15TH IEA HEAT PUMP CONFERENCE
MAY 26–29, 2026 | HOFBURG
VIENNA 2026
DECARBONISATION THROUGH INNOVATION

# Revolutionizing Multifamily Buildings: Integrating ccASHP and mCHP for Immediate Emissions Reductions

Jason LaFleur[a], Alejandro Guada[a]

[a] GTI Energy, 1700 S. Mount Prospect Rd., Des Plaines, IL 60018 U.S.A.

**Abstractal**

The integration of cold-climate air-source heat pumps (ccASHP) and a micro-combined heat and power (mCHP) system can be used to create a microgrid for multifamily buildings that delivers immediate emissions reductions today using off-the-shelf technologies in a novel configuration. A research project demonstrated the performance of this integrated system in consumption, installation cost, and reducing greenhouse gas (GHG) emissions.

The integrated microgrid was developed and tested in a laboratory environment, incorporating commercially available ccASHPs and a 24 kW mCHP system. The system was designed to operate in a simulated 4-unit multifamily building environment, with load-based testing. The heat from the mCHP was used to assist the ccASHP during times of defrost and allowed for simultaneous heating, which significantly reduced the electric loads and equipment costs.

Key findings from the study include a 27% reduction in electric loads using waste heat from the mCHP and a 47% reduction in GHG emissions for electrified multifamily HVAC and water heating systems with on-site power generation. The integrated system demonstrated an average coefficient of performance (COP) of 1.5, indicating high efficiency in its operation. Additionally, the system achieved GHG emission rates that were 25% lower than the local regional transmission organization's marginal operating emission rates.

The study highlights the potential of integrated energy systems, such as the combination of ccASHPs and mCHP, to provide a pathway for decarbonizing the residential sector. The results suggest that such systems can offer significant environmental and economic benefits, making them a viable solution for achieving sustainability targets in multifamily buildings. This research contributes to the growing body of knowledge on integrated energy systems with off-the-shelf technology can achieve emission rates below predicted future grid levels, providing a viable pathway to deep decarbonization in multifamily buildings.



*Keywords: microgrid; cogeneration; cold climate heat pumps; air source heat pumps; micro combined heat and power; mCHP ;*

## 1. Introduction

With today's energy challenges and targets such as a 50% reduction of end-use carbon footprint, researchers have developed holistic approaches to multi-system integration, including fuel-switching, energy storage, and on-site power generation with renewable energy features. Thermal and Power Microgrids (TPM) bundle space conditioning (heating, ventilation and air conditioning – HVAC), water heating (WH), on-site power generation and thermal storage into a single microgrid that can balance supply and demand within a building while interfacing responsibly with the larger utility network. At the nano- and micro-scales these TPMs have demonstrated annual overall efficiencies in excess of 100% on a high-heating value basis, improve operating costs and minimize emissions when properly designed and integrated. The building sector contributes about 40% of the global energy consumption and over 30% of $CO_2$ emissions [1] and is projected to rise by 50% in 2050 [2], with HVAC as the primary energy used in the building sector.

Carbon emissions can be reduced by up to 12% when micro combined heat and power (mCHP) is coupled with high thermal loads [3]. Prior work showed that single-family nanogrid installations combining mCHP, air-source heat pumps (ASHP) and battery energy storage (BESS) can achieve nanogrid annual HVAC & WH efficiencies greater than 110% in cold climates and reduce greenhouse gas emissions to less than half of the U.S. average. However its applicability in multifamily buildings needs further exploration.

Microgrids can serve multiple dwelling units operated with a centralized system and better energy management relative to oversized nanogrid systems. As integrated energy systems, they can provide low operating costs and reduce the carbon footprint of end-use loads relative to advanced single-fuel technologies in multi-family buildings, which represent nearly 25% of residential buildings.

The multifamily sector presents its own set of challenges: natural gas utilization is declining relative to electricity, yet in regions of the U.S.A such as the Northeast and Midwest gas still supplies more than 60% of the HVAC & WH energy. Decentralized HVAC & WH appliances dominate the landscape (> 80% of units), and while space conditioning is readily electrifiable via ASHPs, water heating remains a technical and economic challenge given high costs and operating temperature requirements [4].TPMs in multi-family buildings offer benefits such as improved cold-climate performance, installer expertise with heat pump and micro CHP systems, lower operating costs and emissions, and support for grid demand management. This study expands the nanogrid approach to a multifamily setting by integrating multiple ccASHPs with a shared mCHP hydronic loop, developing control algorithms for balancing power and heat generation, and testing under realistic cold-weather conditions. The main research question is whether a microgrid with mCHP, ccASHPs, and storage can deliver high efficiency, meet space and water conditioning needs, reduce GHG emissions compared to traditional systems, and provide resilient operation on or off-grid. The demonstration aimed for over 100% efficiency, at least a 30% cut in GHGs, and strong energy resilience.

## 2. Methods/Approach

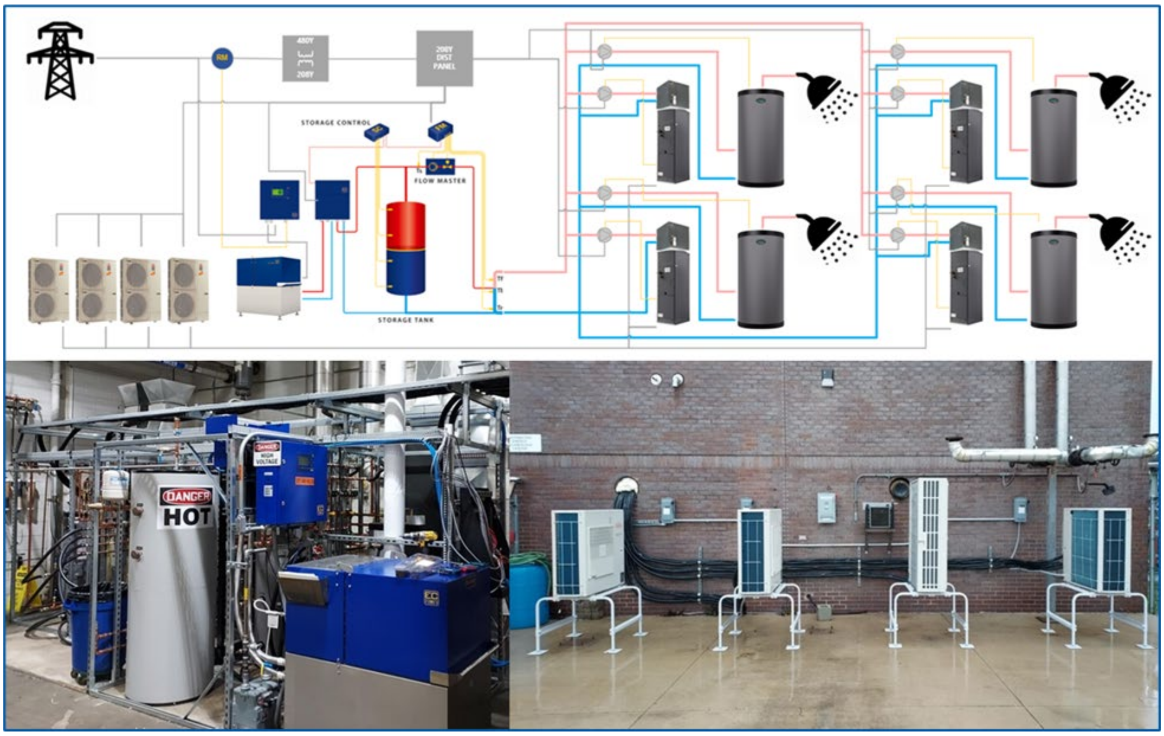


Figure 1. Thermal and power microgrid system architecture (top), outdoor cold climate air source heat pumps (bottom, right), and indoor system components including the mCHP unit (bottom, left).

### Experimental configuration

Figure 1 illustrates the experimental microgrid at GTI Energy’s lab. The setup centers around a mCHP unit (24 kW electrical/163 kBtu/h thermal output; ~28% electrical and up to 85% total efficiency, HHV). The testbed also includes four ducted ccASHPs (delivering up to 36 kBtu/h at -5 °F OAT; HSPF up to 11; SEER up to 18; 410a-refrigerant; 5: turndown ratio), indirect storage tanks, hot-water coils, and a custom controller. A 13 kW PV array with power optimizers and two dual-pole level-2 EV charging stations simulate multi-family building loads. Instrumentation incorporates current and voltage sensors, flow meters, thermocouples, distributed air/refrigerant sensing, and a calorimetric rig for load simulation.

The mCHP operates in load-following mode, adjusting output based on demand, while the controller manages system components—such as ASHP activation, flow modulation, and buffer tank state—to maintain water temperature between 120–140 °F. Simulated heating/cooling and water loads represent four 1,600 ft² townhouses (Building America 2010, IECC zone 5), applied via programmable heat exchangers. Net power usage, including parasitic losses, heat outputs, COP, total efficiency, and GHG emissions (using PJM MOER data) were all measured or calculated as part of the assessment.

**Thermal Power Microgrid Operation Sequence**

Several factors were considered to properly integrate these microgrid components without a microgrid controller, including prioritizing renewable power over mCHP power generation over grid power and HVAC and water heating load operation.

Power Cascade. In order to prioritize solar power generation when installed in an AC-coupled fashion, the mCHP power generation needed to be modulated to serve as a demand response mode device. The mCHP was configured to operate on a load-following basis using a third-party power meter. This power meter was installed upstream in the load center, feeding the simulated multi-family loads.

mCHP Thermal Operation. The mCHP was configured to deliver 180 °F (82 °C) and keep the 119 gallon (450 liter) buffer tank at its minimum of 25% capacity. Given that the mCHP is this microgrid's only water heating source, it will start to produce power and heat at its lowest capacity to heat up the tank while exporting power to the grid.

Simultaneous Heating. The TPM used waste heat to supplement heat pump operations. When the ccASHPs respond to simulated heating loads, single-speed pumps are activated to move hot water from the 119-gal (450 L) tank to its corresponding hot-water coil. That way, heat generation as a function of the power demand of this ccASHP operation will result in a much more efficient process, as described in Figure 2. For example, up to 15% more efficient processes can be achieved when implementing an internal combustion engine (IEC) mCHP to power a ccASHP and combine the cogeneration heat with the ccASHP heating output when operating at 15 °F (-9.4°C) OAT. The hydronic coils from the TPM also helped the ccASHP with shorter defrost cycles and limited use of electric resistant backup heating

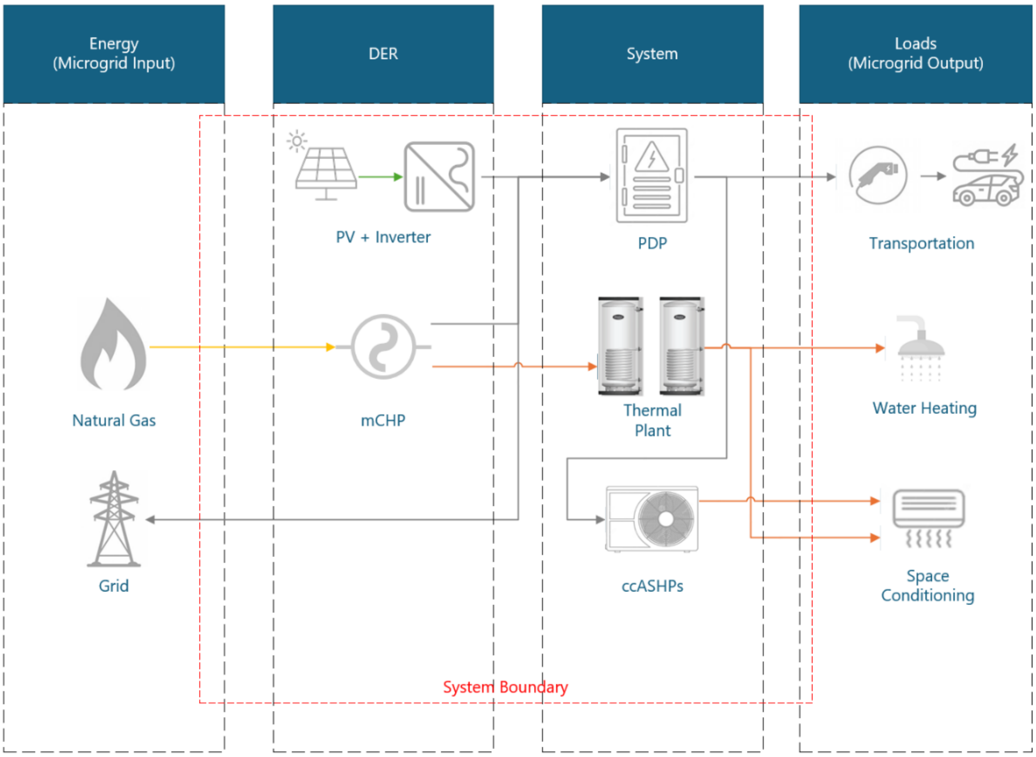


Figure 2: System boundary of the microgrid.

## 3. Results and Discussion

The TPM testing campaign provided several instructive insights into grid-tied performance, efficiency, emissions, resilience and practical operation. These findings encompass hourly thermal and power operations, demonstrate how electric load is reduced compared to a fully electrified building without a microgrid, and detail the microgrid's performance and GHG emissions during both cooling and heating seasons.

Technical Approach

The microgrid sub-components were commissioned per the manufacturer specifications and rating operating conditions by the direct measurements of energy streams and calculating steady state performance of each equipment (mCHP, 4 ccASHPs and 4 indirect storage tanks). Followed to its commissioning, the method of evaluation was based on load-based approach, where simulated hourly space and water heating loads were controlled by hardware-in-the-loop approach. The water heating schedule was based on a recurrent weekly water heating load schedule based on EnergyPlus outputs for residential dwell that ranges between 20- to 150-gallons a day. Using calibrated solenoid valve tree (similar to the one used in the UEF method of test), water was drawn while aquastat configured to 120 °F setpoint engaged circulators for recovery purposes. The space heat load, on the other hand, were managed by the ccASHP thermostat heating a zone of the laboratory with a peak heating load of 205 kBtu at peak conditions of 4.5 °F. When ccASHPs experienced heating calls, the supplemental heating zone was triggered actuating circulators topping off the ccASHP heating output with an additional of 40 kBtu/h using a hot-water coil installed upstream of the ccASHP's AHU. While following heating load, the ccASHP modulate making the mCHP while following power load.

With the research goal to measure daily energy accounting, total system efficiency and greenhouse gas generation, the energy input and output where measured at the system boundary and the electric grid emissions were obtained by WattTime, a real-time marginal operating emission rate provider [4]. The condense instrumentation accuracy and calculation uncertainty are listed in Table 1. Using the system boundary shown in Figure 3, the energy stream were calculated and used to estimate daily COP and greenhouse gas emissions rates. The daily COP efficiencies were computed across all net output (space conditioning, water heating, EV charging and export power) over the energy inputs (grid power and natural consumption). The daily greenhouse gas emissions rates were computed with the net carbon generation of grid and mCHP operation, over the net output.

Table 1: Measurements and Calculation Uncertainties.

| Category | Variable | Accuracy/Uncertainty |
|---|---|---|
| **Measurements** | Temperatures | ± 1.8 °F |
| | Relative humidity | ± 2% of reading |
| | Water flow, electrical energy | ± 1% of reading |
| | Gas flow | ± 0.5% of reading |
| | Gas pressure, velocity pressure | ± 0.5% of full-scale |
| | Heating value | ± 1.5% of reading |
| **Calculation** | Gas firing rate | ± 3.0% |
| | Water heating output | ± 7.0% |
| | Space heating output | ± 11.3% |
| | Space cooling output | ± 12.5% |
| | Gas emissions, lbm | ± 4% |
| | Emissions rate, lbm/MWh | ± 7.4% |
| | COP | ± 8.3% |
| | Airflow | ± 4.1% |
| | Electricity emissions | Methodology+Validation - WattTime |

Hourly Thermal and Power Production

Integrating electrical systems was essential because no microgrid controller was used; balancing the 480Y three-phase (3ph) mCHP generation (three legs, one neutral at 277 VAC hot-to-neutral and 480 VAC hot-to-hot) with single-phase (1ph) HVAC & WH equipment was key. On an hourly basis, grid power consumption and export occurred across individual phases of the 3ph connection. Although mCHP produced ample power, some grid power consumption during the heating season persisted.

Hourly Power Profile During the Heating Season.

Thermal and power demands within the microgrid occasionally led to less efficient operational conditions. For example, if the buffer tank was full while ccASHPs operated on grid power and ISTs provided heat but no space heating load was present, excess power would be exported.

Electric Load Reduction Comparison

The TPM's daily electricity requirements were compared and GHG emissions to those of a simulated advanced electric system, modelled after commercially available systems in the U.S., using performance metrics from prior research. Key findings include: 1) the microgrid lowers grid power usage and exports surplus power, which can support plug loads or be fed back into the grid, 2) HVAC & WH electric loads are 27% lower when mCHP is used alongside heat generation for space and water heating, 3) both grid consumption and electricity export varied each hour, 4) mCHP operating in load-following mode helped reduce excess power generation—a consideration for certain grid interconnection agreements—and base loading the electricity needed for HVAC & WH by 42%, 5) battery energy storage systems (BESS) can address excess power concerns, and 6) advanced electric systems included an 11 HSPF ccASHP and a 3.5 UEF electric heat pump water heater (EHPWH).

Performance and GHG Emissions Assessment

Figure 3 presents daily system coefficient of performance (COP) and GHG emissions relative to daily HVAC & WH load, with the inclusion of 13 kW of onsite PV generation. The microgrid's performance depends on both load and outside air temperature (OAT). Average system COPs were 1.5 for heating and 4.0 for cooling. GHG emissions closely tracked HVAC and water heating loads, averaging below 25% of the local

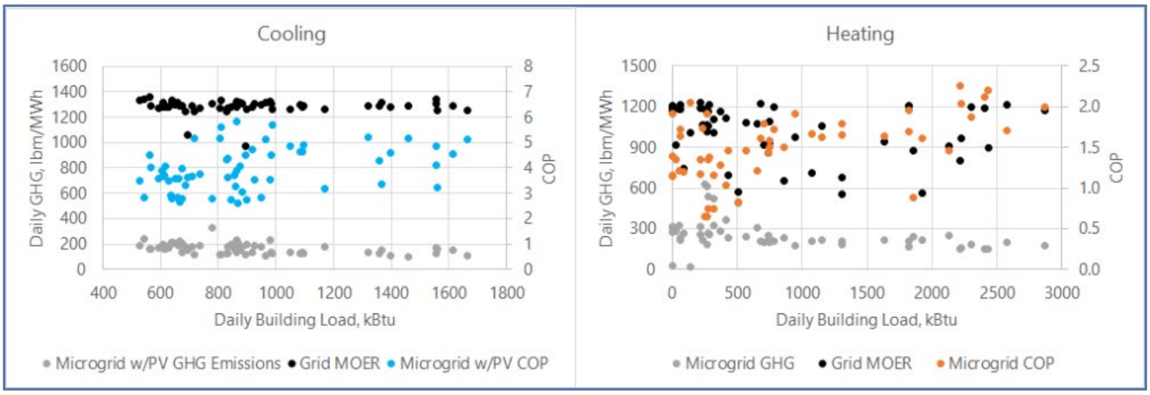


Figure 3: GHG Emissions and Performance (COP) during the Cooling season (left) and Heating season (right)

grid transmission region's marginal operating emission rates (MOER). (1 lb/MWh = 0.45 kG/MWh). The grid GHG emissions rated were collected hourly via WattTime's API.

The microgrid generated about 22% less GHG compared to advanced electric systems during the heating season. These findings suggest integrated energy systems may help achieve decarbonization goals by 2050. The testing campaign under mild heating loads yielded several instructive observations regarding grid-tied performance, efficiency, emissions, resilience and practical operation summarized below.

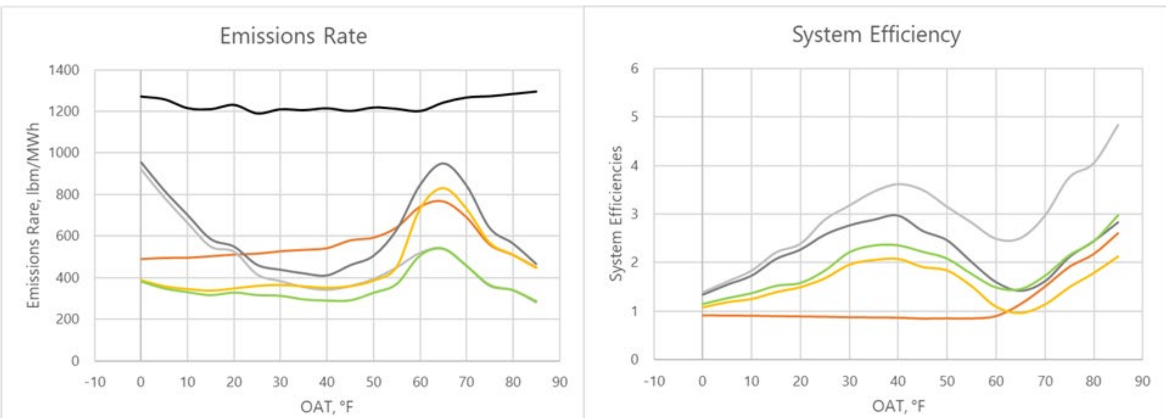


Figure 3: Modelled performance relative to other baselines.

- **Grid–Tied Performance:** Reduced grid power consumption for space and water heating by approximately 27% relative to separate ccASHPs + separate boiler arrangements; excess power export occasionally observed indicating potential for BESS integration.
- **Energy Utilization and Efficiency:** Average system COP defined by the system boundary of 1.5 during demonstration, confirming that heat pumps contribute more heat than the electrical energy they consume; overall efficiency comfortably above 100% HHV when mCHP heat is included.
- **GHG Emission Reduction:** The TPM delivered approximately 22% lower GHG emissions compared to a benchmark advanced electric system (11 HSPF ccASHP + 3.5 UEF EHPWH) during shoulder season conditions; negative emissions at times when exported energy displaces higher-carbon grid generation.
- **Off–Grid Feasibility:** Operation off the grid is feasible with a black-start capable mCHP; for non–black-start mCHP, a BESS is required for synchronization during outages.
- **Operational Practicalities:** Successful load following and ccASHP orchestration; domestic hot water buffer and storage was maintained via Aquastats; with occasional need for auxiliary heater actuation when loads are dominated by space heating; challenges arise when combined loads drop below mCHP minimum turn-down, requiring additional heat rejection strategies.

**Baseline Comparison:** building energy models were developed upon the microgrid results and compared to calibrated models of other baseline performance summarized in Figure 4. From the emissions perspective, the microgrid with and without PV integration resulted in the lowest application relative to MOER implemented on this model. With different MOER, results might vary. The resulting efficiencies of the models are shown in Figure 4.

Thermal power microgrids leveraging air source heat pumps and water heating can be coupled with distributed energy resources and storage. TPM demonstrations in multi-family buildings show reduced emissions and operational costs, increased resilience, and support for self-powered HVAC, water heating, and EV charging. Despite a limited evaluation period, results indicate the technology produces less than 25% of greenhouse gas emissions per unit output compared to local marginal rates and leading electric heat pumps. Grid power use can be cut with mCHP tailored to demand, reaching high performance levels. Off-the-shelf systems already outperform projected 2050 grid emissions, and battery storage or fuel cell upgrades could further improve efficiency. As heat pump and EV adoption grows, TPMs can enhance grid stability and facilitate the shift to electric-driven technologies, especially in colder regions. Including mCHPs in new plug-and-play microgrids may boost reliability and efficiency. This research highlights benefits of pairing mCHPs with battery storage for stakeholders.

**Acknowledgements**

The authors would like to acknowledge the financial and technical support in this study, along with ongoing TPM development and research provided by Utilization Technology Development [7].

**References**

[1] Yang, L. Y. (2014). Thermal Comfort and Building Energy Consumption Implications. Appl. Energy.
[2] IEA. (2013). Directorate of Sustainable Energy Polity. Transition to sustainable buildings: strategies and opportunities to 2050.
[3] Curl, C. R., & Fronk, B. M. (2025). Assessing the emissions reduction potential and economic feasibility of small-scale (<100 kWe) combined heat and power systems with thermal storage for multi-family residential applications in the United States. *Science and Technology for the Built Environment*, *31*(2), 174–193. https://doi.org/10.1080/23744731.2024.2394361
[4] U.S. Environmental Protection Agency (EPA). (2019). *Opportunities for Combined Heat and Power (CHP) in the Multifamily Sector.* Climate Protection Partnerships Division..
[5] Hendron, R., Engebrecht, C. 2010. *Building America Research Benchmark Definition: Updated December 2009*. Golden, Colorado: National Renewable Energy Laboratory; 2010, Technical Report NREL/TP-550-47246. Available at: https://docs.nrel.gov/docs/fy10osti/47246.pdf
Strunk Jr W, White EB. *The elements of style*. 3rd ed. New York: Macmillan; 1979.
[6] WattTime. (2023). Home. WattTime. https://www.watttime.org.
[7] UTD (Utilization Technology Development), 2023.