Research Square

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Locally extreme heat and daily nursing hours reported by US nursing homes: a two-season observational panel study

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Abstract

Background

Extreme heat endangers nursing-home residents, and nursing staff are central to protecting them. How reported nursing hours change around locally unusual hot days remains unclear. We estimated these associations by nursing role across two US warm seasons.

Methods

We linked CMS Payroll-Based Journal reports to county weather for May–September 2024 and 2025. Hot days exceeded county-specific 1991–2020 95th-percentile maximum temperatures. Models with facility–year–weekday, national-date and state–year–month effects estimated cumulative associations over lags 0–7. Estimates represent local contrasts within national dates. Intervals accounted for spatial and temporal dependence.

Results

The panel included 4,366,698 facility-days from 14,514 nursing homes. Per additional hot day, cumulative reported hours differed by + 0.073 for registered nurses (RNs; 95% CI − 0.072 to + 0.218), + 0.082 for licensed practical nurses (LPNs; −0.088 to + 0.253) and − 0.183 for certified nursing assistants (CNAs; −0.556 to + 0.191); all primary intervals included zero. Point estimates equalled approximately + 4, +5 and − 11 minutes, respectively, accumulated over eight response days per additional hot day. Relative to one average facility-day, the intervals were − 0.20% to + 0.61% (RN), − 0.13% to + 0.38% (LPN) and − 0.31% to + 0.11% (CNA). An exploratory CNA profile showed an early decrease (lag 1: −0.19 hours; joint test of eight daily coefficients, three-role adjusted P = 0.0076). A post hoc model adding facility–year–month effects gave CNA − 0.368 hours (− 0.668 to − 0.068; nine-test adjusted P = 0.147).

Conclusions

We found no clear cumulative change in reported RN, LPN or CNA hours around locally hot days; primary intervals were compatible with small cumulative differences on the mean-day reference scale. An exploratory early CNA decrease warrants shift-level follow-up. For nurse managers, matching rosters to clock times on and after hot days can support review of nursing-assistant coverage beyond aggregate payroll totals.

Background

Extreme heat threatens nursing-home residents who rely on staff for daily care and protection from hazardous conditions. Evidence linking extreme heat to mortality, particularly in homes without air

conditioning, makes heat preparedness a care-delivery problem [1]. Nursing hours are a potentially adjustable resource: managers can change rosters, add cover or bring in contract staff. Staff surveys and nurse-leader interviews describe heat-related constraints on care delivery involving staffing, equipment and buildings [2, 3]. The practical question is whether the hours homes report change when locally unusual heat occurs.

Daily Payroll-Based Journal (PBJ) studies have documented substantial variation in nursing-home staffing and associations with quality, hospitalization and emergency department use [4, 5, 6]. A recent quarterly panel examined registered nurse intensity and skill mix in relation to acute-care use [7]. These studies establish the value of examining nursing resources at different time scales, but staffing-to-outcome associations do not describe how homes adjust reported hours around local heat. A multiday total can also combine daily changes with opposing signs.

Studies of Winter Storm Uri and Hurricane Michael have examined staffing changes during discrete disasters [8, 9]. Other work has considered staffing during community distress and COVID-19 outbreaks [10, 11]. Recurrent, locally unusual hot days present a different operational question: whether reported hours increase, decrease or remain similar as homes encounter repeated heat across a warm season.

Two opposing responses are plausible. Staff absences or operational disruption could reduce reported hours, whereas additional shifts or contract cover could increase them. Early decreases and later increases could also offset one another over a week. We linked US nursing-home payroll reports to county weather during the 2024 and 2025 warm seasons to estimate cumulative associations over lags 0–7 for registered nurses (RNs), licensed practical nurses (LPNs) and certified nursing assistants (CNAs). We also described daily profiles, employee and contract components, and resident census. Together, these measures address whether local heat is associated with a change in the cumulative quantity of reported nursing resources or with differences in their daily distribution.

Methods

Study design and data sources

This observational panel study linked second- and third-quarter Centers for Medicare & Medicaid Services (CMS) PBJ public-use records for 2024 and 2025 to National Oceanic and Atmospheric Administration (NOAA) nClimGrid-Daily county weather [12, 13, 14, 15]. Three retained staffing CSVs were direct CMS downloads; the 2024 Q2 input came from a public mirror. Subsequent comparison with CMS-hosted files found three byte-identical files and exact 2024 Q2 key/value agreement despite CSV-format differences. Acquisition routes, fingerprints and comparisons are in Supplementary Methods 1 and Data S10 and S22.

The original analysis plan fixed the cohort, exposure, outcomes, model, inference and 12 analyses locally before outcome associations were estimated. Its dated record accompanies the code in Additional file 3; it was not externally registered. Analyses introduced subsequently are identified as post hoc. Reporting

follows relevant STROBE and RECORD items [16, 17]; the study-specific reporting map is supplied as Additional file 4.

Sample and setting

Eligible observations were valid reported days from May 1 to September 30 in 2024 and 2025 with exact county-weather links in the contiguous states and District of Columbia. Connecticut was excluded in both years because of changes in county definitions; unmatched Lexington City, Virginia, observations were also excluded. Facilities could contribute without appearing in every quarter or experiencing a hot day. Study size comprised all eligible facility-days in the fixed source quarters.

PBJ public-use eligibility requires activity at quarter end and applies quarterly and weekend staffing screens. The analysis therefore concerns the selected reporting population. Missing quarters remained unknown. Included days had complete model variables, and no recorded values were imputed. Valid zero hours and zero Minimum Data Set (MDS)-derived census were retained in absolute-hours analyses. A reported zero means that no category-specific hours for that day were submitted by the deadline; it does not verify the absence of nursing work [12].

Measures of locally extreme heat

A locally hot day exceeded the county's linear 95th percentile of 1991–2020 source-file maximum temperatures during May 2–October 1. Each weather county had 4,590 complete reference dates. We used supplied county-average temperatures in degrees Celsius [14, 18]. The primary assignment linked staffing date t to source-file date t + 1, approximately reflecting predominantly morning-ending weather observation windows. This provides approximate calendar alignment rather than precise shift-level exposure.

Eight heat indicators covered lags 0–7 using actual dates and boundary-month weather. Lags did not bridge the off-season. Source-date t and t + 2 sensitivity analyses retained the historical threshold. The county percentile represents locally unusual outdoor conditions across different temperature backgrounds; indoor exposure and physiological heat stress were not measured.

Measures of staffing

Primary outcomes were reported daily total paid hours for RN, LPN and CNA categories, corresponding to PBJ jobs 7, 9 and 10. Director and administrative categories were separate. Employee and contract hours and MDS-derived census were companion outcomes. Concurrent census was analyzed separately from absolute hours. Total hours equal employee plus contract hours, providing an accounting decomposition [12]. CMS reporting rules allocate cross-midnight shifts to their respective calendar days, using midnight as the cutoff [19].

Hours per resident-day (HPRD) required positive census. Contract share was 100×contract/total hours when the role's total hours were positive. Zero contract hours remained valid; undefined zero/zero shares were excluded. Because daily ratio denominators can change, cumulative HPRD sums do not measure care received by a fixed resident cohort. Share analyses condition on role hours and have role-specific eligible samples.

Statistical analysis

Equally weighted facility-day linear models included all eight heat indicators and fixed effects for facility×year×weekday, national calendar date, and state×year×month. These terms account for facility weekday schedules within years, shared daily changes and state monthly patterns. The primary cumulative contrast C was the sum of lag 0–7 coefficients for each role. Under the additive common-slope model, C is the integrated association with one additional locally hot day, conditional on the other included heat days, in reported hours accumulated over the response interval. National-date adjustment removes shared daily changes. The coefficients therefore summarize local heat contrasts within the same national dates, conditional on the other heat lags and facility/calendar controls; they do not estimate the total response to a nationally shared heat event.

Primary 95% confidence intervals (CIs) used a spatial–temporal heteroskedasticity and autocorrelation consistent (HAC) sandwich with 500-km/14-day working bandwidths and a normal reference [20]. County-date sums of facility-level regression scores retained the equally weighted facility-day target. Holm correction covered the three primary cumulative total-hour tests [21]. Displayed CIs are marginal. Individual-lag intervals are pointwise, and companion-outcome inference is nominal. All eight lags were retained; kernel and covariance details are in Supplementary Methods 3.

Analyses fixed in the original plan

Original one-feature sensitivity analyses examined alternative weather-date assignments, exactly linked 2024 Connecticut observations, positive census, upper-tail winsorization, precipitation, and two facilities with changing reported counties. Companion models used HPRD and conditional contract shares. Fixed inference alternatives used 250-km/7-day and 1,000-km/30-day HAC and 48-state/DC clustering with G/(G − 1) correction and a t(47) reference. All 12 original models were retained; full definitions, scaling rules and samples are in Supplementary Methods 3.

R/fixest cross-checks re-estimated both response windows and rebuilt facility-level HAC scores. Author code review and numerical recalculations are distinguished from AI-assisted programming and execution in Supplementary Methods 4 and 6.

Post hoc extensions

Post hoc reference scaling divided each cumulative estimate and its interval endpoints by pooled mean daily hours for that role. Using one mean day rather than eight mean days as the denominator makes the

percentages eight times larger. No clinical-equivalence margin was specified.

Other post hoc analyses examined future heat and historical-temperature-background groups, and fitted a separate 0–14-day window on the original sample. An added-control model retained lags 0–7 and added facility×year×month effects, extending the original state-month seasonal adjustment. Other diagnostics widened HAC dependence windows or used county clustering. The original three-test family was retained. Separate three-test families covered the extended window and added-control model; further post hoc corrections combined the six role-by-window and nine role-by-model cumulative tests. Joint eight-lag tests addressed daily profiles within another exploratory three-role family. All model definitions, results and testing families are retained in Supplementary Methods 5–7 and Tables S14–S23.

Use of AI assisted tools

OpenAI Codex assisted study planning, literature retrieval, data processing, programming, numerical checks and manuscript preparation. WorkBuddy assisted spreadsheet calculations and verification programming; its model and version were unavailable. The authors reviewed the work and approved the manuscript; individual review roles and dated computational records are detailed in Authors' contributions and Supplementary Methods 4 and 7.

Results

Sample and reported staffing

The primary panel contained 4,366,698 facility-days from 14,514 facilities in 2,818 counties, 47 states and the District of Columbia across 306 dates. There were 289,217 hot facility-days (6.62%), corresponding to 52,311 observed hot county-days. Mean daily RN, LPN and CNA totals were 35.54, 66.17 and 178.47 hours; mean census was 84.17 (Table 1). The selection flow began with 5,319,411 quarterly source rows. Geographic exclusions, annual counts and the 1,606 retained zero-census days are documented in Supplementary Tables S1–S2.

Table 1
Sample characteristics and reported daily staffing

Characteristic	Pooled	2024	2025
Facility-days	4366698	2187070	2179628
Distinct facilities	14514	14430	14352
Distinct counties	2818	2811	2805
Study dates	306	153	153
Locally hot facility-days, n (%)	289217 (6.62)	164679 (7.53)	124538 (5.71)
Zero MDS census days, n	1606	745	861
MDS resident census	84.17 (49.36)	83.51 (49.12)	84.85 (49.59)
RN total hours	35.54 (36.12)	34.66 (35.10)	36.43 (37.09)
RN employee hours	32.85 (33.11)	31.86 (31.83)	33.84 (34.30)
RN contract hours	2.69 (10.70)	2.80 (10.74)	2.58 (10.66)
LPN total hours	66.17 (48.79)	65.97 (49.26)	66.38 (48.31)
LPN employee hours	60.56 (45.40)	59.90 (45.18)	61.23 (45.60)
LPN contract hours	5.61 (16.49)	6.07 (18.28)	5.15 (14.46)
CNA total hours	178.47 (117.17)	175.15 (115.54)	181.80 (118.69)
CNA employee hours	167.67 (110.68)	163.36 (108.47)	171.99 (112.69)
CNA contract hours	10.80 (31.23)	11.80 (32.23)	9.81 (30.17)

Values are counts or facility-day mean (SD), as indicated. Each year covers May 1–September 30. The pooled distinct-facility count is not the sum of annual counts. All primary reported days, including zero hours and zero MDS census, contribute to raw-hour summaries. RN, registered nurse; LPN, licensed practical nurse; CNA, certified nursing assistant; MDS, Minimum Data Set. The public file is already subject to quarter-end activity and quarterly/weekend quality rules. Complete distributions and denominators are in Supplementary Data S11.

Cumulative reported hours and the monthly control comparison

Primary cumulative associations per additional locally hot day were + 0.0726 RN hours (95% CI − 0.0725 to + 0.2177), + 0.0820 LPN hours (− 0.0885 to + 0.2525) and − 0.1825 CNA hours (− 0.5558 to + 0.1907). All three primary Holm-adjusted P values were 0.9803 (Table 2, panel A). The point estimates correspond to + 4.36, + 4.92 and − 10.95 minutes accumulated over lags 0–7. Employee and contract components are shown in Fig. 1 and Supplementary Table S4.

Table 2
Cumulative reported total hour associations under the two 0–7 day models Panel A Original primary model

Role	Cumulative hours [95% CI]	Cumulative % of one mean day [95% CI]	Nominal P	Separate Holm3 P	Joint Holm9 P
RN	+ 0.0726 [-0.0725, + 0.2177]	+ 0.204% [-0.204%, + 0.613%]	0.3268	0.9803	1.0000
LPN	+ 0.0820 [-0.0885, + 0.2525]	+ 0.124% [-0.134%, + 0.382%]	0.3457	0.9803	1.0000
CNA	-0.1825 [-0.5558, + 0.1907]	-0.102% [-0.311%, + 0.107%]	0.3378	0.9803	1.0000
Panel B Post hoc addition of facility year month controls					

Scaling the primary marginal CIs to one pooled mean facility-day's role hours gave − 0.20% to + 0.61% for RN, − 0.13% to + 0.38% for LPN and − 0.31% to + 0.11% for CNA.

For three hypothetical consecutive hot days, the additive model gives a cumulative CNA difference of − 0.55 hours (95% CI − 1.67 to + 0.57), equivalent to − 0.031% (− 0.093% to + 0.032%) of the mean-hours reference for the full 10-day response window (Supplementary Table S12).

Adding facility×year×month controls on the same sample changed the CNA cumulative estimate from − 0.1825 to − 0.3677 hours (95% CI − 0.6678 to − 0.0676; Table 2, panel B). Its separate three-test adjusted P was 0.0490 and its post hoc nine-test adjusted P was 0.1469. The original and added-control CNA CIs overlapped. Results for all three roles are displayed in both panels.

Exploratory daily profile and calendar assignment checks

The exploratory CNA coefficient at lag 1 was − 0.1918 hours (pointwise 95% CI − 0.2784 to − 0.1052), with positive point estimates at lags 5–7 (Fig. 2). The joint test of all eight original CNA lag coefficients had Holm-adjusted P = 0.0076 within its separate three-role exploratory family. This tests the whole profile, not the lag-1 coefficient or the cumulative sum. The added-month-control lag-1 estimate was − 0.2171 hours (pointwise 95% CI − 0.2989 to − 0.1354; Supplementary Table S20).

Under source-date t, t + 1 and t + 2 assignments, the minimum CNA coefficient moved from nominal lag 0 to 1 to 2, corresponding to the same relative weather source-file date (Supplementary Table S13 and Fig. S3). In a model also including next-day heat, the CNA future-heat coefficient was − 0.0494 daily hours (95% CI − 0.1695 to + 0.0707; nominal P = 0.4201; three-role adjusted P = 0.8403; Supplementary Table S14).

Complete employee/contract and census profiles, HPRD and conditional shares, the exploratory 0–14-day window, wider dependence windows, and historical-temperature-background analyses are retained in Additional file 1 and full-precision Additional file 2. Their model-specific samples, intervals and separate

multiplicity families remain available in Supplementary Tables S4–S23; none replaces the primary analysis.

Discussion

Principal findings

Across two US warm seasons, reported RN, LPN and CNA hours showed no clear cumulative change around locally hot days. Primary intervals were compatible with small cumulative differences on the mean-day reference scale: −0.20% to + 0.61% for RN, − 0.13% to + 0.38% for LPN and − 0.31% to + 0.11% for CNA. Substantially larger cumulative changes were less compatible with the data under the primary model. The daily profiles add information about how reported resources were distributed across days.

The exploratory daily CNA profile included negative early and positive later coefficients, while its primary cumulative interval included zero. The added-month-control model retained an early negative CNA coefficient and gave a more negative cumulative estimate; the cumulative intervals overlapped and its nine-test adjusted P was 0.1469. Daily patterns therefore deserve attention alongside cumulative totals when examining nursing resources during heat.

Interpreting the daily assistant profile

The date-assignment comparison describes alignment: reassigning the same weather records shifts the nominal lag label while preserving the source-relative day. The future-heat coefficient is also an alignment diagnostic rather than a clean placebo, because forecasts, persistent heat and overlapping source windows can generate associations. Neither diagnostic validates a causal delay or distinguishes payroll-date allocation from a change in nursing resources.

CMS requires hours crossing midnight to be split across the two calendar dates [19], so each daily total can contain portions of different shifts. Public aggregates do not show how individual facilities implemented the split or how shift timing changed with heat. Matching payroll dates to rosters and clock times would help interpret the early CNA pattern.

Contribution to nursing workforce evidence

Daily staffing research has shown that the observation interval and composition of nursing resources matter for interpreting payroll measures [4, 5, 6, 7]. The Winter Storm Uri study reported lower RN, LPN and CNA staffing than in the preceding week [8], whereas recurrent locally defined hot days showed no clear cumulative change in our primary analysis. This comparison is descriptive because the exposures, designs and outcome scales differ. Research on Hurricane Michael further illustrates variation in disaster-related staffing responses [9]. Our findings complement staff accounts of adapting care during heat [2, 3] by describing reported resources across repeated hot days.

Implications for nursing practice and management

Public payroll data showed no clear average cumulative change in reported RN, LPN or CNA hours around locally hot days across two warm seasons. For nurse managers and workforce planners, this makes shift coverage an important companion to multiday payroll totals. Within heat-preparedness plans [22, 23], managers could specify who checks nursing-assistant coverage on and immediately after hot days, compare planned rosters with clocked hours, and record unfilled shifts or use of cover. Nursing-assistant coverage is a practical focus given assistants' contribution to daily personal care and the early exploratory CNA pattern. These steps require evaluation; the estimates do not establish a staffing threshold or the effectiveness of a management intervention.

Strengths and limitations

The study combines two complete warm seasons, a fixed historical exposure definition, separate nursing-role and employment measures, a locally fixed original plan and reproducible numerical checks. Four limitations frame its interpretation.

First, the PBJ reporting population is selected by quarter-end activity and quarterly staffing screens; missing quarters cannot distinguish closure from nonreporting or upstream exclusion. The OIG audit documented discrepancies in a selected March 2024 RN frame, not an error rate for this warm-season cohort [24].

Second, paid hours and MDS census do not measure attendance, shift coverage, resident acuity or additional heat-related care tasks. County outdoor temperatures can differ from indoor and individual exposure. Supplementary Methods 1–3 detail source selection, zero values and weather-date alignment.

Third, the observational model can retain confounding by humidity, smoke, outages and other time-varying conditions. Its additive common slopes and fixed response window summarize conditional local associations; nationally shared daily changes are absorbed by date effects.

Fourth, uncertainty depends on the working spatial–temporal HAC estimator. Its finite-sample coverage has not been calibrated with many fixed effects and short within-group series; valid alternative uncertainty calculations could change the interval endpoints. Wider dependence windows examine assumptions without establishing coverage. Numerical cross-checks and their scope are detailed in Supplementary Methods 4 and 7.

Conclusions

Across two US warm seasons, reported RN, LPN and CNA hours showed no clear cumulative change around locally hot days, with primary intervals compatible with small cumulative differences on the mean-day reference scale. The exploratory early CNA decrease directs attention to variation in reported daily assistant hours that multiday totals can obscure. For nurse managers, linking payroll dates to planned rosters and clock times on and after hot days is a concrete next step for evaluating coverage during heat preparedness.

Abbreviations

CI, confidence interval; CNA, certified nursing assistant; CMS, Centers for Medicare & Medicaid Services; HAC, heteroskedasticity and autocorrelation consistent; HPRD, hours per resident-day; LPN, licensed practical nurse; MDS, Minimum Data Set; NOAA, National Oceanic and Atmospheric Administration; PBJ, Payroll-Based Journal; RECORD, REporting of studies Conducted using Observational Routinely-collected health Data; RN, registered nurse; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

Declarations

Ethics approval and consent to participate

Not applicable. This secondary analysis used publicly available organizational staffing records and county weather data. The analytic files contained no individual-level resident or employee records or personal identifiers. No participants were recruited, contacted or subjected to an intervention; the unit of analysis was the nursing-home day.

Consent for publication

Not applicable. The manuscript contains no individual person's data.

Availability of data and materials

The staffing data analyzed during this study are publicly available from the CMS Payroll Based Journal Daily Nurse Staffing dataset series [13]; weather data are available from NOAA nClimGrid-Daily [15]. Supplementary Data S10 and S22 identify the exact staffing inputs, acquisition routes, fingerprints and comparisons with CMS-hosted files. Additional file 2 contains 32 machine-readable supplementary result and provenance tables. Additional file 3 contains the analysis code, dated specifications, aggregate results, input fingerprints and numerical-check documentation. Large source and derived facility-day tables are not included in the compact code archive; the source routes and processing code are provided for reconstruction.

Clinical trial number

Not applicable. This study did not involve a clinical trial.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JR: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft. QZ: Investigation, Methodology, Validation, Writing – review & editing. YW: Interpretation of findings, Writing – review & editing. LL: Interpretation of findings, Validation, Writing – review & editing. FZ: Interpretation of findings, Writing – review & editing. ZX: Conceptualization, Methodology, Supervision, Writing – review & editing. JR and QZ reviewed code, outputs, formulas and additional calculations. LL reviewed statistical methods and interpretation. ZX reviewed nursing interpretation and the manuscript. All authors have approved the revised manuscript and its submission to BMC Nursing.

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References

1. Katz GM, Brown KA, Giannakeas V, Stall NM. Air conditioning in nursing homes and mortality during extreme heat. JAMA Intern Med. 2026;186(2):243–51. https://doi.org/10.1001/jamainternmed.2025.6595.
2. Blount H, Ward J, James PAB, Worsley PR, Filingeri D, Koch Esteves N. Understanding the impact of heatwaves on care homes in the United Kingdom and Ireland: a multiregion survey of staff experiences, challenges, and adaptation strategies. Health Soc Care Community. 2026;2026(1):6254170. https://doi.org/10.1155/hsc/6254170.
3. Zink M, Jung F, Riedel-Heller SG, Gabriel KMA. Nurse leaders' perspective on heat-related challenges and work-organizational interventions in inpatient care settings in Germany: a qualitative descriptive study. J Clim Chang Health. 2026;28:100655. https://doi.org/10.1016/j.joclim.2026.100655.

4. Geng F, Stevenson DG, Grabowski DC. Daily nursing home staffing levels highly variable, often below CMS expectations. Health Aff (Millwood). 2019;38(7):1095–100. https://doi.org/10.1377/hlthaff.2018.05322.
5. Mukamel DB, Saliba D, Ladd H, Konetzka RT. Daily variation in nursing home staffing and its association with quality measures. JAMA Netw Open. 2022;5(3):e222051. https://doi.org/10.1001/jamanetworkopen.2022.2051.
6. Mukamel DB, Saliba D, Ladd H, Konetzka RT. Associations between daily nurse staffing levels and daily hospitalizations and ED visits in nursing homes. J Am Med Dir Assoc. 2022;23(11):1793–e17993. https://doi.org/10.1016/j.jamda.2022.06.030.
7. He W, Zhai H, Wu L, Zhou G. Registered nurse staffing intensity, skill mix, and acute-care use among long-stay nursing home residents: a fixed-effects panel analysis. BMC Nurs. 2026;25(1):752. https://doi.org/10.1186/s12912-026-05186-7.
8. Jester DJ, Peterson LJ, Andel R, Dosa DM. Winter Storm Uri reduced availability of daily direct-care nurse staff in Texas nursing homes. J Appl Gerontol. 2023;42(10):2148–57. https://doi.org/10.1177/07334648231175428.
9. Festa N, Alexovitz K, Davis-Plourde K, Marottoli R, Cohen AB, Dosa D, et al. Comparing disaster-related surge staffing practices across rural and non-rural nursing homes. J Am Geriatr Soc. 2025;73(12):3829–35. https://doi.org/10.1111/jgs.70098.
10. Kang YJ, Nielsen KE, McGee BT, Xu H. Nurse staffing disparities in nursing homes: effects of community distress level and COVID-19. Nurs Outlook. 2026;74(4):102841. https://doi.org/10.1016/j.outlook.2026.102841.
11. Shen K, McGarry BE, Grabowski DC, Gruber J, Gandhi AD. Staffing patterns in US nursing homes during COVID-19 outbreaks. JAMA Health Forum. 2022;3(7):e222151. https://doi.org/10.1001/jamahealthforum.2022.2151.
12. Centers for Medicare & Medicaid Services. Payroll-Based Journal public use files: technical specifications. July 2023. https://data.cms.gov/sites/default/files/2023-06/PBJ_PUF_Documentation_July_2023.pdf. Accessed 18 Oct 2026.
13. Centers for Medicare & Medicaid Services. Payroll Based Journal Daily Nurse Staffing. https://data.cms.gov/quality-of-care/payroll-based-journal-daily-nurse-staffing. Accessed 19 Oct 2026.
14. Durre I, Arguez A, Schreck CJ III, Squires MF, Vose RS. Daily high-resolution temperature and precipitation fields for the contiguous United States from 1951 to present. J Atmos Ocean Technol. 2022;39(12):1837–55. https://doi.org/10.1175/JTECH-D-22-0024.1.
15. Durre I, Squires MF, Vose RS, Arguez A, Gross WS, Rennie JR et al. NOAA nClimGrid-Daily Version 1: daily gridded temperature and precipitation for the Contiguous United States since 1951. County-average subset. NOAA National Centers for Environmental Information; 2022. https://doi.org/10.25921/c4gt-r169. Dataset documentation accessed 9 Nov 2026.

16. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. PLoS Med. 2007;4(10):e296. https://doi.org/10.1371/journal.pmed.0040296.
17. Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, et al. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. PLoS Med. 2015;12(10):e1001885. https://doi.org/10.1371/journal.pmed.1001885.
18. NOAA National Centers for Environmental Information. Daily gridded fields and area averages for the contiguous United States (nClimGrid-Daily): user guide. Revision 0.5. 2022. https://www.ncei.noaa.gov/data/nclimgrid-daily/doc/nclimgrid-daily_v1-0-0_user-guide.pdf. Accessed 18 Oct 2026.
19. Centers for Medicare & Medicaid Services. Electronic staffing data submission: Payroll-Based Journal long-term care facility policy manual. Version 2.7. June 2025. Section 2.2, Work Day, Date. https://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/NursingHomeQualityInits/Downloads/PBJ-Policy-Manual-Final-V25-11-19-2018.pdf. Accessed 9 Nov 2026.
20. Conley TG. GMM estimation with cross sectional dependence. J Econom. 1999;92(1):1–45. https://doi.org/10.1016/S0304-4076(98)00084-0.
21. Holm S. A simple sequentially rejective multiple test procedure. Scand J Stat. 1979;6:65–70. https://www.jstor.org/stable/4615733.
22. Ward A, Martin S, Richards C, Ward I, Tulleners T, Hills D, et al. Enhancing primary healthcare nurses' preparedness for climate-induced extreme weather events. Nurs Outlook. 2024;72(5):102235. https://doi.org/10.1016/j.outlook.2024.102235.
23. Baumbusch J, Sloan Yip I, Bandara NA. Always on duty – Fostering climate resilience in the nursing profession: a discussion paper. Int J Nurs Stud. 2025;172:105227. https://doi.org/10.1016/j.ijnurstu.2025.105227
24. US Department of Health and Human Services, Office of Inspector General. CMS's processes were not effective in ensuring the accuracy of staffing information reported in the Payroll-Based Journal. Report A-09-24-02005. 2026. https://oig.hhs.gov/documents/audit/11717/A-09-24-02005.pdf. Accessed 18 Oct 2026.

Figures

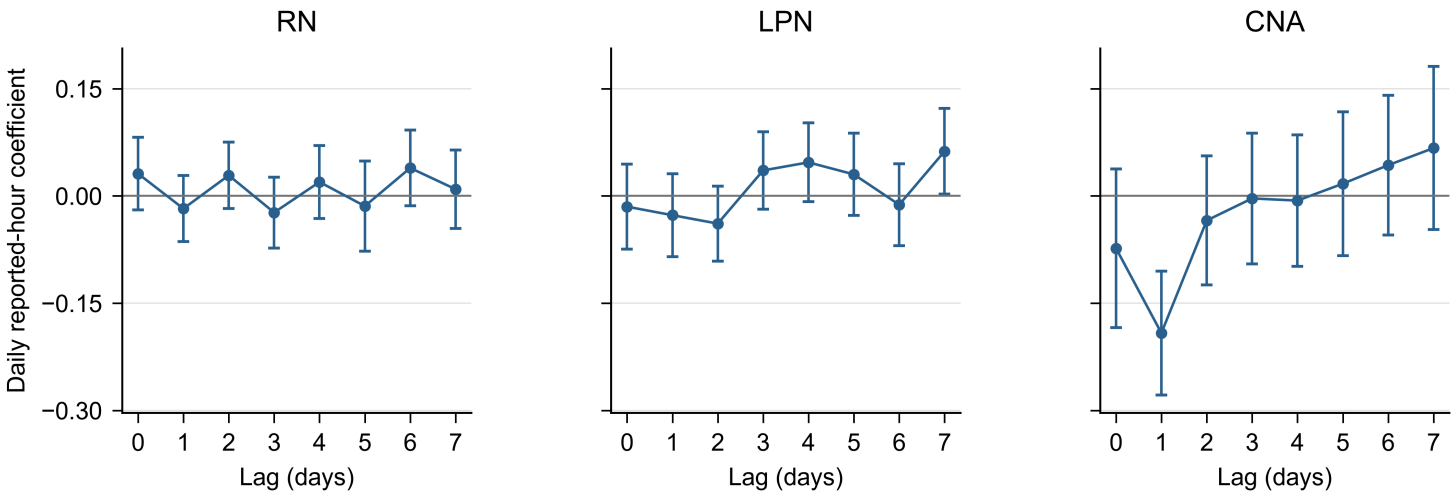

Figure 1

Exploratory daily total hour coefficients

All eight simultaneously fitted heat coefficients per role are shown with pointwise 95% HAC intervals using 500-km/14-day working bandwidths. Panels share vertical and lag scales. Lines connect point estimates for readability. Individual-lag inference is outside the primary Holm family; the primary cumulative contrast is each profile's sum. Post hoc time-control and dependence diagnostics appear in Supplementary Fig. S5.

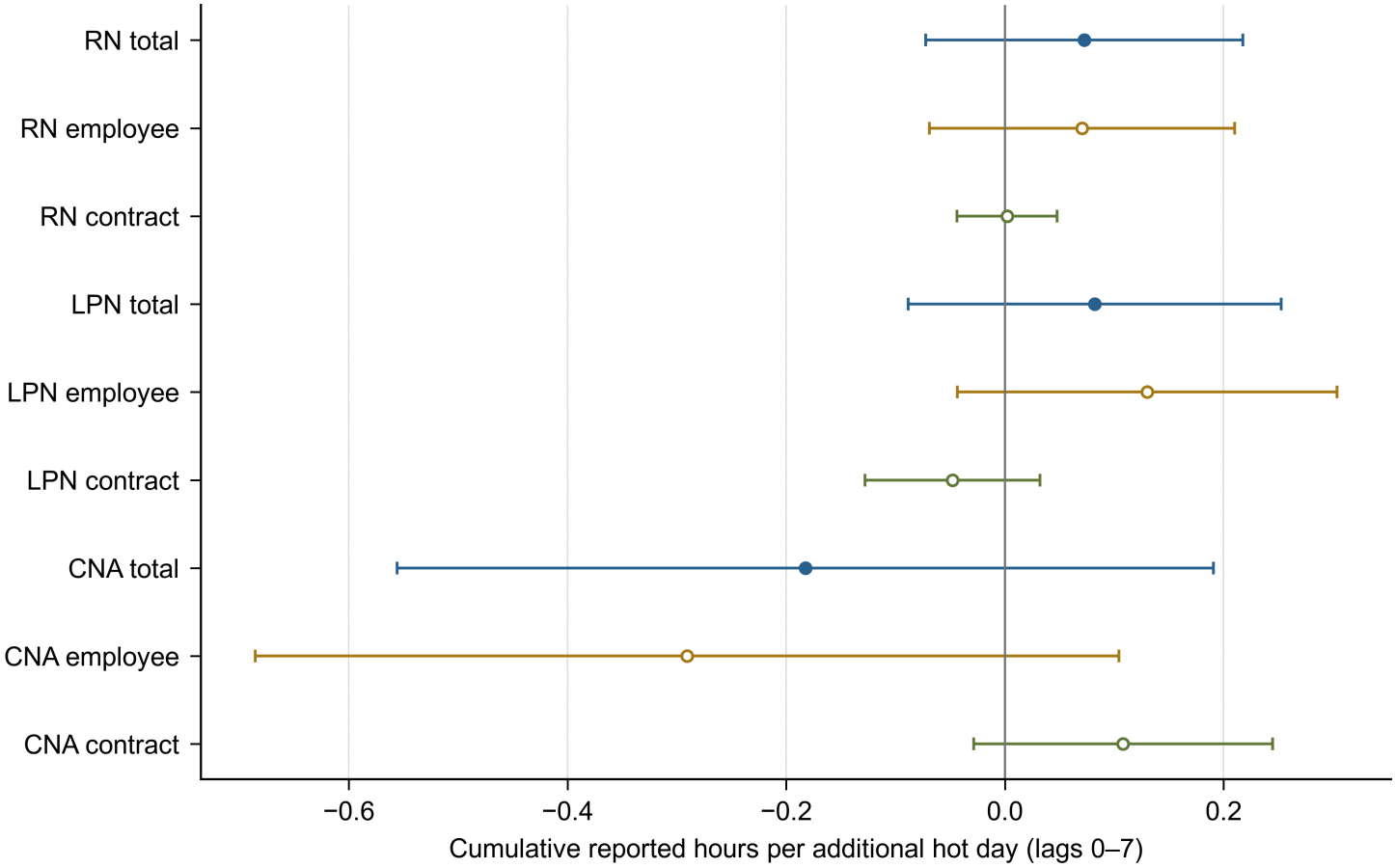

Figure 2

Cumulative reported hours by nursing role and employment component

Points and marginal 95% spatial–temporal HAC intervals use the primary sample and model. Each estimate sums lag 0–7 heat coefficients, giving integrated reported hours per additional hot day. Component inference is nominal; Holm correction covers the three role-total tests in Table 2, panel A. Total hours equal employee plus contract hours. All nine contrasts share one horizontal scale.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- 03Additionalfile1Supplementarymaterial.docx
- Additionalfile2SupplementaryDataTables.zip
- Additionalfile3Reproducibilitycode.zip
- 04Additionalfile4STROBERECORD.docx