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Data Center Waste Heat as an Emerging Urban Thermal Hazard: First Field Measurements of Neighborhood-Scale Air Temperature Impacts

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Data centers are among the fastest-growing sources of concentrated anthropogenic heat in urban environments. Despite heat flux densities that exceed peak solar irradiance by a factor of 2–6, their thermal impacts on adjacent communities have never been directly measured or reported in the peer-reviewed literature. This short communication addresses that gap by presenting the first vehicle-based traverse measurements of air temperature in residential neighborhoods downwind of operational data centers. Five traverses at four facilities in the Phoenix, Arizona metropolitan area, ranging from a 36 MW single-building data center in Mesa to a 169 MW colocation campus in Chandler, reveal downwind air temperature warming as high as 2.2 °C, with average downwind air temperatures 0.7–0.9 °C warmer than corresponding upwind areas. Thermal signatures were detectable at distances up to 500 m from facility perimeters. The 36 MW Mesa facility rejects waste heat equivalent to the electricity consumption of approximately 40,000 households, while the 169 MW Chandler campus is equivalent to over 180,000 households, both concentrated into footprints smaller than a single residential subdivision. With U.S. data center capacity projected to more than double by 2030, these findings establish data center anthropogenic waste heat as a previously undocumented urban thermal hazard demanding attention from the data center and urban planning communities. [DOI: 10.1115/1.4071922]

Keywords: data centers, anthropogenic heat, urban heat island, vehicle traverse, thermal plume, Phoenix, building energy, cooling, environment, heat transfer, measurement

1 Introduction

Anthropogenic heat (Q_f) is the thermal energy released into the environment by human activities—principally fuel combustion, industrial processes, and building heating and cooling systems [1]. In cities, Q_f compounds the urban heat island effect, with citywide fluxes in major United States metropolitan areas typically ranging from 10 to 75 W/m^2 [2–5]. The existing literature documents temperature elevations of 0.5–3.0 °C associated with urban anthropogenic heat fluxes, with an estimated air temperature sensitivity of approximately 1 °C for each 100 W/m^2 [6] at the neighborhood scale. However, data centers generate heat fluxes of thousands of W/m^2, far exceeding any previously studied urban source.

The data center industry is expanding at an unprecedented rate. Global electricity consumption by data centers reached approximately 415 TW h in 2024, about 1.5% of worldwide electricity demand, and is projected to double to 945 TW h by 2030 [7]. The United States data center infrastructure consumed 183 TW h in 2024, over 4% of national electricity, with more than 5000 facilities nationwide [8,9]. The Phoenix, Arizona metropolitan area, is among the fastest-growing hyperscale markets, hosting facilities by NTT, CyrusOne, EdgeCore, Iron Mountain, Stream, and Apple, with hundreds of megawatts of operational capacity and thousands more proposed [10].

For example, the NTT PH1 facility measured in this study has a 36 MW critical IT load housed within 11,700 m^2 of floor space in a two-story building [11]. Because newer data centers in Phoenix generally rely on sensible air-based cooling, virtually all electrical energy consumed by Information Technology (IT) equipment is ultimately converted to sensible heat; this yields a heat rejection density of approximately 3100 W/m^2, exceeding peak solar irradiance (~1000 W/m^2) by a factor of three, concentrated near the ground level. For context, the average U.S. household consumes ~10,500 kW h/year, an average draw of ~1.2 kW (electricity only) [12]. A single 36 MW data center with a power usage effectiveness (PUE) of ~1.3 [13], drawing ~47 MW in total, therefore rejects heat equivalent to that emitted by approximately 40,000 households. The CyrusOne colocation campus in Chandler (PHX1–PHX8), another site measured in this study, comprises eight facilities totaling 186,000 m^2 with 169 MW of critical IT capacity [14]; at the same industry-average PUE, the campus draws approximately 220 MW in total, rejecting heat equivalent to over 180,000 households from a single 34-ha site.

Despite this extraordinary thermal footprint, the localized air temperature impacts of data center waste heat on surrounding communities have never been directly measured or reported in the peer-reviewed literature. This gap is significant because many facilities are sited adjacent to residential neighborhoods (Fig. 1), and their air-cooled condenser arrays discharge air at temperatures 8–14 °C above ambient—often exceeding 50 °C during Phoenix summers—with air velocities of 2–4 m/s [15,16], creating thermal plumes that are advected downwind over inhabited areas. For example, the Iron Mountain Data Center (Fig. 1(*c*)) has

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(c) 4802 E Van Buren St, Phoenix, AZ 85008

(d) 7805 Ellis St, Chandler, AZ 85286

Fig. 1 Aerial imagery of four data center sites in the Phoenix metropolitan area, each situated adjacent to residential neighborhoods: (*a*) Apple Data Center, Mesa; (*b*) NTT PH1 Datacenter, Mesa; (c) Iron Mountain Data Centers (AZP-2), Phoenix; and (*d*) CyrusOne Price Road Tech Corridor (PHX1–PHX8), Chandler. The proximity of rooftop cooling infrastructure to surrounding communities illustrates the potential for thermal plume dispersion into residential areas

cooling equipment located less than 50 m from the nearest three-story apartment building.

The specific contributions of this short communication are (1) we present the first field measurements of air temperature elevations in residential neighborhoods attributed to data center waste heat rejection; (2) we quantify the magnitude (as much as 2.2 °C, with averages of 0.7–0.9 °C) and spatial extent (>250 m) of these thermal impacts at four facilities; and (3) we contextualize data center heat flux relative to other urban anthropogenic heat sources, establishing it as a previously unrecognized dimension of the urban heat challenge that is relevant to building energy, thermal comfort, and public health.

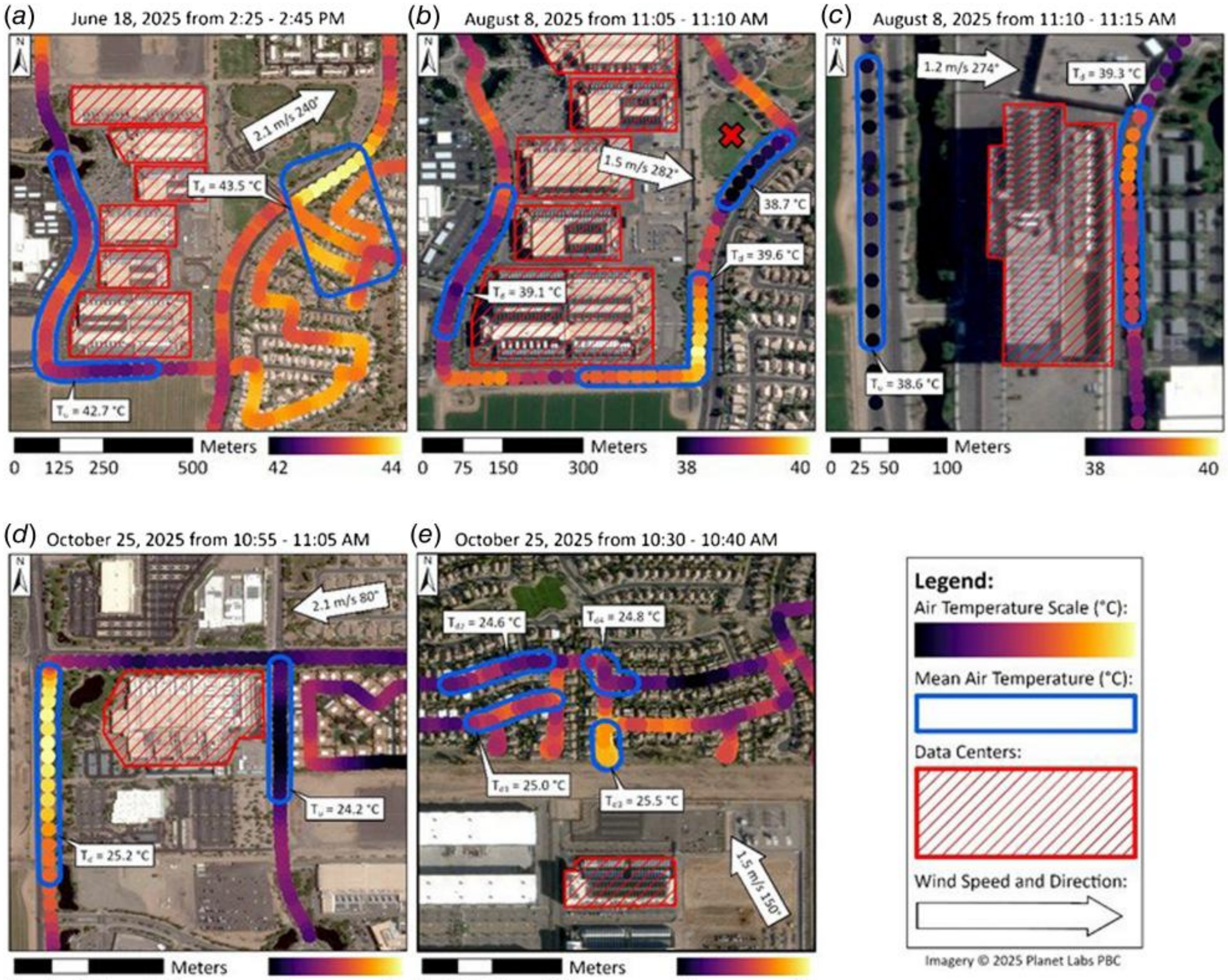
2 Methods

Vehicle-based traverses using established instrumentation and techniques [17–19] were conducted at four data center sites in the Phoenix metropolitan area. The first is the CyrusOne colocation complex (PHX1–PHX8) along the Price Road Technology Corridor in Chandler, Arizona, featuring dense rooftop condenser fan arrays located 130–150 m from the nearest residential neighborhood. The second and third sites, Aligned and Digital Realty, are also located along the Price Road Technology Corridor in Chandler, each situated adjacent to residential neighborhoods. The fourth is the NTT PH1 data center in Mesa (10256 Elliot Rd.), with 36 MW critical IT load across 11,706 m^2 of floor space, using air-cooled chillers with airside economizers [11]. NTT PH1 sits immediately south of the Santa Rita Ranch residential neighborhood, separated by 200 m of undeveloped land. These four data centers are highly representative of modern, hyperscale data center infrastructure. Together, they reflect the industry's shift toward massive multibuilding campuses with primarily air-based cooling systems.

Air temperature was measured using vehicle-mounted, aspirated, and shielded precision 4-wire Resistance Temperature Detectors (RTD with accuracy of 0.1 °C; time constant <3 s) sensors at 1.6–2.2 m height and a data logginging Global Position System (GPS) recorder (∼2.5 m circular error probability), both logging at 2-s intervals. These instruments were mounted on multiple vehicles, which simultaneously drove on public roadways adjacent to data centers and throughout nearby neighborhoods. Measurements were obtained using established mobile urban temperature sensing protocols [18,20,21]. Thermal assessments upwind and downwind of data centers relied on averages of large areas (in each case representing >10 datum points) such that locational uncertainty and sensor time lags were not consequential. Wind speed and direction data were obtained from the Chandler Municipal Airport (KCHD) NWS station for the June 18 CyrusOne and October 25 Digital Realty traverses, from a portable weather station positioned near the facility perimeters for the August 8 CyrusOne and Aligned traverses, and from the Phoenix–Mesa Gateway Airport (KIWA) NWS station for the NTT PH1 traverse. Multiple traverses were conducted across different dates, times of day, and conditions from June 18 to October 25, 2025.

3 Results

Vehicle-based traverse measurements were conducted at four data center sites across three dates in the Phoenix metropolitan area (Fig. 2). All traverses captured clear thermal gradients that appear to be associated with data center waste heat rejection. The



Imagery © 2025 Planet Labs PBC

Fig. 2 Vehicle-based air temperature traverse results at four data center sites in the Phoenix metropolitan area: (*a*) CyrusOne, Chandler, June 18, 2025 (2:25–2:45 p.m.); (*b*) CyrusOne, Chandler, August 8, 2025 (11:05–11:10 a.m.); (*c*) Aligned, Chandler, August 8, 2025 (11:10–11:15 a.m.); (*d*) Digital Realty, Chandler, October 25, 2025 (10:55–11:05 a.m.); (*e*) NTT, Mesa, October 25, 2025 (10:30–10:40 a.m.). Small filled circles represent 1.6 m air temperature collected every 2 s. Outlined polygons denote the averaging areas for mean air temperature. Hatch-filled polygons indicate data center facilities. Wind speed and direction are shown for each traverse. Basemap imagery: PlanetScope, © Planet Labs PBC [22]

magnitude and spatial extent of warming vary by facility size, cooling system configuration, and meteorological conditions.

3.1 Cyrusone, Chandler.

The CyrusOne colocation campus was measured on two dates. The first traverse (Fig. 2(*a*)), conducted on June 18, 2025 (2:25–2:45 p.m.), captured afternoon conditions with winds from 240 deg (WSW) at 2.1 m/s, advecting the thermal plume toward the residential neighborhoods east and northeast of the campus.

The mean air temperature on the upwind side of the facility was approximately 42.7 °C, increasing to 43.5 °C in the neighborhood near the eastern boundary of the data center campus on the downwind side. The observed ΔT of approximately 0.8 °C extended roughly 500 m downwind.

A second traverse at CyrusOne (Fig. 2(*b*)) on August 8, 2025 (11:05–11:10 a.m.), under winds from 282 deg (WNW) at 1.5 m/s, confirmed the thermal signature under different meteorological conditions. Mean air temperatures of 39.1 °C on the upwind side of the data center increased to 39.6 °C in the downwind residential area to the southeast, yielding a ΔT of 0.5 °C. This traverse also revealed an apparent downwind cooling signal near the northeast boundary of the figure. Upon further investigation, this region of apparent cooling is immediately adjacent to a water detention basin in Chuparosa Park (marked with an X on the figure), situated between the data center and the street upon which downwind measurements were made. Chuparosa Park uses a combination of sprinkler irrigation of sports fields and flood irrigation around treed areas of the park. As a result, it is not surprising that the measurements downwind of the park during summer reveal an apparent cooling relative to the areas upwind of the data center, suggesting a possible mitigation strategy to address the effects of data center waste heat.

3.2 Aligned, Chandler.

On the same morning as the second CyrusOne traverse, measurements were conducted at the Aligned data center in Chandler (Fig. 2(*c*); August 8, 2025, 11:10–11:15 a.m.) under westerly winds (274 deg) at 1.2 m/s. The traverse recorded a mean air temperature of 39.3 °C near the eastern border of the facility, where condenser exhaust is discharged, compared with 38.6 °C in the upwind area to the west, yielding a ΔT of approximately 0.7 °C.

3.3 Digital Realty, Chandler.

A traverse at the Digital Realty facility in Chandler (Fig. 2(*d*); October 25, 2025, 10:55–11:05

Table 1 Ranges and averages of air temperatures (°C) measured in the upwind (T_u) and downwind (T_d) boxes depicted in Fig. 2

	(a)		(b)		(c)		(d)		(e)			
	T_u	T_d	T_u	T_d	T_u	T_d	T_u	T_d	T_{d1}	T_{d2}	T_{d3}	T_{d4}
Min	42.1	42.8	38.8	39.4	38.5	39.2	24	25	24.8	24.4	25.4	24.5
Max	43.4	44.3	39.5	40	38.6	39.5	24.4	25.4	25.3	25	25.8	25.1
Mean	42.7	43.5	39.1	39.6	38.6	39.3	24.2	25.2	25	24.6	25.5	24.8

a.m.) was conducted under winds from 80 deg (ENE) at 2.1 m/s. The traverse revealed elevated mean air temperatures downwind, reaching 25.2 °C, compared with 24.2 °C in the upwind (east) area of the facility. The resulting mean and maximum temperature differences between the upwind and downwind areas were 1.0 °C and ∼2 °C, respectively.

3.4 NTT, Mesa. A traverse at the NTT PH1 facility in Mesa (Fig. 2(*e*); October 25, 2025, 10:30–10:40 a.m.) was conducted under winds from 150 deg (SSE) at 1.5 m/s, placing the Santa Rita Ranch residential neighborhood directly downwind. Mean air temperatures of 25.5 °C and 25.0 °C were recorded near the data center boundary, decreasing to 24.8 °C and 24.6 °C with increasing distance northward (80–100 m) into the neighborhood. The resulting air temperature signal ($\Delta T \approx 0.9$ °C) 300–500 m downwind from the data center is consistent with plume dilution and vertical mixing downwind of the condenser arrays.

Across the four data centers observed in this study, the apparent downwind air temperature warming effect was as large as 2.2 °C, with average downwind air temperatures being 0.7–0.9 °C warmer than the corresponding upwind temperatures (Table 1). Temperature elevations were detectable at distances of 100–500 m from the facility perimeter, depending on facility size, wind conditions, and campus layout.

4 Discussion

The measurements presented here are, to our knowledge, the first field evidence that operational data centers produce measurable increases in air temperature in adjacent residential neighborhoods. While it should be emphasized that these are initial observations, the measured elevation of air temperature by as much as 2.2 °C at 100–500 m downwind is physically consistent with the extraordinary heat flux densities involved. The attribution of this warming to data center waste heat is supported by the consistent alignment of the temperature signal with the prevailing wind direction across multiple sites, dates, and meteorological conditions. While the sensitivity relationship of ∼1 °C per 100 W/m^2 from Ref. [6] would suggest much larger warming, data center heat is emitted as a buoyant plume that partially disperses before reaching pedestrian level in downwind neighborhoods. Nevertheless, the measured air temperature elevations represent a nontrivial warming effect, especially in a region where extreme heat already poses serious public health risks. It is important to note that these measurements represent a relatively small sample of initial observations from only four data centers and a few measurement periods. A more exhaustive field campaign is being planned to collect data for a much wider range of times and weather conditions. These data will then support the development of a validated microscale atmospheric model that can be used to explore design alternatives to lessen the downwind thermal impacts of data centers. Nevertheless, these initial data are consistent with expectations from decades of research on anthropogenic heat and support the hypothesis that data centers may result in substantial warming of proximate downwind neighborhoods.

The magnitude of data center heat rejection is remarkable relative to other urban sources [23]. City-wide Q_f in Phoenix averages ∼13 W/m^2 in summer, with peaks of ∼50 W/m^2 in commercial areas [4]. Tokyo's central business district has peak Q_f emissions of ∼1600 W/m^2 [24], but these emissions are distributed vertically across high-rise buildings exceeding 100 m. A single 36 MW data center rejects 2800–6200 W/m^2 at ground or rooftop level from one building footprint—far exceeding emissions from dense urban areas. With hundreds of megawatts of data center capacity currently operational in Phoenix and thousands more proposed [10], the aggregate thermal impact on the urban atmosphere could be substantial, leading to many pockets of data center heat islands, and potentially having wider-scale implications for the urban climate system.

These findings have implications for many aspects of urban operations, including increases in air conditioning energy demand for neighborhoods warmed by nearby data centers [25]. Prior modeling for Phoenix has shown that waste heat from residential air conditioning alone increases summertime nighttime temperatures by more than 1 °C [26]. In Phoenix, where cooling exceeds 50% of household electricity use, even 1–2 °C of additional ambient warming can meaningfully increase peak cooling demand and annual energy consumption in downwind homes, creating a feedback loop where data center operations raise the energy burden on surrounding neighborhoods, precisely during the extended summer cooling season when temperatures already routinely exceed 43 °C.

There are many factors that influence the downwind thermal impacts from data centers. Some, such as background weather conditions, are mostly out of our control. However, the design and configuration of cooling equipment used in data centers may offer some control over these impacts. Exhaust height, velocity, discharge angle, equipment density, and parapet walls all influence plume buoyancy and dispersion. Strategic design informed by high-resolution microclimate modeling now feasible at 1–2 m resolution [27] could substantially reduce the thermal footprints of data center impacts without compromising cooling performance. Such considerations should be integrated into siting and permitting processes, particularly in hot climates.

5 Conclusions

This communication presents the first field evidence that operational data centers produce measurable warming in adjacent residential neighborhoods, with the downwind warming effect as large as 2.2 °C and average downwind air temperatures 0.7–0.9 °C warmer than upwind temperatures, extending more than 250 m downwind. These impacts arise from heat flux densities of 2000–6000 W/m^2, magnitudes 2–6 times peak solar irradiance, equivalent to the heat emitted by thousands of residential buildings concentrated on a single site. As global data center capacity is projected to double by 2030, we establish data center anthropogenic heat as a previously unrecognized urban thermal hazard with implications for residential building energy, outdoor thermal comfort, and public health. With facilities increasingly sited in hot-climate markets across the American Southwest, the Middle East, and Southeast Asia, and a growing reliance on sensible air-based cooling systems, the thermal externality documented here is poised to become a recurring feature of 21st-century urbanization.

Future research should include systematic observational campaigns that integrate additional traverse observations with temporary fixed weather stations and remote-sensed land surface temperature data. These studies should characterize the sensitivity of the observed warming to wind speed, atmospheric stability, and time of day, connect the warming to impacts on residential energy and water use, and translate the resulting temperature elevations into outdoor thermal comfort metrics. The resulting empirical datasets will be important for informing more systematic statistical analyses of the downwind thermal effects of data centers. They will also be essential for developing and validating microscale models, which can then be used to evaluate design interventions aimed at mitigating the downwind thermal impacts of data centers.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The datasets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request.

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