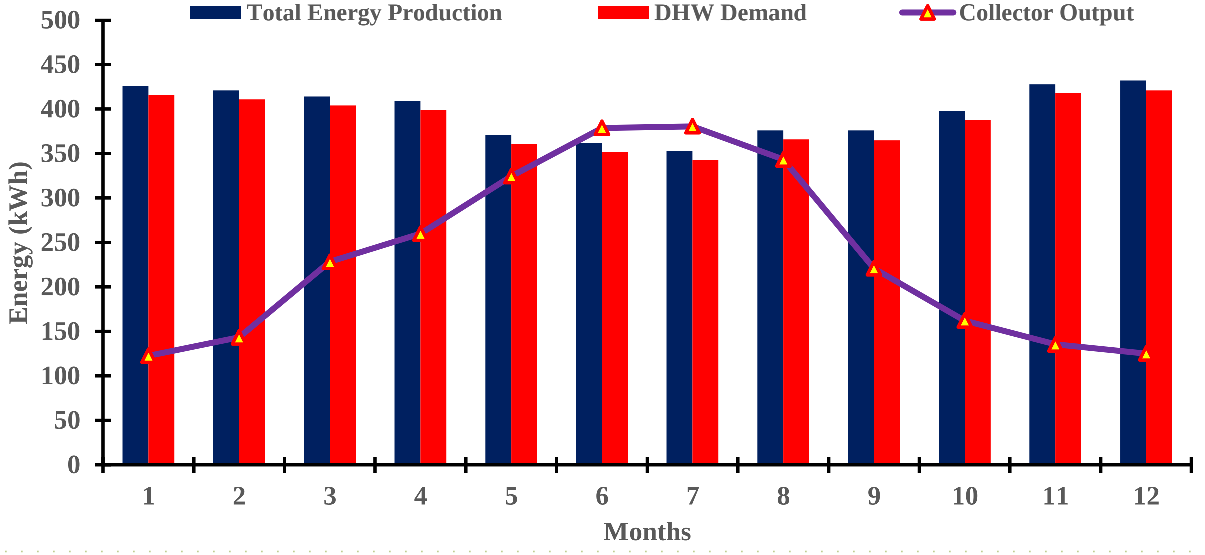


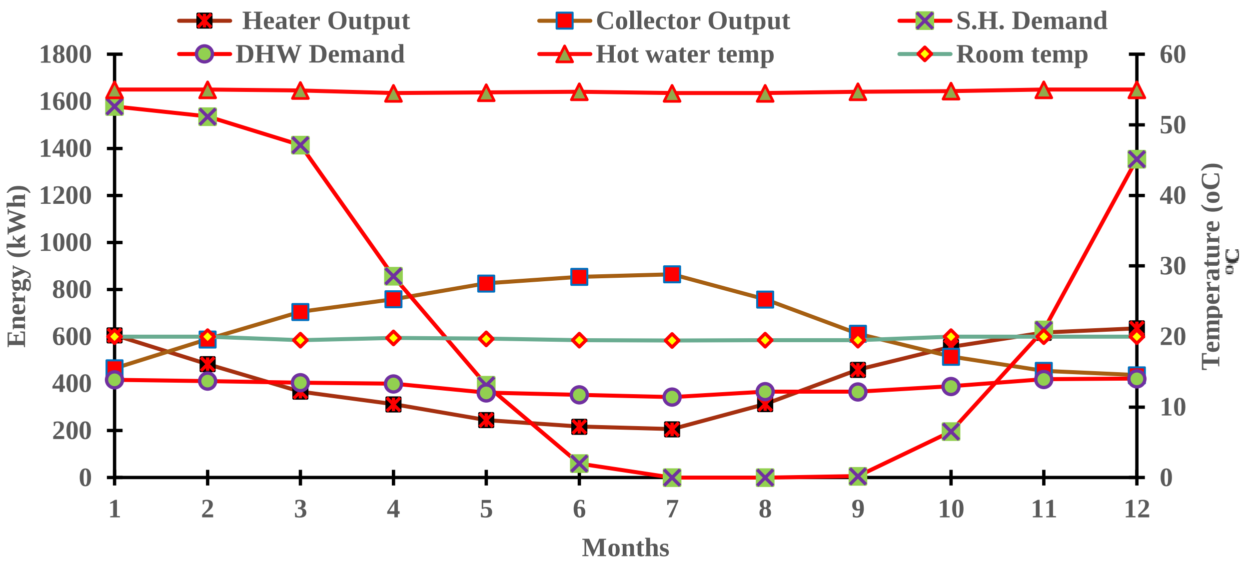
MEMORIAL UNIVERSITY

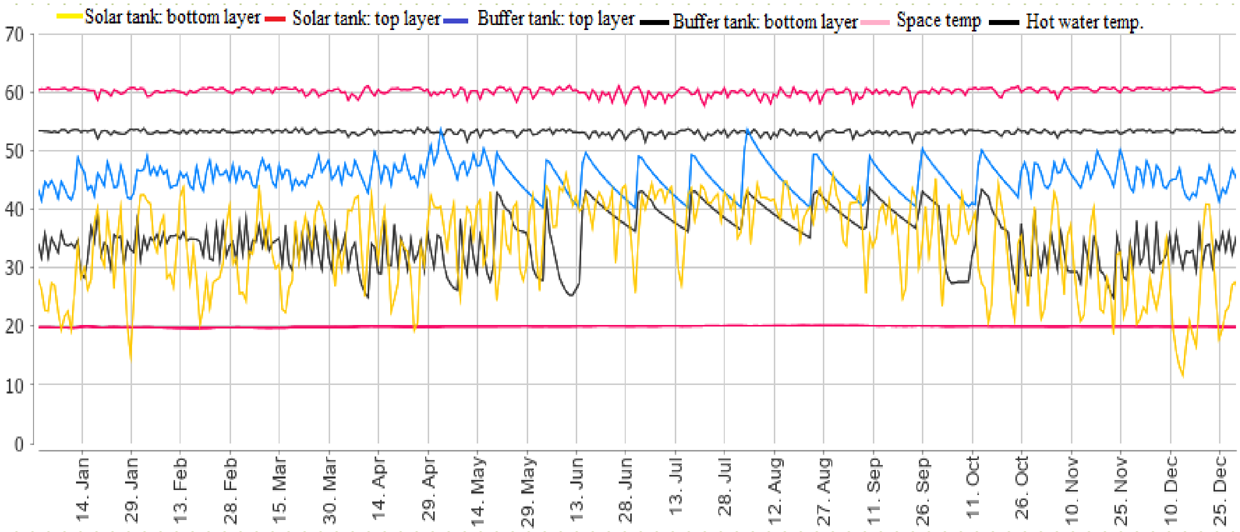
NSERC Energy Storage Technology Network

Presentation Overview:









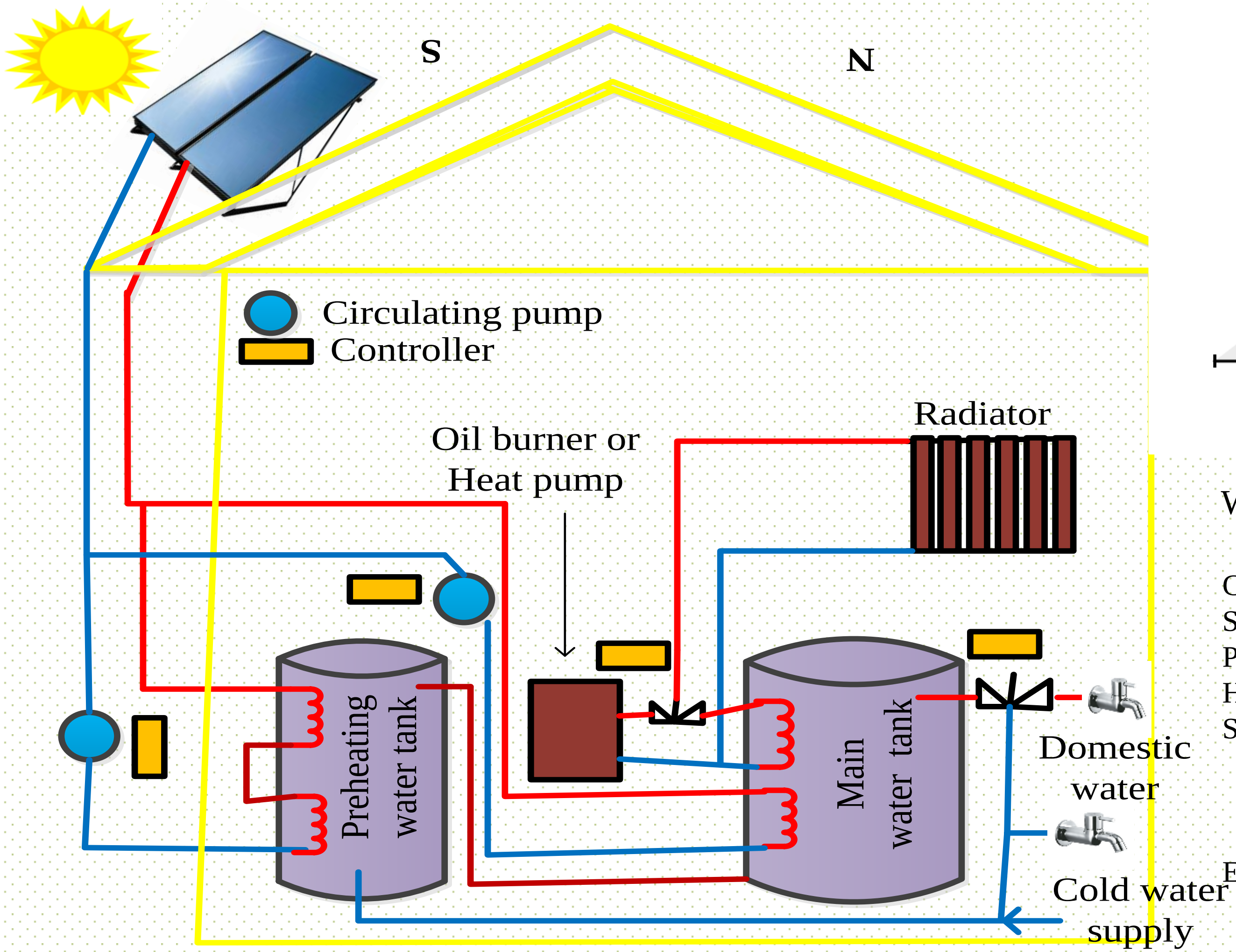
MEMORIAL UNIVERSITY
NSERC Energy Storage Technology Network

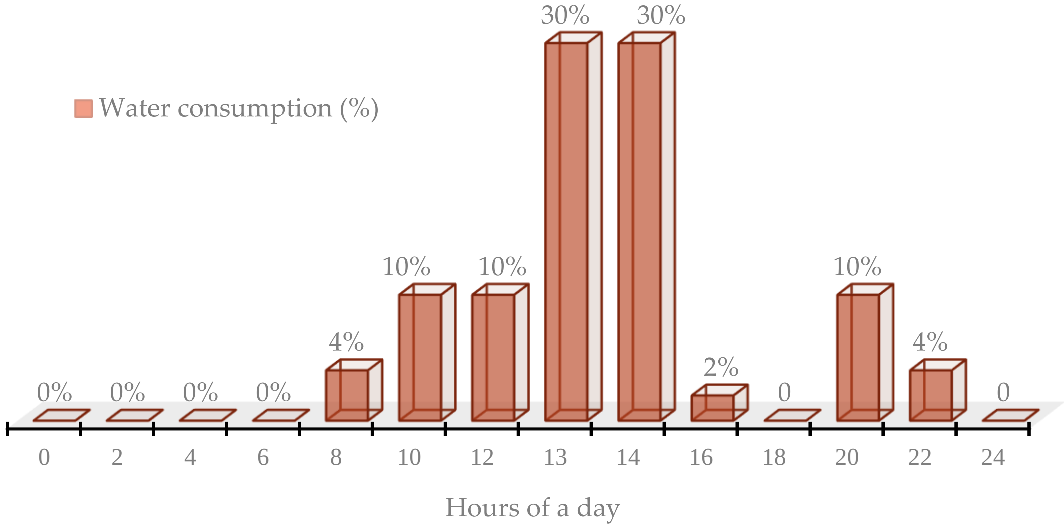
Comparison of Ref and SSTES

particulars	Reference systems (Grid + EH)	SSTES
Total energy demand (kWh)	12873	12573
Space heating temperature (oC)	20	20
Hot water temperature (oC)	55	55
Collector size	N/A	16 m^2
Main tsank size (m^3)	0.189	30
Solar fraction to hot water (%)	0	61
Solar fraction to space heating (%)	0	61
Total thermal energy generation (kWh)	12873	12855
Solar energy production (kWh)	0	7837
Auxiliary heater production (kWh)	12873	5015
CO2 emission (kg)	6224	3556
Electrical energy savings (%)	0	0
Thermal energy savings (%)	0	61%

NSERC Energy Storage Technology Network

Solar Collector Based Systems





Weather and house parameters remains same as mention in Chapter-2

Coldwater temperature=10 ^{0}C.
Storage hot water temperature= 55 ^{0}C.
Per person hot water demand, DHW= 20 liter/day
Hot water demand in kitchen, HWD_k= 30 liter/day
Storage volume,

$$V_{ST} = [(B \times O \times DHW) + HWD_K] \times 1.2$$
$$= [(02 \times 02 \times 20) + 30] \times 1.2$$
$$= 132 \text{ liter} = 0.132 \text{ m}^3$$

Main Tank: 0.2 m3

Energy demand for hot water,

$$Q_S = V_{ST} \times C_p \times \Delta T$$
$$= 0.132 \times 1.16 \times 45 = 6.89 \text{ kWh/day.}$$

MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Solar Collector Based Systems

Collector yield,

$$C_Y = S_R \times \eta_K \times \eta_{sys}$$

$$=2.9\times0.6\times0.8=1.392 \text{ kWh/m}^2.$$

Collector array, $C_A = \frac{Q}{C_Y} = \frac{6.89 \text{ kWh}}{1.392 \frac{\text{kWh}}{\text{s.m}}} = 4.95 \text{ m}^2$

The required number of collectors= $\frac{\text{Daily requirement}}{\text{Collecotor output}}$ =0.0223 (m^2/day)

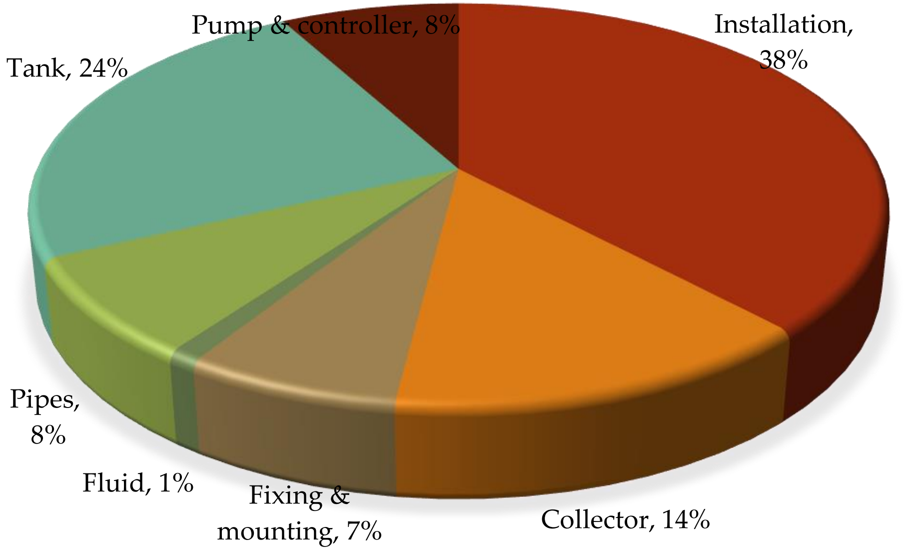
The total number of collectors=0.02231(m^2/day) × 125.27 m^2=2.7 per day.

The surface area of collector array=No of collectors × size of each collector in m^2

$$=2.7 \times 1.9 \text{ m}^2 = 5.13 \text{ m}^2$$

AE-21 model solar collector dimension is considered

Total collector area for space heating and DHW=10.08 m^2 ≅10 m^2



Cost Analysis

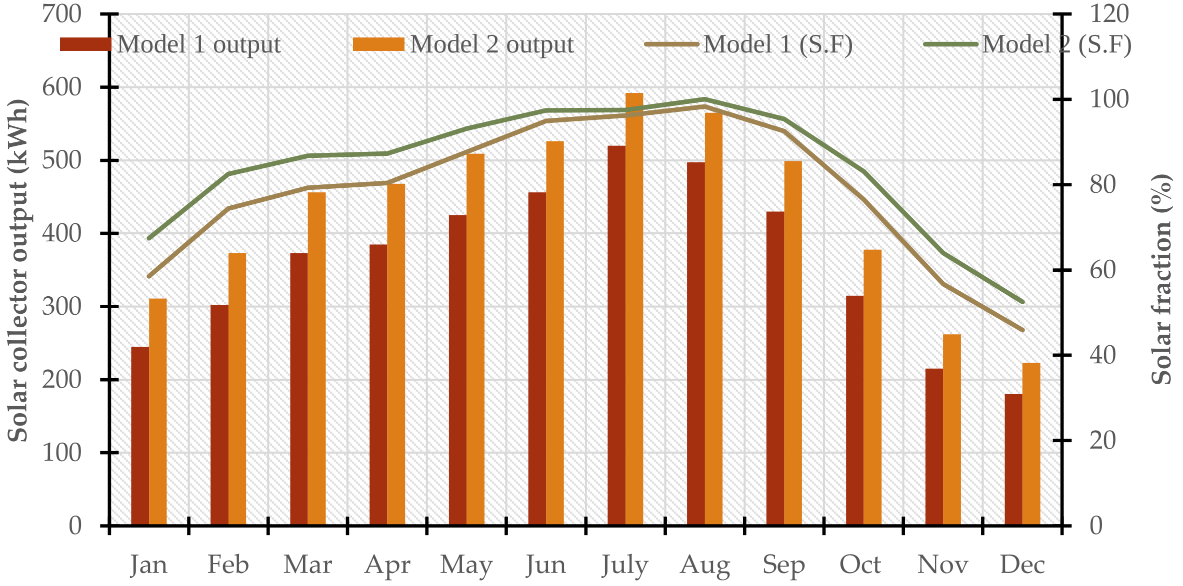
Total Implementation cost:
Oil Burner based TES: CA $ 53600
Heat Pump based TES: CA $ 54600

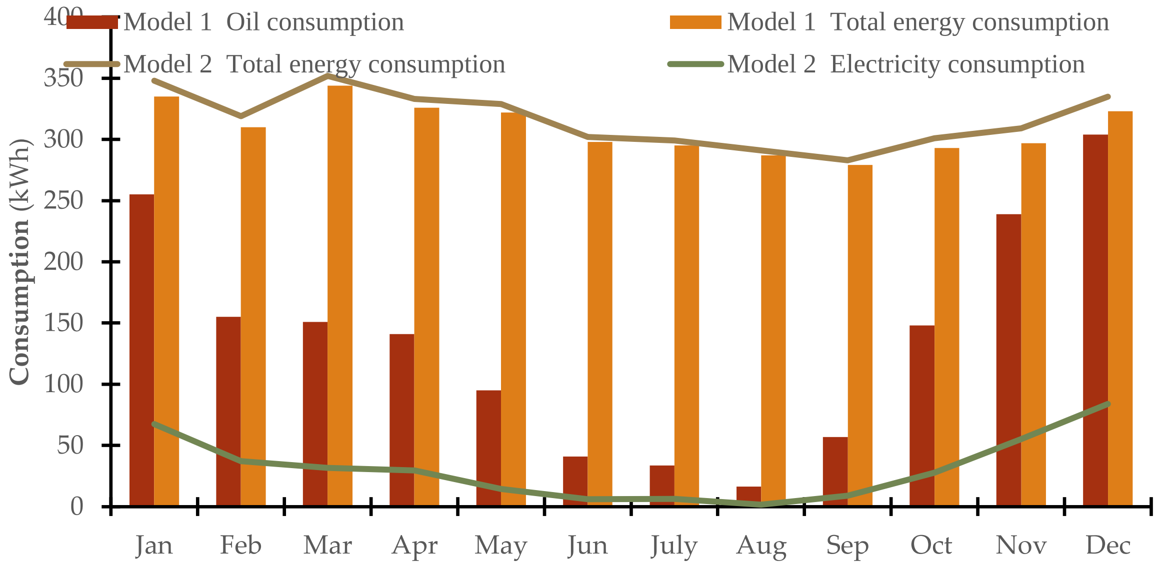
Need Details? Chap. 3, Table 2

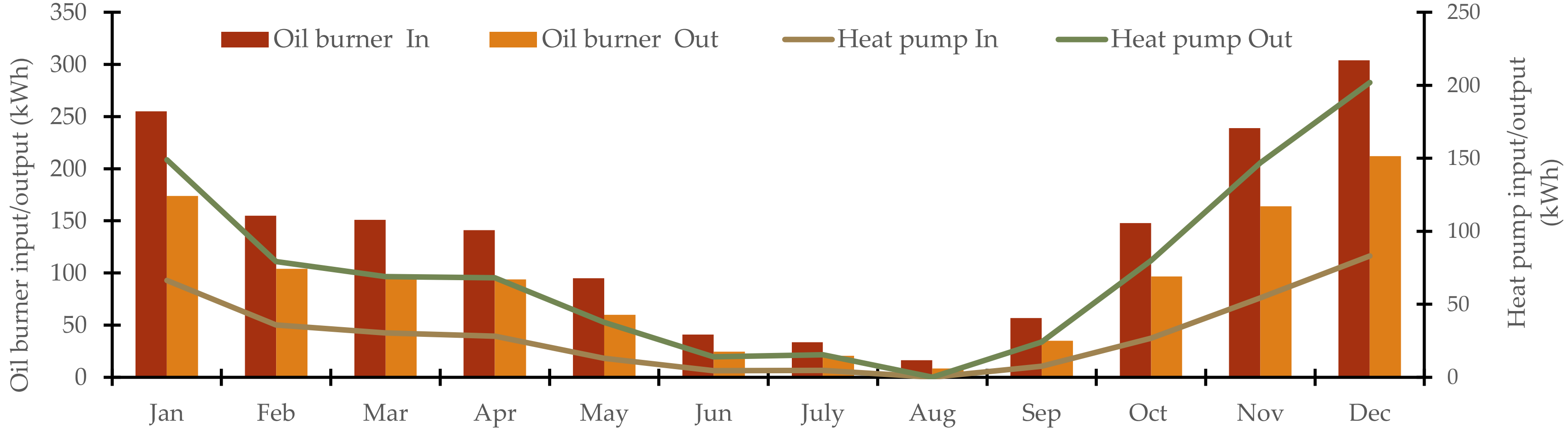
MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Collector Based TES Performance







MEMORIAL UNIVERSITY | NSERC Energy Storage Technology Network

Collector based TES performance summery

Basic sections	Particulars	Existing/ reference system	Model 1 (Oil Burner)	Model 2 (Heat pump)
Solar collector	Type	N/A	Flat plate	Flat plate
	Number of collectors	N/A	05 (No tracking)	05 (No tracking)
	Total gross area	N/A	10 m^2	10 m^2
	Annual Output	N/A	4345 kWh	5161 kWh
Storage tank	Volume	181 Liter	(132+200) Liter	(132+200) Liter
	Functions	DHW only	DHW and space heating	DHW and space heating
Auxiliary burner	Type, capacity	Electric resistance (4 kW)	Oil burner (3 kW)	Heat pump (3 kW)
	Energy input/output	Same	1635/1091 kWh	354/882 kWh
Annual energy consumption	DHW and space heating	17009 kWh	9389.5 kWh + 159.2 L Oil	8320.5 kWh
Annual consumer bill	DHW and space heating	1690 CAD	1201 CAD	998.46 CAD
	Savings	No	29%	44%

MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

PV based TES Systems Sizing

✓ Sizing PV for Water Heating

Required load for water heating= 6.89 kWh/day (standard two rooms for 4 people)
Total PV panels energy needed= 6.89 kWh/day×1.3= 8.957 kWh/day.
Total Wp of PV panel capacity needed= 8957 Wh/day/3.4=2634 Wp.
Number of PV module=2634 Wp/150 W= 17.56 modules ≅ 18 modules.
The area of PV panel=0.93 × 0.675 m^2= 0.6277 m^2/per panel
The total area of PV panel= 11.3 m^2

✓ Sizing for Space Heating

Required load for space heating= 20.27 kWh/day [standard two rooms with 4 people]
Total PV panels energy needed= 20.27 kWh/day × 1.3= 26.35 kWh/day.
Total Wp of PV panel capacity needed= 26350 Wh/day/3.4=7750 Wp.
Number of PV module=7750 Wp/150 W= 51.66 modules ≅ 52 modules.
The area of PV panel=0.93 × 0.675 m^2= 0.6277 m^2/per panel
The total area of PV panel= 0.6277 m^2 × 52= 32.64 m^2
The total number of a solar panel for water and space heating is 70 numbers, which are equal to 43.94 m^2.

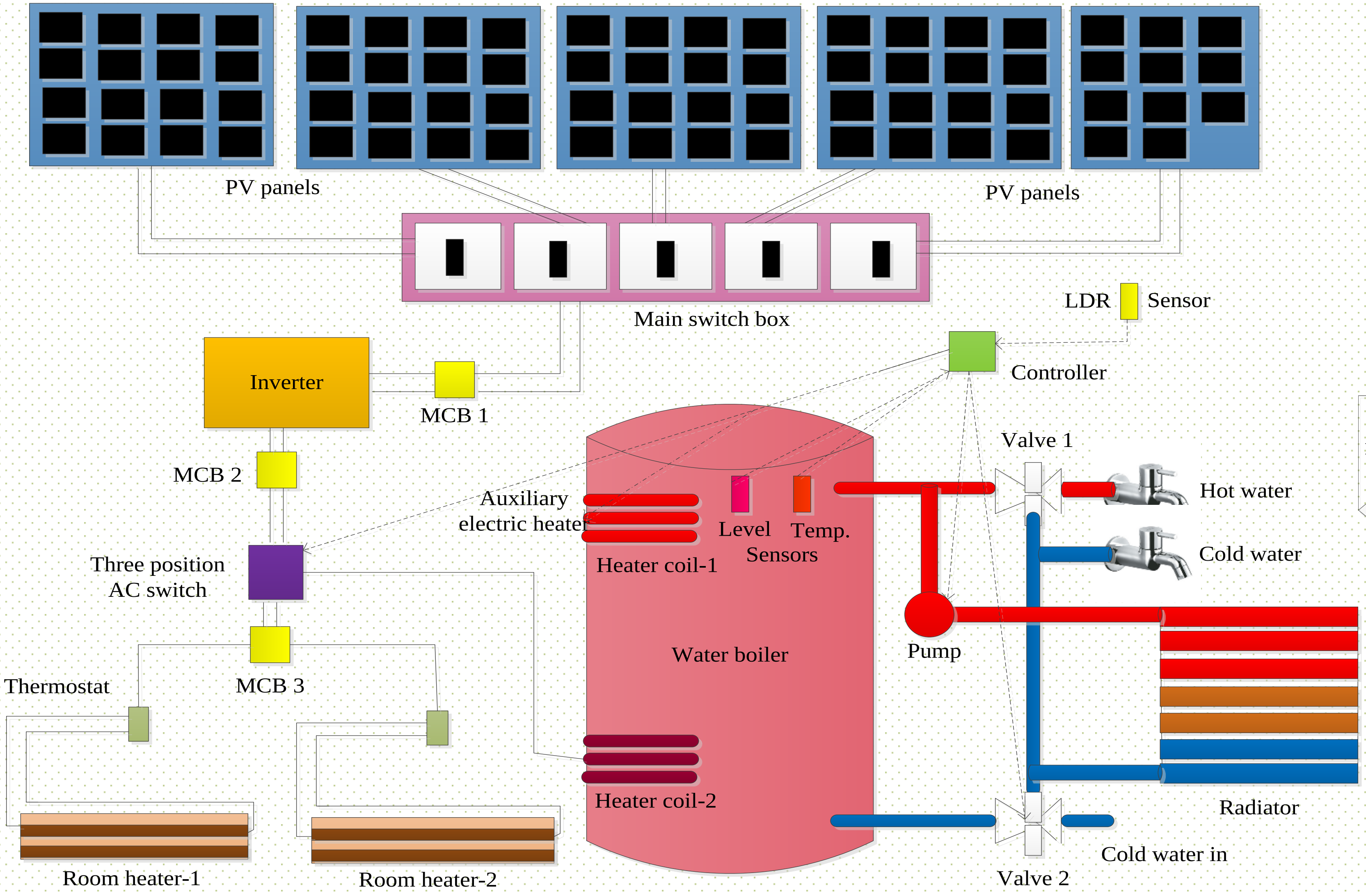
Sizing of Inverter and the MPPT

20-25% bigger size then demand

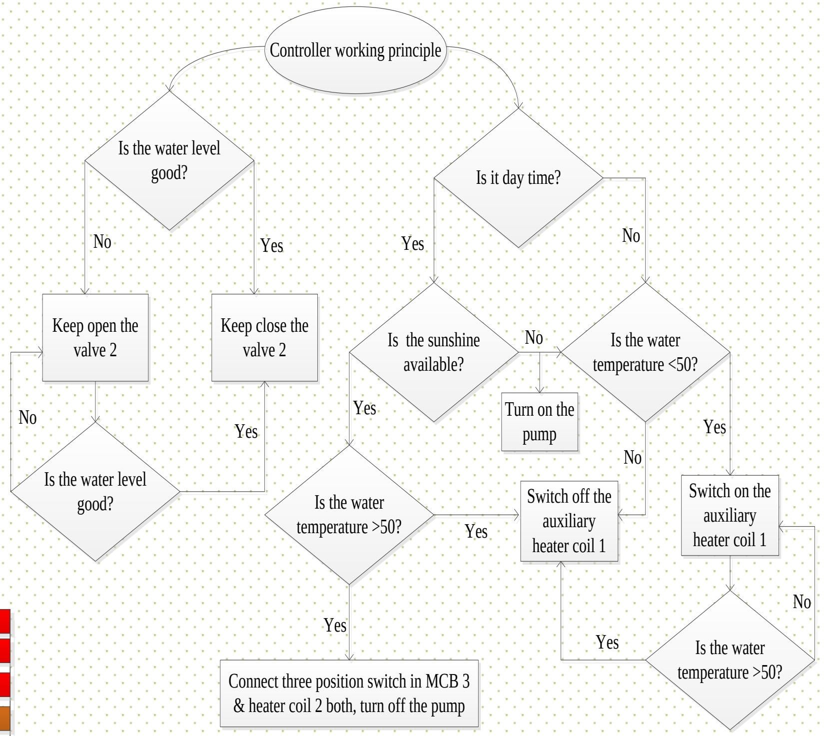
MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

PV based TES Systems Design

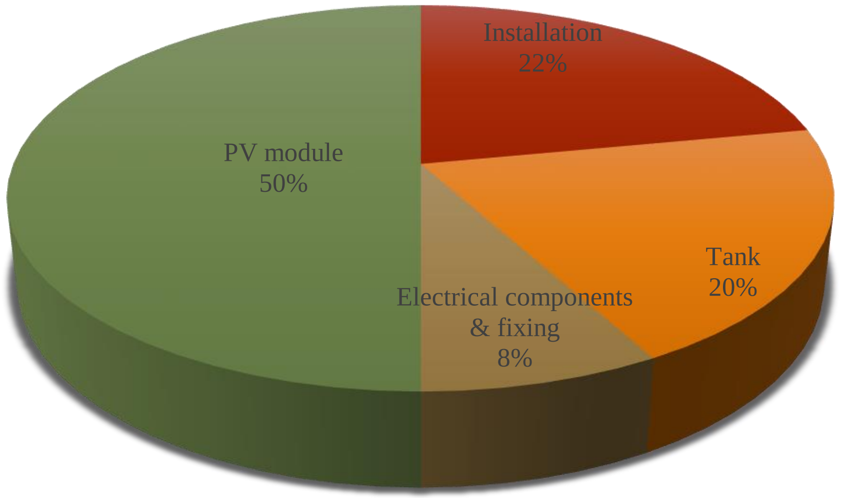


Control Systems

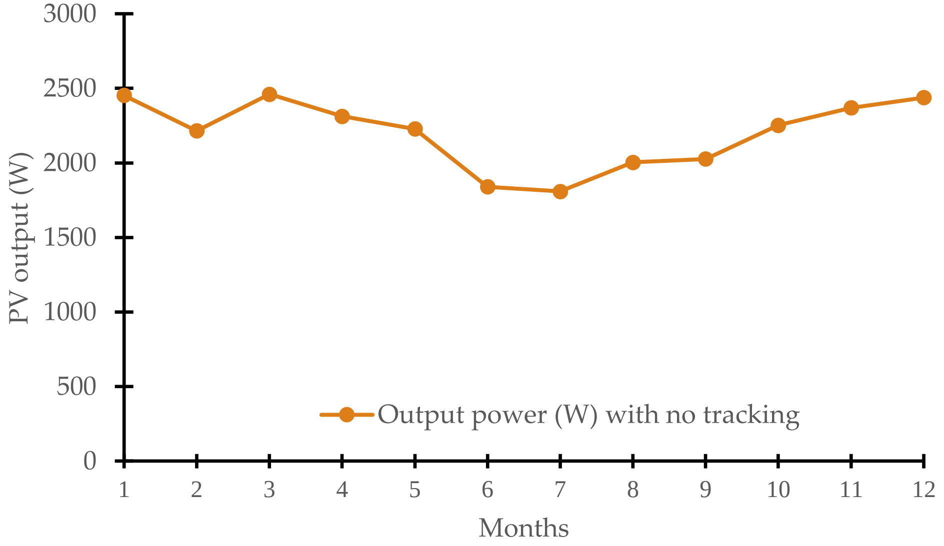


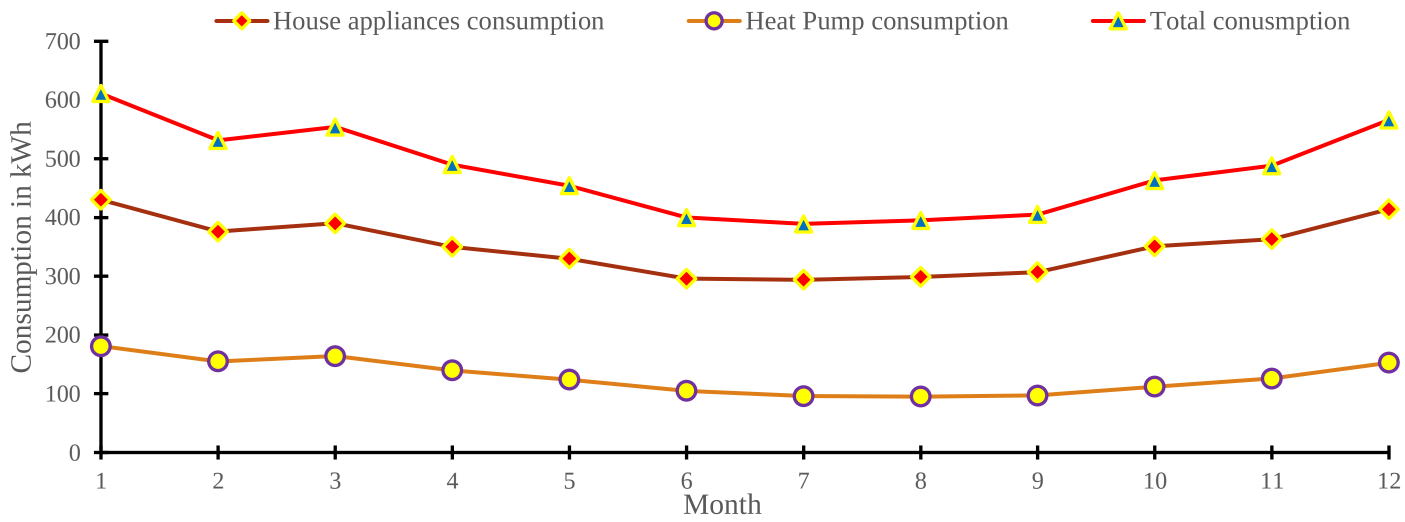
MEMORIAL UNIVERSITY
NSERC Energy Storage Technology Network

PV Basted TES Implementation Cost



Descriptions	**Sizing and Prices**
PV Panel cost	150$×70 no's=10500 CAD.
Installation cost	10500×34%=2310 CAD.
450 L of Electric Water Tank with high insulation cost	3000 CAD
Combiner box (6 String, 250 V AC, 10 A each)	12×225 = 2700 CAD
MPPT installation	optional
Inverter cost (12000 W)	3000 CAD
Electrical components and fixing	10500×8%=840 CAD.
The total investment cost	22350 CAD



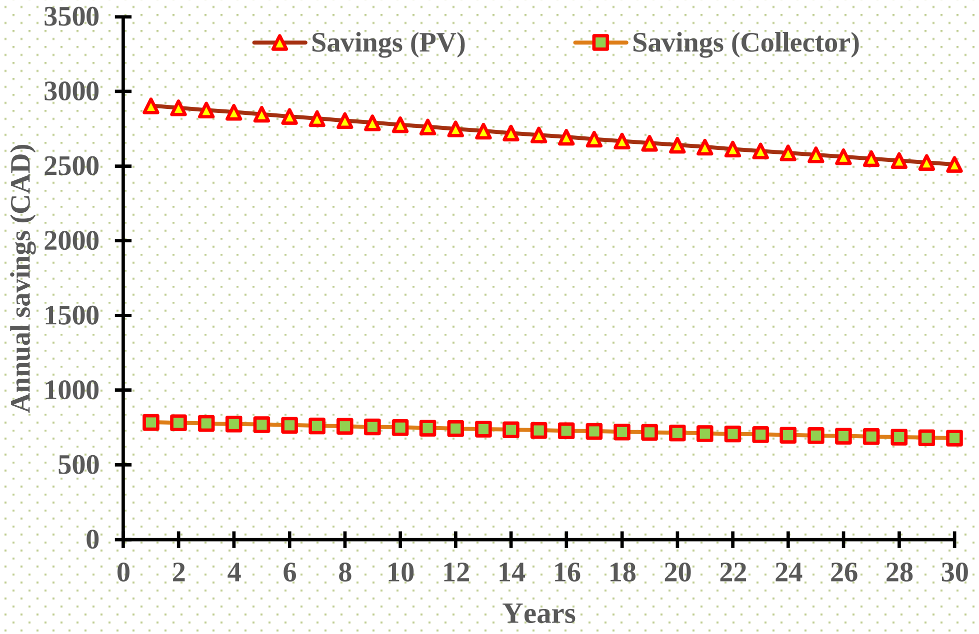


MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

PV Basted TES System Comparison

Particulars	Reference system	Thermal Collector Based		PV Based
		Model 1	Model 2	
Energy generation from a renewable source	0 kWh/year	4345 kWh/year	4345 kWh/year	26412 kWh
Energy is taken from the grid	17009 kWh/year	9389.5 kWh + 159.2 L Oil	8320.5 kWh	0 kWh/year (If net metering is implemented)
Annual energy savings	0 kWh/year	7619.5 kWh/year	8688.5 kWh/year	17009 kWh/year
Surface requirement	---------	10 m^2	10 m^2	43.94 m^2
Storage tank size	181 L	(132+200) Liter	(132+200) Liter	454 L
Investment cost	Nothing change	53,600 CAD	54,600 CAD	22350 CAD
Yearly savings	0 CAD (0%)	914.34 CAD (29%)	1042.62 CAD (44%)	2041.08 CAD (100%)



Comparison of annual savings

MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Collector Based TES Design in MATLAB

Assumptions:

1. The water flow has been considered under steady-state conditions.
2. The tube flow has been assumed fully developed flow.
3. The PVT and collectors layer temperature has been neglected.
4. All other parameters have been assumed; temperature independent.
5. There is no heat gain (or loss) when the water through the pumps and pipes.
6. It is assumed that there is no shading and dust on the PVT and collector panel.

TES system simulation softwares

TRNSYS, ESP-r, POLYSUN, TRNSOL, MINSUN, SOLCHIPS, MATLAB, DYOMLA, SmartStore, EnergyPlus, eQuest, HVACSIM+, GeoStar, GetSolar (GR), Fortran

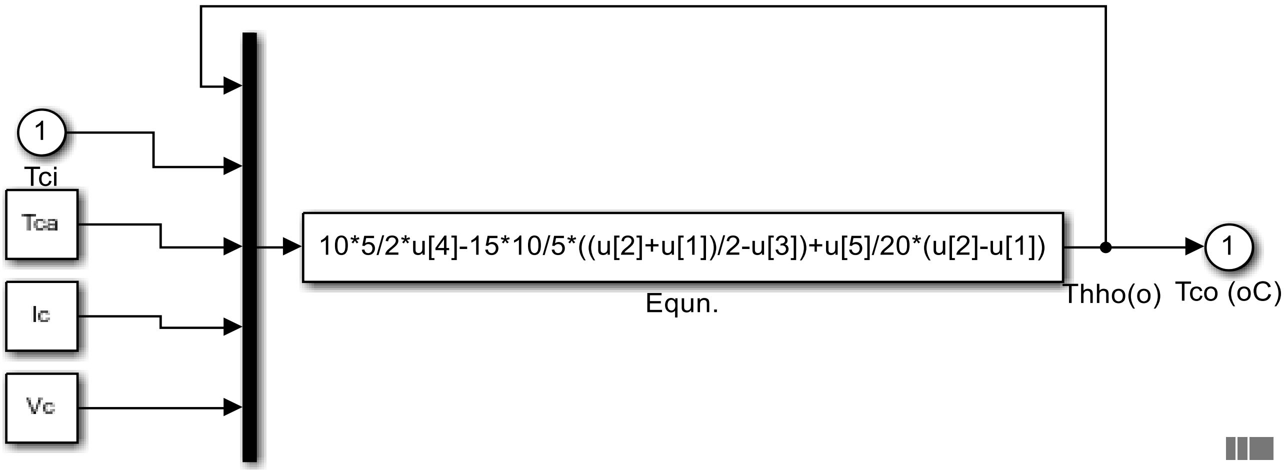
MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Mathematical Modelling of Solar Collector Based TES

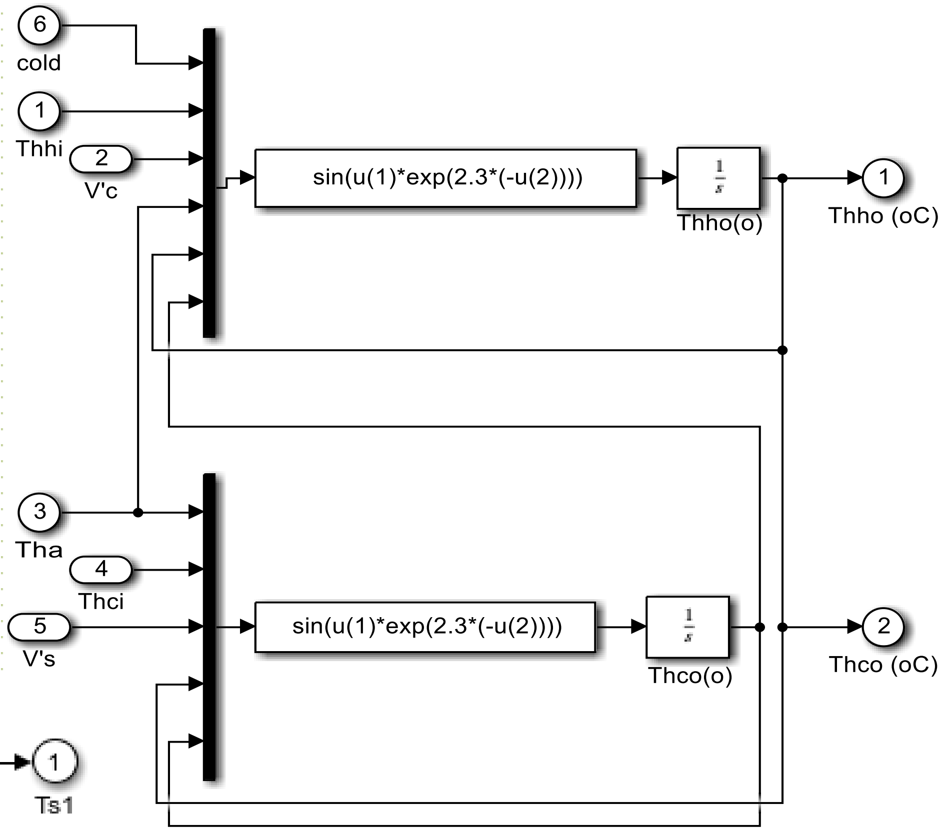
Solar Collector:

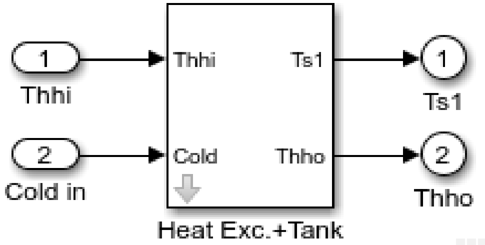
$$\frac{dT_{co}}{dt} = \frac{A_c \eta_o}{C} I_c - \frac{U_L A_c}{C}(T_{av} - T_{ca}) + \frac{\dot{V}_c}{V_c}(T_{ci} - T_{co})$$



$$\frac{dT_s}{dt} = \frac{\dot{V}_l}{V_s}(T_d - T_s) + \frac{\dot{V}_l}{V_s}(T_{hco} - T_s) - \frac{A_s k_s}{\rho_s c_s V_s}(T_s - T_{sa})$$

Heat exchanger



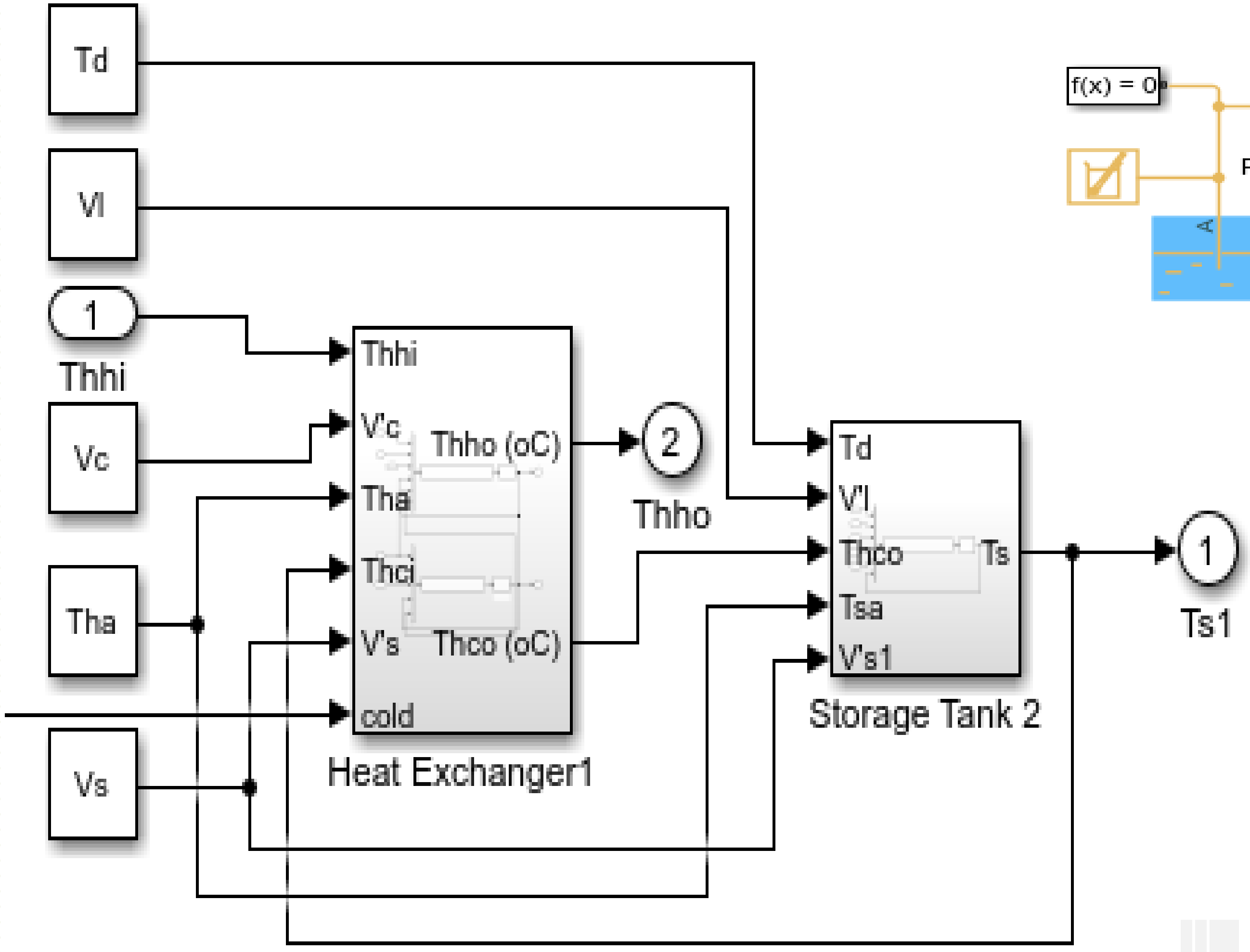


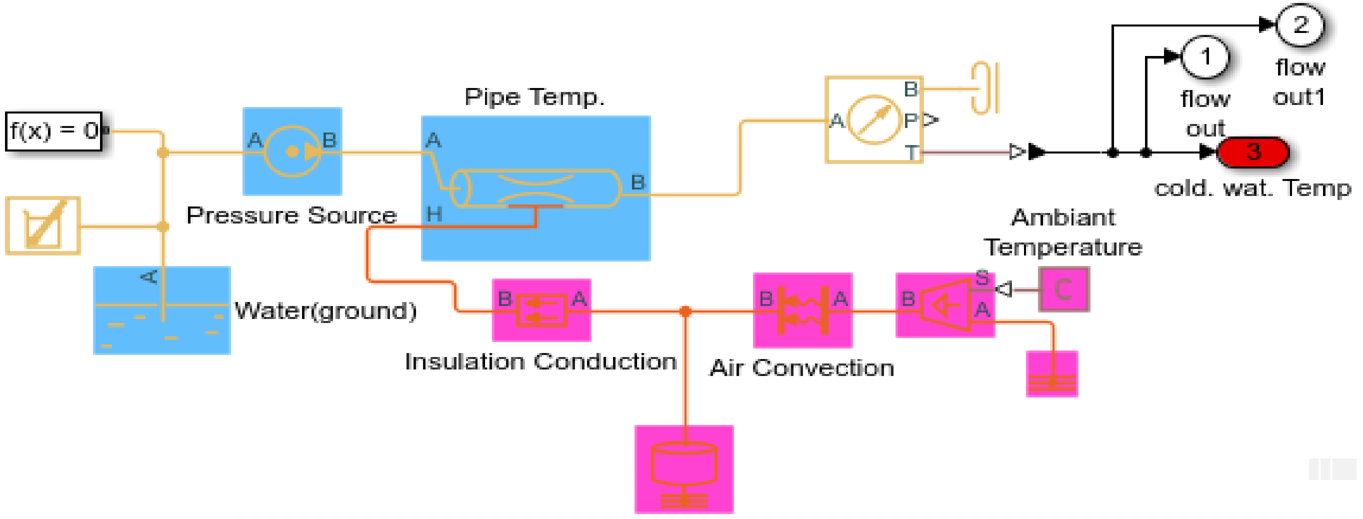
Ref.: J. Buzás and I. Farkas, "Solar Domestic Hot Water System Simulation Using Block Oriented Softwrae," Jun. 2000.

MEMORIAL UNIVERSITY

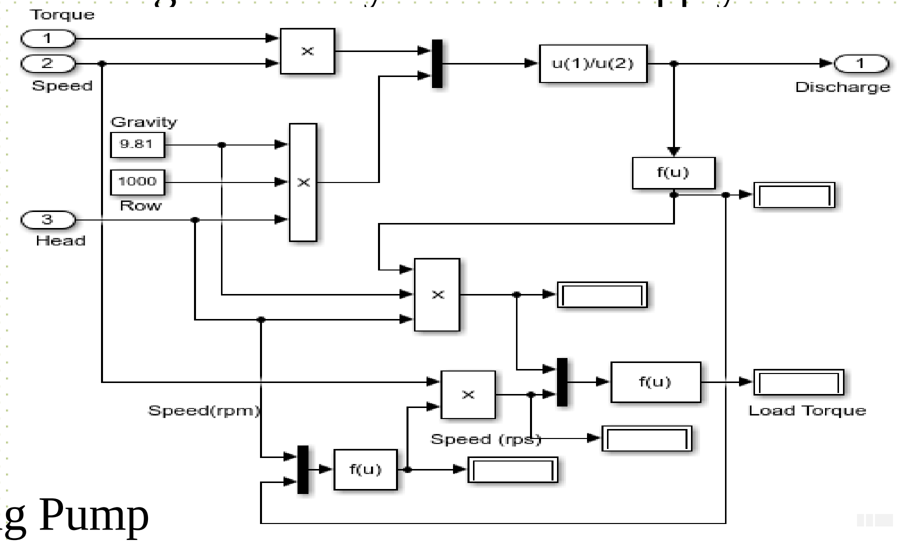
NSERC Energy Storage Technology Network

Mathematical Modelling of Solar Collector Based TES





The Simulink diagram of city cold water supply to the tank.



Circulating Pump

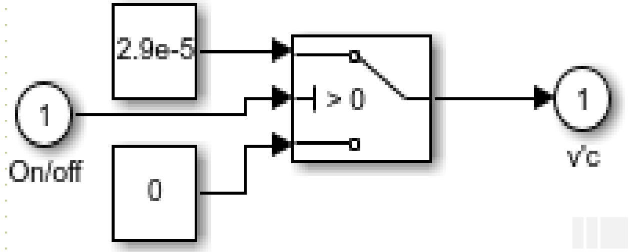
MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Mathematical Modelling of Solar Collector Based TES

The flow rate in the collector to storage tank loop[13]:

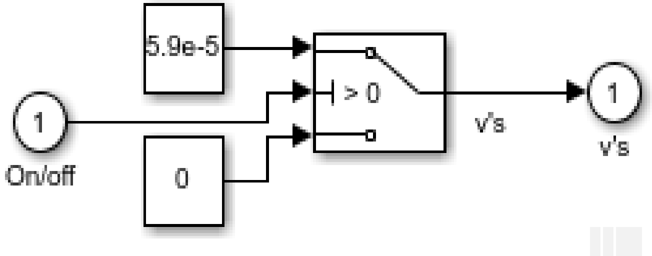
$$\dot{v}_c = \begin{cases} 2.9 \times 10^{-5}\ m^3\ S^{-1} & \textbf{when}\ T_{co} \geq T_s + 3 \\ 0\ \ m^3\ S^{-1} & \textbf{when}\ T_{co} \leq T_s + 3 \end{cases}$$



The pump On/Off control was used

The flow rate in the storage tank to the radiator loop:

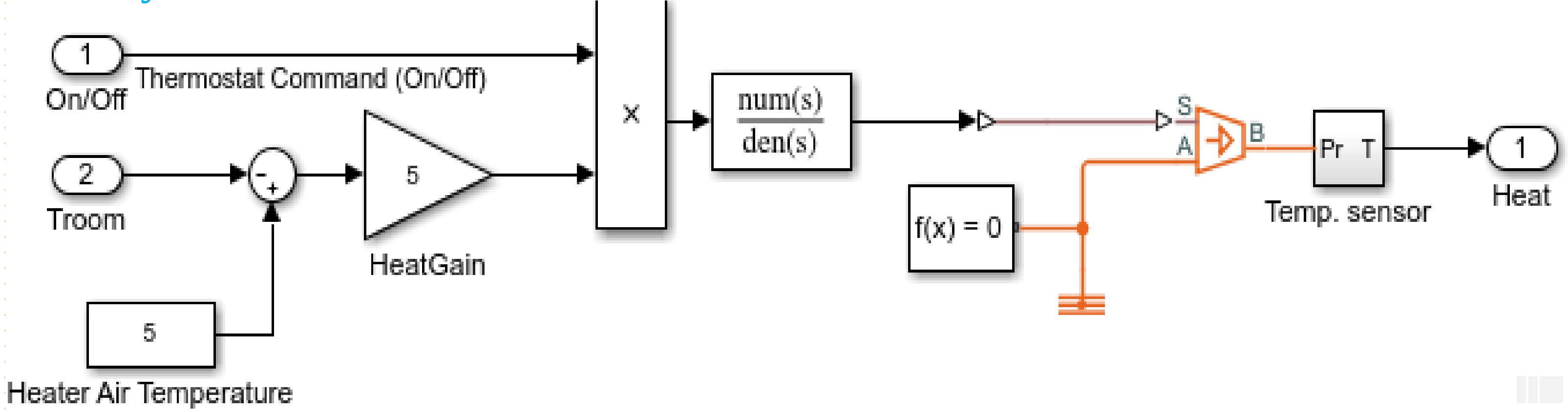
$$\dot{v}_c = \begin{cases} 5.9 \times 10^{-5}\ m^3\ S^{-1} & \textbf{when}\ T_{co} \geq T_s + 3 \\ 0\ \ m^3\ S^{-1} & \textbf{when}\ T_{co} \leq T_s + 3 \end{cases}$$

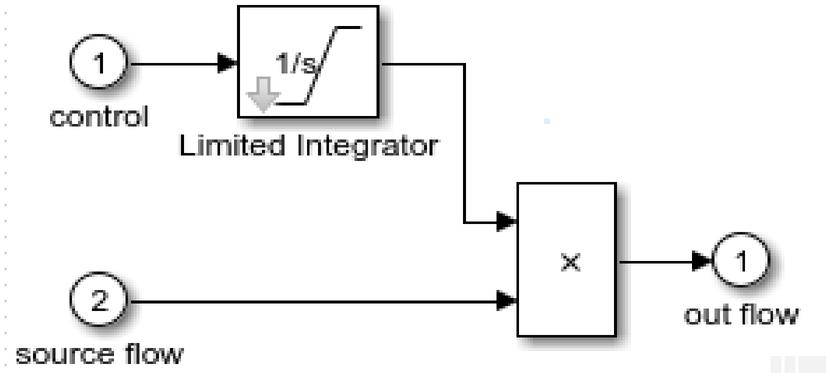


Auxiliary Electric Heater

The flow rate controller modeling

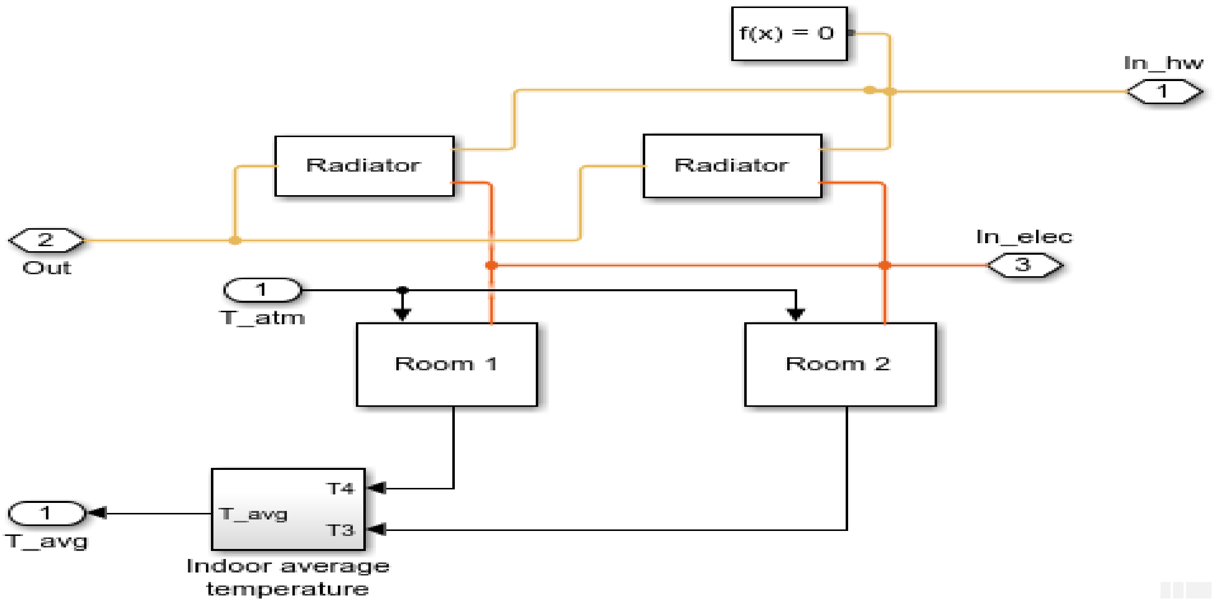
The Controlled Valve



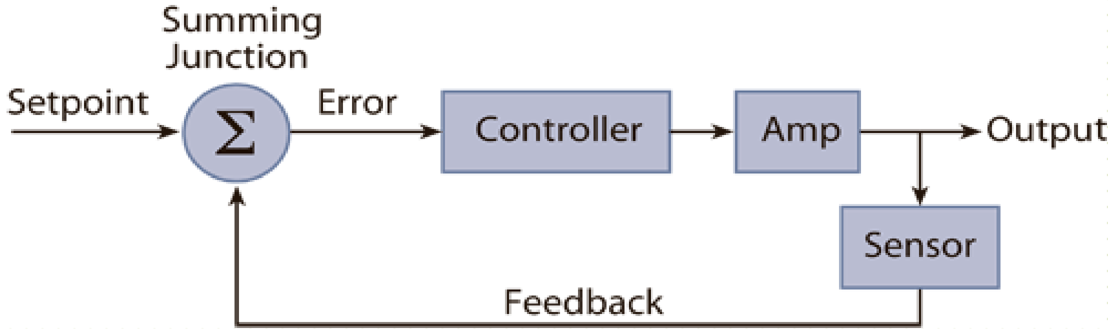


Mathematical Modelling of Solar Collector Based TES

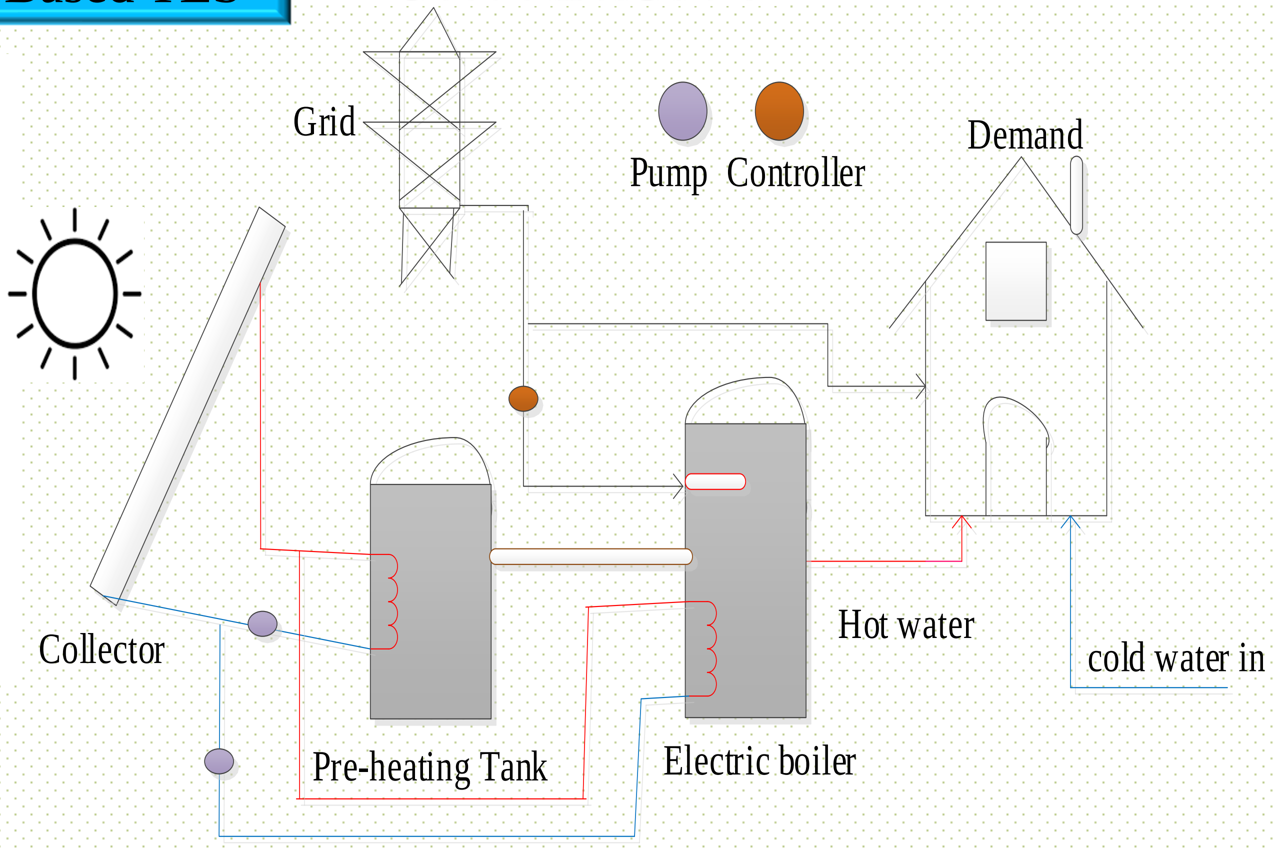
MEMORIAL UNIVERSITY
NSERC Energy Storage Technology Network



Radiator System Design Parameters: Chap. 4, Table 1



Thermostat (Matlab Programming)

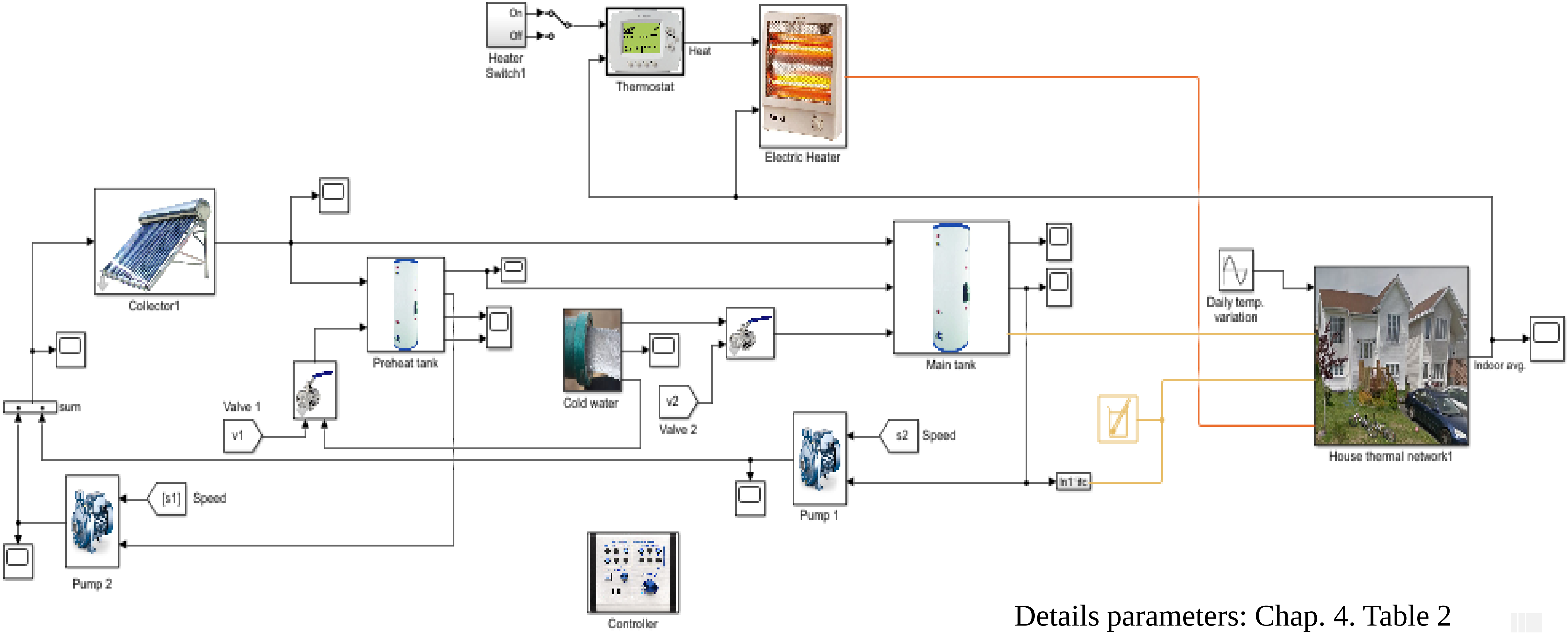


Full TES system

MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Mathematical Modelling of Solar Collector Based TES

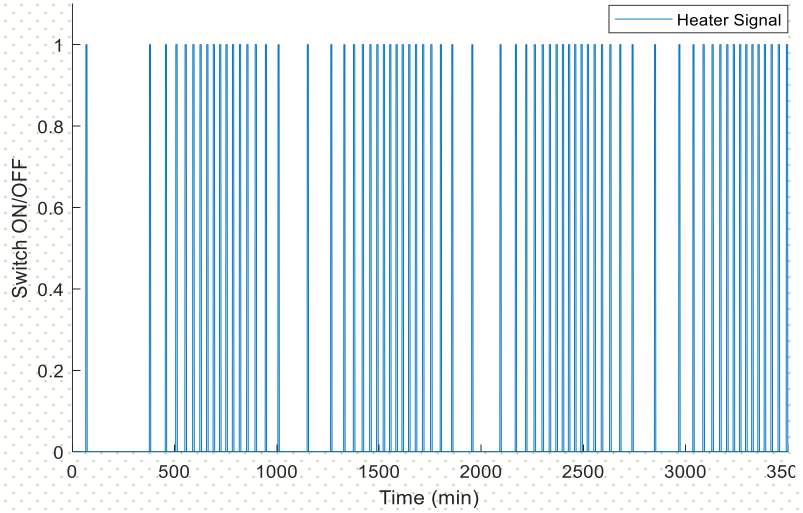


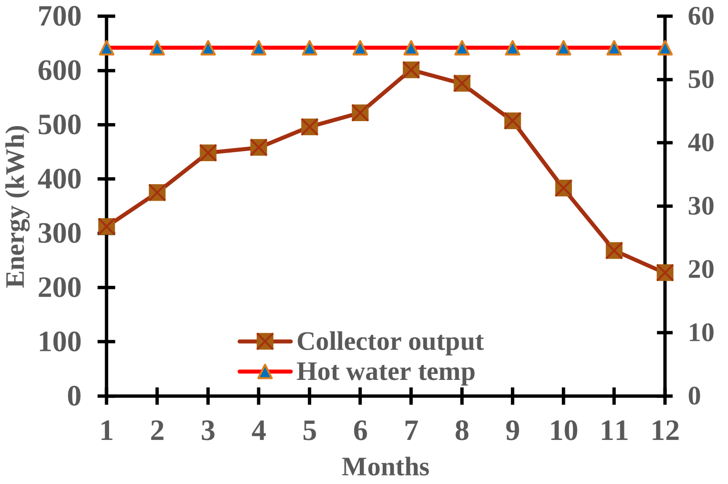
Details parameters: Chap. 4. Table 2

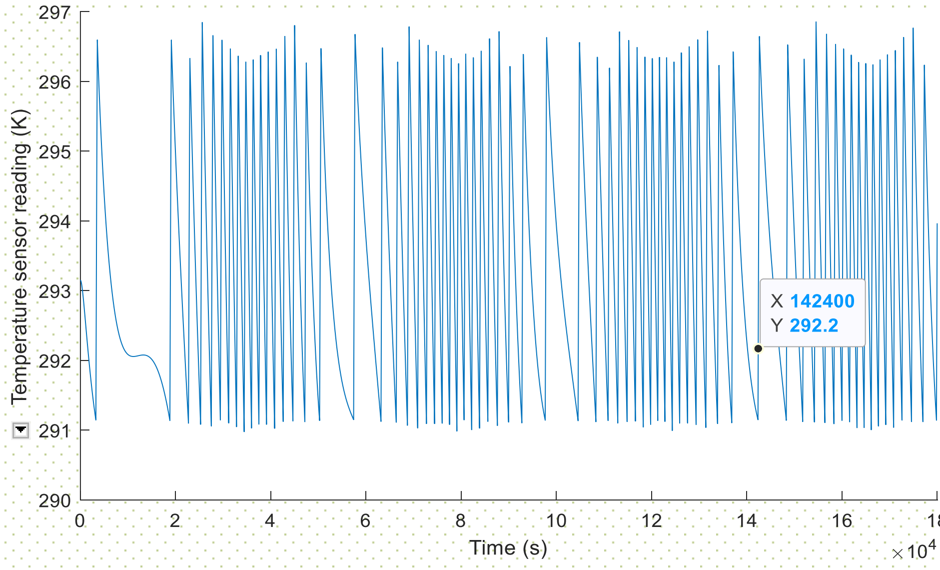
MEMORIAL UNIVERSITY

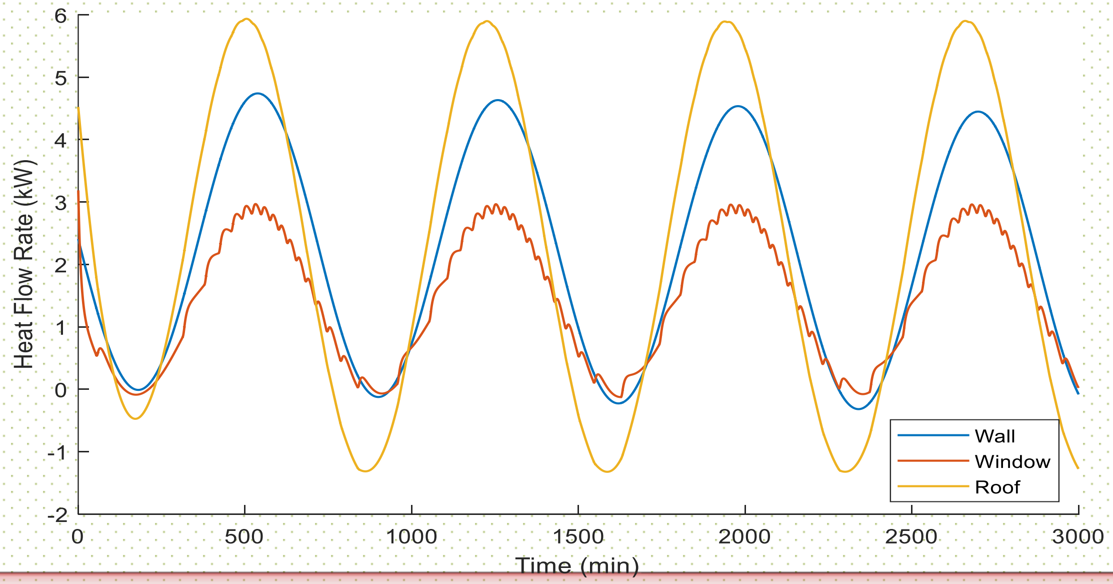
NSERC Energy Storage Technology Network

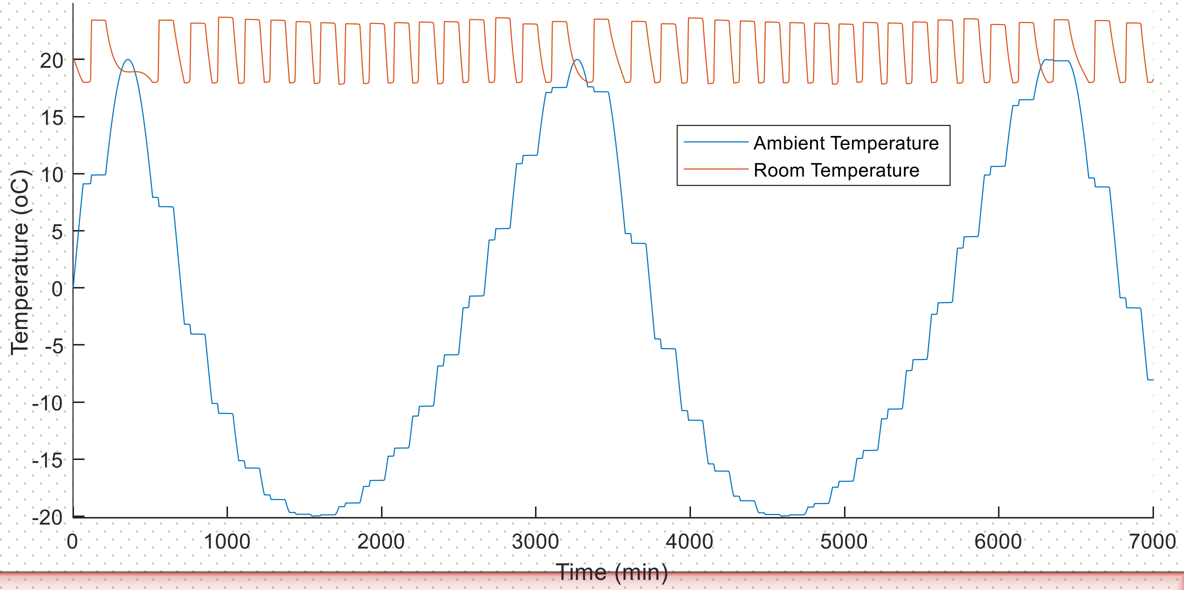
Mathematical Modelling of Solar Collector Based TES







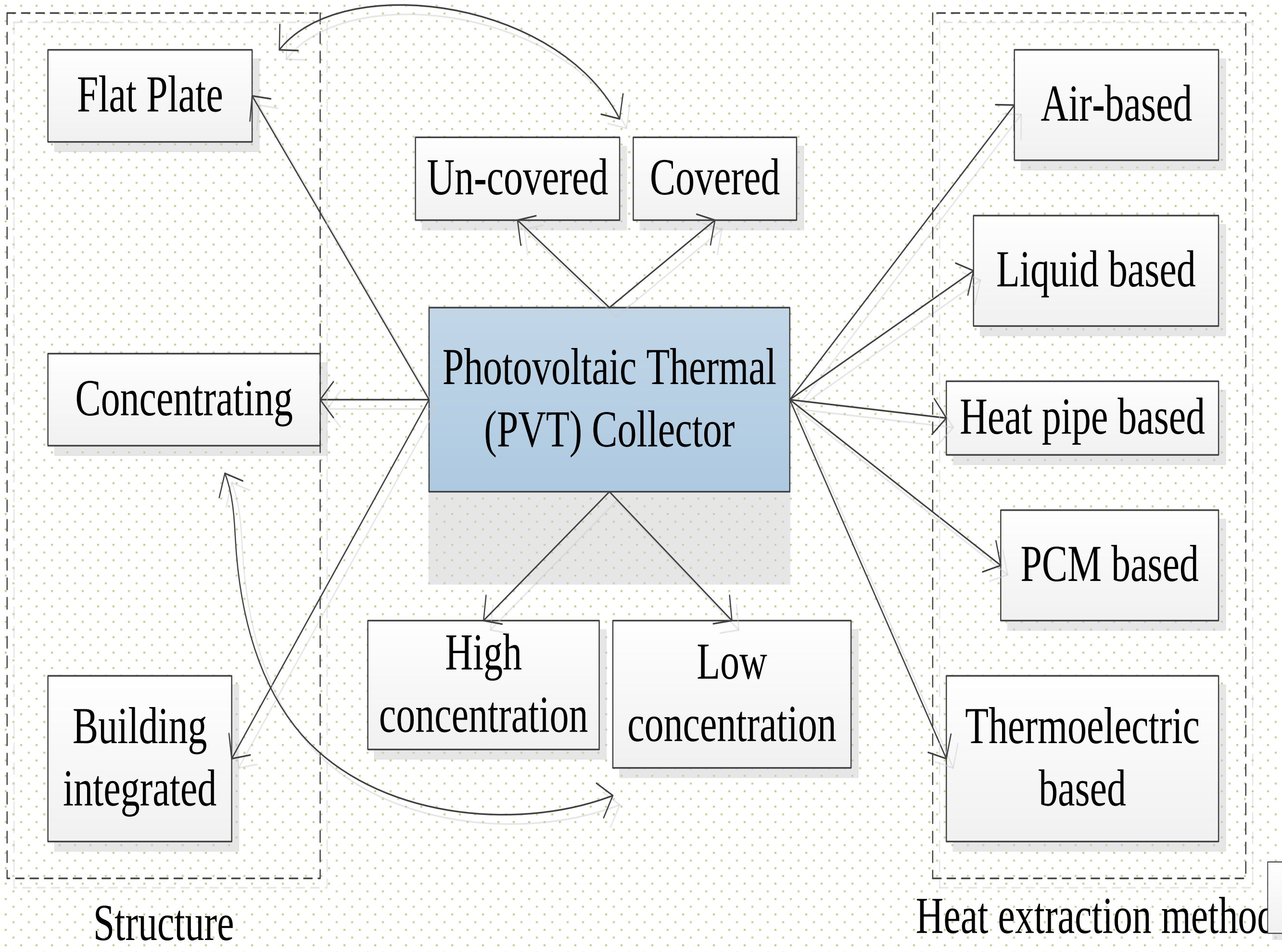


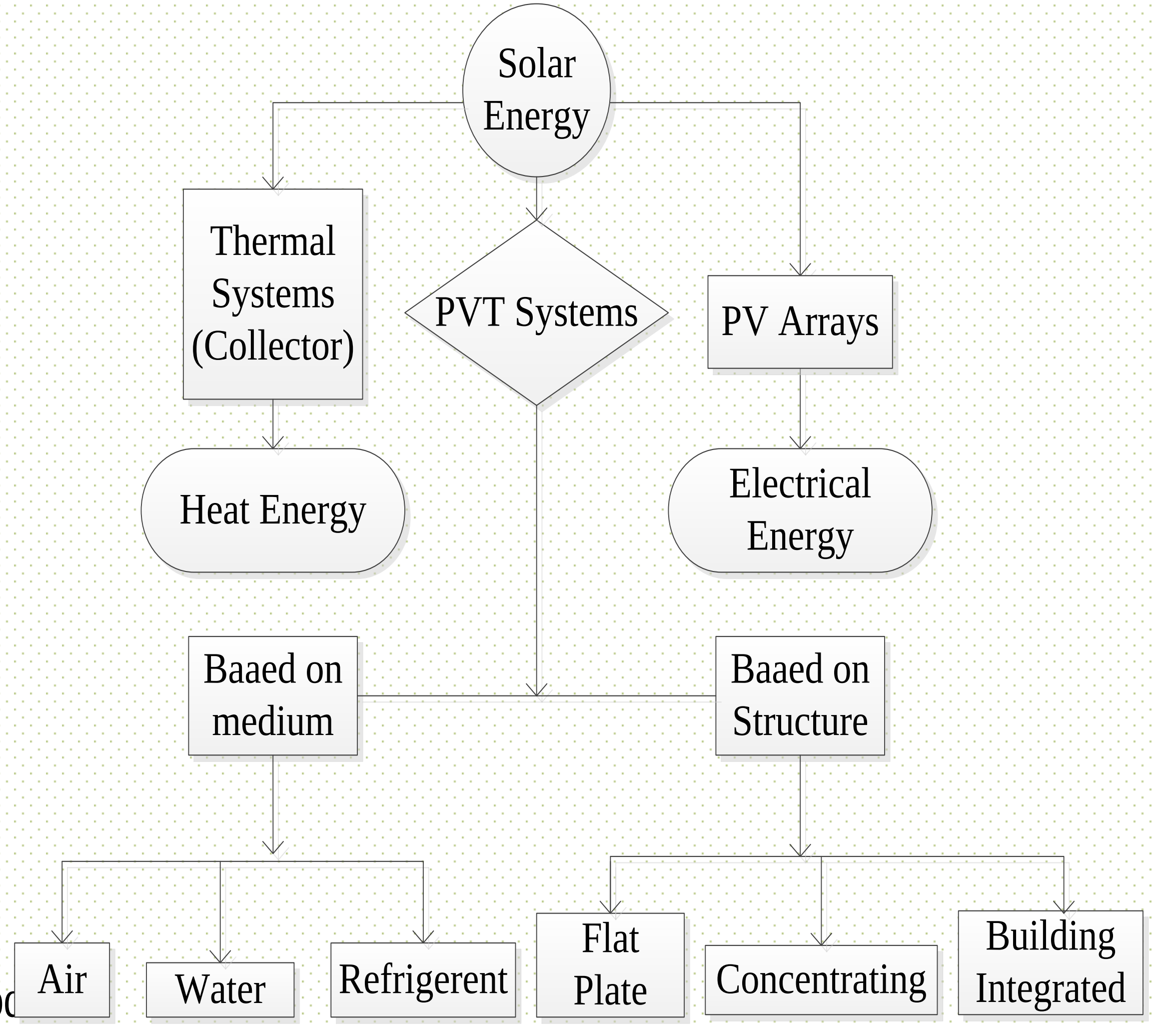


MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

PVT





Mathematical Modelling of PVT Based TES

$$\eta_{thermal} = \frac{Q_{useful-heat}}{I_x \times A_{collector}}$$

$$Q_{useful-heat} = \dot{m} C_p \Delta T$$

$$\eta_{thermal} = \eta_o - \alpha_1 \frac{\Delta T}{I_x}$$

$$Q_{electrical} = \frac{I_m \times V_m}{I_s \times A_{collector}}$$

$$\eta_{electrical} = \eta_o - \alpha_1 \frac{\Delta T}{I_x}$$

$$\eta_{total} = \eta_{electrical} + \eta_{thermal}$$

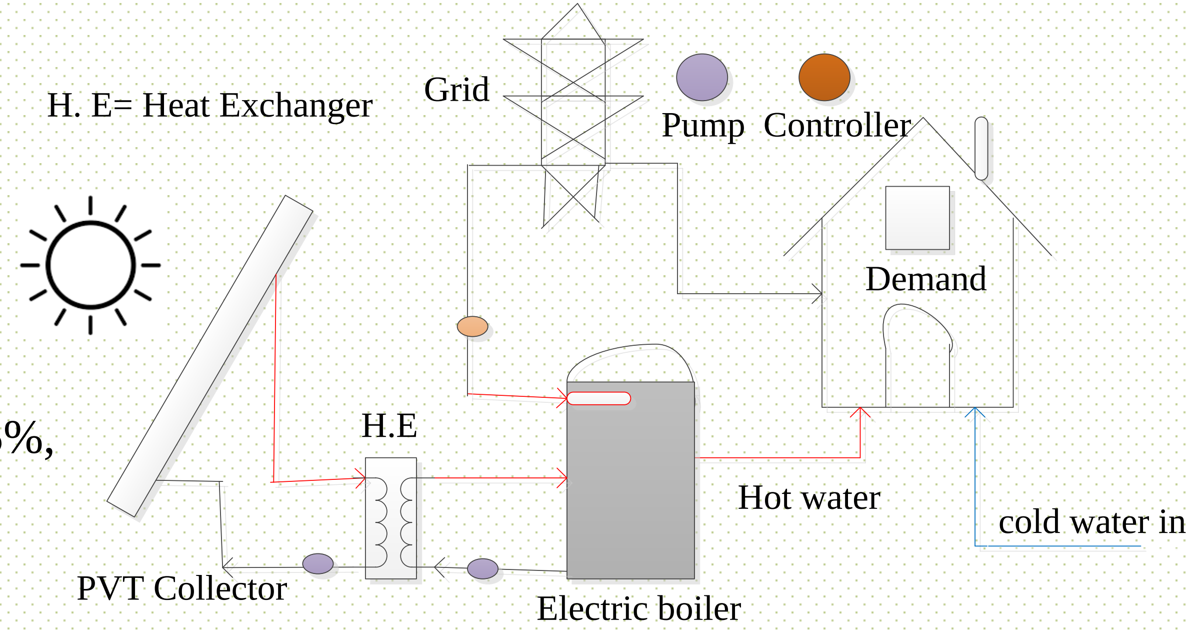
$E_{PV} = A_{PV} \times I_x \times \eta_{module} \times \eta_{inv} \times \eta_{wire}$ =14%, 90%, and 95%,

Solar radiation (I_x) in St. John's, NL is 3.06 kWh/m^2, $A_{collector}$ is the collector absorber area which is 16 m^2

The thermal efficiency of a glazed and unglazed PVT collector is about 48% and 35%,

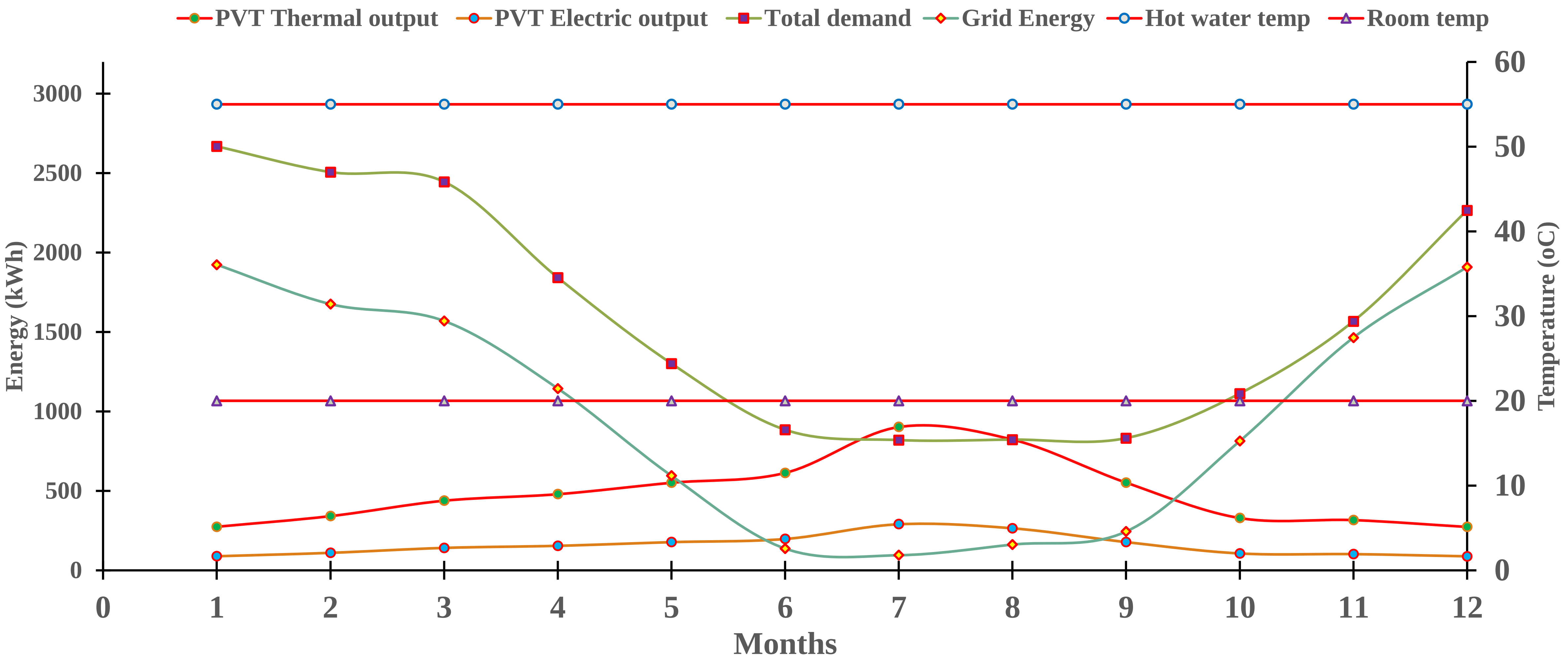
The electrical efficiency of a glazed and unglazed PVT collector is about 11.5 and 13.4%

Total efficiency of glazed and unglazed PVT collectors is 59.5% and 48.4%,



Details parameters: Chap. 4. Table 3

Mathematical Modelling of PVT Based TES



MEMORIAL UNIVERSITY
NSERC Energy Storage Technology Network

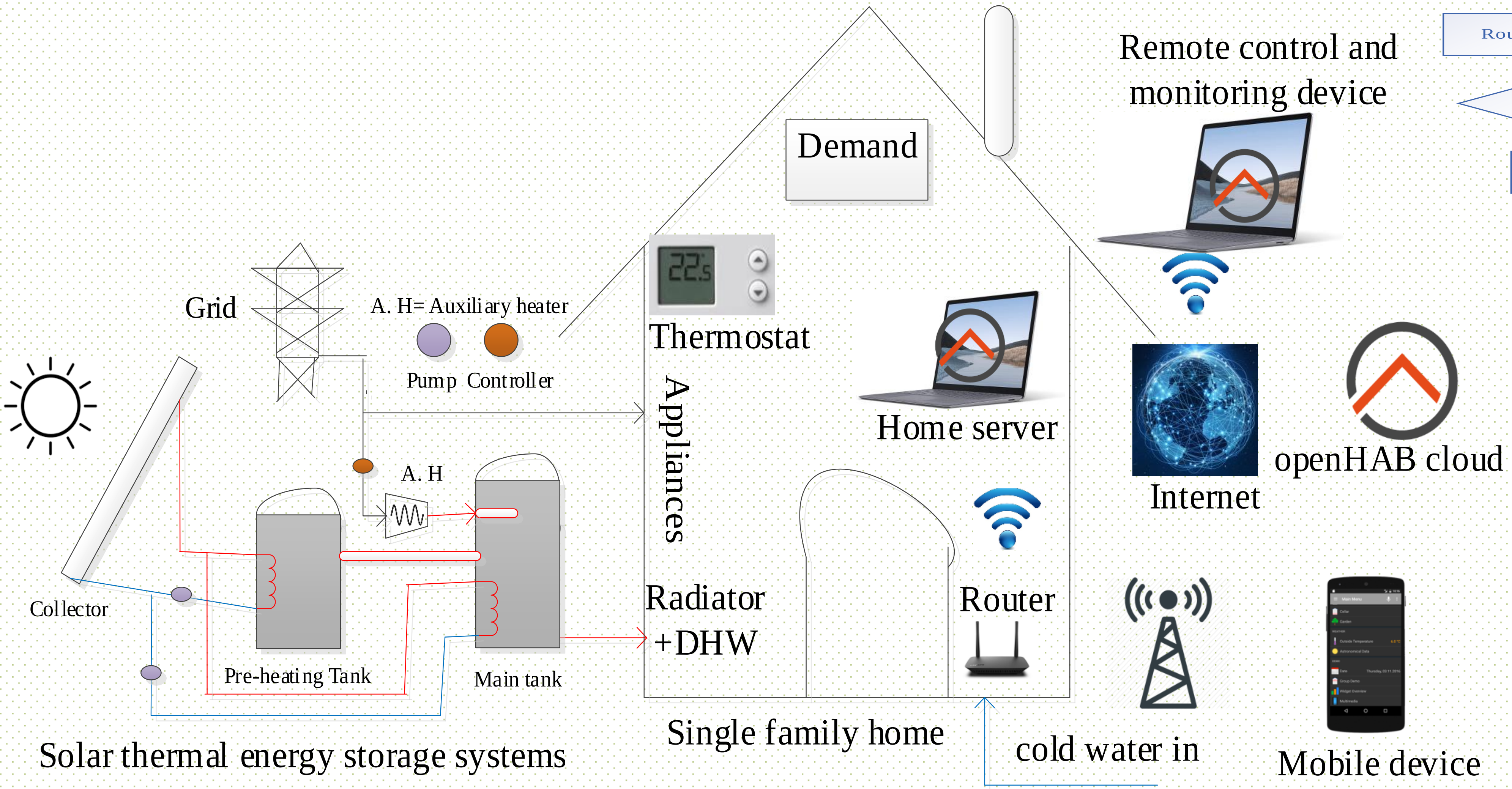
Available Technology in the Market

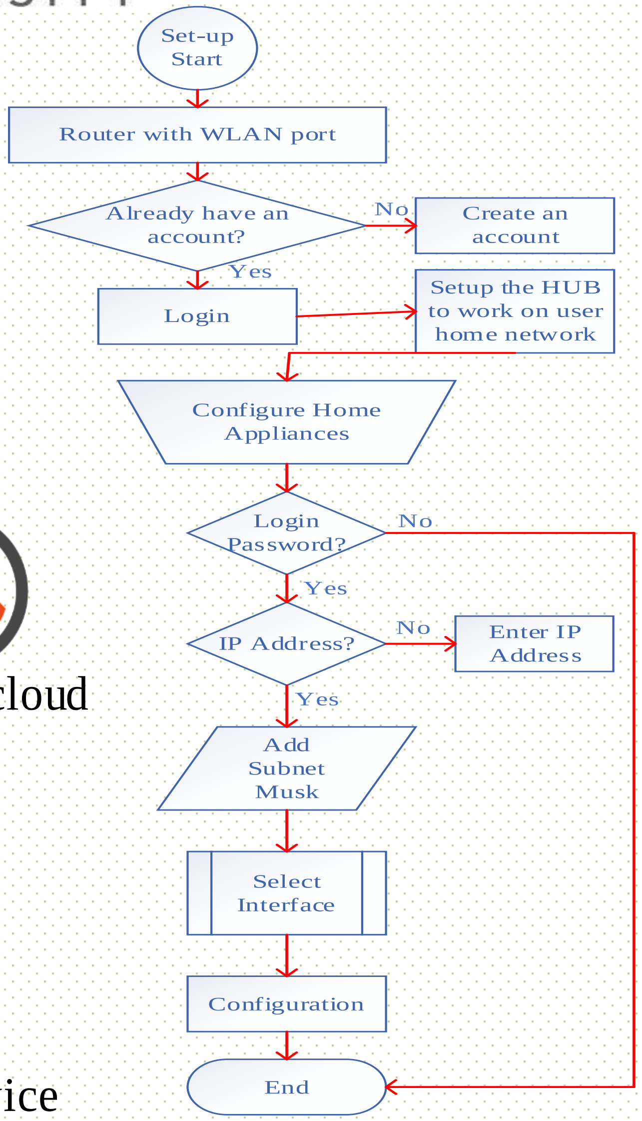
Thermostat Name	Price	Pros	Cons
Google Nest	$329	Smart way to control 3rd Gen are available Support multi-stage, multi-zone Local/Remote control	Customer can not increase the number of channels The development control is with Google team
Honeywell	$149	Local/Remote control digital screen, the humidity, temperature, and thermostat settings options are available	It does not include the wall plate for installation, wiring is too complicated. it is a non-programmable device
ecobee	$229	Compatible with temperature and humidity sensors Local/Remote control	it has only one temperature sensor and two occupancy sensors build in at Ecobee4 systems

NSERC
Energy Storage
Technology Network

MEMORIAL UNIVERSITY

System Architecture

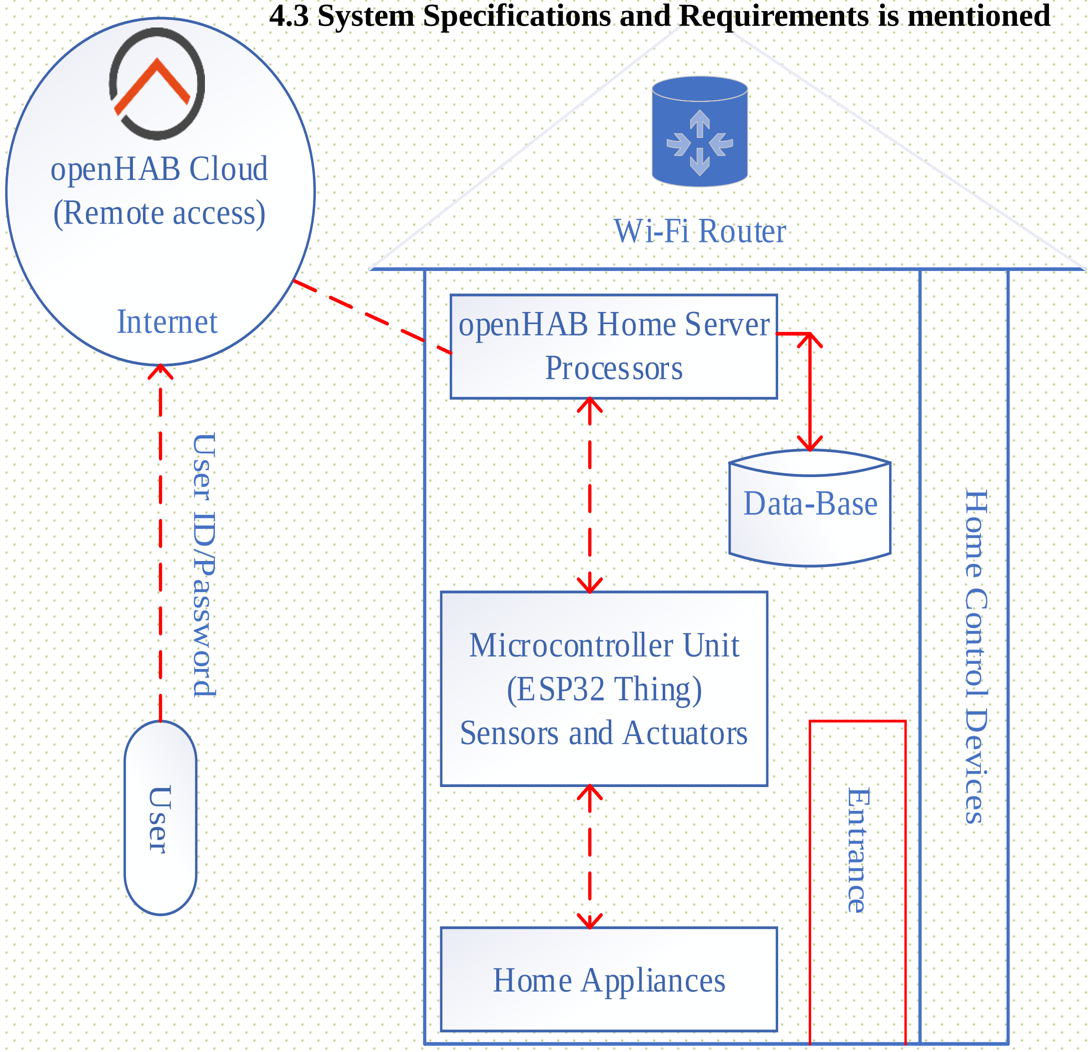




MEMORIAL UNIVERSITY
NSERC Energy Storage Technology Network

Overview of System Development

4.3 System Specifications and Requirements is mentioned



Components Description

5.1 openHAB Home Automation Local Server IoT Platform

5.2 DHT11 Digital Temperature Sensors

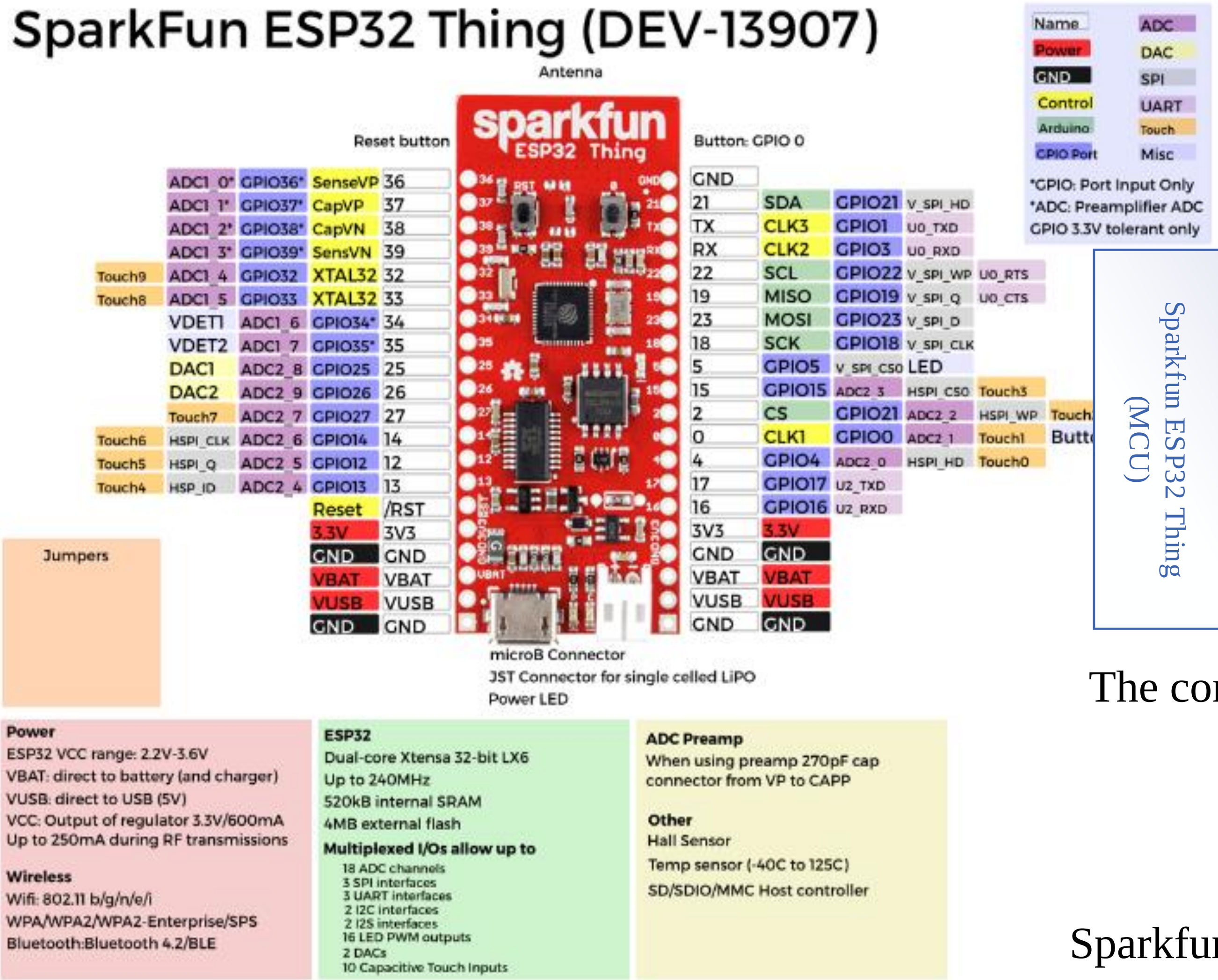
5.4 Wi-Fi Router (Communication Channel)

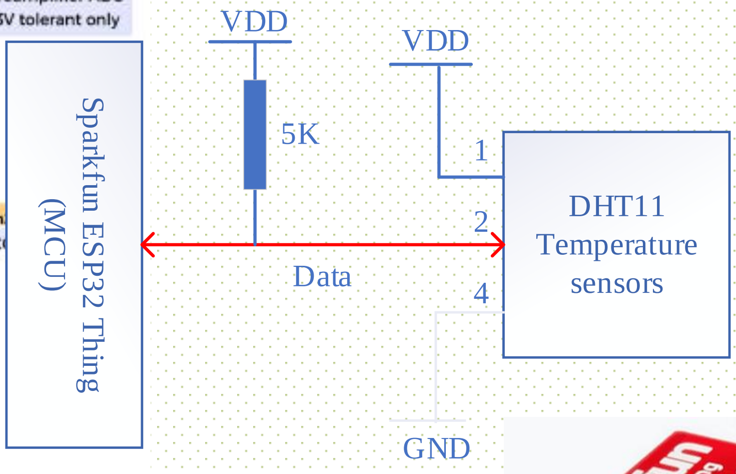
5.5 Digital Thermostat and Heater

MEMORIAL UNIVERSITY

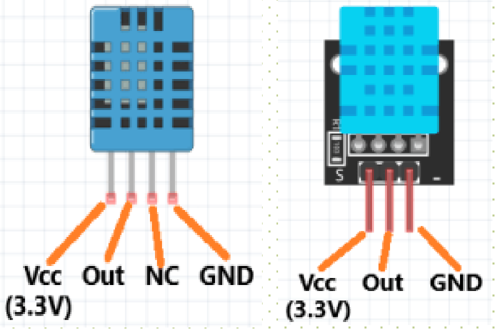
NSERC Energy Storage Technology Network

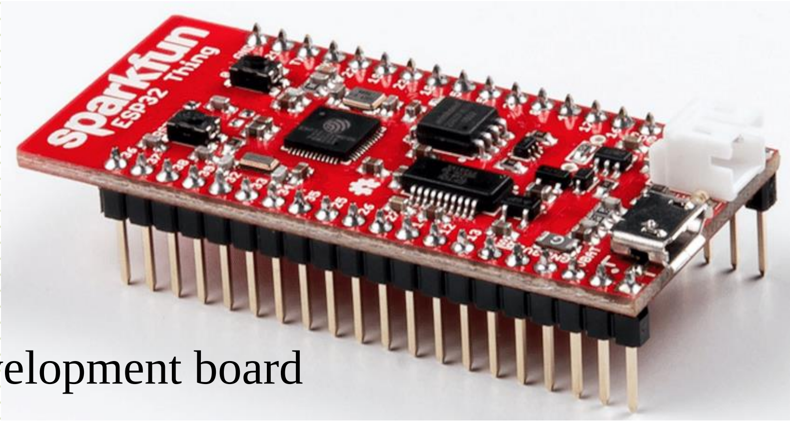
Architecture and Connection of the ESP32 Thing board





The connection diagram





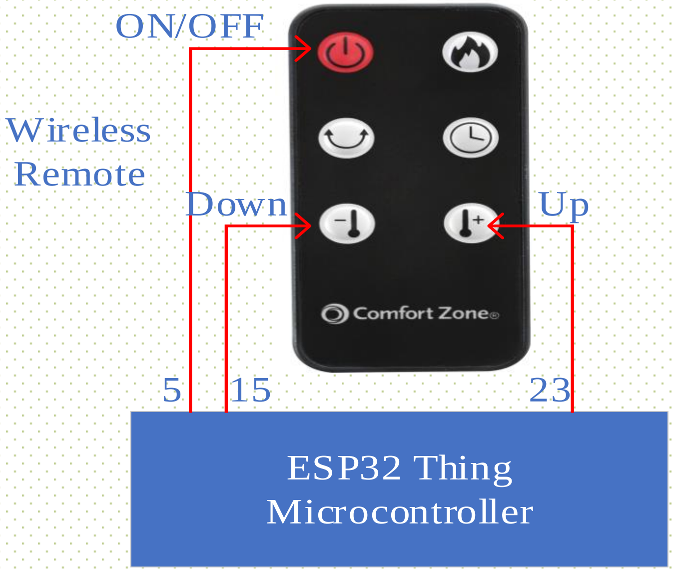
Sparkfun ESP32 Thing development board

NSERC
Energy Storage
Technology Network

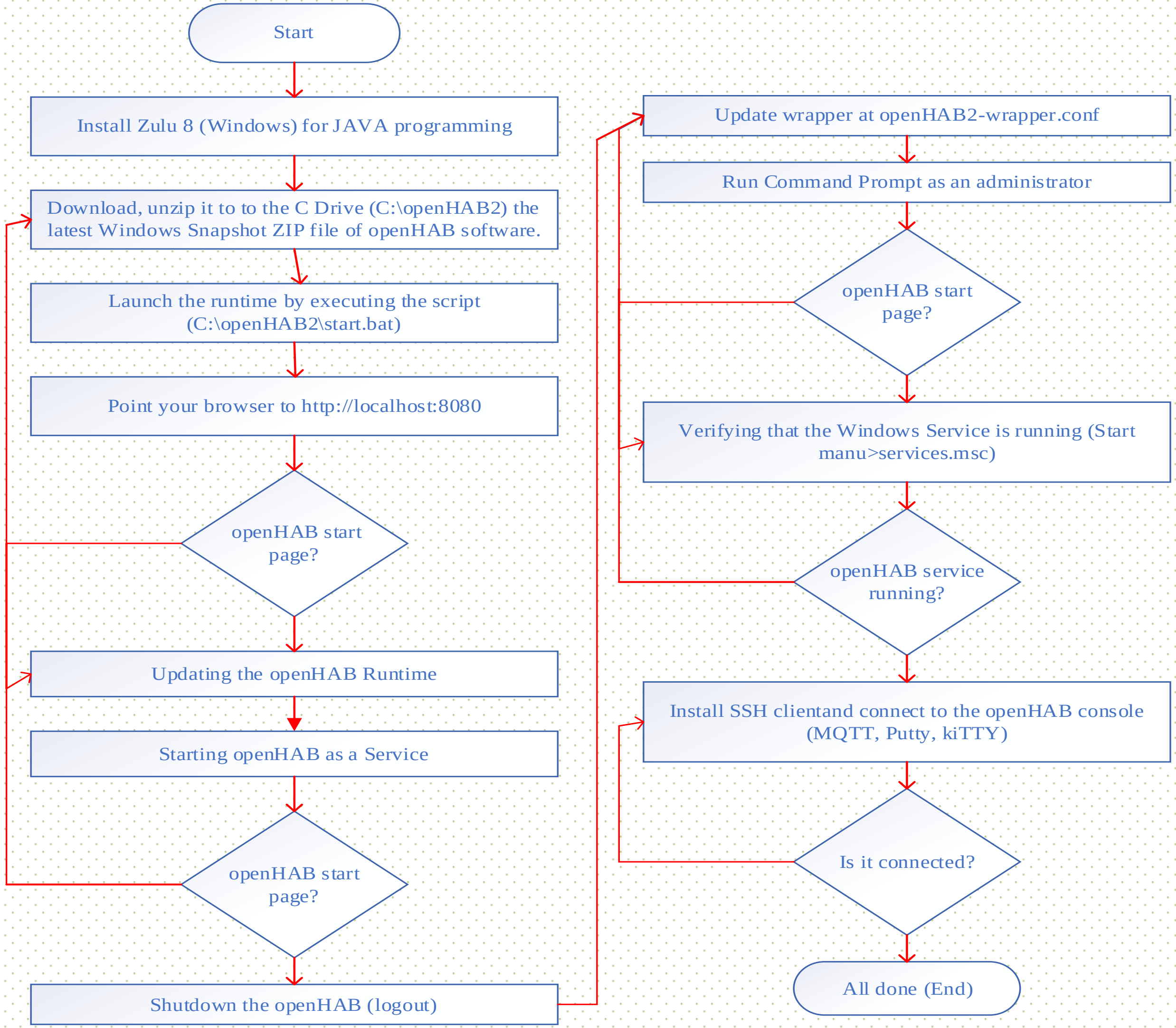
Available Technology in the Market

Model: Comfort Zone CZ523RBK

Thermostat settings



Connection diagram of remote and ESP32 Thing



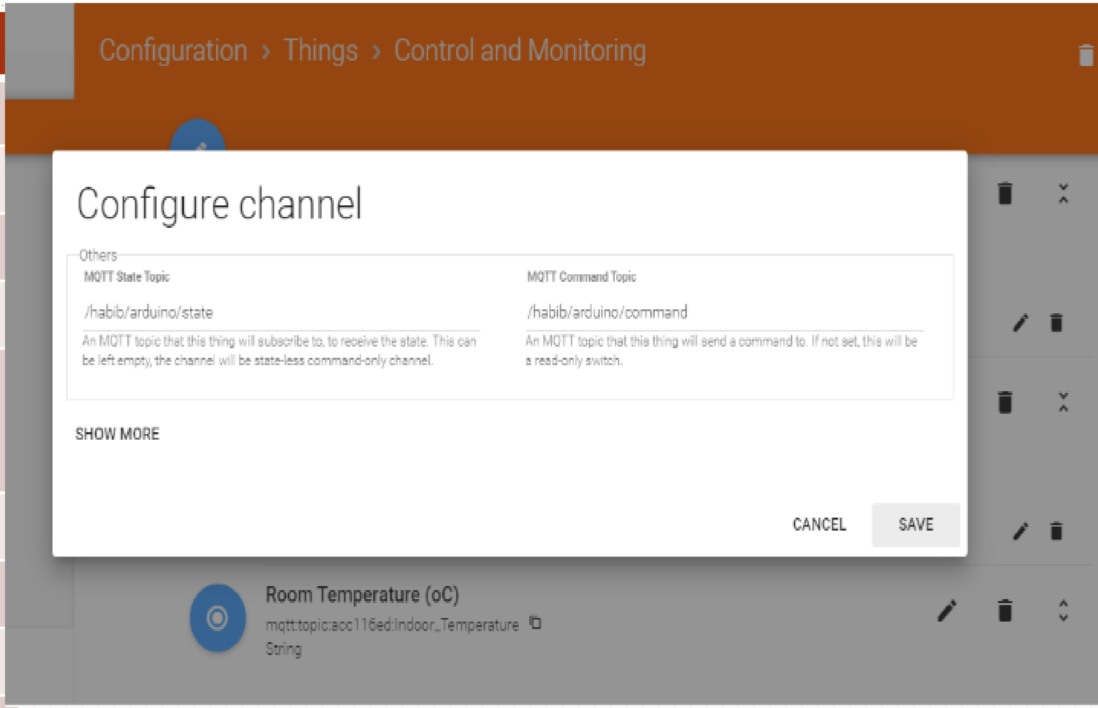
openHAB Setup and JAVA Programming

MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

openHAB Configuration

openHAB components	Short descriptions
Add-ons	To communicate with connected devices
Things	Device representation in openHAB
Items	Things properties and capabilities
Groups	Items collections and categories
Sitemaps	User-defined interface to arrange groups, items, and so on.
Transformations	Functions to transform user data.
Persistence	Store updated data service
Rules	It is used to automate the systems.
Javascript	Define rule and other runtime objects using Java programming.

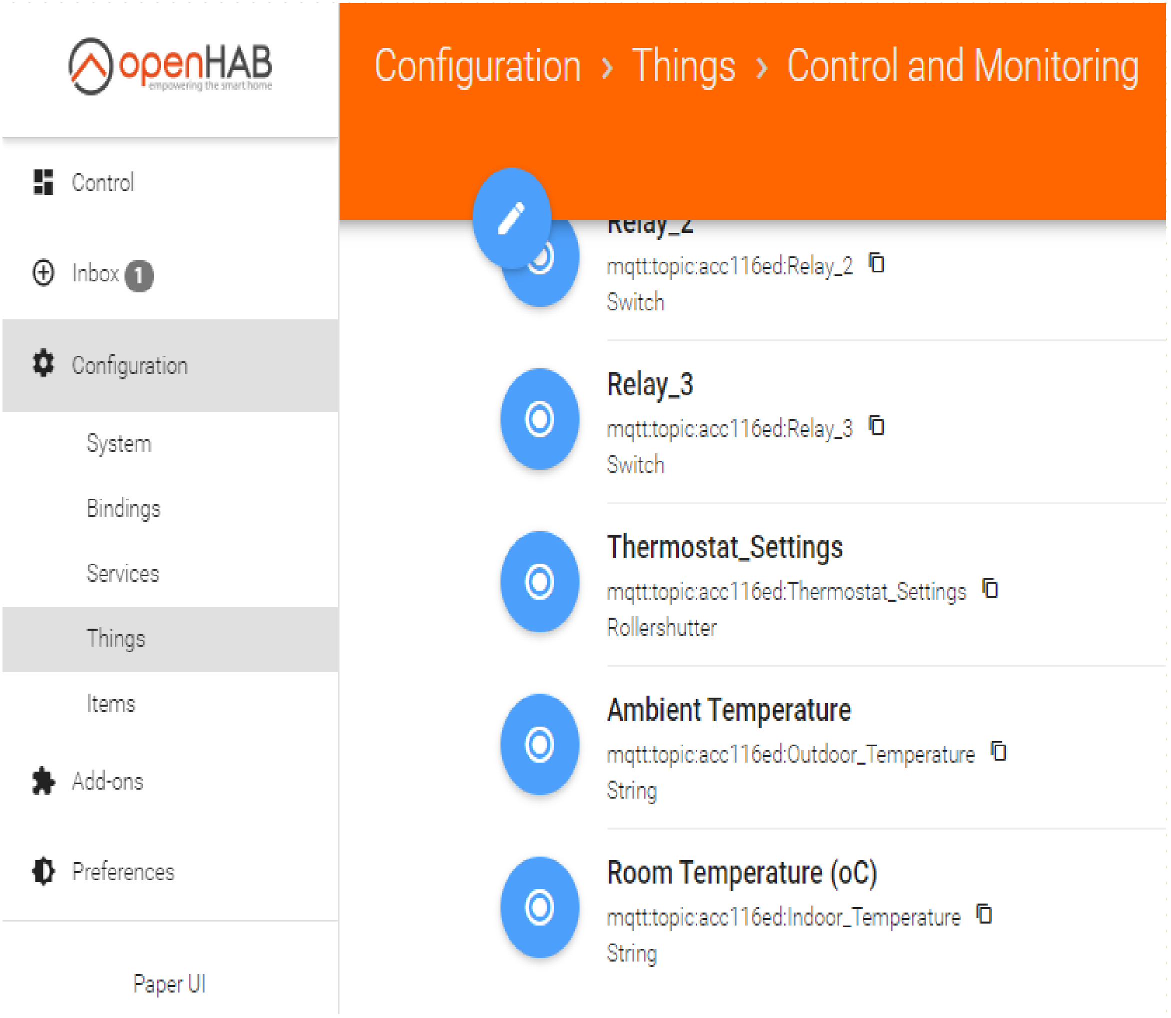


openHAB and MQTT Configuration

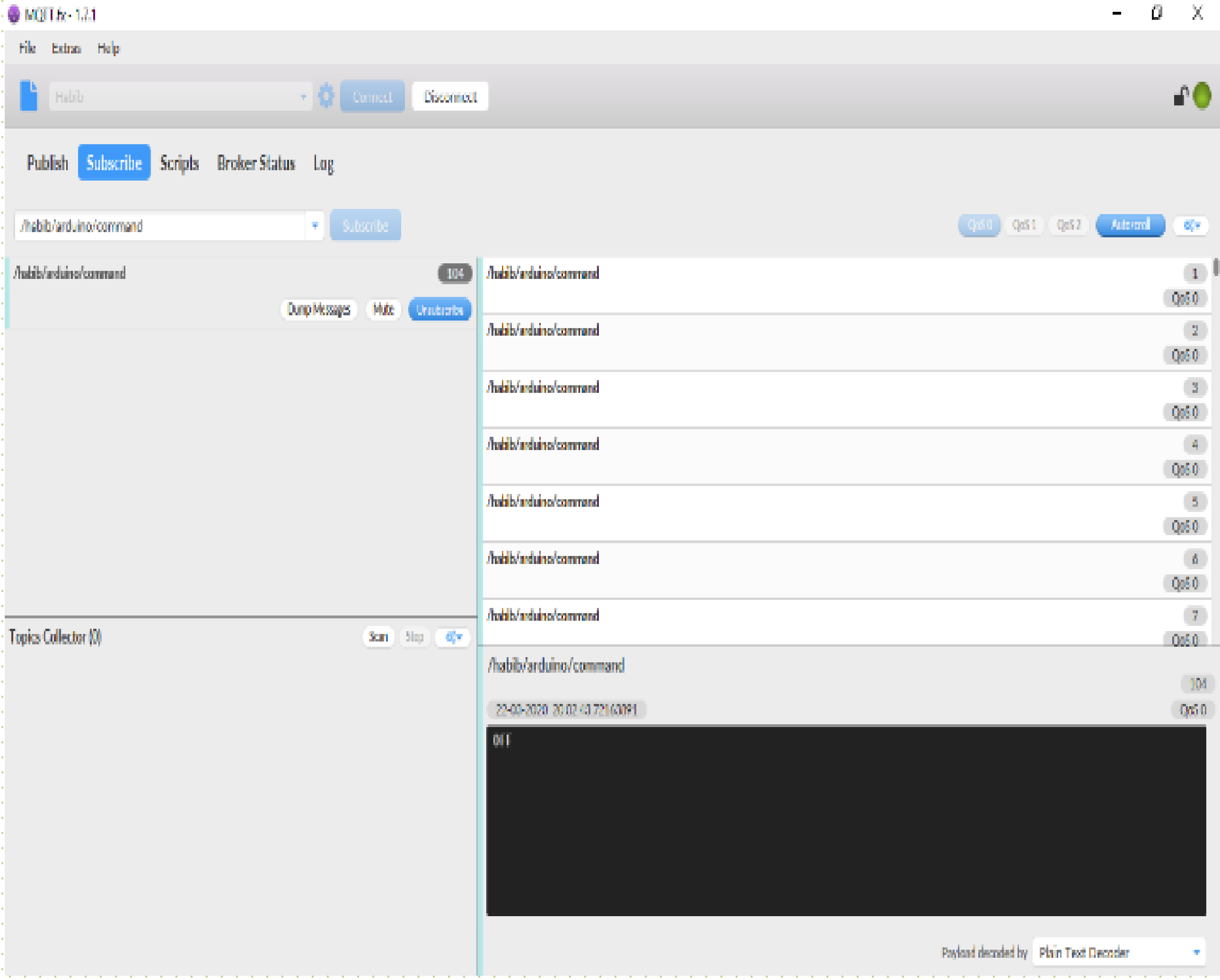
MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Communication Mechanism



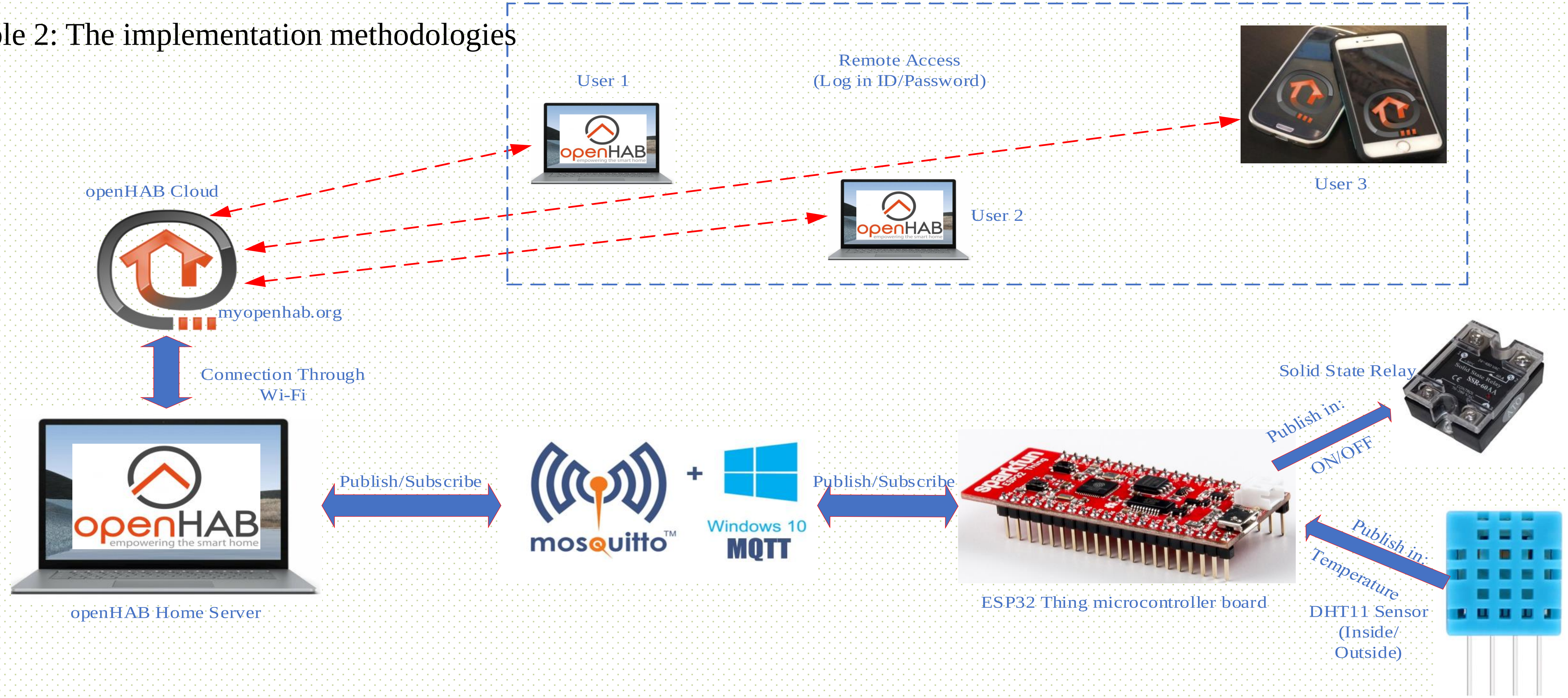
The relation between Things and Items.



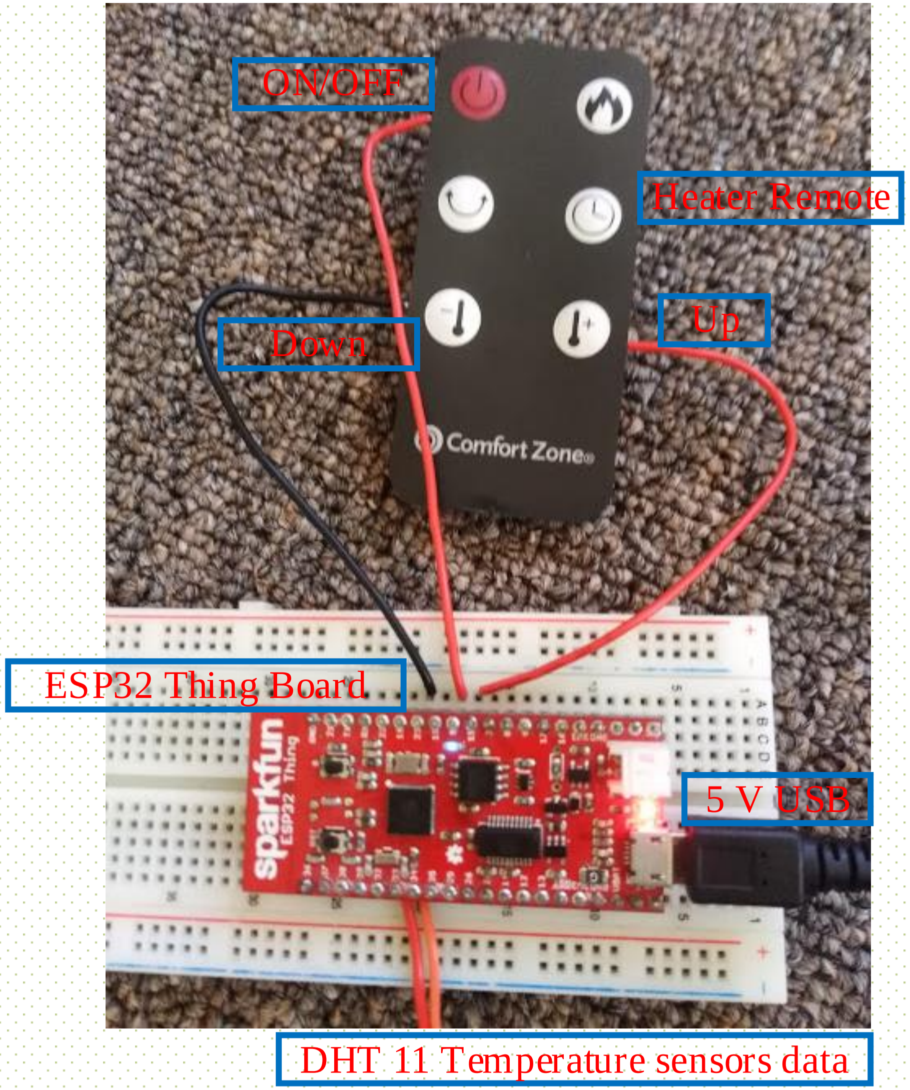
openHAB home server and ESP32 Thing communication via MQTT broker

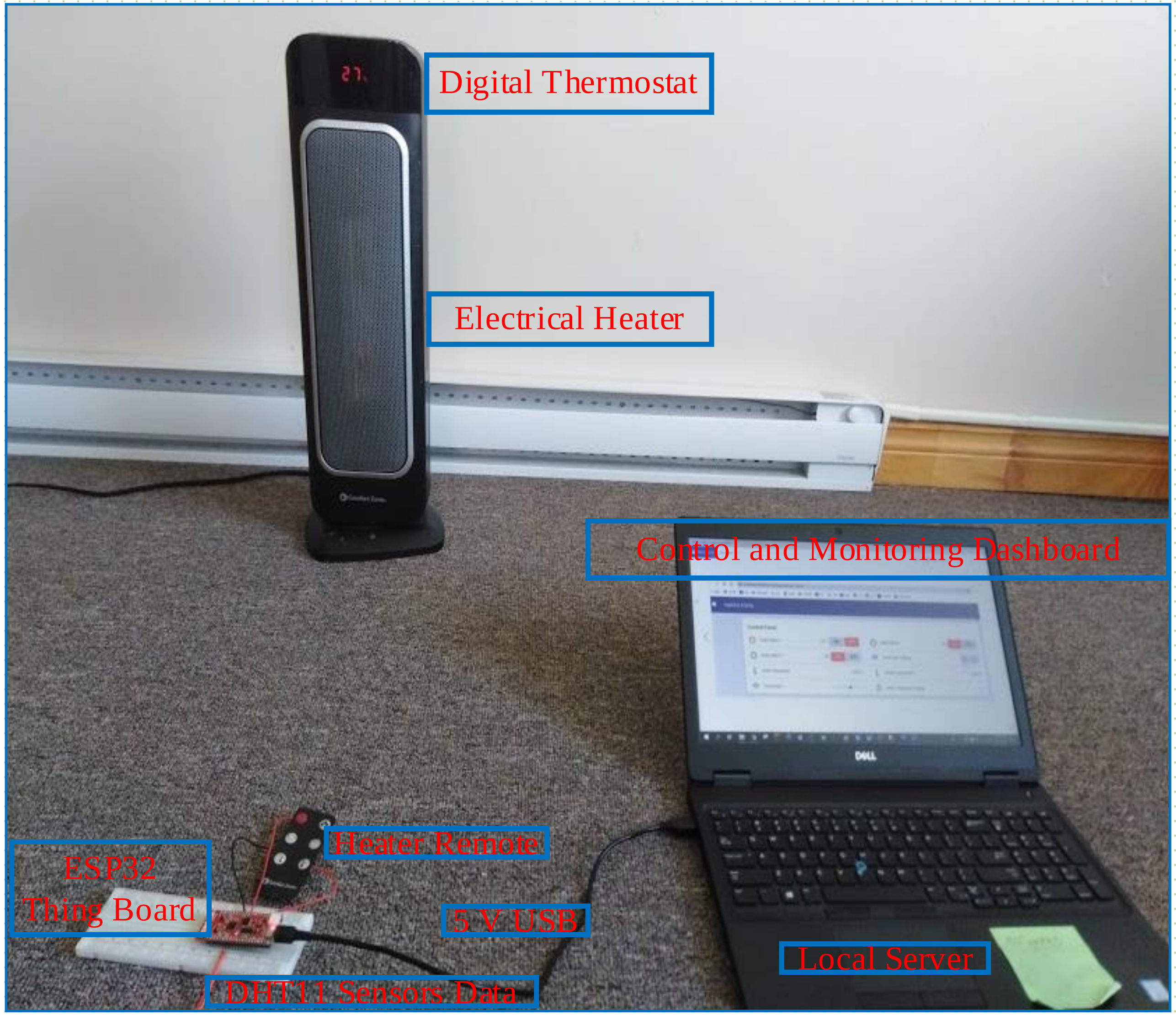
Communication Mechanism

Table 2: The implementation methodologies



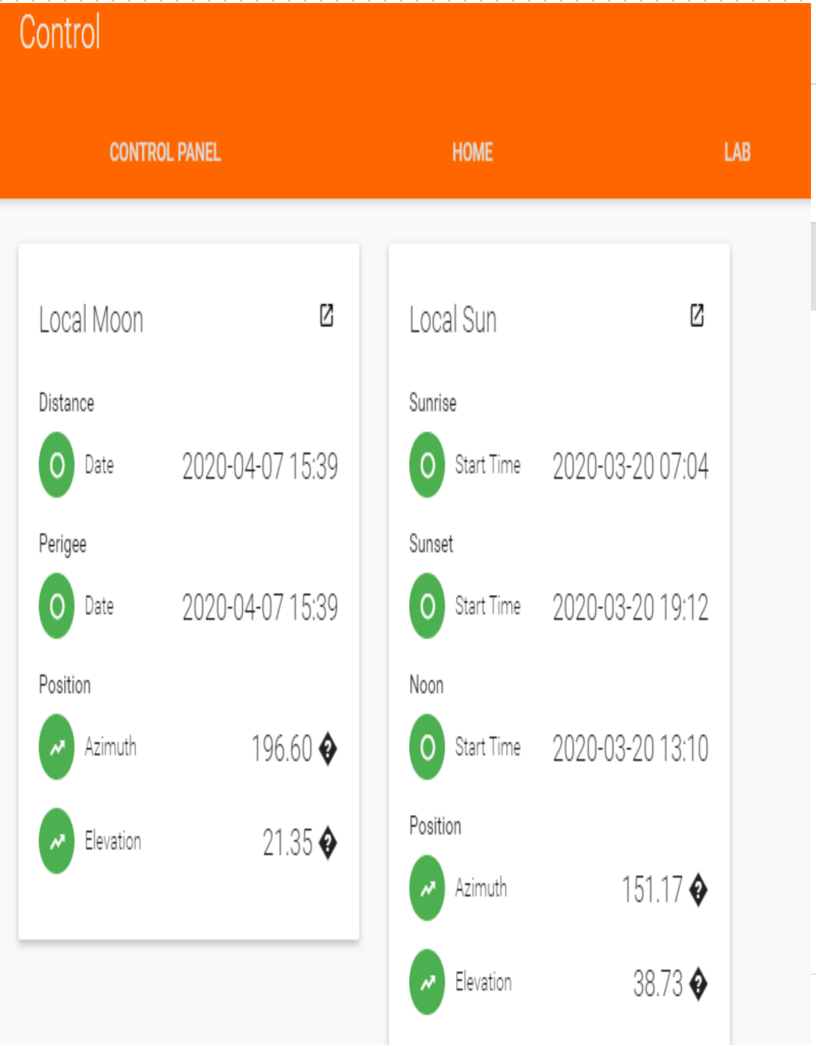
Experimental Setup

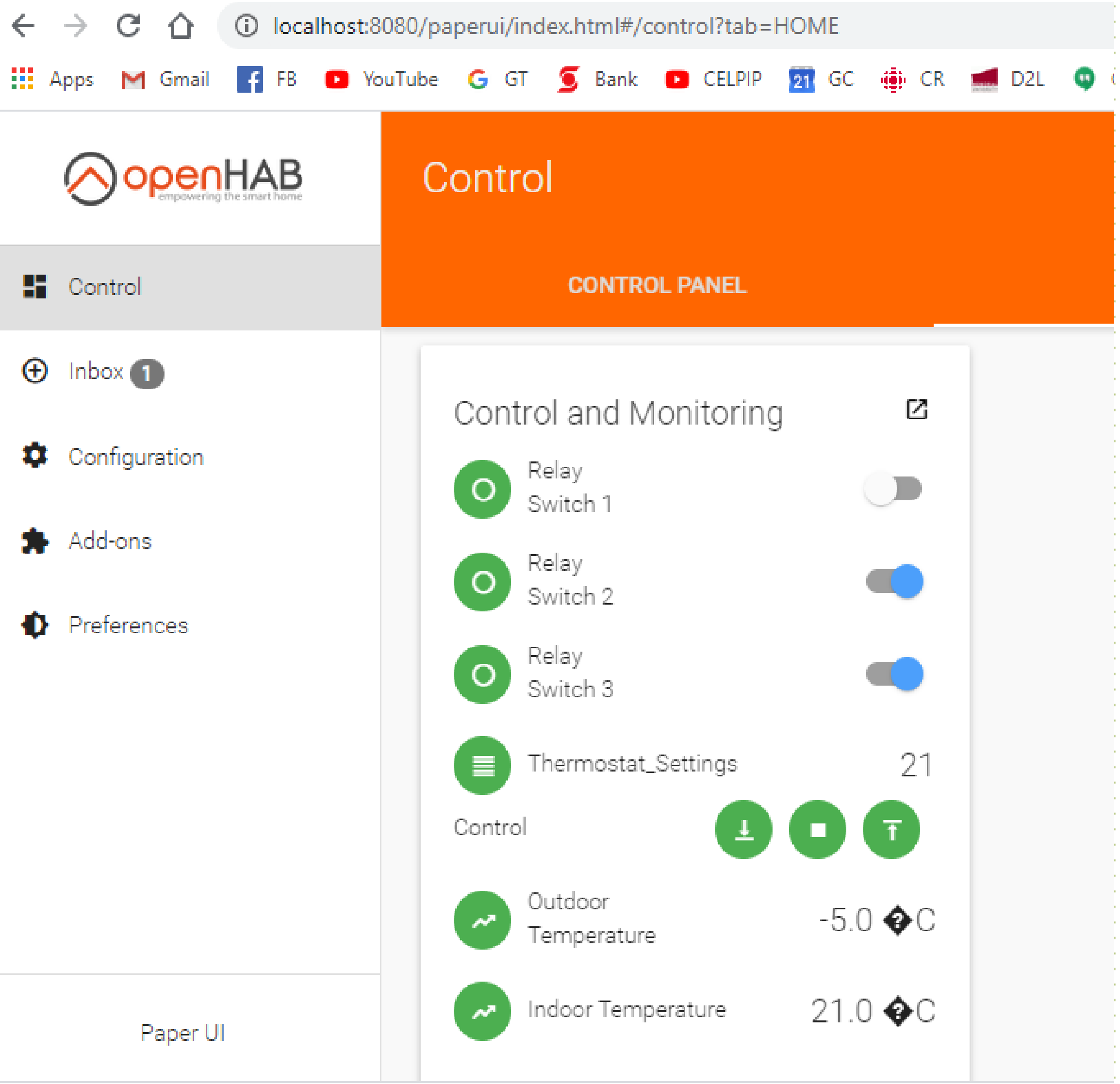


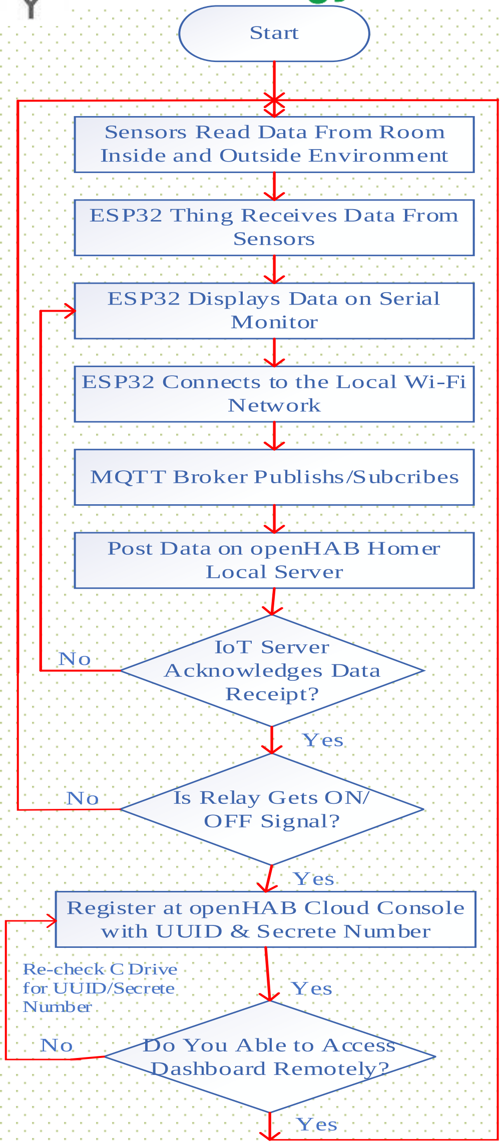


MEMORIAL UNIVERSITY
NSERC Energy Storage Technology Network

 Testing

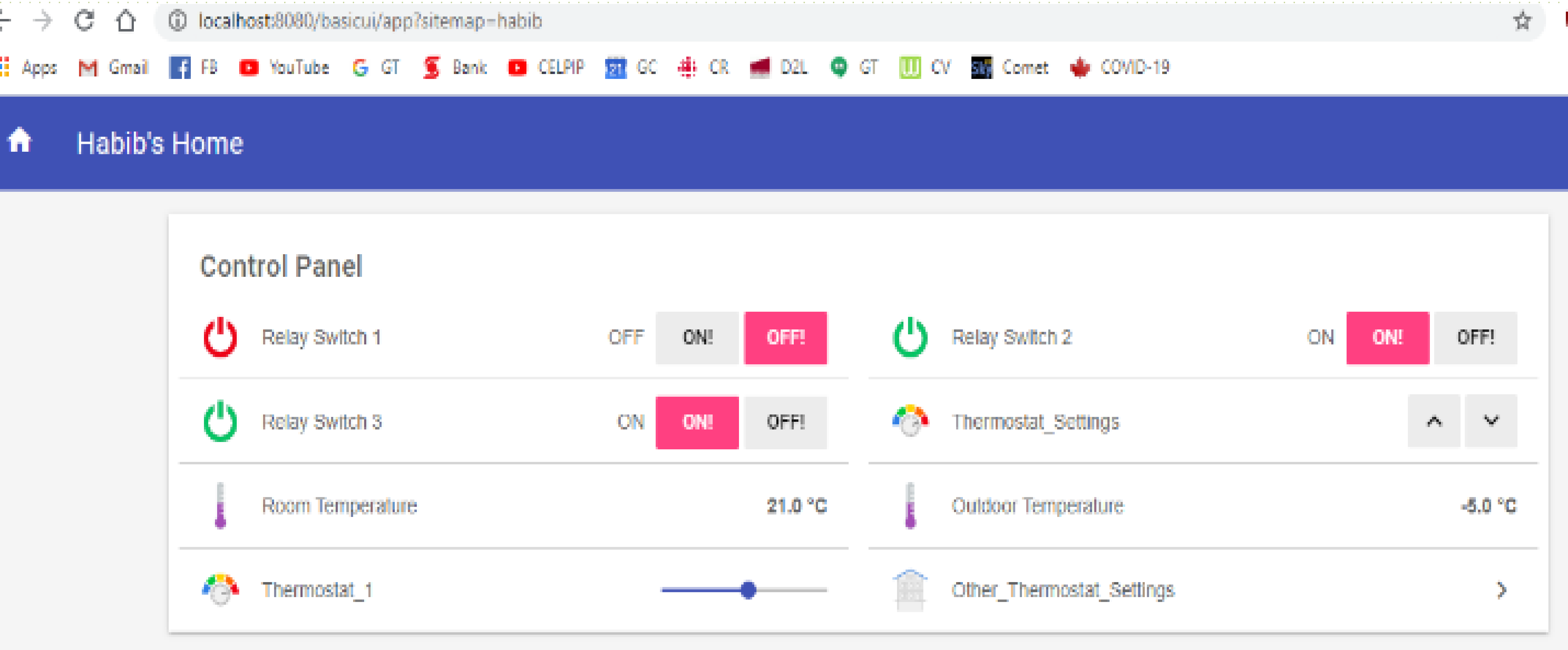






NSERC Energy Storage Technology Network

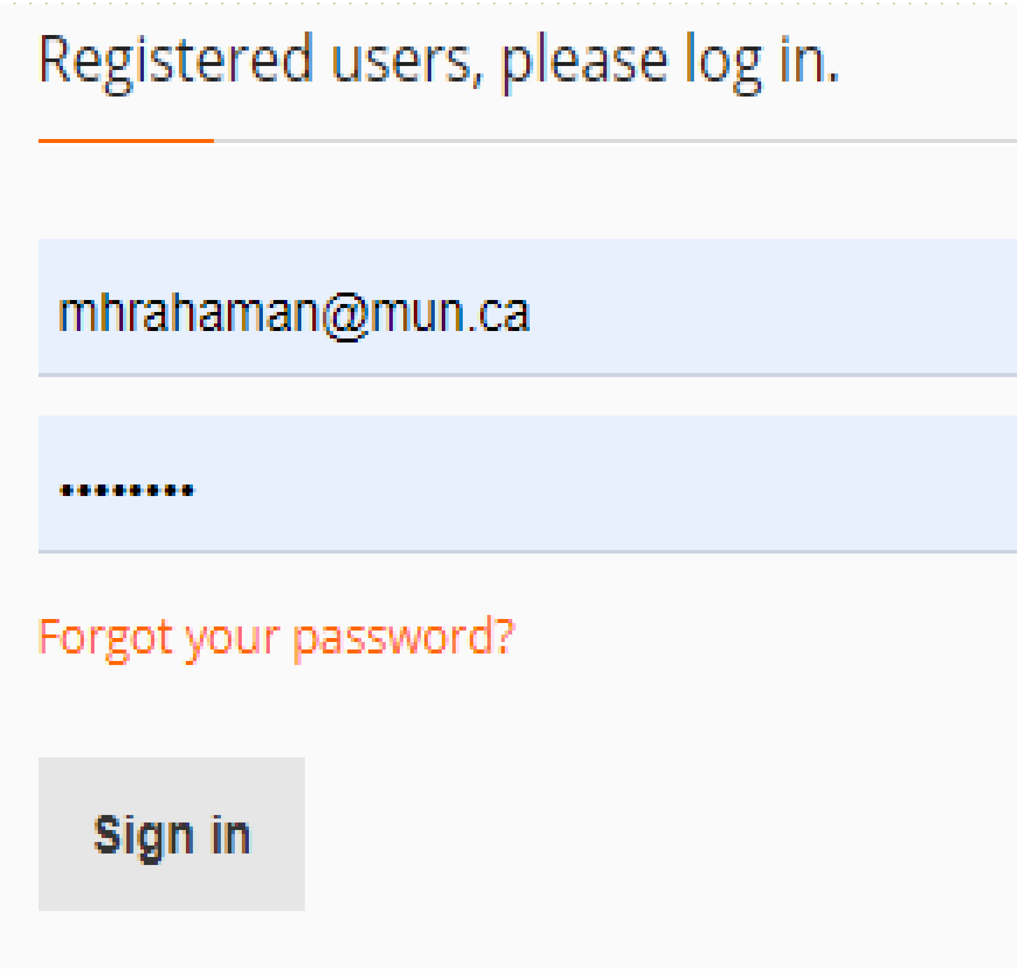
Main control and monitoring dashboards

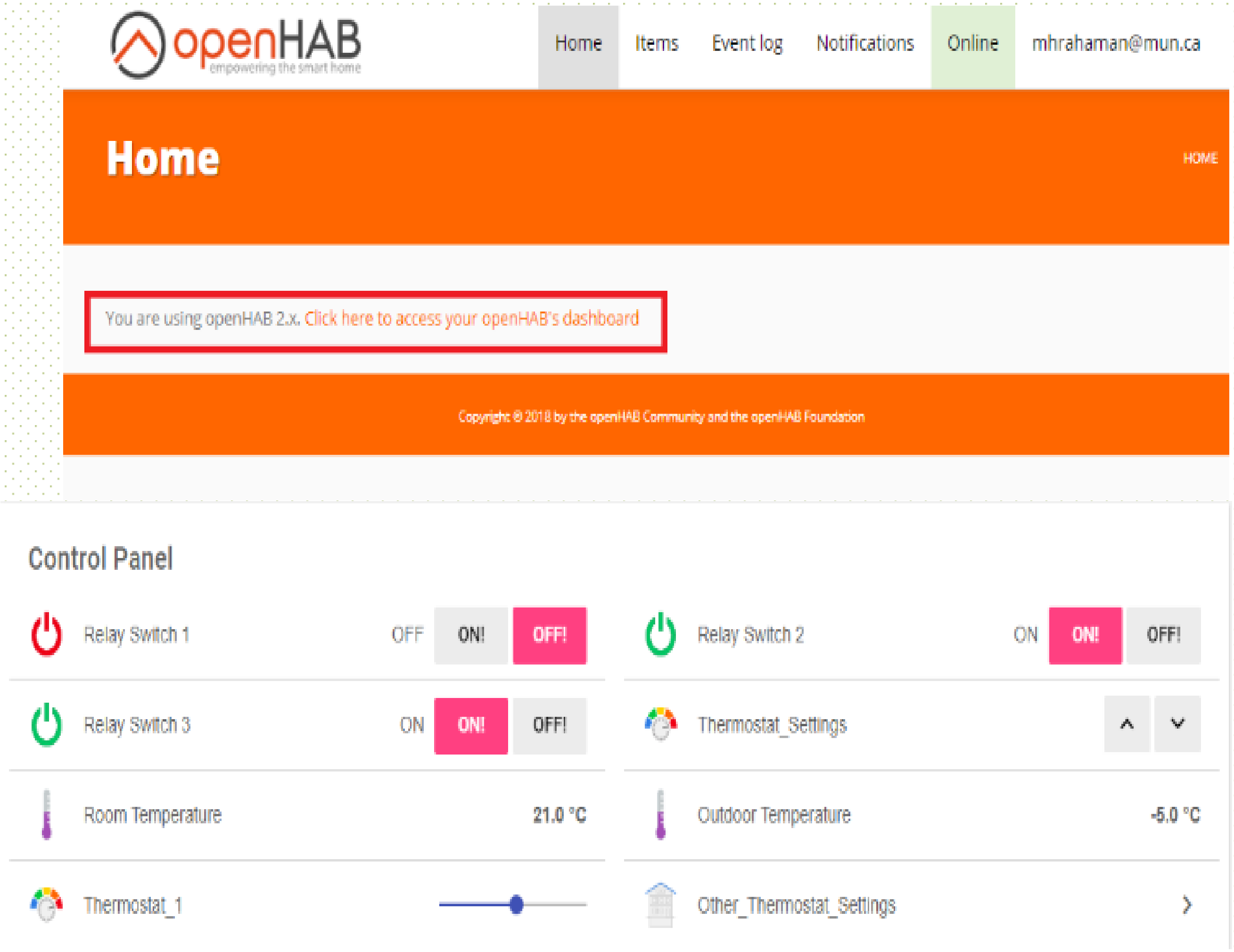


NSERC Energy Storage Technology Network

Remote Control and Monitoring

https://myopenhab.org/login or openHAB App





MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Proposed System Features

S/N	Name of the components	QTY	Price (CA$)
1	ESP32 Thing	1	31.90
2	TMP35 temperature sensors	2	2
3	DHT11 Temperature sensor	2	2
4	Miscellaneous (Breadboard, Resistors, Wires, Boxes, etc.)	1	10
	Grad total:		45.9

S/N	Hardware	Power (W)
1	ESP32 Thing	0.5
2	Breadboard (with Sensors, ESP32, Resistors, etc. connected)	3.3
	Total:	3.8 W

Available product features

Thermostat Name	Price	Pros	Cons
Google Nest	$329	Smart way to control 3rd Gen are available Support multi-stage, multi-zone Local/Remote control	Customer can not increase the number of channels The development control is with Google team
Honeywell	$149	Local/Remote control digital screen, the humidity, temperature, and thermostat settings options are available	It does not include the wall plate for installation, wiring is too complicated. it is a non-programmable device
ecobee	$229	Compatible with temperature and humidity sensors Local/Remote control	it has only one temperature sensor and two occupancy sensors build in at Ecobee4 systems

MEMORIAL UNIVERSITY | NSERC Energy Storage Technology Network

Contributions

- ✓ Space heating and water heating is needed for approximately eight months in a year.
- ✓ The major problem: grid overloading, GHG emission, high electricity bill and so on.
- ✓ A single-family residential house has been analyzed and energy demand is calculated.
- ✓ Proposed four TES systems such as solar collector, solar photovoltaic, hybrid type solar photovoltaic thermal array and a sessional. All systems can save a major portion of electricity consumption.
- ✓ The proposed TES systems implementation cost and their instrumentation has been discussed.
- ✓ A sessional solar thermal energy storage system has been proposed, mathematically designed, simulated and analyzed.
- ✓ All results have been compared with the annual energy demand and annual energy production.
- ✓ Nobody proposed such a system before in such a way and with respect to the Canadian (NL province) weather condition.
- ✓ Proposed a remote control and monitoring systems prototype which is low cost and low power consumption.
- ✓ The user can monitor and control from locally or remotely anywhere in the world.

MEMORIAL UNIVERSITY

NSERC Energy Storage Technology Network

Future Research Scopes

- ✓ Proposed STES systems can be redesigned at residential community, commercial or industrial.
- ✓ Several parameters assumed constant or ignored, can be considered and re-design
- ✓ The thermal and electrical efficiency can be further improved.
- ✓ A robust controller can be proposed in dynamic simulation
- ✓ Proposed STES system can be re-deigned for all cold climate zone.
- ✓ Detailed reliability analysis of IoT based systems can be done in future
- ✓ The remote-control prototype can be made with other type of MCU board to reduce cost
- ✓ Data encryption can be implemented to ensure the more security.
- ✓ Various open source IoT/ SCADA systems can be developed.

Publications

Refereed journal Articles

1. M. H. Rahaman and T. Iqbal, “A Comparison of Solar Photovoltaic and Solar Thermal Collector for Residential Water Heating and Space Heating System,” European Journal of Engineering Research and Science, vol. 4, no. 12, pp. 41–47, Dec. 2019, doi: 10.24018/ejers.2019.4.12.1640.
2. H. Rahaman, M. T. Iqbal, “A Remote Thermostat Control and Temperature Monitoring System of a Single-Family House using openHAB and MQTT,” in Int’l Journal of Renewable Energy and Research (Under Review)

Refereed Conference Publications

1. H. Rahaman, R. Rasha, and M. T. Iqbal, “Design and analysis of a solar water heating system for a detached house in newfoundland,” in 2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE), May 2019, pp. 1–4, doi: 10.1109/CCECE43985.2019.8995175.
2. Rabbani Rasha, Habibur Rahaman, Tariq Iqbal, Sizing, modeling and analysis of a solar seasonal energy storage for space heating in Newfoundland, presented at CSME-CFDSC 2019, London, ON, Canada.

Regional Conference Publication

- ✓ Habibur Rahaman, M. Tariq Iqbal, Load analysis of RUET, ECE building and design of a rooftop PV system to meet all its energy needs, presented at the 28th Annual IEEE NECEC conference, St. John's, November 19th, 2019.

Research Presentations

- ✓ Md Habibur Rahaman and M. Tariq Iqbal, "Design a Low-Cost Remote Monitoring and Control Systems for Thermal Energy Storage System,” Presented at the 3 MT thesis competition, 2019 held at the Memorial University of Newfoundland, St. john’s, NL, Canada. June 1, 2019 [Awarded 3rd Prize].
- ✓ Md Habibur Rahaman and M. Tariq Iqbal, "Design, Analysis and SCADA Interface for Energy Storage Systems," Presented during the poster session at the NESTNet 5th and Final Annual Technical Conference, Ryerson University, Toronto, ON, Canada. June 16 - 17, 2020 (Virtual).

Acknowledgements

- ✓ My thesis supervisor Prof. Dr. M. Tariq Iqbal
- ✓ Memorial University of Newfoundland for providing sufficient funds and support for this project.
- ✓ NSERC, Canada and NESTNet Project.
- ✓ Family members, Research Group Members and Friends

MEMORIAL UNIVERSITY

NSERC CRSNG

NSERC Energy Storage Technology Network

MEMORIAL UNIVERSITY

NSERC
Energy Storage
Technology Network