Heat Recovery from Chillers

Used for DHW production and Humidity / Reheat control

September 2022

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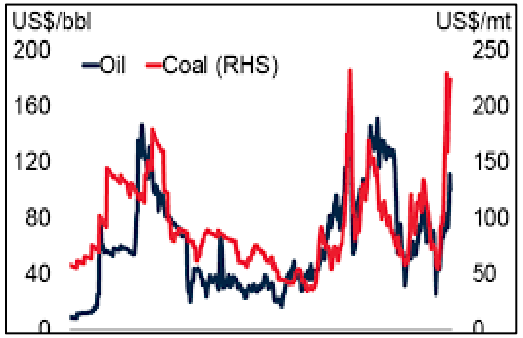
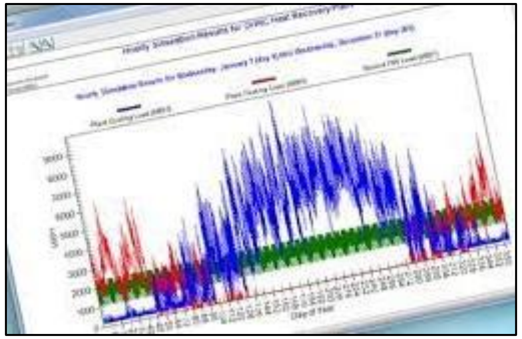
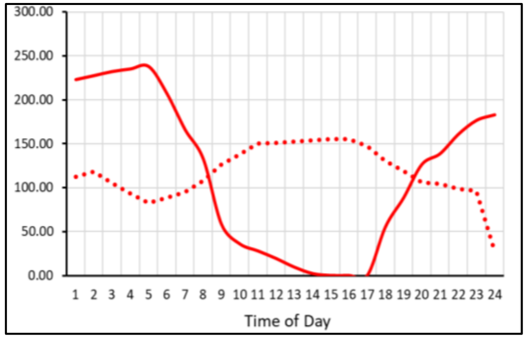
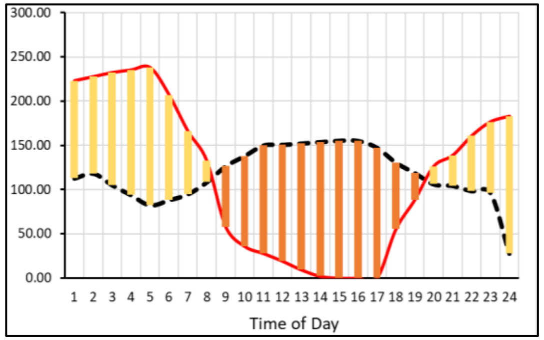
Heat Recovery from Air-Cooled Chillers and HP

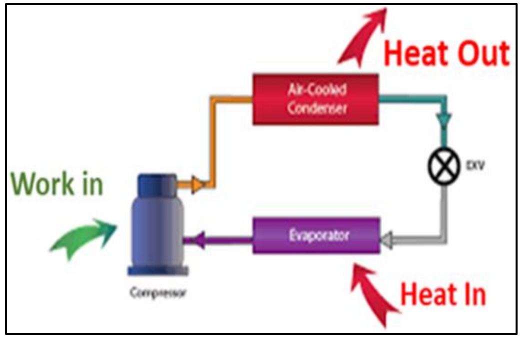
- Why do we care about
- When do we use it
- Trues and faults about heat recovery
- Where it comes from
- How much can we have
- How much do we need
- How much can we use
- Using energy storage
- Design – simulate – redesign - optimize











Why Heat Recovery?

- Cost
  - First cost vs pay back period:
    - Gas boiler size reduction vs higher cost of heat recovery chiller
    - Operation cost reduction
  - National/Local subsidies or tax reduction
  - CO2 gas emissions reduction

- Environment
  - Heat recovery lowers primary energy consumption. Heat recovery is considered as ”green technology”
  - Green technologies and sustainability policies of organizations / companies are used for marketing advertisement and public relations

- Regulations
  - EU F-Gas Regulation for CO_2 gas emissions reduction
  - Ecodesign, LEAD certification, BREEM certification, etc (Buildings energy consumption reduction)

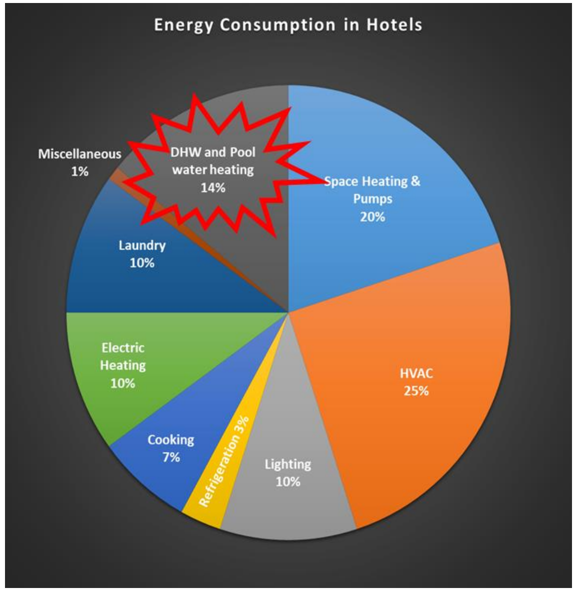
Heat Recovery – When do we consider it?

- Simultaneous cooling and heating loads installations

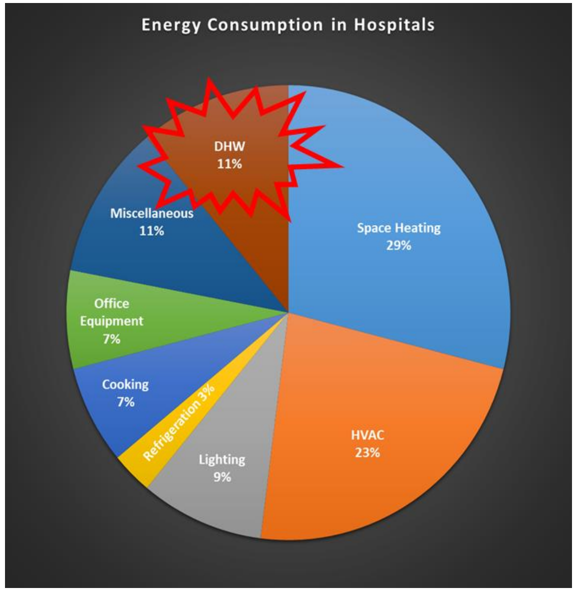
- Heat storage (either cooling of heating) can reduce – separate simultaneous cooling and heating loads needs

- Applications - Candidates:
    - Hotels (heat recovery for DHW, swimming pools, etc)
    - Hospitals (cooling loads of operating rooms, ICUs and DWH production)
    - DOAHUS 100% OA for Hospitals, laboratories, etc (cooling loads and reheat)
    - AHUs with terminal reheat coils (cooling loads and reheat
    - Computer rooms (cooling loads year-round and building heating / district heating, reheat for HR% control)
    - Process – Industrial applications (cooling loads year-round and building heating / district heating, reheat for HR% control)
    - …

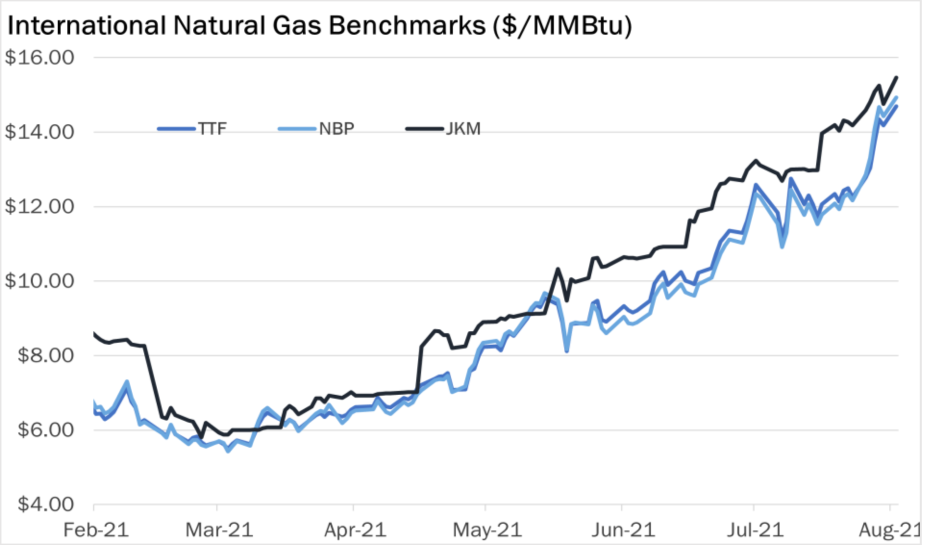
Energy Consumption of DHW vs Building's Total



Energy Wise Hotels
Energy TOOLKIT
City of Melbourne, December 2007



Energies 2019, 12, 3775
Energy Consumption Analysis of Healthcare Facilities in the United States



Myths and Reality

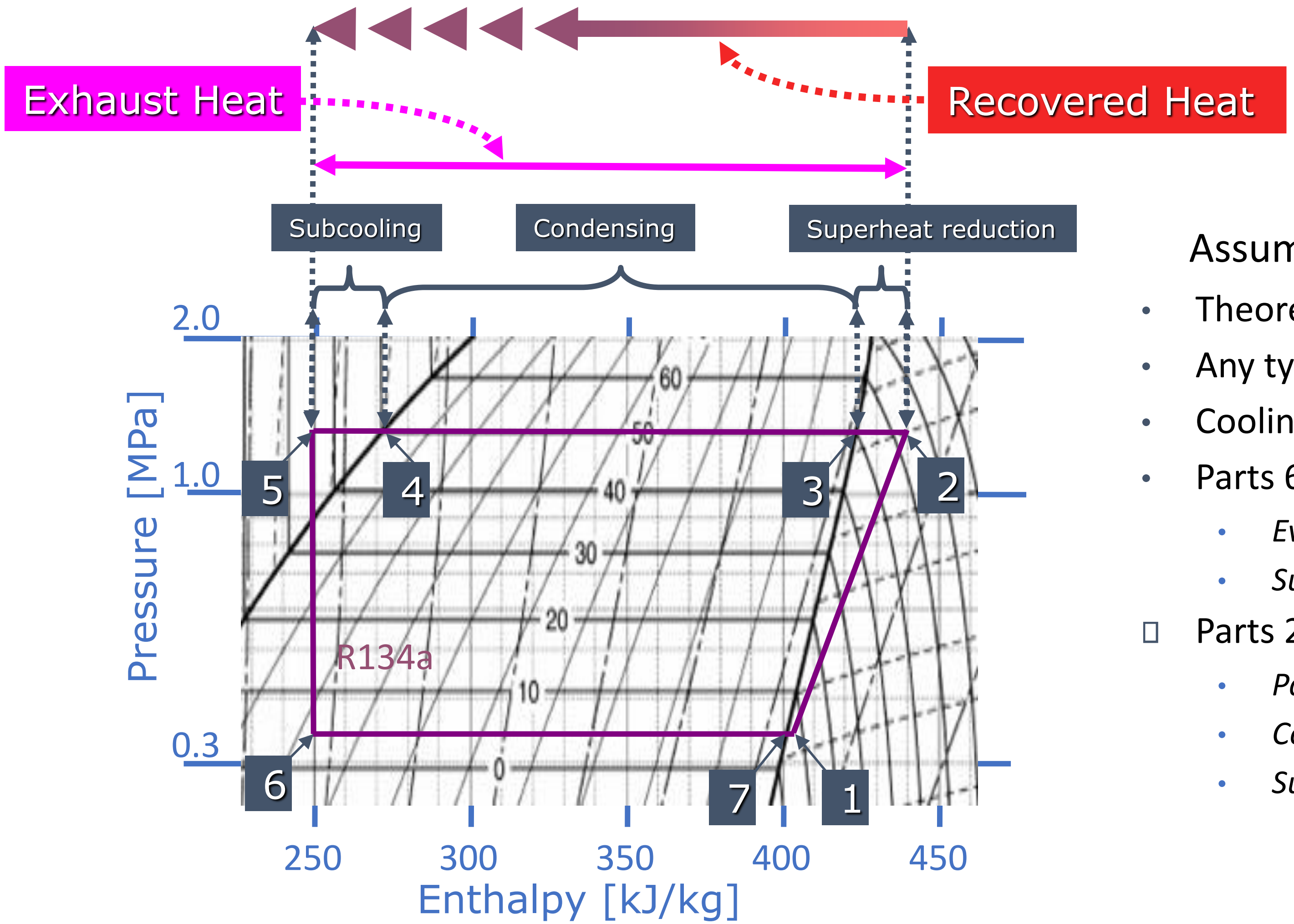
There are many ways to recover exhaust heat.

Heat recovery is “free”.

We are interested both on quantity (recovered heat) and on quality (hot water temperature).

Best way to recover the heat is the less expensive.

Recovered Heat



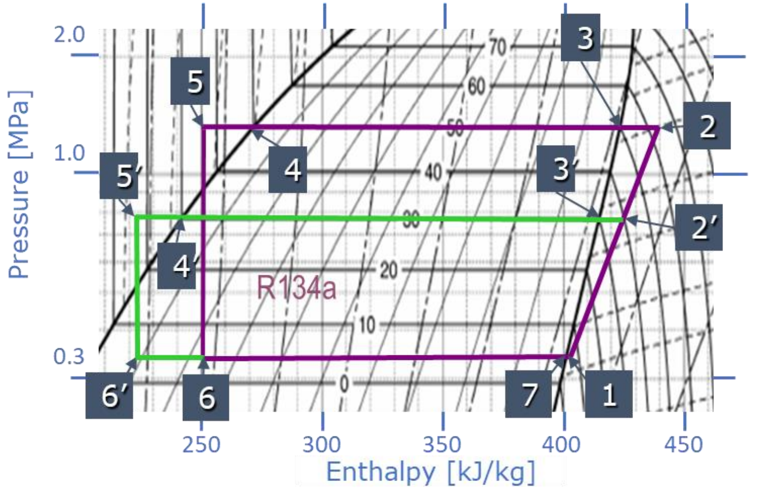
Assumptions:

- Theoretical Refrigeration Cycle
- Any type of Refrigerant: R22, R134a, R407C*, R410A*,…
- Cooling Capacity (part 6-1): 100 kW
- Parts 6-7-1:
  - *Evaporation temperature: part 6-7: 4°C*
  - *Superheated gas: point 1: 7°C*
- Parts 2-3-4-5:
  - *Part 2-3: condenser entering: constant pressure, temperature drop*
  - *Condensing temperature: parts 3-4: 50°C*
  - *Subcooled liquid: point 5: 36°C*

Uncontrolled and Controlled Recovery

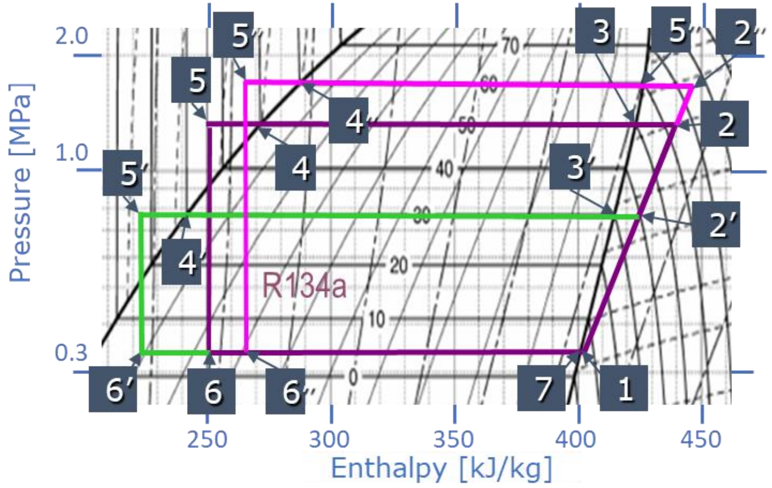
- Pros
  - Operation as cooling only unit
- Cons
  - No control on heat recovered energy (quantity)
  - No control on heat recovered water temperature (quality)

Uncontrolled



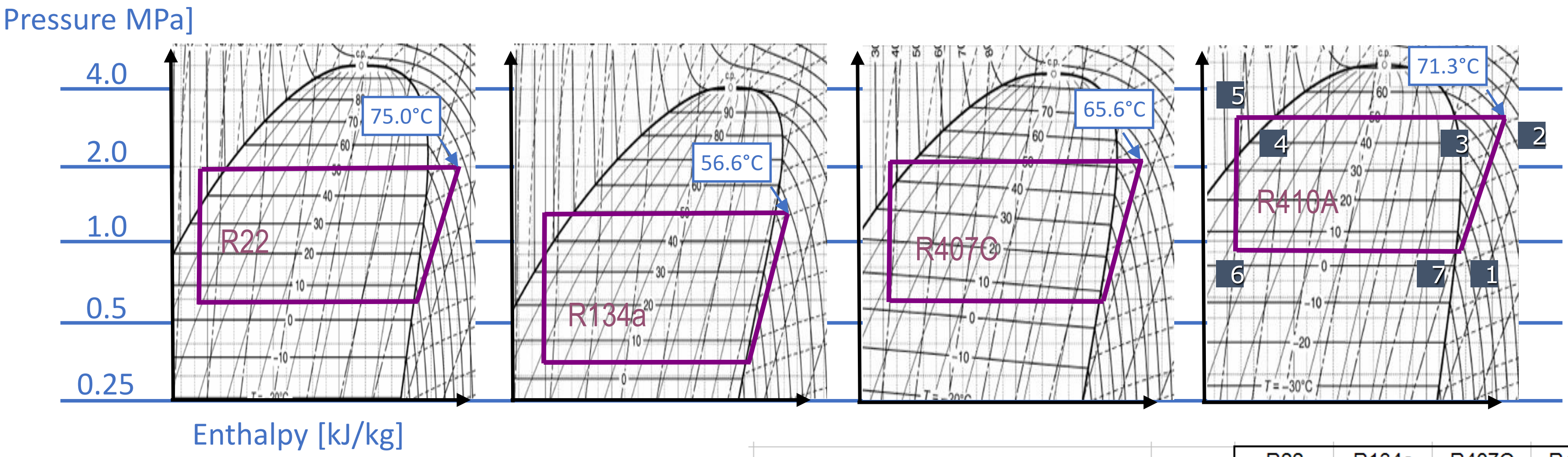
- Pros
  - Controlled heat recovered energy and water temperature
- Cons
  - Possible oversized chiller
  - Increased energy consumption during heat recovery operation mode

Controlled



Design Conditions — Reduced Ambient Temperature — Heat Recovery operation mode

Each Refrigerant is Unique



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		R22	R134a	R407C	R410A
Evaporating pressure	bar	5.66	3.38	5.71	9.12
Condensing pressure	bar	19.33	13.18	21.00	30.83
kW input (segment 1-2) (100% efficient compression)	kW	19.1	18.9	19.8	20.2
Discharge temperature (point 2)	°C	75.0	56.6	67.7	71.3
Cycle Efficiency (Cooling Cap. / kW input)		5.23	5.30	5.04	4.96
Gross Heat Rejection (segment 2-5)	kW	119.1	118.9	119.8	120.2
Desuperheating Capacity	kW	14.4	5.6	13.0	19.8
Condensation Capacity	kW	93.8	99.4	94.9	83.3
Subcooling Capacity	kW	10.9	13.9	11.9	17.0
Cooling Effect (segment 1-2)	kJ/kg	164.3	151.1	161.6	168.9
Gas Density (point 1)	kg/m³	23.6	16.4	23.9	33.9
Volumetric Flow	m³/h	92.7	145.0	93.2	62.8

Table values are valid for the mentioned assumptions

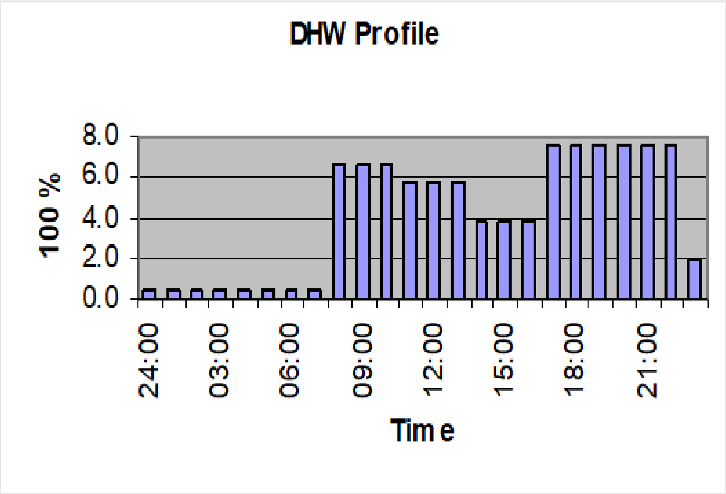
Refrigeration Cycle - Review

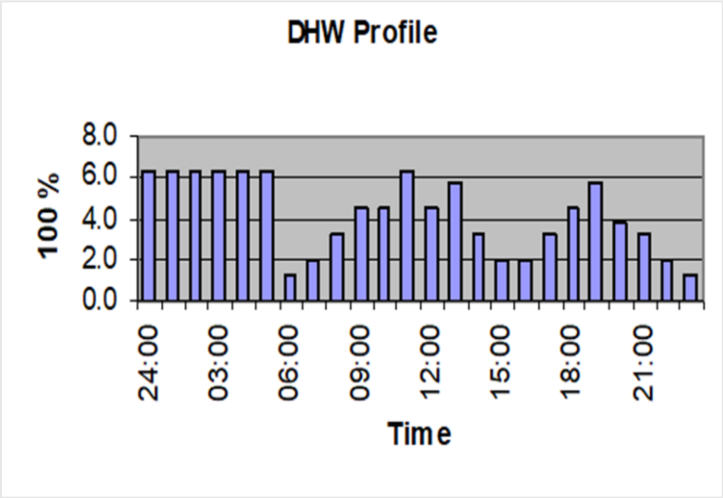
- During refrigeration process we must always reject / subtract heat to have the cycle running
  - If we don’t recover the heat will be exhausted to the atmosphere…

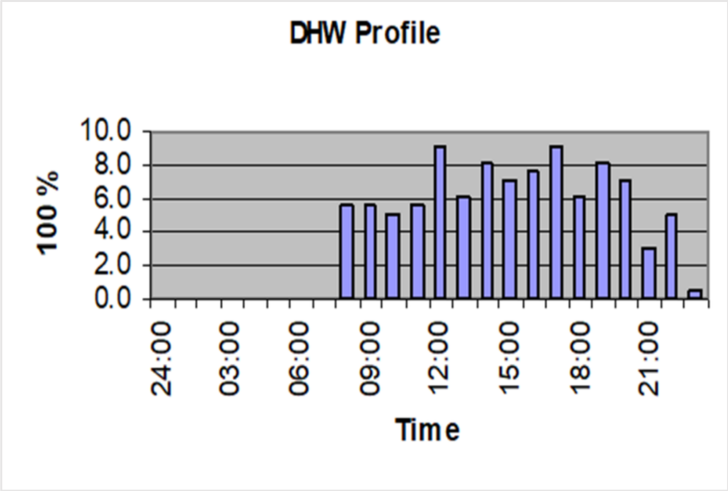
- Amount of recovered heat depends on:
  - Power input and EER/COP.
  - Mode of heat recover operation (controlled / uncontrolled)

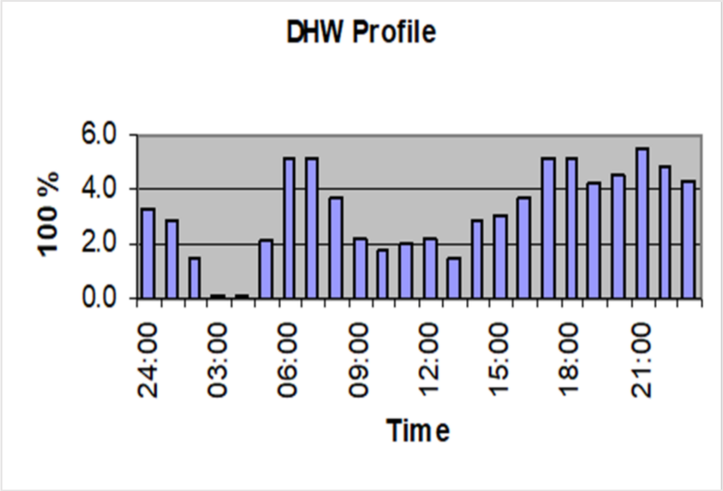
- Hot water temperature depends on:
  - Partial or total heat recovery option
  - Refrigerant type → compressor discharge temperature

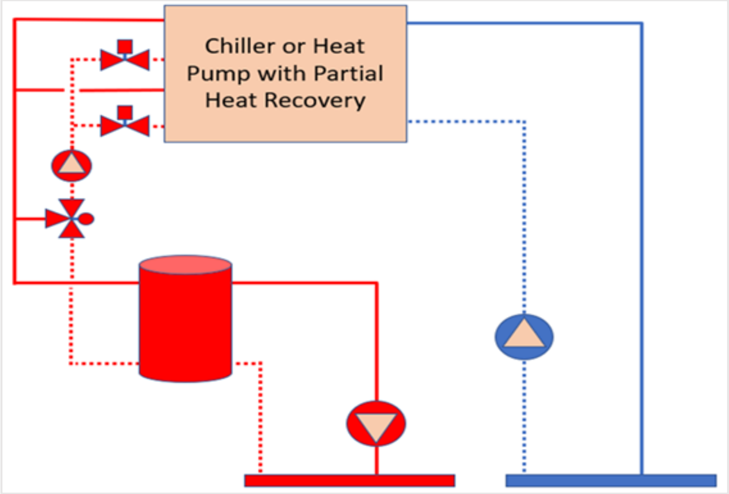
Domestic Hot Water Profiles





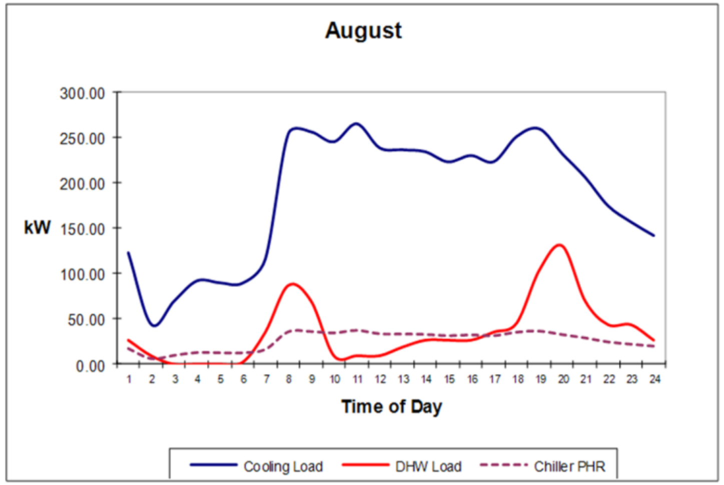


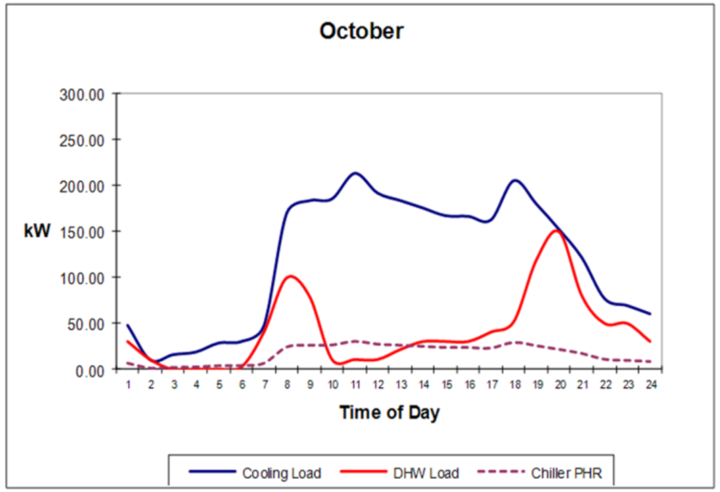


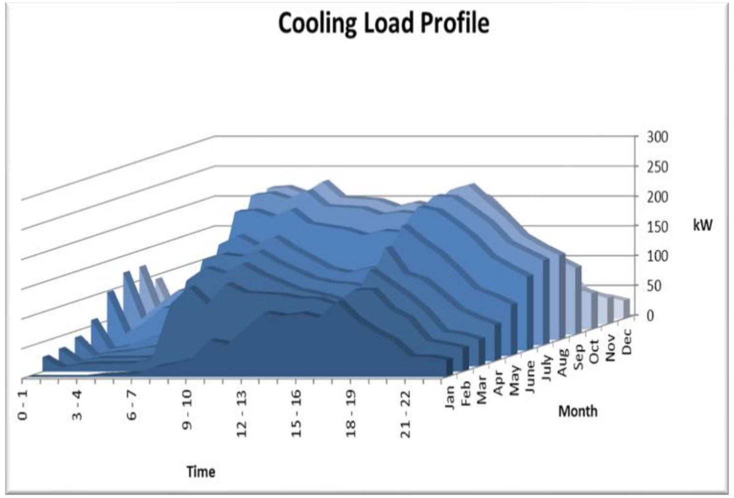


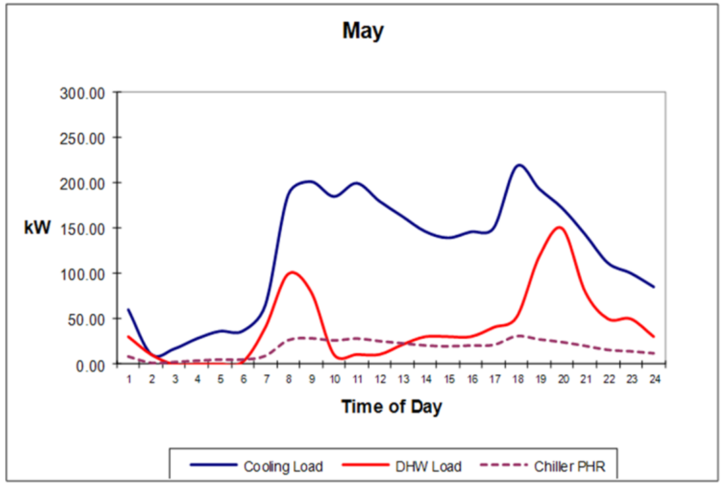
Domestic hot water consumption profiles are necessary for energy analysis

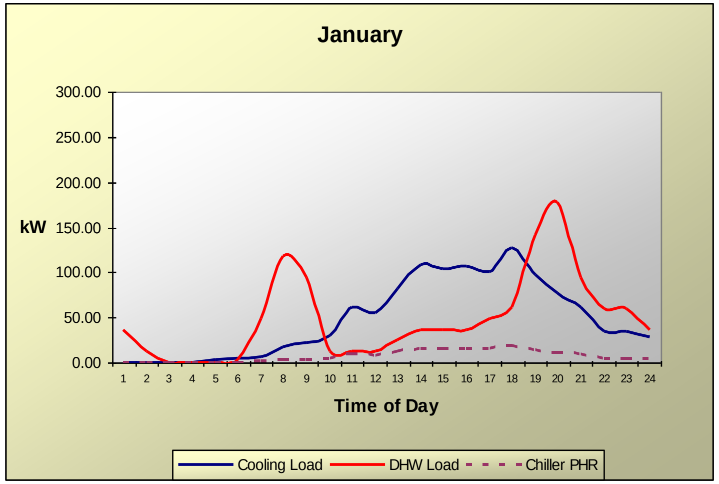
Cooling Load and DWH Profiles

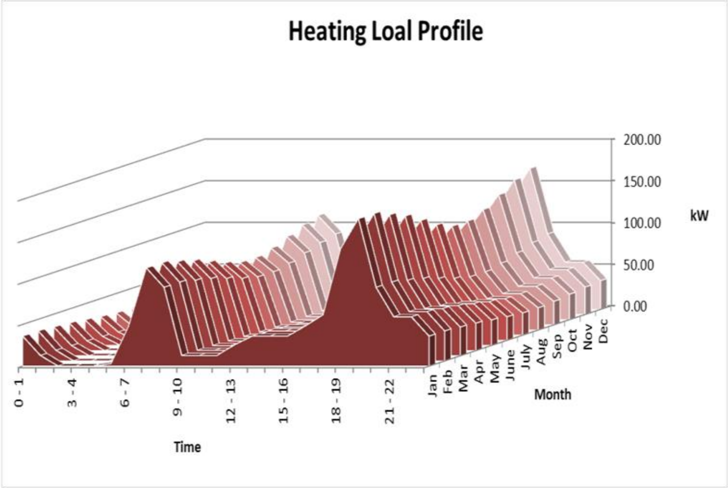






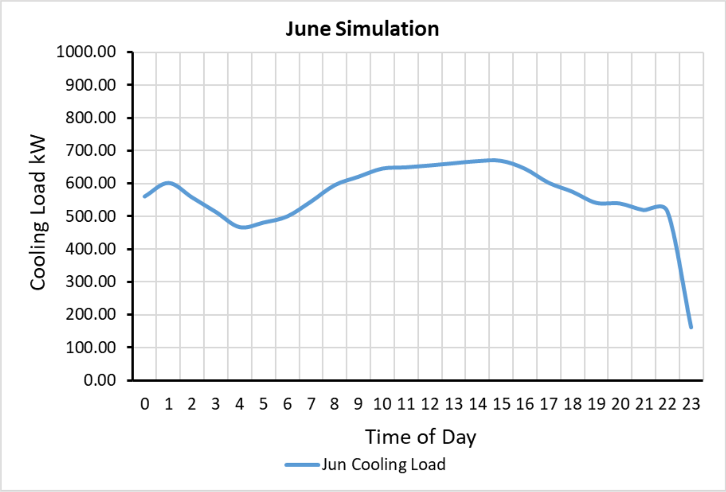


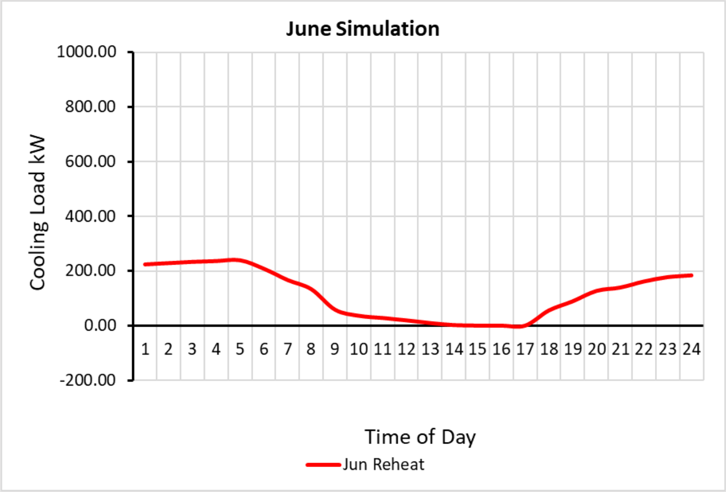


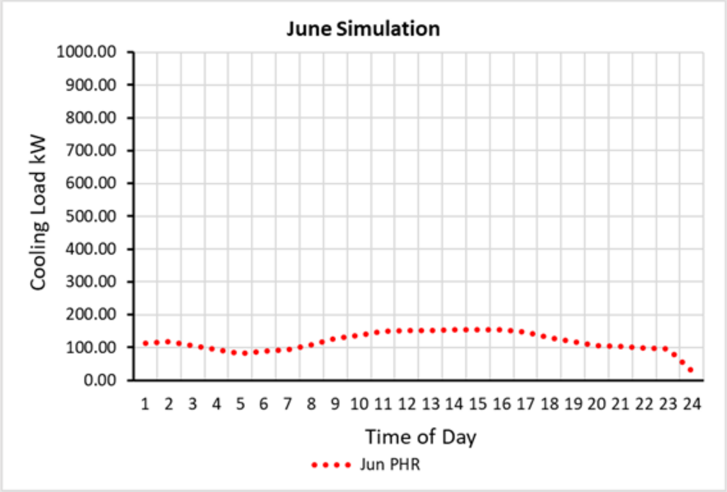


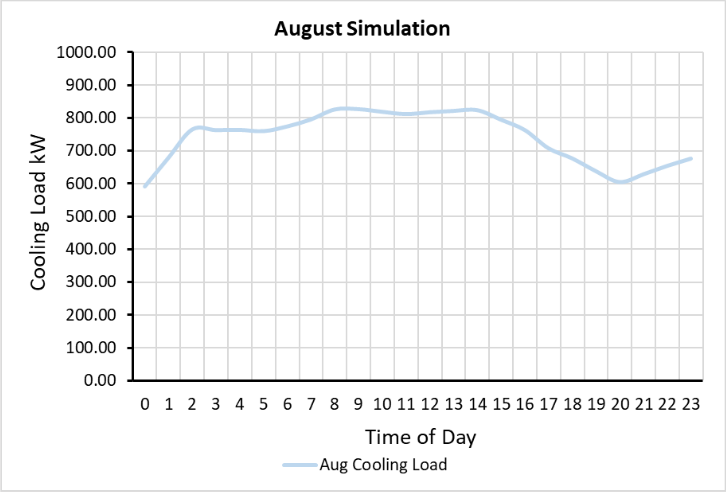
Reheat load profiles are necessary for energy analysis

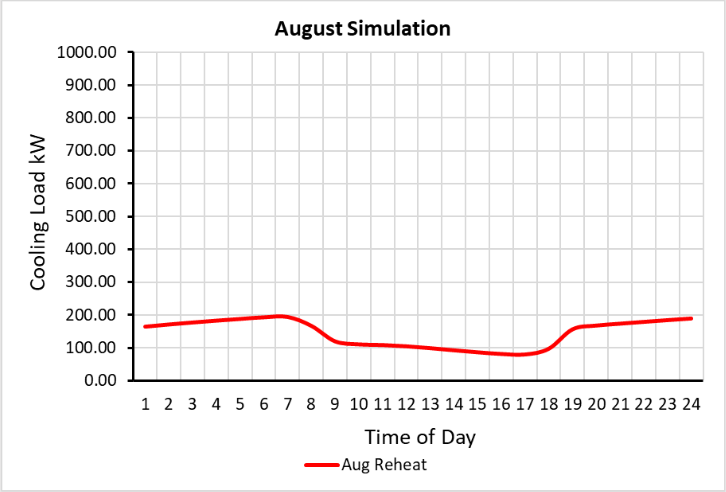
Cooling Load and Reheat Profiles

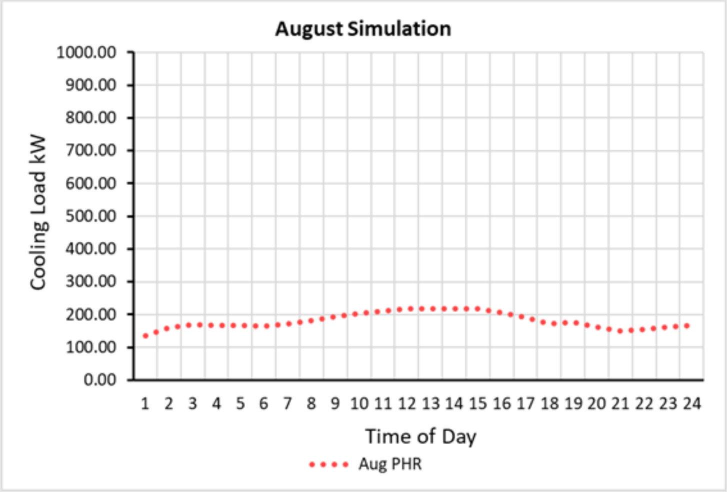






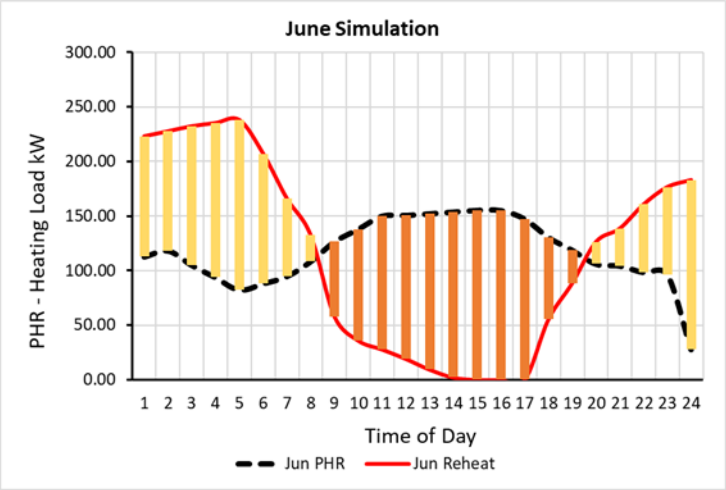


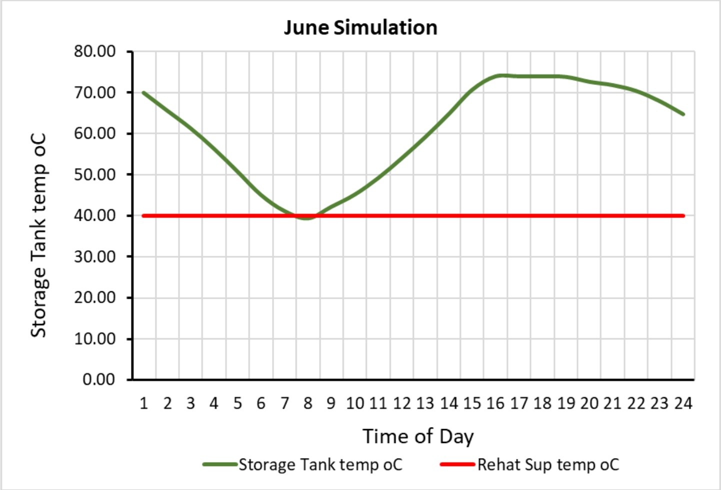


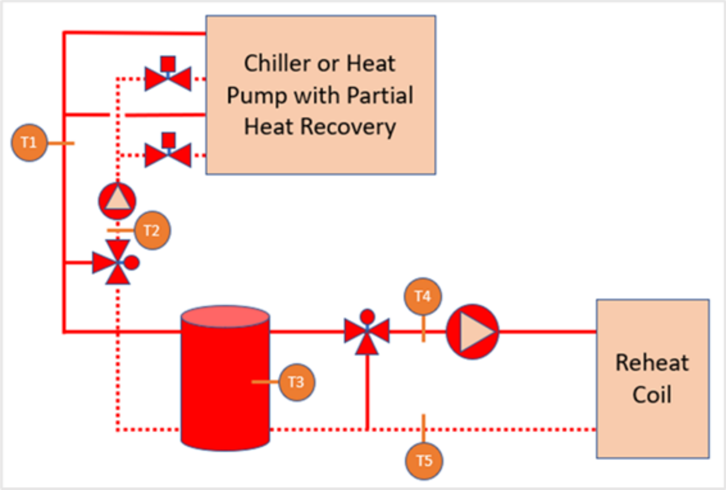


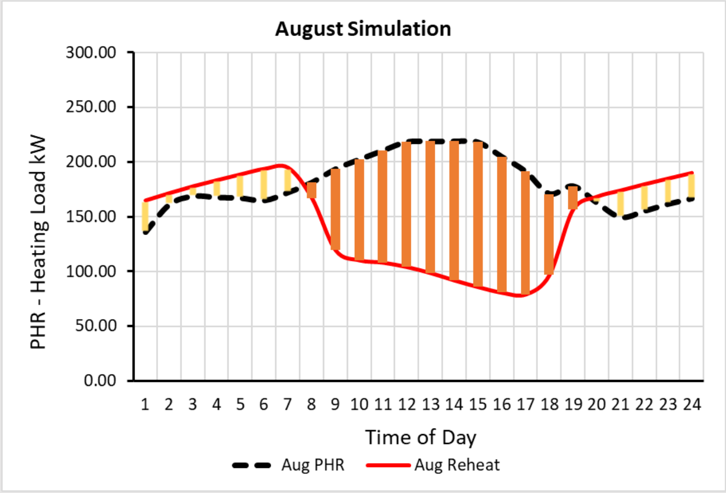
Reheat load profiles are necessary for energy analysis

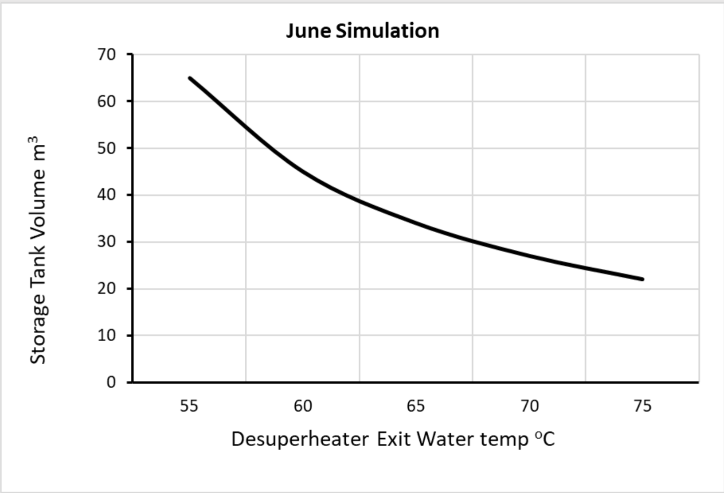
Using Storage to Shift Loads

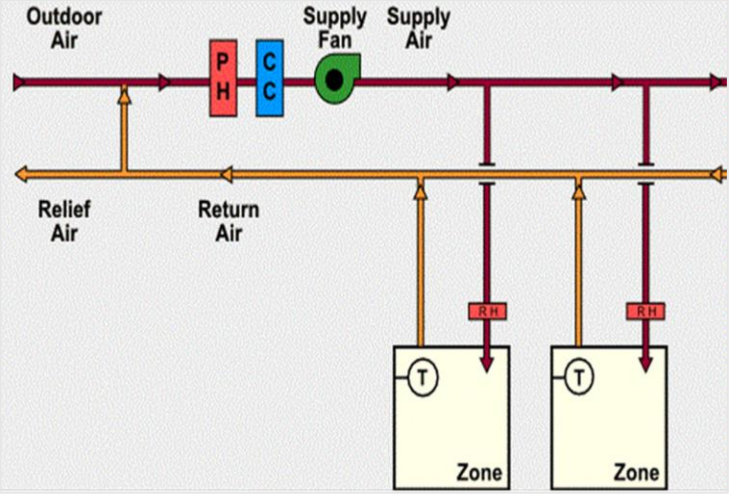










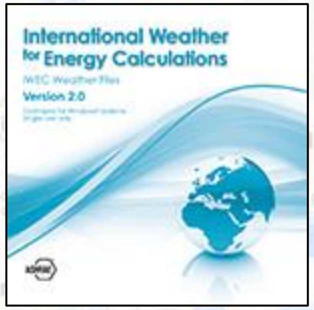


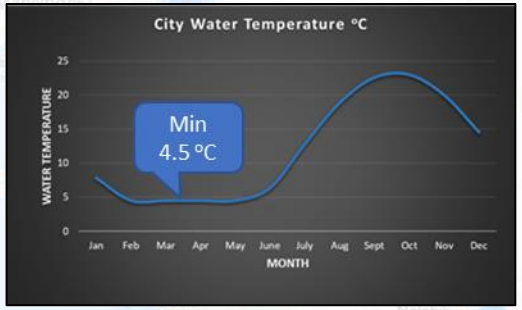
Water storage volume as a function of water storage temperature

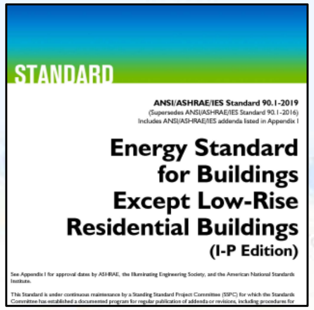
Simulation Tool – Methodology

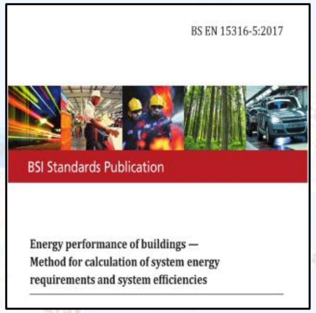
Build in Algorithms

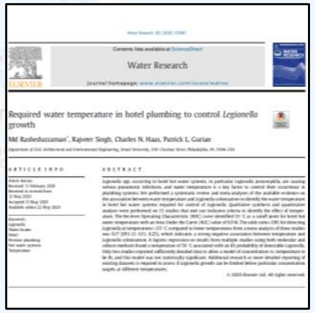
- Weather Data
- City water temperature
- DHW daily Profile
- DHW annual profile
- Reheat load profiles
- A/C chillers data points
- Burner data points
- Storage tank simulation
- Buffer tank calculation
- Distribution water pumps
- A/C chillers water pumps
- Storage control algorithm
- A/C chillers sequencing
- Fuels and energy tariffs

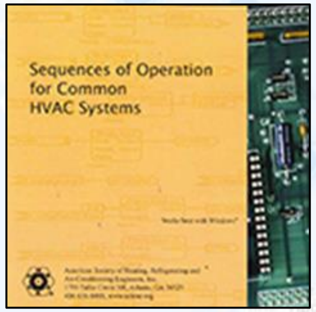


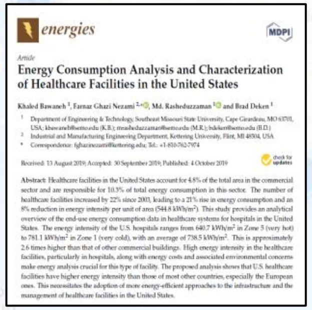


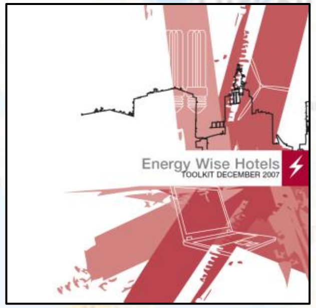


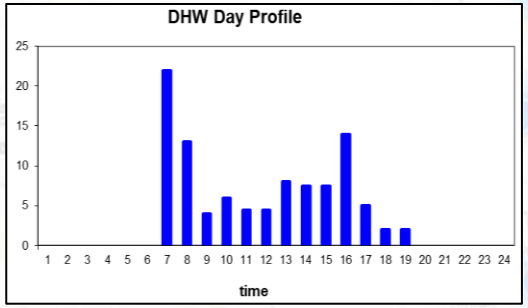




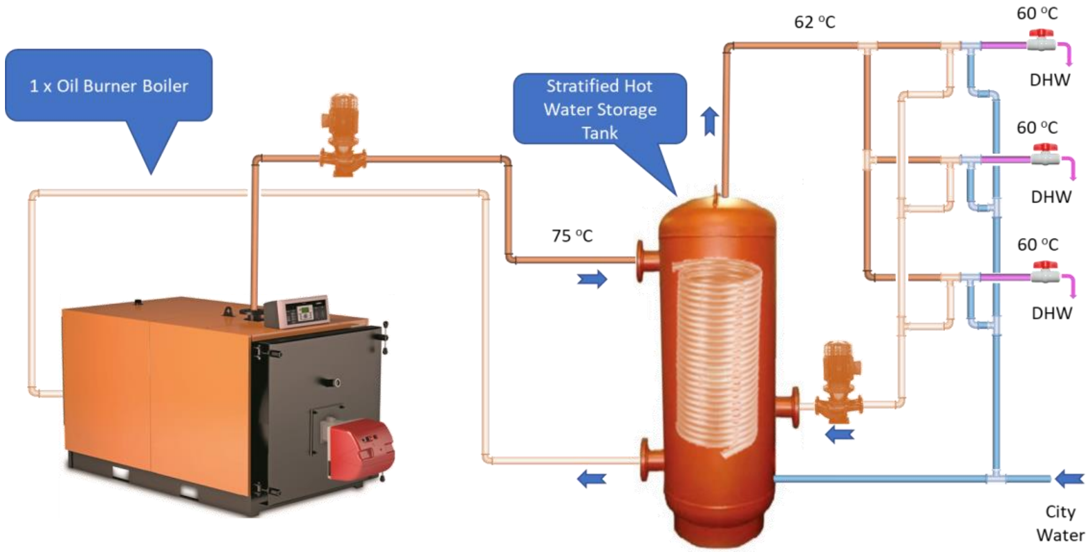


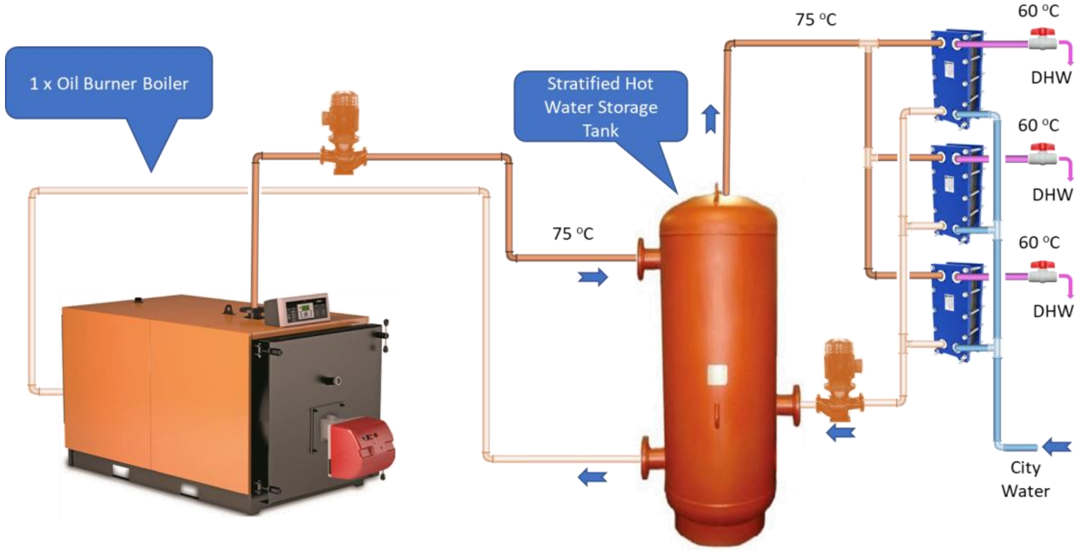


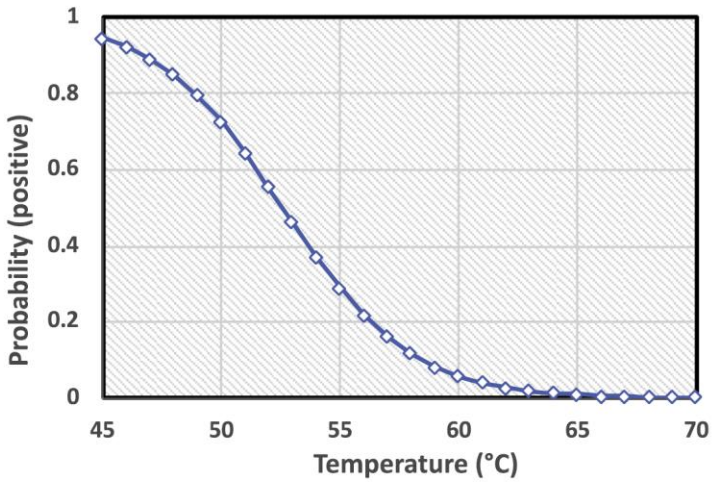




DHW Production / Storage – Legionella and Scale Control





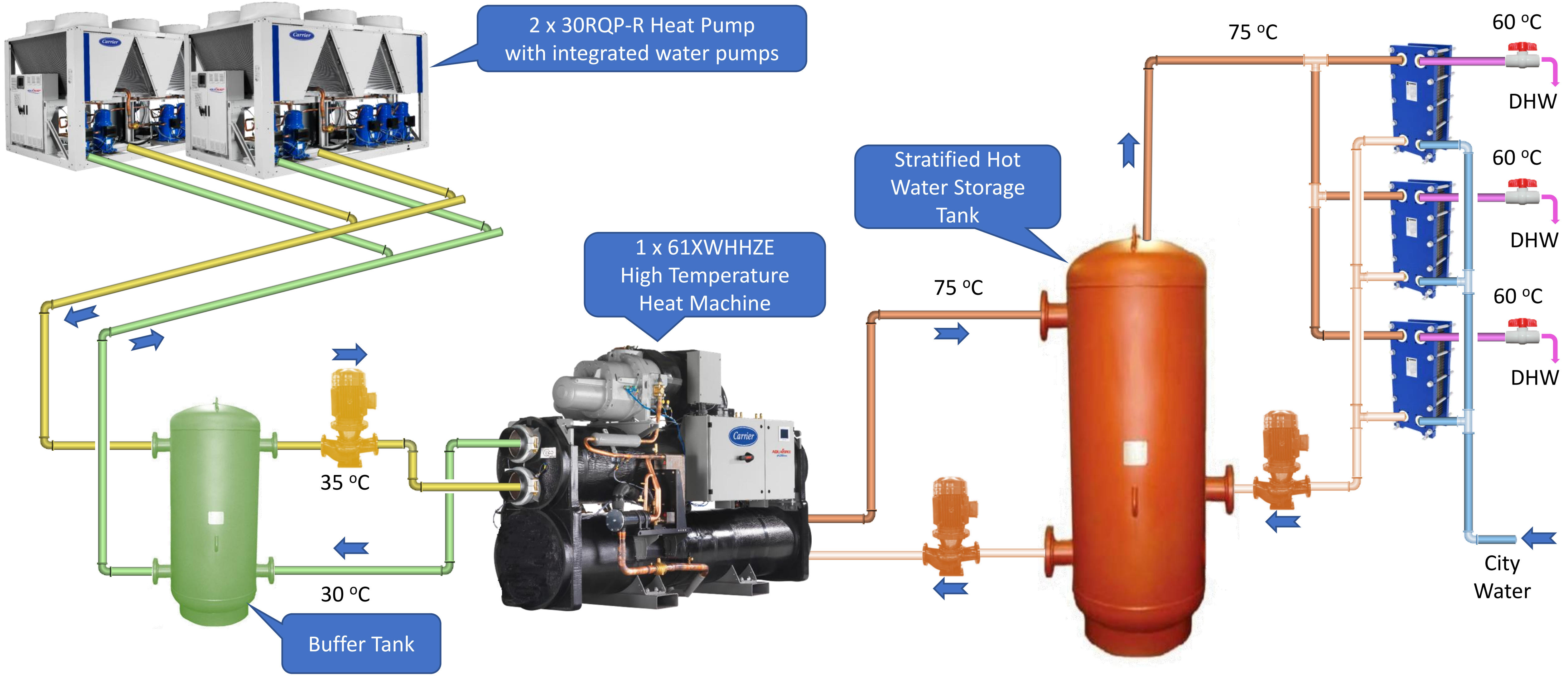


Probability of Legionella positive events at different hot water tap temperatures
Md Rasheduzzaman, Rajveer Singh, Charles N. Haas, Patrick L. Gurian
Department of Civil, Architectural and Environmental Engineering, Drexel University, Philadelphia, USA

Key findings
- Scale reduces energy efficiency of the water heater by up to 50%
- Water temperature decreases 5°C with a limescale thickness of 2mm
- A water heater's useful life can be reduced by as much as 50% through scale build-up
- 0.5 mm of hard scale increases fuel costs by 9.4%

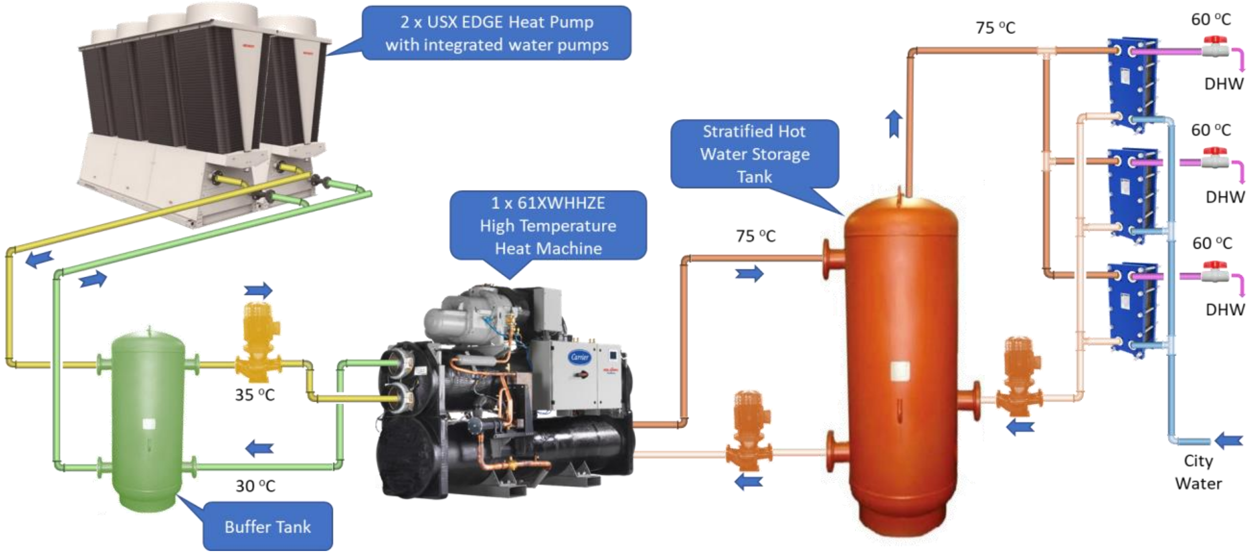
- References
- i) Battelle Memorial Institute, Columbus, OH, Study on Benefits of Removing Hardness (calcium & magnesium ions) from a water supply, 2009
- ii) Influence of Limescale on Heating Elements Efficiency http://www.comsol.it/conference2013/europe/abstract/id/15419/pezzin_abstract.pdf
- iii) Ministry of Health UK, Report of the Subcommittee of the Central Advisory Water Committee, 1949 iv) The Office of Saline Water, U S Department of the Interior

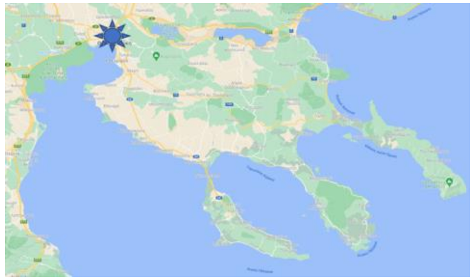
DHW Production – Installation Layout

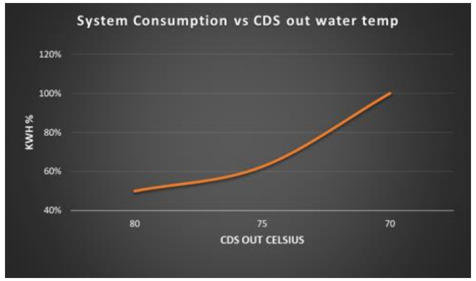


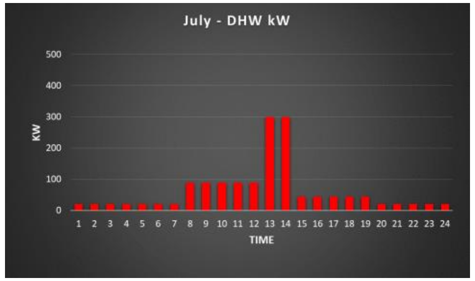
Key Study – Hospital in Thessaloniki / Greece - DHW

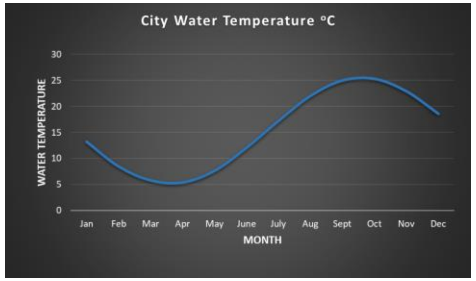
City:	Thessaloniki - Greece
Type:	Hospital
Size:	210 beds
Total DHW:	35 m^3 per day @ 60 °C (Engineering Toolbox data)
Weather file:	ASHRAE IWEC2
DWH profile:	ASHRAE(daily), ADEME guide technique (annually)
Tap water temp. profile:	Buried @ 1.3 m (8760 hours simulation)
Simulation analysis:	8760 hours (in house SW / Charging Storage Tank)
A/C and W/C HP data:	Manufacturer selection and part load data
Oil / Gas Boiler data:	COMNET Manual (Building Descriptions Reference)

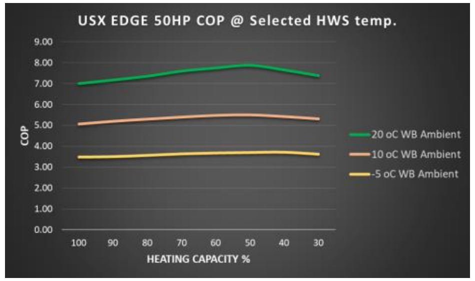


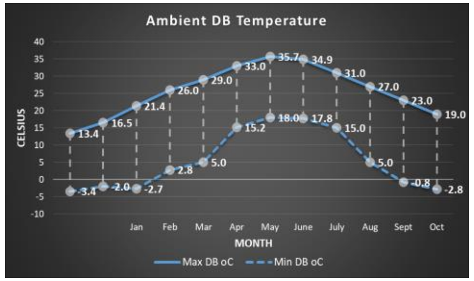


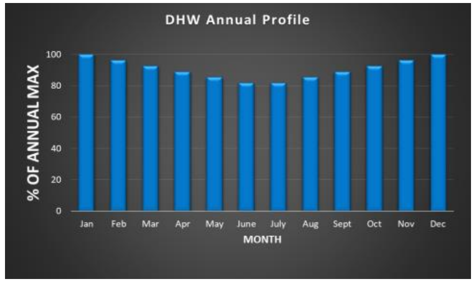


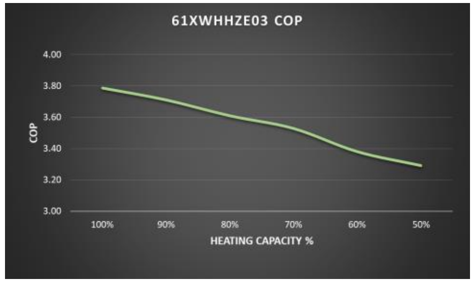












$$Fuel_{partload} = Fuel_{design} \times FHeatPLC(Q_{partload}, Q_{rated})$$

$$FHeatPLC = \left(a + b \times \frac{Q_{partload}}{Q_{rated}} + c \times \left(\frac{Q_{partload}}{Q_{rated}}\right)^2\right)$$

where

FHeatPLC	The Fuel Heating Part Load Efficiency Curve
$Fuel_{partload}$	The fuel consumption at part load conditions (Btu/h)
$Fuel_{design}$	The fuel consumption at design conditions (Btu/h)
$Q_{partload}$	The boiler capacity at part load conditions (Btu/h)
Q_{rated}	The boiler capacity at design conditions (Btu/h)
a	Constant, 0.082597
b	Constant, 0.996764
c	Constant, -0.079361

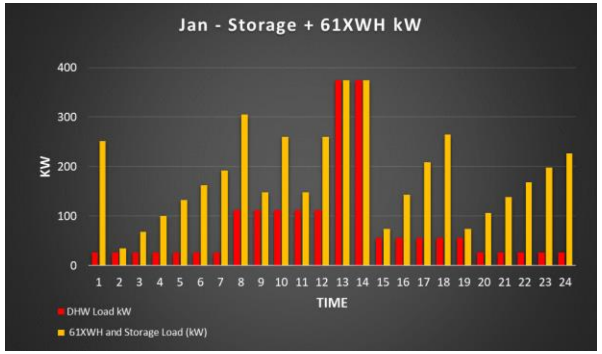
Simulation – Hospital in Thessaloniki (output)

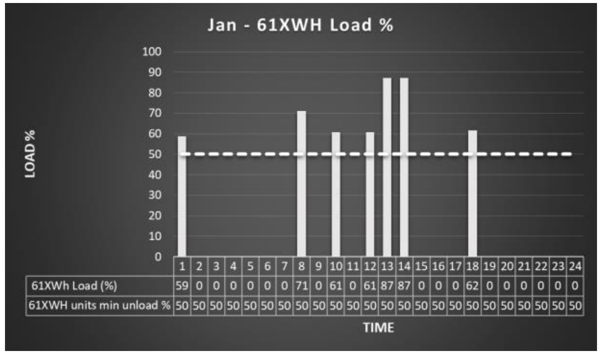
Running Cost Heat Pumps

Powered by AHI CARRIER

Running Cost Boiler / Burner

Month	Operation	Heating Load kWh	61XWH System Total kWh_{el}	A/C HP System Total kWh_{el}	SCOP (Includes Water Pumps)	Heat Pump System Total Cost €	Boiler System Total kWh_{el}	Burner Fuel Type	Diesel Energy kWh	Diesel Consumption kg	Boiler System Total Cost €
Jan	Yes	64,749	19,103	16,187	1.83	3,882	73	Diesel Heating	79,662	6,700	8,484
Feb	Yes	61,446	17,942	14,953	1.87	3,618	69	Diesel Heating	74,944	6,303	7,981
Mar	Yes	68,635	20,001	16,383	1.89	4,002	77	Diesel Heating	83,548	7,027	8,898
Apr	Yes	64,267	18,883	13,127	2.01	3,521	73	Diesel Heating	78,790	6,627	8,391
May	Yes	61,294	18,314	10,855	2.10	3,209	71	Diesel auto	76,153	6,405	12,200
June	Yes	52,647	15,623	8,454	2.19	2,648	60	Diesel auto	65,163	5,480	10,439
July	Yes	48,104	14,214	7,741	2.19	2,415	54	Diesel auto	58,669	4,934	9,399
Aug	Yes	47,239	13,961	7,718	2.18	2,385	53	Diesel auto	57,615	4,846	9,230
Sep	Yes	43,535	12,926	7,621	2.12	2,260	50	Diesel auto	53,565	4,505	8,581
Oct	Yes	45,856	13,531	9,005	2.03	2,479	51	Diesel Heating	55,605	4,677	5,922
Nov	Yes	49,354	14,781	9,814	2.01	2,706	57	Diesel Heating	61,422	5,166	6,541
Dec	Yes	56,179	16,685	12,980	1.89	3,263	64	Diesel Heating	69,269	5,826	7,377
Total		663,305	195,965	134,837	2.01	**36,388**	752		814,404	68,495	**103,444**

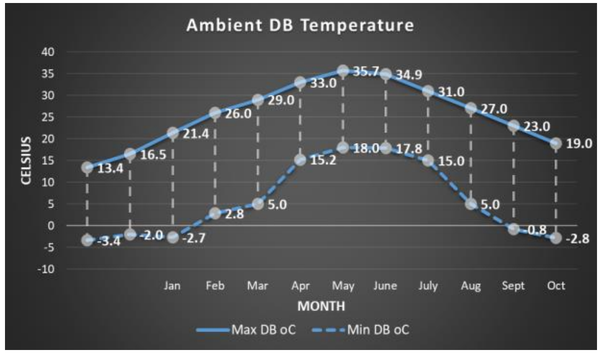




61XWHHZE03 Annual Operating Hours:	2,232
Selected # of Units 61XWHHZE03 is:	1
Selected # of Units USX EDGE 60HP is:	2
Selected # of Boiler Diesel is:	1
A/C HP Possible Load Unmet Hours	0
Burner Boiler Possible Load Unmet Hours	0

Heating Weather File	
99.6% DB °C	-3.0
MIN DB °C	-3.4
MCWB WB °C	-4.0
Cooling Weather File	
0.4% DB °C	34.8
MCWB °C	21.7
MAX DB °C	35.7
MCWB WB °C	18.1

Fuel Type	Market Cost	Unit
Electricity	0.11	€/kWh
Diesel Heating	1.05	€/lt
Diesel Auto	1.58	€/lt
Natural Gas	0.50	€/m^3
Butane	1.40	€/kg
Propane	1.52	€/kg
Wood	15.00	€/m^3



Number of Units

Weather Data

Fuel Cost


Questions
Answers

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THANK YOU

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