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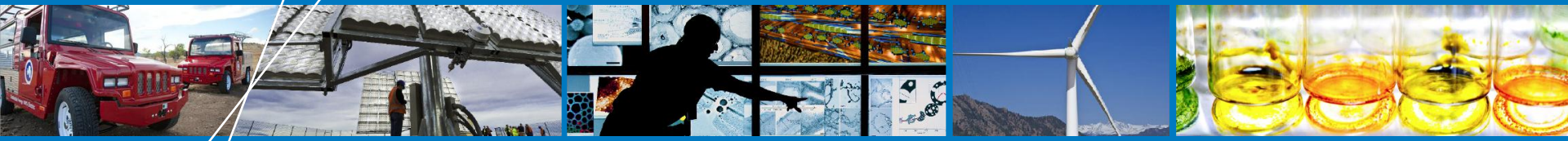
SIMPLIFIED SOLAR WATER HEATER SIMULATION USING A MULTI-MODE TANK MODEL



Solar 2014

Craig Christensen, Jeff Maguire, Jay Burch, Nick DiOrio

July 9, 2014

Outline

- Background
- Detailed Model Results
- Simple Model
- Validation
- Conclusions
- Future Work

Background – SWH models

Detailed ⟷ Simple

TRNSYS
- Sub-hourly
- Multi-node tank
- Equation solver
- Flexible
- Complex

?

F-CHART
- Monthly
- Correlations based on TRNSYS simulations
- Simple

With today's computing resources, calculation speed is less of an issue.

For parametric runs and optimization, speed still matters.

Objective

To develop a new Solar Water Heater model:

- **Simple, easy to use, reliable**
- **Physics based**
- **Computationally efficient**
  (for parametrics and optimization)

SWH System Characteristics

Parameter	Value	Units
Collector area	4	m^2
Collector thermal capacitance *	17.7	kJ/C
Collector F_RU_L	3	W/m^2C
Collector $F_R(\tau\alpha)$	0.7	--
Incident angle modifier	0.2	--
Collector slope	30	degrees
Collector azimuth (South=0)	0	degrees
Collector flow rate/area	0.015	$kg/s\text{-}m^2$
Collector fluid specific heat	3.35	kJ/kgC
Tank side flow rate/area.	0.015	$kg/s\text{-}m^2$
Heat exchanger effectiveness	0.75	--

Parameter	Value	Units
Solar storage tank environment temperature	20	C
Solar storage tank size	300	liters
Solar storage tank UA	2.2	W/C
Solar storage tank maximum fluid temperature	100	C
Pipe length (outdoors)	10	m
Pipe insulation conductivity	0.03	W/m^2C
Pipe insulation thickness	0.02	m
Ground reflectance	0.2	--
ΔT on/off *	10/2	C
Hot water draw per day	200	liters

* not used in the simple model

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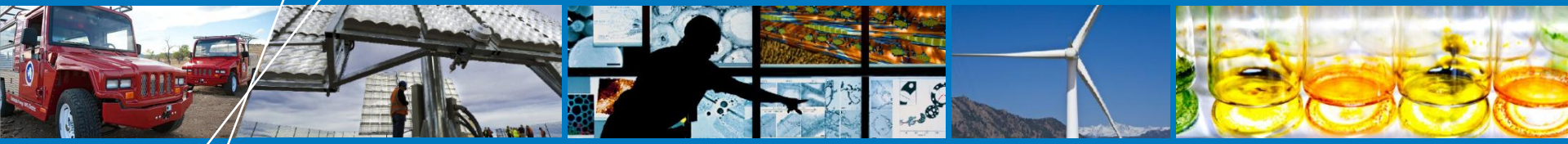
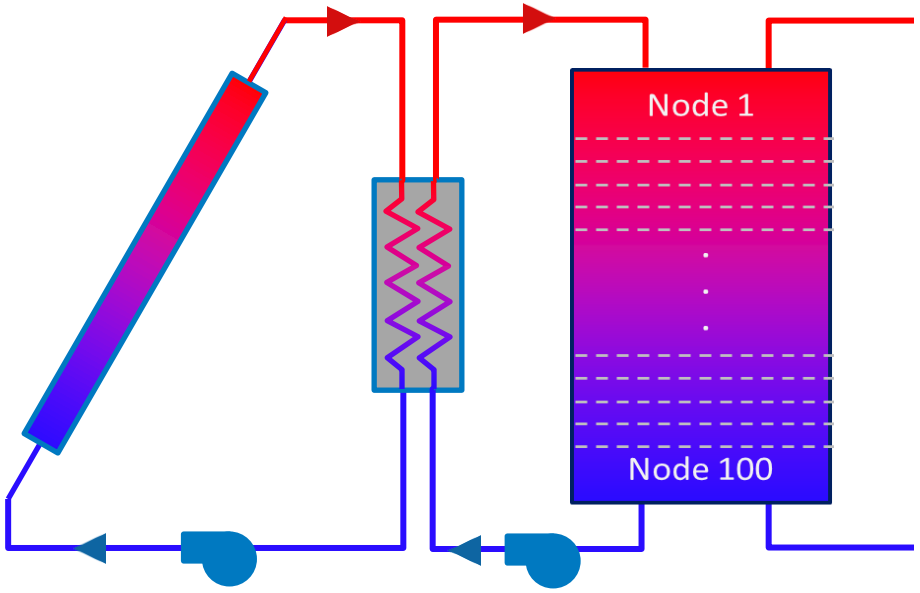


Solar Water Heater: Detailed Tank Model

Detailed Tank Model (TRNSYS)

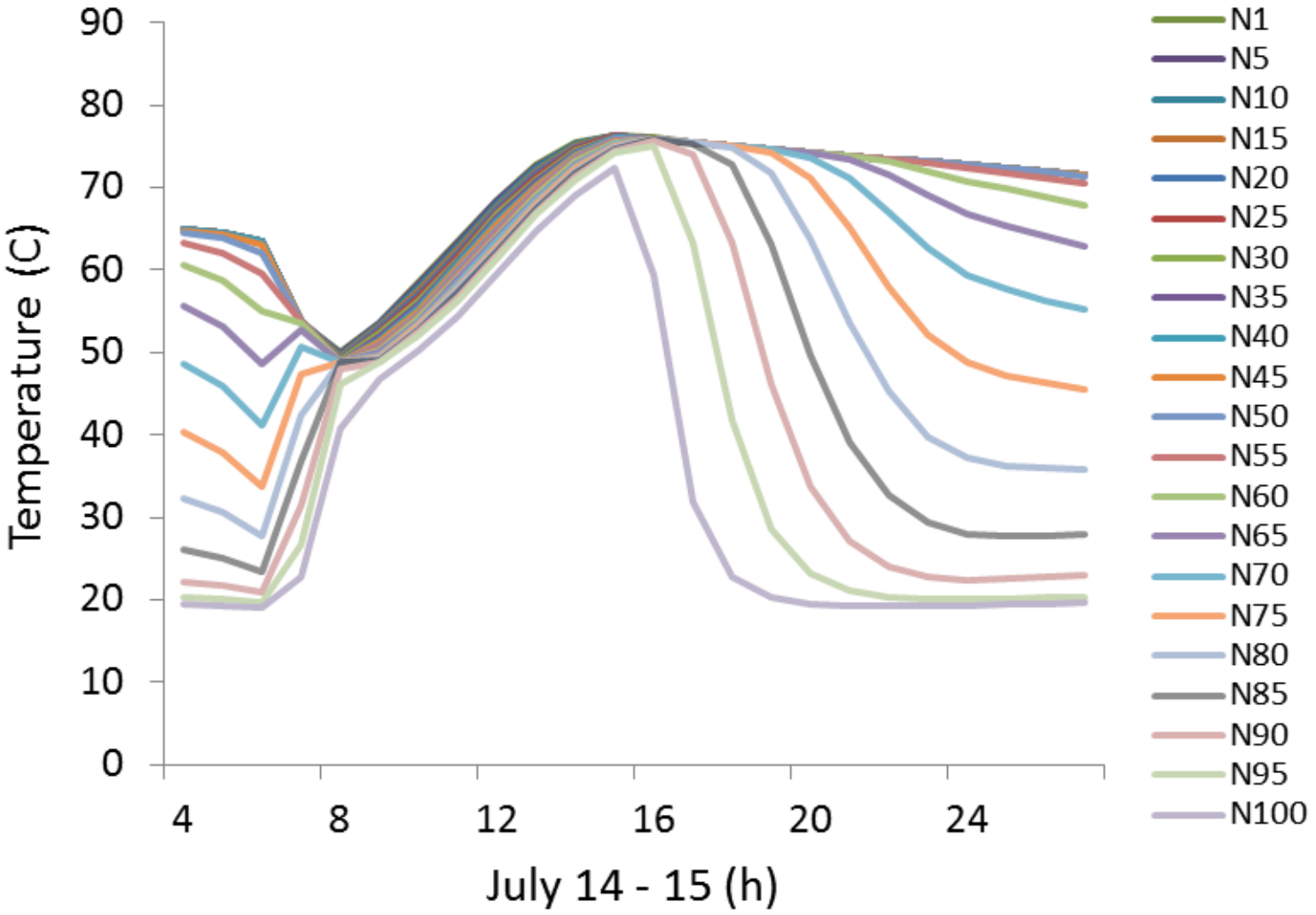


T_{Out}

Multi-Node, Stratified

T_{In}

Detailed Tank Model (TRNSYS)



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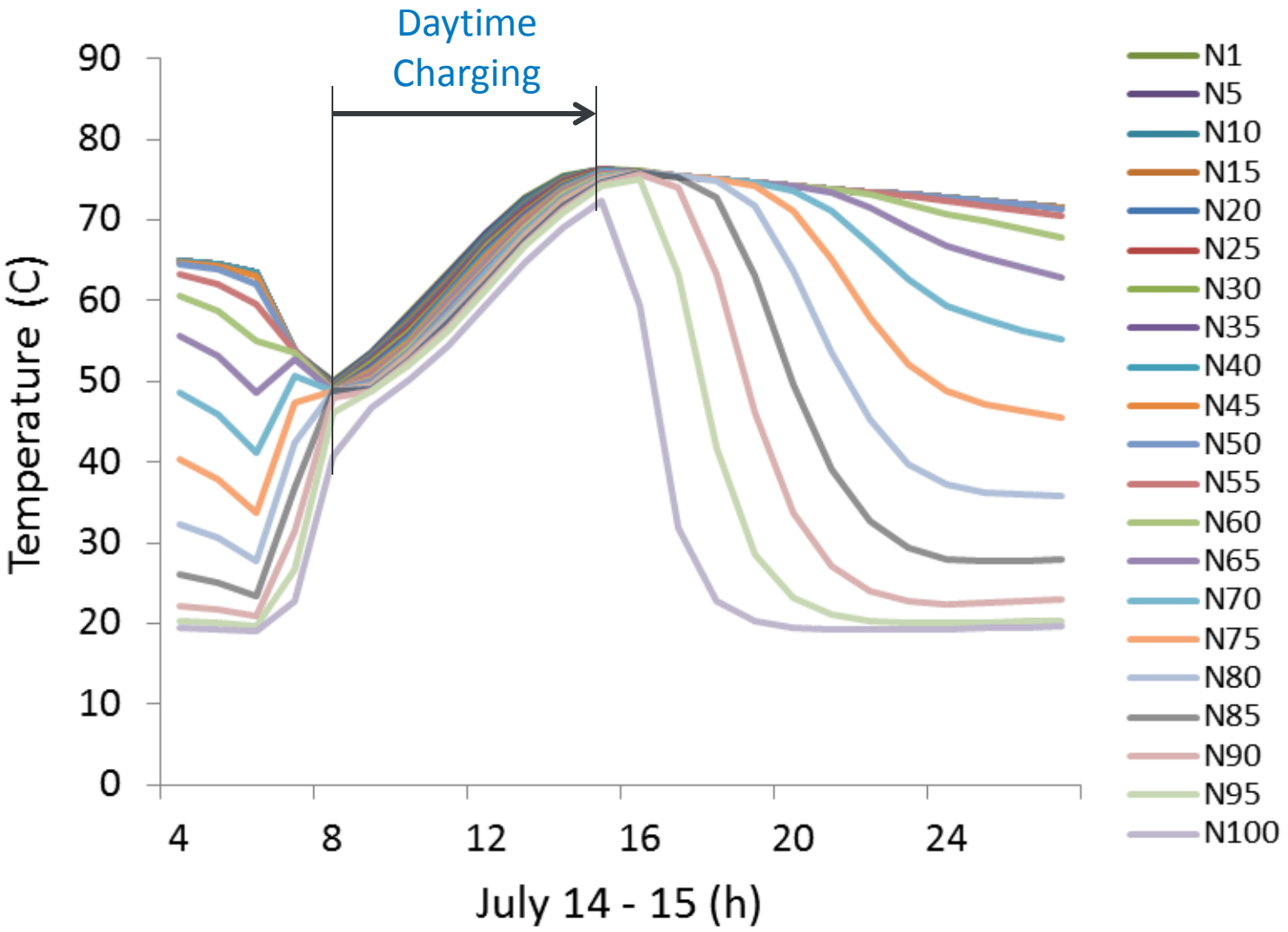

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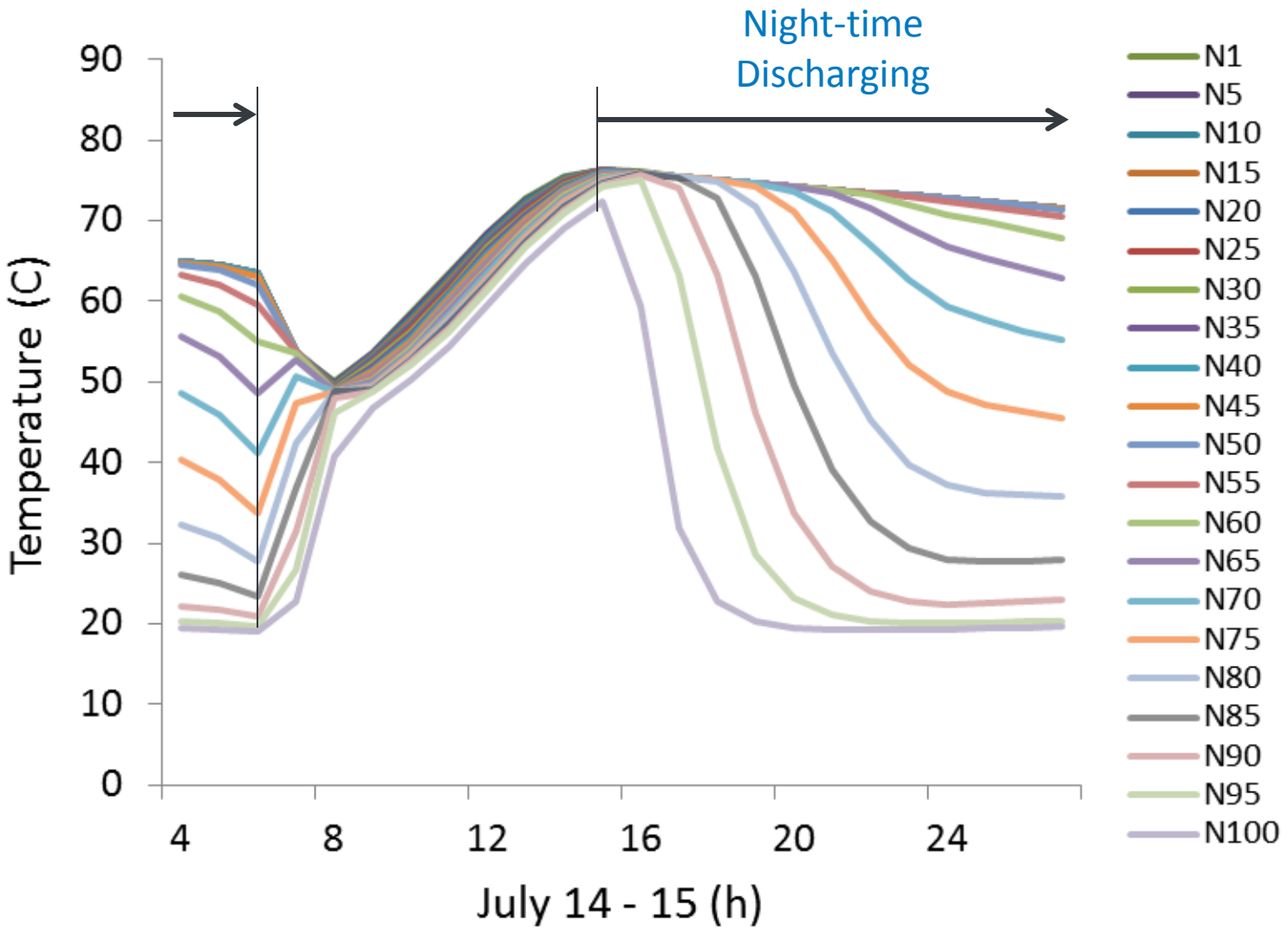

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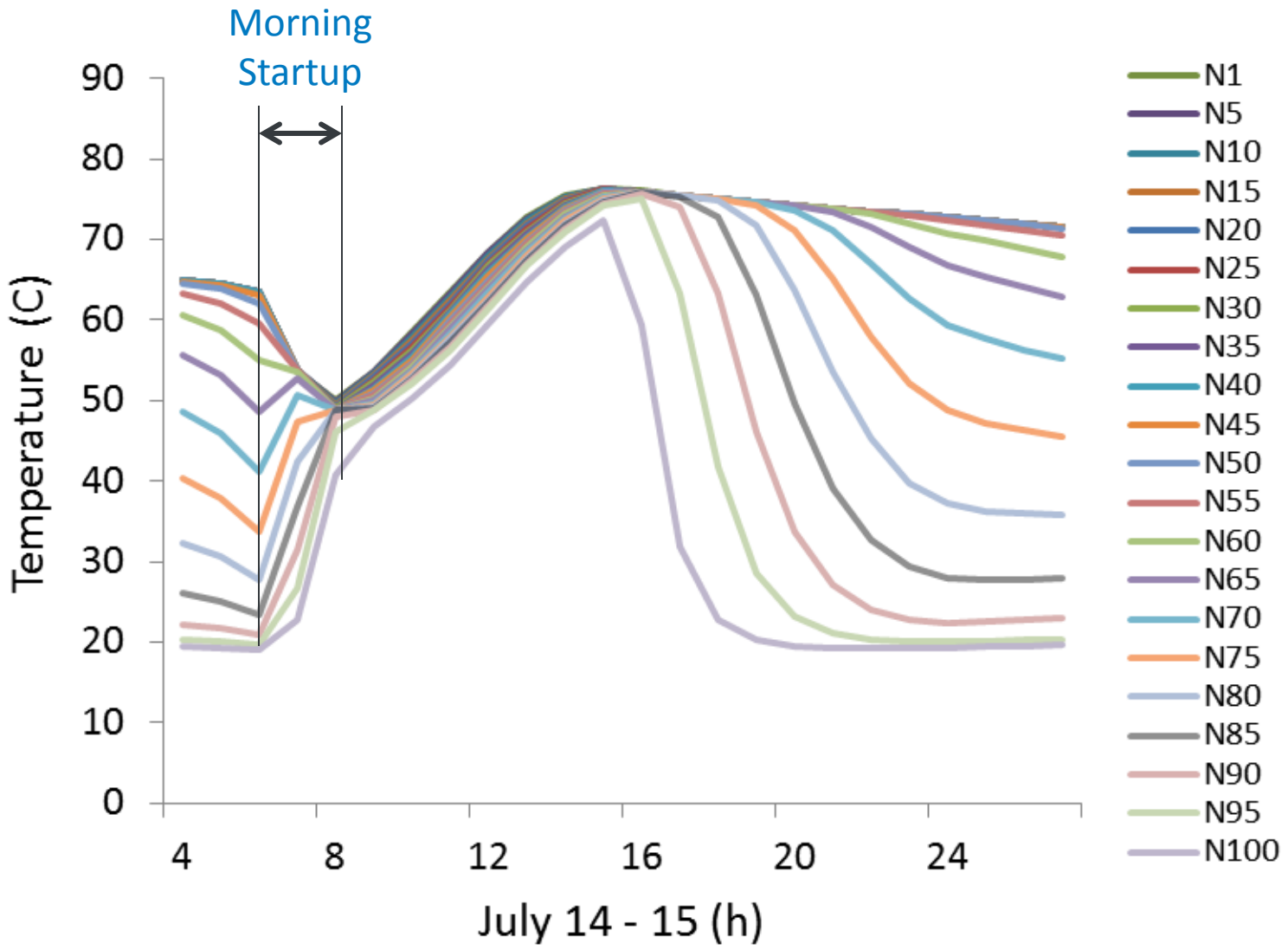
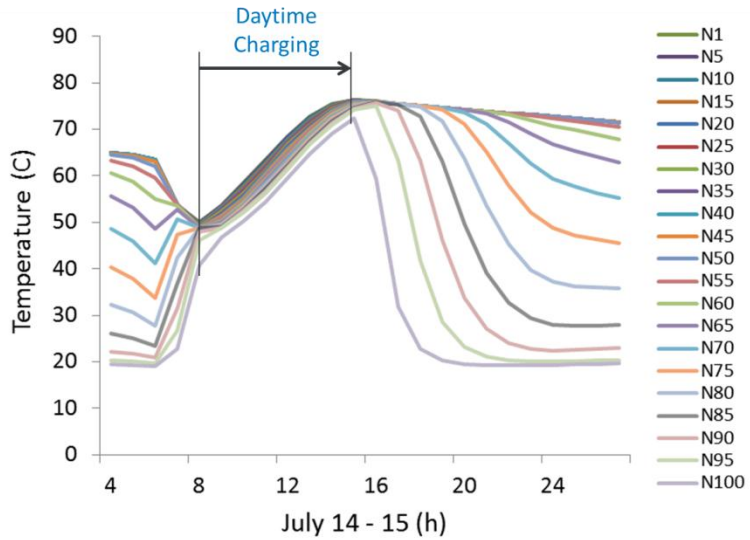
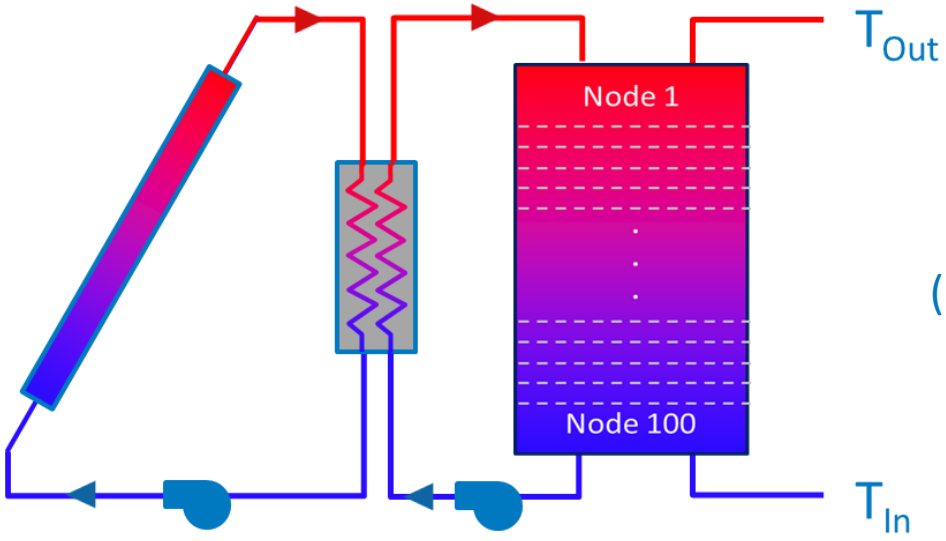


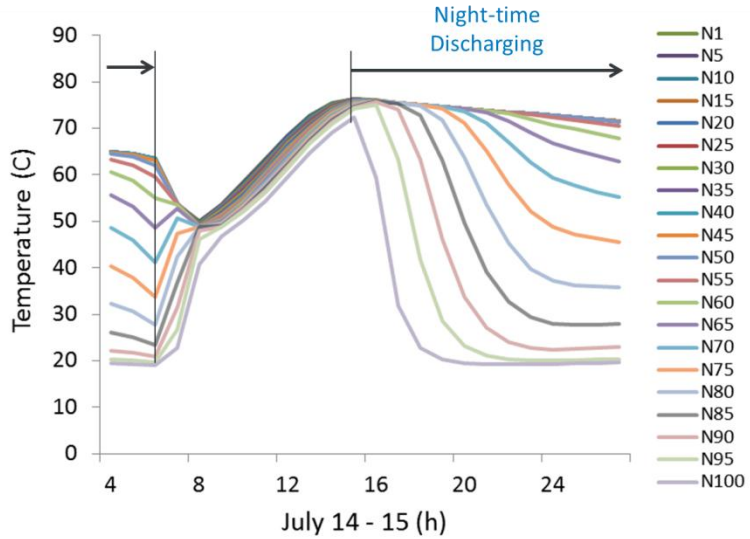
Detailed Tank Model – Daytime Charging

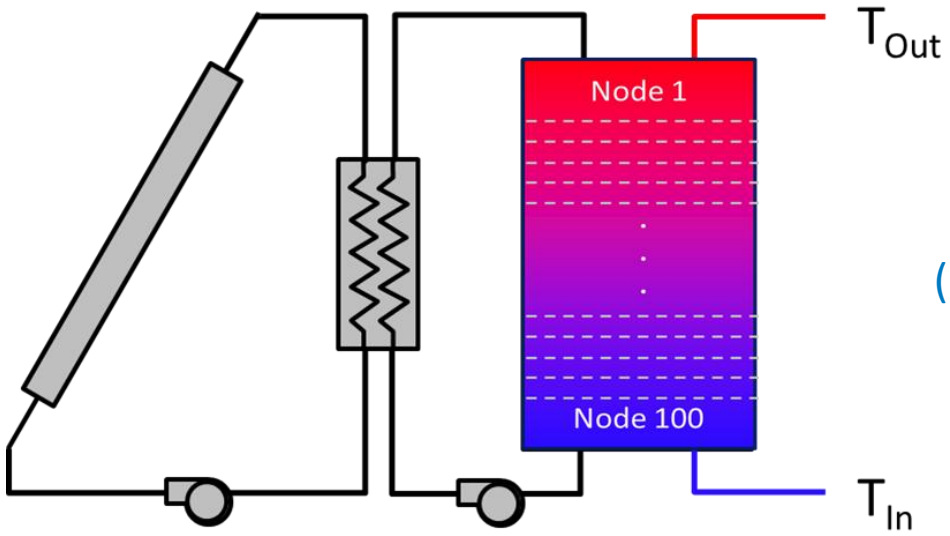




Charging
(Multi-Node, Stratified)

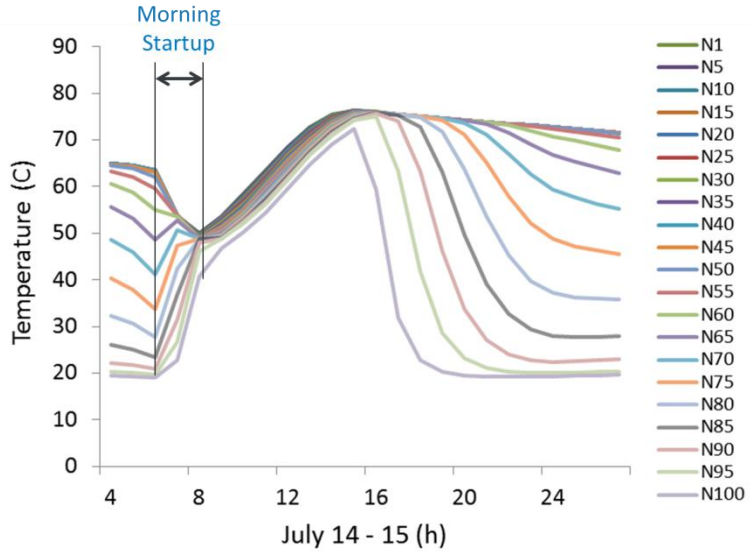
Detailed Tank Model – Night-time Discharging

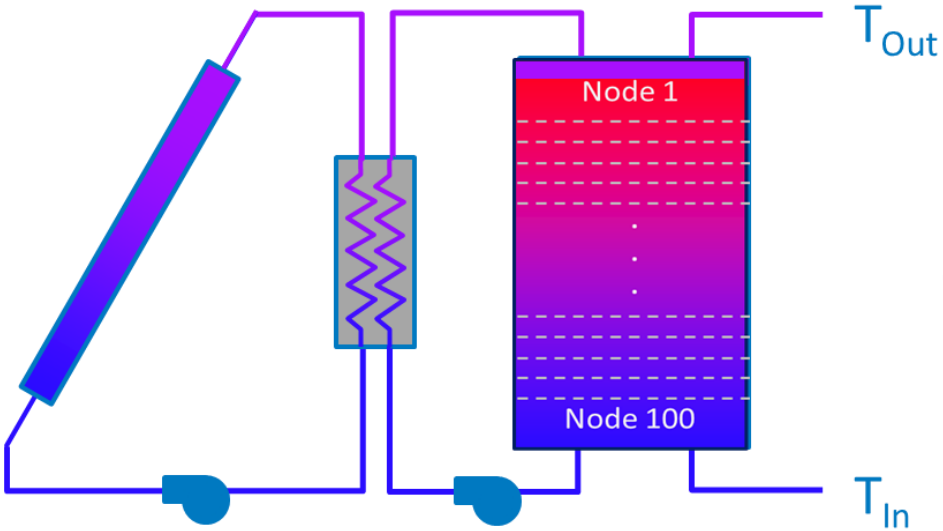




Discharging
(Multi-Node, Stratified)

Detailed Tank Model – Morning Startup





Startup
(Multi-Node, Stratified)

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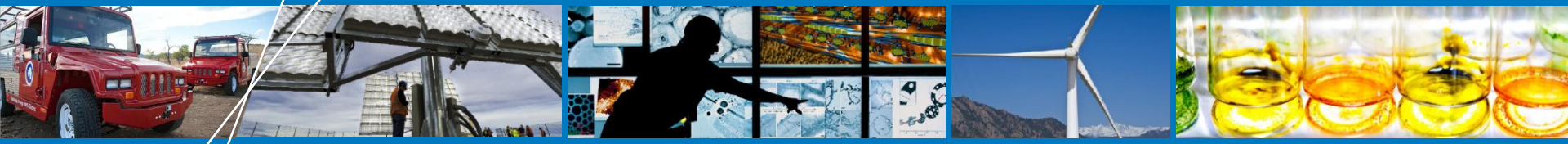
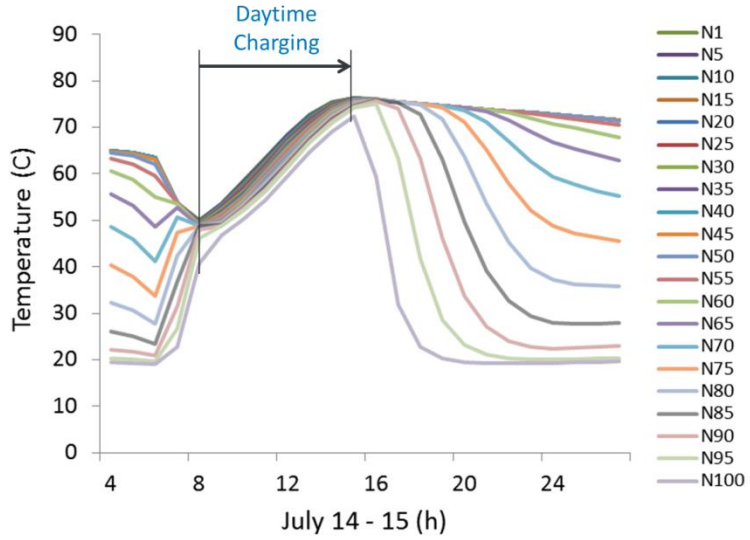
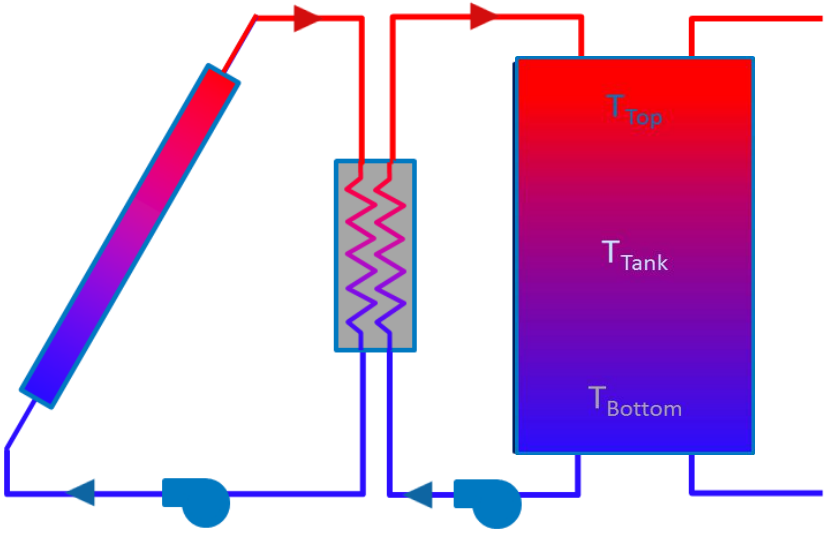


Solar Water Heater: Simple Tank Model

Simple Tank Model – Daytime Charging



- T_{tank} (average tank temperature) single-node energy balance:
  $Q_{coll,hx} + Q_{room} + Q_{cold}$
- $T_{top} = T_{tank} + 0.35\ dT_{coll,hx}$
- $T_{bottom} = T_{tank} - 0.65\ dT_{coll,hx}$

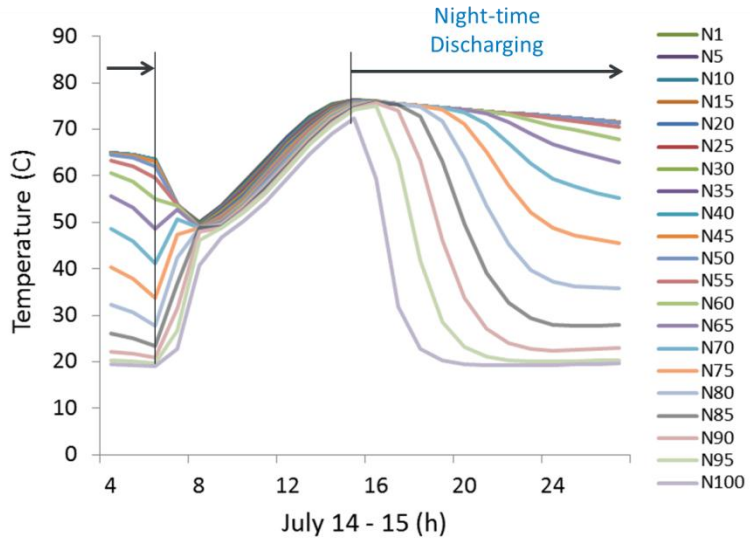


T_{Out}

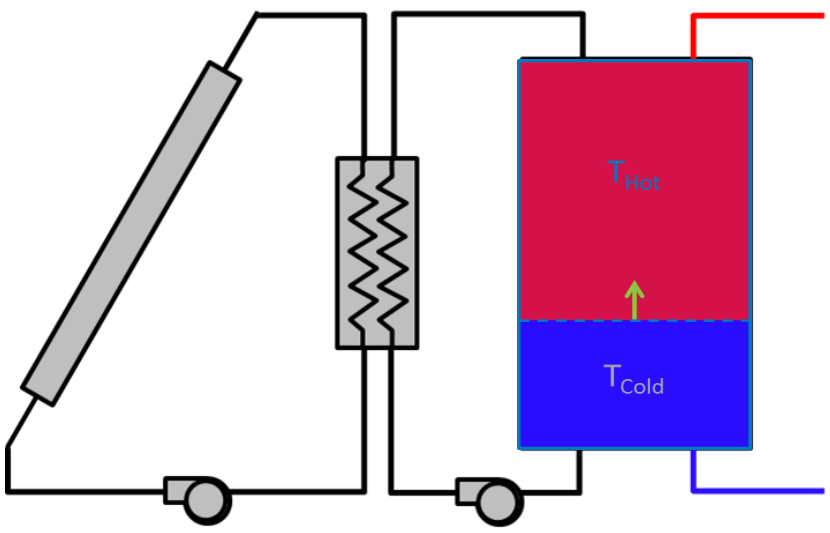
1-Node Stratified

T_{In}

Simple Tank Model – Night-time Discharging

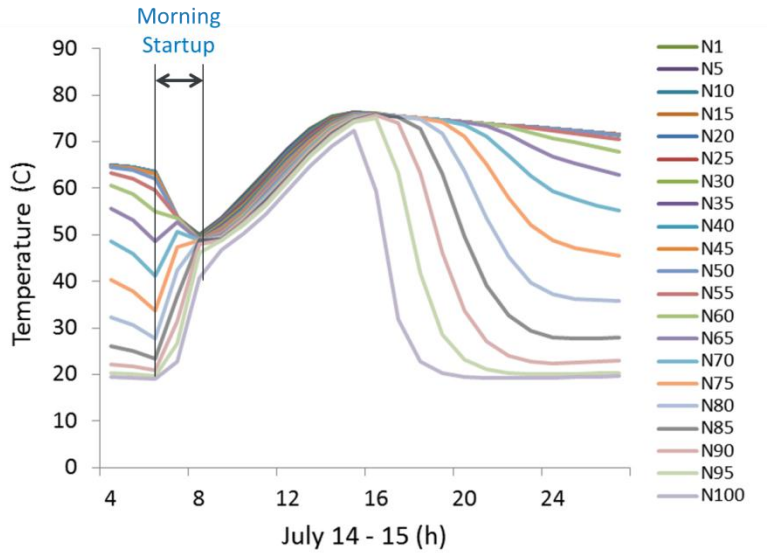


- V_{cold} expands as cold water enters bottom of tank
- V_{hot} shrinks as hot water leaves the top of tank
- T_{cold} and T_{hot} depend on Q_{room}



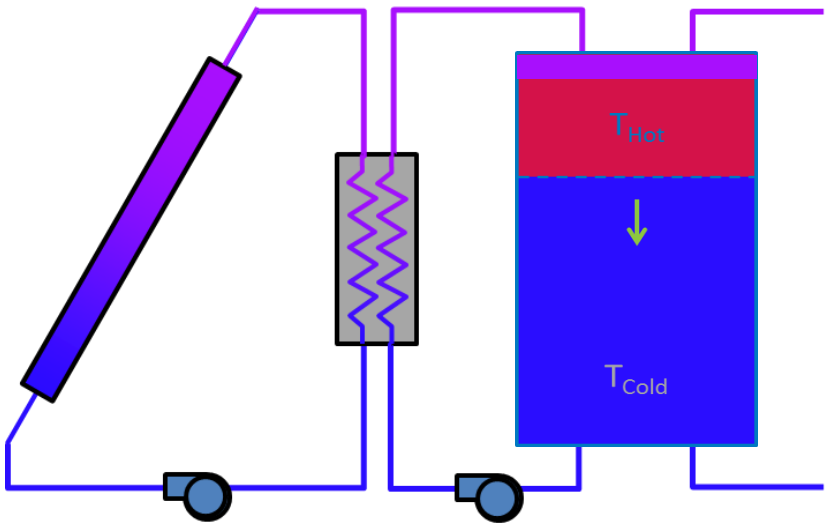
2-Node
Plug Flow

Simple Tank Model – Morning Startup



Water pumped through the heat exchanger to tank top:

- Warm water at tank top mixes with hotter water below
- V_{hot} expands downward
- Tank becomes fully mixed (except the bottom node)



2-Node
Plug Flow
top node mixed

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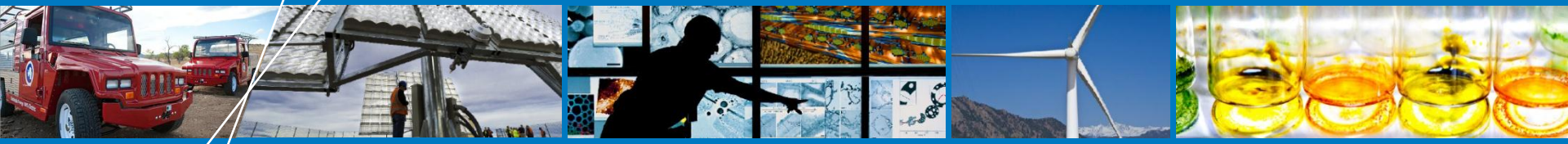
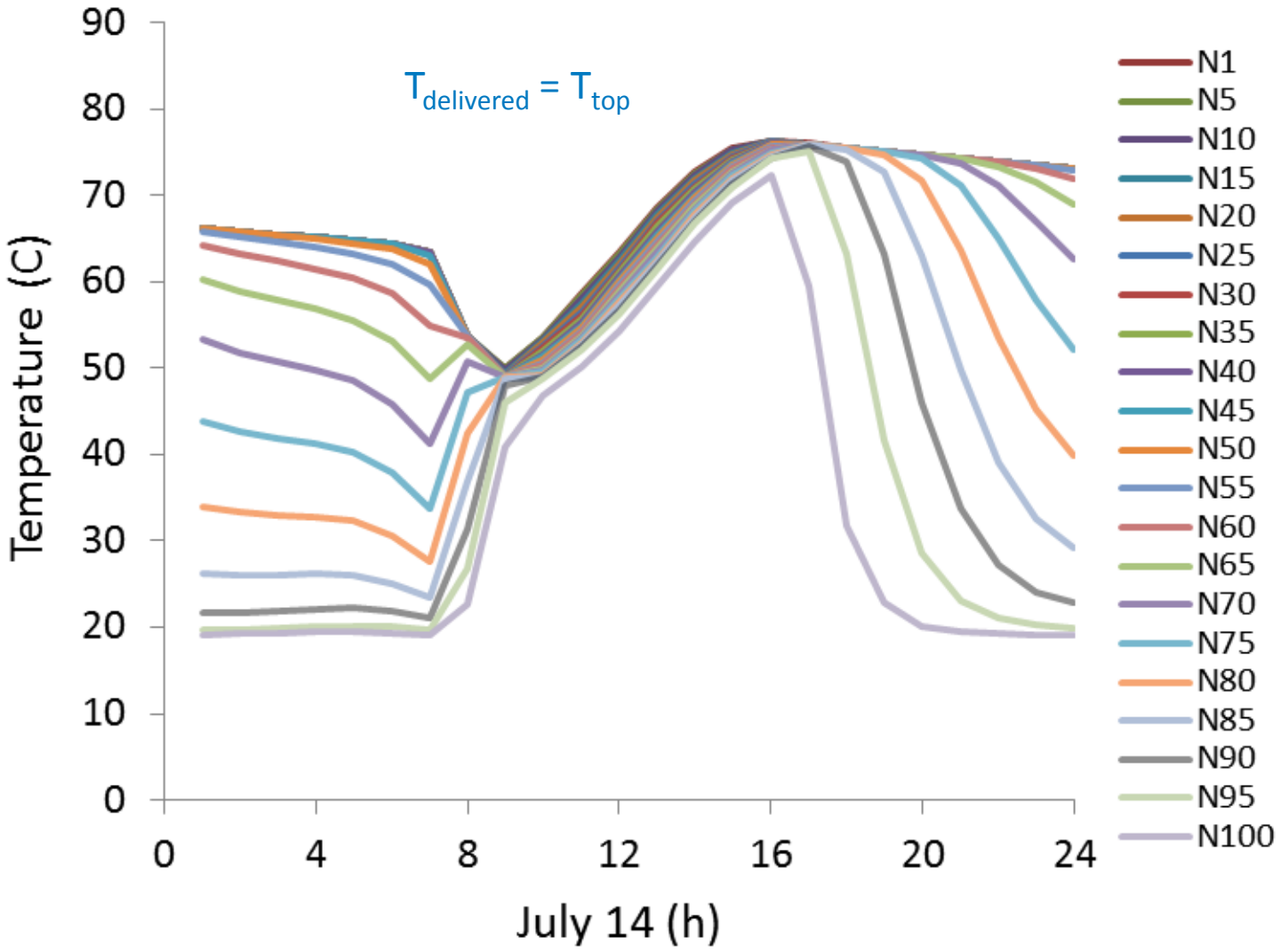
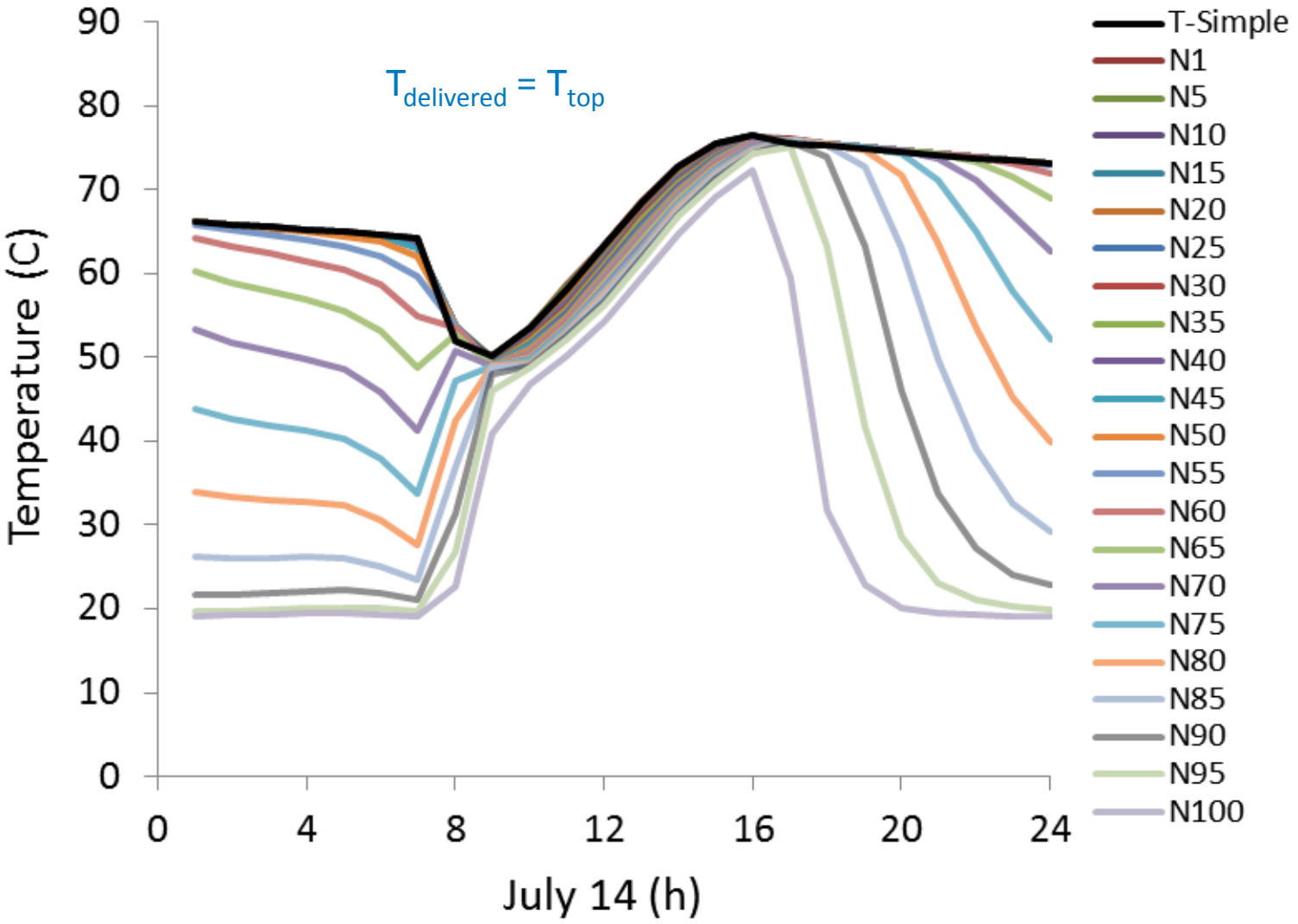


Validation:
Simple Model vs. Detailed Model

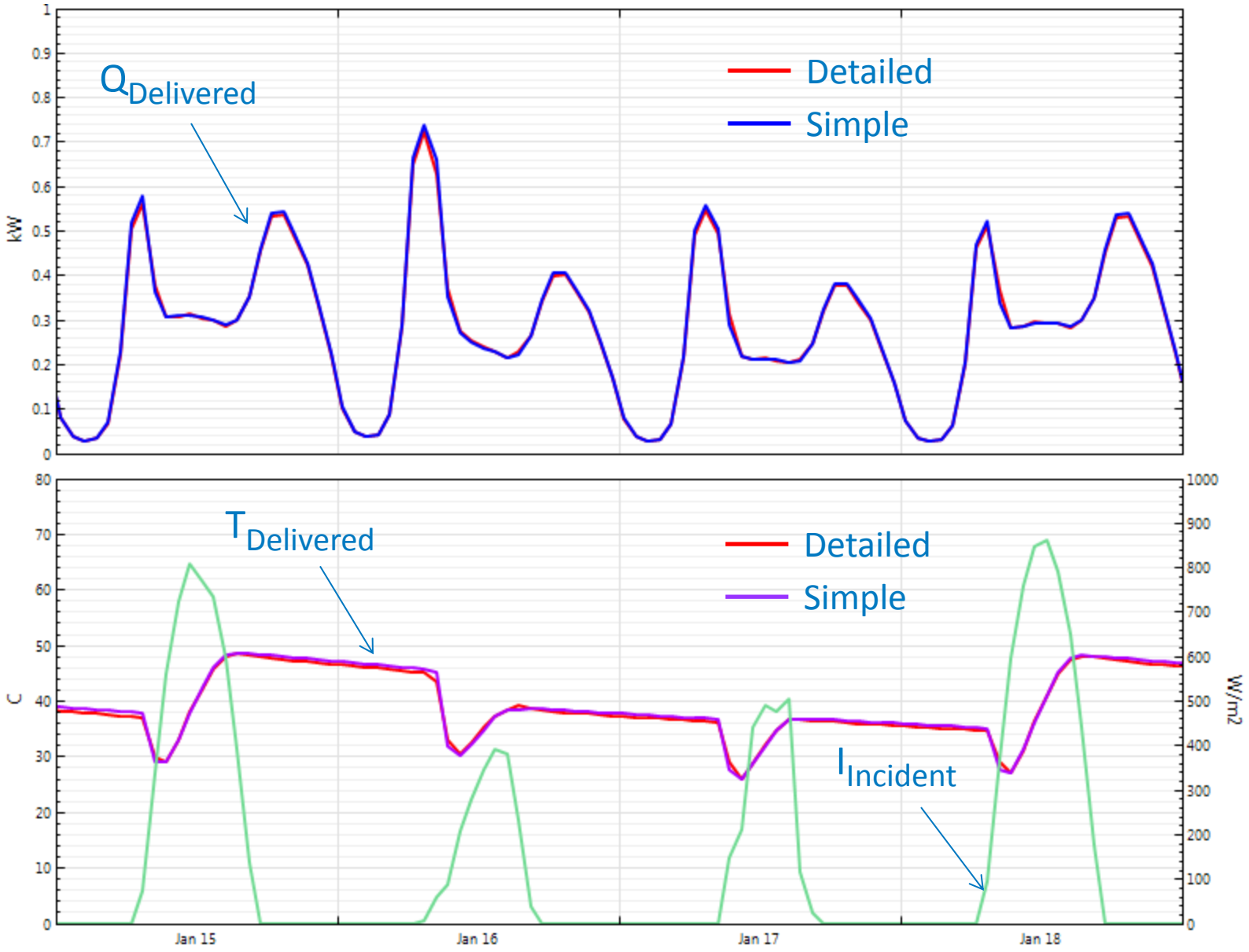
Detailed Tank Model (TRNSYS)



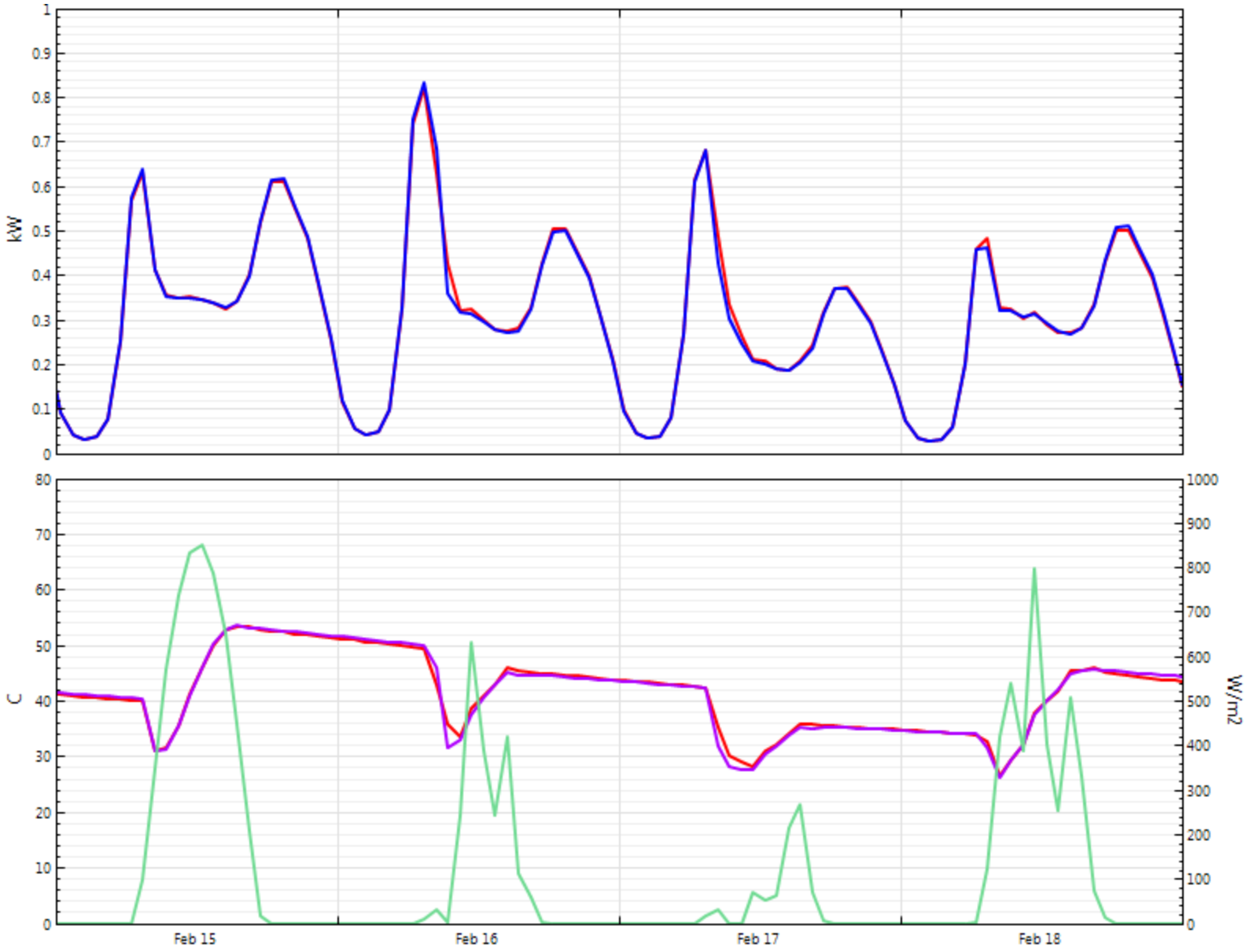
Delivered Temperatures (Sample Day)



January


Q Delivered
Detailed
Simple
kW
T Delivered
Detailed
Simple
I Incident
C
W/m2
Jan 15
Jan 16
Jan 17
Jan 18

February



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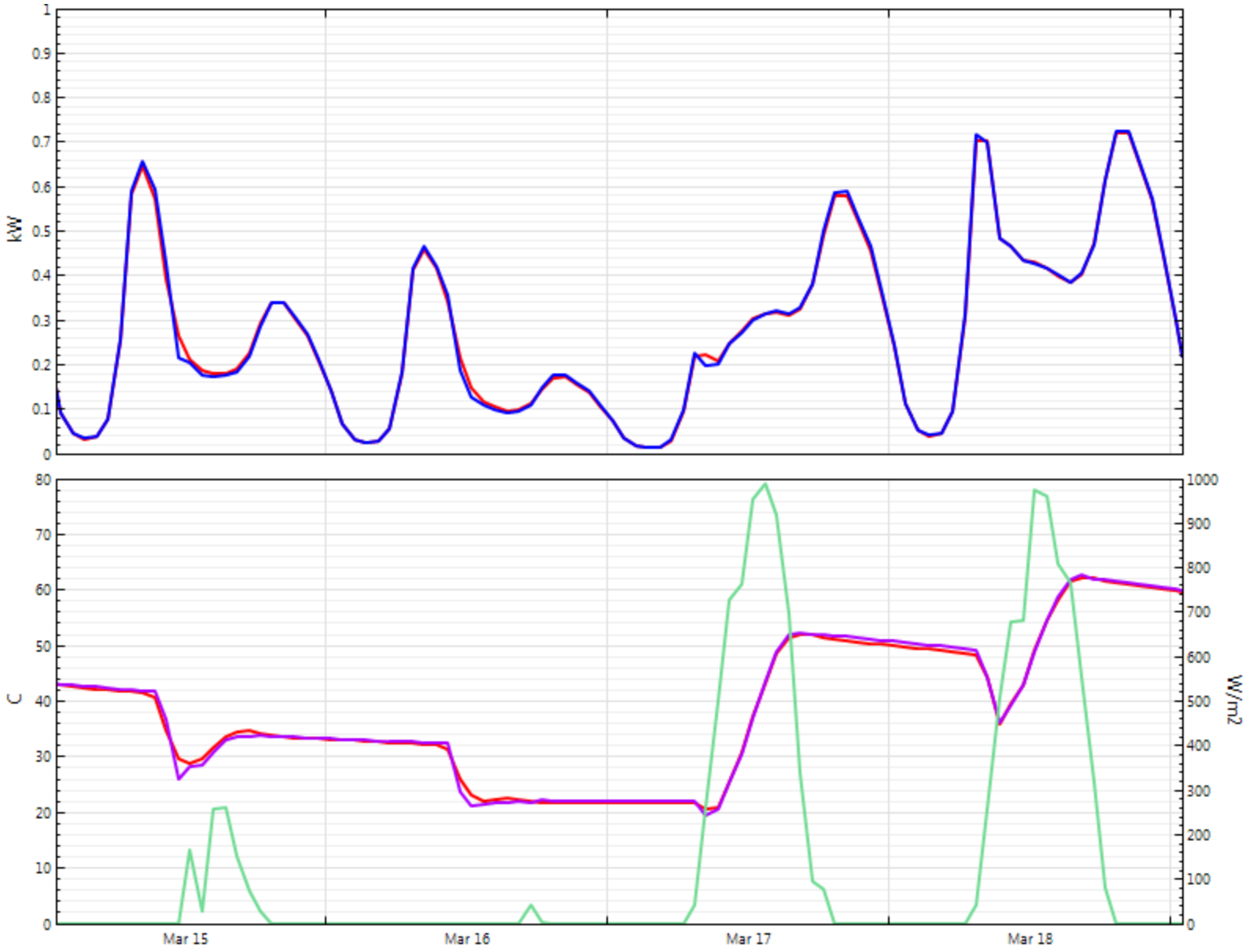
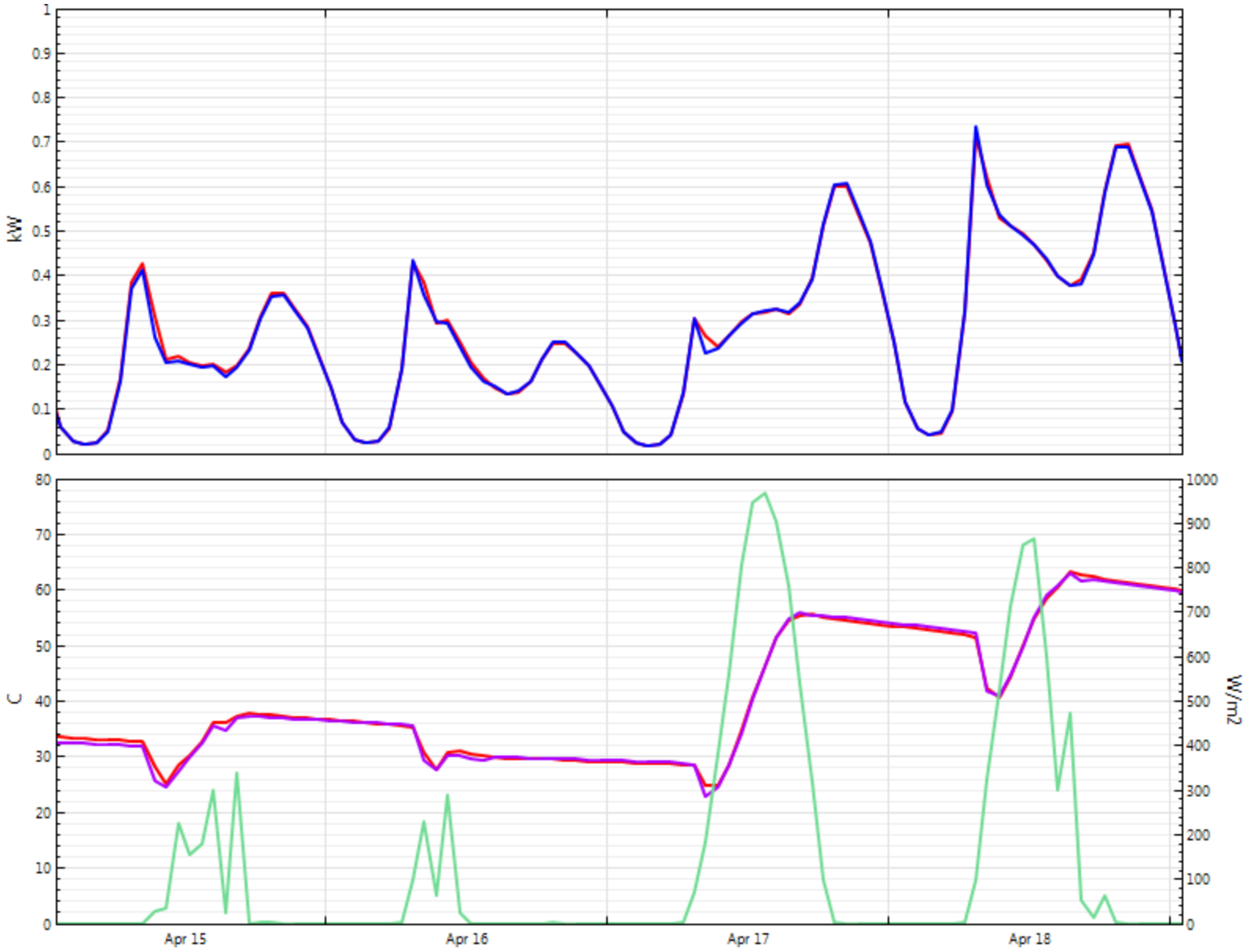
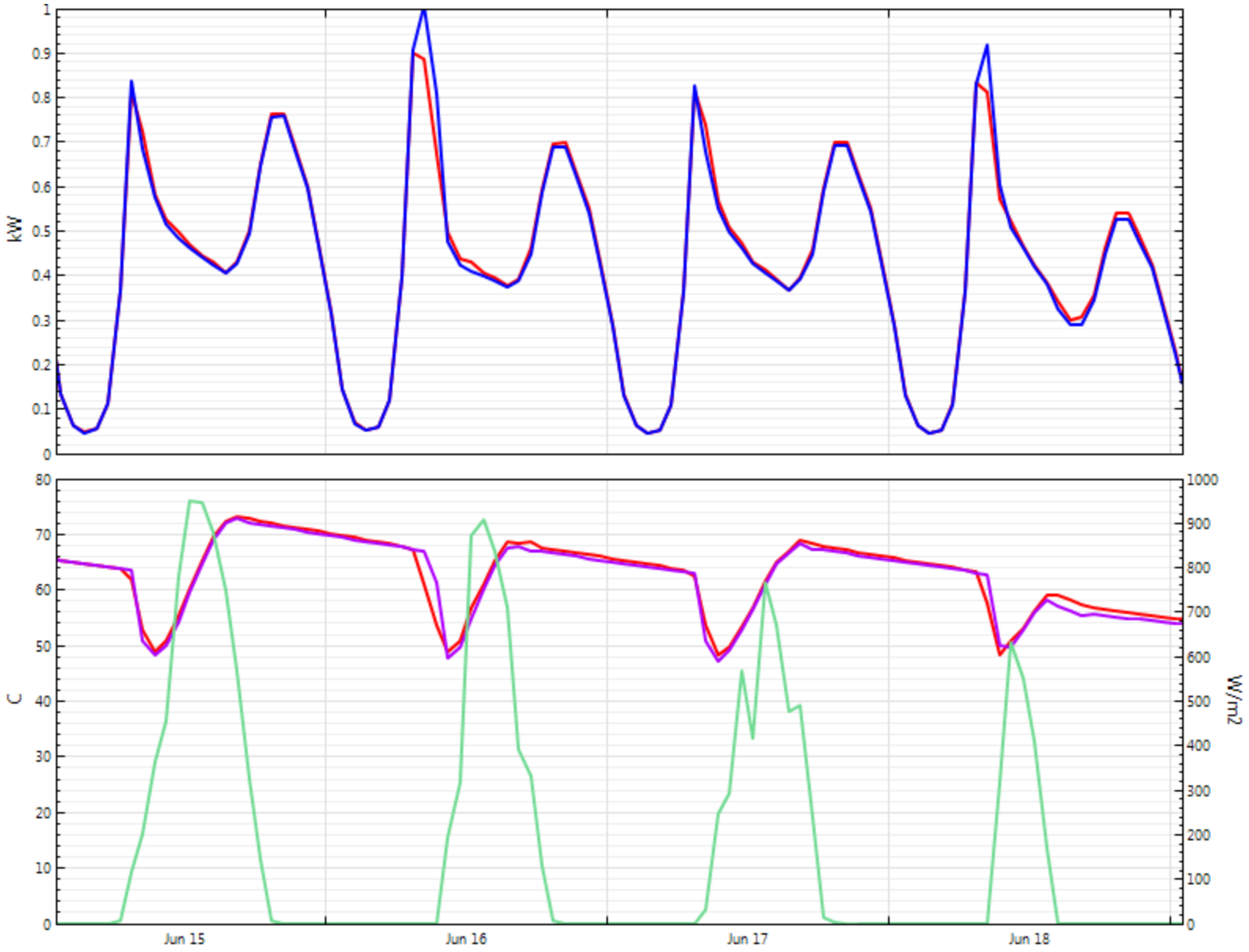


April

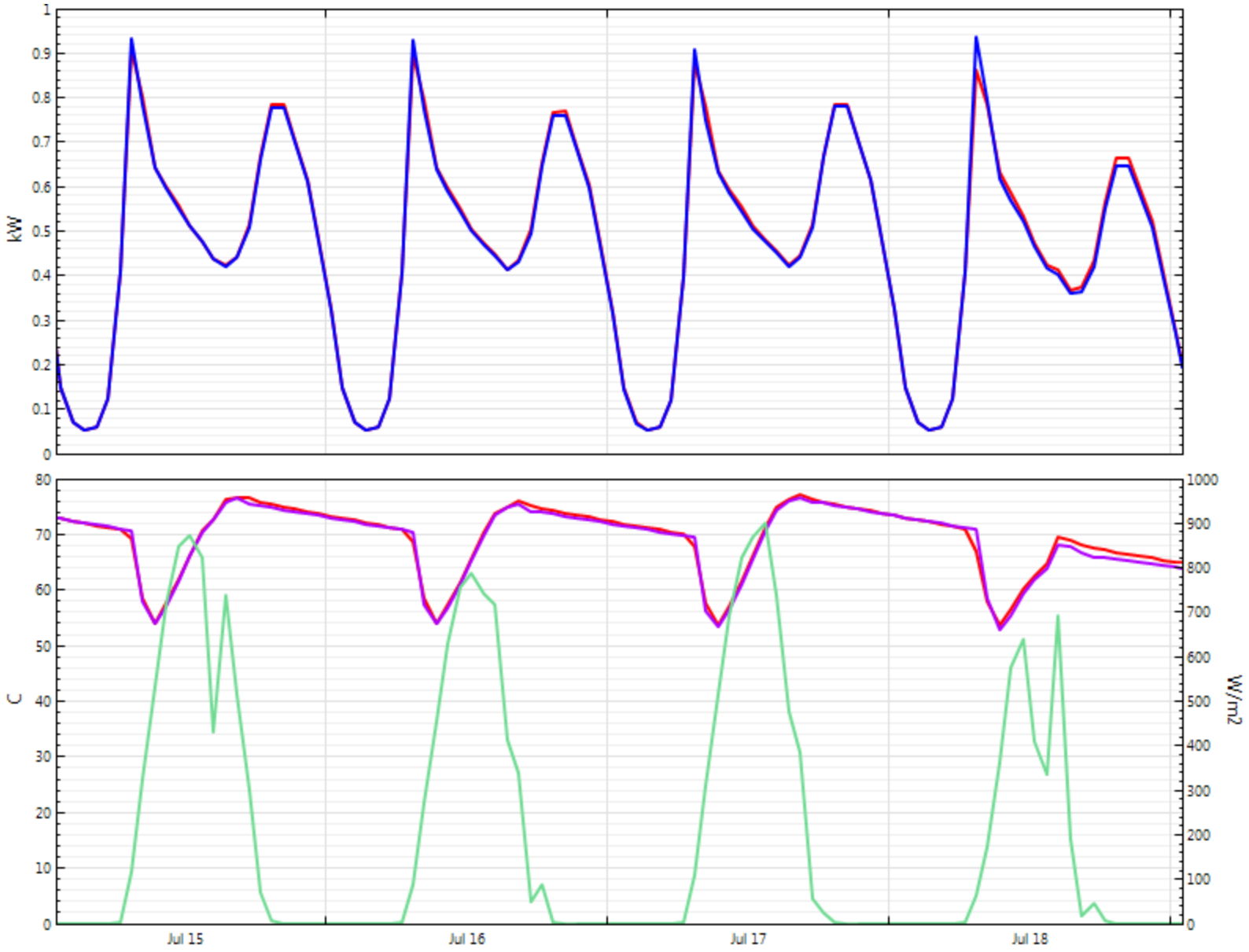


May

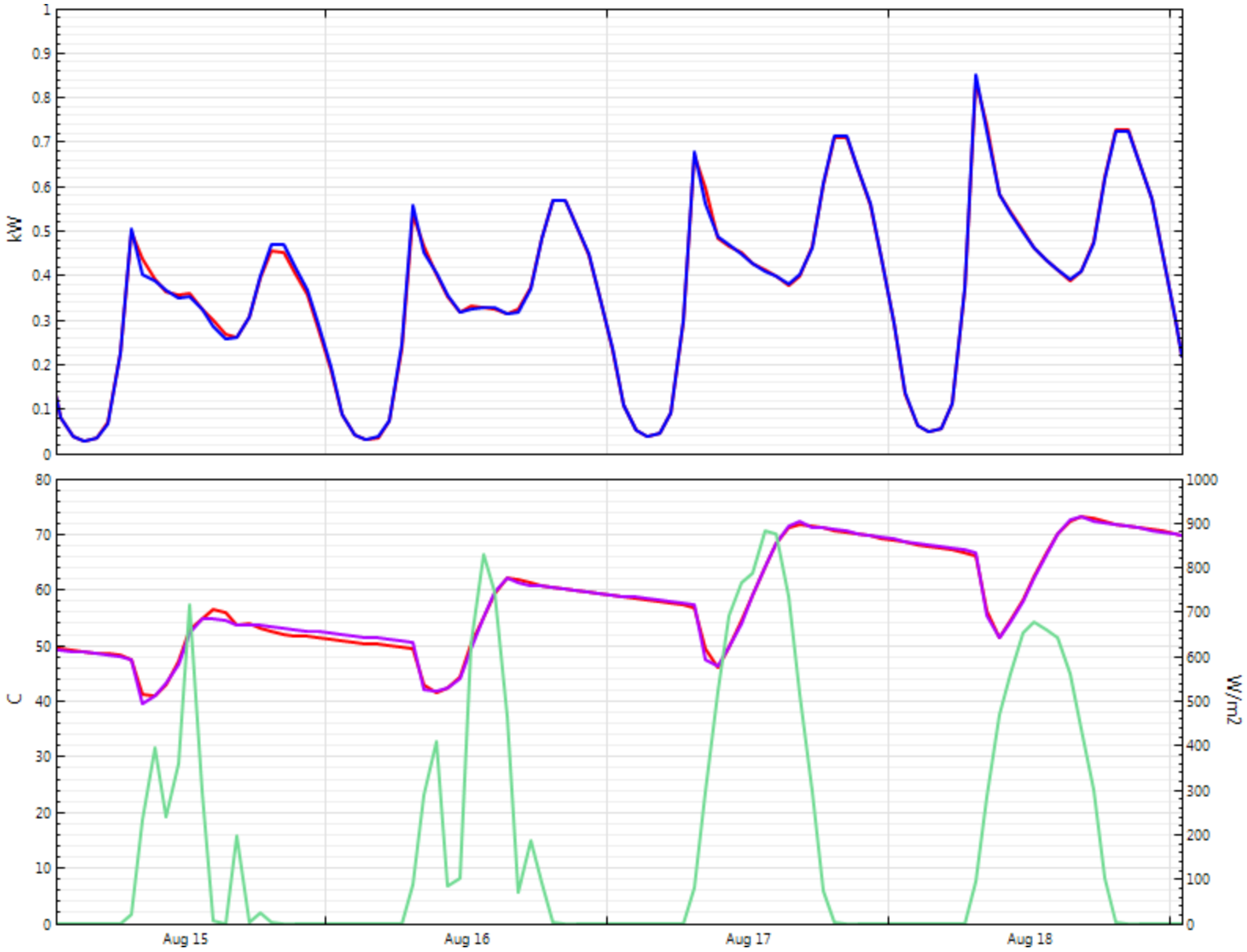
June



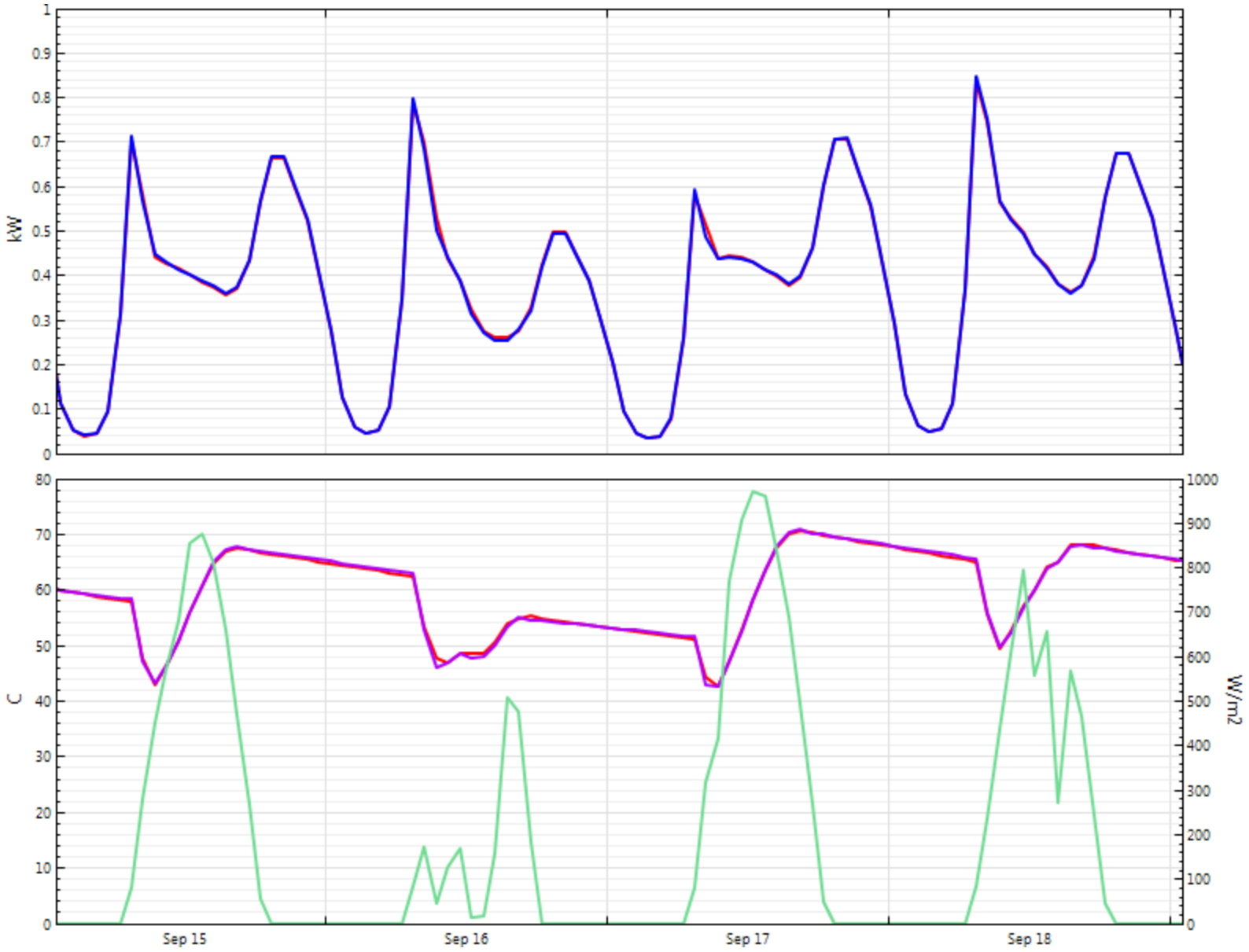
July



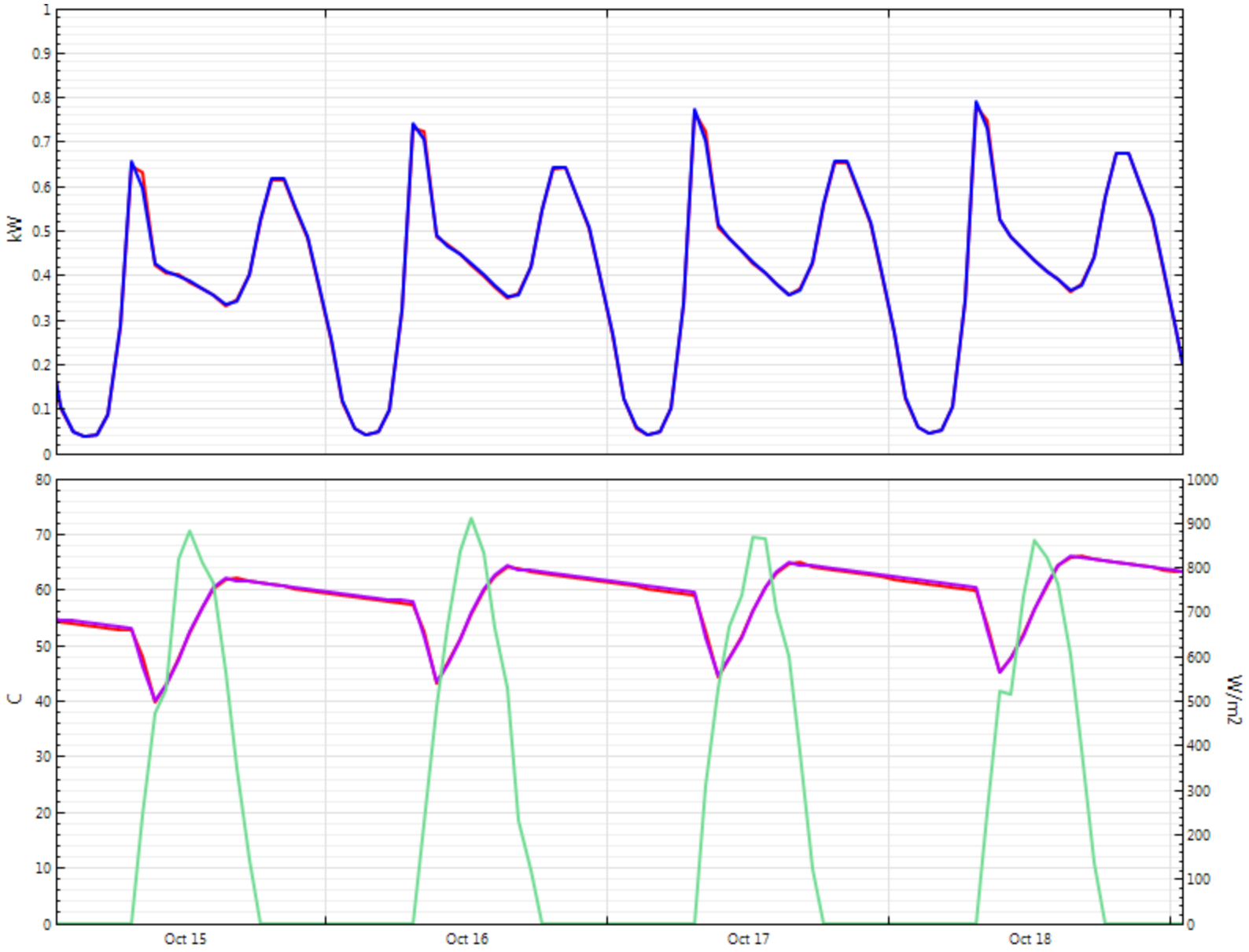
August



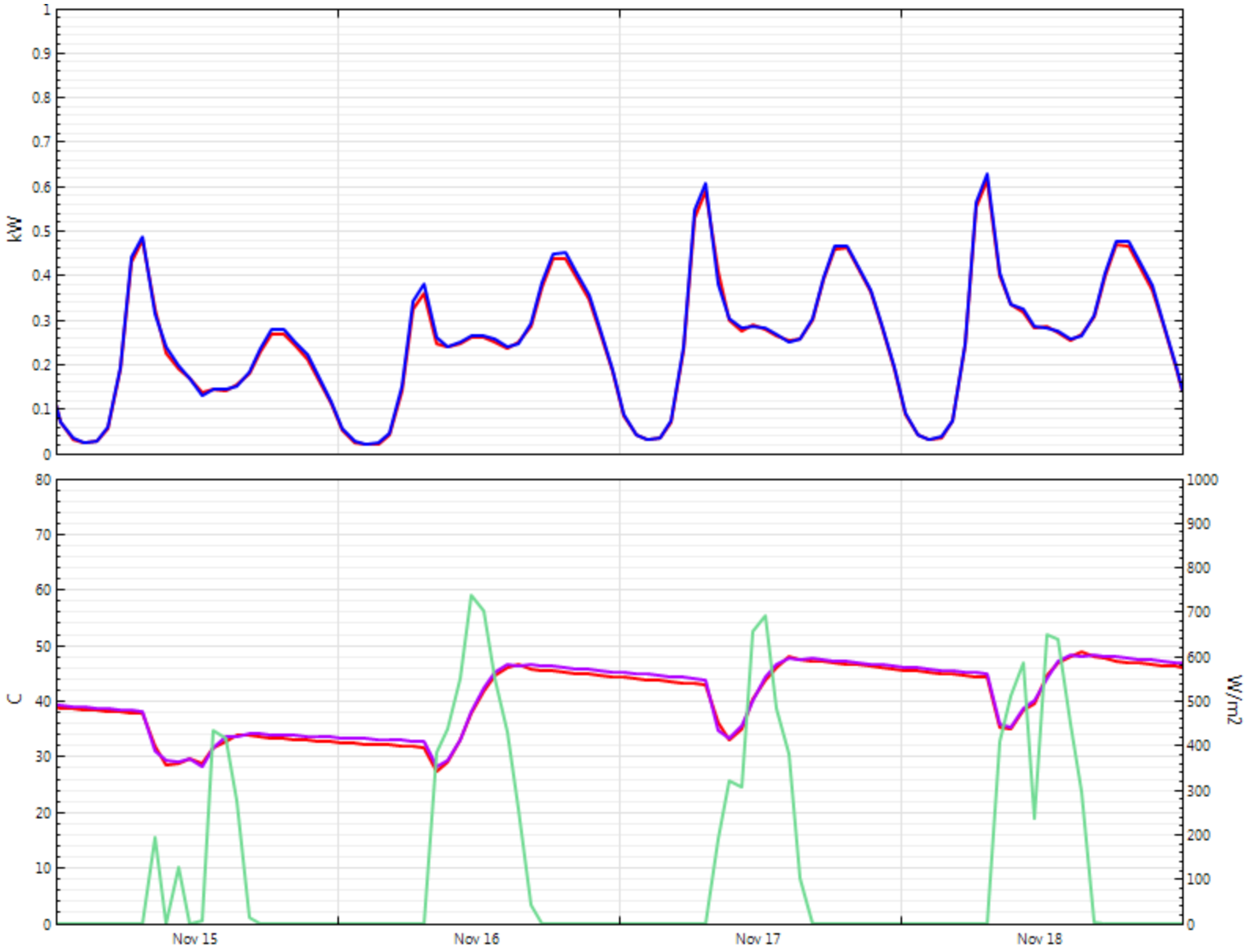
September



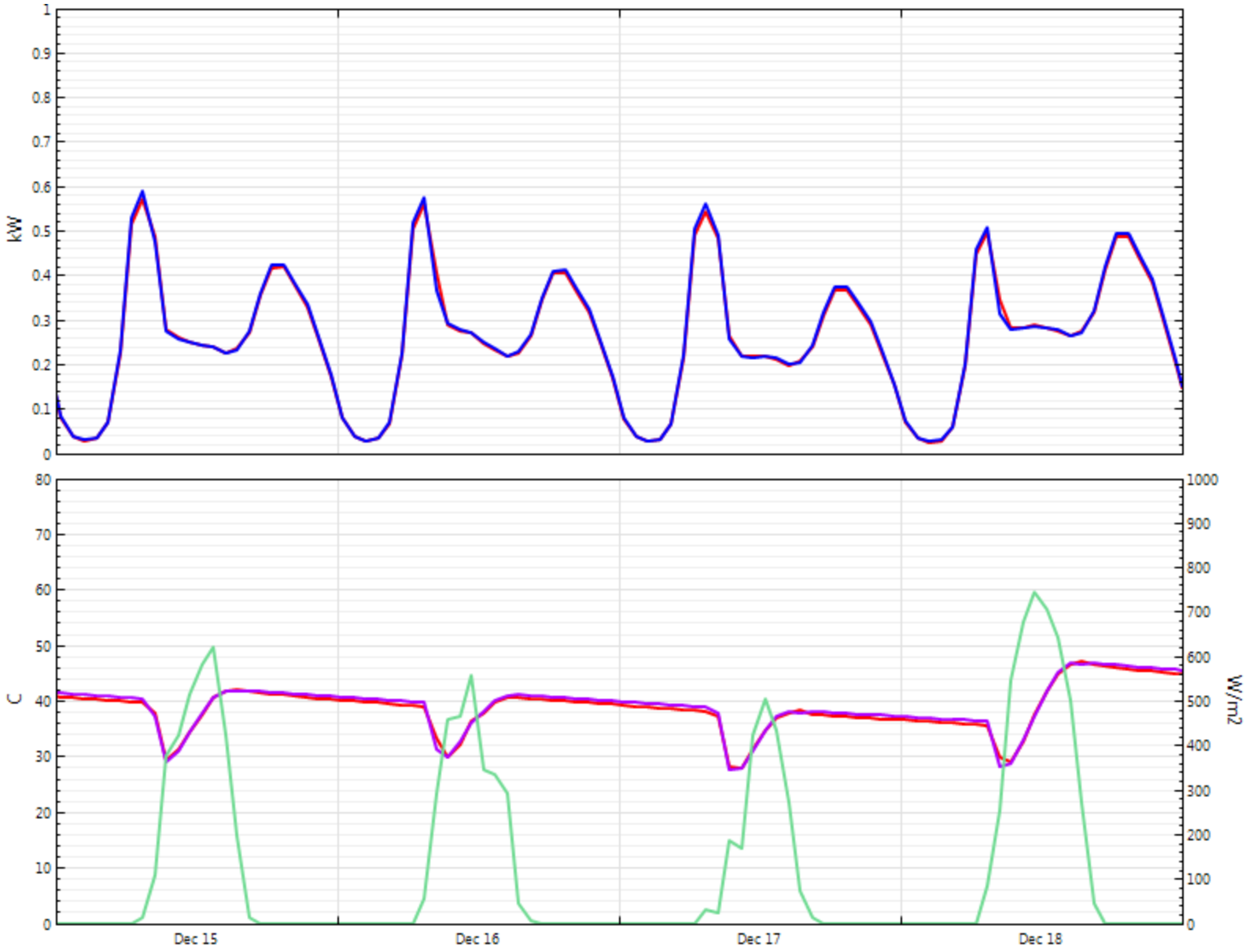
October



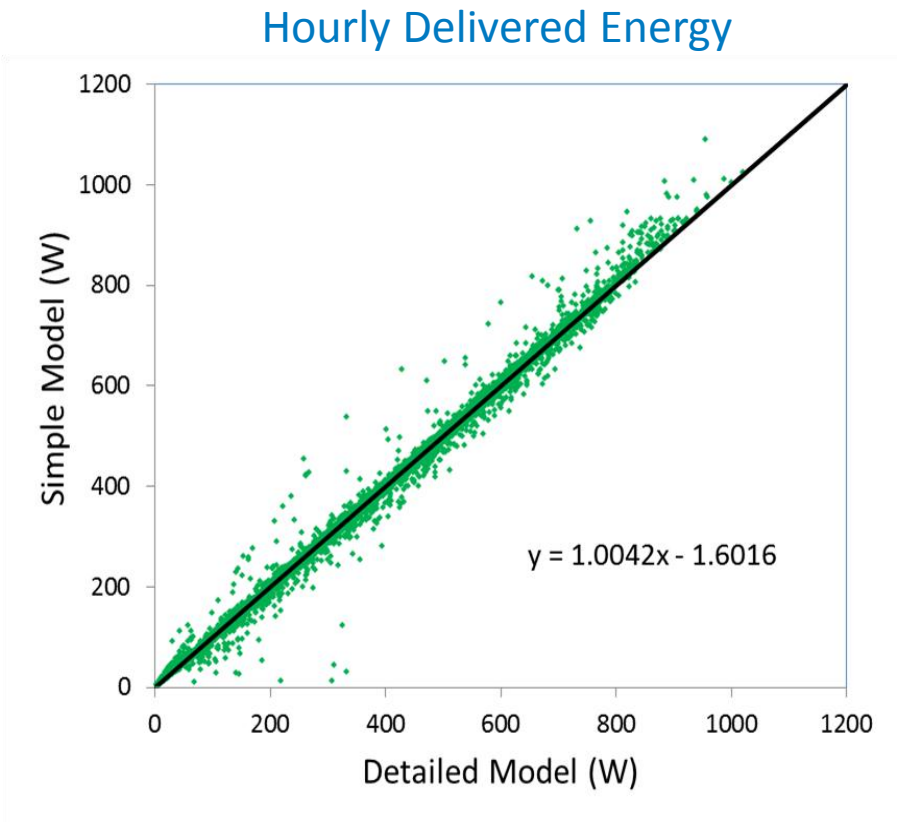
November



December

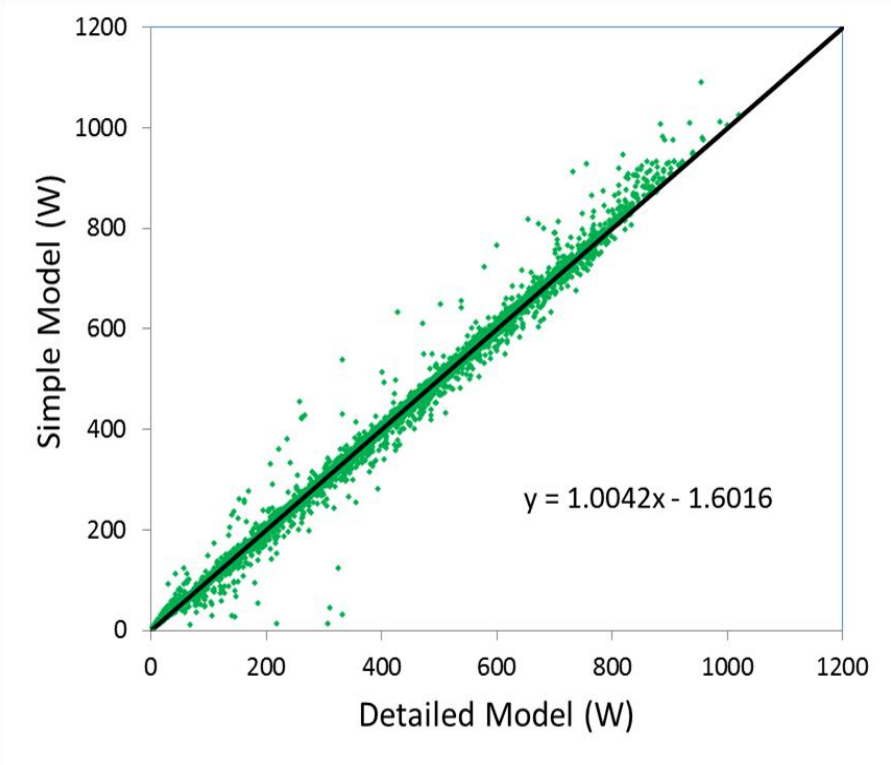


Hourly and Daily Delivered Energy

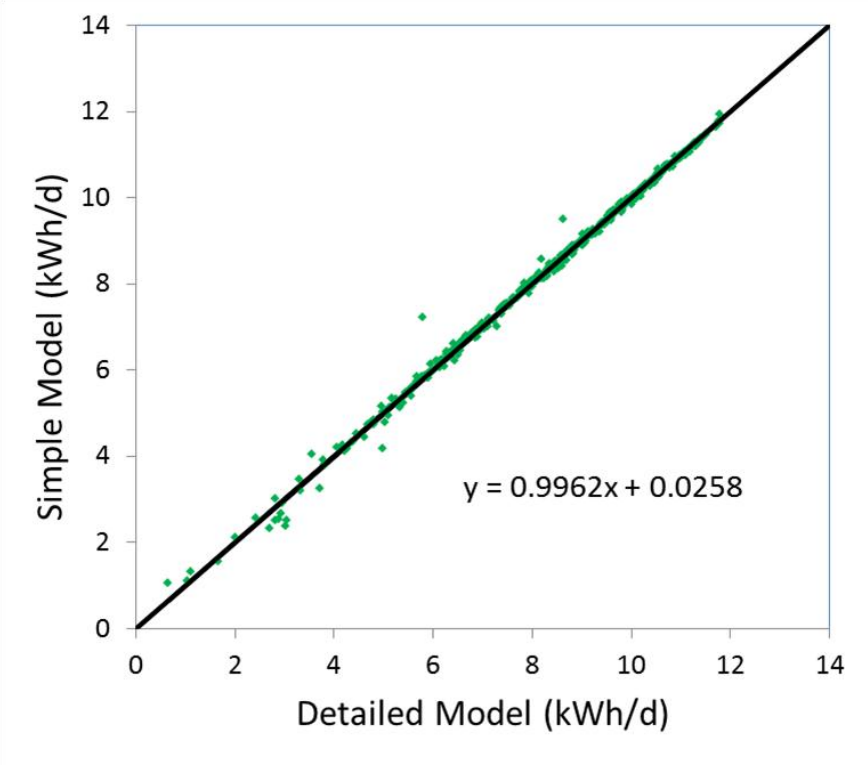


Hourly and Daily Delivered Energy

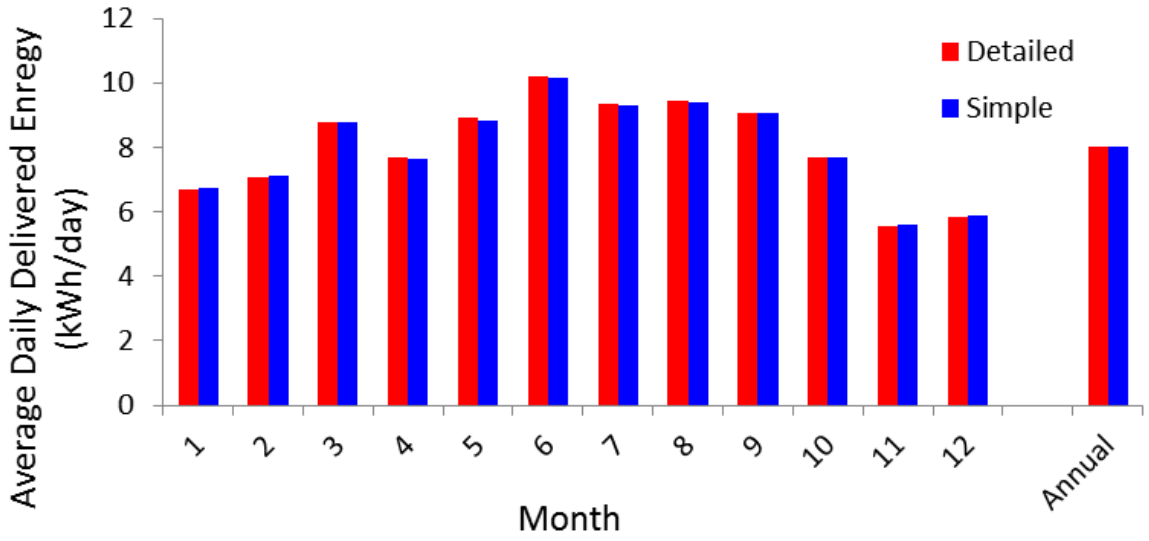
Hourly Delivered Energy



Daily Delivered Energy



Monthly Delivered Energy and Differences



	Tank Nodes (#)	Time Step (min)	Run Time (sec)	Bias Error (%)	Hourly RMSE (%)	Daily RMSE (%)
TRNSYS*	100	0.6	1266	--	--	--
TRNSYS	10	15	42	-2.82	7.06	3.21
TRNSYS	10	60	22	-6.92	14.46	7.64
Simple*	1,2	0.6	1.4	-0.06	4.70	1.80
Simple	1,2	15	0.6	1.01	5.70	2.68
Simple	1,2	60	0.5	1.92	8.25	2.78

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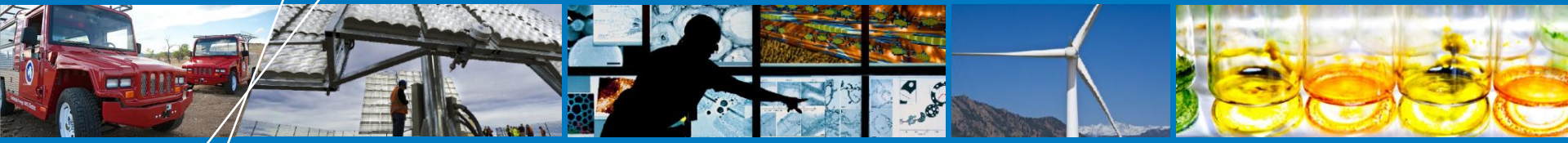


Conclusions

Conclusions

- Simple SWH simulation model with multi-mode tank:
  - Charging (single node, stratified)
  - Discharging (two variable-volume nodes)
  - Startup (two variable-volume nodes, top/down mixing)
- Excellent agreement with detailed TRNSYS model
- Simple, fast, easy and portable

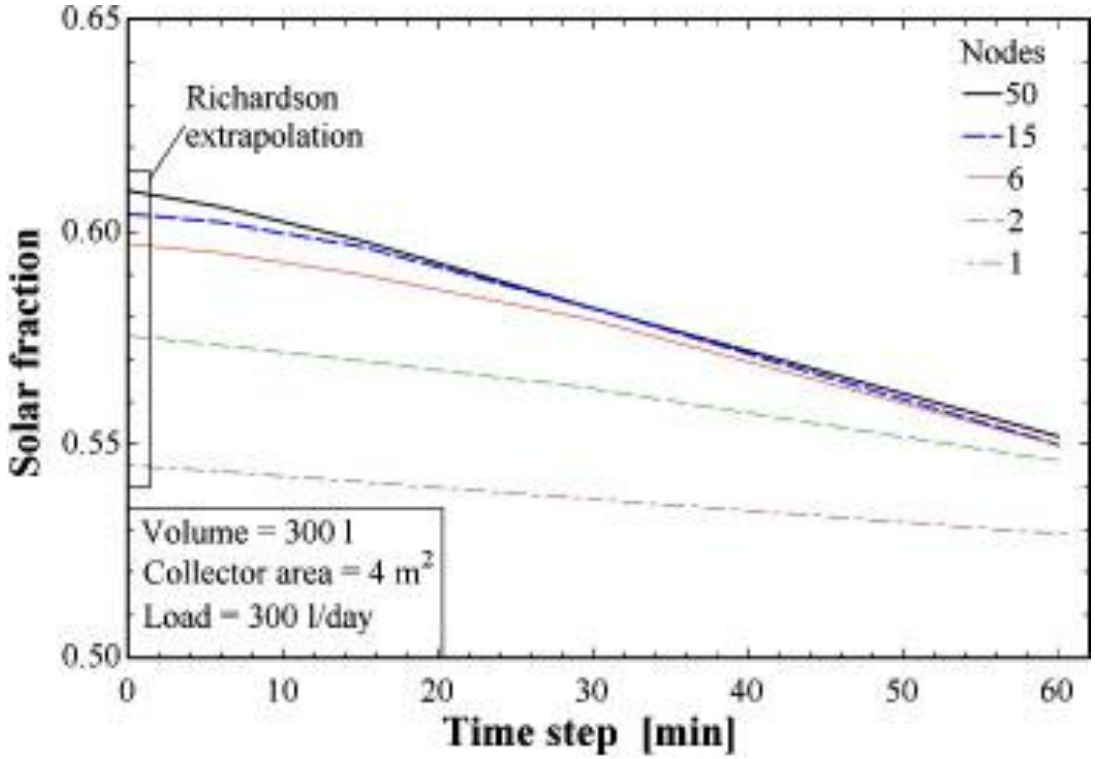
Future Work

- Other climates
- Other systems configurations

Thank you!

craig.christensen@nrel.gov

Effect of Time Step on Annual Solar Fraction



From: Arias DA, McMahan AC and Klein SA. Sensitivity of Long-Term Performance Simulations of Solar Energy Systems to the Degree of Stratification in the Thermal Storage Unit: International Journal Of Energy Research, 2008; 32:242–254 (www.interscience.wiley.com)

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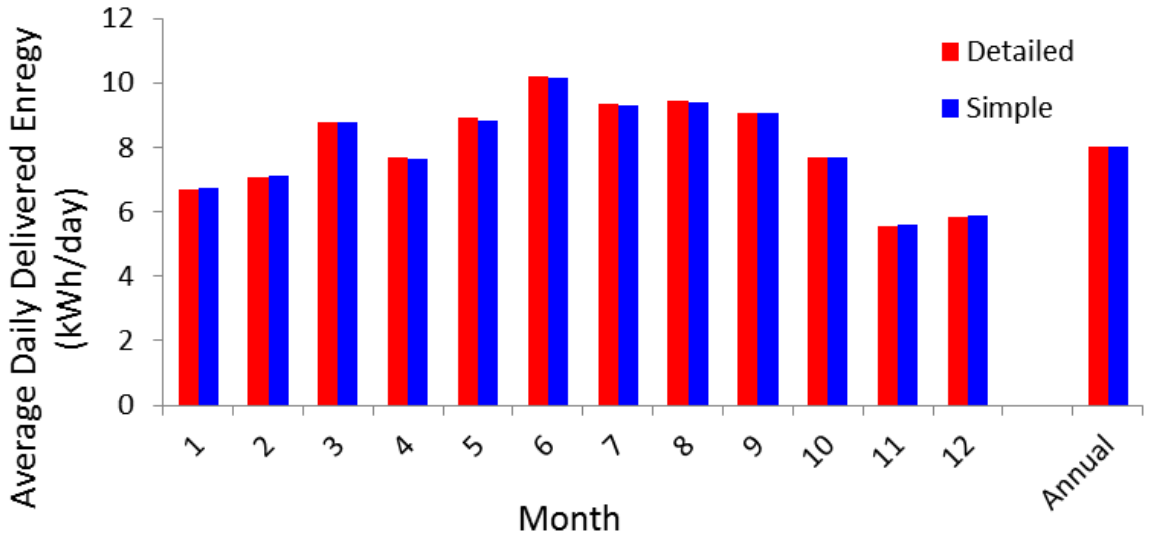

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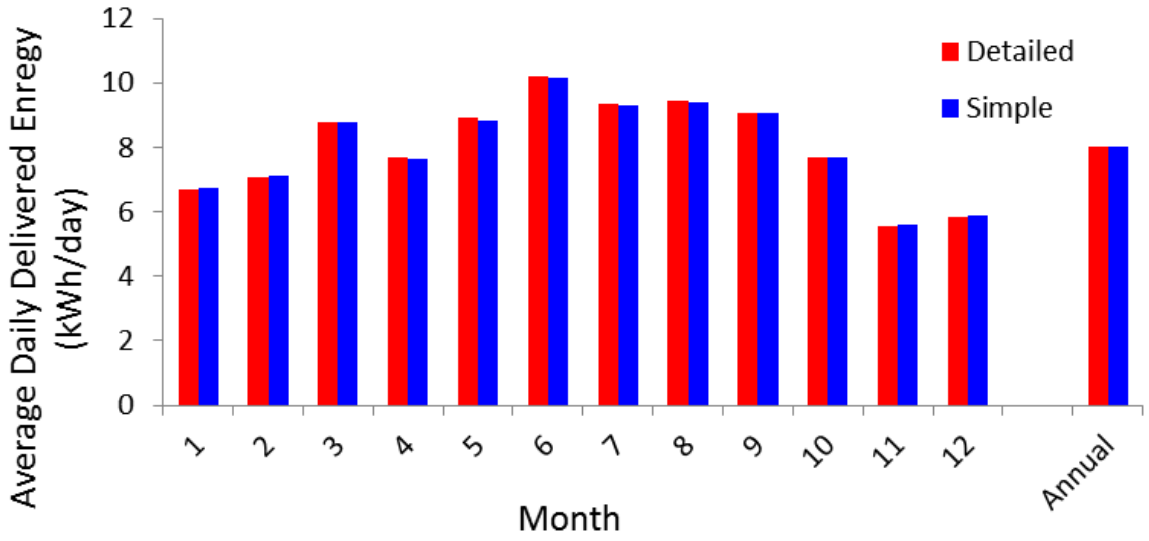

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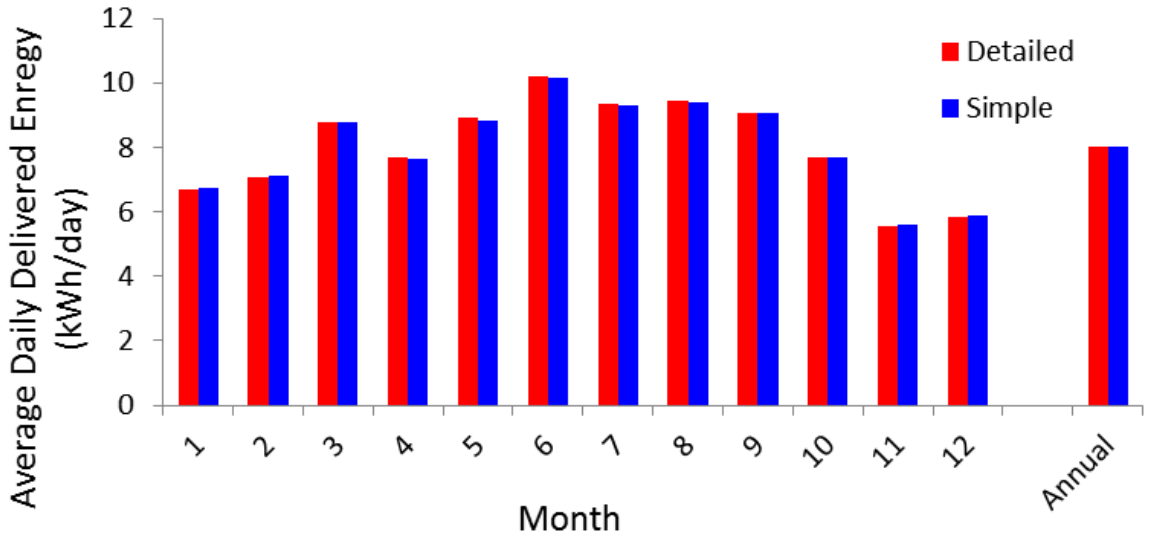

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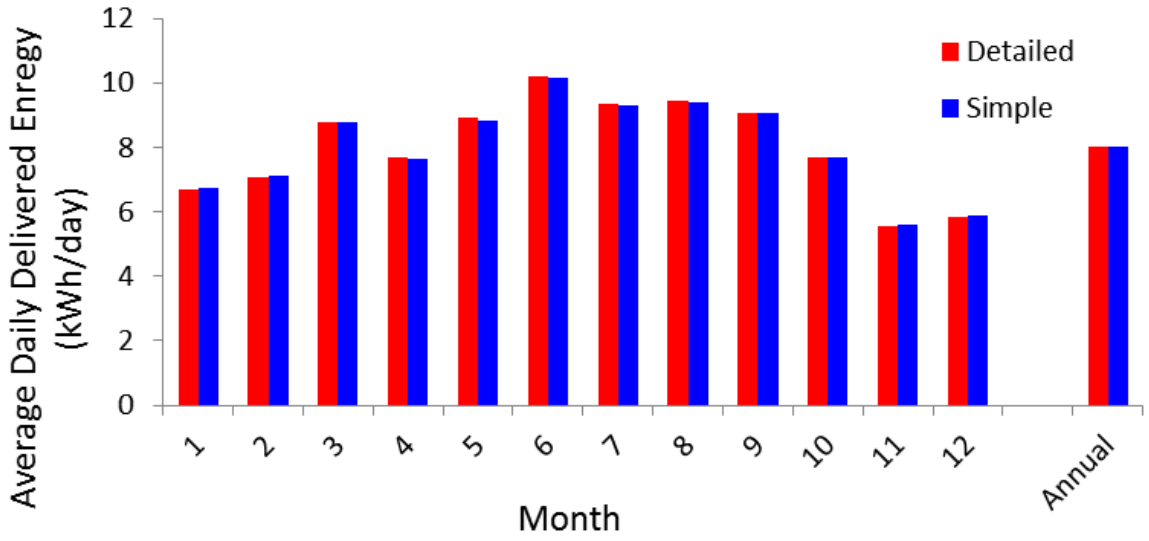

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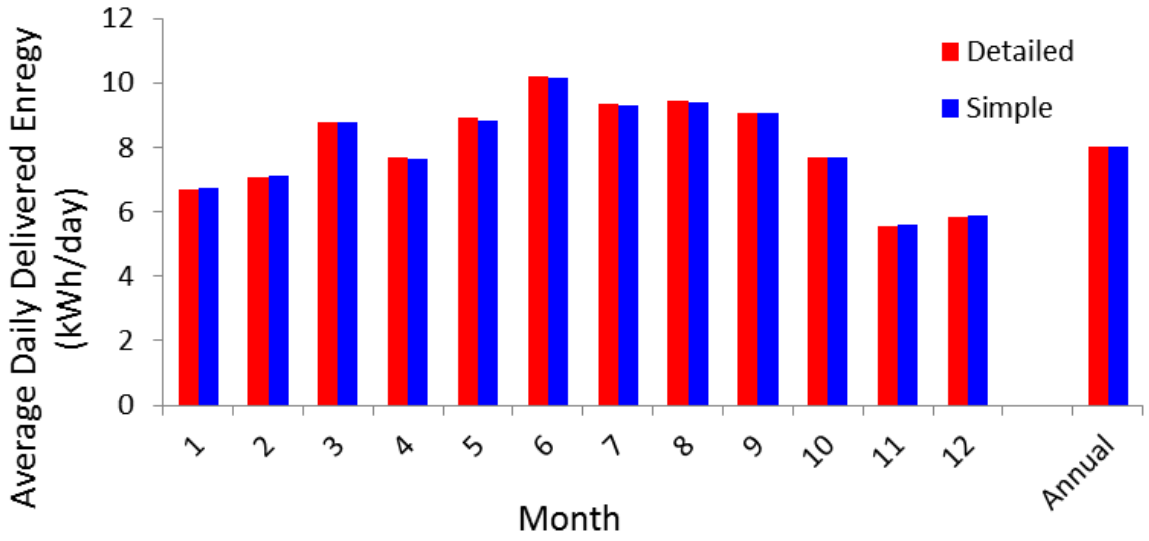
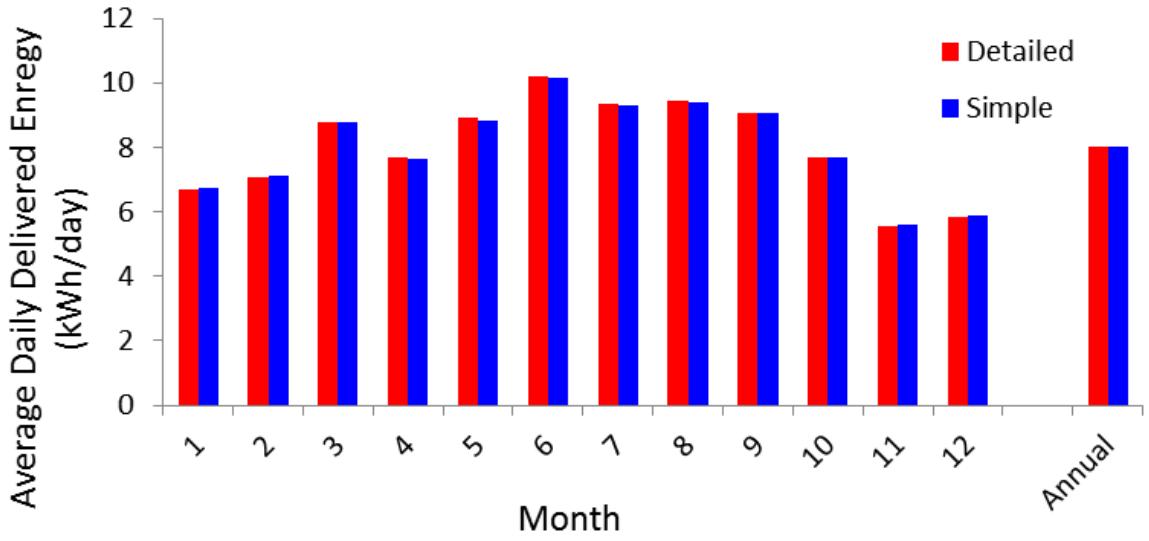
Monthly Delivered Energy and Differences



	Tank Nodes (#)	Time Step (min)	Run Time (sec)	Bias Error (%)	Hourly RMSE (%)	Daily RMSE (%)
TRNSYS*	100	0.6	1266	--	--	--
TRNSYS	10	15	42	-2.82	7.06	3.21
TRNSYS	10	60	22	-6.92	14.46	7.64
Simple*	1,2	0.6	1.4	-0.06	4.70	1.80
Simple	1,2	15	0.6	1.01	5.70	2.68
Simple	1,2	60	0.5	1.92	8.25	2.78

Monthly Delivered Energy and Differences



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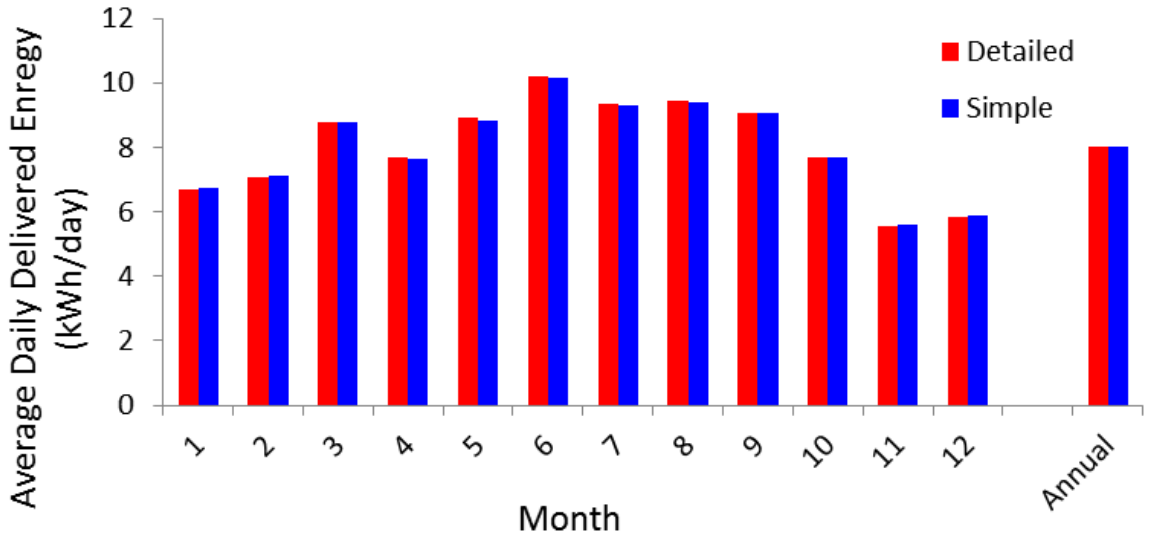
Monthly Delivered Energy and Differences



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