Cloud Operations & Innovation ("CO+ I")

A Feasibility Framework for Waste Heat from Data Centers to a Water Capture System from Uravu Labs

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Contents

Summary

The present work explores integrating data center waste heat with Uravu's FromAir solution, an atmospheric water harvesting (AWH) technology, to enable simultaneous cooling and freshwater production. The study begins by outlining the process schematic of the Uravu unit coupled with the data center facility, followed by a detailed feasibility assessment conducted across fifteen globally distributed locations with varying climatic conditions. The results indicate that the system's operational viability is predominantly influenced by the local dry bulb and wet-bulb temperature (WBT) and the temperature of the available waste heat. For low-grade waste heat conditions (30–35°C), an alternative operational mode, comprising a hybrid electric-waste heat configuration, was analyzed, demonstrating comparable water yields but with increased specific energy consumption. Among the configurations examined, the purely waste heat–driven baseline exhibited the most favorable performance, achieving electrical energy consumption of 60 $\mathrm{kWh/m^3}$ and while substantially reducing external cooling demand.

1. Introduction

Data centers' operations release heat at $30-55℃$, which must be brought down to lower temperatures for efficient operations. Generally, waste heat from the data center is recovered using water exiting at a higher temperature ($T_{\mathrm{fac,in}}$). The facility's water is being cooled using energy-intensive technologies. Uravu proposes a solution where data center cooling is achieved while producing fresh atmospheric water. The process flow of the integrated Uravu system and data center cooling is described below:

Uravu system: In this study, two waste heat reuse systems are discussed, the first one is a hybrid electric-waste heat driven system suitable for low temperature waste heat (30-35℃) options, and the second one is an entirely waste heat driven system ideal for higher waste heat temperatures (> 40℃).

i. Uravu's proprietary liquid desiccant absorbs moisture from ambient air
ii. Facility water carrying waste heat is used to heat the moisture-laden desiccant in the Uravu unit.
iii. Once the desiccant reaches the required temperature, it enters the regenerator to release water vapor.
iv. Depending on operational conditions, a portion of the total produced water may be used for precooling via an indirect evaporative cooler (IEC).

v. If needed, the remaining usable water is then employed for additional cooling of the facility water down to the desired temperature (T_{target}).

Data Center cooling: Cooling is achieved using a waste heat recovery heat exchanger that uses facility water load to heat the desiccant solution. If the heat is not sufficient to cool the water to the target temperature, then the following methods can be implemented for the given condition:-

i. If the desired facility water temperature (T_{target}) is below ambient but above the wet bulb temperature (WBT), IEC is used to cool the water to a specific intermediate temperature ($T_{\text{fac,out,evap}}$).
   - If the cooling demand exceeds the available net water, additional cooling is provided using a chiller, resulting in zero net water delivery.

ii. If T_{target} is below WBT, both an IEC and a chiller are necessary for cooling.

After fulfilling the evaporative cooling needs, any surplus water is delivered to the customer. During Uravu system downtime (due to operational constraints), cooling is fully managed by a water-cooled chiller. The simplified layout of this integrated system is shown in **Figure 1**.

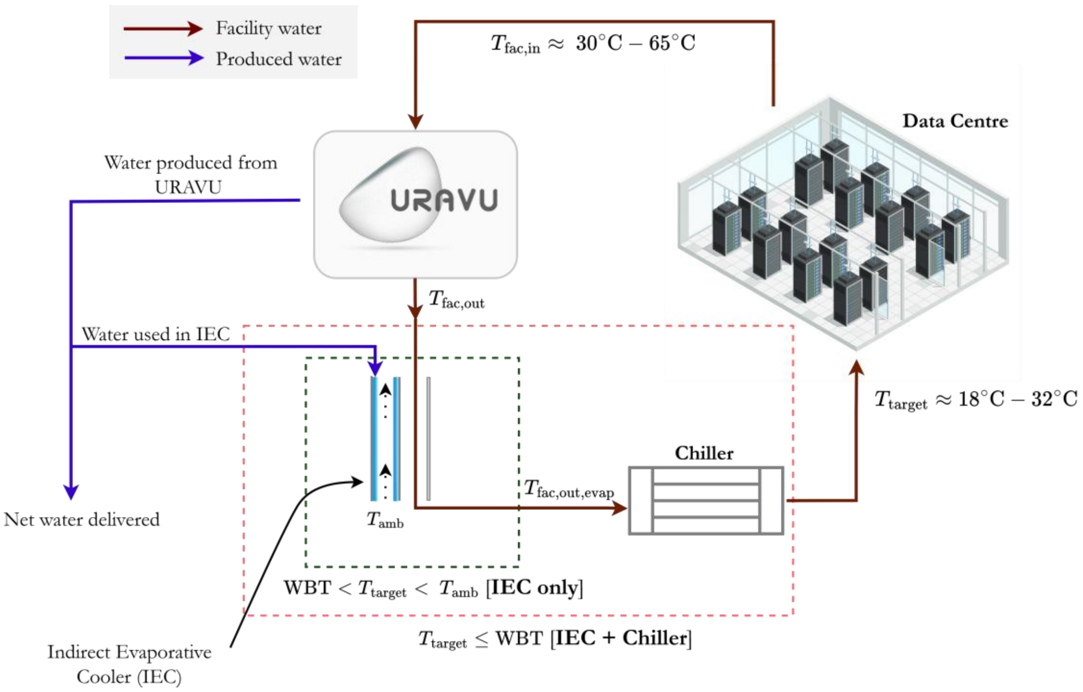

Figure 1: Integrated Data Center and Uravu system for waste heat utilization

For performance benchmarking, the integrated setup is compared with a conventional system where cooling is achieved via a dry cooler, cooling tower, or chiller—depending on environmental conditions and technology limitations. The evaluation considers the energy comparison with waste heat and electric systems, with a reduced cooling load and net water available from the integrated system.

2. Feasibility analysis

The integrated system's performance is assessed across 15 cities worldwide, with key metrics including gross water production by the Uravu system, net water delivered, and the corresponding energy consumption. The cities analyzed include New Delhi (NDL), Mumbai (MUM), Bengaluru (BLR), Dubai (DUB), Seattle (STL), Frankfurt (FRT), Dublin (DLN), Tokyo (TOK), Raipur (RPR), Riyadh (RDH), Seoul (SEL), Sydney (SYD), Paris (PAR), São Paulo (SAP), and Toronto (TOR). A parametric study is also performed by changing one of the key variables and keeping the remaining constant.

2.1 Low-temperature waste heat

For comparison, two waste heat inlet temperatures ($T_{\text{fac,in}}$) 30°C and 35°C are considered, corresponding to a 12°C temperature difference at a flow rate of 1.3 kg/s. As outlined in **Section 1**, employing a hybrid electric–waste heat configuration is the only practical approach for utilizing such low-grade waste heat. In this hybrid setup, Uravu's unit operates continuously, using the available waste heat to preheat the liquid desiccant, reducing the thermal load on the system's heat exchanger. Since the liquid desiccant typically enters the system at a temperature slightly above the ambient level, the extent of waste heat recovery from the data center depends on the local dry-bulb temperature.

When the waste heat temperature is approximately 2°C higher than the ambient air temperature, it can still be effectively used for desiccant preheating. However, if the desired temperature level is not met, the facility water is directed to an indirect evaporative cooler (IEC) for further cooling. The applicability of the IEC depends on the required target temperature, as its cooling capability is restricted by the local wet-bulb temperature (WBT). If the target temperature lies below the WBT, an auxiliary chiller becomes necessary for additional cooling. However, incorporating the IEC for precooling will reduce the subsequent cooling load on the chiller, thereby improving energy efficiency.

In cases where the ambient temperature exceeds the waste heat temperature, the waste heat loop is bypassed. Even under such conditions, water generation continues uninterrupted, with a portion of the produced water being diverted to the IEC to cool the waste heat stream, thus maintaining continuous facility water cooling.

Figure 2 illustrates the net water production from the integrated system after the facility water is cooled to the target temperature. At a fixed temperature difference, when the waste heat temperature is 30°C, the available heat load is insufficient to achieve the desired cooling, thereby increasing the dependence on the indirect evaporative cooler (IEC). This low waste heat load increases water consumption, particularly in hotter climatic regions. At 30℃ waste heat conditions, the net water production ranges between 5915 and 13340 m^3/MW. The IEC's water consumption decreases at a higher waste heat temperature of 35°C, resulting in greater overall net water output from the integrated unit. The corresponding net water production varies from 7782 to 13370 m^3/MW. Riyadh records the lowest water production among the locations analyzed, while Dublin achieves the highest. In colder climates, the net water consumption approaches the gross water (13370 m^3/MW) produced by the Uravu unit, as the cooling demand from the IEC is significantly reduced.

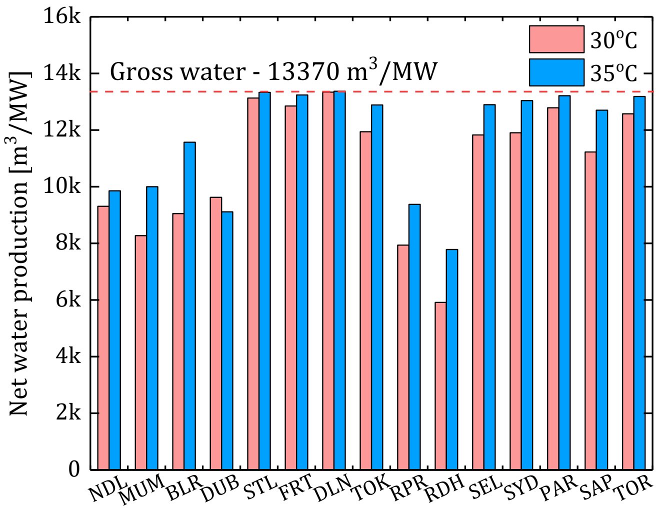

Figure 2: Net water production for 1 MW of cooling load at waste heat temperatures of 30℃ and 35℃.

The overall chiller demand is significantly reduced by utilizing waste heat for desiccant preheating and the IEC for supplementary cooling. **Figure 3** illustrates the variation in chiller dependency and the corresponding annual percentage reduction in chiller load. The local ambient conditions strongly influence the extent of chiller reliance and cooling load reduction.

At a waste heat temperature of 30°C, the target cooling temperature drops below the wet-bulb temperature (WBT) in most regions for the given cooling load. In hot and humid locations such as Mumbai, the annual dependency on the chiller can reach up to 91%, as shown in **Figure 3**(a). Nevertheless, the chiller cooling load decreases by approximately 48%, as depicted in **Figure 3**(b), indicating that the waste heat desiccant preheater and IEC handle about 48% of the total cooling demand, and the chiller handles the remaining 52%.

In contrast, in cooler climates such as Seattle, Dublin, and Frankfurt, the reliance on chiller cooling is minimal, up to only 3% of the time, and for a waste heat temperature of 35°C, it becomes nearly negligible, resulting in energy savings close to 100%. Moreover, for all selected cities at 35°C waste heat, the overall energy savings exceed 80%, as presented in **Figure 3**(b).

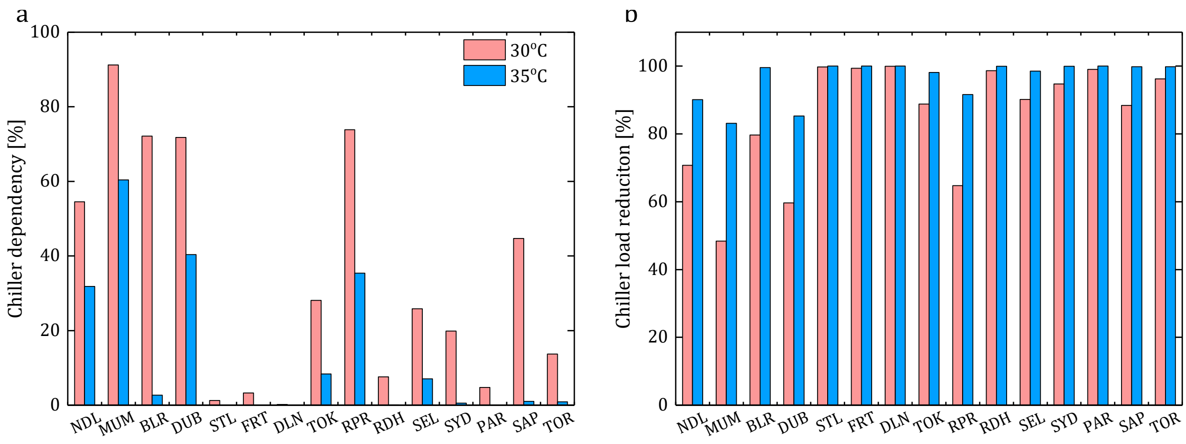

Figure 3: (a) Chiller dependency and (b) load reduction annually for different cities at 30°C and 35°C waste heat temperature.

The net water production directly influences the specific energy consumption (SEC) of the hybrid system. Since the electrical consumption and gross water output remain constant, the SEC primarily depends on the net water yield achieved after additional cooling in the IEC. As illustrated in **Figure 4**, when the waste heat temperature is 30°C, the SEC values are relatively high because of increased water consumption under a fixed electrical load, ranging from 200 to 450 kWh/m^3. The highest SEC is recorded in Riyadh, attributed to the greater water usage in the IEC, consistent with the trend observed in **Figure 2**. When the waste heat temperature increases to 35°C, the SEC values decrease by a maximum of 23% compared to the 30°C case. For colder cities, the SEC values are nearly identical for both waste heat temperature cases.

2.2 High-temperature waste heat

When the temperature of waste heat exceeds 40°C, the Uravu system can be entirely run with waste heat, with only electrical consumption accounting for auxiliary power consumption. Like the hybrid (electric + waste heat) configuration, the standalone waste heat configuration operations are strongly influenced by the local atmospheric conditions discussed in the later sections.

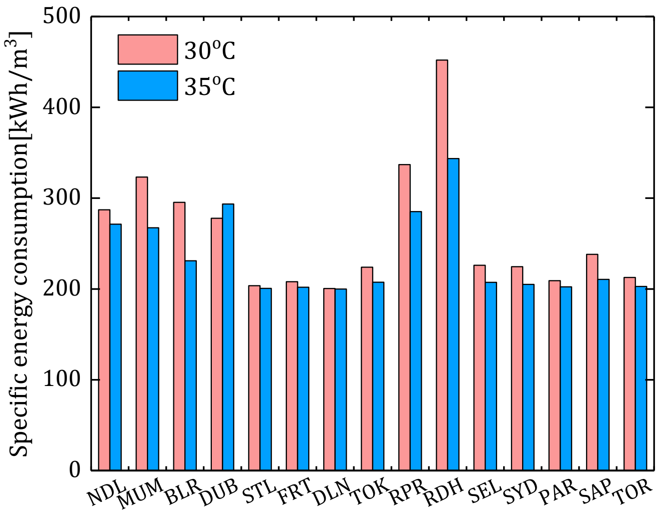

Figure 4: Specific energy consumption annually for different cities at waste heat temperatures of 30°C and 35°C.

2.2.1 Uravu operational limit due to geographical constraints

In the present analysis, the governing parameters for Uravu system operation, such as vacuum pressure, boiling point elevation (BPE), and operating temperatures, are kept constant. The local wet bulb temperature (WBT) strongly influences the system runtime. When the WBT exceeds the defined downtime trigger temperature set at 22°C in this study, the Uravu system ceases operation. **Figure 5** presents the annual variation of WBT for four representative cities and the downtime trigger threshold, indicating the duration for which the Uravu system remains non-operational.

Figure 5 shows that in Mumbai, where the wet bulb temperature remains elevated most of the year, the Uravu system records a downtime of nearly 70% of the total annual operating hours. In comparison, cities such as Sydney and Riyadh, which experience relatively lower wet bulb temperatures, exhibit negligible non-operational hours. For Bengaluru, higher wet bulb temperatures during the middle of the year contribute to an annual downtime of approximately 12% of the available operating hours. In the downtime period of the Uravu system, the cooling will be provided through the backup chiller for the continuous operation of the data center facility.

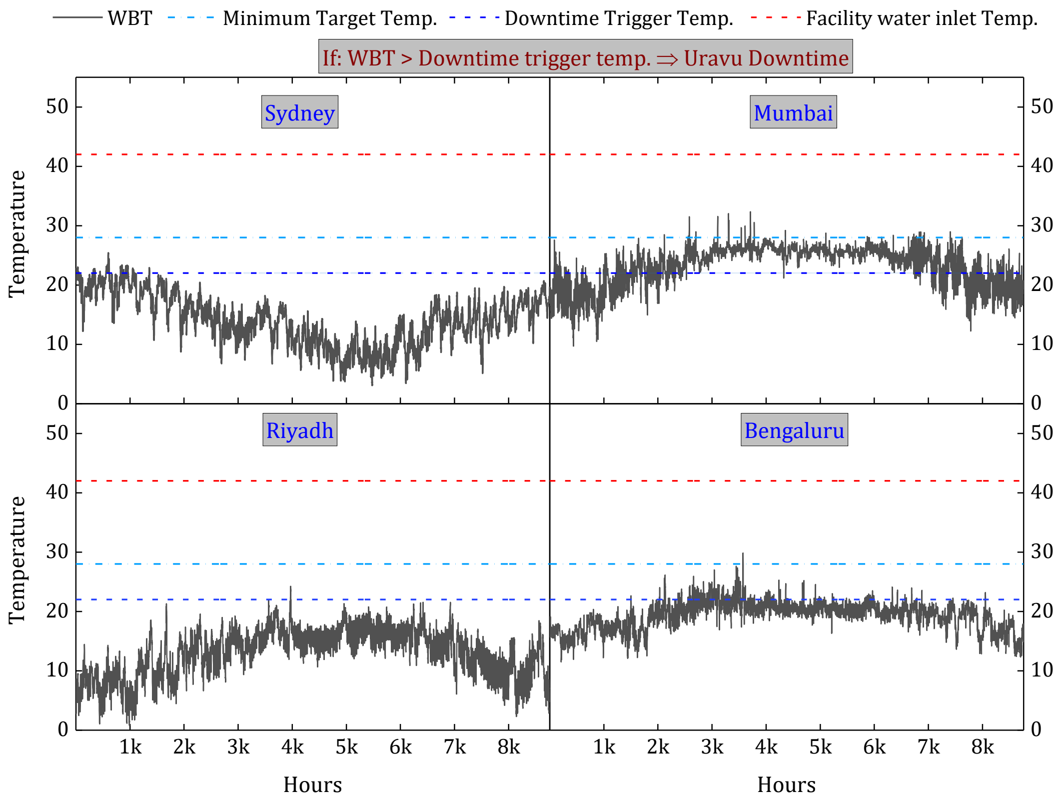

Figure 5: Variation of WBT through the year for Sydney, Mumbai, Riyadh, and Bangalore against the downtime trigger temperature.

2.2.2 Performance at high-temperature waste heat

The facility water temperature exiting the data center is critical for effectively integrating the Uravu system with the available waste heat. The minimum inlet temperature must satisfy the conditions of the whole operation using the waste heat stream. $T_{\text{fac,in}} \geq T_{\text{vap}} + \Delta T_{\text{system}} + BPE$, where T_{vap} is the vapor temperature at the applied vacuum pressure, ΔT_{system} is approximately 5°C, and the boiling point elevation is around 12°C. **Figure 6** illustrates the variation of gross and net water production across 15 representative cities over an annual cycle, considering a facility inlet temperature of 45°C and a target outlet temperature of 28°C. In most cases, the close difference between gross and net water values suggests minimal demand for water in the indirect evaporative coolers (IECs). This indicates high water-use efficiency and confirms that the system maintains a ***water-positive profile—producing more water than it consumes***.

However, the amount of water produced is not uniform across all locations, where gross water production varies from 2100 to 9450 m^3/MW and net water delivered vary from 2100 to 9400 m^3/MW. The variation in gross water output is primarily governed by the operational availability of the Uravu system, which is constrained by the downtime trigger temperature and water consumption in IEC for its desiccant cooling use, as mentioned in **Section 2.2.1**. Due to operational constraints, the number of hours the Uravu system can run varies throughout the year across different locations. The wet-bulb temperature (WBT) limit can be adjusted relative to the facility water temperature. If the facility water temperature increases, the system can operate at a higher WBT through vacuum pressure adjustments. This increases potential operational hours in the hotter regions, as discussed in **Section 2.2.3**.

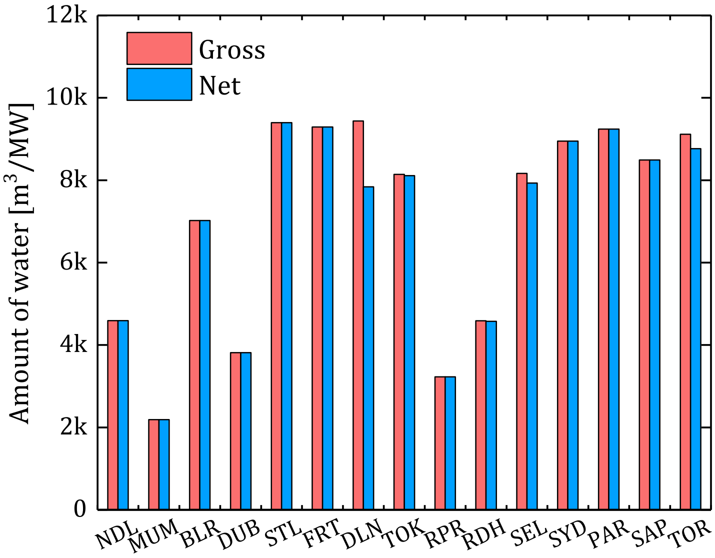

Figure 6: Gross and net water delivered throughout the year at different cities across the globe.

In cities like Mumbai, where WBT frequently stays above the threshold for much of the year, the system cannot operate continuously because of occasional dips below the limit. The WBT constraints, along with the excess water consumption in IEC for some part of the year, result in the annual operational uptime across different cities ranging from 23% to 48%, as shown in **Figure 7**. In these regions, for a fraction of the time when the system is not operational, cooling is provided through a backup chiller, resulting in continuous operation. In contrast, cities like Seattle, Frankfurt, Dublin, and Toronto experience more moderate or stable weather patterns, allowing the WBT to remain below the trigger temperature for most of the year. These regions have continuous operation of the Uravu system and significantly higher net water production due to lower load on the IEC, with no seasonal interruptions to its functionality.

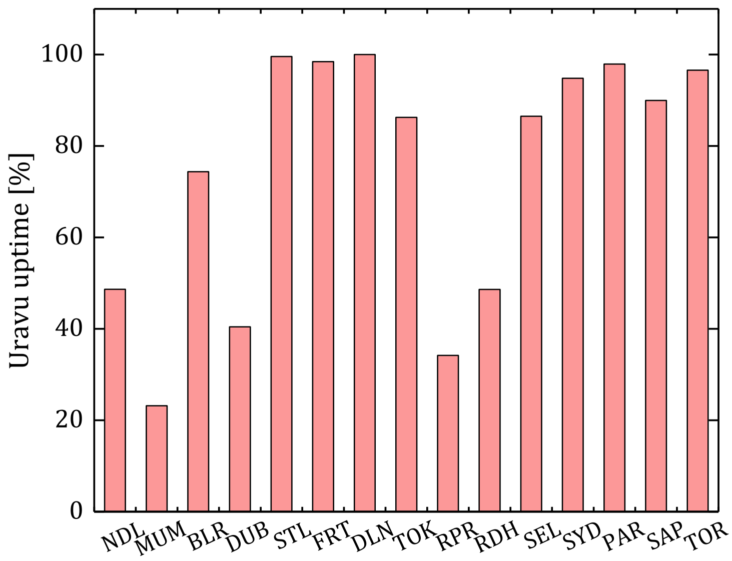

Figure 7: Fraction of time the Uravu system is operational for a year at different locations.

A standalone waste heat configuration's specific energy consumption value is almost one-fourth of the hybrid system due to a lower electricity demand. The SEC values vary from 60 to 80 $\mathrm{kWh/m^3}$, as shown in **Figure 8**. In conventional cooling systems such as dry coolers, cooling towers, or mechanical chillers, lowering the data center facility water temperature from 45°C to 28°C imposes a cooling load of approximately 92 kW for a given flow rate, which will affect their electrical power consumption based on the coefficient of performance (COP). In contrast, with the integration of the Uravu system, the waste heat from the facility water is harnessed for desiccant regeneration, while simultaneously cooling the facility water to the desired target temperature at lower power consumption than the conventional technology without any additional cooling component.

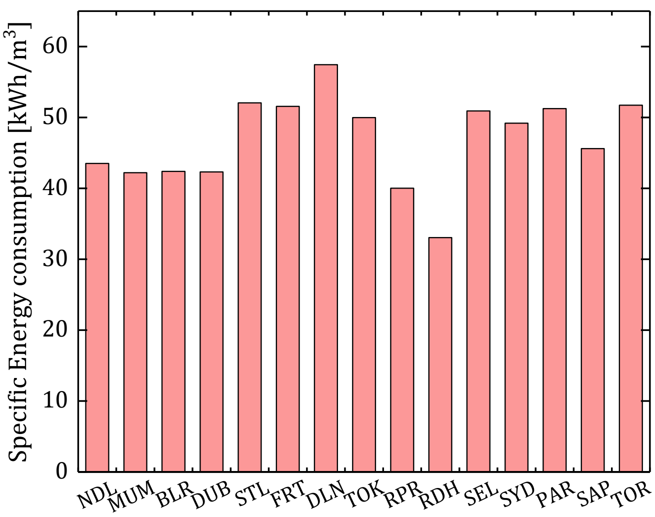

Figure 8: Specific energy consumption (SEC) for different cities at waste heat temperature of 45℃.

2.2.3 Potential to increase Uravu uptime with high waste heat

Integration of the Uravu system with data center waste heat is strongly influenced by the waste heat temperature, local atmospheric conditions, and the vacuum level maintained within the Uravu unit. Until now, system performance has been analyzed at a fixed vacuum level. As shown in **Figure 7**, the system's operational hours in hot and humid climates remain limited for any given waste heat temperature. For instance, in Dubai, the uptime is only about 40% at a facility water temperature of 45°C.

The Uravu system experiences downtime under two conditions: (i) when the facility water temperature drops below the operational threshold, and (ii) when the wet bulb temperature (WBT) exceeds the downtime trigger limit. Since data center cooling water temperatures can vary between 30°C and 55°C, the vacuum level can be dynamically adjusted to maximize uptime. Increasing the vacuum level raises the WBT downtime trigger threshold, expanding the system's operational window.

Figure 9 illustrates the optimal vacuum temperature corresponding to each facility water temperature that yields the maximum uptime and water productivity for a constant waste heat load. The achievable uptime for a 40°C facility water temperature is approximately 28% due to WBT and IEC water consumption constraints. This means the backup chiller will provide most of the cooling at this waste heat temperature, increasing energy consumption. However, the allowable WBT limit increases at higher facility water temperatures, enabling continuous operation (up to 100%), as shown in **Figure 9**(a). Consequently, the net water production increases from about 3000 to 10200 m^3/MW up to 60°C, as depicted in **Figure 9**(b).

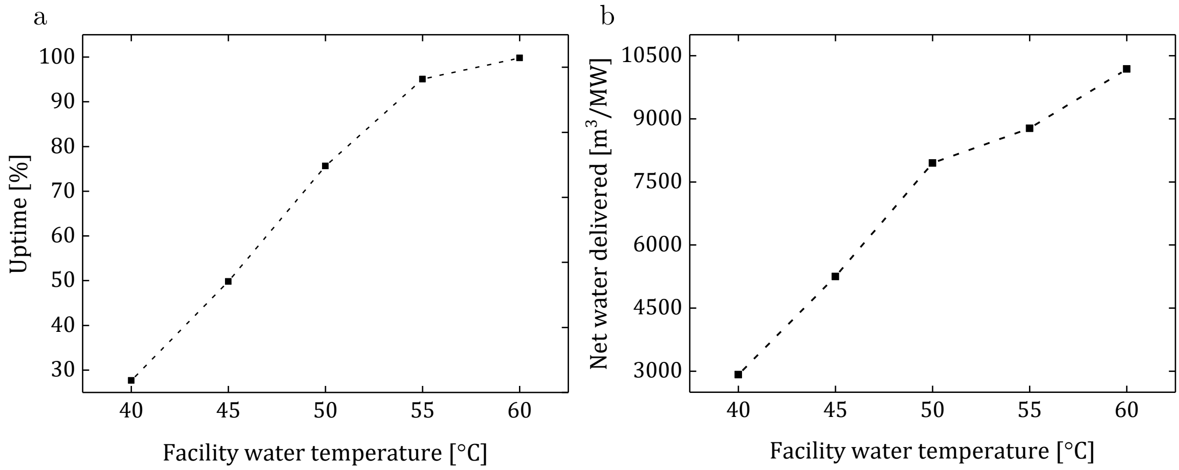

Figure 9: Impact of facility water temperature on (a) maximum operational hours and vacuum level, and (b) net water delivered to the customer for Dubai.

3. Concluding remarks

This study evaluates the integration of the Uravu atmospheric water generation (AWG) system with data center waste heat to enable simultaneous freshwater production and facility water cooling. System feasibility depends on local wet bulb temperature (WBT) and waste heat temperature. The key findings are:

- **Operational feasibility**:
  - For a hybrid (electric + waste heat) system, the Uravu unit can continuously produce water and provide cooling for low waste heat temperatures of 30-35℃.
  - For a standalone waste heat configuration, the system requires WBT below the downtime trigger temperature of ~22°C. Cities such as Mumbai experience ~75% downtime annually, whereas Frankfurt and Dublin have negligible downtime.
- **Waste heat constraint**:
  - For a hybrid system, the available waste heat should be 2℃ higher than the ambient temperature to utilize the waste heat efficiently.
  - For a standalone waste heat system, for the whole operation, the facility water inlet must satisfy $\Longrightarrow T_{\text{fac,in}} \geq T_{\text{vap}} + \Delta T_{\text{system}} + BPE$.
    - The vacuum temperature can be adjusted based on the facility's water temperature. Higher facility water temperature can lead to higher operational hours and water production from the integrated system for the same waste heat load in cities like Mumbai and Dubai, where downtime is usually high.
- **Water production**:
  - For a hybrid system, the net water production will depend on the IEC load required to cool the data center's waste heat source.
  - In the standalone waste heat system, the gross water production will vary depending on the geographical locations based on the system's uptime, further impacting the net water production.
- **Energy performance and cooling load reduction for the chiller**:
  - Due to more electricity consumption, the hybrid system shows, on average, four times higher SEC values than the standalone waste heat system. However, it also simultaneously reduces the chiller cooling load.

- 1 MW of cooling load requires ~300 kW of electrical load, while with Uravu's integration, the electrical load reduces to 50-200 kW. Depending on the configuration, this load reduction may lead to 33 to 83% energy savings.

Integrating Uravu with data center waste heat significantly reduces the load on the conventional cooling technologies while producing freshwater, offering a sustainable and water-positive alternative to traditional cooling systems.