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Design and economic analysis of liquid cooled data centres for waste heat recovery: A case study for an indoor swimming pool

Eduard Oró[a,*], Ricard Allepuz[b], Ingrid Martorell[b,1], Jaume Salom[a]

[a] Catalonia Institute for Energy Research, IREC. Jardins de les Dones de Negre 1, 08930, Sant Adrià de Besòs, Barcelona, Spain

[b] Department of Computer Science and Industrial Engineering, Universitat de Lleida, Campus de Cappont, Jaume II 69, 25001, Lleida, Spain

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ABSTRACT

A vast amount of waste heat is produced in urban areas from a range of local sources such as metros, large buildings and urban waste. Data centres are another rapidly growing sector generating heat that could potentially be recovered and reused for heating and cooling. The integration of heat reuse solutions in the data centre industry will decrease the operational expenses by reducing the cooling demand and will create new business models by selling the excess heat to nearby heat demand applications. On one hand, the manuscript demonstrates how liquid cooled data centres can reduce the overall data centre consumption up to 30% in comparison with state-of-the-art air cooled data centres. On the other hand, the liquid cooling configuration of on-chip servers is evaluated numerically for a case study of an indoor swimming pool. For the best favourable solution, the data centre operator reduces its operational expenses and generates additional incomes by selling the excess heat, achieving a net present value after 15 years of 330,000 €. Moreover, the indoor swimming pool operator reduces its operational expenses 18%. Finally, the results of the case study are extrapolated to study the impact of heat reuse usage in Barcelona.

1. Introduction

More than half of the global population lives in cities which are responsible for about 70% of the overall primary energy consumption, share which is expected to increase to 75% by 2030. In particular, heating and cooling in buildings, businesses and industry totalled 50% of the final energy consumption in the EU in 2012, making it the EU's biggest energy sector (546 Mtoe) (European Commission, 2017). Reducing the impact of urbanisation through increasing urban energy efficiency and switching to clean and low carbon resources is critical for cities to continue to thrive as engines of economic growth and human creativity.

The increase in share of waste heat captured and utilized in urban areas is one of the most interesting energy efficiency strategies studied recently. It is estimated the total EU waste heat to be around 3140 TWh (Stratego project, 2017), indicating a huge and uncapped available potential. Perhaps one of the most unused resources in heating systems is the utilization of industrial and or commercial excess or waste heat (Abdurafikov et al., 2017). Among the urban sources of waste heat, data centres characterize for providing low temperature, high capacity and reliable heat. Currently, the European data centre industry has a waste heat potential of about 56 TWh (Ascierto, Lawrence, Donoghue, & Bizo, 2016). Indeed, this unique industry has high heat recovery potential in urban areas, where many of Information Technology (IT) services are needed and located, allowing primary energy savings and GHG emission savings by the implementation of waste heat reuse solutions. Exploiting this huge potential requires understanding how to combine data centres with the surrounding heating applications as well as the design and control of these heat reuse solutions. In its turn, understanding requires analysing the economic and environmental perspectives for different data centres design typologies.

Traditionally the refrigeration of data centres has been done by air through chilled water systems and Computer Room Air Handling (CRAH) units (Ebrahimi, Jones, & Fleischer, 2014; Oró, Depoorter, Garcia, & Salom, 2015). In these conventional data centres, the energy required for cooling purposes can reach up to 40% of the overall energy consumption. Cho, Chang, Jung and Yoon (2017) analysed the economic performance of seven air cooling strategies commonly used in data centres. The most feasible one was the air-side economizer and supplementary cooling by a mechanical system. However, due to the fast increase in IT density, the unique use of air cooling systems cannot be enough and other strategies, mainly liquid cooling systems are

* Corresponding author.
E-mail address: eoro@irec.cat (E. Oró).
[1] Serra Húnter Fellow.

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Nomenclature

Roman letters

A	Area [m^2]
a	Thermal diffusivity
C	Capacitance [kW/K]
Cp	Specific heat [kJ/kg K]
E	Energy [kWh]
e	Walls thickness [m]
Effec	Heat exchanger effectiveness
h	Enthalpy [kJ/kg K]
h_c	Convective heat transfer coefficient [W/m^2 K]
$\dot{m}$	Mass flow[kg/s]
nl	Number of air change per hour [renovations/h]
P	Pressure [bar]
$\dot{Q}$	Power [W]
T	Temperature [°C]
U	Thermal transmittance [W/m^2 K]
V	Volume [m3]

Greek letters

α	Heat transfer coefficient [W/m^2 K]
β	Mass transfer coefficient [m/s]
ε	Total evaporation coefficient [kJ/s m^2]
ε_w	Emissivity of water
ϵ	Effectiveness [-]
φ	Relative humidity
γ	Heater control signal
Δh	Enthalpy difference [kJ/kg]
σ	Stefan-Boltzmann constant [W/m^2 K^4]

Acronyms

AMD	Advanced micro devices
CAPEX	Capital expenditures
COP	Coefficient of performance
CPU	Central processing unit
CRAH	Computer room air handling
ERF	Energy reuse factor
ESCO	Energy services company
GHG	Global greenhouse gas
HPC	High performance computing
HVAC	Heating, ventilation, and air conditioning
IREC	Catalonia institute for energy research
ISO	International organization for standardization
IT	Information technology
NPBP	Discounted payback period
NPV	Net present value
OPEX	Operational expenditures
PDU	Power distribution unit
PLR	Part load ratio
REC	Replacement cost
RH	Relative humidity
RV	Residual value
St	Stanton dimensionless number
TCO	Total cost of ownership
TRNSYS	Transient system simulation tool
UPS	Uninterruptable power supply

Subscripts

air	Air
amb	Ambient (external ambient)
aw	Air-water system
chw,in	Chiller water inlet
chw,out	Chiller water outlet
chw,set	Chiller water set point
cond	Conduction
conv	Convection
cold	Cold side
DC	Data centre
e	Electrical
evap	Evaporation
evap,in	Evaporation inlet
evap,out	Evaporation outlet
h	Swimming pool hall
Heater,cap	Boiler capacity
Heatgain	Heat gain into the swimming pool
Hot	Hot side
in	Inlet
indoor	Indoor air
inf	Infiltration
IT	IT
load	Load
nom	Nominal
max	Maximum
met	Met
out	Outlet
ORC	Organic rankine cycle
p	Pool
rack	Rack
rack-air	Rack to air
rad	Radiation
rated	Rated
ratio	Ratio
Real	Real
rejected	Rejected
ren	Renovated
Return	Return
Reused	Reused
sat	Saturation
skin	Skin
supply	Supply
sur	Surroundings
Tap	Tap water
total	Total
th	Thermal
w	Water
wallspool	Walls of the pool
ws	Whitespace

already being implemented in data centre industry. On one hand, the use of this technology can reduce the energy consumption of traditionally air cooling systems up to 50%. On the other hand, the use of heat reuse solutions allows the data centre operator selling the excess heat to a heat demand application such as buildings, indoor swimming pools or greenhouses. While air cooling can provide air return temperatures up to 35 °C, liquid cooling can provide return water temperatures up to 75 °C, depending on the technology (Ebrahimi et al., 2014). Because of this phenomenon, the use of liquid cooling technology, especially in urban areas where the space occupied by the data centre should be minimized, has a great potential to decrease the energy consumption of the cooling system and to create new business models by selling the