CI246 Project Data heat waste recovery

Group 13

Team G13

Generators: Aditya Prasad, Shivaji Yadav

Ideators: Piyush Anand, Darshan Bitla

Planners: Naufran Neyas, Ramresh Meena

Solvers: Krishna gaggar, Pranjal Sankhwar

Table of contents

User Story

A revived interest in the collection and reuse of waste energy is being driven in part by the depletion of the planet's finite reserves of fossil fuels, the global warming crisis, and the high cost of energy. As the need for cloud-based connection and performance rises, data centers are becoming a significant source of energy waste. In fact, according to current data, data centers account for more than 2% of all power used in the US, and this is predicted to reach 15-20 % by 2030. This electricity is almost entirely used to cool the electronics, which generates a sizable amount of waste heat. Due to the low quality of the heat, it is challenging to recover and reuse this stream of waste heat. In this report, the most promising approaches and technologies for efficiently and economically recovering low-grade waste heat from data centers are identified and discussed.

Technical Problem Catered

Part 1 -

Consider a rack with dimensions 78 in x 28 in x 24 in, containing 2184 pipes. Each pipe has a dimension of 1.41 mm x 11.6 mm x 28 in and 52 of them correspond to a server or 1U. The rack is simplified into a uniform box with a temperature of 25 C. Water-glycol mixture is flowing through the 42 pipes acting as heat sink for cooling the rack. The Objective is to find temperature difference between inlet and outlet so as to omptimize waste heat production and utilization.

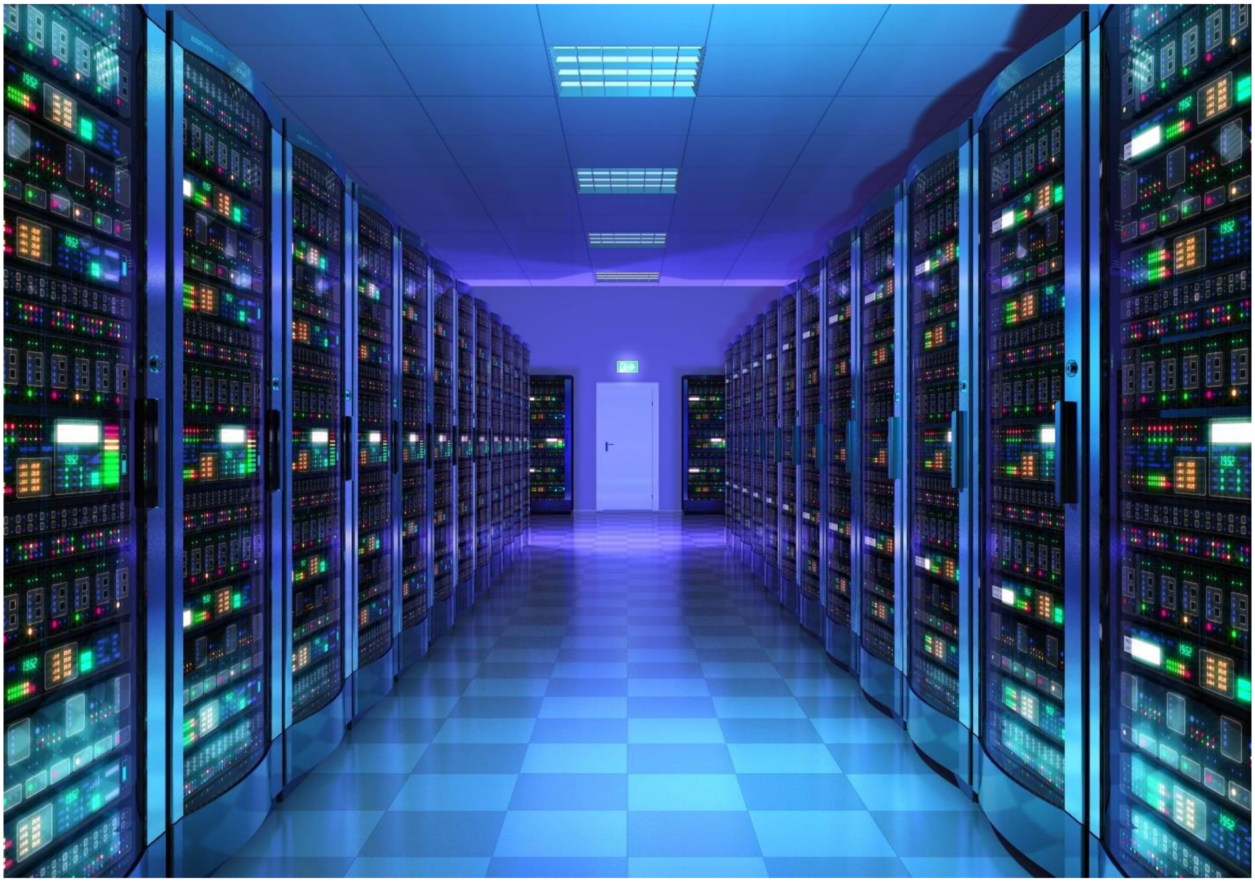
Part 2 -

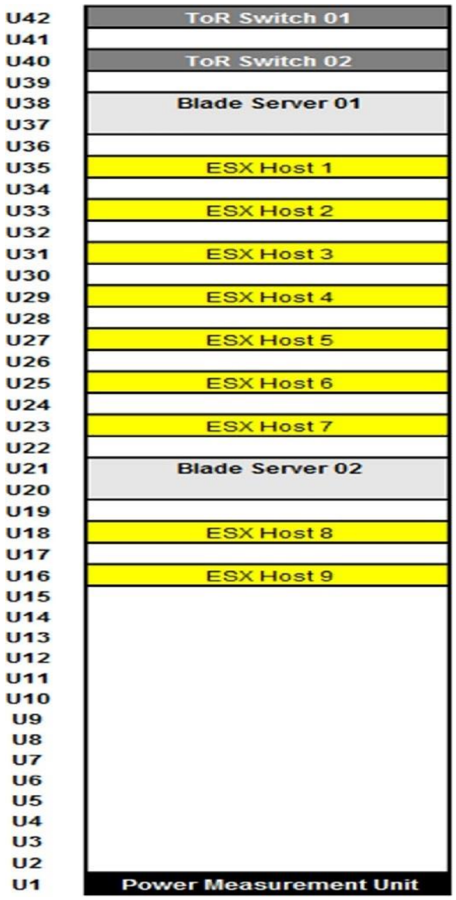
The suitability of popular waste heat recovery strategies for low temperature, high volume waste heat generation is examined using the waste heat generated. District/plant/water heating, direct power generation (thermoelectri), indirect power production (organic Rankine cycle and steam), are a few of the recovery strategies. In order to evaluate each technology's applicability and efficacy for data centre applications, these methods are assessed together with their operational needs.

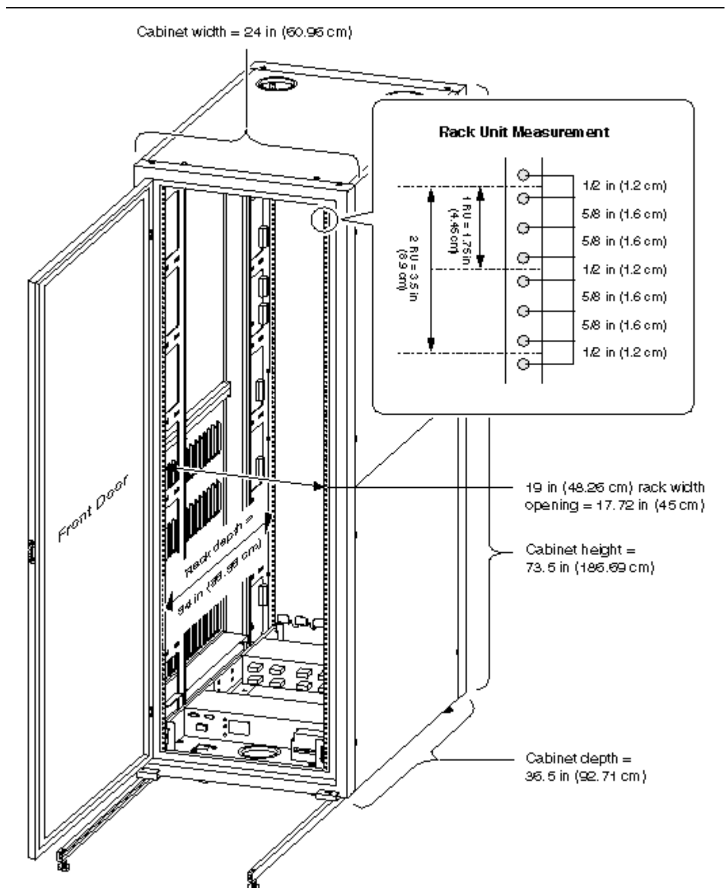
Introduction

1.Data center physical organization and overview

The majority of ICT (Information and Communication Technology) modular assets, including servers, switches, and storage facilities, are housed in a data center, which also controls the environmental factors (temperature, humidity, and dust) to ensure that the ICT systems function dependably, safely, and efficiently. A data center may contain a single rack of equipment, a couple, or even many racks and cabinets, depending on the size of the company. A rack is a metal frame or container that is standardized and into which ICT modular components are fitted horizontally. A typical rack measures 78 inches in height, 23 to 25 inches in breadth, and 26 to 30 inches in depth. The unit of measurement "U" is used to define the height or thickness of a modular asset installed in a rack. U about translates to 1.8 inches. The majority of servers (often those with one or two socket processors) are one unit thick (U), although some bigger servers (such those with four socket multiprocessors) may be two U or more thick. A typical full-size rack may hold 42 modular 1 U assets in total.





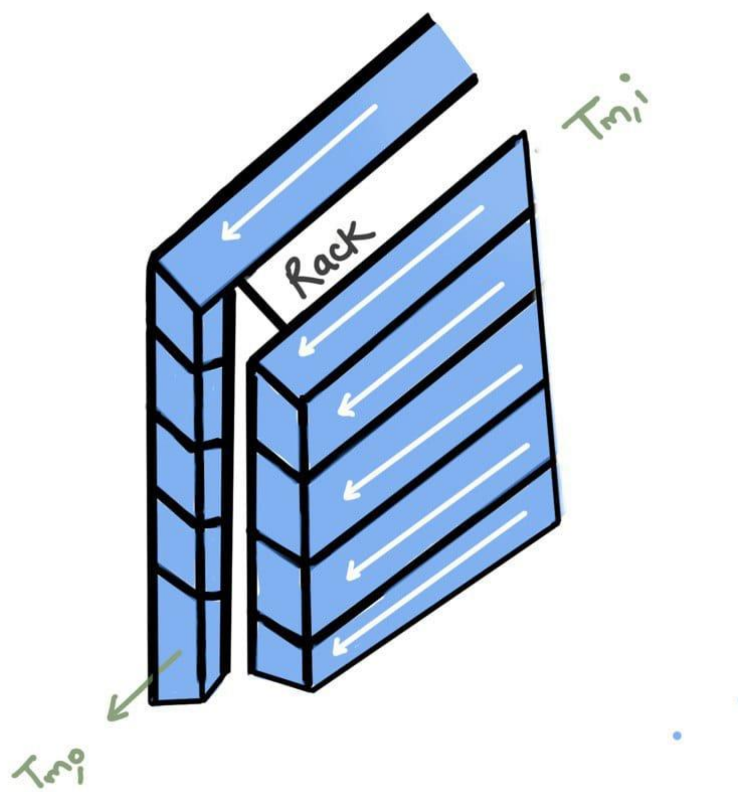


2.Data center thermal loads and temperature limits

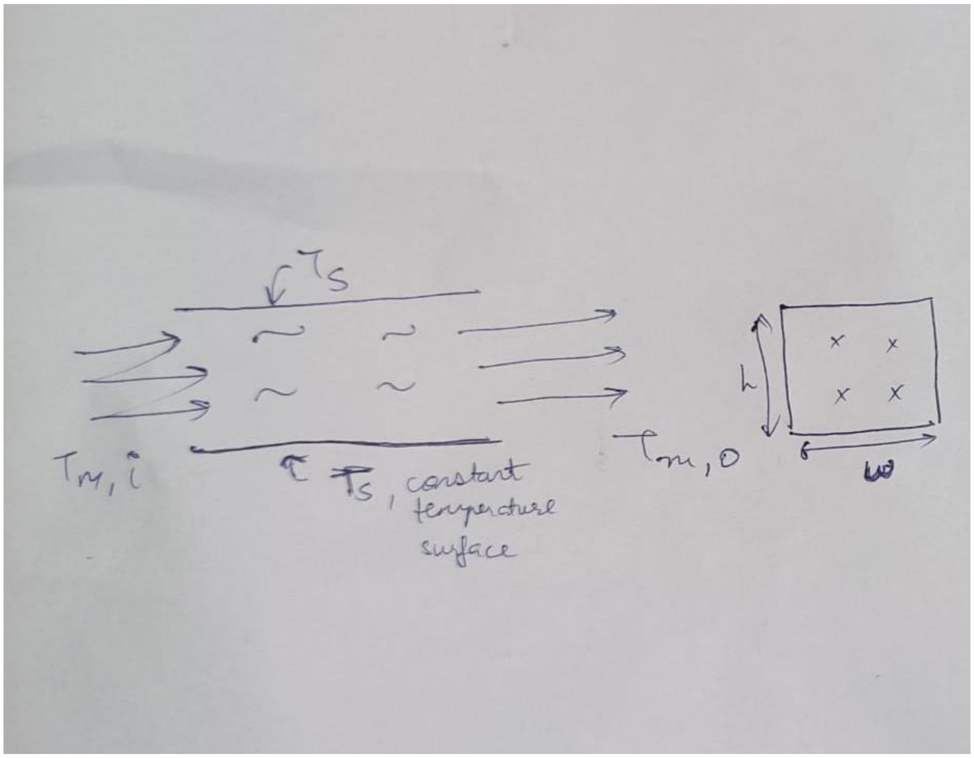
Manufacturers are designing and producing more compact and higher power modules as a result of the rising demand for ICT services on the one hand and the direct correlation between data center expenses and floor area on the other. The energy flux dissipated by older generations of data centers has grown at least ten times (from 6458 to 10,764 W/m2), whereas the energy flux dissipated by traditional data centers is in the range of 430 to 861 W/m2. The design and production of thermal management systems is one of the most difficult parts of data center architecture when compared to the capability of traditional HVAC systems for rooms of a comparable size (40-86 W/m2).
While in traditional data centers, per-rack power consumption is around 7 kW, a high performance fully used rack's power consumption is in the range of 10-15 kW, and racks stacked with blade servers may dissipate up to 21 kW of electricity.

For the safe and efficient operation of microprocessors, 85 °C is generally accepted as the highest permissible junction temperature in electronics thermal management research. The literature does contain a few more references, though, that suggest somewhat higher or lower ranges as the temperature limit. For instance, it is thought that 78 to 100 °C is the maximum working temperature for microprocessors. The same 85 °C maximum temperature is often applied to DIMMs as well. Hard disc drive temperature limits are substantially lower than those for microprocessors and DIMMs, though. In reality, operating at temperatures exceeding 40–45 °C for extended periods of time raises the risk of HDD failure. For their product disc drives, several manufacturers have still established greater temperature restrictions of up to 60 °C.

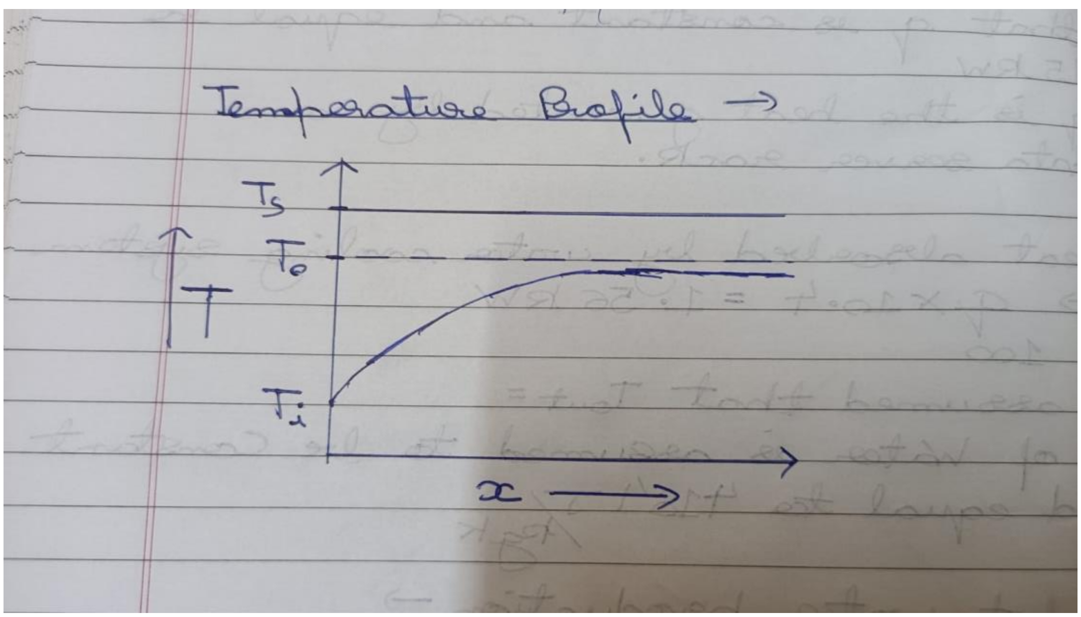
Simplified Geometry



Control Volume



1-D Temperature Profile



Known Factors:
We know average power/heat generated by a rack, demand Temperatures by different waste heat utilization technologies, Geometry of control volume.

Unknown factors:
Water mass flow rate, Inlet temperature, Surface temperature of rack,

Three modes of estimation:

1. **Conduction**
   We have water flowing in pipes acting as a heat sink for rack, the pipe walls will conduct heat from processors to water flowing inside. This will have a heat transfer coefficient associated with it which we can find using resistance theory.

2. **Radiation**
   The temperatures are low so radiation won't have an appreciable effect. (In our midterm report we got radiation of order 100 W which is negligible compared to convectional and conduction components.)

3. **Convection**
   Convection is the main form of heat transfer through which we are extracting waste heat. The associated heat transfer coefficient can be calculated using Nusselt number.

General assumptions:

1. Radiation is neglected in analysis.
2. The rack is modelled as a constant temperature surface of 75 °C.
3. The flow is assumed to be fully developed.
4. Flow of water is in steady state, no temporal variation.
5. Flow resistance in pipe is neglected in analysis.
6. Pipe is insulated on its vertical walls, negating any air convection effects.
7. All fluid properties are taken at median temperature of operation

Approximate estimates:

Approximate Estimates

* From our midterm report, we got efficiency of the system to be 10.4%. We will take that as base to get a rough estimate for input temperatures.

* Also, for the estimates, we will assume that q is constant and equal to 15 kW

  q is the heat generated by one data server rack.

* heat absorbed by water cooling system

  $\rightarrow \dfrac{q \times 10.4}{100} = 1.56$ kW

* We assumed that T_{out} =

  C_p of Water is assumed to be Constant and equal to 4184 J/kgK

  For hot water production →

  $T_{out} = 45°C$

  Using $q_{abs} = \dot{m} C \Delta T$, we got $\Delta T = 40°C$.

  Also, the temperature of surface is 25°C.

Now we will treat this problem as that of a fully developed flow with Constant Surface Temperature and ~~&~~ cross-check with our midsem results.

Solution Methodology:

Solution Methodology →

We will use equations for fully developed internal flow.

Nusselt Number for a square pipe →
2.98

For Constant Surface Temperature →

$$\dot{m} c \frac{dT_m}{dx} = Ph(T_S - T_m)$$

$$\Rightarrow \dot{m} c \frac{d\Delta T}{\Delta T} = -Ph\,dx$$

★ $$\Rightarrow \frac{\Delta T}{\Delta T_i} = e^{-\left(\frac{Px}{\dot{m}c} U\right)}$$

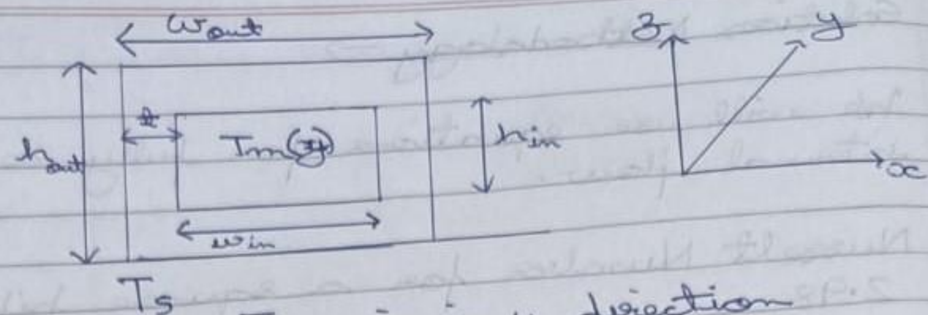
★ $$(\bar{h}_{x})_{conv.} = \frac{\overline{Nu}\, k_{water}}{D}$$

$k_{water} = 0.6071$ (assumed to be constant with temperature)

★ $$D = \frac{2hw}{h+w}$$

★ $$\frac{1}{U} = \frac{1}{h_{conv.}} + \frac{1}{h_{cond.}}$$

★ $$h_{cond.} = \frac{2\pi L k_{pipe}}{\ln\left(\frac{D_o}{D_i}\right)}$$



Flow is in y direction

Values of Known Quantities and Calculating the Unknowns →

$\dot{m} = \rho \times$ Volume flow rate

Dimensions of a Data Rack → 28 × 24 × 78 inches

Height of a Data server Unit → 1.8 inch

Number of Data server Unit in 1 Rack = 42

$\Rightarrow$ height of one pipe $= \left(\frac{78}{42} - 1.8\right) \cdot \frac{2.54}{100}$

$h_{out} = 1.45$ mm

Thickness of pipe = 0.3 mm

$\Rightarrow h_{in} = 1.45 - 0.3 \times 2 = 0.85$ mm

$\Rightarrow \dot{m} = 1000 \times \left(\frac{0.85}{1000}\right)^2 \times \frac{2.54 \times 28}{100}$

$= 0.0005\,15$ kg per pipe

$C_{p_{water}} = 4184$ J/kgK

$$D_i = \frac{2 w_{in} h_{in}}{h_{in} + w_{in}} = 0.00085\, m$$

$$(h_a)_{conv} = \frac{2.98 \times 0.6071}{0.00085} = 2124.85$$

$D_o = 0.00112\, m$

$$h_{cond.} = \frac{2\pi L k_{pipe}}{\ln(D_o/D_i)} = 163134.35$$

$$\frac{1}{U} = \frac{1}{h_{conv}} + \frac{1}{h_{cond}}$$

$\Rightarrow U = 2097.53$

Temperature of surface is constant ~~and equals to 175°C~~

$$\frac{T_s - T_o}{T_s - T_i} = e^{-\frac{PLU}{mc}}$$

Substituting the values

$$\boxed{\frac{T_s - T_o}{T_s - T_i} = 0.0948}$$

efficiency of the system $= \dfrac{n(\dot{m}\, c_p (T_{out} - T_{in}))}{q}$

$q = 15\ kW$

Waste heat recovery

In this section we review eight potential waste heat recovery technologies and their temperature demands. We find out for each method what is the operating temperature conditions (inlet temperature, outlet temperature and surface temperature for data center) and efficiency achieved.

1.Hot water production

HVAC or hot water production systems are two frequent and reasonably easy applications for the reuse of low-quality energy. The server waste heat may be recovered at temperatures between 35 and 45 °C, which is more than enough to be used for heating purposes. Depending on the size and operating conditions of the data center, the space heating provided by data centers can range from the HVAC needs of the data center itself to that of a single-family home, an apartment complex, a neighborhood or even several neighborhoods (district heating). The use of remotely siting servers in individual homes to provide domestic heating is referred as a “Data Furnace”.

Based on this temperature demand (35 - 45 °C), applying our solution methodology we get,

Inlet temperature = 25 °C
Outlet temperature = 35 - 45°C
Surface temperature = 36 - 47 °C
Efficiency = 6.04 – 12.08 %

2.District heating

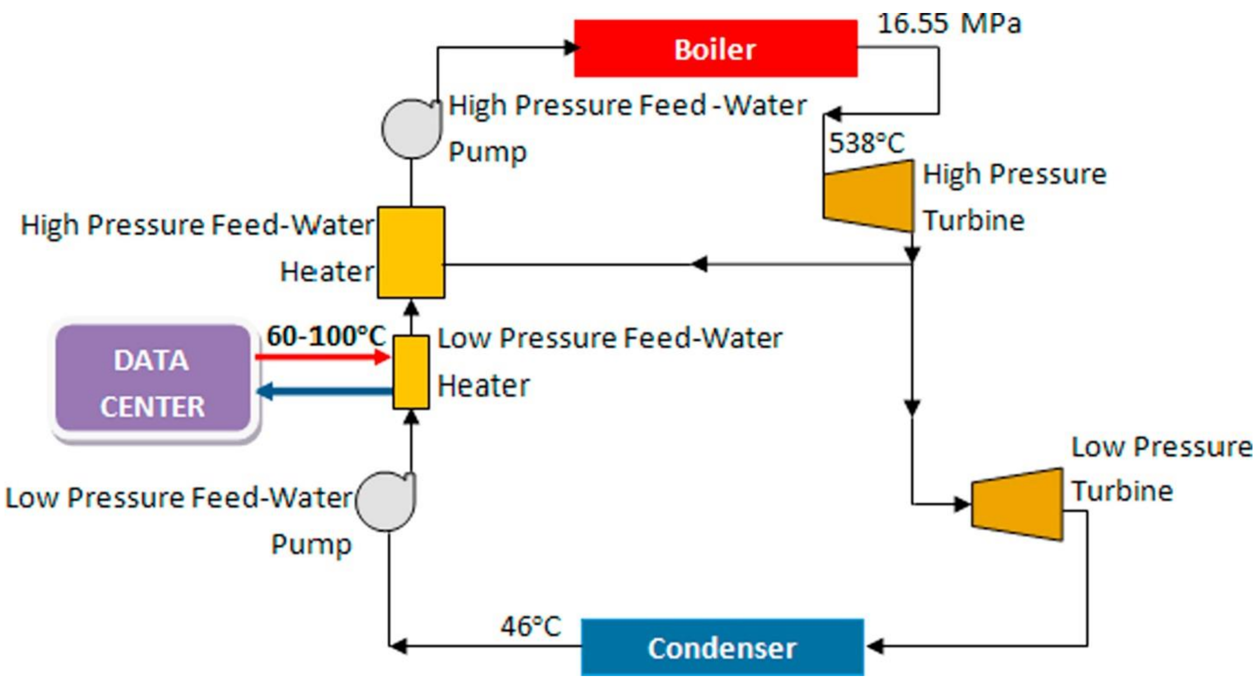
Another popular low-quality waste heat recovery technique that is both economically and environmentally advantageous is district heating. By using liquid cooling, it is possible to capture waste heat with a somewhat higher quality (up to 50–60 °C as opposed to 35–45 °C), which may then be utilized to heat a larger area. Thus, the data center operator may benefit financially from this heat.

Based on this temperature demand (50 - 60 °C), applying our solution methodology we get,

Inlet temperature = 25 °C
Outlet temperature = 50 - 60 °C
Surface temperature = 52.6 – 63.66 °C
Efficiency = 15.1 – 21.1 %

3.Power Plant

The use of waste heat to provide heating of water in the thermal Rankine cycle of a major power plant is a common waste heat recovery technique. The most effective waste heat source for power plant boiler feed-water preheating is better quality waste heat than is typically provided by data centers. The normal minimum requirement is between 60 and 100 °C, which is the maximum amount of waste heat from water-cooled data centers that is accessible. The advantages of employing data center waste heat for boiler feed-water preheating in power plants include potential revenue from selling heat to the power plant as well as potential carbon offsets for the data center operator.

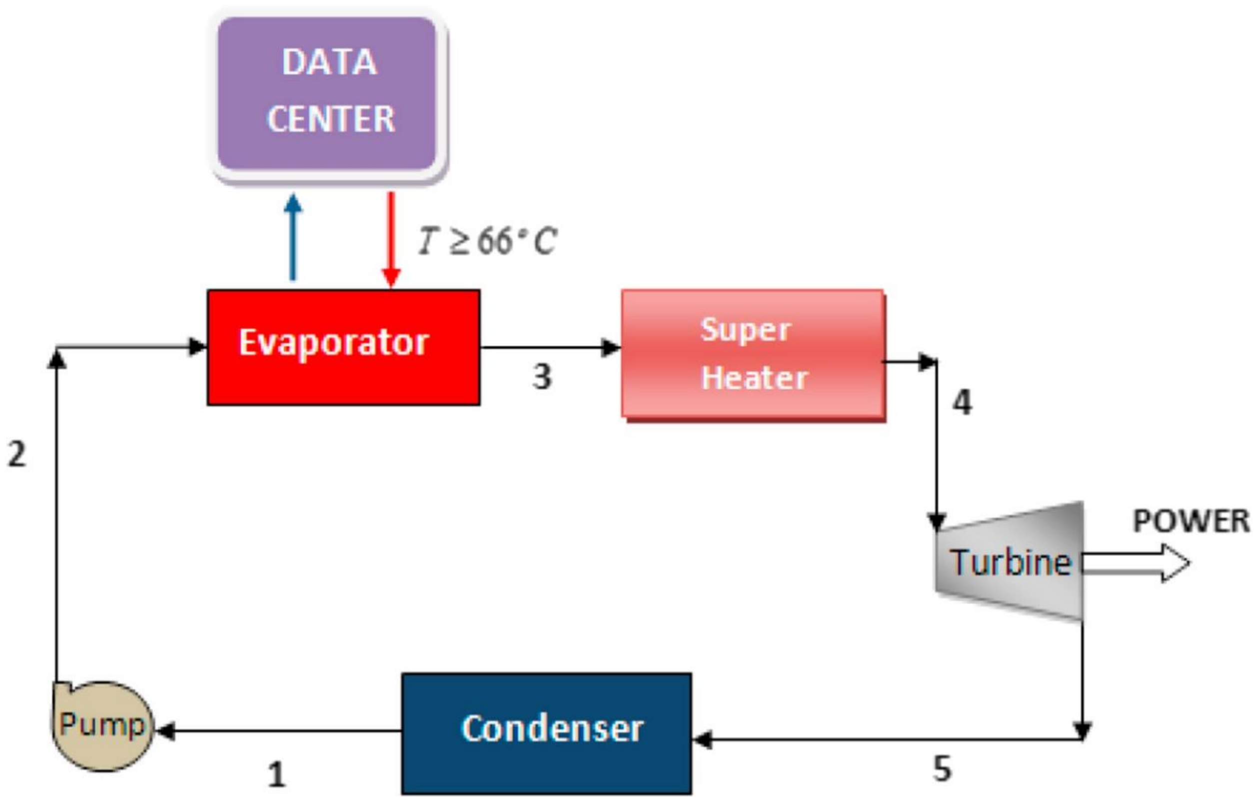


Based on this temperature demand (60 - 100 °C), applying our solution methodology we get,

Inlet temperature = 45 °C
Outlet temperature = 60 - 80 °C
Surface temperature = 61.57 – 83.67 °C
Efficiency = 9.06 – 21.14 %

4.Organic Rankine Cycle

An organic Rankine cycle (ORC) may be utilized to directly generate power from data center waste heat. Similar to the steam Rankine cycle, organic fluids with much lower boiling temperatures are used as the working fluid in ORCs. The thermodynamic properties of the working fluid strongly influence cycle efficiency and ORCs can operate successfully with waste heat streams of 65 °C and higher and can even run as low as 32 °C with reduced efficiency. The advantages of employing data center waste heat in organic Rankine cycle power generation include the on-site energy production from waste heat and the lack of any particular siting requirements, making it suitable for a variety of data center designs.

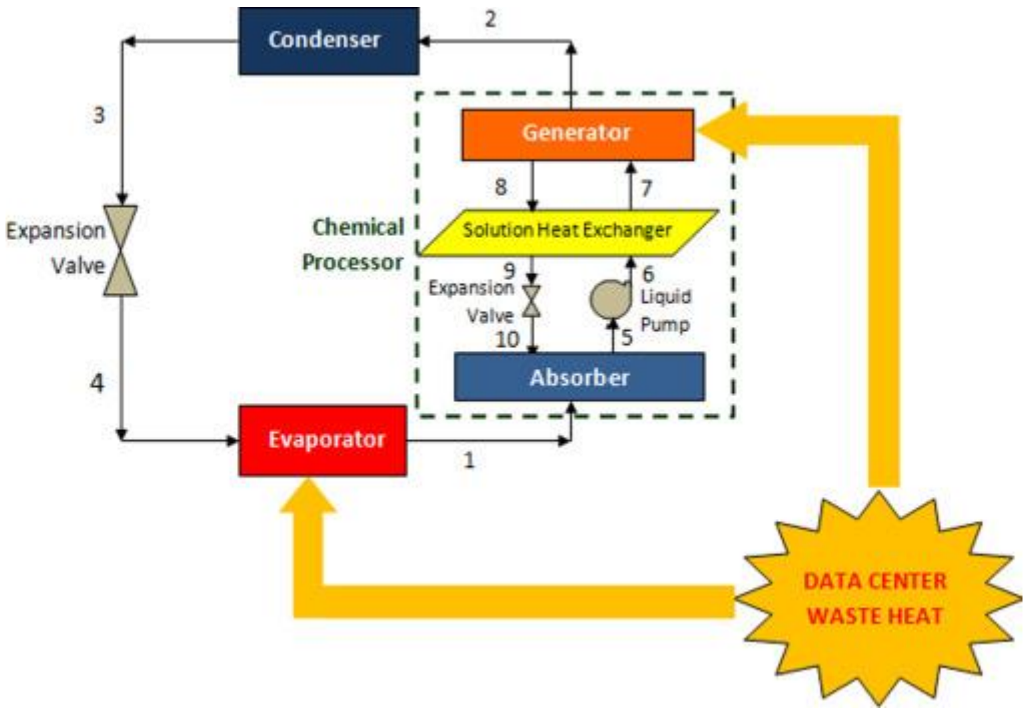


Based on this temperature demand (32 - 65°C), applying our solution methodology we get,

Inlet temperature = 25 °C
Outlet temperature = 32 - 65 °C
Surface temperature = 32.73 – 69.11 °C
Efficiency = 4.3 - 24.16 %

5.Absorption cooling

Generator temperatures of 70 to 90 °C, which are commensurate with the available waste heat from water-cooled, are sufficient for absorption refrigeration systems to function. By producing chilled water for chilling, the use of data center waste heat in absorption refrigeration systems directly reduces the load on data center CRAC systems, which is advantageous economically for the majority of data center owners. Furthermore, there are no concerns with site co-location, and if there is enough room, the technology may be retrofitted into existing data centers.



Based on this temperature demand (70 - 90°C), applying our solution methodology we get,

Inlet temperature = 50 °C
Outlet temperature = 70 - 90 °C
Surface temperature = 72.1– 94.19 °C
Efficiency = 12.1 - 24.16 %

Waste recovery methods Summary:

Waste Recovery Technique	Inlet Temperature	Outlet Temperature	Surface Temperature	Efficiency
Hot water production	25	35-45 °C	36 – 47 °C	6.04 – 12.08 %
District Heating	25	50 - 60	52.6 – 63.66	15.1 – 21.11 %
Power Plant	45	60 - 80	61.57 – 83.67 °C	9.06 – 21.14 %
Organic Rankine Cycle	25 °C	32 - 65 °C	32.73 – 69.11 °C	4.3 - 24.16 %
Absorption cooling	50 °C	70 - 90 °C	72.1– 94.19 °C	12.1 - 24.16 %

Conclusion

In this report we reviewed data center cooling via water cooling mechanism. We applied Internal Flow concepts to develop the model and obtain the temperature profiles and working efficiency. Then we looked at various waste heat recovery technologies and their individual operating temperatures and efficiency. District heating seems to be most appropriate technique to realize heat waste recovery goals while at the same time keeping data center equipment working conditions a priority.

References

1. A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities - ScienceDirect
2. Table 8.1 from Fundamentals of Heat and Mass Transfer for Nusselt number.
3. Eqn 8.45a from Fundamentals of Heat and Mass Transfer for relating outlet, inlet and surface temperatures in problem.
4. Calculation