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Modeling and simulation of solar ORC system for regional feasibility test

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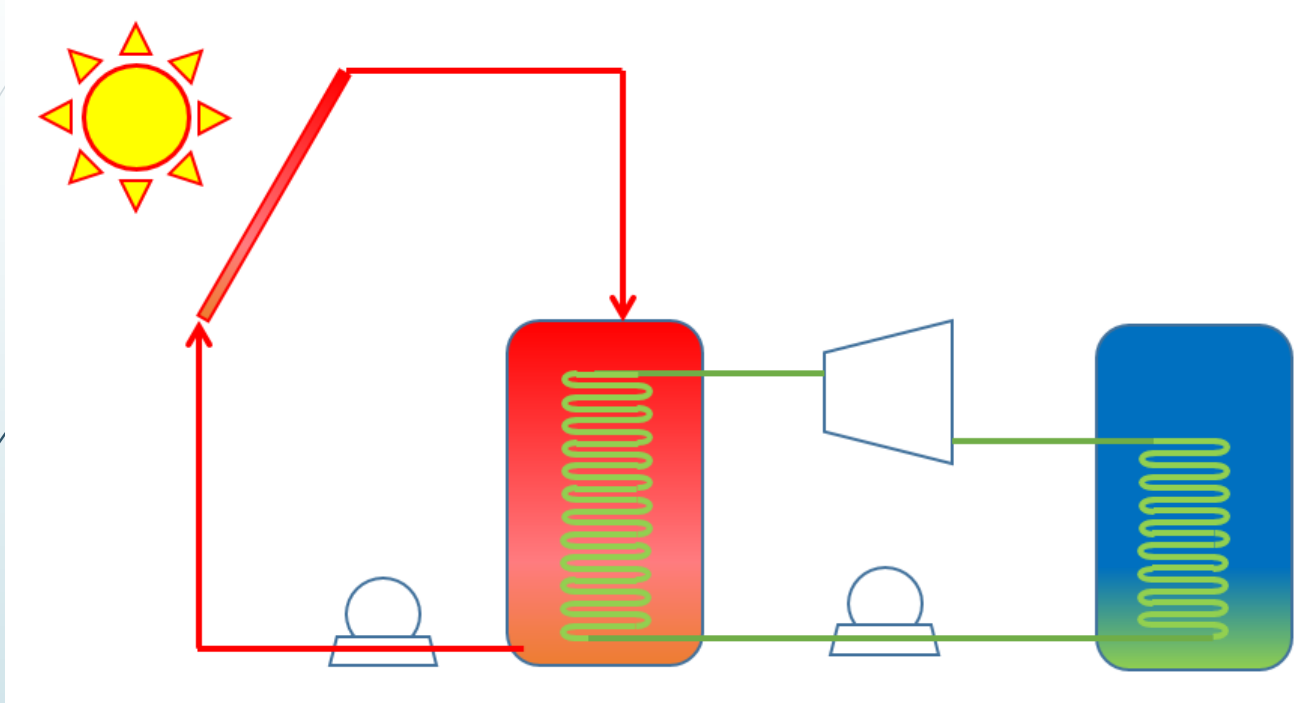
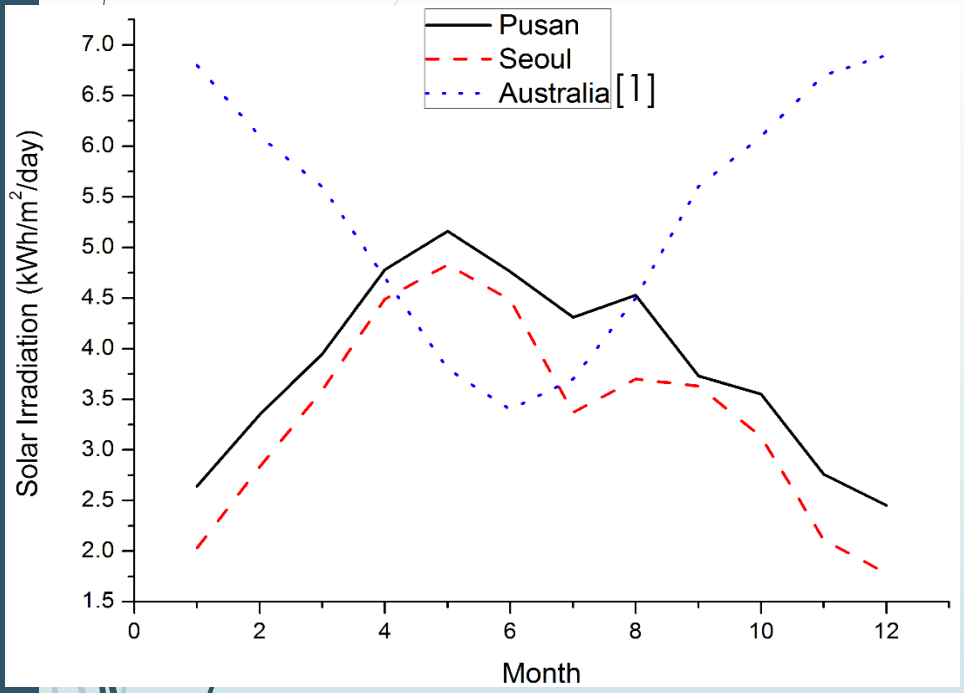
Contents

Target system

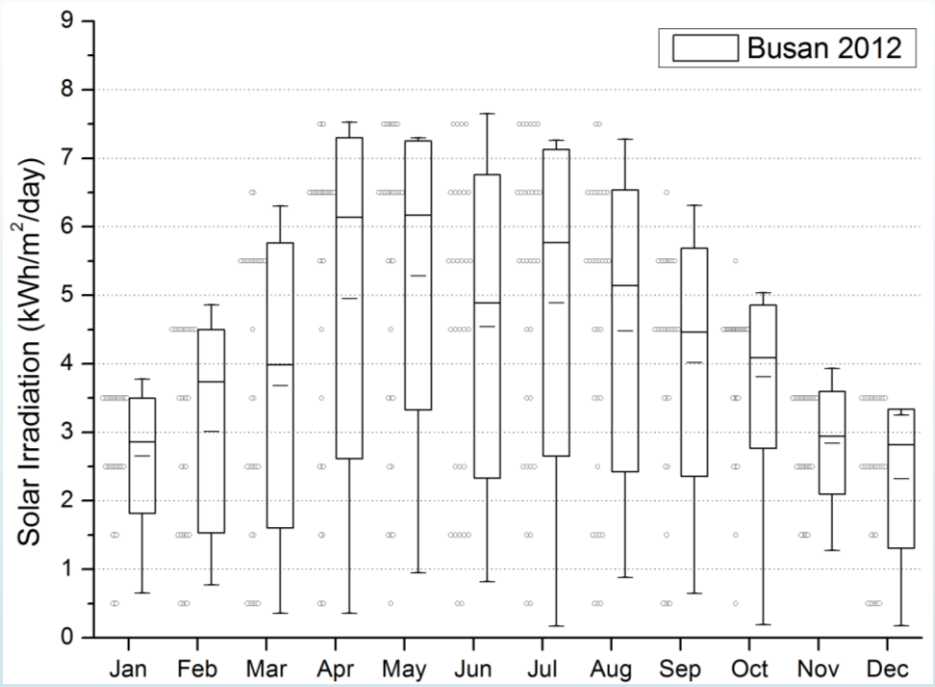


- Solar ORC with Storage tank and R245fa refrigerant
- Test feasibility of Solar ORC system by dynamic simulation of ORC system

Background



Monthly Solar Irradiation

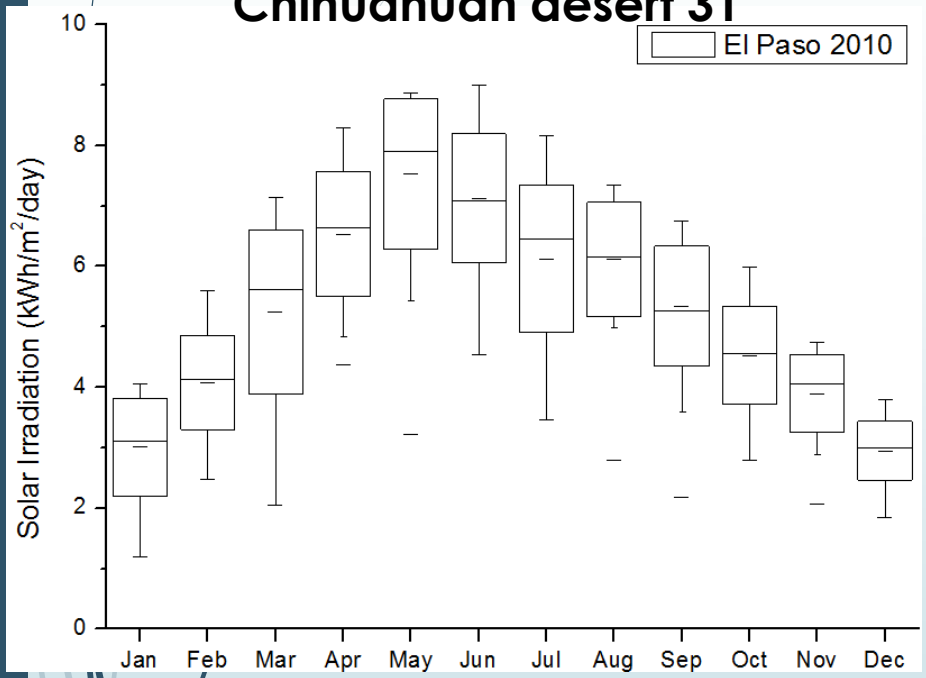


Monthly Solar Irradiation and Every day distribution

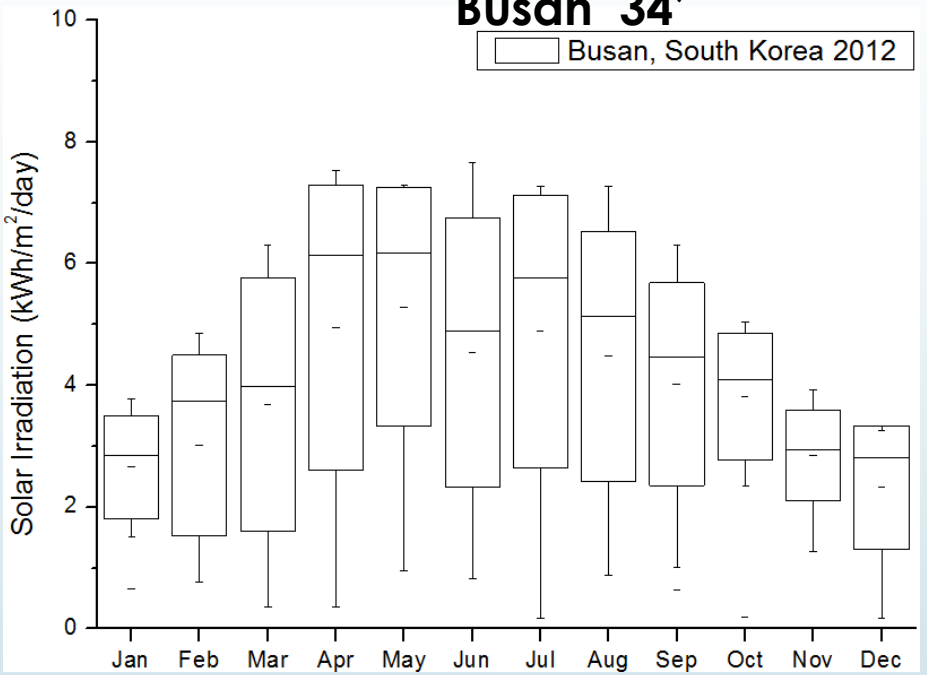
- Current Solar ORC system is developed at monthly averaged daily dynamic simulation.

Weather variation

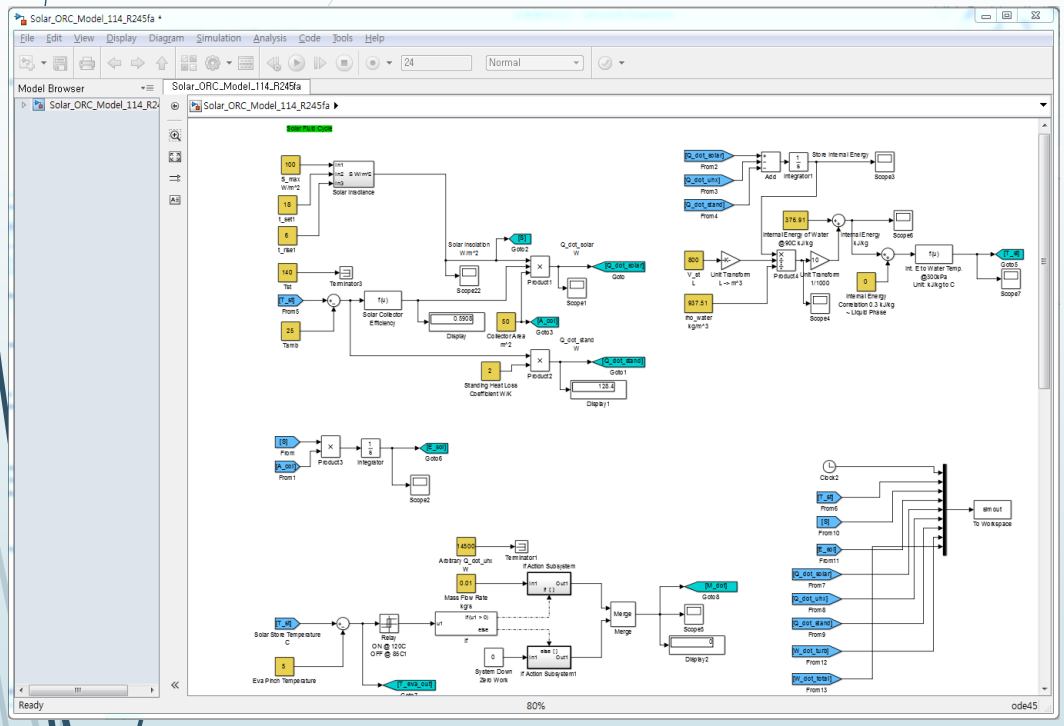
Chihuahuan desert 31'



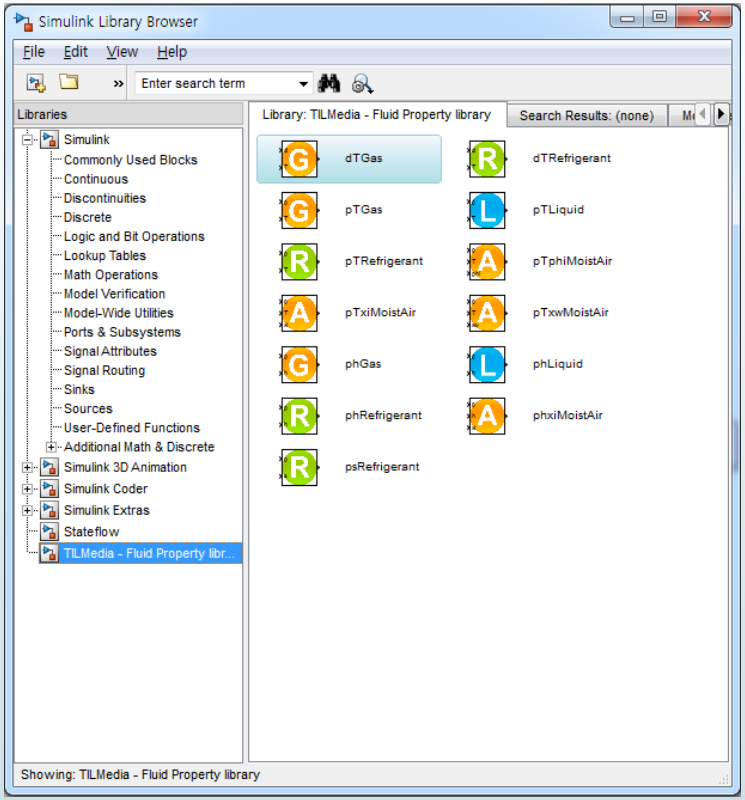
Busan 34'



Modeling



Modeling in MATLAB/Simulink

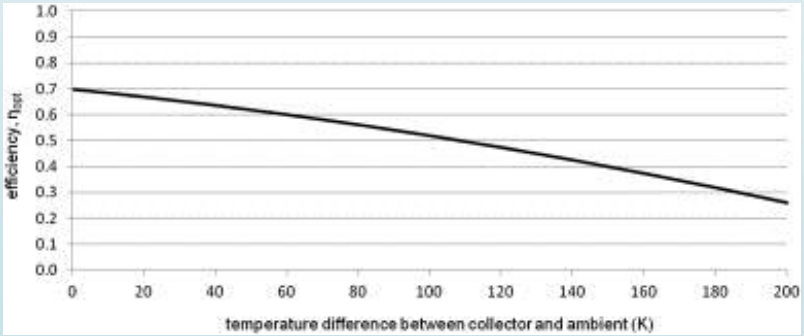


Fluid Package: REFPROP with TilMedia Suit

Solar Cycle

$$\frac{dU_{st}}{dt} = \dot{Q}_{sol} - \dot{Q}_{ORC} - \dot{Q}_{stand} \qquad [1]$$

- ✓ 50m^2 solar collector area
- ✓ 800L solar storage
- ✓ Standing heat dissipation 2W/K

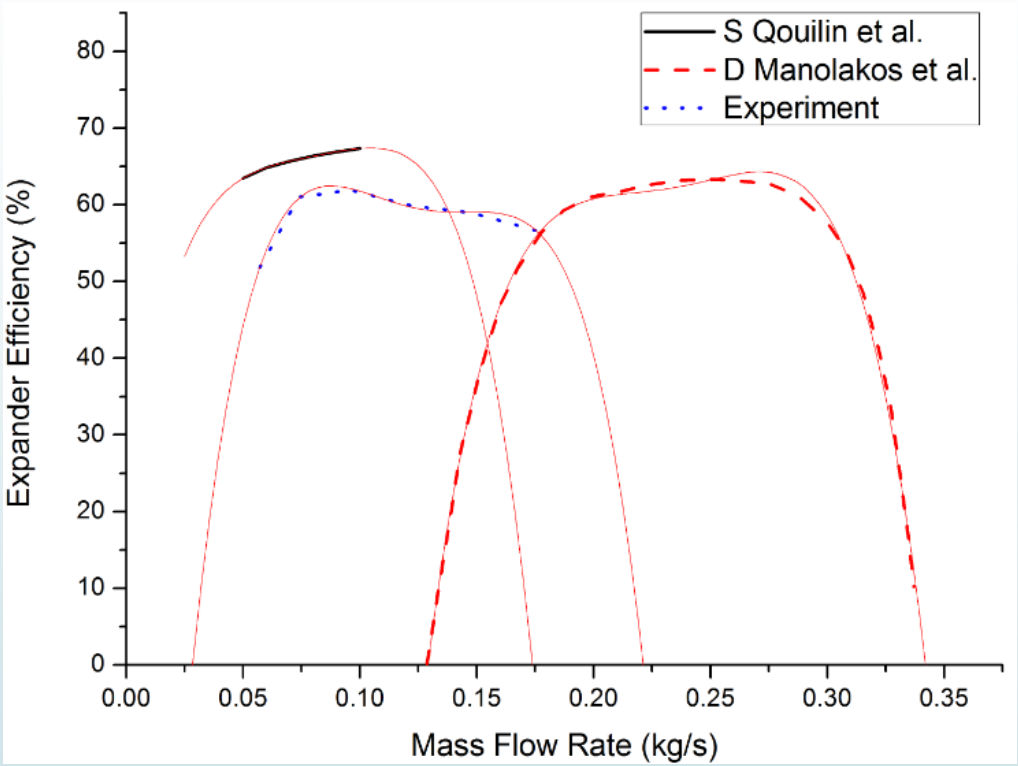


Solar Collector Efficiency Curve

ORC Cycle

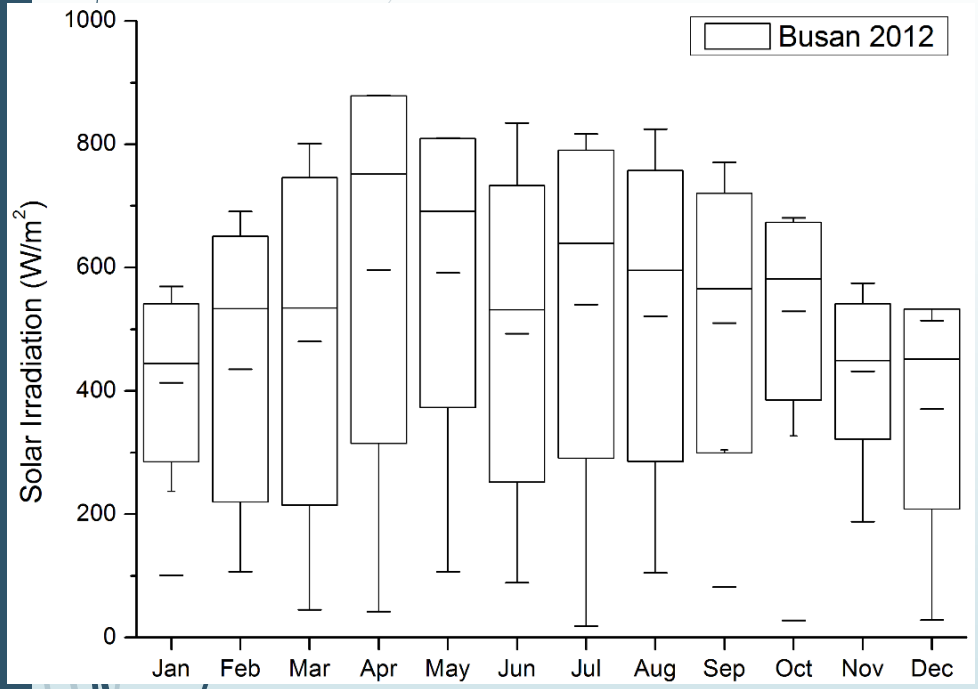
- R245fa
- Fixed cycle
  - Evaporate at 6 bar (70.0C)
  - Condense at 2 bar (33.4C)
- System operation start at 125C
- System operation end at 85C

Scroll Expander Modeling

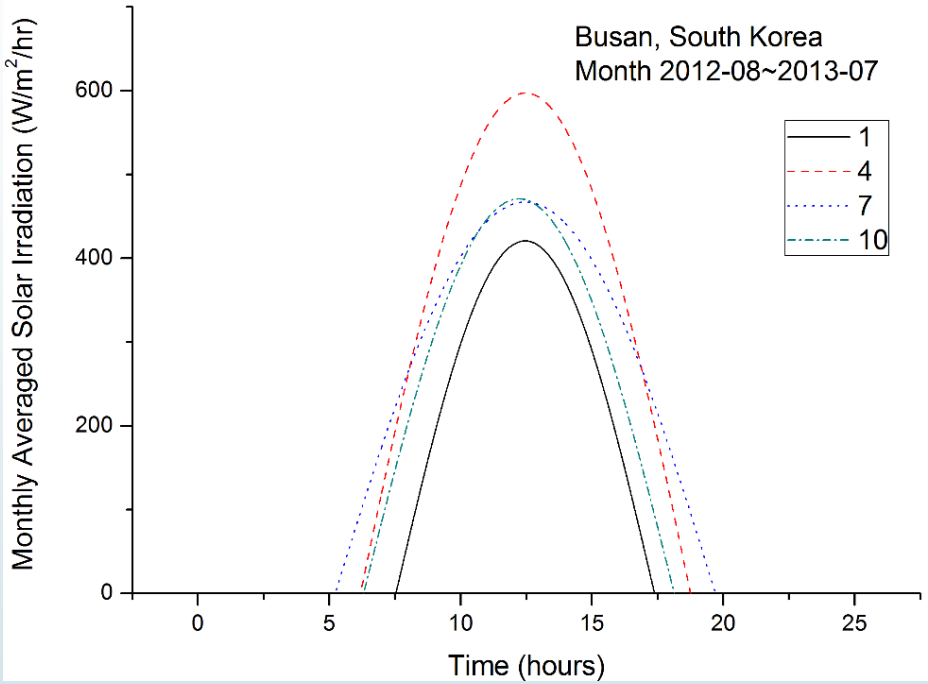


In experiment large operating range can be possible but it must be limited due to safety issue
In simulation 60% of maximum operating mass flow rate is applied

Weather Analysis



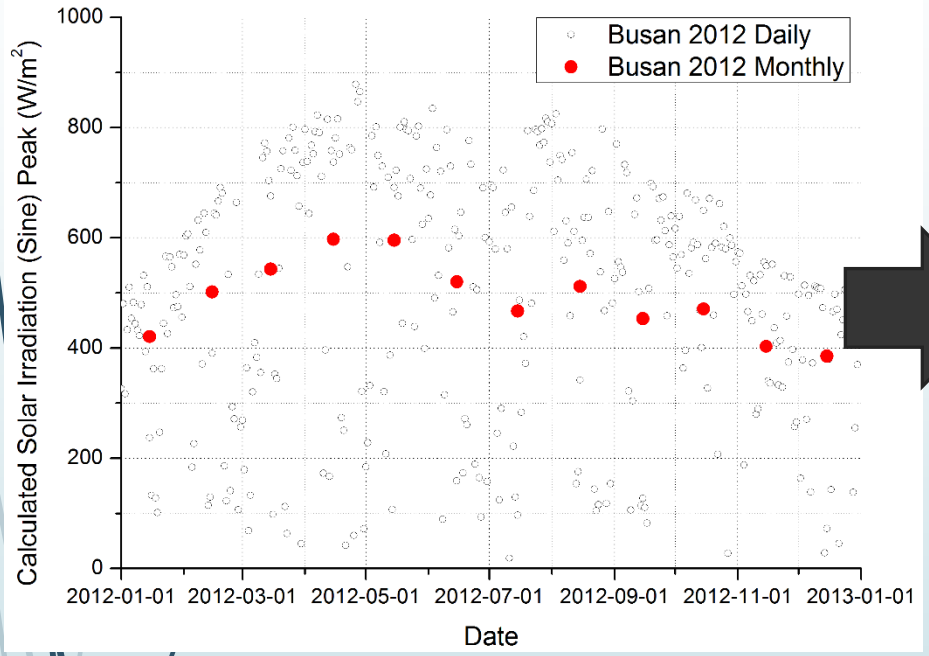
Re-organized solar irradiation



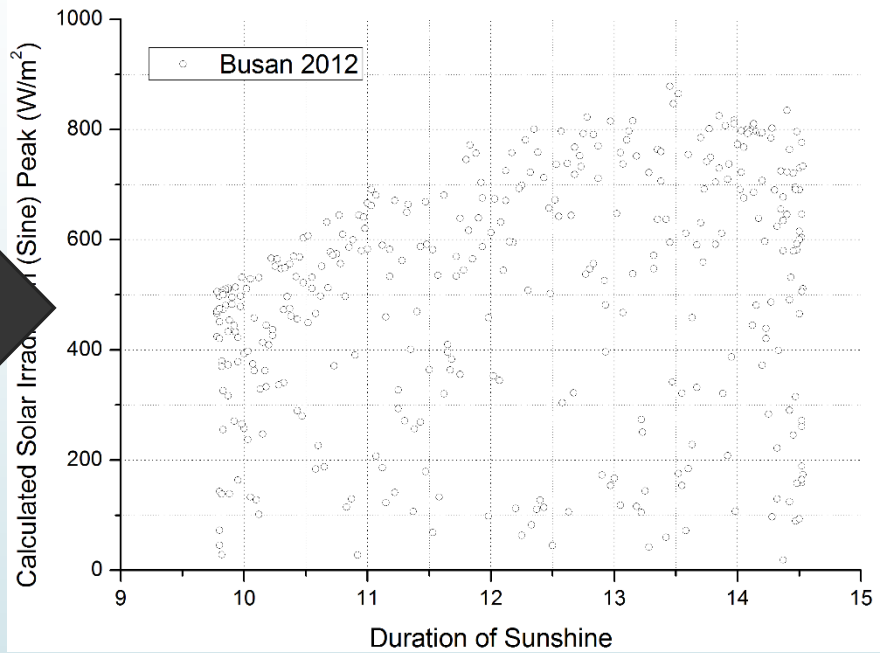
Daily Irradiation Curve

- Weather data is re-organized by sine fitting.

Annual Irradiation Classification



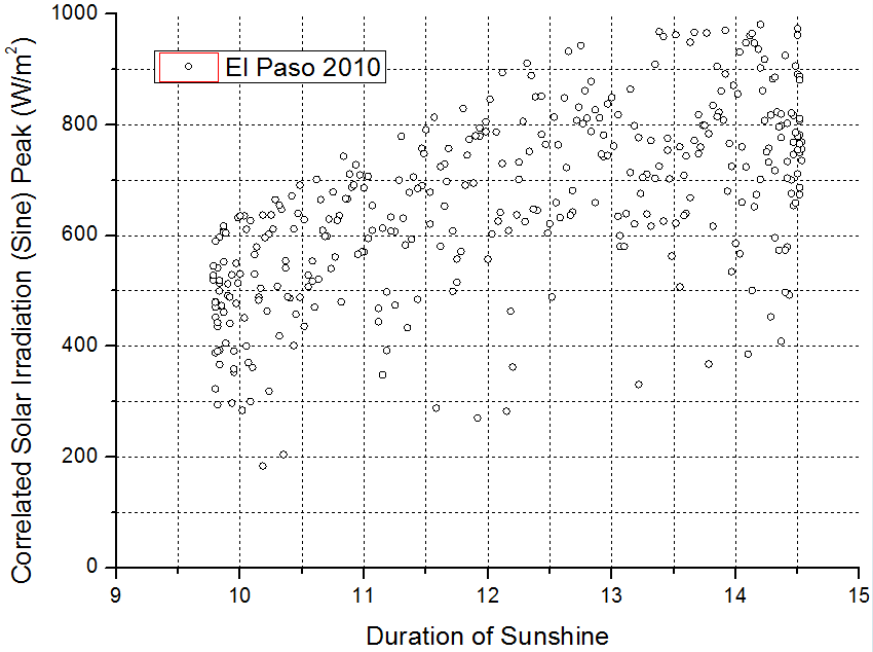
Annual variation of solar irradiation

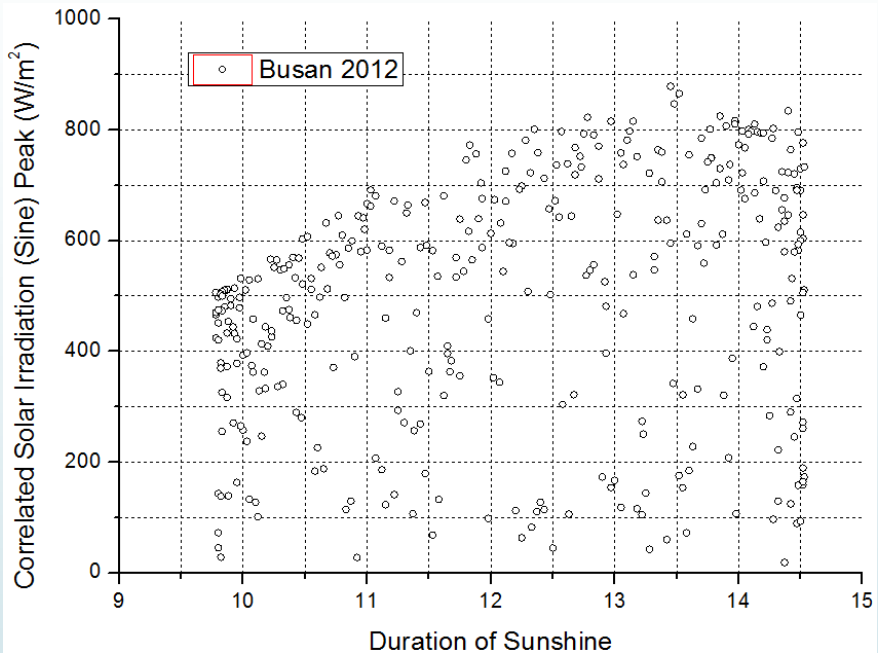


Duration of sunshine vs. solar irradiation

- ✓ Weather can be classified with season (duration of sunshine and ambient temperature) and daily solar irradiation amounts.

Annual Irradiation Classification

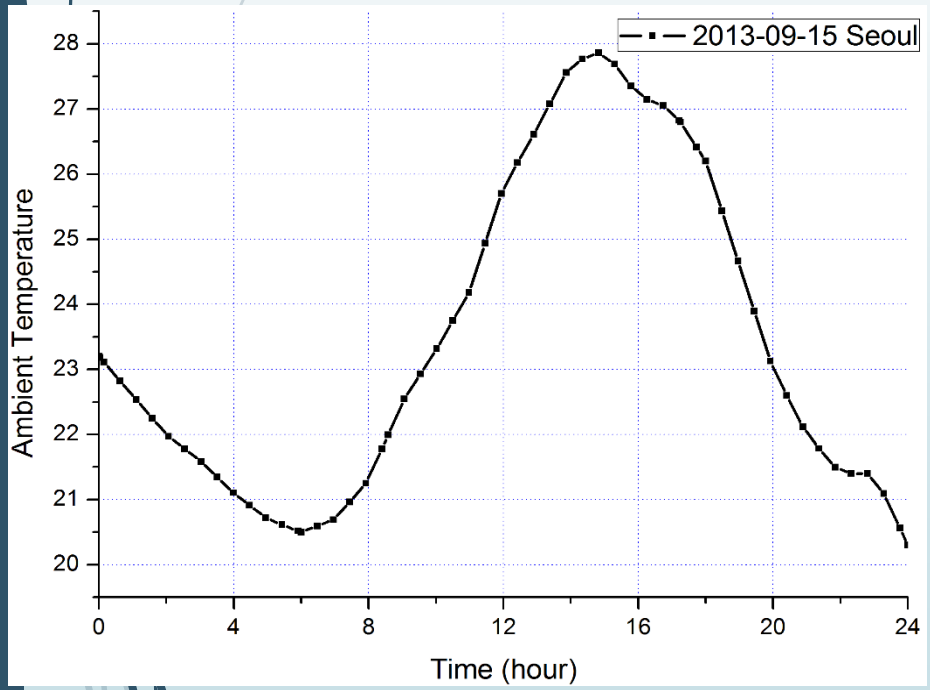


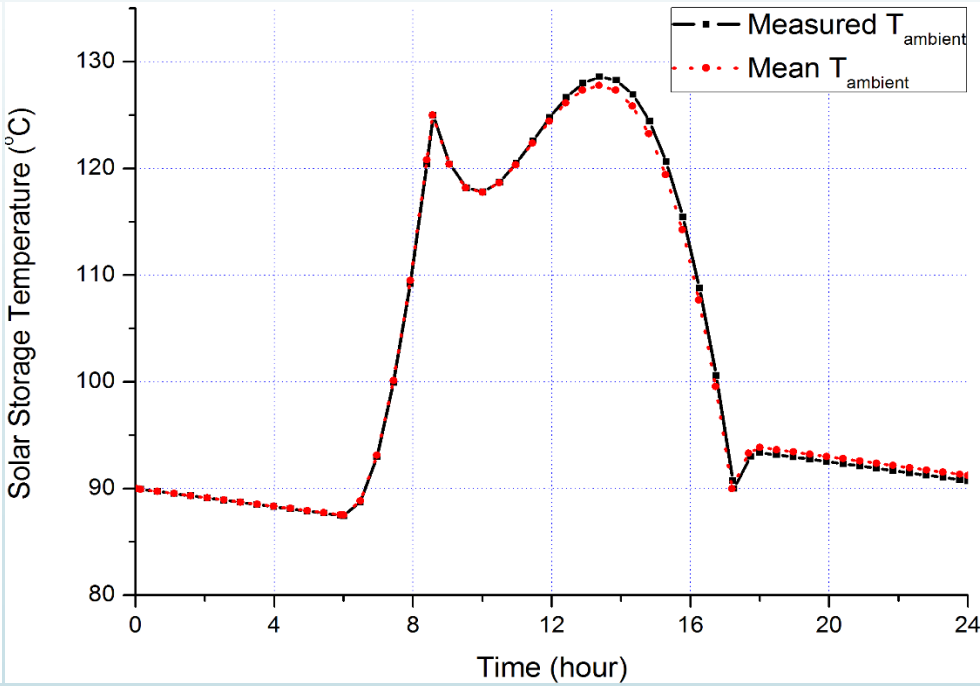


- ✓ In El Paso (desert), solar irradiation distribution is concentrated to fine weather condition.
- ✓ In Busan (city), the distribution is very large.

Ambient Temperature Effect

- Mean temperature and measured temperature effect comparison

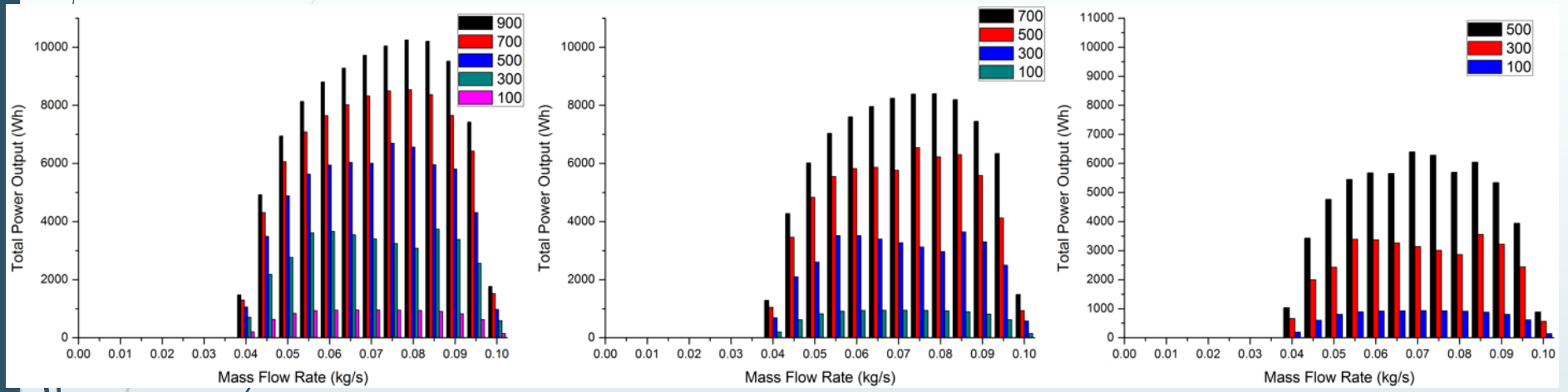




Measured temperature

Effect of temperature

Single Expander Operation



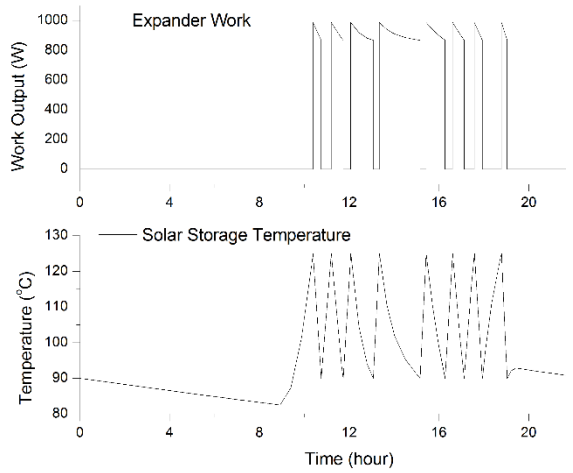
Summer
14 hours of duration of sunshine
25 °C

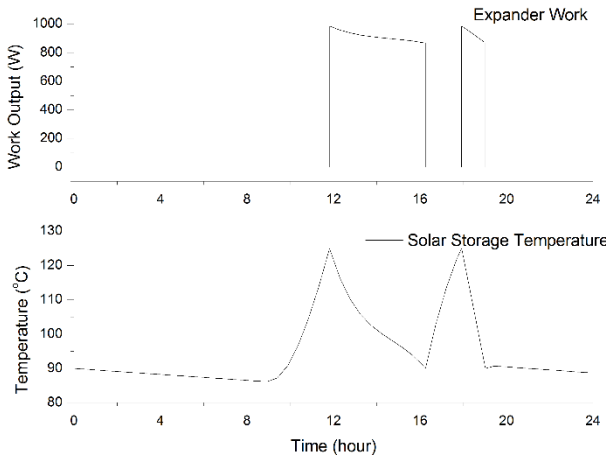
Spring & Fall
12 hours of duration of sunshine
15 °C

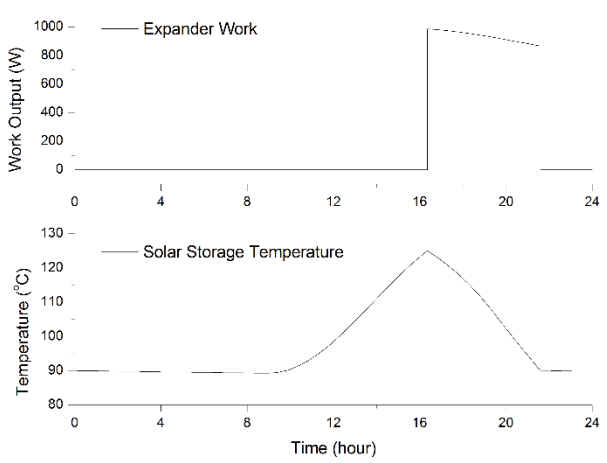
Winter
10 hours of duration of sunshine
5 °C

1. Scroll expander can be appropriate for large range of solar heat flow
2. When solar irradiation is small, optimum operation mass flow of system is shifted into left (maximum power output at low flow rate)

On/off Fluctuation







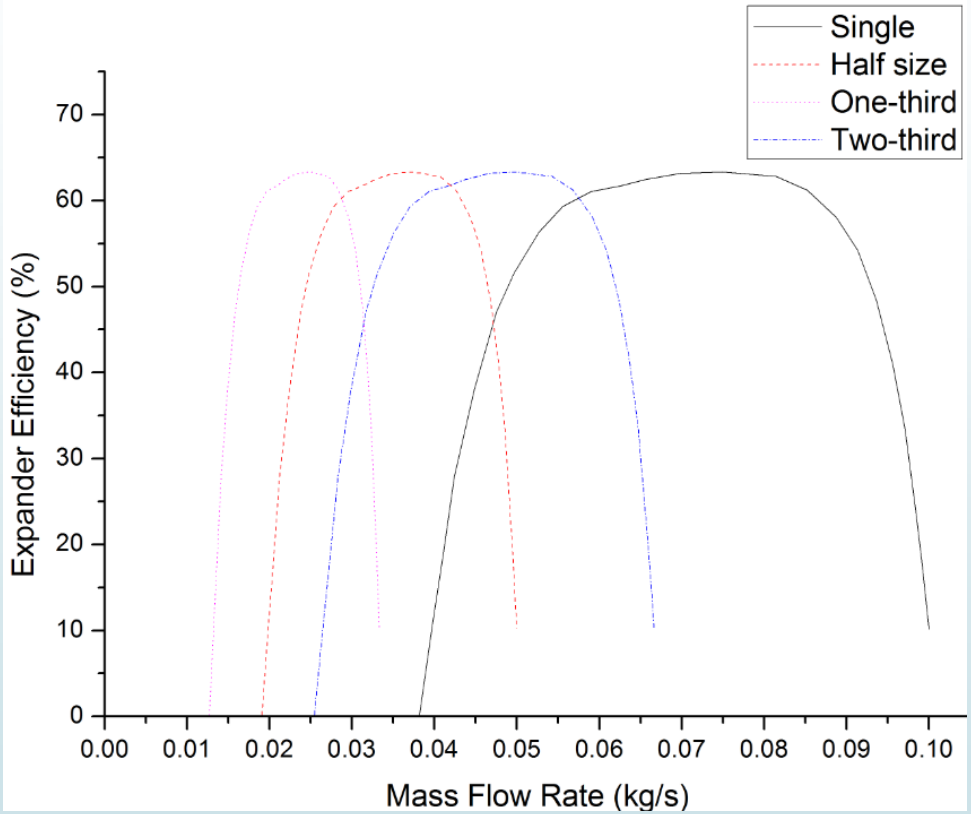
Water storage: 200L

Water storage: 800L

Water storage: 4000L

- ✓ If mass flow rate is overbalanced, the speed of heat consumption in solar storage is very high then on/off fluctuation is occurred due to small capacity of solar storage robustness

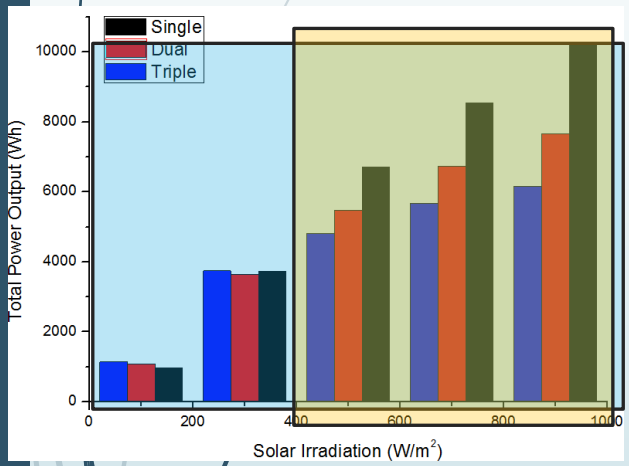
Expander sizing



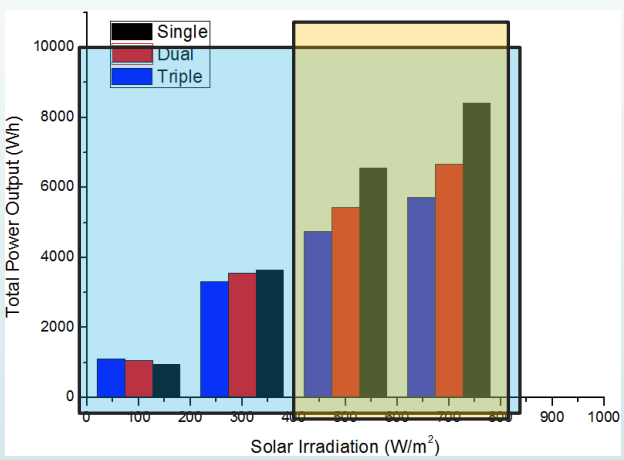
✓ Expander efficiencies duplicated from single expander

Seasonal Comparison

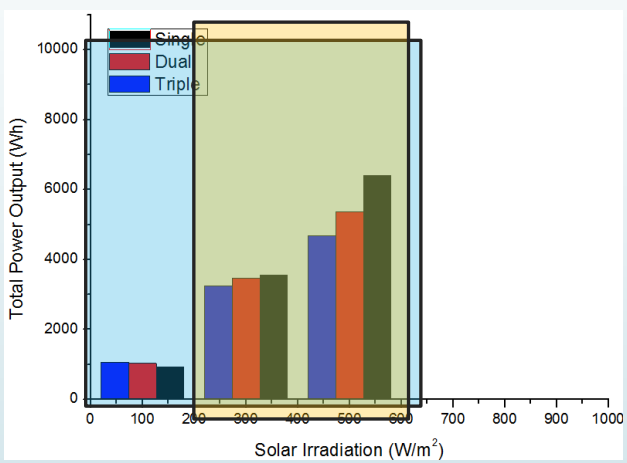
Maximum Power Output Comparison



Summer



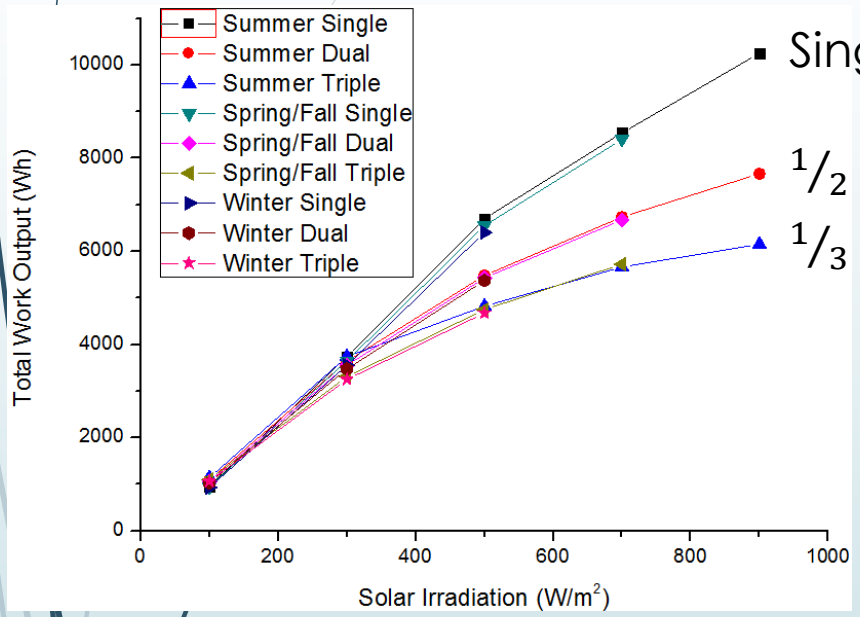
Spring/Fall



Winter

- Desert: Region with low weather variation
- City: Region with large weather variation

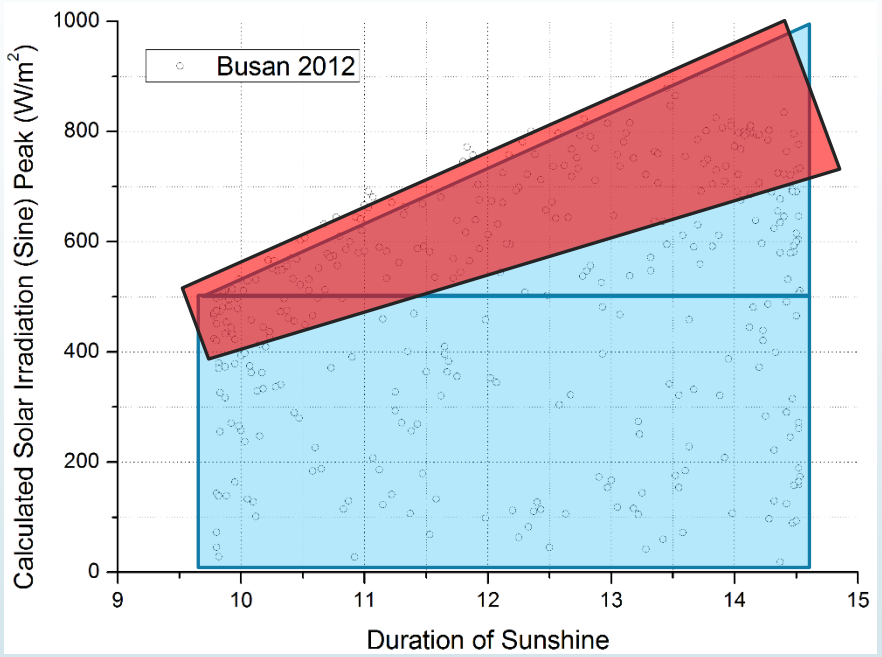
Regional feasibility test



Single

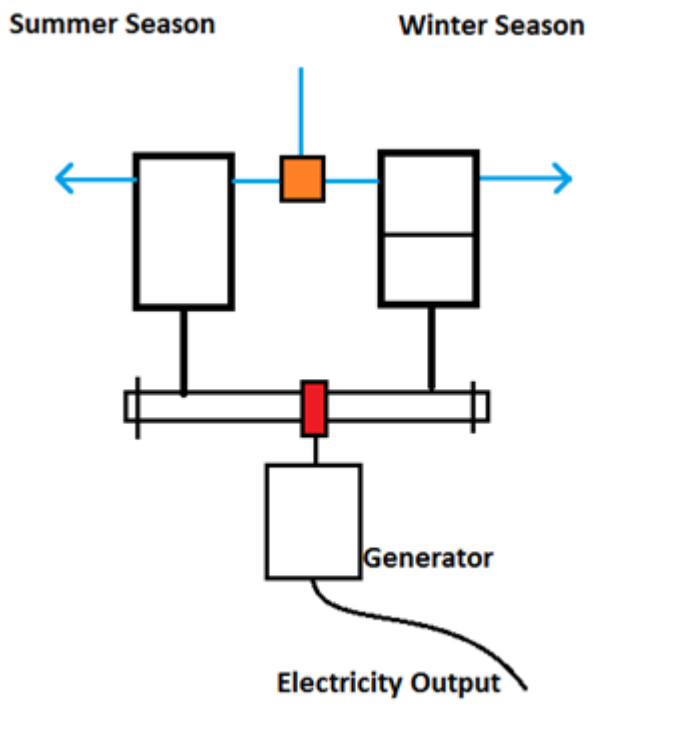
$^1/_2$ size

$^1/_3$ size

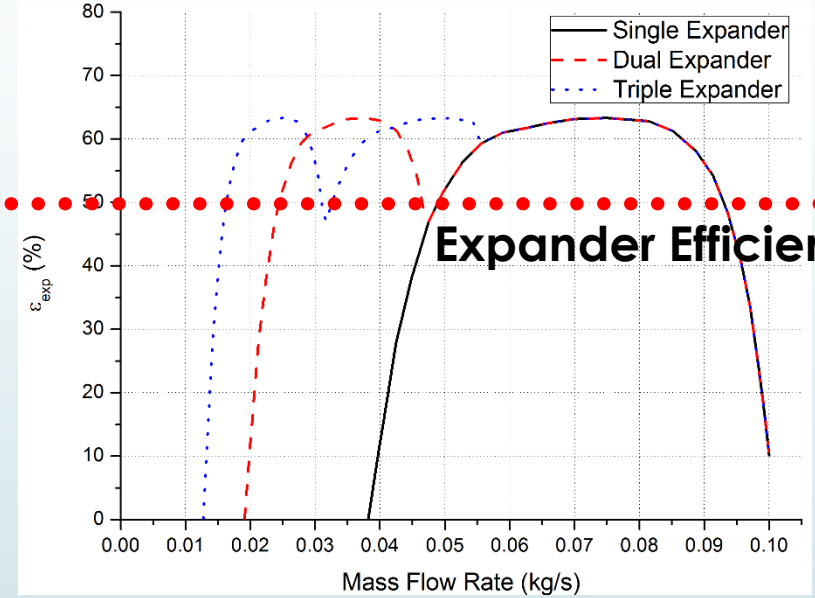


- Weather fluctuation is small: single scroll expander with small size storage tank is possible
- Weather fluctuation is large: single scroll expander can draw power but system fluctuation is occurred
- Small size dual and triple expander can overcome without installing large size solar storage

Multi expander



Expander Modeling



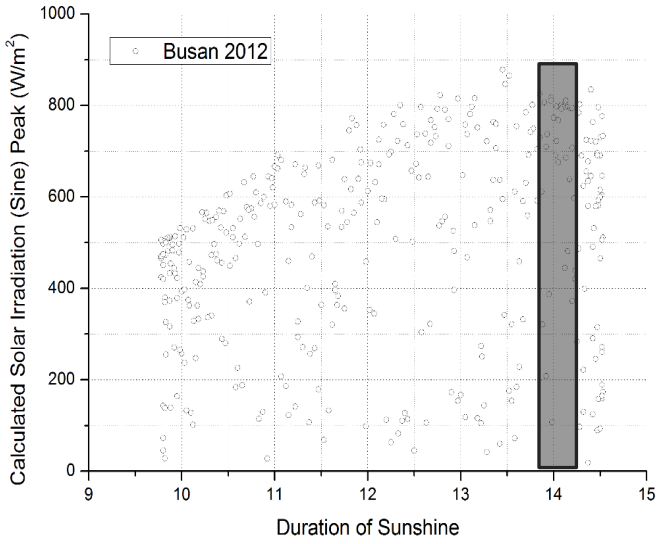
Expander Efficiency 50%

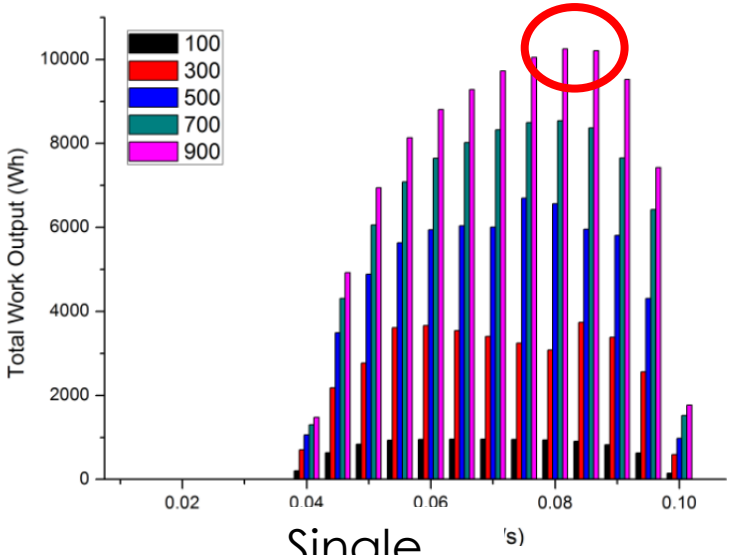
50% Efficiency line

- Single Expander: 0.48~0.93 kg/s
- Dual Expander : 0.24~0.93kg/s
- Triple Expander: 0.16~0.93kg/s

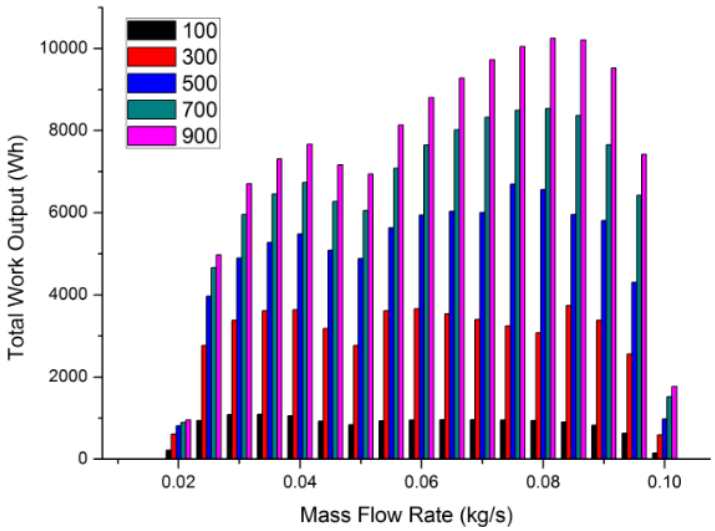
Expander efficiencies duplicated from single expander

Case study: Summer

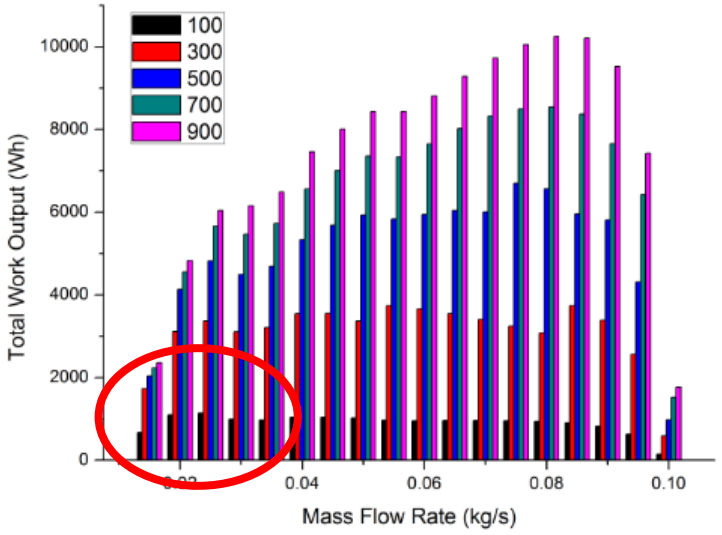




Single

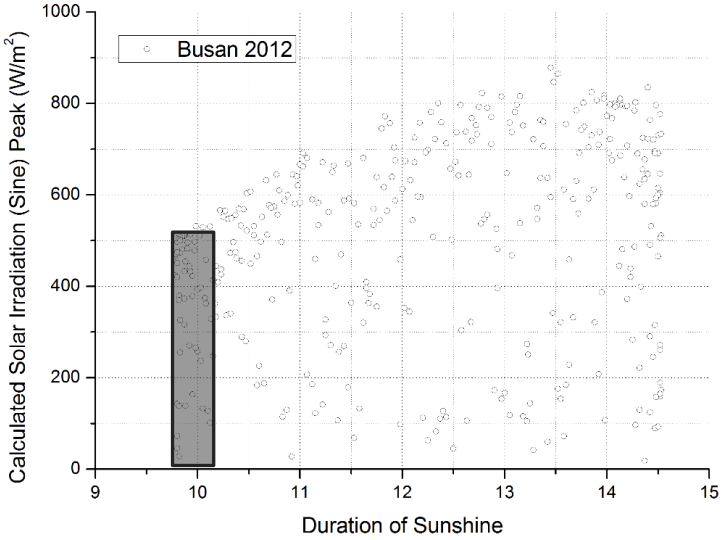


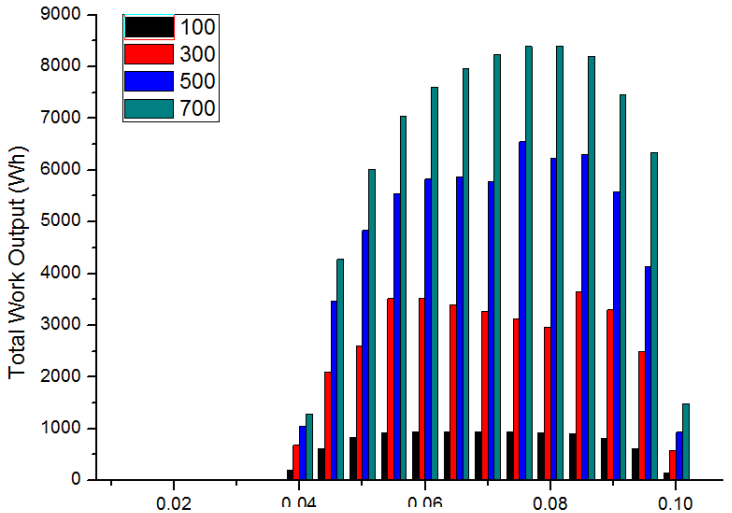
Dual



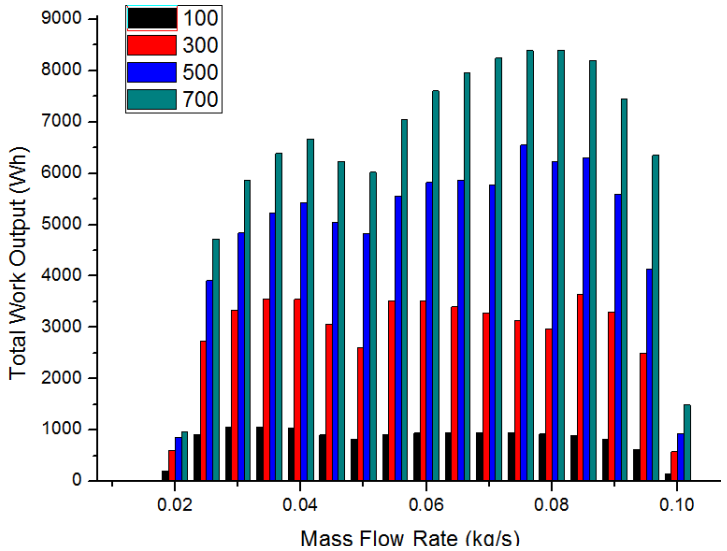
Triple

Case study: Winter

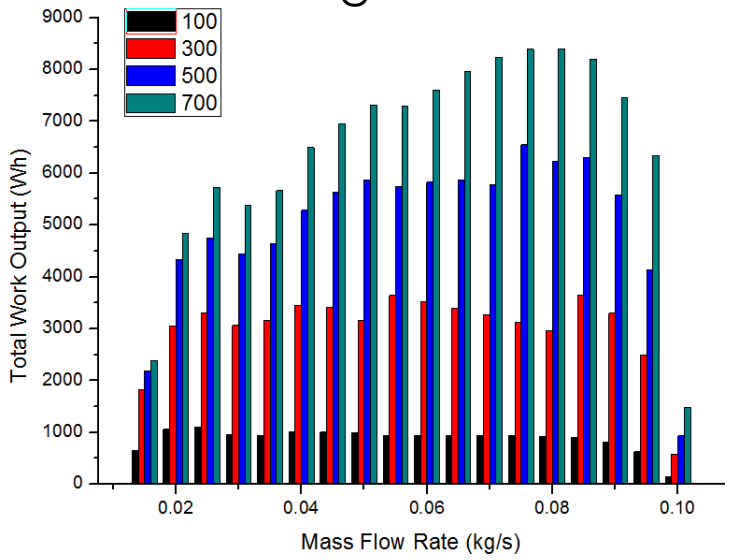




Single



Dual



Triple

Conclusion

- Performance analysis of various scroll expander sizing according to the variance of duration of sunshine and daily solar irradiation is performed.
- Total power output simulation shows designed-size scroll expander can be used in both big and small weather fluctuation area.
- In large weather variation area, system on/off control is occurred due to fast temperature decrease in solar storage. By sizing solar storage the fluctuation can be overcome.
- By introducing small-size multiple expander in parallel both power output and control can be overcome.

References

[1] Twomey, B., P. A. Jacobs, and H. Gurgenci. "Dynamic performance estimation of small-scale solar cogeneration with an organic Rankine cycle using a scroll expander." *Applied Thermal Engineering* (2012).

[2] Manolakos, D., et al. "On site experimental evaluation of a low-temperature solar organic Rankine cycle system for RO desalination." *Solar Energy* 83.5 (2009): 646-656.

[3] NREL, Solar Irradiation Database, http://rredc.nrel.gov/solar/old_data/nsrdb/

[4] Korea Metrological Administration, Monthly Weather Report, http://www.kma.go.kr/weather/observation/data_monthly.jsp

Acknowledgement

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