# Simulation based optimisation of energy efficiency in data centres

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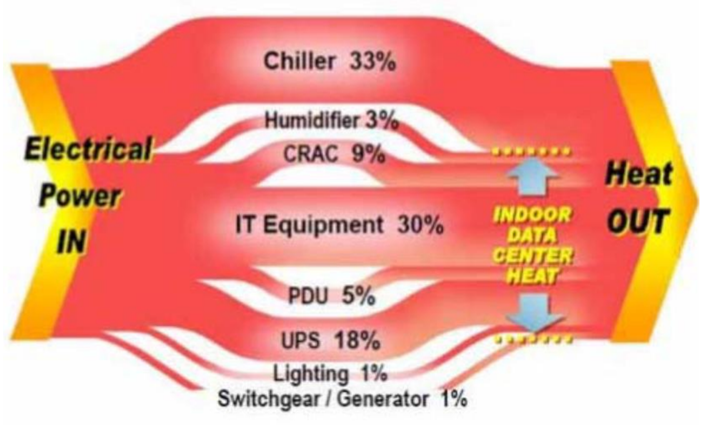
# Trade-off relationships between energy consumptions by cooling & IT devices in DC

- Two major energy consumers in DCs: cooling and IT devices
- Higher temperature may reduce the energy consumption by cooling devices but may also decrease energy efficiencies of IT devices
- Lack of understanding of the dynamics caused by cooling, IT devices, workloads and temperature controls
  - EnergyConsumption (Coolers) = *f* (Temperature)
  - EnergyConsumption (IT devices) = *g* (Temperature)
  - Temperature = h (workloads)

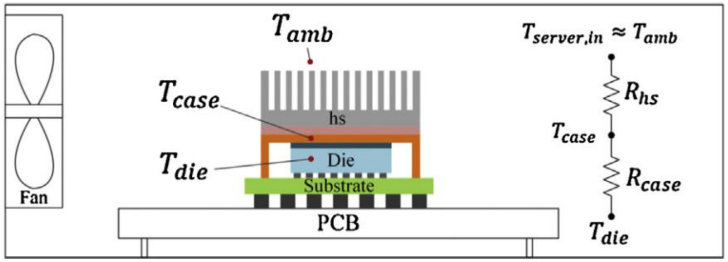



<source: Ohadi et al. (2012)>

# Recent works

- Estimate power consumption of a DC
  - Ham et al. (2015) estimate DC power consumption using very simple server model
    - $T_{die}$: temperature of a CPU which measured from the server directly
    - $U_{cpu}$: CPU utilization in percent

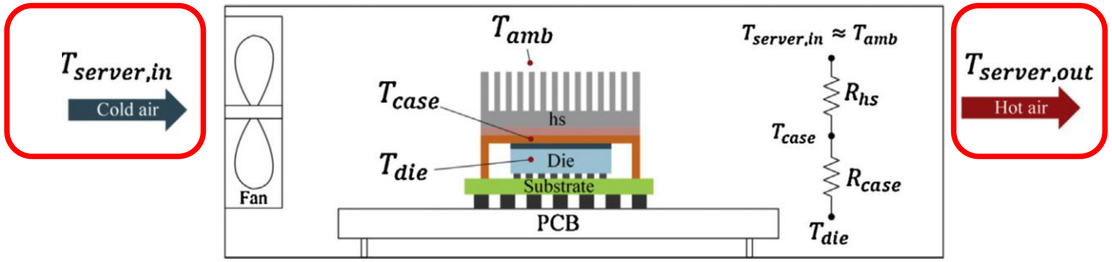
$$P_{\text{IT}} \propto P_{\text{cpu}} = c_0 + c_1 u_{\text{cpu}} + c_2 T_{\text{die}} + c_3 T_{\text{die}}^2$$




- Other studies use simpler models than Ham et al. (2015)'s
  - Choo et al. (2017) estimate power consumption of cooling systems only
  - Bash & Forman (2007) conduct experiments to shutdown servers if they have finished workload that received.
  - Cho and Kim (2016) suggest optimal cooling strategies using dedicated cooling systems based on the assumption that IT devices use energy homogeneously regardless the variances of workloads.

# Research gap (1)

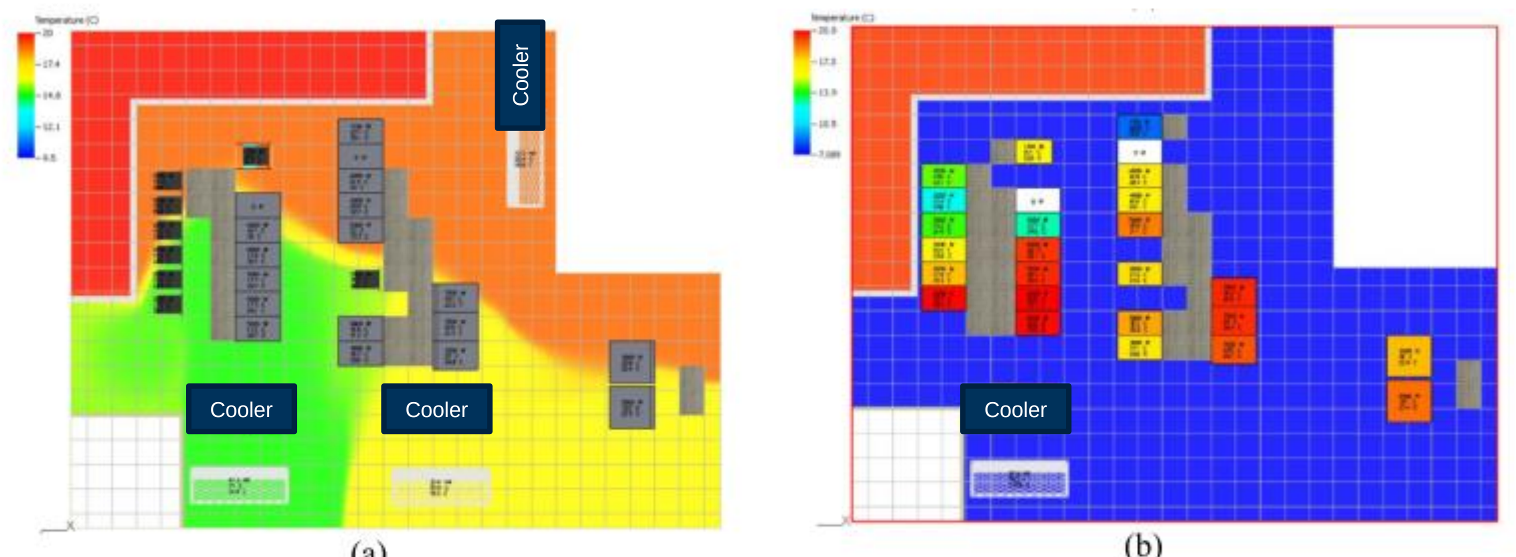
- No studies done for power consumption of a server based on workload and inflow and exit air temperature
  - Recent servers and CPUs have functions if the temperature is higher than is expected in normal, it limit speed of CPU and servers




  - If the temperature of inflow air and exit air and the fan speed are known, then we can calculate how much heat has been removed
  - Prior studies estimate energy consumption by devices through CPU activities and ignore other components.
  - Calculating the temperature difference between in and out air flows can reflect activities of all components including CPUs of IT devices.

# Research gap (2)

- Since each server does not have a dedicated cooler, temperature of inflow air is different.
  - As we can see in the simulated result below, each server's temperature is different due to relative location from coolers and the working status of coolers
  - If we distribute workloads for servers within various locations, the perceived temperature of a server (inflow air temperature of a server) can affect its performance.



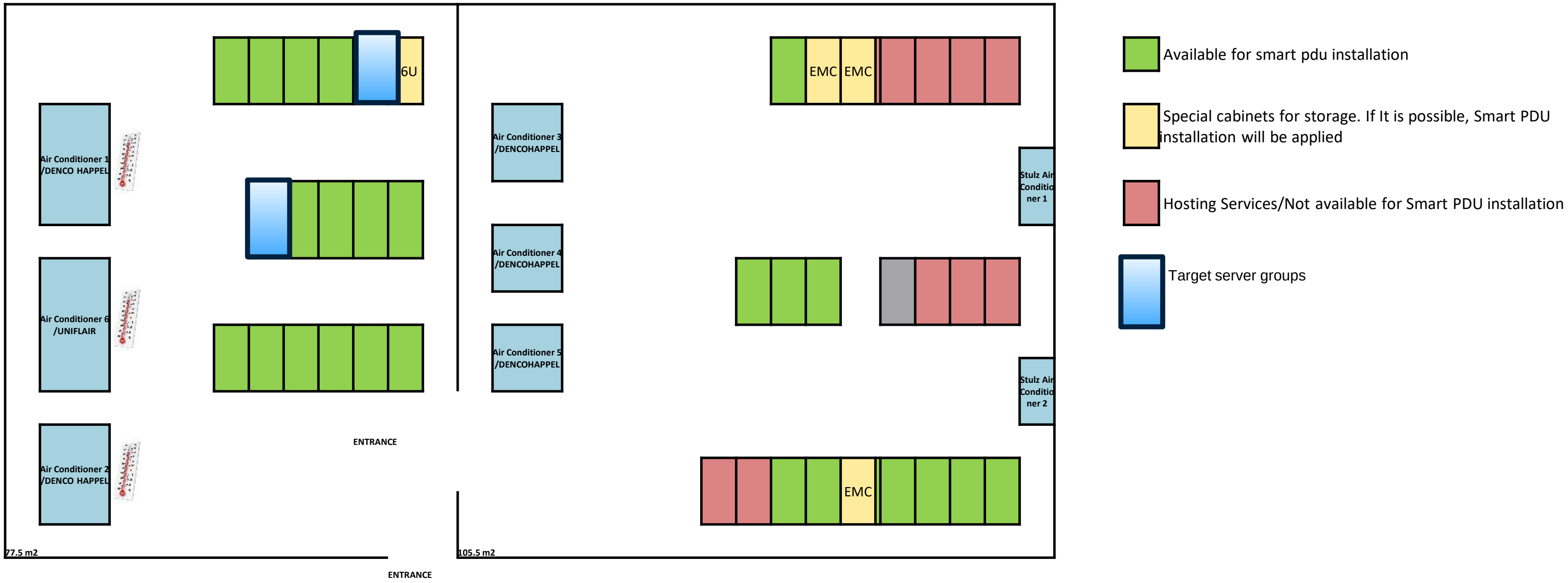

<source: Choo et al. (2017)>

# Research Questions

- Does high temperature inflow air affect energy consumption of the server for given workload?
- Does a server located between two air-conditioner performs more efficiently than a server located in the side (or behind other servers)?
- How energy efficiency of coolers and servers are affected as temperature increases (or decreases)?
- What are the best rules for activating coolers and IT devices for a given workloads?

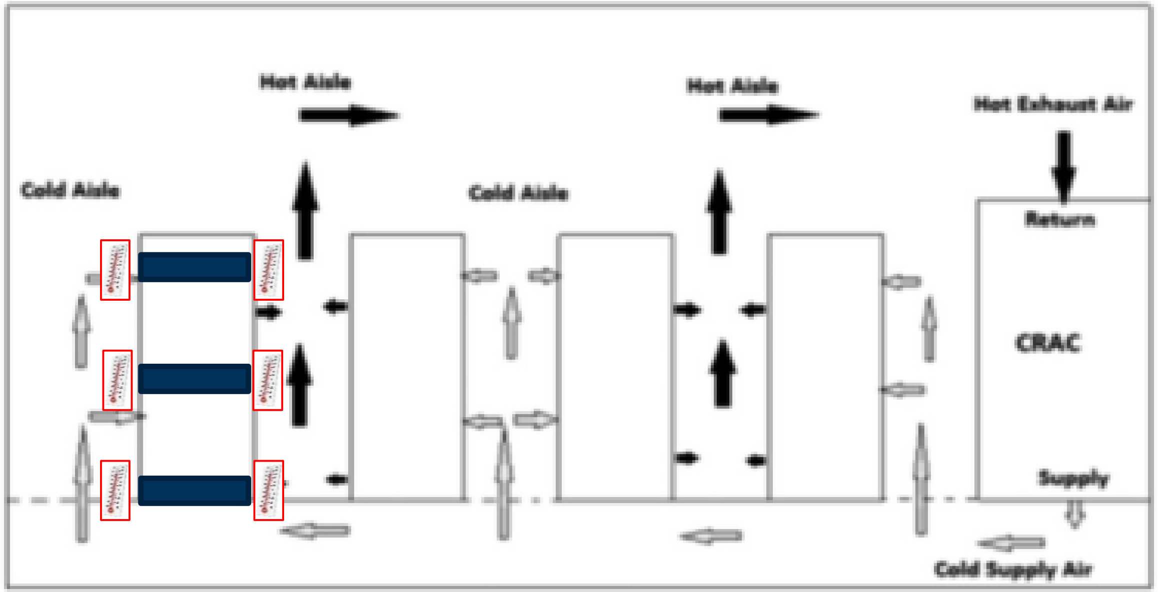
# Target devices to be installed: Server room

- Target server groups (racks): two racks in the left server room
  - Two server racks (gray location in the below picture)
    - One rack is one of the closest positions to air conditioners, the other is a farthest location
  - Four SmartPDU – it is configured for two racks due to redundant power supply



# Target devices to be installed: Rack

- To install sensors aligned with server location
  - Due to installation feasibility, sensors are installed on the rack / not on the server directly
  - Install inflow/exit temperature sensors aligned with specific servers (the top/middle/bottom server)
    - Six sensors will be installed front and rear of each server rack



# Data collection solutions (suggested by Turksat)

- Every sensor and equipment will be connected to a server using SNMP card
  - SNMP card send monitoring values to the target hosts
  - It will be stored using monitoring software such as Zabbix / SolarWinds

| Target Equipment | Measuring equipment | # of equipment | Measurement | Status |
|---|---|---|---|---|
| Sensors | Server racks<br>Air conditioners | 12 for server racks<br>6 for air conditioners | Temperature<br>Humidity | To be installed |
| Energy meter | Power consumption | 3 for air conditioners<br>3 for chillers | Power consumption | To be installed |
| SmartPDU | Equipment installed in the server racks | 4 for server racks | Power consumption | To be installed |
| UPS | UPS itself | 2 UPS | Power consumption of UPS | Installed |
| Chiller | Chiller itself | 3 Chillers | Outside air temperature | Installed |

# Measurement variables and specification

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| Variables | Description | Target Equipment | Measure Equipment | Install location | Unit | Decimal places | Measure Frequency | DB | Comment |
|---|---|---|---|---|---|---|---|---|---|
| $In_{Temp}$ | Inflow air temperature | Rack/2 | Temperature Sensor | Rack | ℃ | 2 | 1 sec (realtime) | DCIM | Synchronize recording time with WL |
| $In_{H}$ | Inflow air humidity | Rack/2 | Temperature Sensor | Rack | % | 2 | 1 sec (realtime) | DCIM | Use the same sensor with $In_{Temp}$ |
| $Out_{Temp}$ | Exit air temperature | Rack/2 | Temperature Sensor | Rack | ℃ | 2 | 1 sec (realtime) | DCIM | Synchronize recording time with WL |
| $Server_{Fan}$ | Fan speed of the server | Server/6 | On board sensor | Installed | RPM | 0 | Use system report value | Zabbix | Synchronize recording time with WL |
| $CPU_{Vol}$ | Input voltage of CPUs | Server/6 | On board sensor | Installed | V | 2 | Use system report value | Zabbix | Measure for each CPU |
| $CPU_{temp}$ | Temperature of CPUs | Server/6 | On board sensor | Installed | ℃ | 2 | Use system report value | Zabbix | Measure for each CPU |
| WL | Workload | Server/6 | Zabbix | Zabbix | % | 2 | Use system report value | Zabbix | |
| $Rack_{pc}$ | Power consumption | Rack/2 | PDU | installed | kW | 2 | 1 sec (realtime) | New db or Zabbix | Total power consumption of PDU |
| $Server_{PC}$ | Power consumption | Server/6 | PDU | Installed | kW | 2 | 1 sec (realtime) | New db or Zabbix | Synchronize recording time with WL |
| $CRAC_{temp}$ | Air temperature from AC | Air conditioner | Temperature Sensor | Front of air inlet | ℃ | 2 | 1 sec (realtime) | New db or Zabbix | Synchronize recording time with WL |
| $CRAC_{H}$ | Air humidity from AC | Air conditioner | Temperature Sensor | Front of air inlet | % | 2 | 1 sec (realtime) | New db or Zabbix | Use the same sensor with InT |
| $CRAC_{pc}$ | Power consumption | Air conditioner | Power meter (?) | Power cord (?) | kW | 2 | 1 sec (realtime) | New db or Zabbix | Synchronize recording time with WL |
| $Ch_{Temp}$ | Ambient outside temperature | Chiller | Built-in (Available) | Front of air inlet | ℃ | 2 | 1 sec (realtime) | New db or Zabbix | Synchronize recording time with WL |
| $Ch_{PC}$ | Power consumption | Chiller | Power meter (?) | Power cord (?) | kW | 2 | 1 sec (realtime) | New db or Zabbix | Synchronize recording time with WL |
| $UPS_{pc}$ | Power consumption | UPS | Built-in (available) | | kW | 2 | 1 sec (realtime) | Zabbix | Synchronize recording time with WL |

# Simple analysis model

- Temperature data (InT, OutT, and Ct) and power consumption data (Pc and Cp) have correlation between each other
- Workload data is given at specific server and time. But workload processing can be affected by other conditions and vice versa
- To deal with endogenous variables (temperature and power consumption), we use panel vector auto regression (PVAR) model as a base model

$$\begin{bmatrix} Pc_{i,t} \\ Cp_{i,t} \\ InT_{i,t} \\ WL_{i,t} \\ OutT_{i,t} \\ CT_{i,t} \end{bmatrix} = \sum_{j=1}^{J} \begin{bmatrix} \phi_{1,1}^{i,j} & \cdots & \phi_{1,6}^{i,j} \\ \phi_{2,1}^{i,j} & & \phi_{2,6}^{i,j} \\ \phi_{3,1}^{i,j} & & \phi_{3,6}^{i,j} \\ \phi_{4,1}^{i,j} & & \phi_{4,6}^{i,j} \\ \phi_{5,1}^{i,j} & & \phi_{5,6}^{i,j} \\ \phi_{6,1}^{i,j} & & \phi_{6,6}^{i,j} \end{bmatrix} \begin{bmatrix} Pc_{i,t-j} \\ Cp_{i,t-j} \\ InT_{i,t-j} \\ WL_{i,t} \\ OutT_{i,t-j} \\ CT_{i,t-j} \end{bmatrix} + ControlVars + Const + \varepsilon_{i,j-1}$$

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