Using Biofuels with CCHP technology in pursuit of "Nearly Zero Energy Buildings"

Martin Ratcliffe

School of Engineering and Design

Brunel University, London, UK

Inno Week, Patras Greece

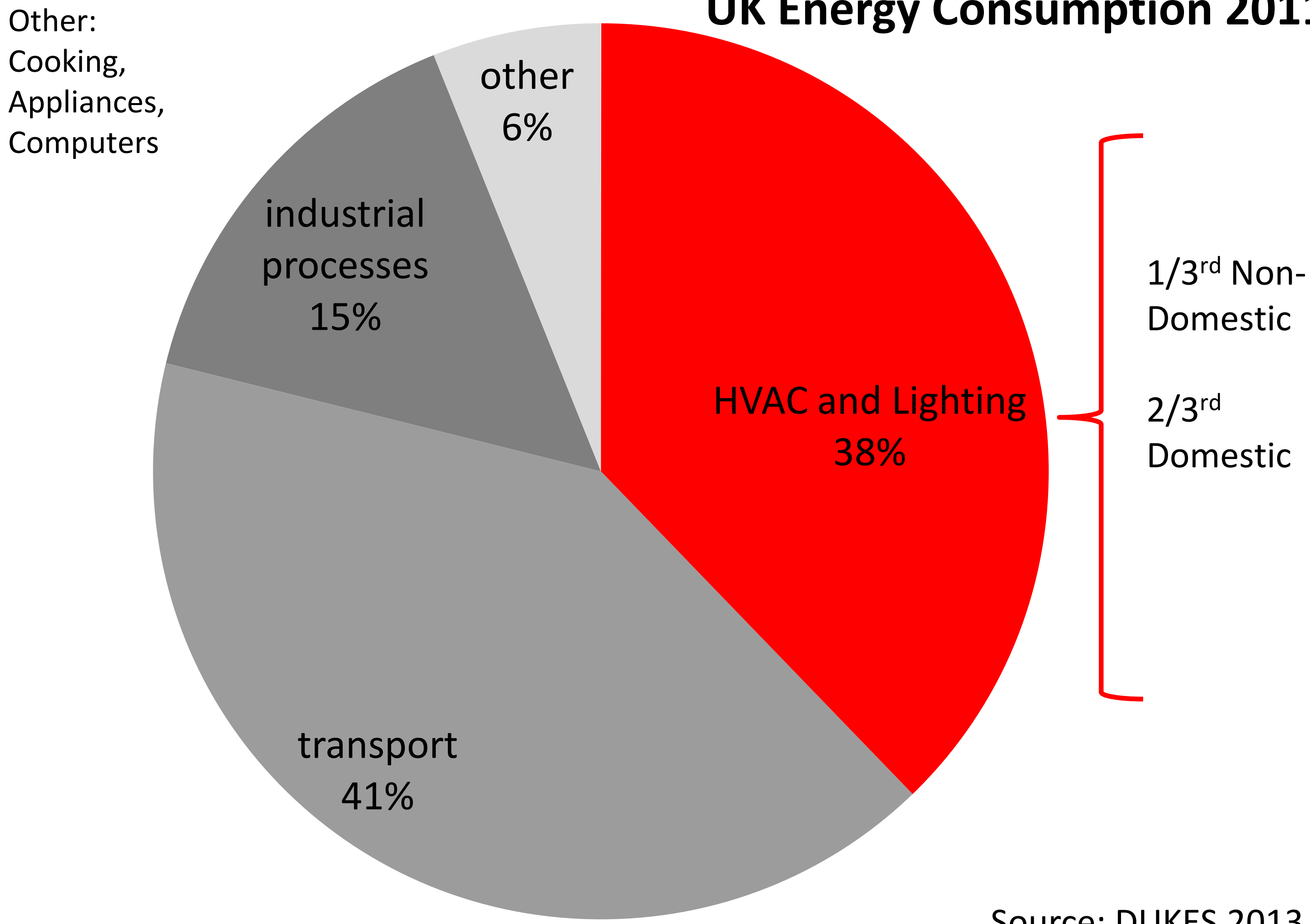
9th July 2013

Brunel UNIVERSITY LONDON

Agenda

- Nearly Zero Energy Buildings
- CCHP Technology
- Case Study
- Further work needed

UK Energy Consumption 2011



Source: DUKES 2013

Nearly Zero Energy

- European Directive EPBD-2 2010

  all new and extensively refurbished buildings to be “nearly zero energy” from:
  - 2019 – public buildings
  - 2020 – all other buildings

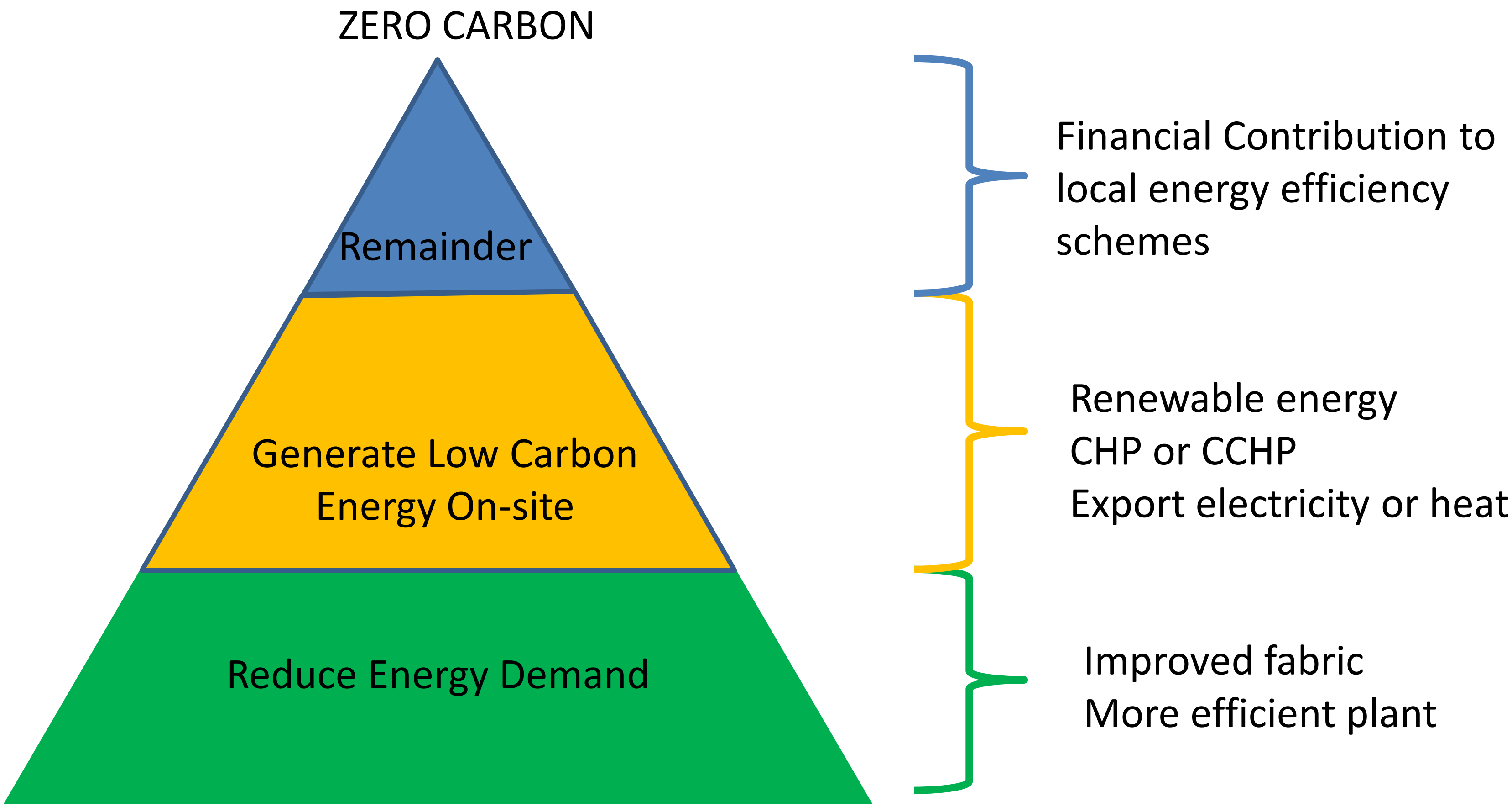
- Definition of “nearly zero energy” to be produced by each member state

- Calculations to be carried out using accredited software

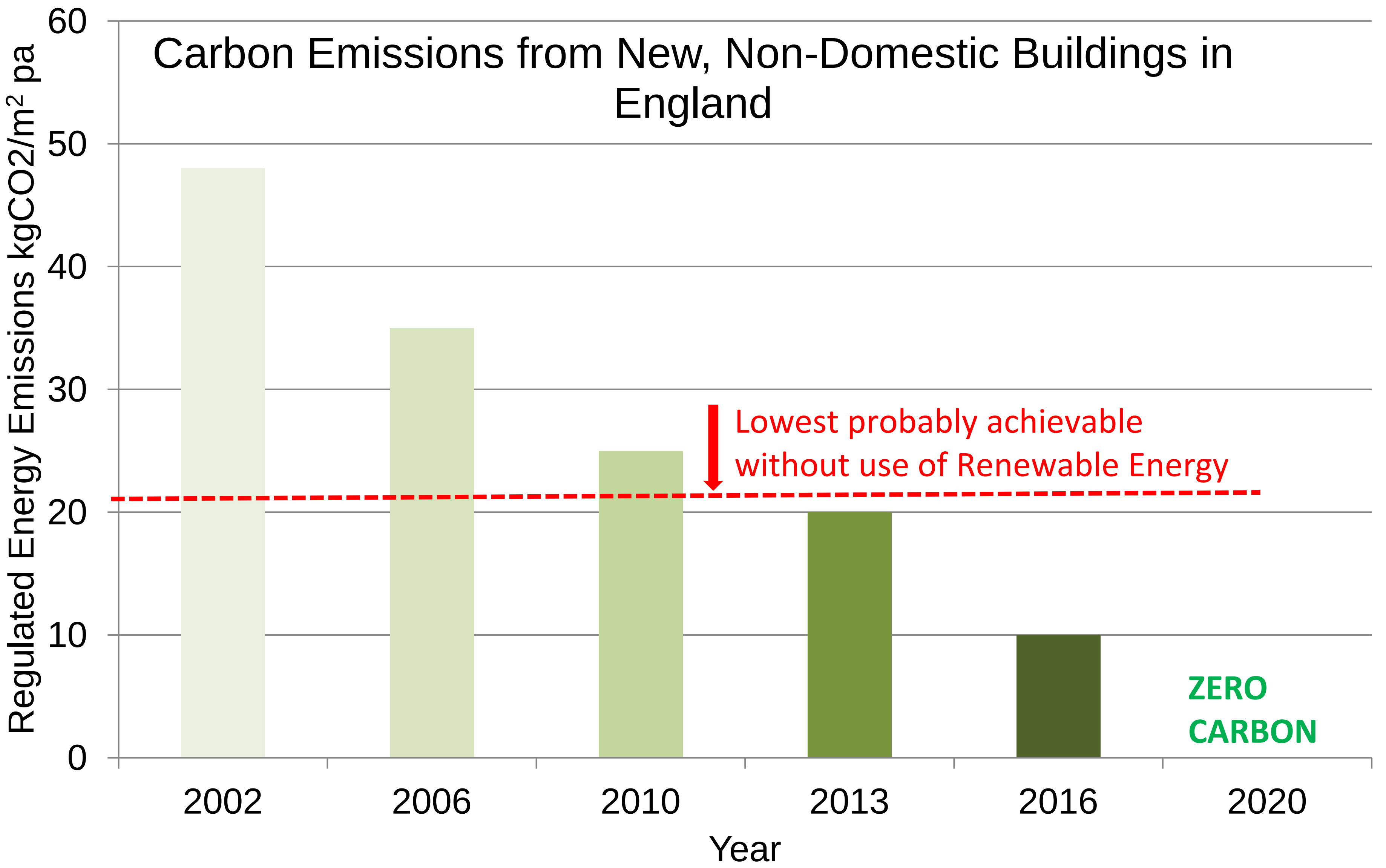
UK - Zero Carbon

- Net zero CO_2 emissions *over whole year* based arising from energy used by building HVAC and Lighting (“Regulated Energy”)
- Allows for exporting energy
- Excludes lifts/escalators, small power, server rooms etc, industrial processes (“Unregulated Energy”)

(Likely) Zero Carbon Strategy



VERY energy efficient but on-site renewable contribute very little
(Courtesy of Grontmij UK)


Carbon Emissions from New, Non-Domestic Buildings in England
Regulated Energy Emissions kgCO2/m² pa
60
50
40
30
20
10
0
Lowest probably achievable without use of Renewable Energy
ZERO CARBON
2002
2006
2010
2013
2016
2020
Year

Case Study – London Office Building

New-build 10 storey office

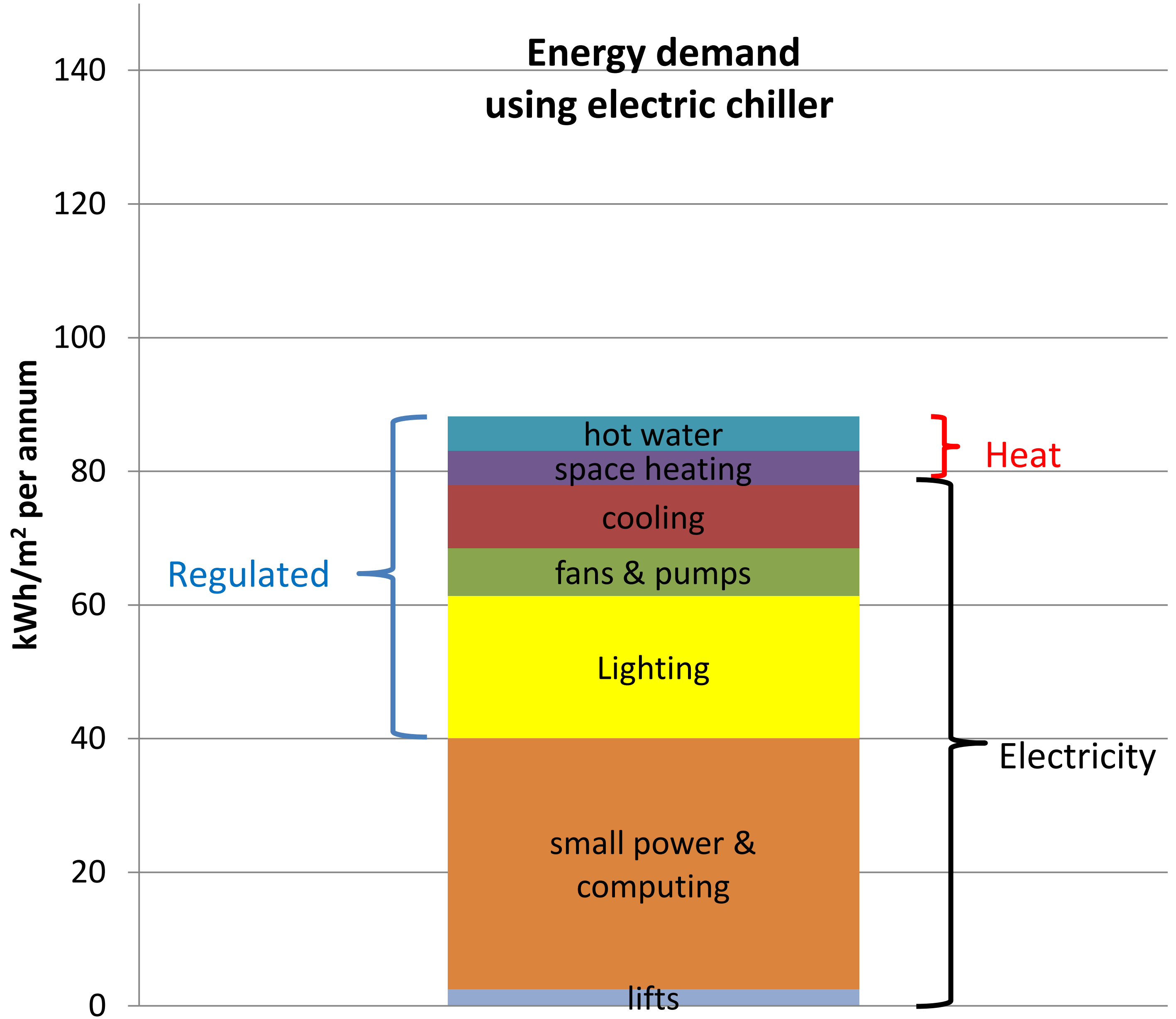
61,000m^2 gross floor area

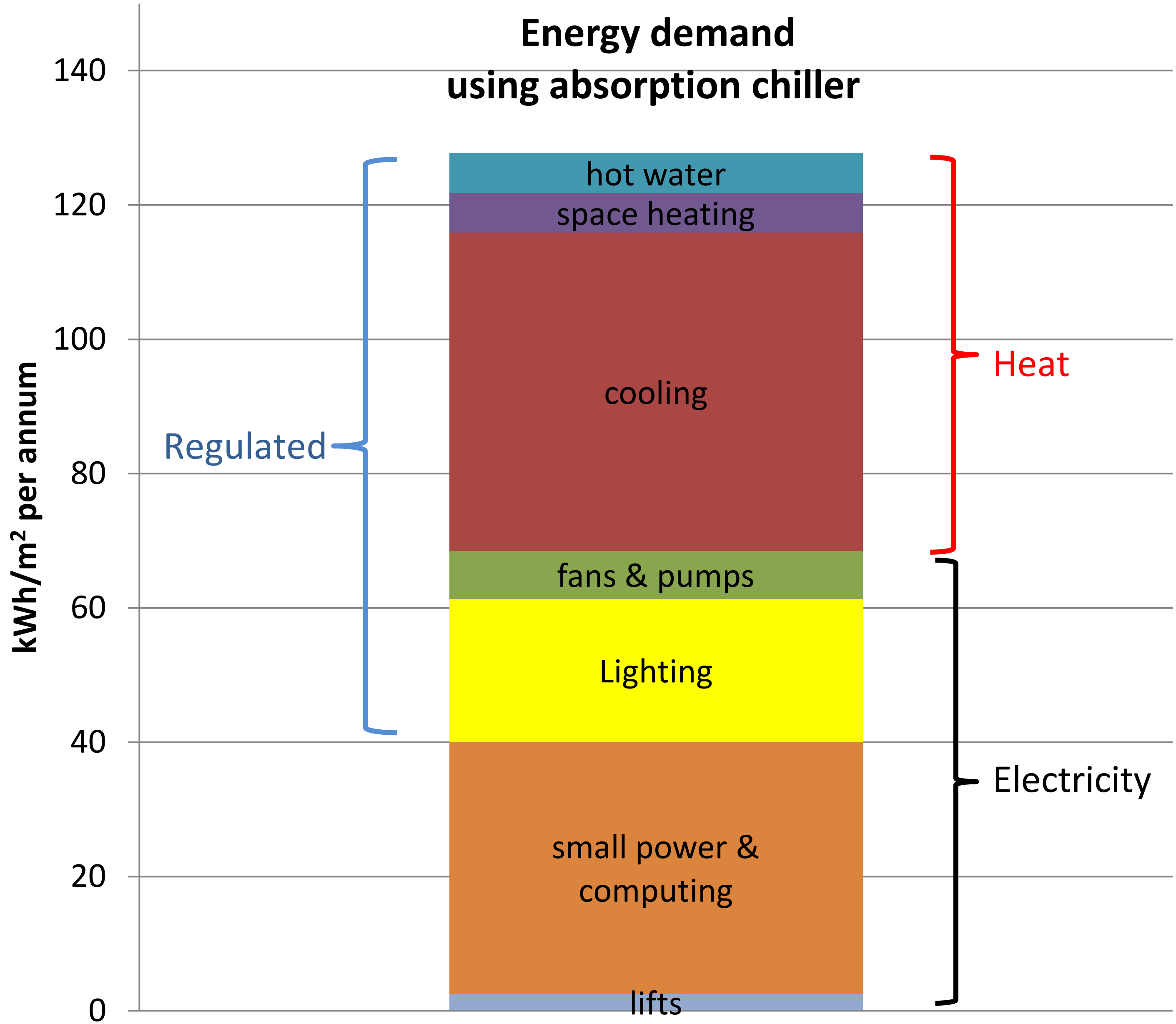
Completed 2011

Designed to approach Zero Carbon:

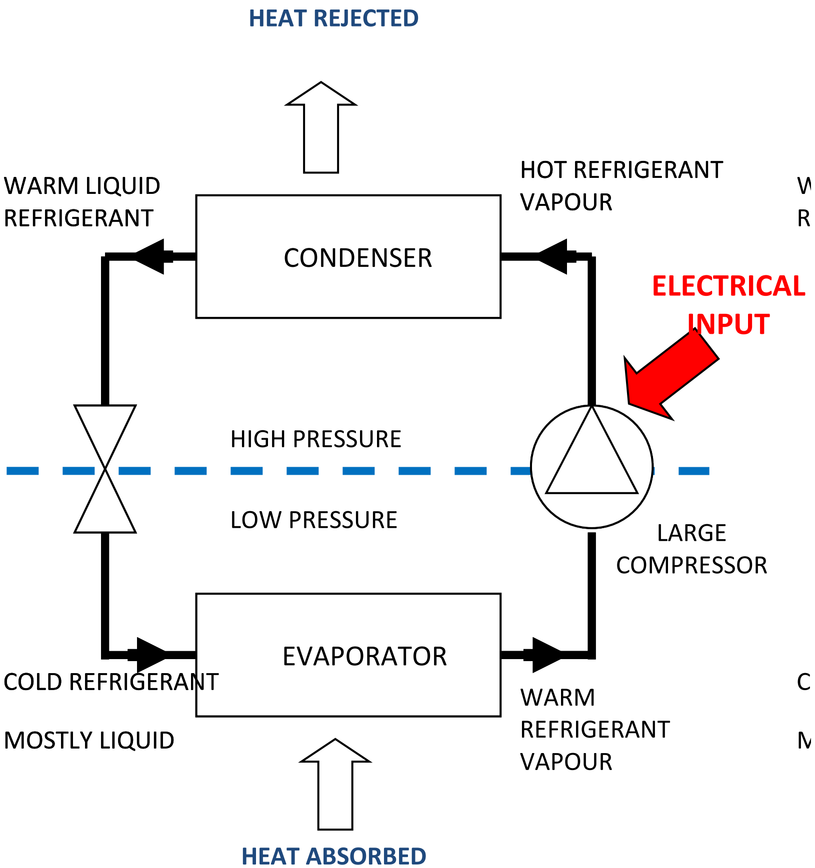
- High Efficiency Facade
- High Efficiency HVAC & L
- Solar Hot Water
- **Bio-fuel Tri-generation**

(Courtesy of Grontmij UK)

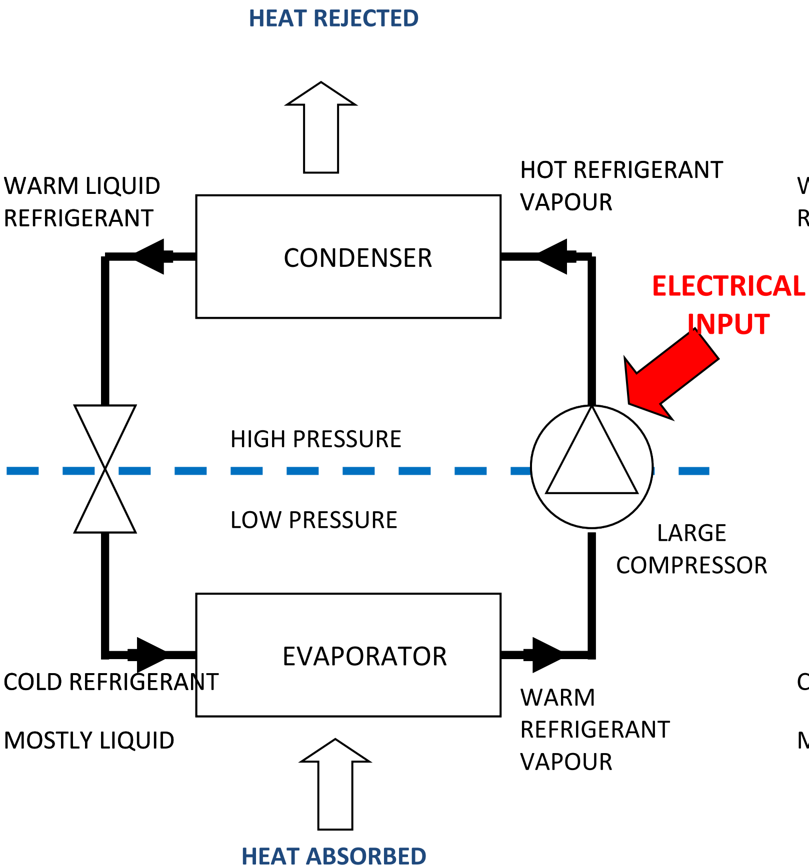

Energy demand
using electric chiller
kWh/m² per annum
140
120
100
80
60
40
20
0
Regulated
hot water
space heating
cooling
fans & pumps
Lighting
small power &
computing
lifts
Heat
Electricity



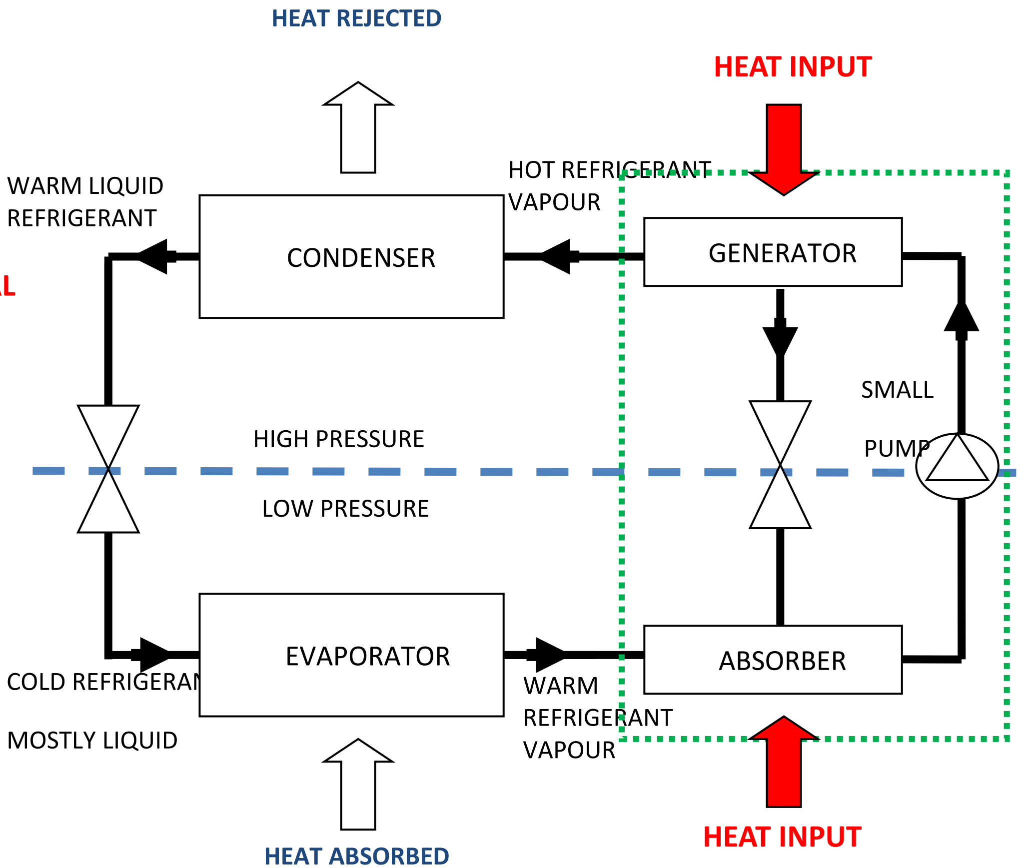
Energy demand
using absorption chiller
140
120
100
80
60
40
20
0
kWh/m² per annum
hot water
space heating
cooling
fans & pumps
Lighting
small power & computing
lifts
Regulated
Heat
Electricity



ELECTRIC VAPOUR COMPRESSION REFRIGERATION



ELECTRIC VAPOUR COMPRESSION REFRIGERATION



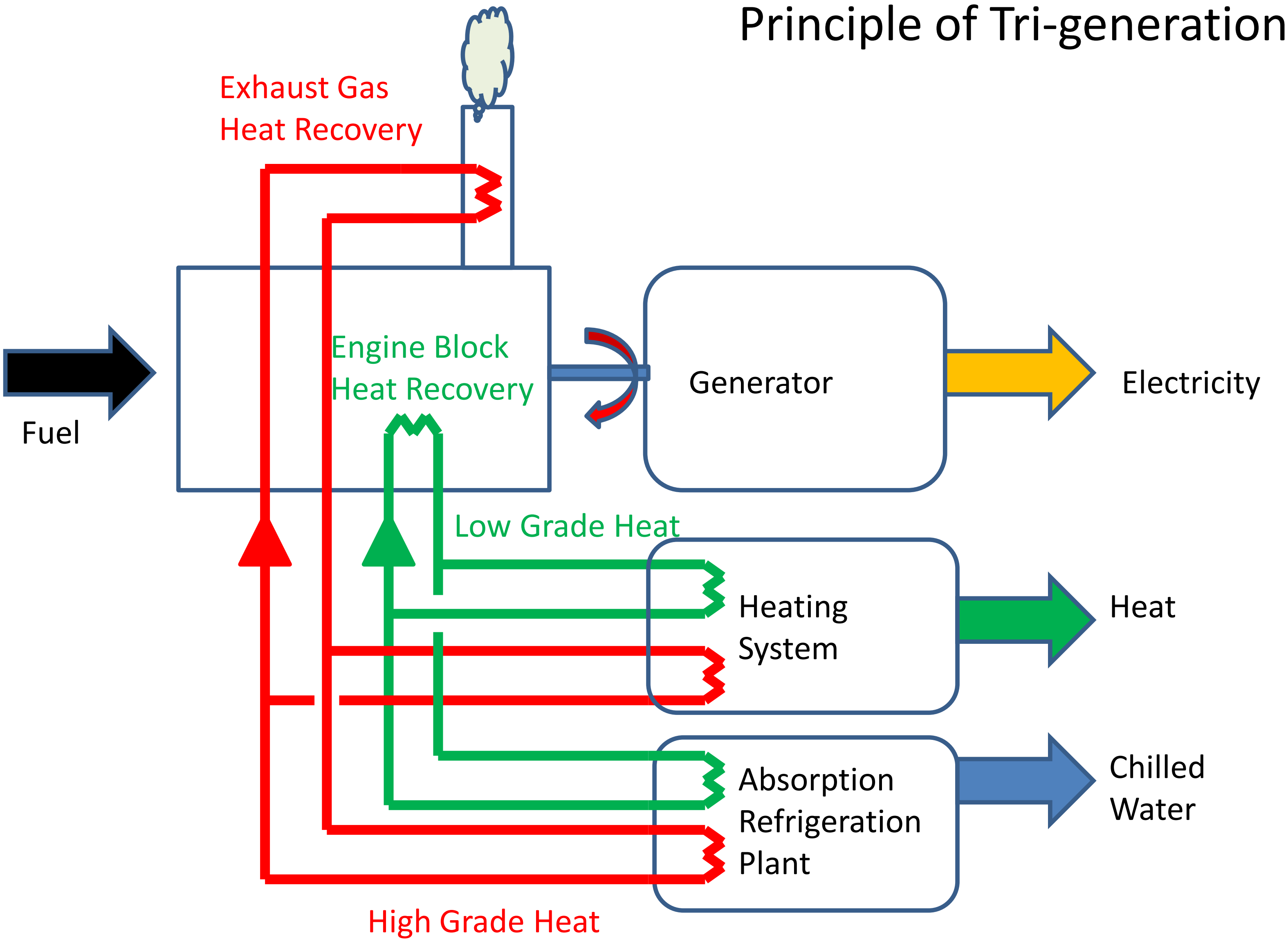
HEAT DRIVEN ABSORPTION REFRIGERATION

Comparison between Vapour Compression and Absorption Chillers

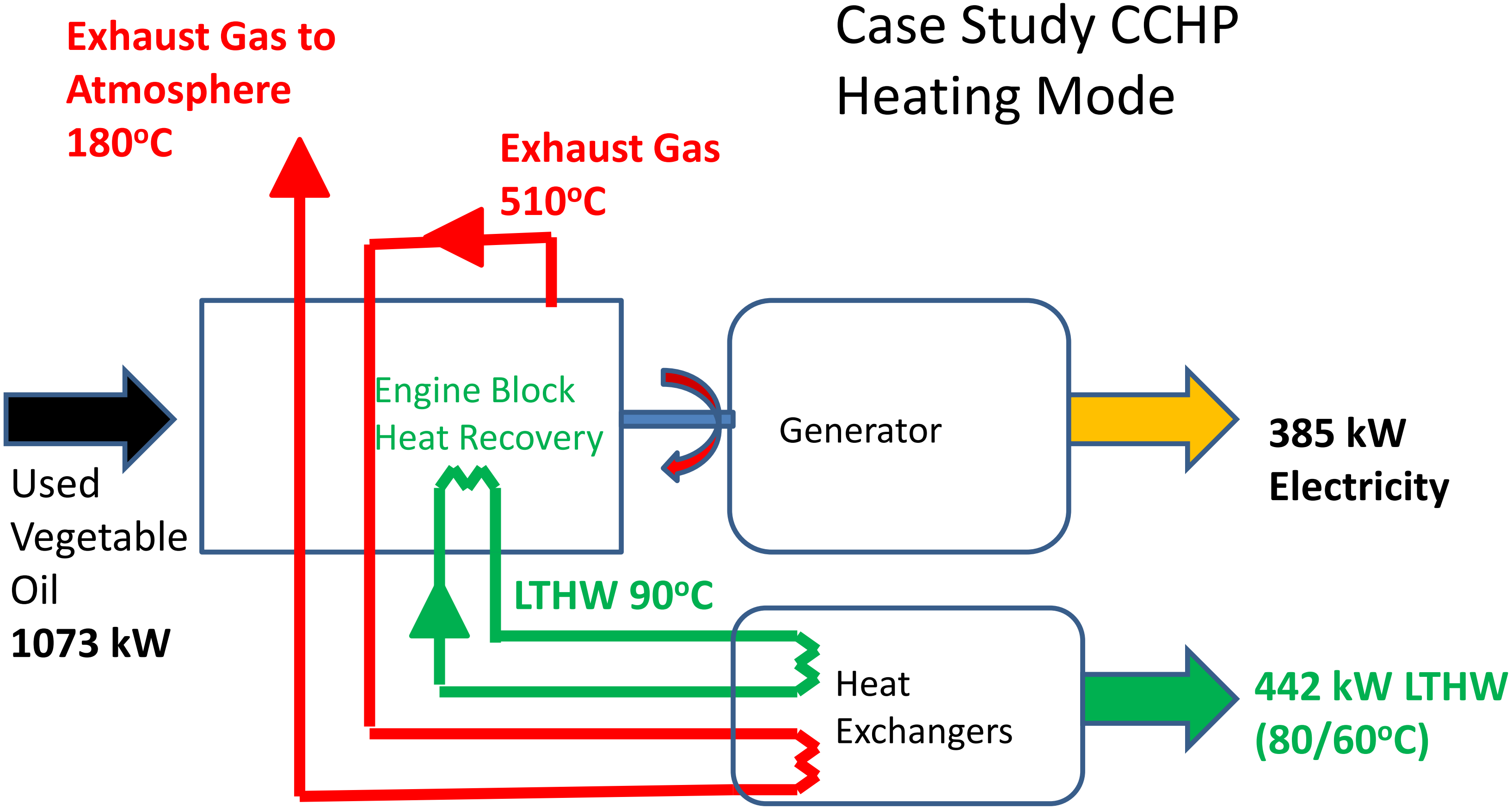
Based on commercial size machines 200-1000 kW

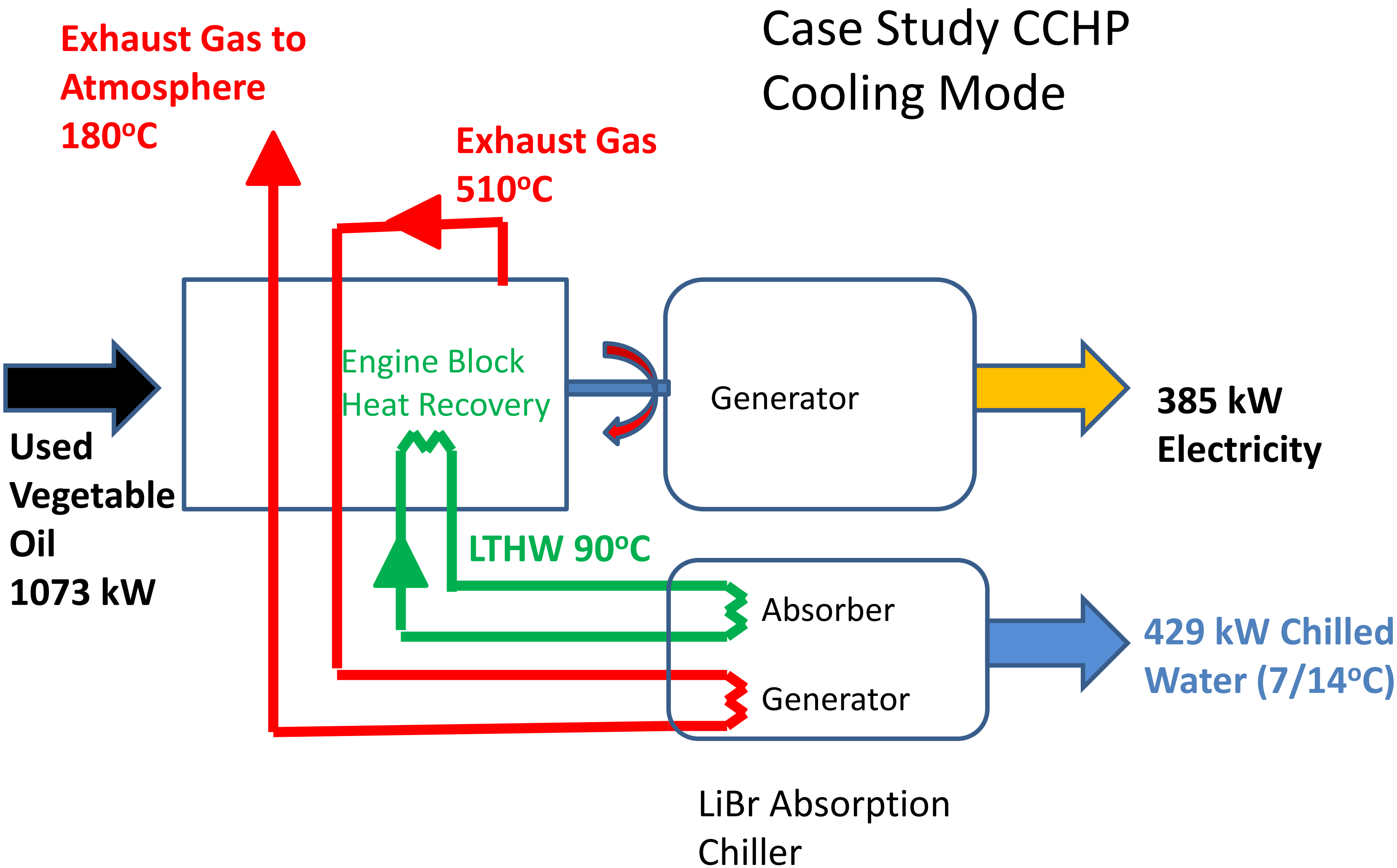
	Vapour Compression	**Absorption**
COP $\frac{\text{Cooling duty (kW)}}{\text{Power input (kW)}}$	COP typically about 5	COP is function of temperature of heat source: 90°C - 0.6 to 0.7 500°C - 0.9 to 1.0
Fuel	Electricity	LTHW MTHW Flue Gas Natural Gas
Heat Rejection Rate (1 +1/COP)) x cooling duty	Typically about 1.2 x cooling duty	Between 2 and 2.7 x cooling duty
Condenser water temperature	T Typically 45°C	Typically 35°C

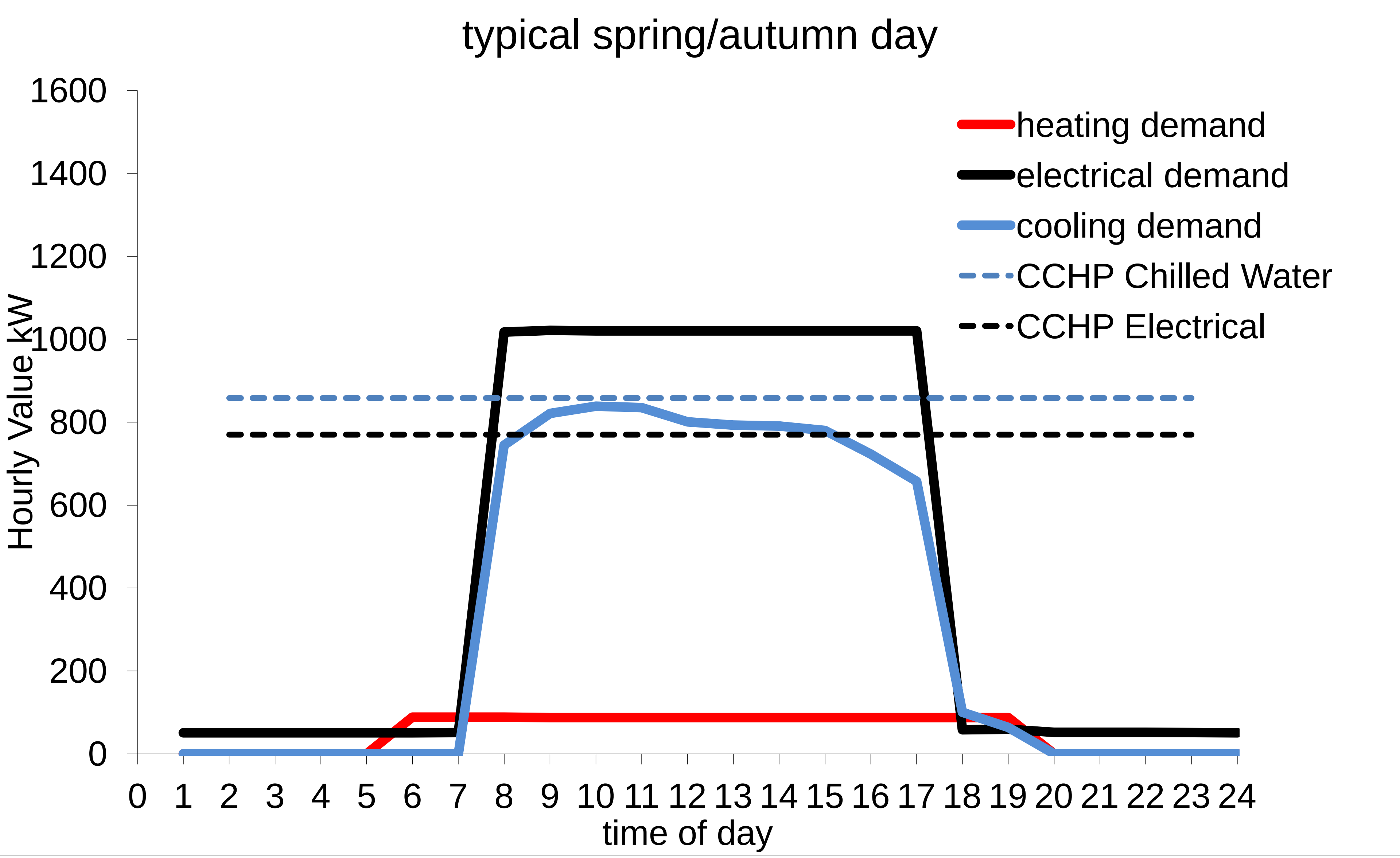
Principle of Tri-generation



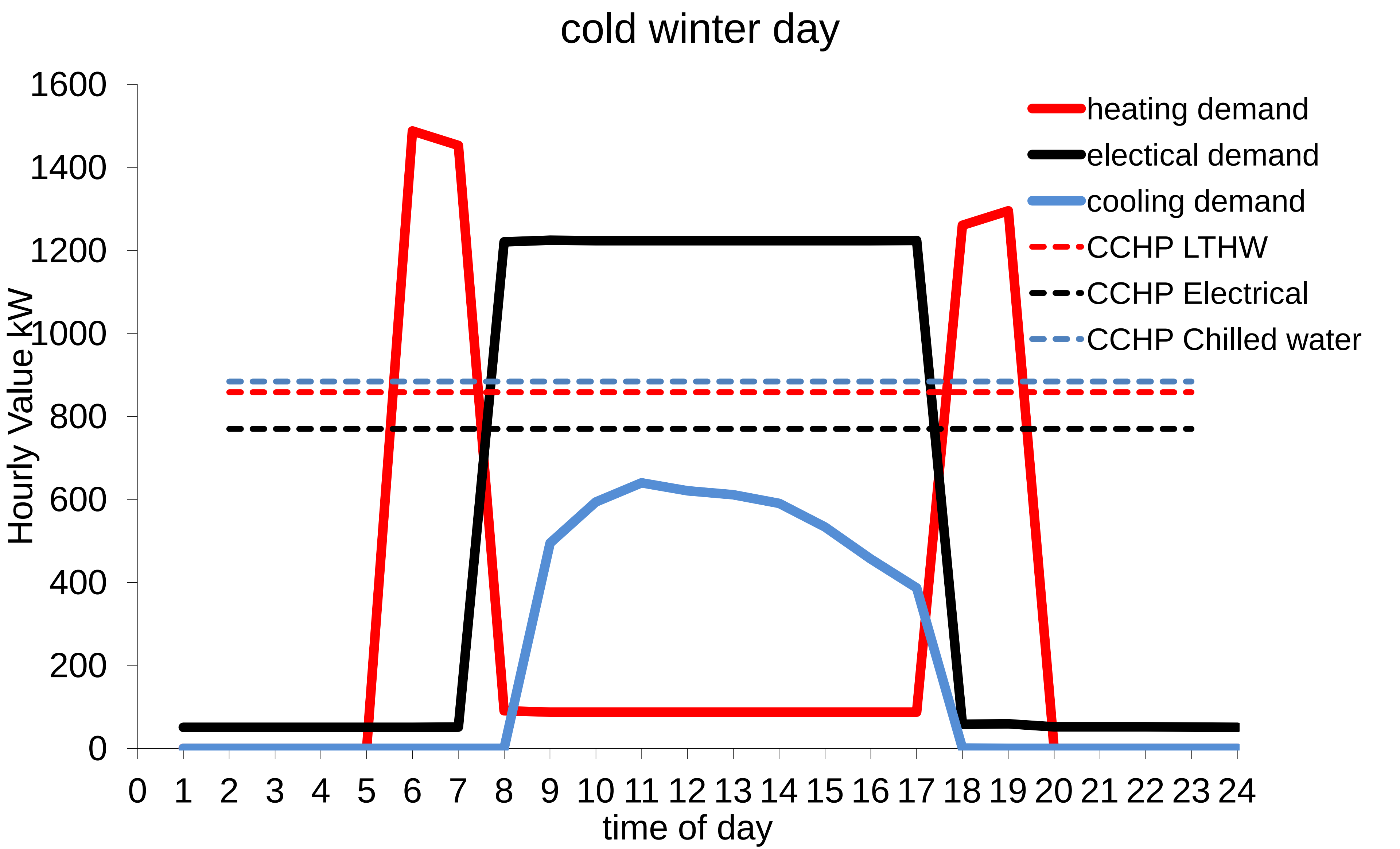
Case Study CCHP
Heating Mode



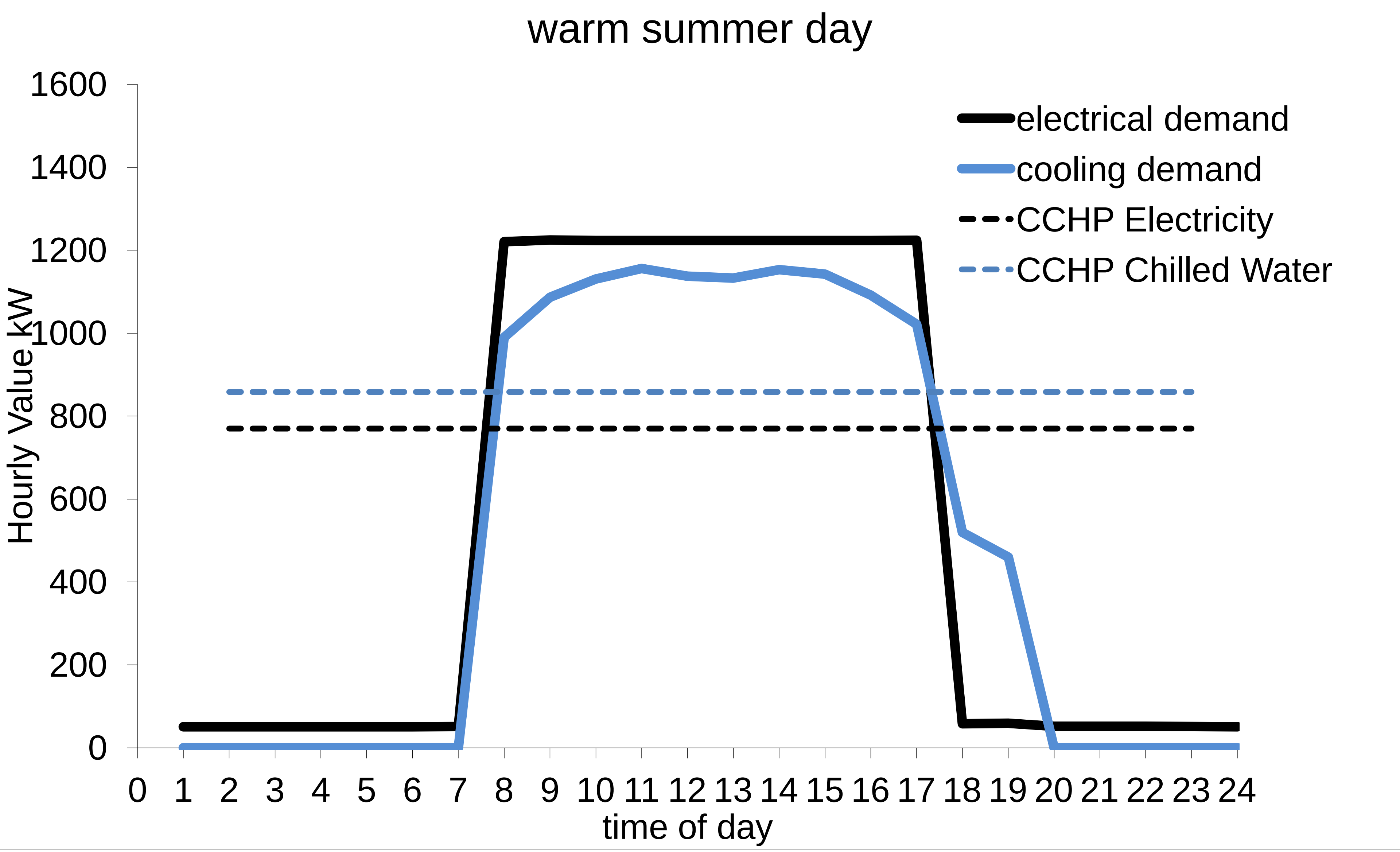

Case Study CCHP
Cooling Mode
Exhaust Gas to Atmosphere 180°C
Exhaust Gas 510°C
Engine Block Heat Recovery
Generator
385 kW Electricity
Used Vegetable Oil 1073 kW
LTHW 90°C
Absorber
Generator
429 kW Chilled Water (7/14°C)
LiBr Absorption Chiller



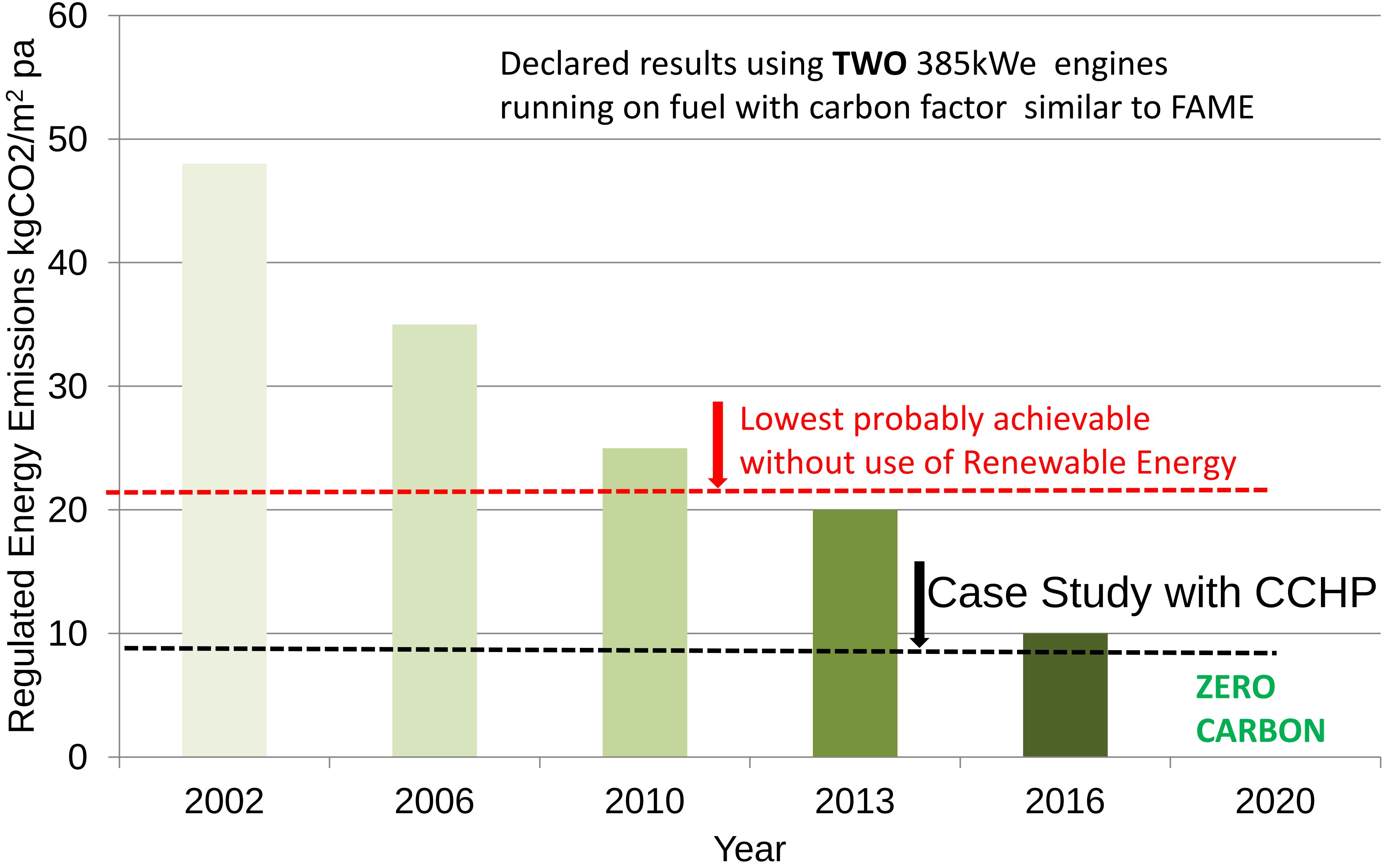
typical spring/autumn day
Hourly Value kW
1600
1400
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
time of day
heating demand
electrical demand
cooling demand
CCHP Chilled Water
CCHP Electrical



cold winter day
1600
1400
1200
1000
800
600
400
200
0
Hourly Value kW
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
time of day
heating demand
electical demand
cooling demand
CCHP LTHW
CCHP Electrical
CCHP Chilled water



warm summer day
1600
1400
1200
1000
800
600
400
200
0
Hourly Value kW
electrical demand
cooling demand
CCHP Electricity
CCHP Chilled Water
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
time of day



Declared results using **TWO** 385kWe engines running on fuel with carbon factor similar to FAME
Lowest probably achievable without use of Renewable Energy
Case Study with CCHP
ZERO CARBON
Regulated Energy Emissions kgCO2/m2 pa
60
50
40
30
20
10
0
2002
2006
2010
2013
2016
2020
Year

Simple analysis

Input Output Rates for CCHP (KW)			**Carbon factors ($kgCO_2/kWh$)**		
E	Electrical output		C_{ge}	Grid electricity	
L	Low grade heat output		C_{hf}	Heating fuel	
H	High grade heat output				
F	Fuel input		C_f	Fuel used by engine	
Plant efficiencies/COP			**Derived factors**		
η_{hg}	Alternative Heat generator		η_E	Electrical efficiency = E/F	
η_{vc}	Vapour Compression chiller		R	Total heat to power ratio =(H+L)/E	
η_{abs}	Absorption chiller				

simple analysis -heating

It can be shown that (when operating at full load):

If all (high grade and low grade) heat produced is used for heating then

$$\frac{S}{E} = C_{ge} + C_{hf}\left(\frac{R}{\eta_{hg}}\right) - C_{f}\left(\frac{1}{\eta_{E}}\right)$$

Where S/E is the savings in carbon emissions per unit of electrical output produced ($kgCO_2/kWh_e$)

simple analysis- cooling

If all (high grade and low grade) heat produced is used for cooling:

$$\frac{S}{E} = C_{ge}\left\{1 + R\left(\frac{\eta_{ABS}}{\eta_{VC}}\right)\right\} - C_f\left(\frac{1}{\eta_E}\right)$$

Where S/E is the savings in carbon emissions per unit of electrical output produced ($kgCO_2/kWh_e$)

simple analysis

In reality, not all of the heat produced might be used for either heating or cooling but rejected in which case:

Heating only:

$$\frac{S}{E} = C_{ge} + XC_{hf}\left(\frac{R}{\eta_{hg}}\right) - C_f\left(\frac{1}{\eta_E}\right)$$

Cooling only:

$$\frac{S}{E} = C_{ge}\left\{1 + XR\left(\frac{\eta_{ABS}}{\eta_{VC}}\right)\right\} - C_f\left(\frac{1}{\eta_E}\right)$$

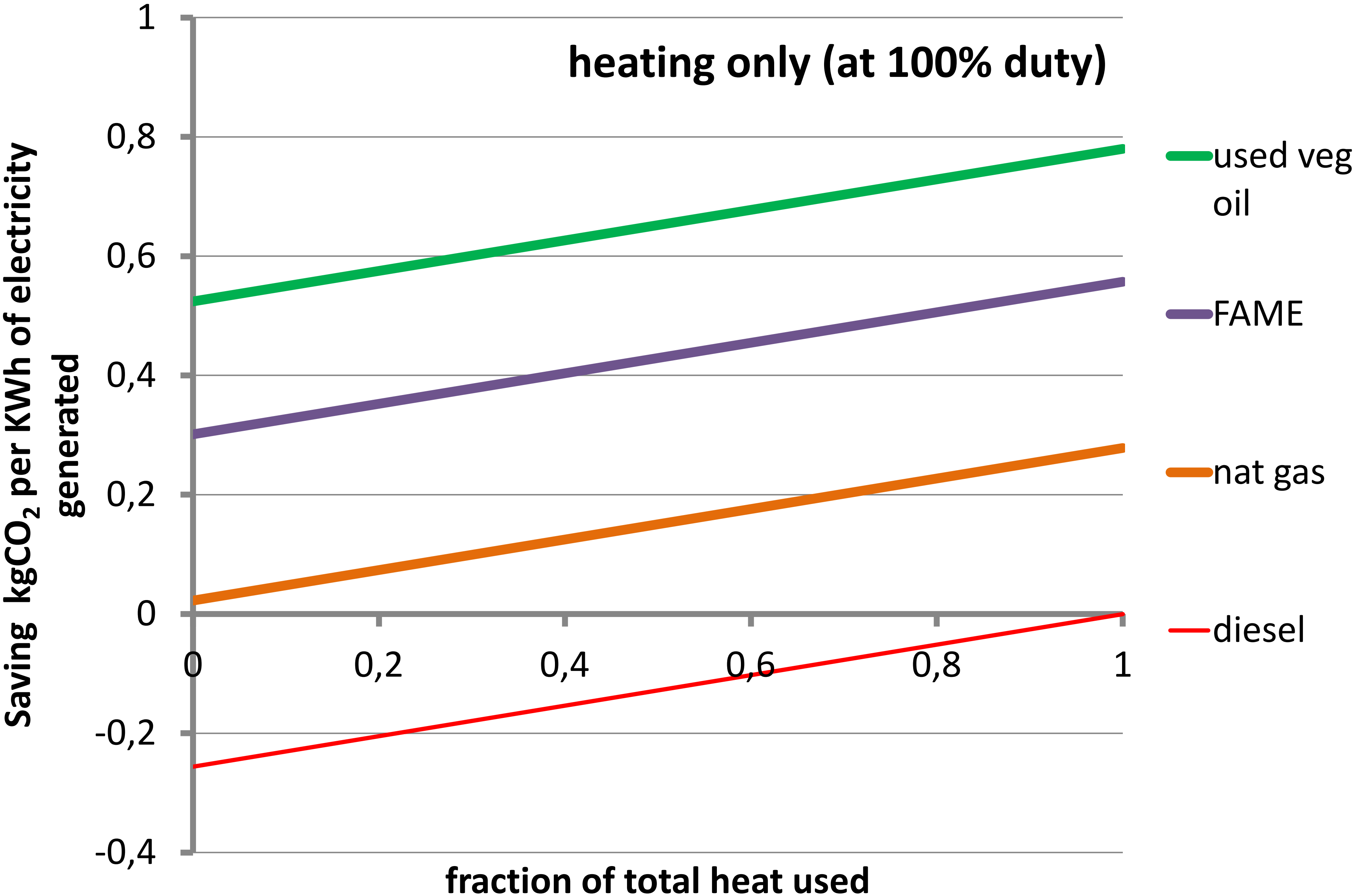
Where *X* is the fraction of available heat used

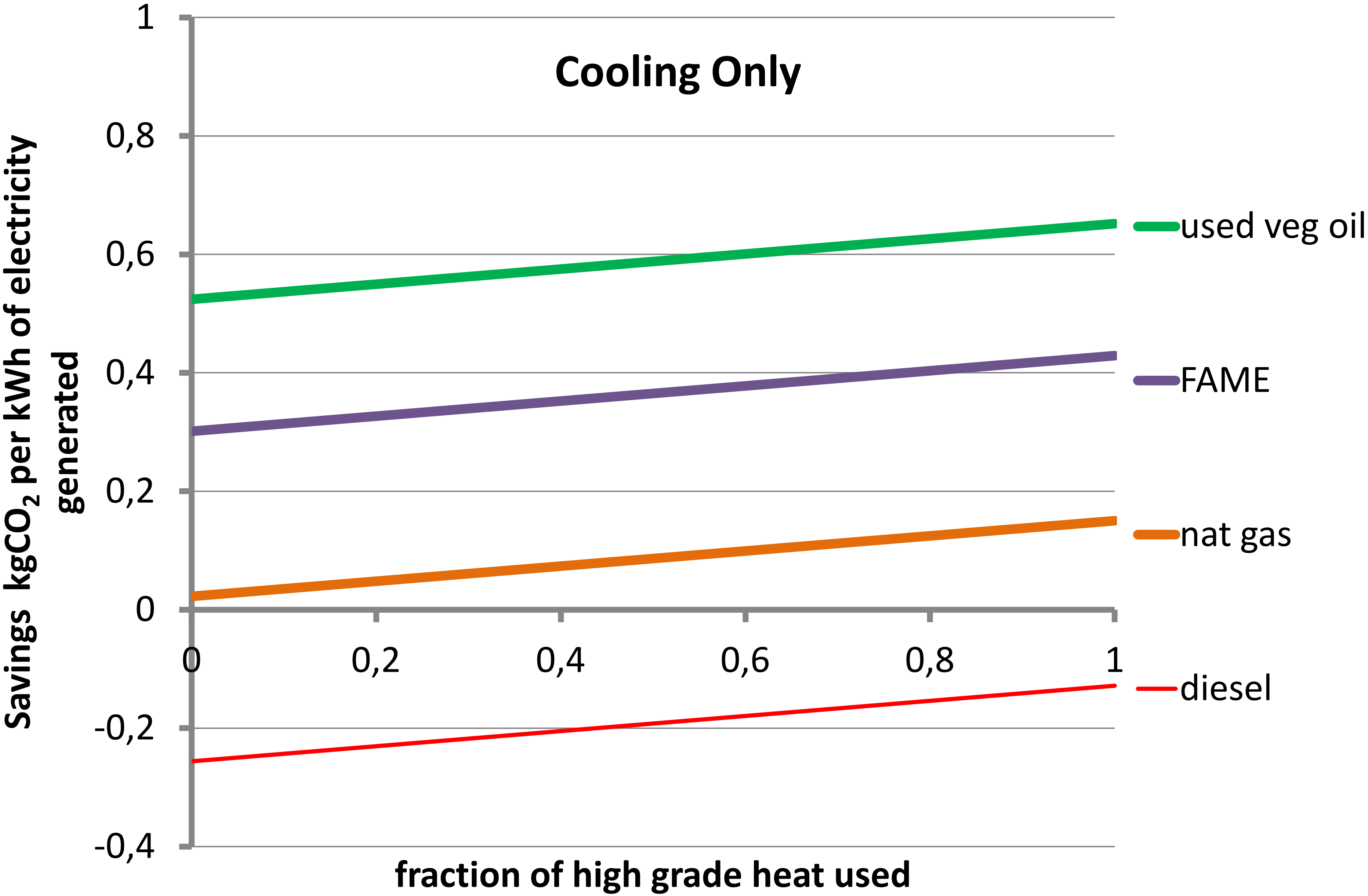
Based on case study

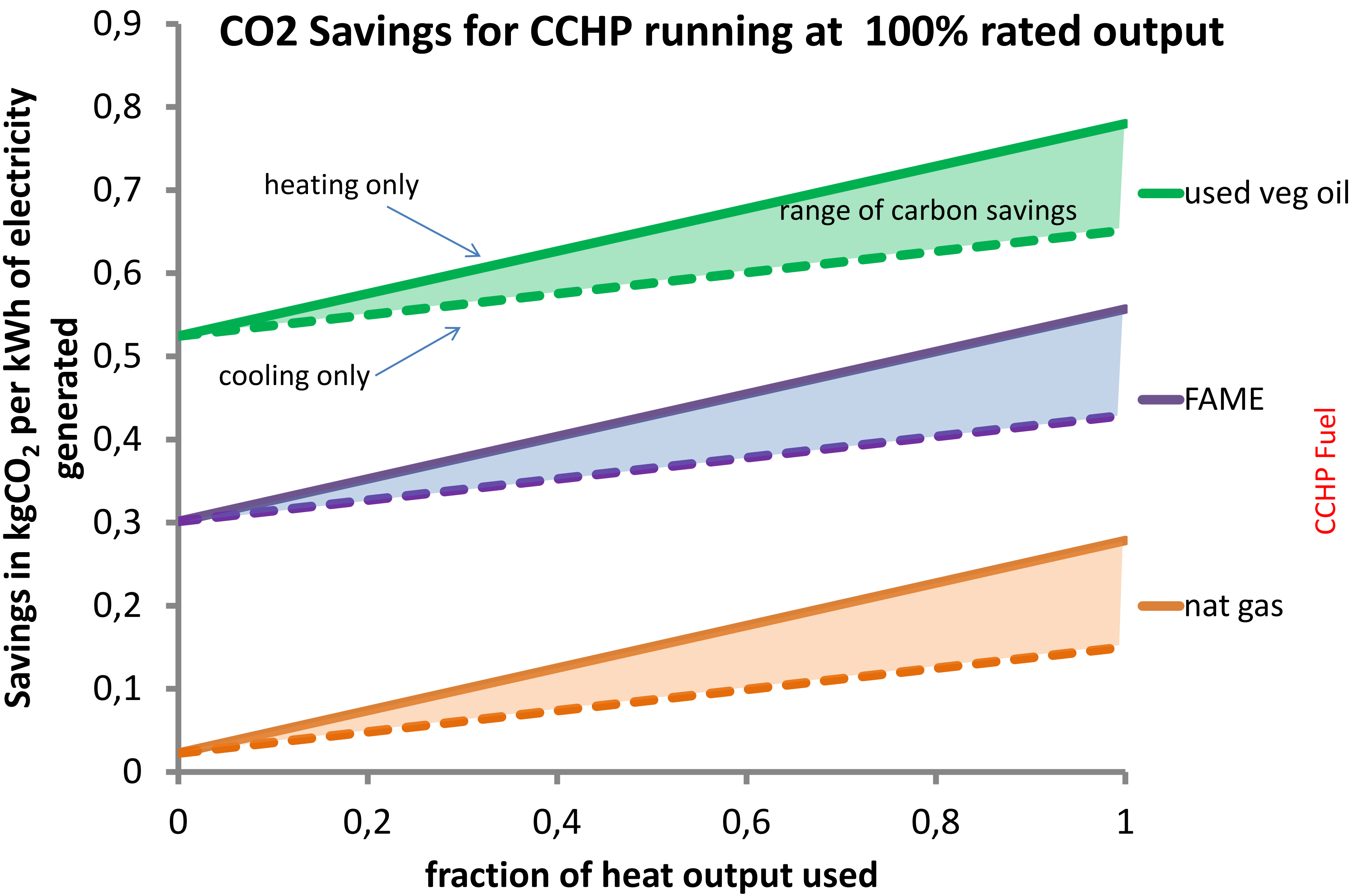
Input Output Rates for CCHP (KW)			**Carbon factors (kgCO2/kWh)**		
E	Electrical output	385	C_{ge}	Grid electricity	0.58
L	Low grade heat output	193	C_{hf}	Heating fuel (nat gas)	0.20
H	High grade heat output	250			
F	Fuel input (LCV)	1073	C_f	Fuel used by engine	various
Plant efficiencies/COP			**Derived factors**		
η_{hg}	Heat generator (gas boiler)	0.90	η_E	Electrical efficiency = E/F	0.36
η_{vc}	Vapour Compression chiller	5.0	R_H	High grade heat to power ratio =(H+L)/E	1.15
η_{abs}	Absorption chiller	0.96			

Available fuels for reciprocating engines

	Approximate Carbon factor (kgCO2/kWh)
Natural Gas	0.20
FAME (bio-diesel)	0.10
Used Vegetable Oil	0.02
Petroleum Diesel	0.30

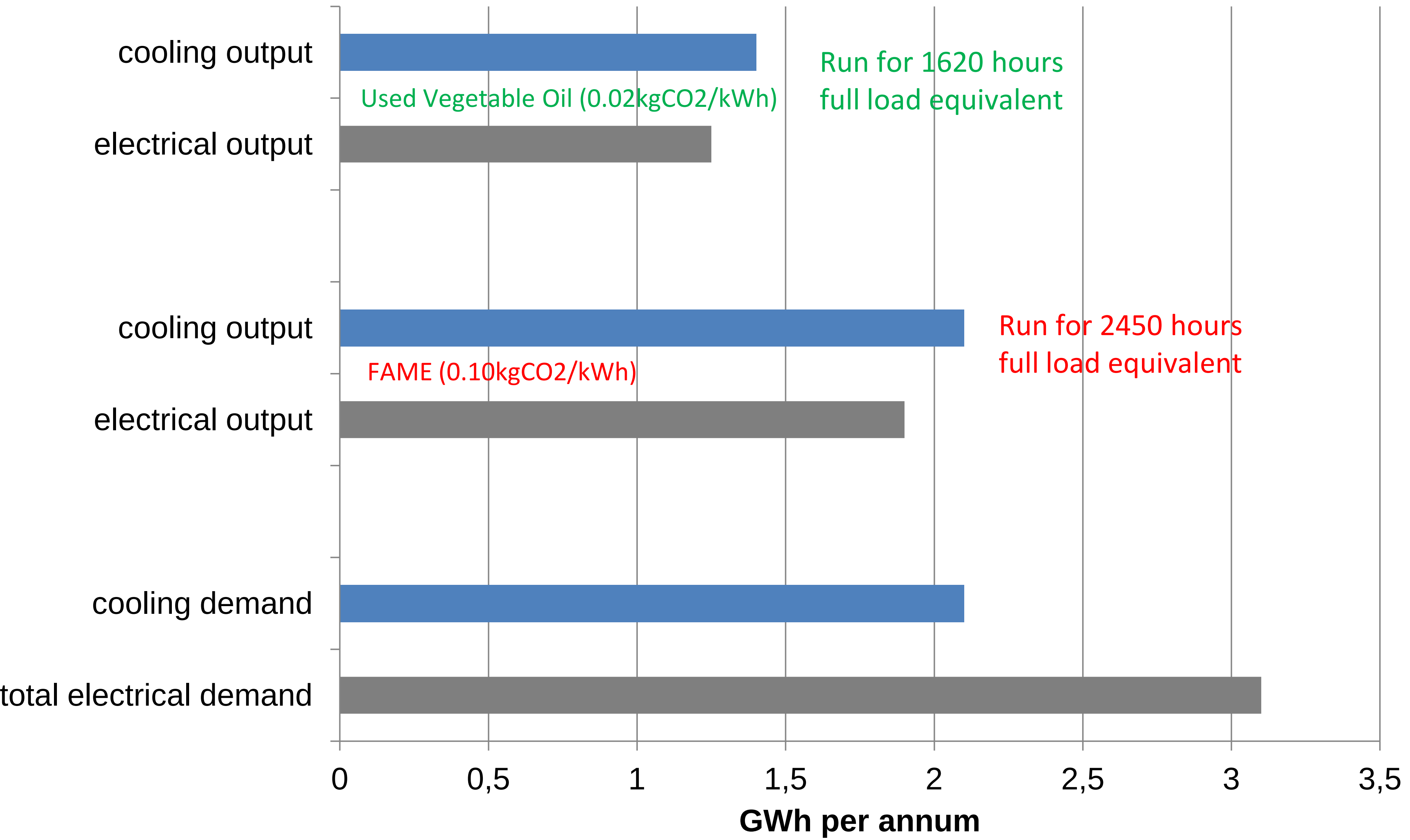

heating only (at 100% duty)
Saving kgCO2 per KWh of electricity generated
fraction of total heat used
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
0
0,2
0,4
0,6
0,8
1
used veg oil
FAME
nat gas
diesel


Cooling Only
Savings kgCO2 per kWh of electricity generated
fraction of high grade heat used
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
0
0,2
0,4
0,6
0,8
1
used veg oil
FAME
nat gas
diesel



CO2 Savings for CCHP running at 100% rated output
Savings in $kgCO_2$ per kWh of electricity generated
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
heating only
cooling only
range of carbon savings
used veg oil
FAME
nat gas
CCHP Fuel
0
0,2
0,4
0,6
0,8
1
fraction of heat output used

Run Hours to achieve Zero Carbon



Further Work

- Need to improve accredited software so can model CCHP more realistically

- Need to bridge the gap between predicted and actual energy consumption

Using Biofuels with CCHP technology in pursuit of "Nearly Zero Energy Buildings"

Martin Ratcliffe
School of Engineering and Design
Brunel University, London, UK

Inno Week, Patras Greece
9th July 2013

Brunel UNIVERSITY LONDON