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Mapping emergency department asthma visits to identify poor-quality housing in New Haven, CT, USA: a retrospective cohort study

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EAS, SLB, AS, and ALH conceived and designed the study. EAS, ASM, AKV, and AP conducted the literature search. EAS, RAT, and ERL collected data. ALH, RAT, AS, EAS, SLB, and AKV contributed to the methodology. ALH analysed the data and produced the figures. ALH, EAS, AP, and ASM wrote the original draft of the manuscript. EAS, ALH, AP, ASM, RAT, and AKV reviewed and edited the manuscript. EAS and ALH acquired funding for the study. EAS, RAT, and ALH accessed and verified the data underlying the study. All authors had access to data used in this study and were responsible for the decision to submit for publication.

Declaration of interests
We declare no competing interests.

Summary

Background—Housing conditions are a key driver of asthma incidence and severity. Previous studies have shown increased emergency department visits for asthma among residents living in poor-quality housing. Interventions to improve housing conditions have been shown to reduce emergency department visits for asthma, but identification and remediation of poor housing conditions is often delayed or does not occur. This study evaluates whether emergency department visits for asthma can be used to identify poor-quality housing to support proactive and early intervention.

Methods—We conducted a retrospective cohort study of children and adults living in and around New Haven, CT, USA, who were seen for asthma in an urban, tertiary emergency department between March 1, 2013, and Aug 31, 2017. We geocoded and mapped patient addresses to city parcels, and calculated a composite estimate of the incidence of emergency department use for asthma for each parcel ($N_v \times N_p/\log_2[P]$, where N_v is the estimated mean number of visits per patient, N_p is the number of patients, and P is the estimated population). To determine whether parcel-level emergency department use for asthma was associated with public housing inspection scores, we used regression analyses, adjusting for neighbourhood-level and individual-level factors contributing to emergency department use for asthma. Public housing complex inspection scores were obtained from standardised home inspections, which are conducted every 1–3 years for publicly funded housing. We used a sliding-window approach to estimate how far in advance of a failed inspection the model could identify elevated use of emergency departments for asthma, using the city-wide 90th percentile as a cutoff for elevated incidence.

Findings—119429 asthma-related emergency department visits from 6366 unique patients were included in the analysis. Mean patient age was 32·4 years (SD 12·8); 3836 (60·3%) patients were female, 2530 (39·7%) were male, 3461 (57·2%) were Medicaid-insured, and 2651 (41·6%) were Black. Incidence of emergency department use for asthma was strongly correlated with lower housing inspection scores (Pearson's r=−0·55 [95% CI −0·70 to −0·35], p=3·5 × 10^{-6}), and this correlation persisted after adjustment for patient-level and neighbourhood-level demographics using a linear regression model (r=−0·54 [−0·69 to −0·33], p=7·1 × 10^{-6}) and non-linear regression model (r=−0·44 [−0·62 to −0·21], p=3·8 × 10^{-4}). Elevated asthma incidence rates were typically detected around a year before a housing complex failed a housing inspection.

Interpretation—Emergency department visits for asthma are an early indicator of failed housing inspections. This approach represents a novel method for the early identification of poor housing conditions and could help to reduce asthma-related morbidity and mortality.

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Introduction

Social and economic factors are primary drivers of individual and community health outcomes.[1,2] Housing is a key health determinant, and poor housing quality has been associated with increased asthma prevalence and severity.[1] Housing characteristics that affect the development and progression of asthma include mould and pests, structural building problems (eg, water leaks), and air quality (eg, dampness and airborne particulate matter).[3] These risk factors are disproportionately common in poor neighbourhoods, particularly in communities of colour, because of underinvestment, lack of routine maintenance, and higher concentrations of environmental pollutants[4] driven by structural racism.[5,6]

US emergency department asthma visits decreased overall from 2006 to 2018, but racial, regional, and socioeconomic inequities persist, with higher visits among communities of colour, low-income communities, in southeastern USA, and in metropolitan areas.[7] Interventions aimed at improving neighbourhood and housing conditions that produce indoor allergens have been shown to reduce the use of emergency departments for asthma.[8] An increasing number of emergency departments are employing tools to screen patients for individual health-related social needs, such as housing instability and poor housing quality. However, these programmes can be difficult to scale and standardise in an already strained emergency care system. A novel approach not reliant on individual-level screening is the reverse scenario, which investigates whether emergency department use can be used to identify poor housing conditions. This population-level approach could trigger community or public health interventions, such as housing inspections or targeted social service delivery, to address social determinants of health without relying on individual-level screening or housing complaints.

In the USA, women, Black and Latinx people, and people who earn less than US$15 000 annually have significantly higher rates of asthma than men, White people, and people in higher income brackets.[7] Healthcare outcomes, such as emergency department use, can be considered meaningful indicators of social conditions, such as housing quality. To determine whether emergency department use could be used to identify poor housing quality, we conducted an observational retrospective analysis of emergency department visits for asthma in New Haven, CT, USA. The Greater New Haven metropolitan area is served by one health system and has one of the highest rates of asthma prevalence in the USA due to a combination of older housing stock, high rates of poverty, a high proportion of rented housing, and poor air quality.

The goal of the study was to determine whether emergency department visit data can generate an accurate geospatial signal to identify poor housing conditions in public housing, and whether such data can detect poor housing conditions earlier than can the currently used means of identification for federally subsidised and public housing (ie, US Department of Housing and Urban Development [HUD] housing inspections).

Methods

Study setting

We conducted a retrospective cohort study of children and adults living in Greater New Haven (CT, USA) who were seen for an asthma-related problem in the emergency departments of Yale New Haven Hospital (YNHH; New Haven, CT, USA) from March 1, 2013 (when YNHH established their current electronic health record system) to Aug 31, 2017 (1 year after residents moved out of a major subsidised public housing complex, Complex A, following a court-ordered building closure due to poor housing conditions).

YNHH is a level 1 trauma, tertiary regional referral centre and has emergency departments at two hospital campuses serving Greater New Haven, with more than 155 000 annual visits.[9] There are no other emergency departments serving Greater New Haven.

New Haven has the fifth highest asthma prevalence in the USA.[10] In general, factors contributing to increased asthma prevalence include air quality, pollens, and housing quality. New Haven has an older housing stock, with more than half of residencies built before 1940 (*vs* 13% nationally). In 2021, 22% of households were below the federal poverty line (*vs* 11% nationally) and 72% were renter occupied (*vs* 36% nationally).[11] According to the American Community Survey, as of 2021, Greater New Haven had approximately 861 113 residents, of whom 29·1% were White non-Hispanic, 36·6% were African American, 0·5% were Native American, 5·2% were Asian, 0·1% were Pacific Islander, and 30·8% were Hispanic or Latinx.[12]

There are several examples of New Haven public housing complexes identified to be of poor quality and with increased rates of respiratory illnesses, including asthma. The prime example was Complex A, a HUD-subsidised, 301-unit complex of 22 low-rise buildings. In June, 2018, the complex was demolished after a prolonged community organising campaign and legal struggle to remediate poor housing conditions, particularly the widespread presence of black mould.[13,14] A survey of the tenants reported that 81 (48%) of 170 children and 36 (37%) of 98 adults living in this complex had asthma (*vs* 8% nationally in the USA).[7,15] All of the 66 adults with pre-existing asthma or respiratory problems reported onset or worsening of symptoms after moving into Complex A, and 49 (74%) reported improvement upon leaving.[15] Complex A represents a definitive case of confirmed poor-quality housing associated with increased incidence of asthma. Previous studies have shown increased use of emergency departments for asthma among residents living in poor-quality housing.[16] This study is a proof-of-concept analysis of the reverse scenario, evaluating whether emergency department visits for asthma can be used to identify poor-quality housing (figure 1).

This study was approved by the Yale University Institutional Review Board.

Study population

The study was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for cohort studies. Study visits were identified using International Classification of Diseases, Clinical Modification ninth and tenth editions diagnostic codes for asthma, ICD-9 493.XX and ICD-10 J45.XX, and totalled 12 004 emergency department visits. Patient addresses were geocoded to longitude and latitude coordinates using the Google Maps API and the R package ggmap,[17] of which 11489 (95·7%) of 12 004 were accurately geocoded (appendix p 3). After removing 60 out-of-state addresses, we retained 11429 visits (appendix p 3) from 6366 unique patients (table 1; appendix p 3).

Linkage to tax assessor parcels

We linked patient addresses at the time of the emergency department visit to tax assessor parcels. To link patients living in large housing complexes, which have several different addresses (appendix p 4), we spatially joined each geocoded address to the closest polygon representing tax assessor's parcels (appendix p 4)—individual divisions of land indexed by a municipal appraiser—which were downloaded from the City of New Haven Geographic Information System website.[18] All parcels corresponded to one residential building, with the exception of four large complexes, including Complex A, where several component parcels were manually merged (appendix pp 1, 4). We assigned each patient's address either to the parcel that it fell directly within, or to the closest parcel up to a maximum of 100 m. In this manner, 11339 (99·2%) of 11429 emergency department visits were assigned to one of 10560 unique parcels. 1654 of these parcels had more than one emergency department visit. Parcels with more than one visit were used for all analyses, while parcels with one or fewer visits were excluded (table 2). By allocating census population estimates to each parcel in proportion to its total living area, we estimated that 32681 people lived in these parcels (appendix p 4).

External validation of model predictions

Although there are no independent, city-wide measures of housing conditions, housing that is owned or subsidised by HUD is legally required to pass independent Real Estate Assessment Center (REAC) inspections to demonstrate that it is decent, safe, and sanitary.[19] REAC inspections occur every 1–3 years, with the frequency of inspections based on scores from previous years and whether any complaints or grievances have been filed. Inspections are scheduled with notice and follow a standardised evaluation of the building site, building exterior, building systems, dwelling units, common areas, and health and safety.[19] These inspections provide a quantitative assessment of housing conditions. Inspection scores range from 0 to 100 and are publicly available. Scores between 90 and 100 are considered great scores, scores between 80 and 89 are considered acceptable, and scores of 79 or less indicate areas of concern. We linked REAC inspection scores for 2015–19 (appendix p 5) to parcels by using the same spatial join procedure used to link patients to parcels, described in the previous section. This resulted in REAC scores, modelled as a continuous variable, for 62 parcels (28 public and 34 subsidised, designated as Complex A to Complex K2; table 2), which were used as a ground truth dataset to validate model predictions made across all 1654 parcels.

Computing asthma exacerbation incidence

We hypothesised that parcels with higher-than-expected emergency department use for asthma represented parcels with poor housing conditions and concomitant elevated exposure to indoor allergens. To test this hypothesis, we examined the relationship between asthma emergency department use incidence and the minimum (worst) inspection score for each complex over the study period using Pearson's correlation (appendix p 5). Inspection scores were available for 62 HUD-owned or subsidised complexes that had more than one emergency department visit for asthma over the study period. We computed asthma emergency department use incidence using the estimated population per parcel and the total number of emergency department visits from patients from that parcel (appendix p 5). We then calculated a composite estimate of the incidence of emergency department use for asthma (appendix p 5), which captures both number of patients and number of visits, defined as the ratio of the product $N_V \times N_P$ to $\log_2(P)$, where N_V is the estimated mean number of visits per patient, N_p is the number of patients, and P is the estimated population, all calculated at the parcel level.

Controlling for patient and neighbourhood demographics

We linked parcels to neighbourhood demographic data from the 2014–18 5-year American Community Survey (ACS). Census blocks are the smallest geographical unit used by the Census Bureau and often refer to a single city block in a major metropolitan area. Of the 279867 parcels in New Haven County, 264989 (94·7%) were within a census block and joined to an ACS tract using a spatial join. We identified neighbourhood demographic variables[20] (appendix p 7) and obtained estimates aggregated at the census block level for race, ethnicity, median household income, median age, proportion of residents with limited English proficiency, proportion of vacant homes, and crowding (proportion of homes with more than one person per room; appendix p 7). We also incorporated proximity to major roadways, an additional known environmental factor that contributes to asthma morbidity.[21] To examine the role of neighbourhood, control for neighbourhood impact, and isolate the effect of housing, regressions incorporate neighbourhood-level variables (such as the racial make-up of the neighbourhood), overall socioeconomic status, and the percentage of renter-occupied homes.

We used electronic health record data to control for individual demographic differences of housing units at the parcel level (appendix p 7). For each parcel, we used generalised linear mixed models to estimate the average age; proportion of individuals in each racial and ethnic demographic category; proportion of each gender; proportion of individuals reporting smoking, drinking alcohol, or use of illicit drugs; and insurance type, as a proxy for socioeconomic status. We fit two regression models—a linear regression model and a non-linear random forest regression model—to produce asthma emergency department use incidence adjusted for both neighbourhood-level and individual-level characteristics. In both models, the outcome variable was the asthma emergency department use incidence (defined above), and the predictor variables were all neighbourhood and individual characteristic variables. The residuals after fitting these models were used as the linear and non-linear adjusted incidence, respectively. Statistical significance was defined as $p<0·05$ and 95% CIs were calculated.

Estimating advance warning of poor conditions

To identify poor-quality housing before problems become severe, we estimated how far in advance of documented poor conditions the model could identify elevated rates of asthma, using a sliding-window approach (appendix p 9). We recomputed adjusted and unadjusted estimates of asthma emergency department use incidence with data for emergency department patients treated within a window period of 1 year, which was shifted in monthly increments along the study period, so that at each timepoint, only data from the previous year was included in the model. The time in days (dt) in advance of an inspection was defined as the earliest timepoint at which incidence rose above a cutoff, defined as the 90th percentile of all parcels. We defined a true positive as a housing complex where the prior estimated incidence rate in the lead up is above this threshold and the REAC inspection score is below 80, indicating a level of unsatisfactory conditions that require the inspection team to return within 12 months.[22] False positives, conversely, are when the model identifies risk for that housing complex, but the HUD inspection returns an acceptable score (80 or higher; appendix p 9). True negatives refer to a complex with an acceptable score that was not flagged by the model as high risk, whereas false negatives had unsatisfactory scores but were not flagged by the model.

All analyses were done using R version 4.0.3.

Role of the funding source

The funder had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

11429 asthma-related emergency department visits by 6366 unique patients (table 1) were included in the analysis. The mean age was 32·4 years (12·8), 3836 (60·3%) patients were female, 2530 (39·7%) were male, and 3461 (54·4%) were Medicaid insured. Black patients (2651 [41·6%]) were overrepresented relative to the demographics of New Haven (36·6% Black).[12] There were 10560 unique parcels with at least one asthma emergency department visit (of which 1654 parcels had more than one visit and were included in the regression analyses), geographically distributed throughout New Haven (table 2). However, there was an increased density of visits from people living in low-income neighbourhoods with majority Black and Latinx residents (appendix p 3). For Complex A, the observed number of unique patients with asthma who visited the emergency department was 50·4 (95% CI 50·0–50·9) higher than the expected value based solely on parcel population—the greatest difference of all parcels in the city (appendix p 5).

For the 62 public and subsidised complexes for which REAC scores were available, asthma burden and housing complex REAC inspection score were significantly negatively correlated (Pearson's r=−0·47 [95% CI −0·64 to −0·24], p=1·4 × 10^{-4} for visits; r=−0·51 [−0·67 to −0·30], p=2·3 × 10^{-5} for unique patients); housing complexes with the highest numbers of emergency department asthma visits and unique patients had the lowest physical inspection scores (appendix p 5). A composite weighted average accounting for both the number of visits and the number of unique patients from a parcel ($A=N_p \times N_V / \log_2[P]$) was even more strongly correlated with lower inspection scores (r=−0·55 [−0·70 to −0·35], p=3·5 × 10^{-6}; figure 2A; appendix p 5).

The association between inspection scores and asthma emergency department use persisted after adjustment for both patient-level and neighbourhood-level demographics within and around each parcel (across all 1654 parcels with more than one emergency department visit) when using a linear regression model (r=−0·54 [−0·69 to −0·33], p=7·1 × 10^{-6}; figure 2B) and non-linear regression model (r=−0·44 [−0·62 to −0·21], p=3·8 × 10^{-4}; figure 2C). Crude estimates of emergency department use were higher for public housing residents, but not after adjustment using the non-linear model (appendix p 7), indicating that their higher use is associated with a different mix of residents. Notably, of the parcels with the top three incidence rates (the same complexes in all models), all have since been closed or demolished (figure 2).

Emergency department asthma visit rates for Complex A were elevated throughout the study period, while for Complex D1 (a subsidised complex of comparable size), estimates hovered near zero throughout, a so-called true negative (figure 3A, B). Adjusted and unadjusted estimates produced highly specific warnings of a low HUD inspection score a mean 351·7 days in advance, with no significant differences in the length of advance warning between models (figure 3C). Using unadjusted estimates, two complexes were classified as false positives (appendix p 9), and in the non-linear adjusted model, there was a third false positive. The calculated specificity of the non-linear adjusted model was 92·3% (figure 3D). On the other hand, all models produced several false negatives, resulting in low sensitivity, although sensitivity was higher in the unadjusted model (23·5%) than in the adjusted models (17·6% for linear and 11·8% for non-linear; figure 3D). Qualitative visual examination of the spatial distribution of buildings with high emergency department use showed little obvious clustering (figure 4), emphasising the importance of assessing use at the individual building level, rather than at the level of neighbourhood or zip code.

Sensitivity analysis of n (the minimum number of patients per housing unit included in the models) showed improved performance for larger n (assessed by correlation with minimum HUD inspection score for each parcel) up to a maximum of $r=-0{\cdot}79$ (n=10). Thus, although the model performs well across all parcels, it is most accurate for parcels in which many patients are observed (appendix p 10).

Discussion

We found that geospatial analysis of emergency department asthma visits in a large, urban health system can identify poor housing conditions approximately a year before a housing complex fails an HUD inspection. Our results show high specificity for poor housing conditions, making our model a potentially useful public health and social service tool to direct housing inspections and protect residents' health. Several housing complexes identified by this model as having poor conditions not only failed inspections, but were also subsequently deemed uninhabitable and have been, or are slated for, demolition or major repairs (figure 2).[23,24]

This proof-of-concept analysis shows that geospatial analysis of emergency department asthma visits can successfully identify poor quality housing in advance of current means of identification. Because HUD inspections occur on average every 760 days for public housing and 896 days for HUD-subsidised housing in Connecticut, these values impose a ceiling on the maximum early warning the model can indicate. Our estimates of advance warning are likely to be conservative: that is, they are underestimates of the true benefit in early warning achievable for market-rate rental or owneroccupied housing, which comprises the majority of housing and is not regularly or systematically inspected.

In most US jurisdictions, poor housing conditions are identified through complaint filing by tenants or by public housing inspections every 1–3 years. Tenants can file grievances about poor conditions outside of regular inspections. Previous work has shown that relying on complaints results in underreporting and delayed reporting, as many residents are reluctant to file a complaint for fear of landlord retaliation.[25,26] Indeed, complaint-based inspections are a source of discrimination,[26–28] the response time to complaints is often delayed, and inspections frequently result in no changes to identified unhealthy conditions.[28–30]

False positives in our model highlight the inadequacy of the current system. Specifically, Complex A was given a passing score (81) in 2014, which is counter to the well documented poor conditions cited in resident complaints. Indeed, there was outcry from tenants and city officials over the misleading nature of the passing HUD inspection score.[31] This false positive is, in reality, a true positive, as the model showed elevated asthma visits from Complex A, despite the first acceptable HUD inspection score, which was followed by a lower, failing score of less than 60. In the case of the second false positive in our model, the score on the inspection was 80: the cutoff for concerning conditions. The third false positive in the adjusted estimates is likely to be related to an underestimation of the number of people living in the building, and thus an overestimate of the rate of emergency department visits per occupant, due to the building being very large (16 stories) but the available parcel value being incorrectly noted ($2 million; appendix p 9). Therefore, the calculated specificity of 92·3% probably underestimates the accuracy of the model estimates of housing-associated risk.

Development of asthma and asthma exacerbations are associated with both individual-level and neighbourhood-level factors.[5] Our research builds on existing literature showing the association between housing quality and asthma, and housing code violations and acute care use for asthma. Beck and colleagues[16] showed that increased density of housing code violations in a census tract is associated with increased asthma-related emergency department visits and hospitalisations. Geospatial analysis of emergency department use can provide additional data that can support resident grievances, direct housing inspections, track improvements in housing quality, measure housing department performance, and inform funding allocation decisions. Our sensitivity analysis showed that model performance was best for large housing complexes where multiple residents used the emergency department (appendix p 9), making this approach most suitable for urban cores with high asthma rates.[7]

Our study maps the residual rate of emergency department visits for asthma not explained by race and income (approximated by insurance type). The inclusion of race in our model raises important considerations. Race in itself is not a risk factor for asthma; however, structural racism, the racialisation of the built environment, and racialised poverty produce higher incidence and prevalence of asthma among people who are Black or Latinx or have a low income.[32] The question of whether to adjust for race, then, is not straightforward. Because structural racism results in an increased proportion of people of colour in substandard housing, and exposure to environmental risk factors for developing asthma, controlling for race could potentially eliminate any observed effect due to an increased expected asthma prevalence, thereby potentially concealing health inequities and missing locations of poor housing conditions. Our model, then, would be reinforcing and reproducing structural racism. Although adjusting for race in our model did not qualitatively change our results, it remains an important consideration in model construction and interpretation and has real-life implications. In the court case proceedings about Complex A, the landlord's defence team argued that there was no evidence of increased asthma prevalence among Complex A residents because there was an expected higher prevalence of asthma among people who are Black or Latinx or have low income.[15] To the contrary, we found that asthma burden at Complex A was the highest of any housing complex in the city (figure 2; appendix p 5).

Events at Complex A illustrate the consequences of substandard conditions brought about by so-called demolition by neglect,[33] an economic imperative in which landlords are incentivised to neglect properties, either to avoid paying for repairs or, as in the case of Complex A, because of the potential profits to be realised if the property is condemned and low-income tenants of subsidised housing can be replaced with higher-paying market-rate tenants. Marginalised tenants most at risk of asthma often face dismissal of their concerns, as shown by the case of Complex A. Given the known delays in complaint-based inspections, there is a clear need for proactive, early identification of sites with dangerous indoor exposures.[3,8,28] Our findings identify a new type of epidemiological evidence for proactive inspections to improve housing conditions.

As a proof of concept, our study was strengthened by being conducted in an area with high asthma burden and by the use of comprehensive emergency department asthma visit data from the sole provider of emergency care in Greater New Haven. The model might not be as effective in areas with lower population density or with lower asthma prevalence. Given that an emergency department visit is a relatively rare event, our model depends on observing such visits with adequate frequency, and might be less effective at identifying small residences or places with fewer occupants. Furthermore, many regions are served by multiple emergency departments without comprehensive health information exchanges. Generalising to metropolitan areas without integrated health record systems will require the integration of data from multiple sources. In the USA, near-real-time, longitudinal syndromic surveillance data from over 70% of emergency departments in 49 states is integrated through the Center for Disease Control and Prevention's BioSense platform.[34] State health departments currently use BioSense to identify infectious disease outbreaks, changes in occupational injuries, and increases in overdose, and the platform could be one avenue by which to widely apply this model.

Although the REAC physical inspection scores provide an invaluable dataset with which to validate our estimates, questions have been raised about the accuracy of the REAC inspection process, noting that HUD has often given passing scores to housing units with poor conditions.[22,35] Because we did not have access to housing quality data for private housing, we were also unable to validate our comparison of the differences between public and subsidised housing and private housing in detecting unhealthy housing. Another important limitation is that our analysis is specific to building parcels and does not consider detailed individual-level variables such as housing instability or houselessness, which are also contributors to asthma exacerbations. We also did not have access to other socioeconomic indicators in the electronic health record and were limited to using insurance status as a proxy indicator. Although insurance status is widely used as a proxy for socioeconomic status,[36] other individual-level factors not included in this analysis could influence emergency department asthma visits.

Finally, while our model is highly specific, its sensitivity is limited. Not everyone having an asthma exacerbation goes to the emergency department. Some, for example, might be managed as an outpatient by their primary care provider or in urgent care. The sensitivity of the model could be improved by adding primary care visits. However, specificity is the appropriate measure to use to trigger an inspection or housing remediation.

Despite these limitations, our study shows the potential of using emergency department visits for asthma as an indicator for public health intervention. Emergency care use data for asthma are a leading ex-ante indicator of poor housing conditions, and emergency department visits are elevated approximately 1 year before a concerning housing inspection score. This approach represents a novel method of early identification of dangerous housing conditions, which could aid in the prevention of asthma-related morbidity and mortality.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Data sharing

De-identified study data and analytic code will be made available upon request following publication and ending three years following article publication to researchers by request to the corresponding author and at the discretion of the research team.

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Research in context

Evidence before this study

Previous research has shown that housing quality is a key determinant of asthma incidence and severity. Housing quality characteristics that impact development and progression of asthma include mould and pests, structural building problems (eg, water leaks), and poor air quality (eg, dampness and other airborne particulate matter). Interventions aimed at improving neighbourhood and housing conditions that produce indoor allergens have been shown to reduce emergency department use for asthma. Less well studied, however, is the reverse scenario, investigating whether emergency department asthma use can be used to identify unhealthy housing conditions at the building level. In existing literature, asthma-related emergency department visits and hospitalisations have been mapped to the level of census blocks and neighbourhoods (eg, one study showed that increased density of housing code violations in a census tract is associated with increased asthma-related emergency department visits and hospitalisations). We conducted an initial search for literature between Jan 15, 2018, and May 31, 2019. At that time, we searched MEDLINE and Google Scholar for articles published in English to identify studies that examined identification of poor housing quality and emergency department use for asthma at the building level. Search terms, used alone and in combination, included “emergency department utilization”, “emergency department visits”, “hospitalization”, “asthma”, “asthma exacerbation”, “housing”, “public housing”, “social determinants of health”, “health inequities”, “health disparities”, “hot spots”, and “neighborhood”. We conducted subsequent, brief literature reviews to determine whether new literature had been published during the conduct of the study, in November, 2019, March, 2020, May, 2021, and January, 2022. Our searches revealed few quantitative research studies examining the association between emergency department use for asthma and neighbourhood and census block characteristics, but did not yield any research examining the association between emergency department visits for asthma and housing quality.

Added value of this study

Previous studies have examined neighbourhood-level associations with acute care use for asthma, but, to our knowledge, this study is the first to examine whether poor housing quality can be identified by analysing emergency department use for asthma at the building parcel level, taking into account size of housing complex and estimated residents per parcel. This study also used public housing inspection scores to validate study findings, which had not previously been done. We also examined whether there is a temporal relationship between increased emergency department visits for asthma and housing code inspection scores. We found that increased emergency department visits for asthma are strongly correlated with lower housing inspection scores, and that a geospatial analysis of emergency department asthma visits can identify poor housing conditions approximately 1 year before a housing complex fails a housing inspection. Our results show high specificity for poor housing conditions, making our model a potentially useful public health and social service tool. Scaling this analytic approach could proactively identify potentially unhealthy housing and direct housing inspections by municipalities or community-based organisations. This could help to decrease reliance on complaint-based inspections and be a useful tool to protect the health of people living in public, subsidised, or rental housing.

Implications of all the available evidence

Emergency care use data for asthma are a leading ex-ante indicator of failed public housing inspections, and visits are elevated at least 1 year before a concerning housing inspection score. Geospatial analysis of emergency department use for asthma can provide additional data that can be used to support resident grievances, direct housing inspections, track improvements in housing quality, measure housing department performance, and inform funding allocation decisions. This approach represents a novel method of early identification of dangerous housing conditions, which could aid in the prevention of asthma-related morbidity and mortality.

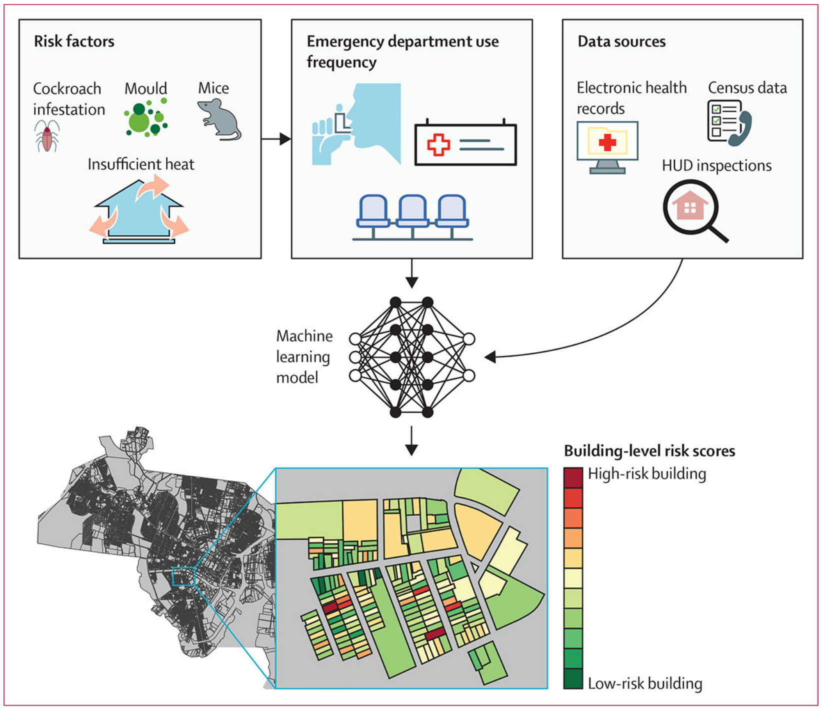

Figure 1: Schematic of research design

Indoor exposures associated with low-quality housing can exacerbate asthma. A statistical model trained on emergency department visits for asthma, along with individual-level and neighbourhood-level predictors, can identify the location of dangerous housing. HUD=US Department of Housing and Urban Development.

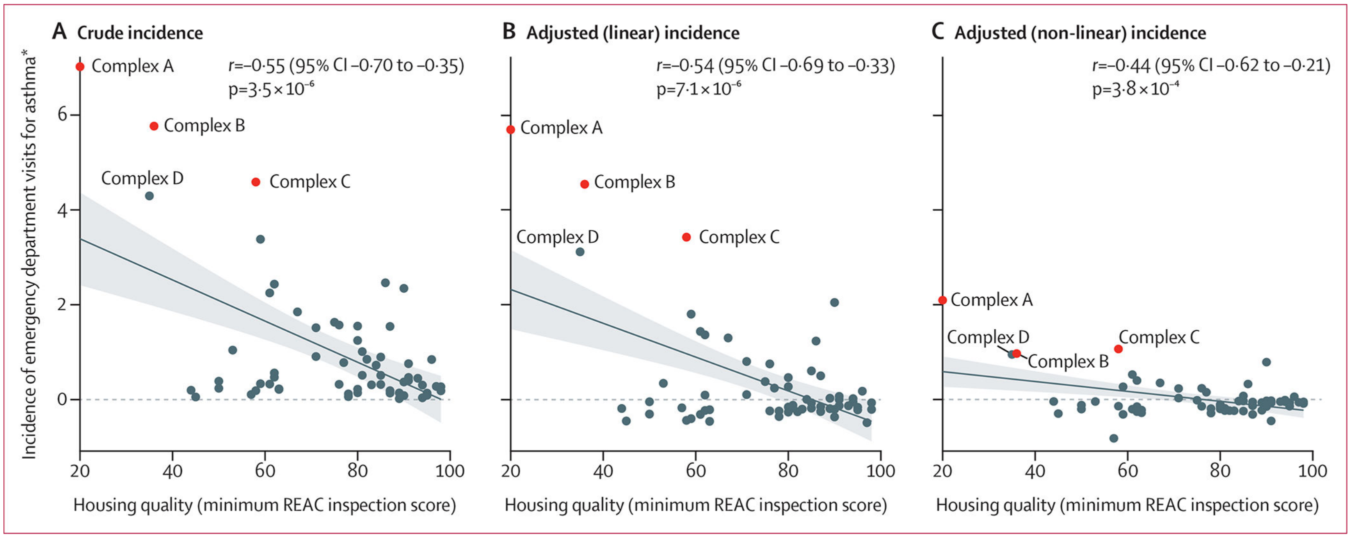

Figure 2: Association between incidence of emergency department use for asthma and HUD physical inspection scores

Scatter plots show the minimum REAC inspection score and model risk estimates for each HUD-subsidised or public housing complex (each represented as a point on the graphs). Of the four housing complexes with the highest incidence rates (complexes A–D), three are complexes that have since been closed or demolished (red points). The line and shaded region in each graph represent the trend and 95% CI. (A) Crude estimated incidence of emergency department use for asthma. (B) Adjusted (linear) estimated incidence of emergency department use for asthma (for all included variables, see appendix pp 7, 11). (C) Adjusted (non-linear, random forest regression) estimated incidence of emergency department use for asthma. HUD=US Department of Housing and Urban Development. REAC=Real Estate Assessment Center. *Composite estimate $N_v \times N_p/\log_2(P)$, where N_v is the estimated mean number of visits per patient, N_p is the number of patients, and P is the estimated population, all at the parcel level.

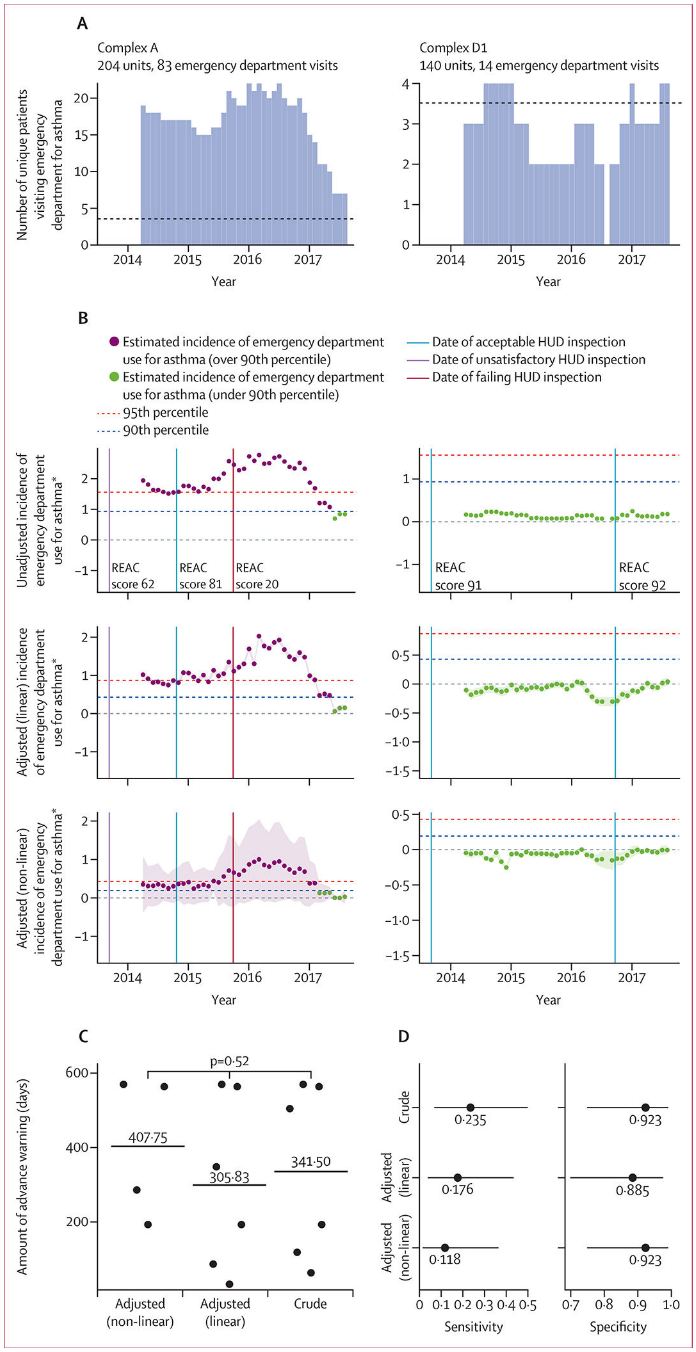

Figure 3: Temporal relationship between incidence of emergency department use for asthma and housing inspection scores

(A) Raw emergency department patient counts in 1-year sliding windows with monthly increments (such that counts and rates are computed at monthly intervals using 1 year of data each time). The black line is the expected emergency department visit count for a complex of that size. (B) Crude and adjusted monthly incidence of emergency department visits for asthma for Complex A (left) and a true negative housing complex, Complex D1 (right), from 2014 to 2017. Coloured vertical bars indicate the dates of HUD inspections classified as acceptable (REAC score 80–100), unsatisfactory (60–80), or failing (<60). (C)

Time in days between the earliest warning of elevated incidence of emergency department use for asthma (with elevated defined as a rise in incidence above the 90th percentile) and a HUD inspection, calculated for true positive complexes only (ie, those in which emergency department use for asthma was high and the HUD inspection score indicated poor conditions). Dots represent individual true positive complexes and horizontal bars show the mean. (D) Accuracy metrics for incidence of emergency department use for asthma as a leading indicator of a failed HUD inspection. Error bars are 95% CIs. HUD=US Department of Housing and Urban Development. REAC=Real Estate Assessment Center. *Composite estimate $N_V \times N_p / \log_2(P)$, where N_V is the estimated mean number of visits per patient, N_p is the number of patients, and P is the estimated population, all at the parcel level.

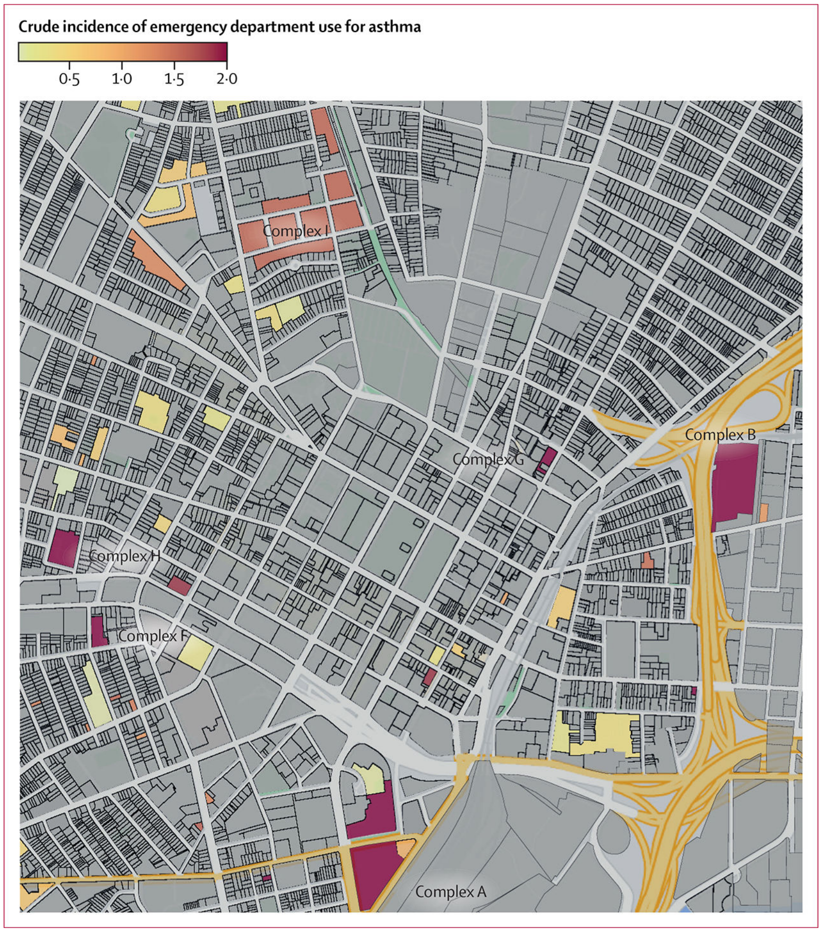

Figure 4: Spatial distribution of asthma incidence rates at the parcel level

Choropleth map overlaid on a road map of downtown New Haven, showing each parcel boundary, coloured by the estimated crude incidence of asthma emergency department use, or grey if no patients were observed. The locations of several housing complexes with high incidence, including Complex A, are marked. Map data © 2022 Google.

Table 1:

Demographic characteristics of patient cohort who visited the Yale New Haven Hospital emergency department for an asthma-related concern, 2013–17

	Overall (N=6366)	Age <18 years (N=2048, 32·2%)	Age 18–40 years (N=1867, 29·3%)	Age 40–65 years (N=1859, 29·2%)	Age 65–80 years (N=417, 6·6%)	Age 80–99 years (N=175, 2·7%)
Mean emergency department visits per patient	1·82 (2·47)	1·65 (1·64)	1·97 (3·18)	1·94 (2·56)	1·66 (2·09)	1·35 (1·11)
Sex						
Female	3836 (60·3%)	841 (41·1%)	1226 (657%)	1310 (70·5%)	321 (77·0%)	138 (78·9%)
Male	2530 (39·7%)	1207 (58·9%)	641 (34·3%)	549 (29·5%)	96 (23·0%)	37 (21·1%)
Ethnicity						
Hispanic or Latinx	1922 (30·2%)	715 (34·9%)	592 (31·7%)	503 (27·1%)	89 (21·3%)	23 (13·1%)
Non-Hispanic and non-Latinx	4415 (69·4%)	1323 (64·6%)	1270 (68·0%)	1345 (72·4%)	327 (78·4%)	150 (85·7%)
Other or unknown	29 (0·5%)	10 (0·5%)	5 (0·3%)	11 (0·6%)	1 (0·2%)	2 (1·1%)
Race						
Asian	47 (07%)	21 (1·0%)	13 (0·7%)	8 (0·4%)	4 (1·0%)	1 (0·6%)
Black or African American	2651 (41·6%)	903 (44·1%)	828 (44·3%)	775 (41·7%)	117 (28·1%)	28 (16·0%)
Native American	19 (0·3%)	3 (0·1%)	8 (0·4%)	8 (0·4%)	0	0
Native Hawaiian or Pacific Islander	20 (0·3%)	4 (0·2%)	6 (0·3%)	9 (0·5%)	1 (0·2%)	0
Other or unknown	1648 (25·9%)	635 (31·0%)	498 (26·7%)	415 (22·3%)	77 (18·5%)	23 (13·1%)
White	1981 (31·1%)	482 (23·5%)	514 (27·5%)	644 (34·6%)	218 (52·3%)	123 (70·3%)
Insurance						
Medicaid	3461 (54·4%)	1427 (69·7%)	1086 (58·2%)	896 (48·2%)	49 (11·8%)	3 (1·7%)
Commercial	1770 (27·8%)	528 (25·8%)	475 (25·4%)	566 (30·4%)	158 (37·9%)	43 (24·6%)
Medicare	602 (9·5%)	0	58 (3·1%)	218 (11·7%)	199 (47·7%)	127 (72·6%)
Other or unknown	479 (7·5%)	77 (3·8%)	229 (12·3%)	161 (8·7%)	10 (2·4%)	2 (1·1%)
Self-pay	54 (0·8%)	16 (0·8%)	19 (1·0%)	18 (1·0%)	1 (0·2%)	0
Cigarette smoking						
Yes	1607 (25·2%)	19 (0·9%)	779 (41·7%)	764 (41·1%)	45 (10·8%)	0
No	3425 (53·8%)	855 (41·7%)	999 (53·5%)	1043 (56·1%)	358 (85·9%)	170 (97·1%)
Unknown	1334 (21·0%)	1174 (57·3%)	89 (4·8%)	52 (2·8%)	14 (3·4%)	5 (2·9%)
Alcohol use						

	Overall (N=6366)	Age <18 years (N=2048, 32·2%)	Age 18–40 years (N=1867, 29·3%)	Age 40–65 years (N=1859, 29·2%)	Age 65–80 years (N=417, 6·6%)	Age 80–99 years (N=175, 2·7%)
Yes	1030 (16·2%)	7 (0·3%)	475 (25·4%)	439 (23·6%)	83 (19·9%)	26 (14·9%)
No	3896 (61·2%)	782 (38·2%)	1290 (69·1%)	1354 (72·8%)	328 (78·7%)	142 (81·1%)
Unknown	1440 (22·6%)	1259 (61·5%)	102 (5·5%)	66 (3·6%)	6 (1·4%)	7 (4·0%)
Illicit drug use						
Yes	258 (4·1%)	12 (0·6%)	177 (9·5%)	64 (3·4%)	5 (1·2%)	0
No	4629 (72·7%)	760 (37·1%)	1585 (84·9%)	1716 (92·3%)	401 (96·2%)	167 (95·4%)
Unknown	1479 (23·2%)	1276 (62·3%)	105 (5·6%)	79 (4·2%)	11 (2·6%)	8 (4·6%)

Table 2:

Aggregate demographics of parcels included in regression models

	Overall (N=1654)	Market-rate rental housing (N=1592)	Public housing (N=28)	Subsidised housing (N=34)
Age, years	41·3 (12·8)	40·9 (12·4)	46·3 (15·8)	54·1 (18·7)
Sex, % *				
Female	56·7% (2·0)	56·6% (1·9)	58·9% (3·6)	57·8% (3·7)
Male	43·3% (2·0)	43·4% (1·9)	41·1% (3·6)	42·2% (3·7)
Race, % *				
Asian	0·3% (0·1)	0·3% (0·1)	0·3% (0·0)	0·3% (0·1)
Black	38·3% (31·3)	37·6% (31·2)	60·9% (20·8)	51·9% (34·4)
Native American	0·2% (0·0)	0·2% (0·0)	0·2% (0·0)	0·2% (0·0)
Native Hawaiian or Pacific Islander	0·2% (0·0)	0·2% (0·0)	0·2% (0·0)	0·2% (0·0)
Other or unknown	17·1% (16·8)	17·2% (16·7)	16·1% (11·5)	16·4% (23·5)
White	34·1% (29·4)	34·4% (29·4)	19·0% (19·7)	29·9% (30·4)
Ethnicity, % *				
Hispanic or Latinx	21·7% (24·2)	21·8% (24·3)	20·9% (14·3)	19·8% (27·4)
Non-Hispanic and non-Latinx	78·2% (23·1)	78·2% (23·1)	79·0% (14·3)	78·7% (27·4)
Other or unknown	0·4% (0·0)	0·4% (0·0)	0·4% (0·0)	0·4% (0·1)
Insurance, % *				
Medicaid	42·9% (22·1)	42·8% (21·9)	54·7% (24·0)	40·5% (23·7)
Medicare	19·3% (11·7)	19·0% (11·4)	23·7% (16·7)	29·1% (18·2)
Commercial	26·6% (12·1)	26·8% (12·1)	18·2% (10·1)	24·9% (13·2)
Other or unknown	3·6% (2·3)	3·6% (2·3)	3·3% (1·3)	3·5% (2·3)
Self-pay	0·4% (0·1)	0·4% (0·1)	0·4% (0·1)	0·4% (0·0)
Cigarette smoking, %				
Yes	25·4% (9·7)	25·2% (9·5)	33·0% (13·8)	25·0% (11·4)
No	60·6% (10·2)	60·7% (10·1)	54·9% (12·4)	64·6% (12·2)
Other or unknown	10·4% (3·6)	10·4% (3·5)	11·0% (5·9)	9·3% (4·6)
Alcohol use, % *				
Yes	17·7% (3·4)	17·7% (3·3)	15·9% (4·1)	15·1% (4·1)
No	68·5% (5·0)	68·4% (4·9)	71·1% (6·8)	74·1% (7·3)
Other or unknown	11·5% (4·1)	11·5% (4·0)	12·3% (7·7)	9·7% (4·3)
Illicit drug use, % *				
Yes	2·2% (0·9)	2·2% (0·9)	2·92% (1·6)	2·4% (1·4)
No	83·9% (3·5)	83·9% (3·4)	83·0% (6·9)	85·6% (4·7)
Other or unknown	12·8% (3·7)	12·8% (3·6)	13·2% (6·8)	11·1% (4·1)
Distance to freeway, km	1·3 (0·9)	1·3 (0·9)	0·9 (0·7)	1·4 (0·7)
Estimated population per parcel	19·8 (68·2)	15·5 (54·1)	133·4(148·4)	123·3(226·5)

Data are mean (SD) across parcels. Included parcels were those in which more than one patient visited the Yale New Haven Hospital Emergency Department for an asthma-related concern between 2013 and 2017.

*Proportion of residents within a parcel.

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