

Cloud Operations & Innovation (“CO+ I”)

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

Milestone-2 Report



Date of Submission

18 November 2025

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1. Introduction

The preliminary report findings demonstrate how the Uravu system enables simultaneous cooling and water generation by utilizing waste heat from data centers. This report presents the conceptual layout for integrating the Uravu system with data center operations, provides a detailed analysis of integration across eight priority sites, and highlights key risks and corresponding mitigation strategies.

2. Integration schematic

Integrating the Uravu system with a data center requires a dedicated heat exchanger to enable efficient thermal energy transfer, complemented by engineered piping networks that establish interconnections between the two systems. The integration incorporates instrumentation such as **flow meters, control valves, and actuators** to ensure accurate monitoring and automated control of thermal and hydraulic parameters. The heat exchanger increases the temperature of Uravu's proprietary liquid desiccant to the required desorption temperature. This section outlines the conceptual design, highlighting the configuration of multiple loops tailored for different operating scenarios.

The conceptual CAD and integration schematic is illustrated in **Figure 1** and **Figure 2**. Key components of the Uravu system, including the **absorber, desorber, desiccant-facility water heat exchanger, and condenser**, which all together occupy less than 60 m² of footprint area, along with the associated piping and control infrastructure.

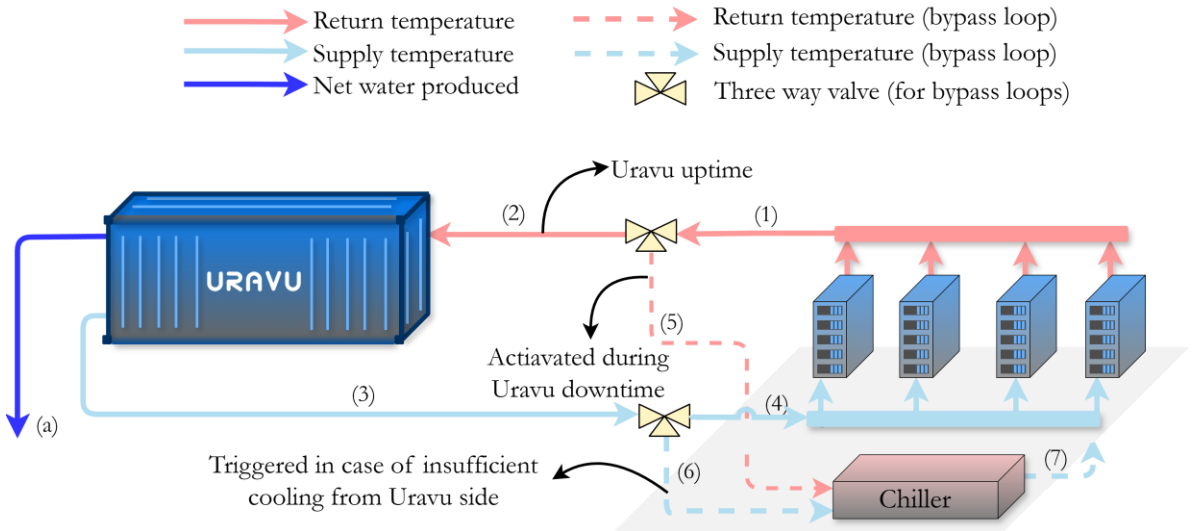


Figure 1: Conceptual schematic layout design of the Uravu system with the data center.

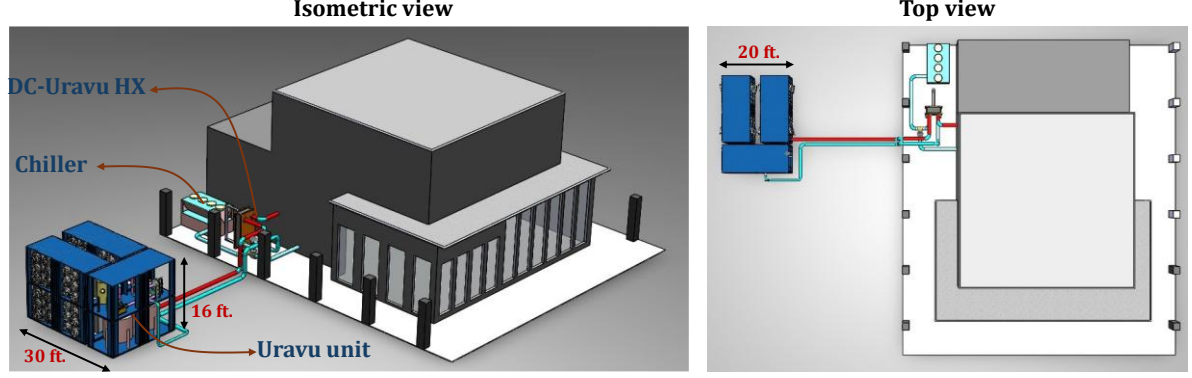


Figure 2: Conceptual CAD layout design of the Uravu system with the data center.

Depending on the operating state of the data center and prevailing ambient conditions, specific fluid loops and components are selectively activated to support cooling requirements. In particular scenarios, **the use of chillers** ensures normal data center operations, regardless of the availability of the **Uravu system**. Various case scenarios are mentioned in **Table 1**.

Table 1: Active loop and component for different scenarios for Uravu integration with the data center.

Scenario	Active loop	Components active
1. The target temperature is achieved with desiccant-facility water HX	$1 \rightarrow 2 \rightarrow 3 \rightarrow 4$ and (a)	Uravu unit only
2. The target temperature is not achieved with the desiccant-facility water HX	$1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 6 \rightarrow 7$ and (a)	Uravu with IEC, and Chiller
3. Target temperature $>$ WBT, and water consumed in IEC exceeds the generated water	$1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 6 \rightarrow 7$ and (a)	Uravu with IEC, and Chiller
4. WBT $>$ downtime trigger temperature	$1 \rightarrow 5 \rightarrow 6 \rightarrow 7$	Chiller only

Types of Uravu configurations:

1. **Uravu-waste heat:** The data center **waste heat** is **directly utilized** to drive the **evaporation** in the Uravu unit. Any remaining cooling is provided through the chiller.
2. **Uravu-electric:** The evaporation in the Uravu unit is driven by an electrically driven mechanical device, and the **waste heat** is **only utilized for partial preheating** of the liquid desiccant. Any remaining cooling is provided through the chiller.

3. Site-specific deep dive

Fourteen data center sites have been selected, four from the European Union (EU), four from the United States (US), and six from Asia, for detailed evaluation of the integrated system's performance. The chosen locations are Frankfurt (FRK), Madrid (MRD), London (LON), Stockholm (SHM), Phoenix (PNX), Chicago (CHG), Seattle (STL), Houston (HSN), Hyderabad (HYD), Bengaluru (BLR), Mumbai (MUM), New Delhi (NDL), Chennai (CHN), and Paya Lebar in Singapore (SGP).

Based on operational conditions and local climate, various scenarios may be applicable, as listed in Table 1. For the baseline, the facility water inlet temperature/return temperature ($T_{\text{fac,in}}$) is maintained at 30°C, with a target outlet temperature/supply temperature (T_{target}) of 18°C. The facility water is maintained at a rate of 1.3 kg/s, and the desiccant flow rate is adjusted based on the available waste heat. Additionally, the **Uravu system is programmed with a downtime trigger temperature (T_{trigger}) of 9.5°C, specific to 30°C operating conditions only.** Based on the available waste heat temperature, the downtime trigger temperature can also be adjusted. **The downtime trigger temperature indicates that Uravu's waste heat-based system is suspended whenever the ambient wet-bulb temperature (WBT) falls below this threshold.**

Also discussed in the Milestone-1 report, the facility water temperature should follow the given constraint, where, $T_{\text{fac,in}} \geq T_{\text{vap}} + \Delta T_{\text{system}} + BPE$, where ΔT_{system} (Uravu unit temperature adjustment including losses) is approximately 5°C, and the boiling point elevation (BPE) is around 12°C, along with saturation temperature (T_{vap}) which can be adjusted by controlling the vacuum according to the available waste heat temperature.

3.1 Operational threshold for different sites

Figure 3, Figure 4, and Figure 5 illustrate the annual variation of wet bulb temperature (WBT) across the selected locations. For stable operation of the Uravu-waste heat system, the downtime trigger temperature must be maintained above the prevailing WBT. Considering the downtime trigger temperature of 9.5°C for facility water temperature of 30°C, the system is programmed to suspend operation whenever WBT surpasses this threshold, in which case the data center cooling shifts to Scenario 4, as described in Table 1.

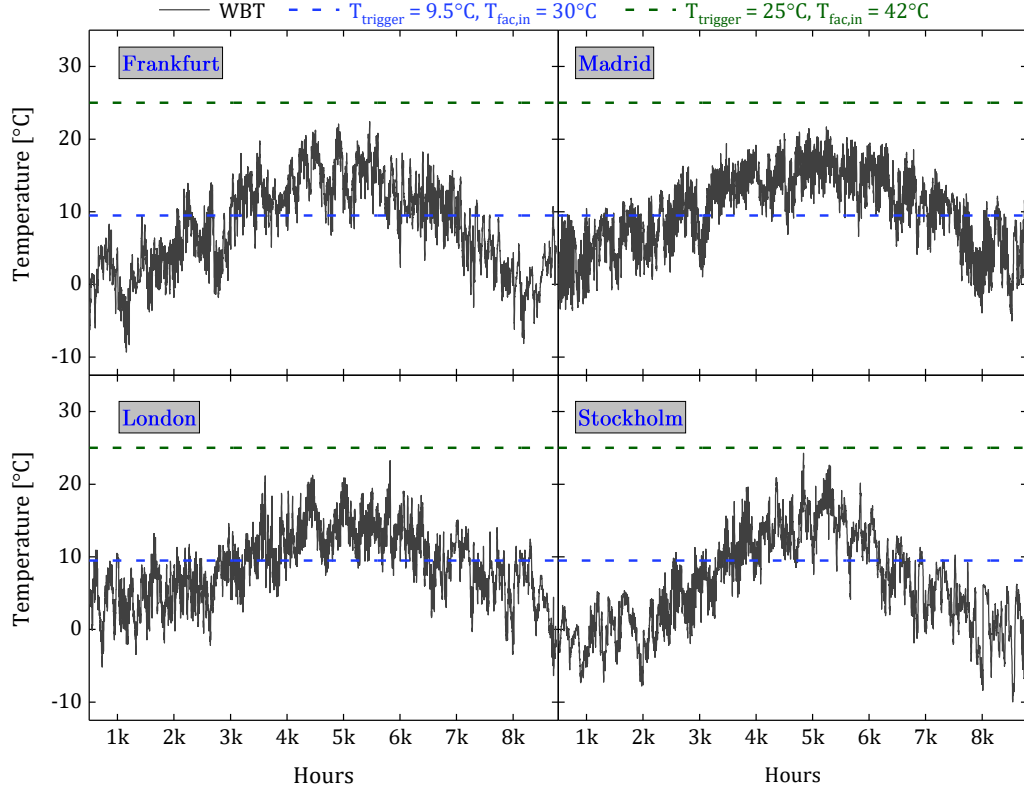


Figure 3: Variation of WBT through the year for the European Union cities against the downtime trigger temperature.

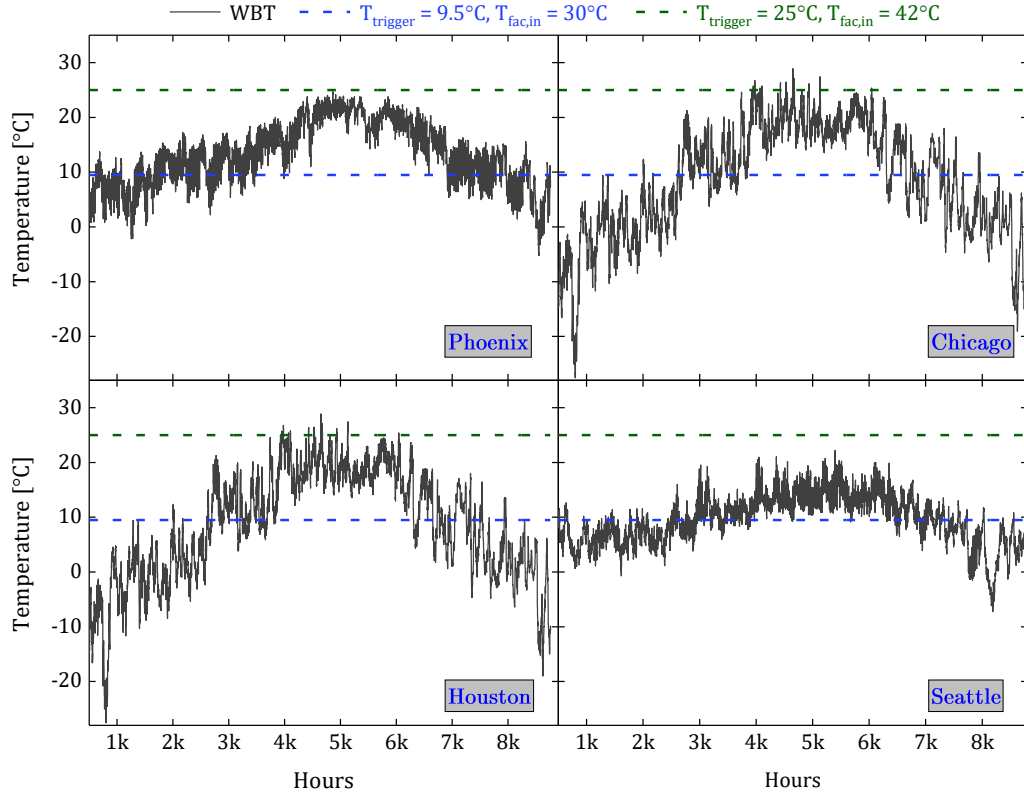


Figure 4: Variation of WBT throughout the year for US-based cities against the downtime trigger temperature.

For EU: The proportion of time that the complete waste heat-operated integrated system remains active is 57% in Frankfurt, 44% in Madrid, 48% in London, and 67% in Stockholm, when considering the EU cities.

For the US: the system is operational for 30% in Phoenix, 54% in Chicago, 16% in Houston, and 51% in Seattle.

Based on a 30°C waste heat temperature, the feasibility rankings for system uptime in the EU are Stockholm > London > Frankfurt > Madrid, and for the US, they are Chicago > Seattle > Phoenix > Houston.

For India and Singapore: Due to the high ambient and wet-bulb temperatures in India and Singapore, at 30°C, the Uravu-waste heat unit experiences almost 100% downtime for each selected city, as the low downtime trigger temperature (red dotted line in Figure 5) for the Uravu system is not met. However, with a change in the waste heat temperature, the downtime trigger is also adjusted (green dotted line in Figure 5), which can lead to higher uptime for the Uravu system.

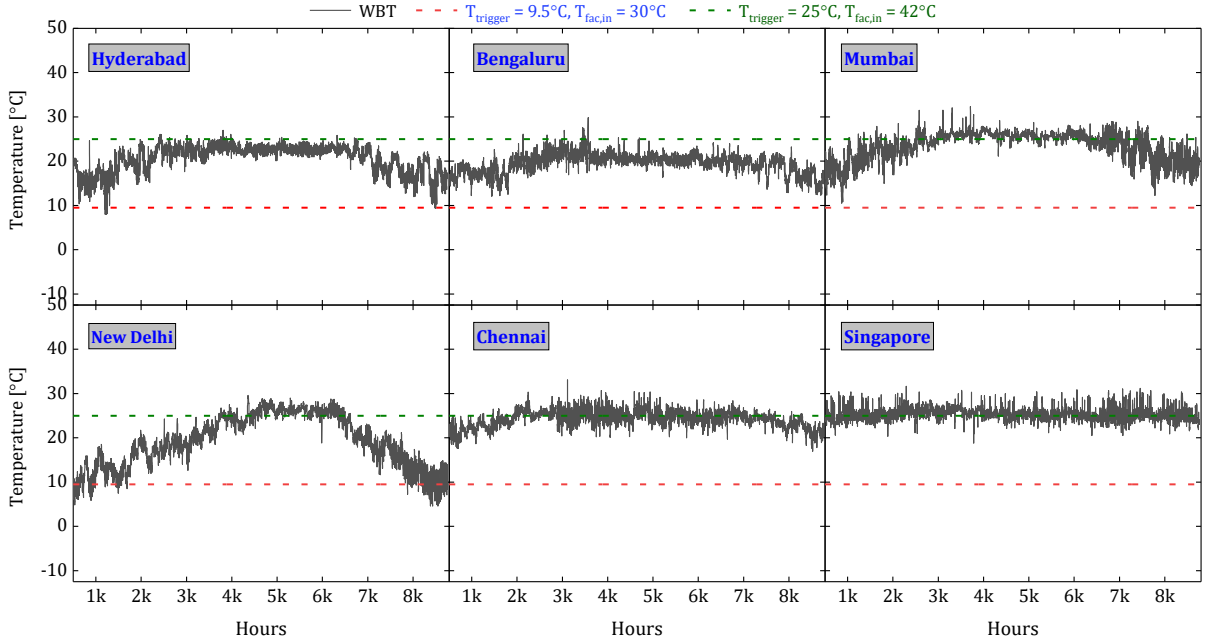


Figure 5: Variation of WBT throughout the year for Asian cities against the downtime trigger temperature.

3.2 Reduction in chiller load

With Uravu-unit, the cooling load on the existing chiller or cooling facility will reduce. The reduction in annual chiller load for the complete Uravu-waste heat-based system and the Uravu-electric (electric + waste heat) system has been reported for EU and US cities. For the same available waste heat load at a 30°C facility water temperature and

18°C target temperature, the **Uravu-waste heat system** results in a reduction in chiller load of approximately **45-68% for the EU and 16-54% for the US annually**, as shown in **Figure 6**. US-based cities experience a lower reduction in chiller load compared to EU-based cities, primarily due to differences in their natural climatic conditions, as explained in Section 3.1. However, in contrast, the **Uravu-electric system** leads to a **reduction in chiller load of approximately 100%** in almost every city, except for Houston, due to its hot weather, which results in more chiller utilization. It should also be noted that the reduction in chiller load for a complete waste-heat-based system is directly proportional to Uravu's uptime. However, for the Uravu-electric system, since Uravu's is operational for 100% of the time, the chiller load reduction is proportional to the cooling provided by the Uravu-electric system.

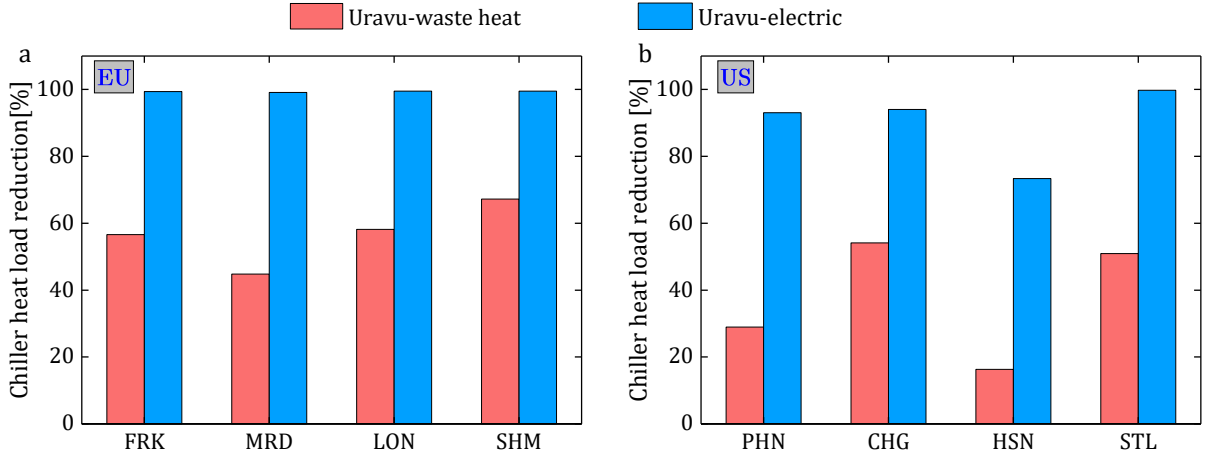


Figure 6: Reduction in chiller load annually for waste heat and Uravu-electric integrated system for data center cooling for (a) the European Union and (b) the US.

3.3 Gross and net water production

Gross water production represents the total amount of water produced from the Uravu-unit. While net water production represents the value of water that is left (or that can be delivered to customer) after additional cooling requirement in the indirect evaporative cooler (IEC). Gross and net water production across the selected sites was evaluated for both the Uravu-waste heat and Uravu-electric configuration, under the same waste heat load. **Figure 7** illustrates that gross water production for a complete waste-heat-driven system varies depending on the total annual uptime at different locations. The net water production of the system will be less than the gross because of the additional water consumption required for desiccant and facility water cooling in the IEC. However, **with a Uravu-electric system, the gross water production will remain constant throughout the year at 13,369 m³/MW due to 100% uptime of the Uravu system.** Similar to a

waste-heat system, the net water production will depend on the consumption in IEC for additional cooling load. The **net water production is increased by 2 to 8 times** for the Uravu-electric system compared to the waste-heat system, ranging from 8000 to 13,300 m^3/MW .

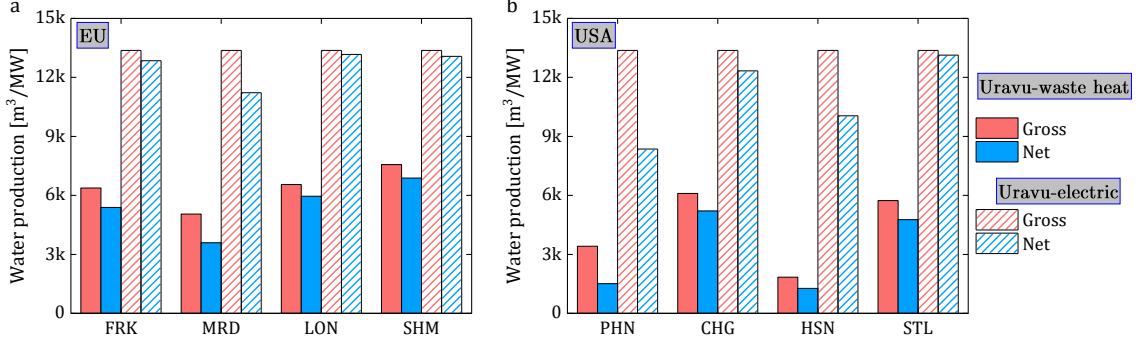


Figure 7: Gross and net water production for Uravu-waste heat and Uravu-electric integrated system for data center cooling for (a) the European Union and (b) the US.

3.4 Specific energy consumption

Specific energy consumption (SEC) represents the amount of energy required to produced per cubic meter of net water from the Uravu unit. Similar to water production, the SEC varies significantly with the different configurations. For the complete waste-heat-based system, the Uravu system's electrical energy consumption will be up to 6 kW, which accounts for pumping and fan power. For a Uravu-electric configuration, the electric energy consumption can reach up to 20 kW, allowing the system to run continuously for 100% of the time.

Figure 8 illustrates that the **waste-heat configuration yields SEC values in the range of approximately 69 to 142 kWh/m^3** . The higher value corresponds to Phoenix and Houston due to low net water production. An increase in SEC values of about three times can be observed with the Uravu-electric configuration due to increased electrical power consumption. The SEC value of the Uravu-electric system rises to about 204 kWh/m^3 and 319 kWh/m^3 for handling the same amount of waste heat load.

This SEC data indicates that while Uravu-electric configuration integration enables system operation for 100% of the time, it leads to higher energy input. Therefore, it can be concluded that to achieve 100% cooling with low-temperature waste heat reuse using the Uravu-electric system, there will be an increase in net water production, but with an increase in SEC value. **For low-temperature waste heat integration, there always exists a trade-off between the SEC and net water production.**

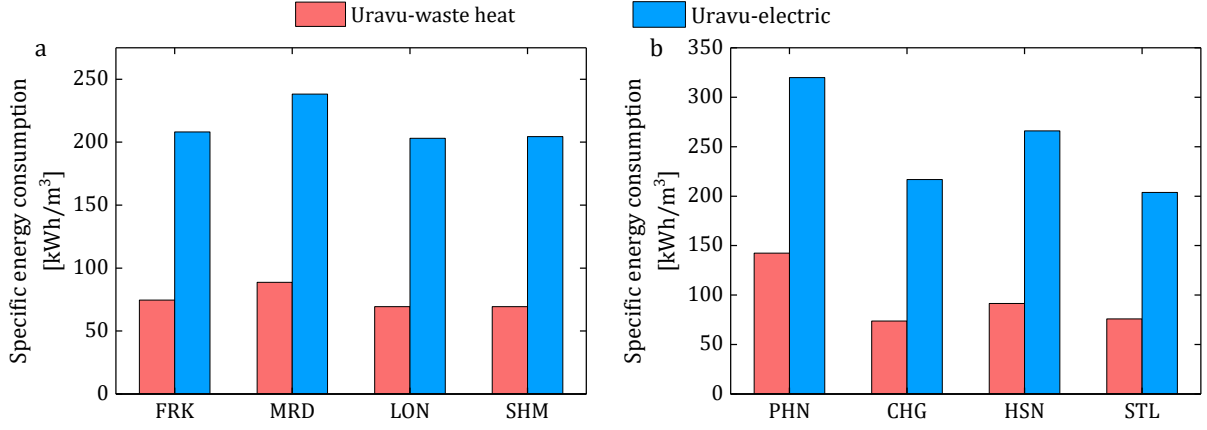


Figure 8: Specific energy consumption for Uravu-waste heat and Uravu-electric integrated system for data center cooling for (a) the European Union and (b) the US.

3.5 Impact of facility water temperature

The waste heat temperature plays a critical role in the appropriate integration of the Uravu atmospheric water harvesting system with the data center cooling application. The results reported up to Section 3.5 are based on low-temperature waste heat at 30°C. Due to the low temperature, the Uravu's downtime trigger temperature must be kept low, which results in more downtime hours for the Uravu-waste heat system. This section illustrates the effect of waste heat temperature on the system's overall performance for both configurations at the same waste heat load.

3.5.1 Impact on chiller load

In EU cities with a minimum waste heat temperature of 40°C, the chiller load can be reduced by up to 100% for Frankfurt, London, and Stockholm. For Madrid, the minimum waste heat temperature requirement is 45°C. As discussed in Section 3.2, with a Uravu-electric system, the reduction in chiller load is consistently close to 100%, regardless of the different waste heat temperatures, as shown in Figure 9.

Due to the varying local climatic conditions across the US, there is non-uniformity in the chiller load reduction for both configurations compared to EU cities. As depicted in Figure 10, to achieve 100% chiller load reduction with a complete Uravu-waste heat system, the minimum waste heat temperature required for Phoenix, Chicago, Houston, and Seattle is 55°C, 45°C, 50°C, and 40°C, respectively. For a Uravu-electric configuration, except for Houston, for which the minimum waste heat temperature required for 100% chiller load reduction is 40°C, while other cities obtain it at 35°C.

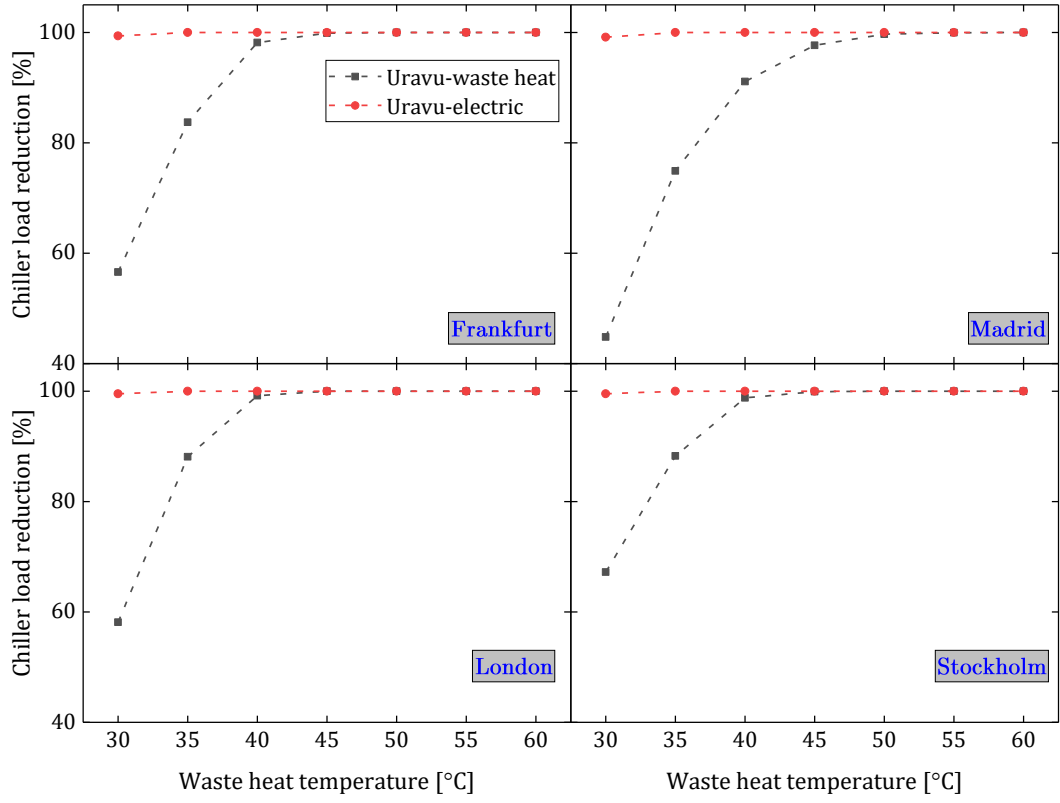


Figure 9: Reduction in chiller load for different European Union cities at varying waste heat temperatures.

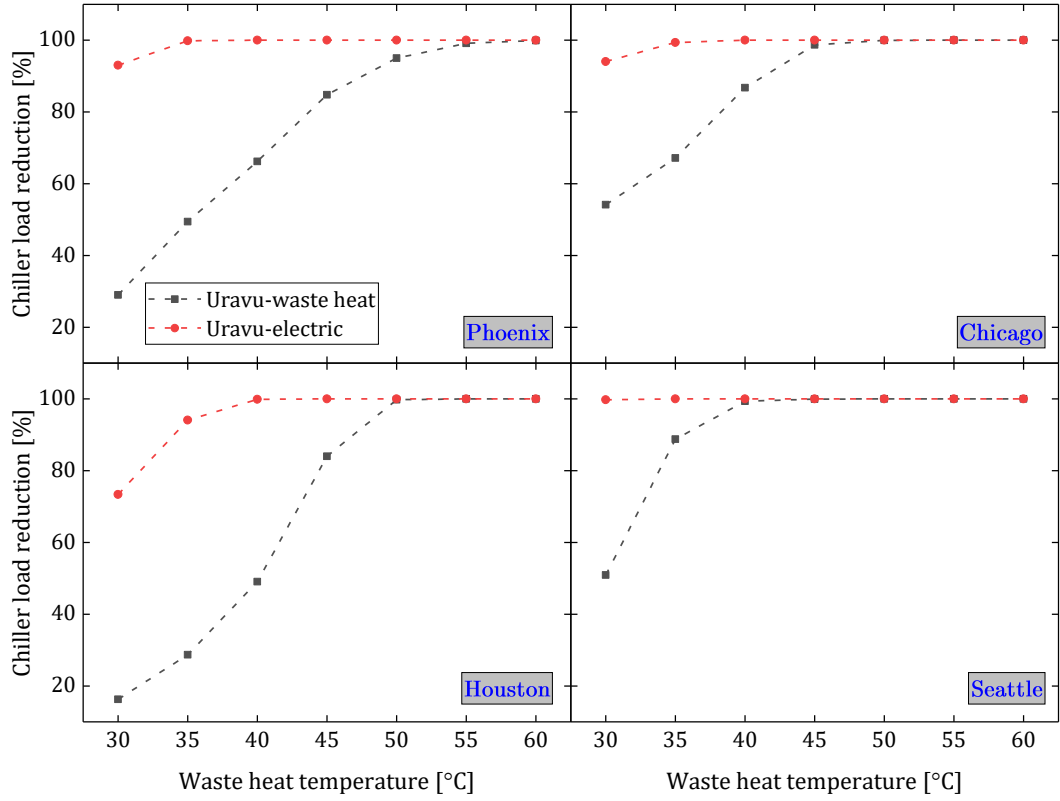


Figure 10: Reduction in chiller load for different US cities at varying waste heat temperatures.

For India and Singapore, the Uravu-waste heat system is effective only when the temperature is greater than 40°C for most cities. For cities like Bengaluru, Hyderabad, and New Delhi, the Uravu-waste heat is effectively operational beyond 35°C, as shown in Figure 11. With the Uravu-electric system, a chiller load reduction of 30 to 80% can be observed at 30°C. Beyond 30°C, a chiller load reduction of 80 to 100% can be achieved.

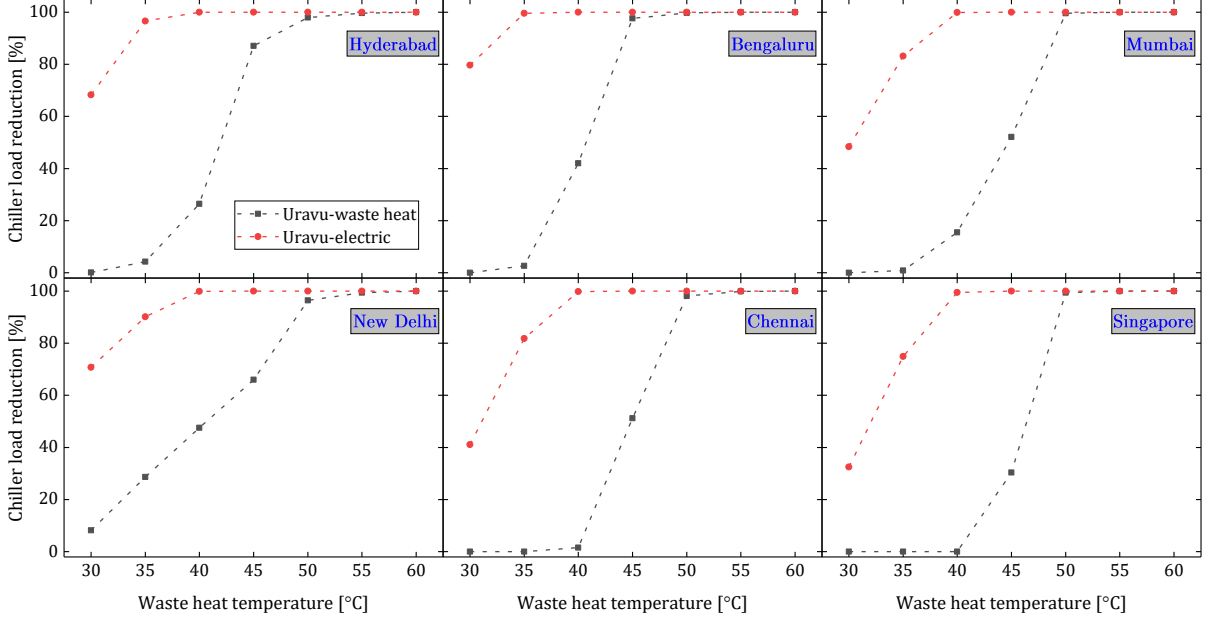


Figure 11: Reduction in chiller load for different Asian cities at varying waste heat temperatures

3.5.2 Impact on water production

For EU cities utilizing Uravu-electric configurations, the net water production remains almost steady at around 13,400 m³/MW across different waste heat temperatures. In contrast, for systems fully powered by waste heat, the net water output changes with the temperature of the available waste heat. Additionally, depending on the waste heat temperature and local climatic conditions, the water usage in the IEC for Uravu's internal consumption and facility water cooling also fluctuates, thereby influencing the overall net water production, as illustrated in Figure 12.

For US cities, variations in net water production are observed with changing waste heat temperatures in a fully Uravu-waste heat system. These variations primarily result from local climatic conditions, which affect the water demand for supplementary cooling in the IEC. In contrast, for the Uravu-electric configuration, water production tends to stabilize at temperatures above 40°C across different cities, as shown in Figure 13. This stabilization occurs because, at higher waste heat temperatures, the ambient temperature is relatively lower, enabling greater free cooling in the air-liquid heat exchanger and consequently reducing the IEC load.

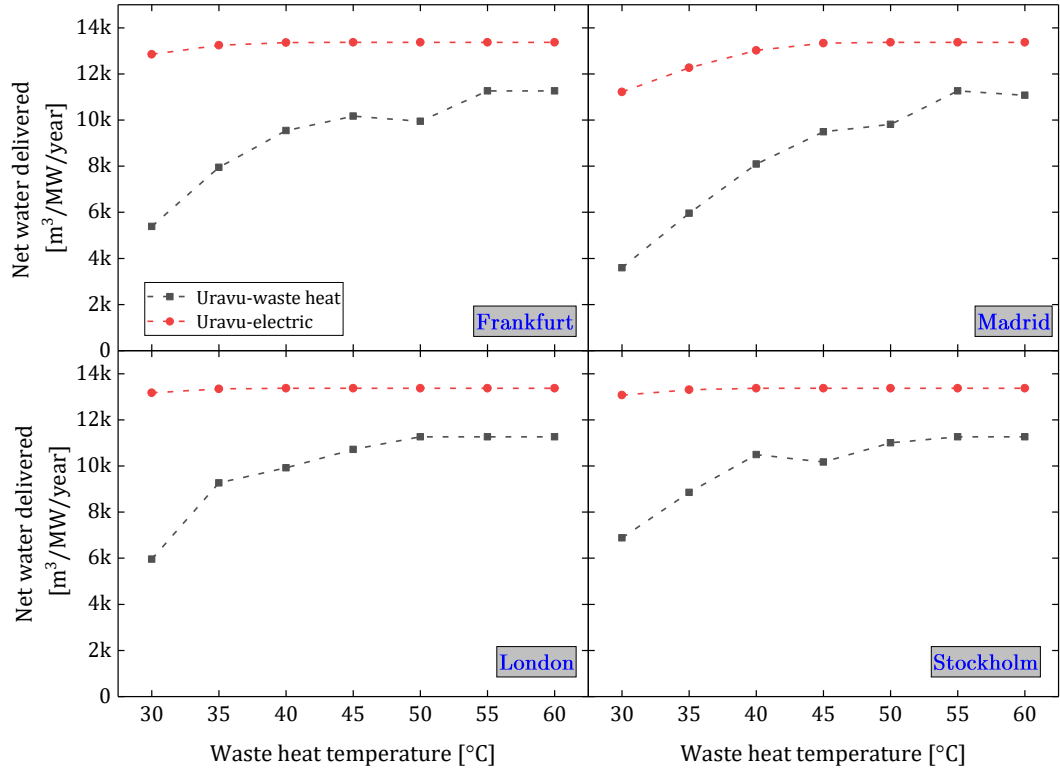


Figure 12: Net water production for different European Union cities at varying waste heat temperatures.

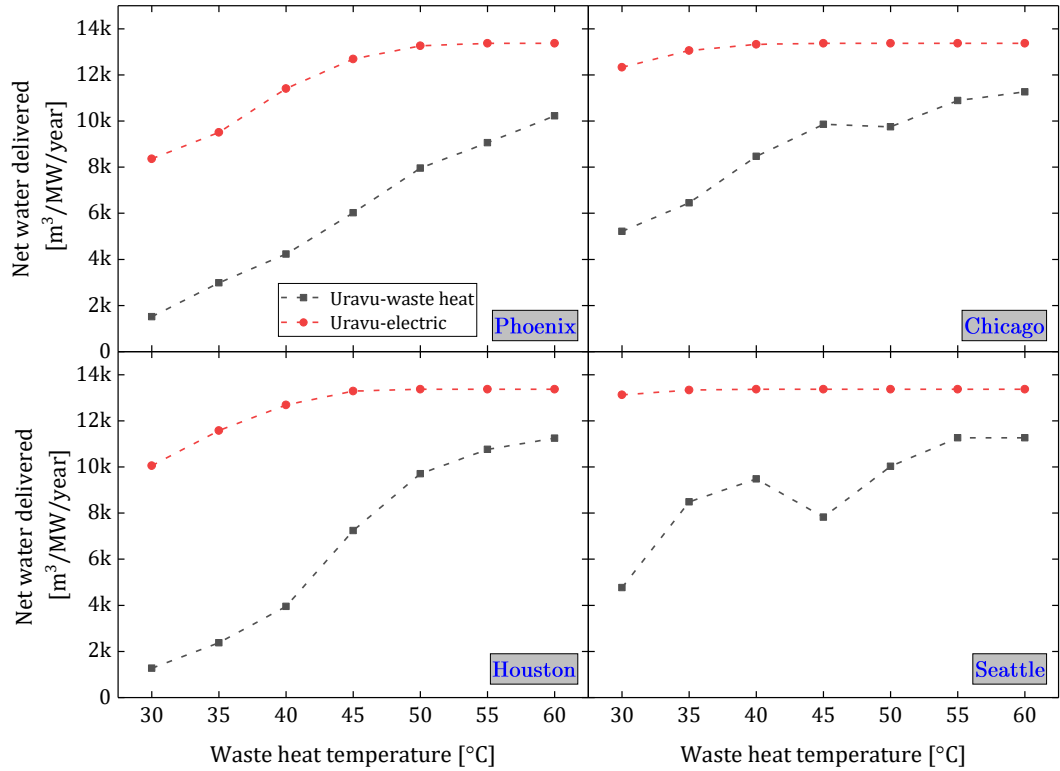


Figure 13: Net water production for different US cities at varying waste heat temperatures.

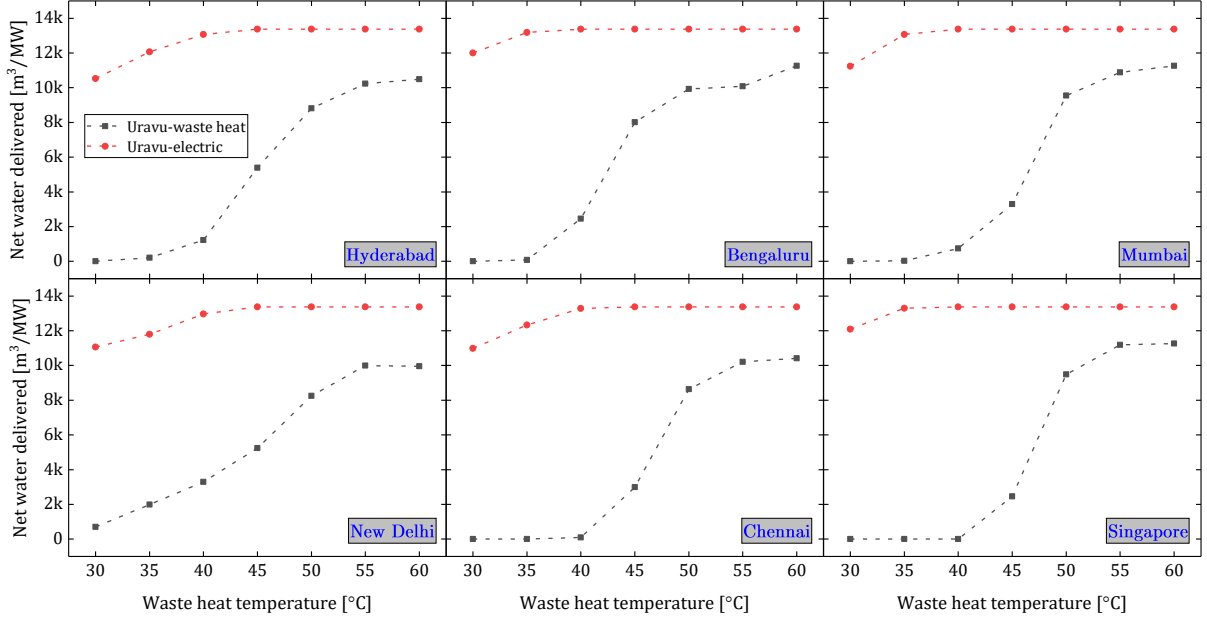


Figure 14: Net water production for different Asian cities at varying waste heat temperatures.

For India and Singapore, water production from low-temperature waste heat is low compared to EU and US cities. A water production of $4000 \text{ m}^3/\text{MW}/\text{year}$ is possible at a waste heat temperature of 40°C , as shown in Figure 14. With the Uravu-electric system, water production values are comparable to those of EU and US cities with the same amount of energy consumption.

3.5.3 Impact on specific energy consumption

The specific energy consumption is a strong function of electricity consumption and net water production. Therefore, in the EU, where net water production remains nearly constant, the SEC trends are also constant for both waste heat and Uravu-electric configurations, as shown in Figure 15. The Uravu-electric configuration yields a value three times higher than the waste heat configuration, with the maximum value being close to $250 \text{ kWh}/\text{m}^3$, due to increased electricity consumption, as discussed in Section 3.4.

Whereas, in the US, the SEC values become constant after 45°C due to variations in uptime and net water production, as reported in Sections 3.5.1 and 3.5.2. For Uravu-electric configurations, due to increased water consumption in IEC at low waste heat temperatures, the SEC values rise to $320 \text{ kWh}/\text{m}^3$ and $250 \text{ kWh}/\text{m}^3$ for Phoenix and Houston, respectively, and reduces to $200 \text{ kWh}/\text{m}^3$ after 45°C . For Chicago and Seattle, it results in a constant SEC value of $200 \text{ kWh}/\text{m}^3$ at all waste heat temperatures. Similar trends can be observed for the waste heat-driven configuration with a lower SEC value ranging from 150 to $50 \text{ kWh}/\text{m}^3$, as shown in Figure 16.

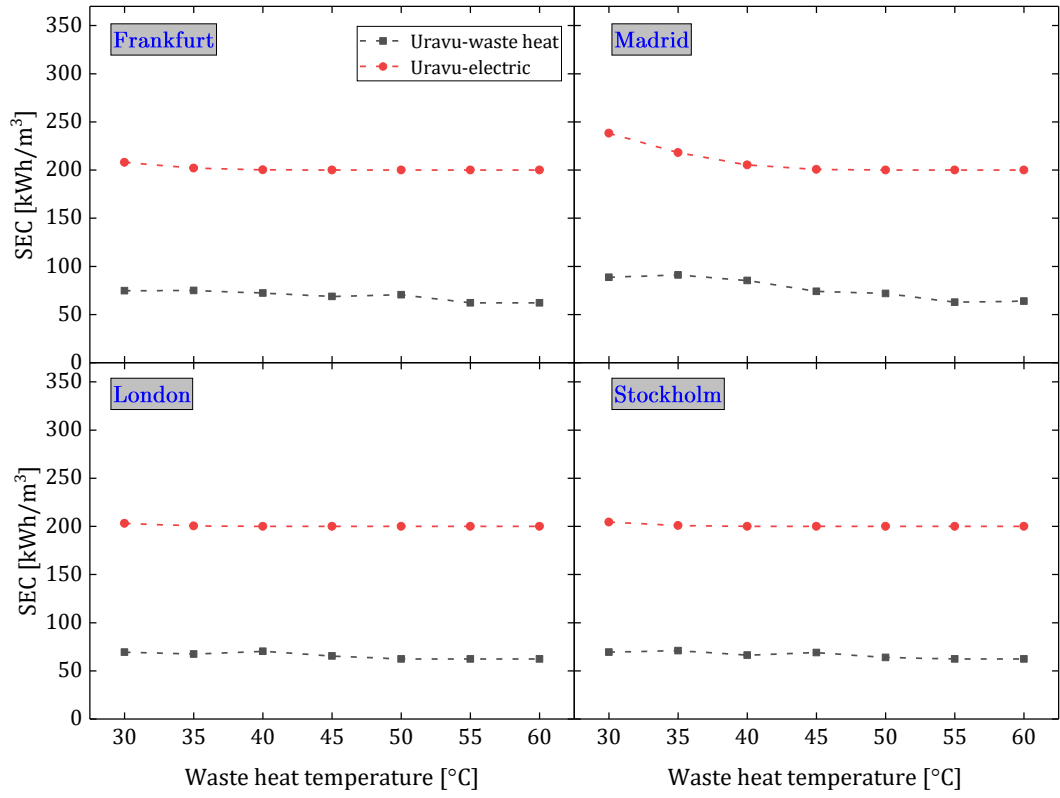


Figure 15: Specific energy consumption for different European Union cities at varying waste heat temperatures.

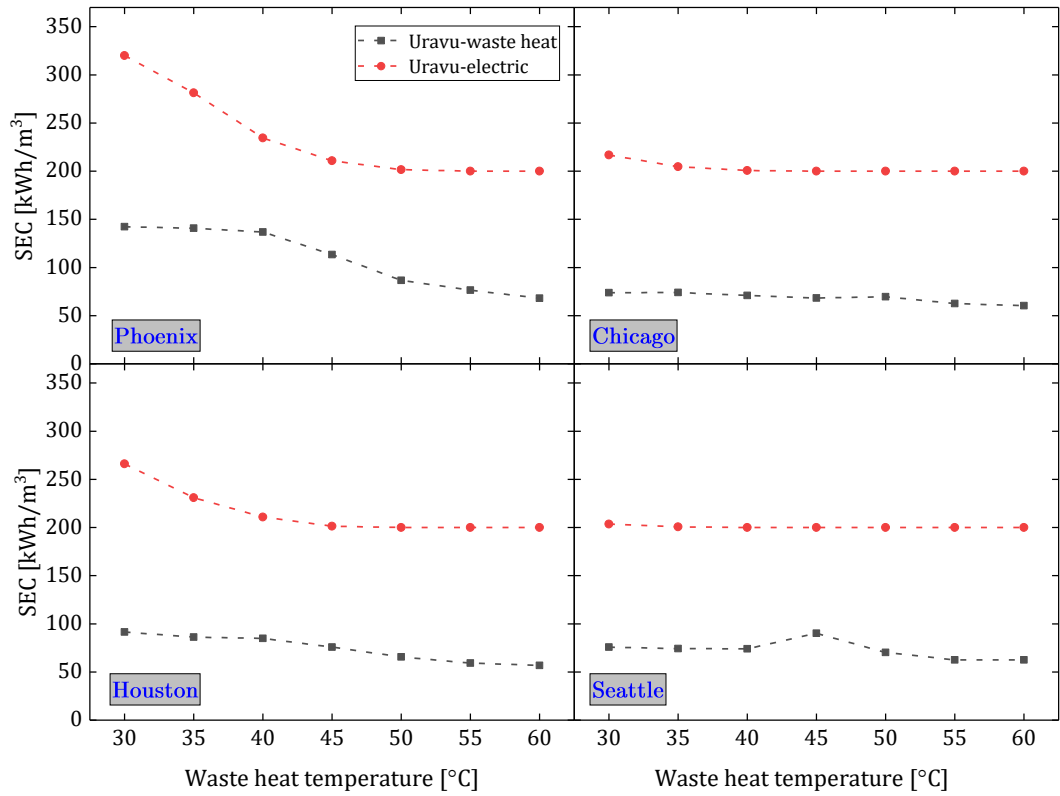


Figure 16: Specific energy consumption for different US cities at varying waste heat temperatures.

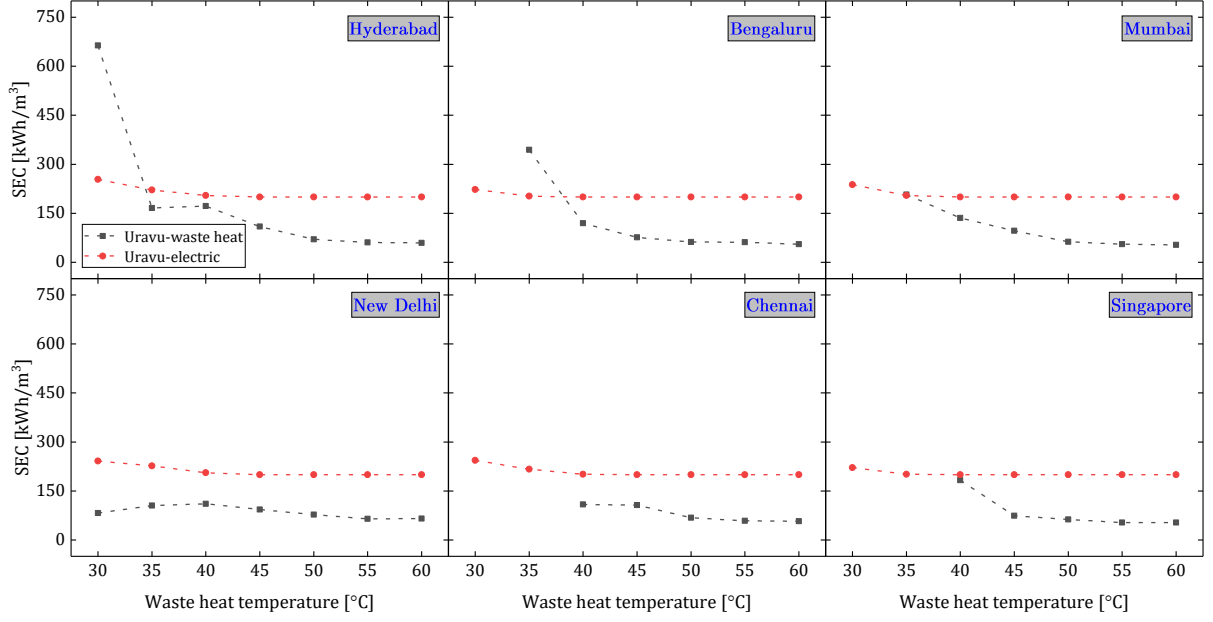


Figure 17: Specific energy consumption for different Asian cities at varying waste heat temperatures.

For India and Singapore, with the Uravu-waste heat system at low temperatures, there is negligible to zero water production in most cities due to low-temperature waste heat, leading to high SEC values at these temperatures. At temperatures exceeding 40°C, the SEC values decrease from 180 kWh/m³ to 55 kWh/m³, as shown in Figure 17. With the Uravu-electric system, the SEC values are comparable to those of EU and US cities, ranging from 200 to 300 kWh/m³.

4. Preliminary risk assessment

Potential risk and reliability factors have been identified for the data center cooling operations using the Uravu system, and are reported in Table 2 and Table 3, respectively.

Table 2: Potential risk identification and mitigation measures

Aspect	Risk/impact	Mitigation strategy
Thermal integration	Change in IT load and slow response from the thermal system	Use of thermal buffer tanks, adaptive thermal controls, and secondary cooling loops
Environmental condition	Seasonal variation affecting the water yield	Hybrid operation with a bypass loop to the chiller for continuous cooling
Cooling loop pressure drops	Additional piping and heat exchangers may increase	Optimize HX sizing, parallel flow arrangement,

	the pressure drop, which can affect the flow rates and return temperature	and install VFD-controlled pumps.
System redundancy	Failure of the key heat exchanger or piping in the AWH unit can affect the cooling performance	Adding one additional redundant key equipment with separate valves and controls during failure

Table 3: Scalability assessment with reliability concerns and measures

Scaling factor	Impact	Reliability concerns	Measures
Efficiency improvement	Better waste heat utilization	Uneven waste heat load on the module	Flow balancing with appropriate sensors
Installation complexity	Higher footprint area and coordination are needed	Commissioning delays	Modular fabrications
Monitoring complexity	More parameters and equipment to track	Risk of undetected localized error or fault	Predictive maintenance

5. Concluding remarks

Considering the varying geographical and climatic conditions, the following insights summarize the performance of the Uravu integrated system for data center cooling:

- **European Union:** Due to relatively uniform weather conditions across the region,
 - The chiller load can be reduced by **40–60%** in a fully Uravu-waste heat system for **low-temperature waste heat**, and by **100%** in a **Uravu-electric system** for both low-and high-temperature waste heat.
 - Water production ranges from **4,000 to 10,000 m³/MW/year** for the **low-temperature waste heat** configuration and reaches **13,000 m³/MW/year** in the Uravu-electric configuration.
 - Specific energy consumption (SEC) varies between **60 and 100 kWh/m³** for the Uravu waste heat system and between **200 and 250 kWh/m³** for the Uravu electric system.
- **United States:** Due to diverse climatic conditions across regions, system performance exhibits more variability,

- Chiller load reduction ranges from **20% to 100%** for Uravu waste heat systems and **70% to 100%** for Uravu electric configurations.
- Water production ranges from **2,000 to 10,000 m³/MW/year** for Uravu waste heat configurations and from **8,000 to 13,400 m³/MW/year** for Uravu electric systems.
- SEC values range from **60 to 100 kWh/m³** for Uravu waste heat operation and **200 to 320 kWh/m³** for Uravu electric operation.
- **India and Singapore:** Due to high ambient and wet bulb temperatures:
 - The Uravu waste heat unit experiences high downtime **at low-temperature waste heat**, resulting in a **negligible reduction in chiller load**. At **high temperatures**, the waste heat chiller load can be reduced by **up to 100%**.
 - Water production is almost **zero at low-temperature waste heat**, which increases **up to 10000 m³/MW/year** at **high-temperature waste heat** for the Uravu-waste heat system. For Uravu-electric, water production remains significantly higher, ranging from **11,000 to 13,400 m³/MW/year** at all temperatures.
 - Specific energy consumption falls within the **same range (55 to 100 kWh/m³) as that of EU and US cities**, for **high-temperature waste heat** in the Uravu waste heat system.