Skidmore, Owings & Merrill LLP
Performative Design Group

Reducing Carbon Impact in Singapore through On-Site Tri-Generation and Bio-Fuels

Brian D. Griffith – SES Team Leader
Jason Kirkpatrick – Building Performance Analyst

06/09/2014

Project and Program Information

TOWER COMPETITION SINGAPORE

- **Singapore, China**
- Hotel Program
- 150 Floors
- 2,750 M^2 Floor Plates
- 100 M^2 per room
- One person per room
- 412,500 M^2 Total

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Project and Program Information

TOWER COMPETITION SINGAPORE

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Design Day Information

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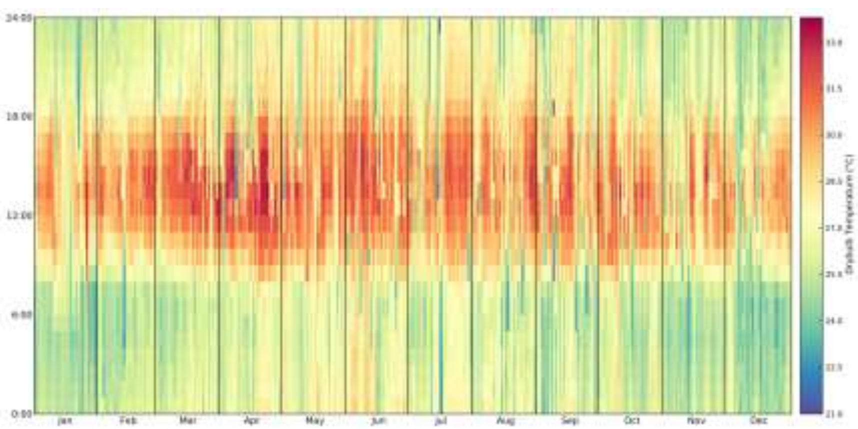
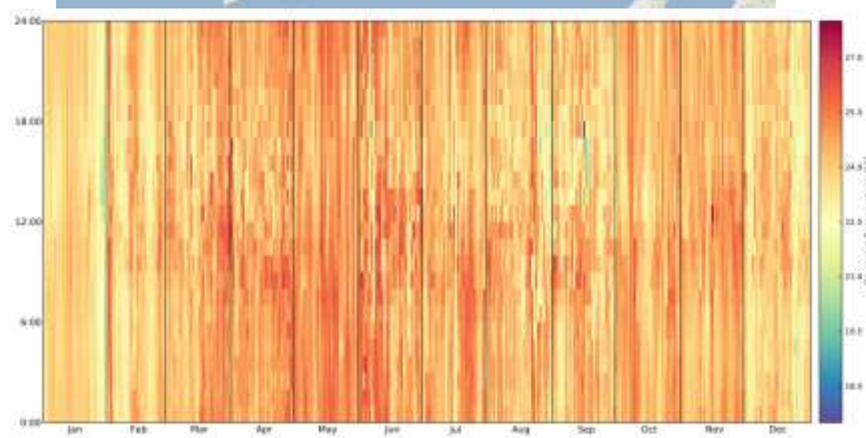
	ASHRAE 99.6% Heating Design Conditions for Singapore CZ 1A
	73°F (22.9°C) Design Dry-Bulb Temperature
	73°F (22.9°C) Wet-Bulb at Max Dry Bulb
	101133 Pa Barometric Pressure
	2.1 m/s Wind Speed
	340° Wind Direction {N=0, S=180}

	ASHRAE 1% Cooling Design Conditions for Singapore CZ 1A
	91°F (32.8°C) Design Dry-Bulb Temperature
	79°F (26.2°C) Wet-Bulb at Max Dry Bulb
	10°F (5.6°C) Daily Temperature Range
	101133 Pa Barometric Pressure
	4.3 m/s Wind Speed
	30° Wind Direction {N=0, S=180}



Dry Bulb Temp [Scale: 21°C to 33°C]
Year round cooling requirement



Dew-point Temp [Scale: 18°C to 27°C]
Year round dehumidification requirement

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SOM High Performance Design Goals

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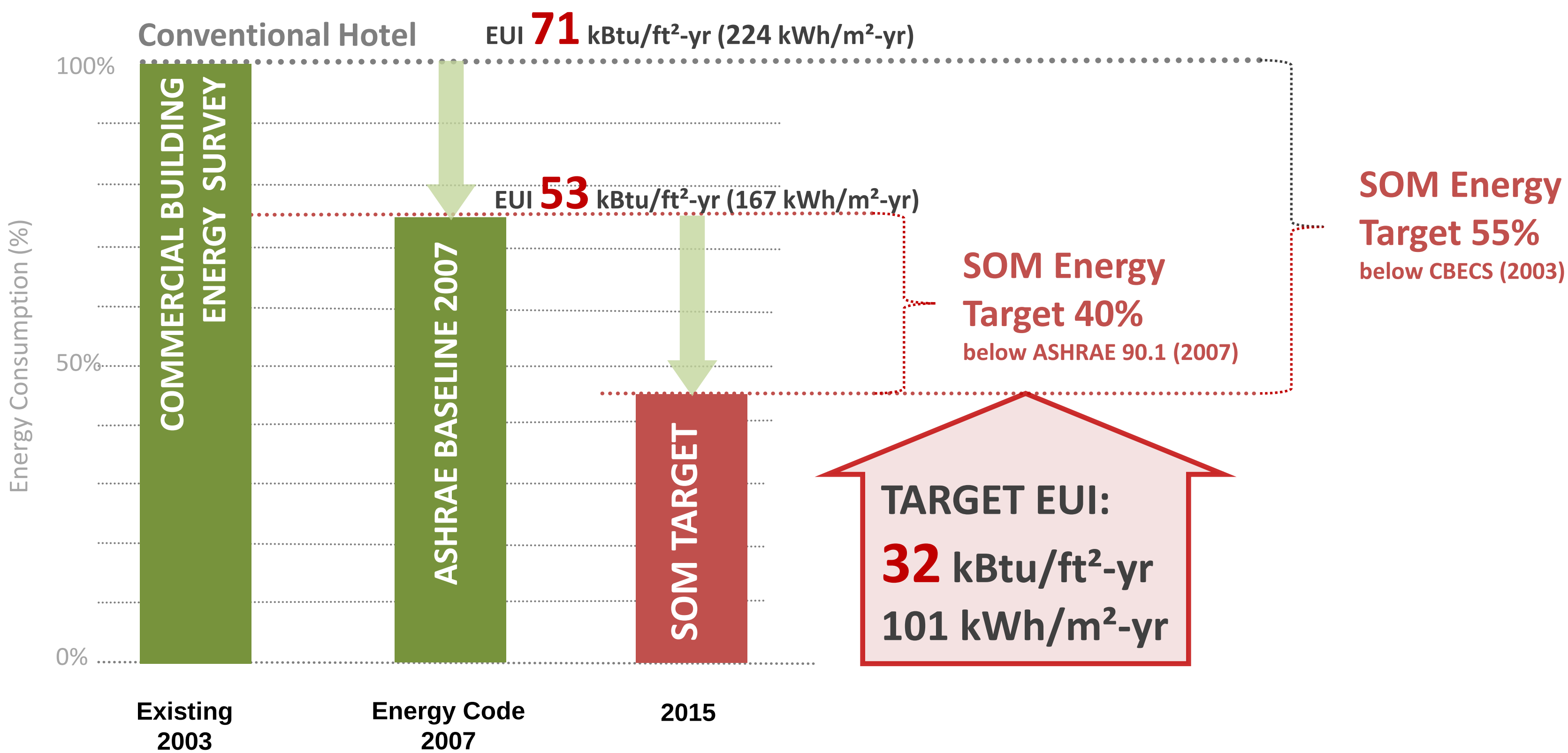
Fossil Fuel Sourced Energy Reduction Goal



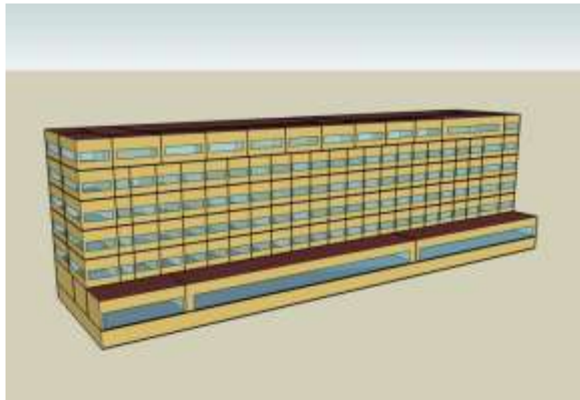
DoE Reference Hotel run in Singapore

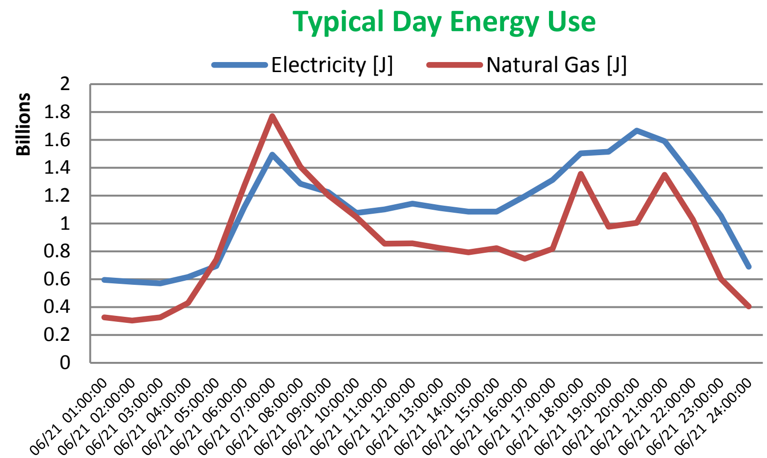
TOWER COMPETITION SINGAPORE

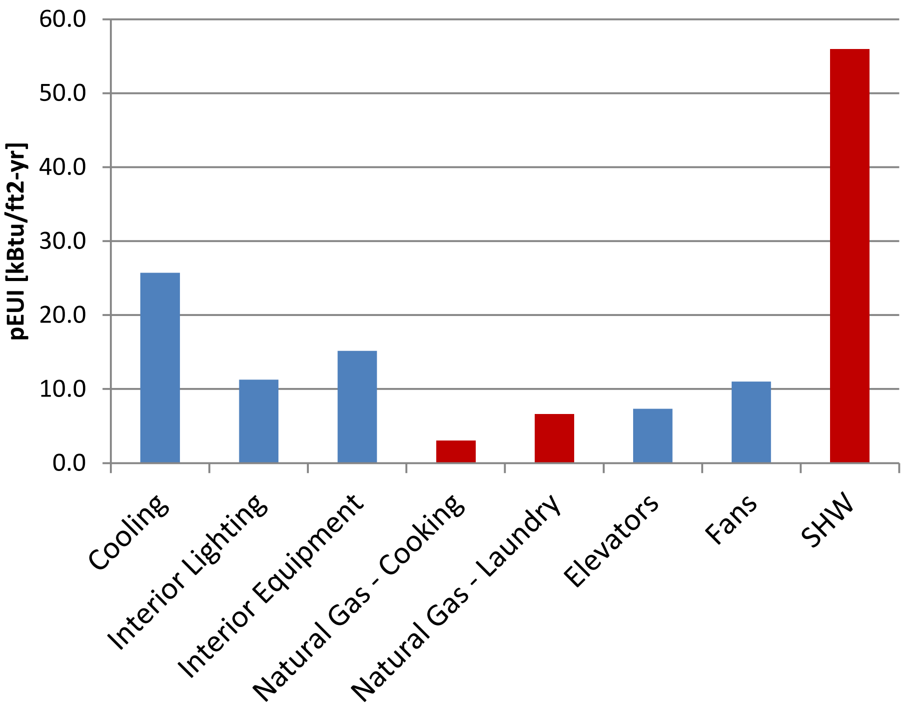
pEUI:

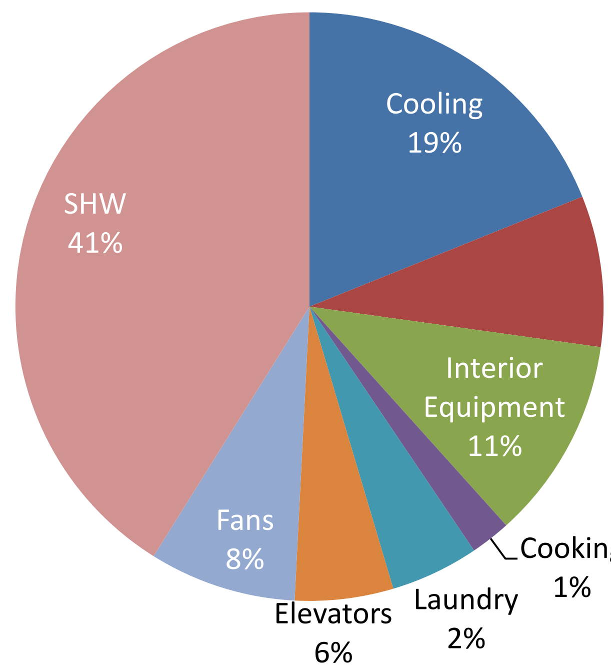
140 kBtu/ft²-yr

441 kWh/m²-yr



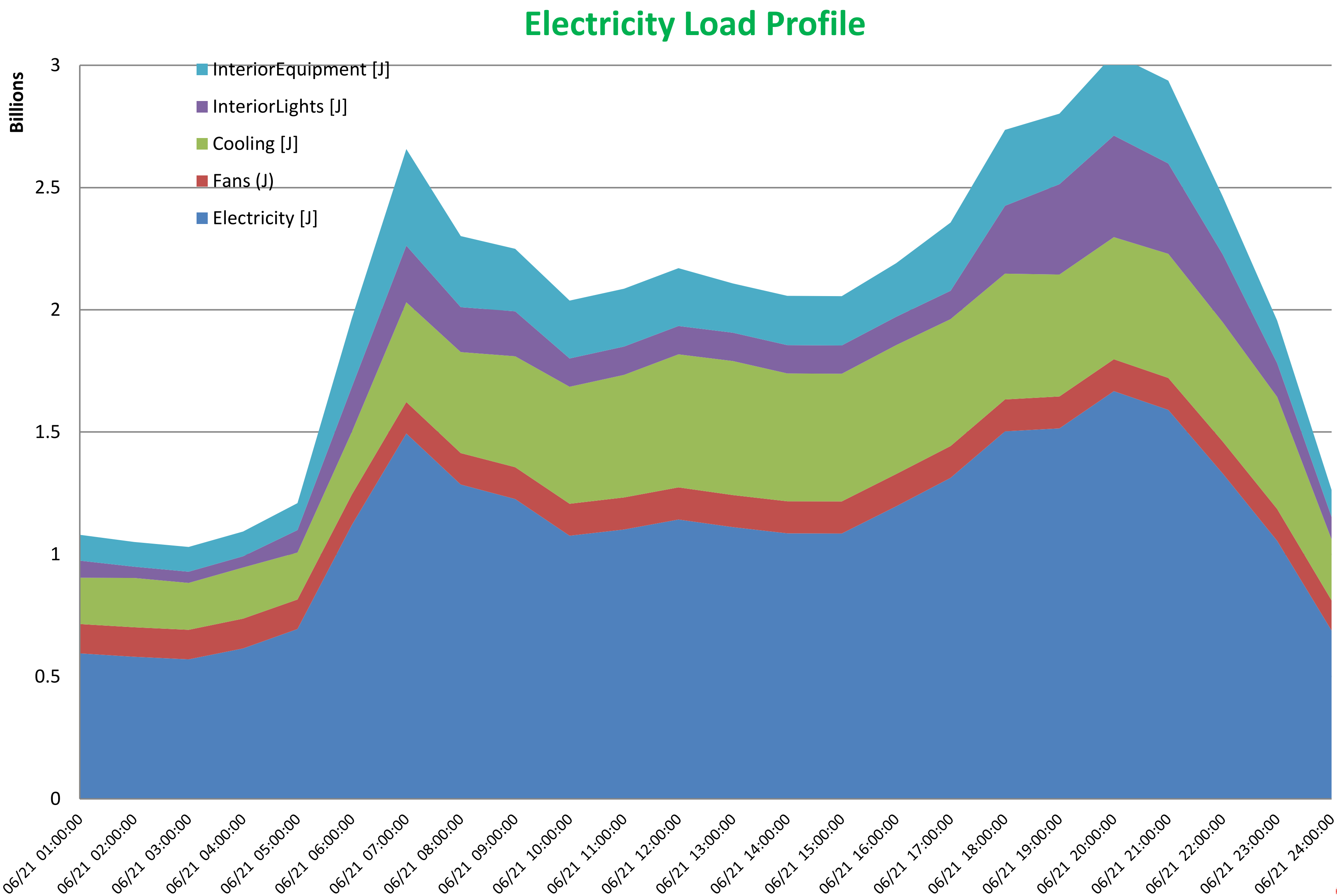






DoE Reference Hotel Load Profiles

TOWER COMPETITION SINGAPORE



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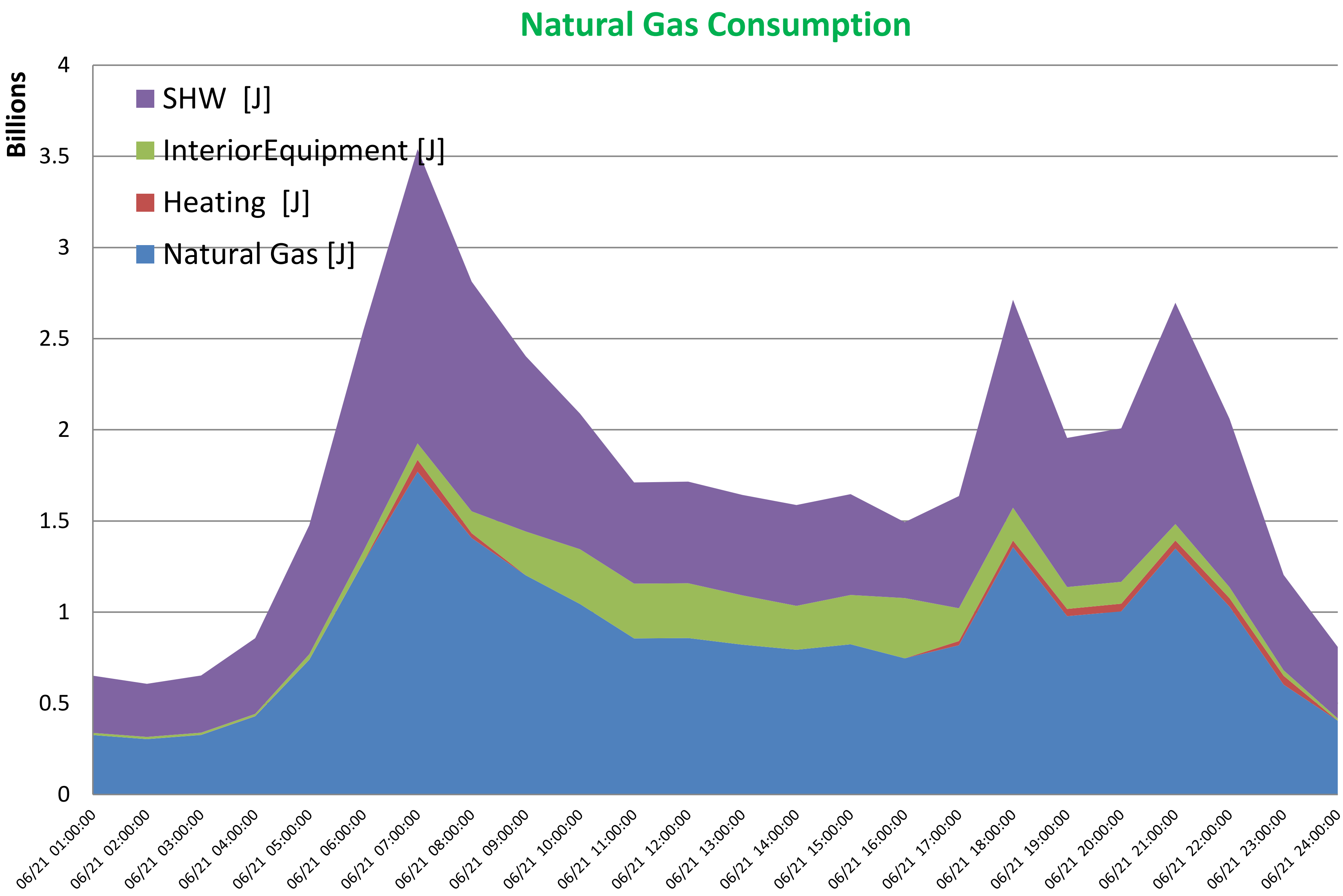
DoE Reference Hotel Use Profiles

TOWER COMPETITION SINGAPORE



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Project Specific Concept Analysis Model Parameters

TOWER COMPETITION SINGAPORE

Base Shape: Square

Length: 52.5 m

Width: 52.5 m

 # Floors: 150

Floor to Floor: 4.0 m

WWR – 40%

Envelope Properties: 90.1-2007 Climate Zone 1A Defaults

HVAC: Packaged Terminal Heat Pumps System 2

Lighting Power Density = 1 W/ft2

Miscellaneous Power Density = 1 W/ft2

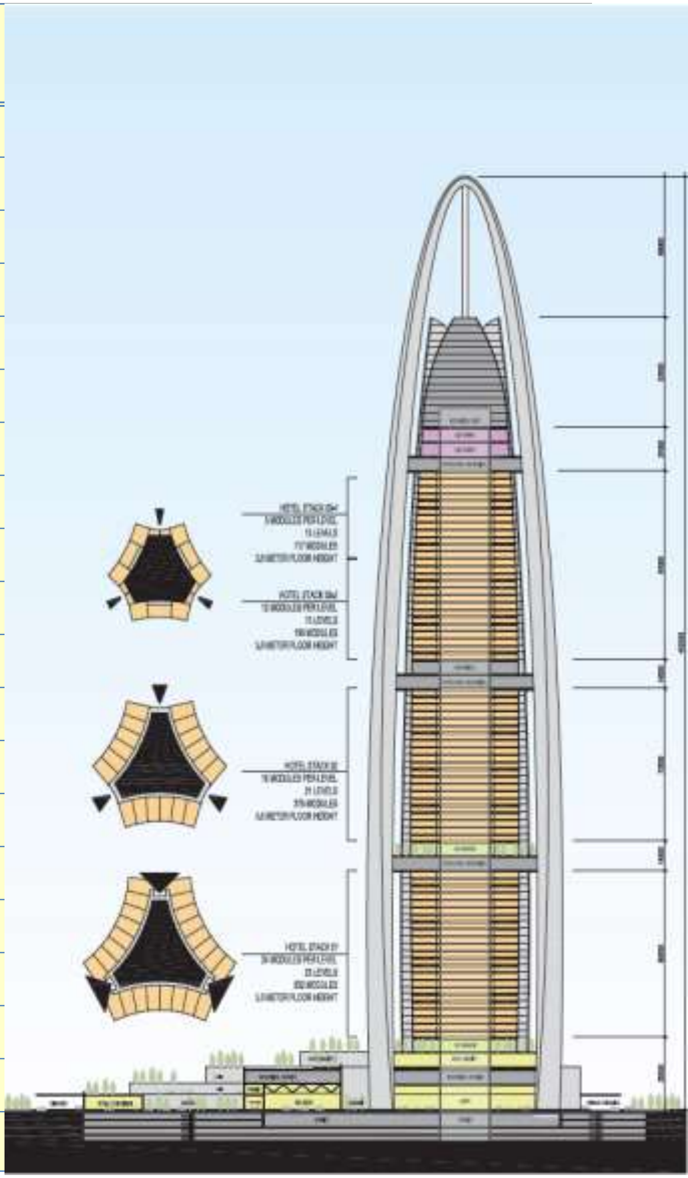
Infiltration = 0.06 cfm/ft2 ext wall area

Service Hot Water:

- *Peak flow of 3.0 GPM per Guest room*
- *(2.5 GPM Shower, 0.5 GPM Faucet)*
- *Peak flow of 90 GPM for all Kitchen SHW consumption*
- *Peak flow of 90 GPM for all Laundry SHW consumption*

Natural Gas Equipment:

- *500 kW peak natural gas demand for cooking*
- *500 kW peak natural gas demand for laundry*



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Parametric WWR Analysis of Square Floor Plate

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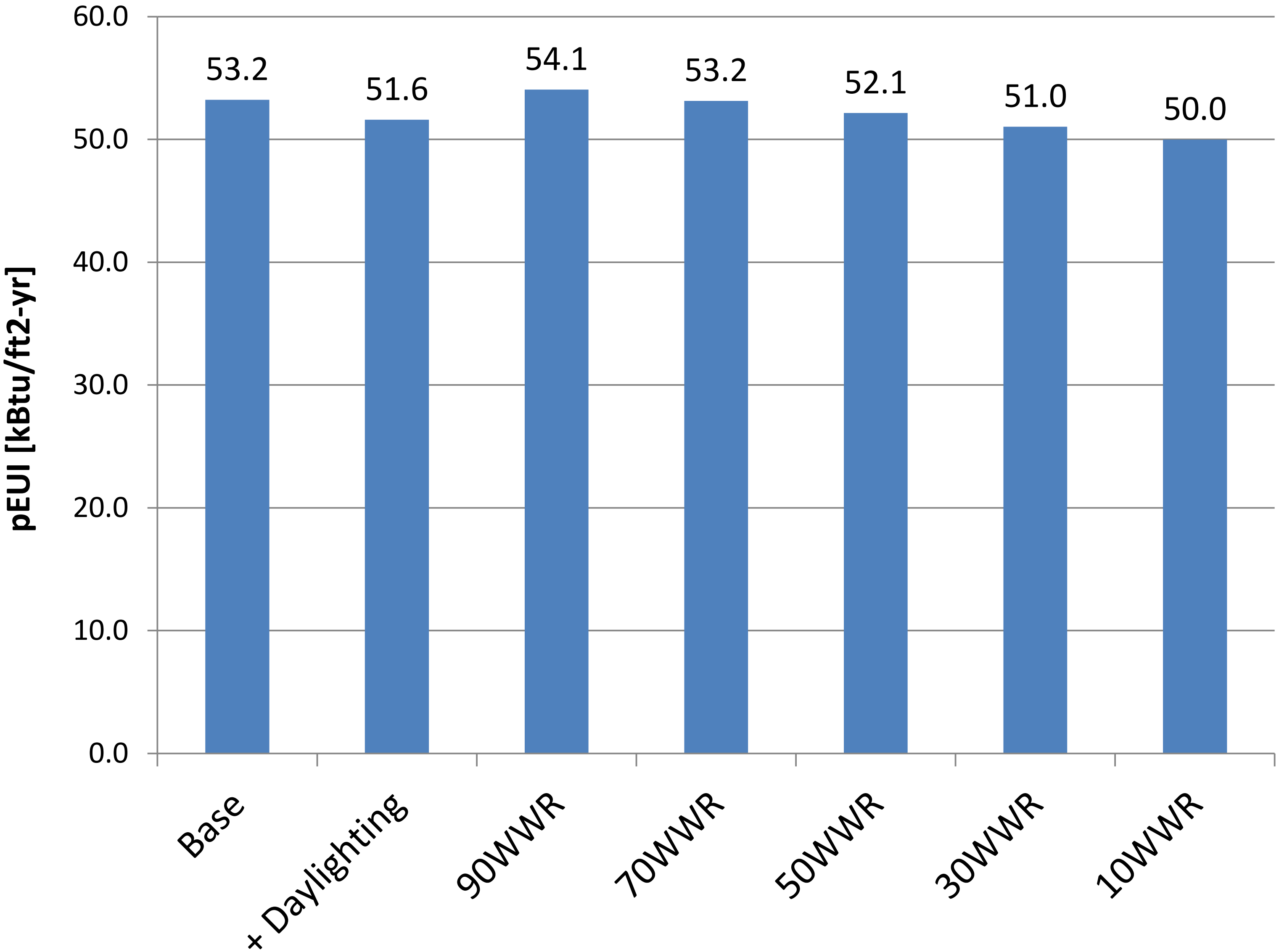

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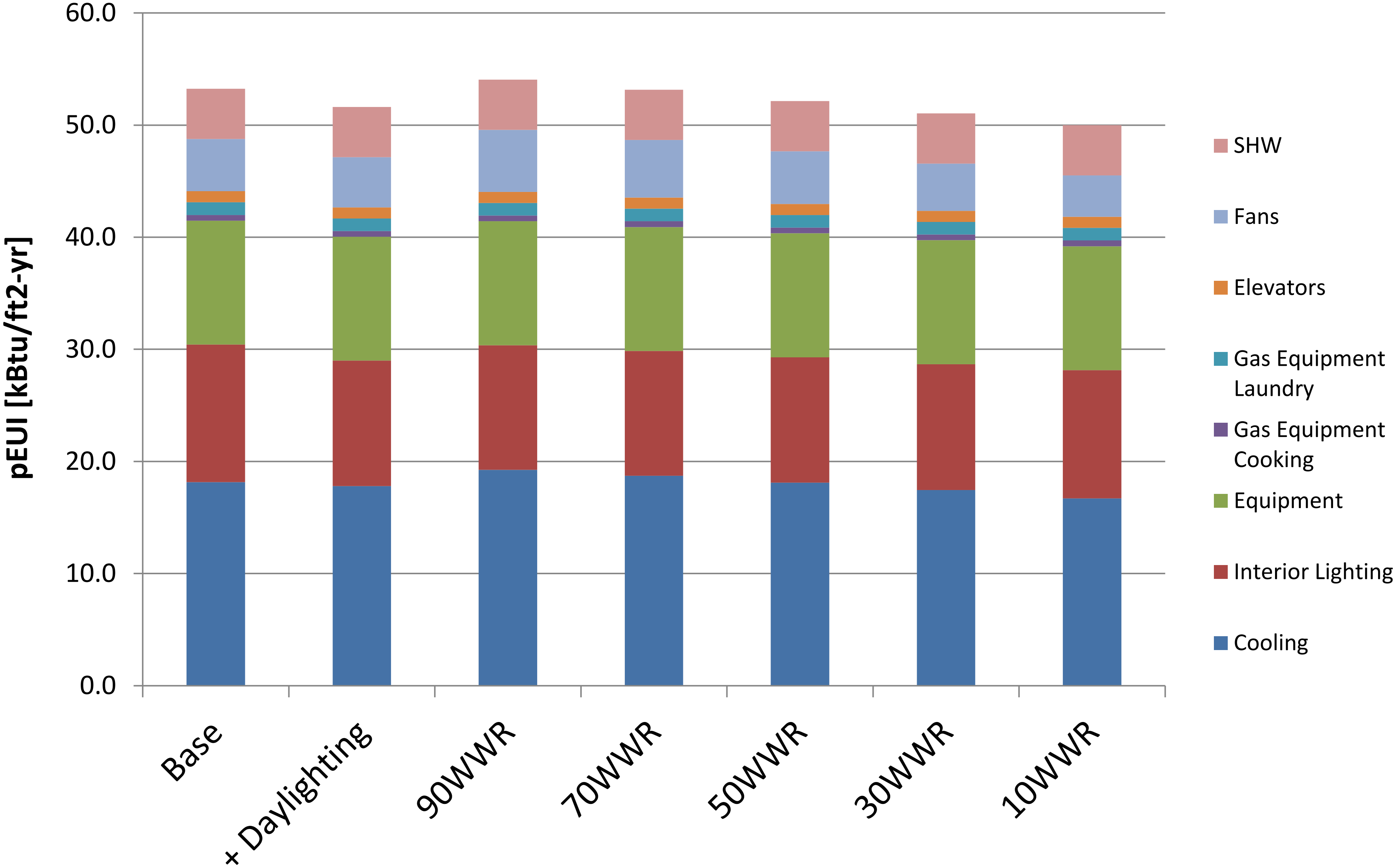

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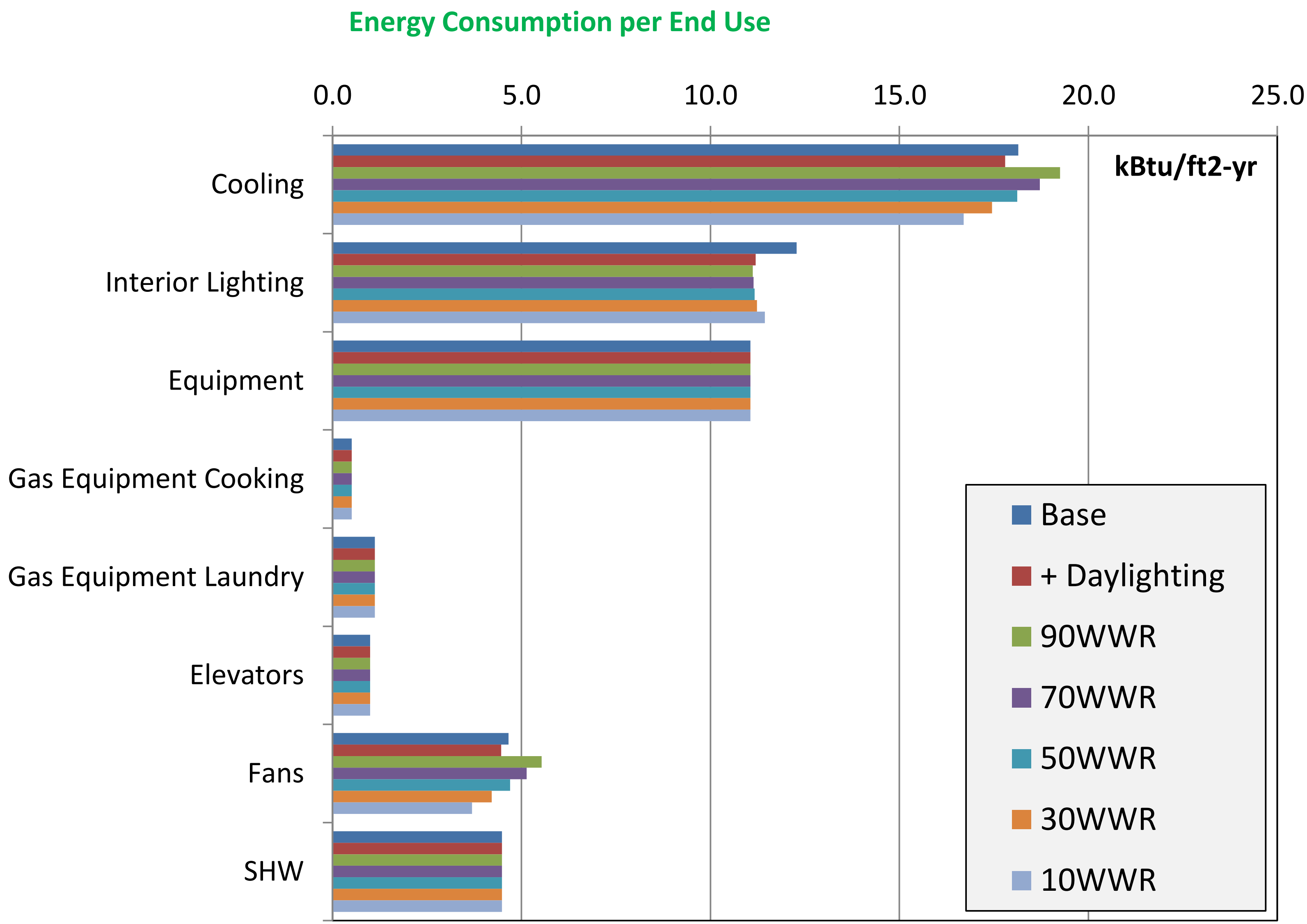

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CHP Studies Utilized as Basis of Analysis

http://www.epa.gov/chp/documents/wwtf_opportunities.pdf

http://www.epa.gov/chp/markets/wastewater.html

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69400/anaerobic-digestion-strat-action-plan.pdf

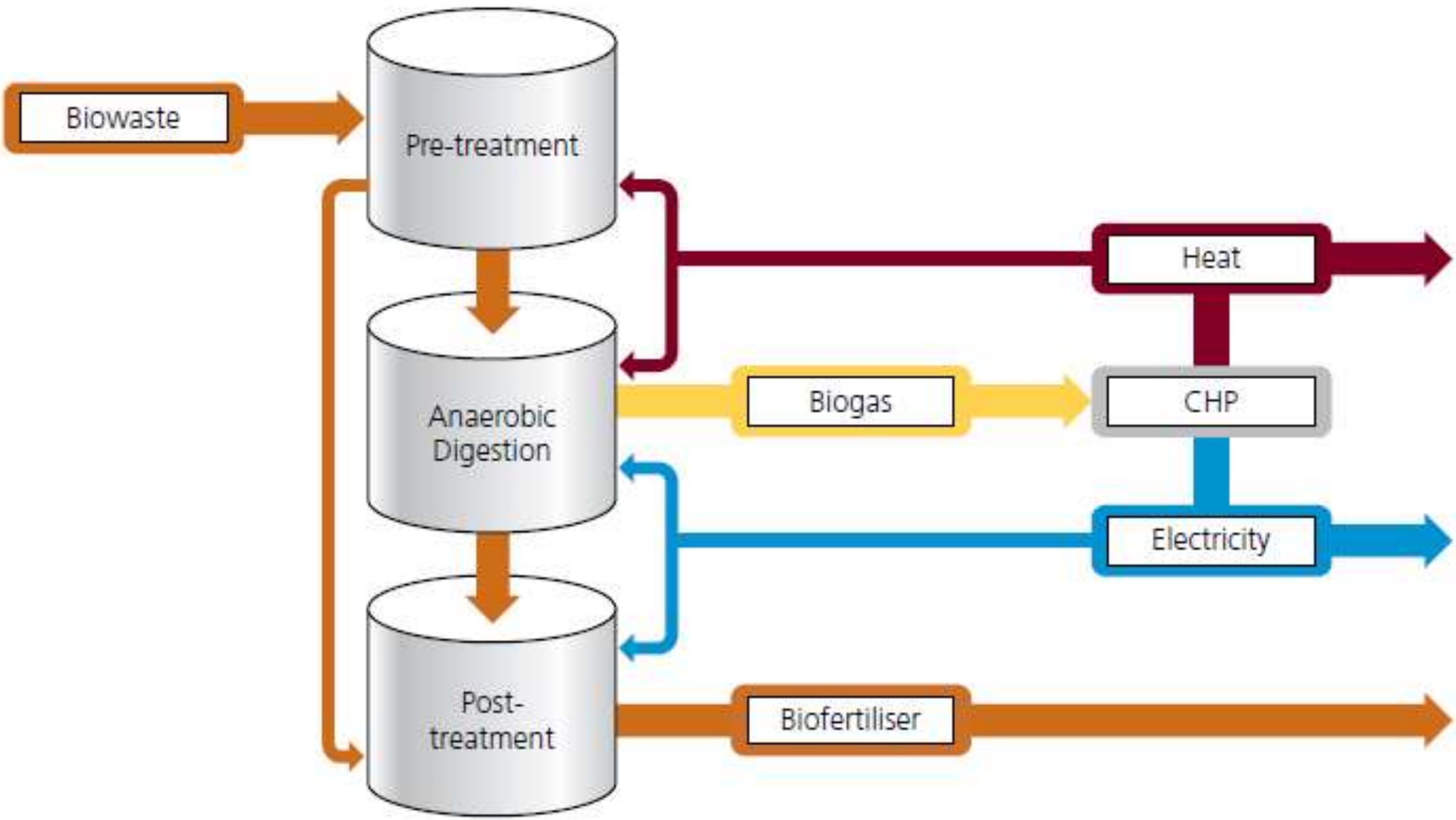
http://www.diva-portal.org/smash/get/diva2:409206/FULLTEXT02

http://www.diva-portal.org/smash/get/diva2:324228/FULLTEXT01.pdf

Anaerobic Digester Diagram

TOWER COMPETITION SINGAPORE

Figure 1: Example of an AD plant configured to produce energy and biofertiliser from biowaste feedstock



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CHP Diagram

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Thermally driven cooling coupled with municipal solid waste-fired power plant: Application of combined heat, cooling and power in tropical urban areas

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Tropical urban areas

A B S T R A C T

Energy recovery from flue gases in thermal treatment plants is an integral part of municipal solid waste (MSW) management for many industrialized nations. Often cogeneration can be employed for both enhancing the plant profitability and increasing the overall energy yield. However, it is normally difficult to justify traditional cogeneration in tropical locations since there is little need for the heat produced. The main objective of this article is to investigate the opportunities and potentials for various types of absorption technologies driven by MSW power plants for providing both electricity and cooling. Results show that cogeneration coupling with thermally driven cooling is sustainably and economically attractive for both electricity and cooling production. The thermally driven cooling provides significant potential to replace electrically driven cooling: such systems are capable of providing cooling output and simultaneously increasing electricity yield (41%). The systems are also capable of reducing the fuel consumption per unit of cooling in comparison with conventional cooling technology: a reduction of more than 1 $MW_{fuel}/MW_{cooling}$ can be met in a small unit. MSW power plant coupled with thermally driven cooling can further reduce CO_2 emissions per unit of cooling of around 60% as compared to conventional compression chiller and has short payback period (less than 5 years).

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CHP Diagram

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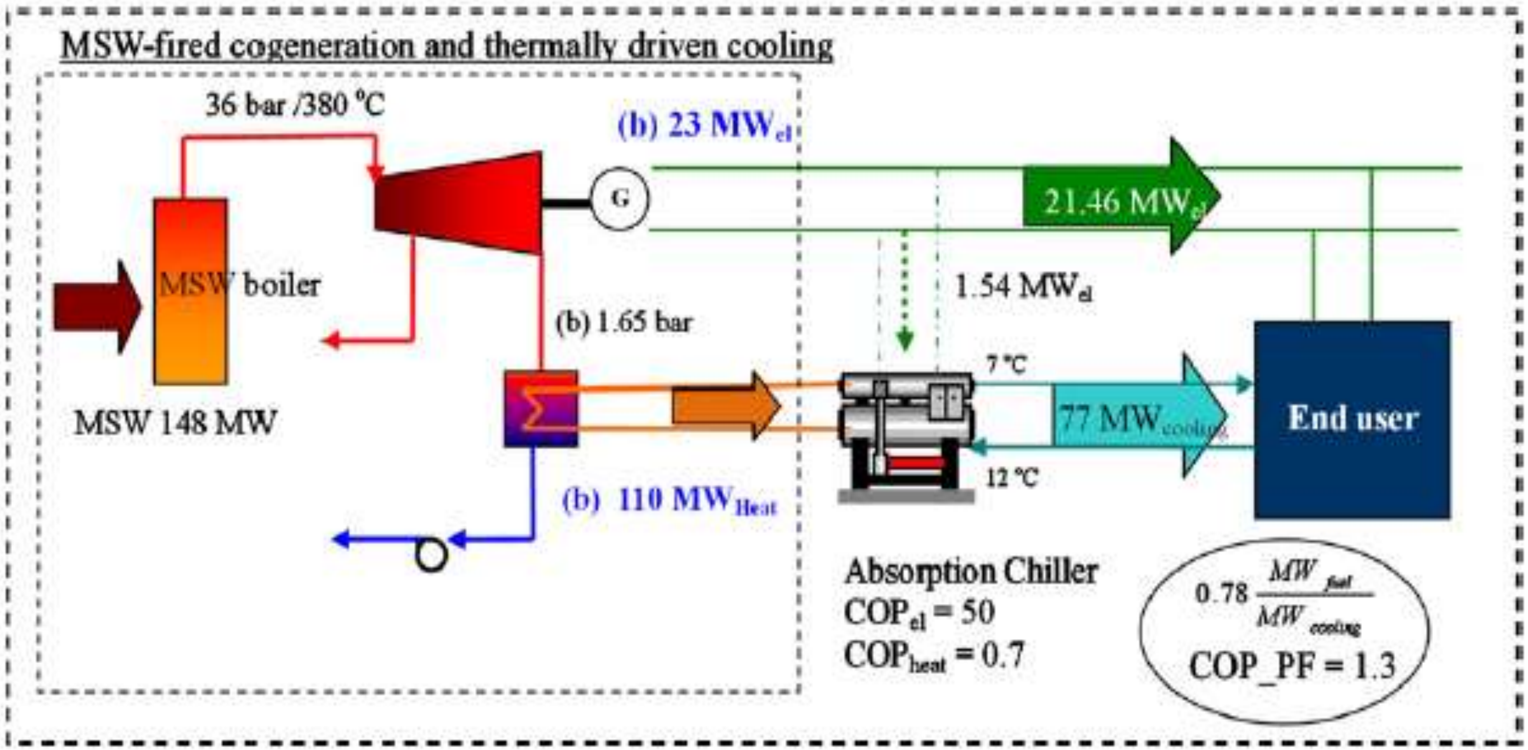

Fig. 3. Energy conversion chain from cogeneration of MSW power plant and thermally driven cooling from absorption chiller.

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CHP Diagram

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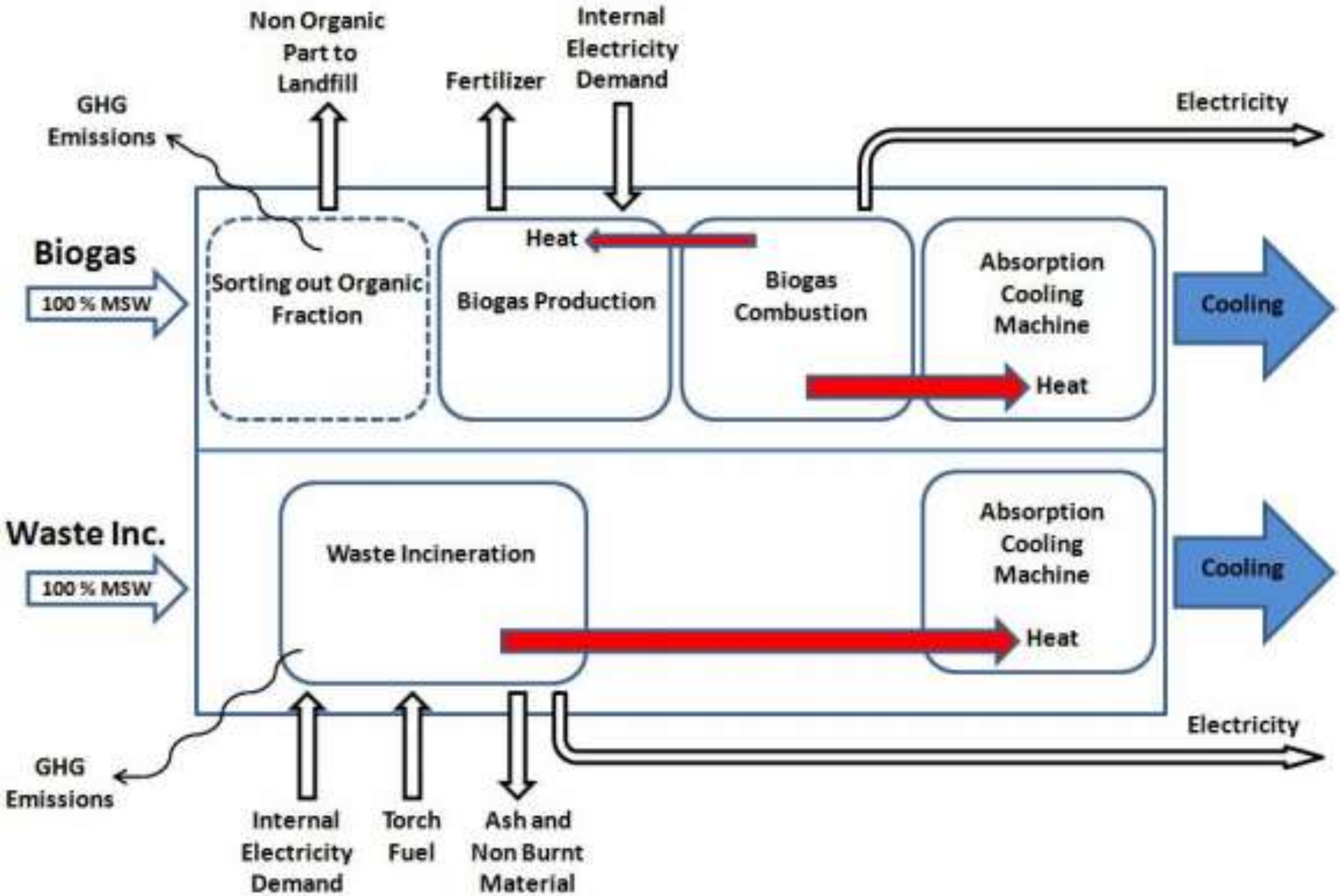

Figure 5-1 – A schematic figure of the different flows in the model

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Energy Potentials – Prime Movers

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Table 6: Electric and Thermal Energy Potential with CHP for Typically Sized Digester

	No CHP System	Reciprocating Engine CHP/ Rich-Burn	Reciprocating Engine CHP/ Lean-Burn	Microturbine CHP	Fuel Cell CHP
Total WWTF Flow (MGD)	9.1	9.1	9.1	9.1	9.1
Heat Requirement for Sludge (Btu/day)	6,693,375	6,693,375	6,693,375	6,693,375	6,693,375
Wall Heat Transfer (Btu/day)	591,725	591,725	591,725	591,725	591,725
Floor Heat Transfer (Btu/day)	1,109,484	1,109,484	1,109,484	1,109,484	1,109,484
Roof Heat Transfer (Btu/day)	741,013	741,013	741,013	741,013	741,013
Total Digester Heat Load (Btu/day)	9,135,597	9,135,597	9,135,597	9,135,597	9,135,597
Fuel Required for Digester Heat Load* (Btu/day) (HHV)	**11,419,496**				
Energy Potential of Gas (Btu/day) (HHV)	58,901,700	58,901,700	58,901,700	58,901,700	58,901,700
% of Gas Used for Digester Heat Load (Btu/day)	19.4%				
Excess Digester Gas (Btu/day)**	**47,482,204**				
Electric Efficiency (HHV)		29.1%	32.6%	26.0%	42.3%
Power-to-Heat Ratio		0.62	0.86	0.88	1.26
Total CHP Efficiency (HHV)		76%	71%	56%	76%
Electric Production (Btu/day)		**17,140,395**	**19,201,954**	**15,314,442**	**24,915,419**
Electric Production (kW)		**209**	**234**	**187**	**304**
Heat Recovery (Btu/day)		**27,645,798**	**22,327,854**	**17,402,775**	**19,774,142**
Digester Heat Load (Btu/day)		**9,135,597**	**9,135,597**	**9,135,597**	**9,135,597**
Additional Heat Available* (Btu/day)**		**18,510,201**	**13,192,257**	**8,267,178**	**10,638,545**

Note: Analysis assumes 50 percent summer and 50 percent winter digester operation.
*Assumes 80 percent efficient boiler.
**Assumes no other uses except boiler.
***Available for non-digester heating uses at the facility (e.g., space heating, hot water).

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Energy Flow & Fuel Mix

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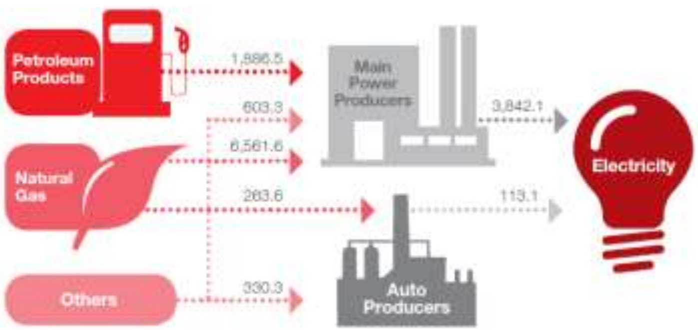
ENERGY FLOWS IN THE POWER GENERATION SECTOR

In 2011, a total of 3,955.2 ktoe of electricity was generated by the power generation sector in Singapore. Main Power Producers consumed 1,886.5 ktoe of petroleum products, 6,561.6 ktoe of natural gas and 603.3 ktoe of other energy products to produce 3,842.1 ktoe of electricity. Autoproducers consumed 14.9 ktoe of petroleum products, 263.6 ktoe of natural gas and 330.3 ktoe of other energy products to produce 113.1 ktoe of electricity, primarily for their own consumption.

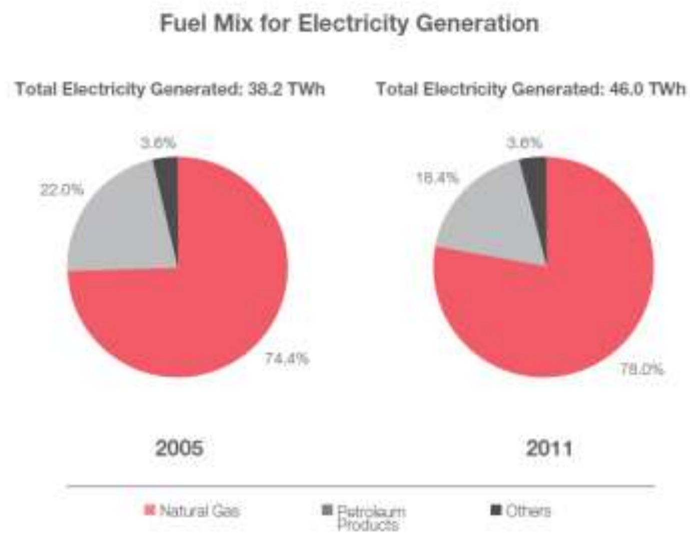
	Petroleum products	Natural Gas	Others	Electricity
Total Transformation Sector	**-1,901.4**	**-6,825.2**	**-933.6**	**3,955.2**
Main Power Producers	-1,886.5	-6,561.6	-603.3	3,842.1
Autoproducers	-14.9	-263.6	-330.3	113.1



*The amount of fuel involved in electricity generation activity is indicated with a negative sign to represent consumption. The resulting amount of electricity produced is indicated in positive figures.

FUEL MIX FOR ELECTRICITY GENERATION

Singapore's fuel mix for electricity generation has been trending towards increasing usage of natural gas. In 2011, natural gas accounted for 78.0% of electricity generated, up from 74.4% in 2005. This was largely due to the greater role played by cleaner and more efficient Combined Cycle Gas Turbine (CCGT) plants in the Singapore power generation sector in recent years. CCGT plants primarily use natural gas as fuel to generate electricity.



http://www.ema.gov.sg/media/files/publications/EMA_SES_2012_Final.pdf

http://www.ema.gov.sg/media/files/publications/SES%202013.pdf

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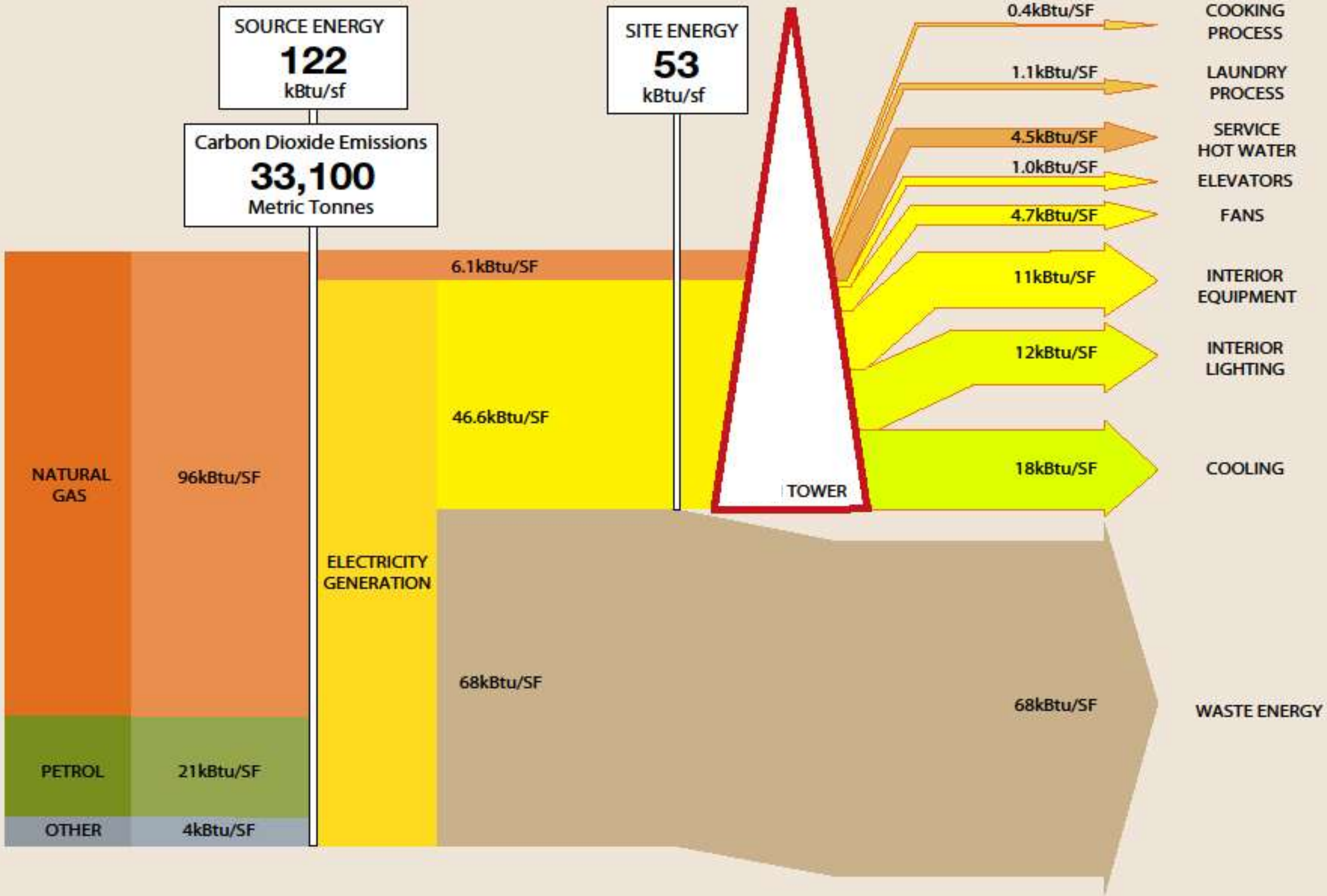
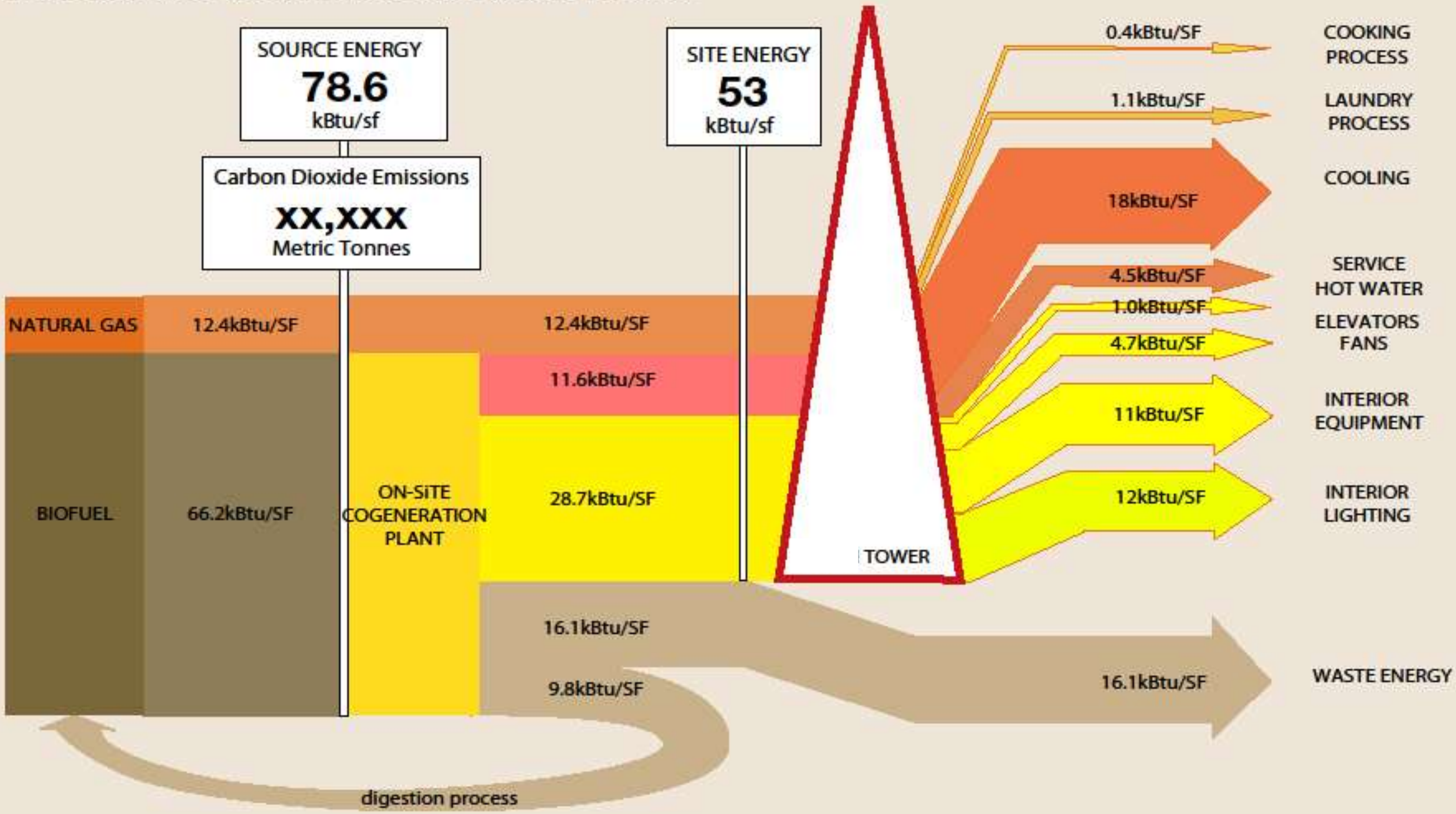
Energy Flow Diagram - ASHRAE 90.1 Code Compliant Building



Source to Site Energy Flows for a code compliant building in Singapore. Fuel use ratio determinations from Singapore Energy Statistics 2012.
Based on the multiplier for this region, it takes 2.438 MBtu of energy to produce and deliver each 1.0 MBtu used at a building site.
Based on Singapore's Electricity Grid Emission Factors, delivering 1.0 MBtu of electricity to the buiding site produces 150.8 kg Carbon Dioxide equivalent emissions
Note the amount of waste energy relative to the energy used on the site.

Energy Flow Diagram - On-site Tri-Generation with waste heat used in Anaerobic Digester Process



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Energy Densities of Various Waste Streams

Table 2

COD and methane emissions from various feedstock common in tropical regions

Feedstock Source	COD Range (g/L)	**Average Methane Yield (m^3/kg volatile solids)**
Palm Oil Mill Effluent	50 – 150	**0.39**
Pig Manure	30 – 90	0.38
Dairy Manure	18 – 48	0.24
Sugar Beat	1.5 – 5.5	0.20
Municipal Solid Waste	15 – 50	0.35

Thank You!

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