HEALTH IMPACTS OF MICROENVIRONMENTS IN THE SUMMER

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ABSTRACT: Economically deprived communities in urban areas face disproportionately significant health risks; children and the elderly are particularly affected. While socioeconomic factors are commonly associated with health disparities, the role of the outdoor environment, especially during extreme *heat* events, has been less frequently studied. This research investigates the heat stress index (HSI) and ultrafine particle (UFP) exposure in 24 microenvironments. The data were recorded during an extreme heat event in 2016; the goal was to better understand how residents experience environmental exposure as a part of their daily routine when the boundaries between microenvironments are repeatedly crossed. Additionally, a statistical analysis of such exposure along both spatial and temporal scales is presented here, in order to assess the dual roles of development patterns and overlapping loci of social interactions within these microenvironments. The results of this study shows that HSI and UFP exposure varies in space and time. The HSI in 54% of the microenvironments tested was within the danger zone identified by the National Weather Service (104°F to 124°F), while the remaining 46% of the microenvironments fell within the extreme caution zone (91°F to 103°F). The average five minute walk among these microenvironments indicated that 70% of the time, residents would be subjected to a danger zone, and the remaining 30% of the time they would fall within extreme caution conditions. The average UFP exposure varied from 7,633 to 34,751 particles/cm3. Microenvironments with a high percentage of sealant surfaces and lack of vegetation showed increased HSI values; close proximity to traffic and the freeway further elevated HSI and UFP exposure. These results are useful in understanding the health outcomes previously recorded by a community health survey in which heat and respiratory illnesses were substantial. The evidences presented here provide crucial context-specific information for re/designing urban communities to minimize health disparities.

KEYWORDS: microenvironment, development pattern, heat stress index, ultrafine particle exposure, low-income communities

INTRODUCTION

Economically deprived communities in urban areas face disproportionately high health risks. Children and the elderly are particularly affected (CDC). In addition, due to increased heat and high precipitation/flash flooding, the general urban landscape and built environment make low-income communities particularly vulnerable to heat-related illnesses such as heat stress and stroke, and respiratory afflictions like asthma (D'Amato et al. 2015). Demographic factors such as race, gender, age, and income are frequently-cited denominators for negative health outcomes in socio-economically impoverished communities (Claudio, Stingone, and Godbold 2006, O'Neill 2005). However, the responses of such communities to these health outcomes are not consistent (Beck et al. 2014) and vary per geographic location and the associated context-specific impact (e.g., proximity to industry, freeways, brownfields, etc.). Conversely, the role of the urban landscape and built environment has been less frequently addressed in medical literature, particularly in terms of how these issues intertwine with the design of buildings and complexes, as well as their interaction with the environment and society as a whole.

If communities hope to improve upon this situation, then documenting such dis/associations is crucial and green buildings and the new urbanism movement (i.e., form-based zoning) that claim to improve health can be adopted. However, the financial hardship faced by the residents of low-income communities, as well as decades of ignorance regarding appropriate development by their political leadership, make it challenging to implement such strategies, mostly when it is a top-down approach. While there are examples of successful reform, the resulting inner-city gentrification (Checker 2011) is a major concern. For instance, when Cincinnati economically developed the Over the Rhine community, it gravely underestimated the displacement of local residents that would result (Addie 2008). Alternatively, bottom-up approaches such as do-it-yourself urbanism show promise (Kinder 2016); however, their success depends on occupants being provided with the necessary tools and support to implement resident-led change. Further, such efforts are gaining popularity in urban communities, the role of urban microenvironments within which the residents of low-income communities live, learn, play, and work continue to be poorly understood.

This study focuses on microclimates (Erell, Pearlmutter, and Williamson 2011), spaces between buildings and along sidewalks, green areas, street intersections, parking areas, and playgrounds within public housing complexes that are modified by development patterns such as land use, land cover, tree canopy, street network, building typology, or development density. Environmental exposure within such microenvironments varies, due to urban processes and infrastructure systems. Residents overlap with them as a part of their daily lives, but are unaware of how such interactions affect their health. A health survey conducted in a South Cumminsville community (Cincinnati 2016) reported that 61% of residents felt irritable in summer due to heat exposure where 60% residents spent less than nine hours indoors and 42% of local children used parking lots and vacant lots as play areas. Thus, understanding how microenvironments act as a context for design interventions is essential to successfully improving the quality of residents' health.

The overall goal of this research is to examine how low-income residents' health is affected by their urban landscape, built environment, system infrastructure, and social patterns. In service of this goal, this study seeks answers to questions such as: How does the urban landscape and built environment contribute to local health risks? What are residents' levels of environmental exposure within certain microenvironments during extreme heat events, in terms of the heat stress index and air pollution? How do social patterns affect environmental exposure? How do the data on microenvironments relate to and compare with the demographics and mental health records established in the case-study health survey?

1.0 THE CASE-STUDY COMMUNITY

The low-income community of South Cumminsville, located in the heart of Cincinnati, Ohio, was selected for this study because of its health concerns related to its increased exposure to heat, air pollution, and combined sewer overflow for the past 30 years. The existing urban landscape and built environment, which includes brownfields, empty warehouses, large parking lots, and facilities for the trucking industry, as well as proximity to a freeway and vacant buildings and lots, makes this location uniquely appropriate for this research. The study area was annexed by Cincinnati in 1873; at that time, it was known as Cumminsville. Subsequently, it was split into North and South Cumminsville by the construction of Interstate 74 in 1970. The east side of the study area is bounded by Mill Creek, certain areas of which are protected by the Mill Creek Conservatory. The west side of the study area is bounded by a hill and dense vegetation. The southwest is populated by low-income communities facing a fairly uniform level of development and health problems. Since construction of the freeway, the study area and vicinity have been adversely affected by flash flooding and traffic-related air pollution (TRAP). These phenomenon associated with health issues including heat stress, respiratory allergies and asthma guides the focus on outdoor environmental exposure.

South Cumminsville is one of the smallest of Cincinnati's 52 neighborhoods, with a population of 801 in 2010 (Census Bureau). The majority of the population is African American (93.5%); White (3.9%) and other races are marginal. The average household income is $15,357, which is less than a third of Hamilton County's median household income. Approximately 64% of the residents live at or below the poverty line. The majority of the households in South Cumminsville are headed by working class, single mothers. The majority of the population is female (53%) rather than male (47%). A study conducted by Cincinnati's Health Department reported that the residents of South Cumminsville had a life expectancy of 71.2 years, which is nearly 16 years less than residents of more affluent Cincinnati neighborhoods.

2.0 HEALTH SURVEY

Due to a lack of timely health data on the area, a health survey of randomly selected residents was conducted in 2015 (n=118, including children), in an effort to better understand the health issues faced by the community. This effort was a subset of the City of Cincinnati's "Project Cool It," funded by the Center for Disease Control and Prevention's Agency for Toxic Substance and Disease Registry (Cincinnati 2016). The survey collected neighborhood data and demographics such as gender, race/ethnicity, and age. In addition, respondents were asked to report their occupancy status (rent/own) and perceptions of their indoor and outdoor environments, so that researchers could investigate how self-perception of the environment might affect reported health outcomes. Respondents' average length of residency was 18.8 years; moreover, 52.2% (n=64) owned their own homes, 48.8% (n=52) rented, and the remaining data (from two residents) were missing. This trend is consistent with the 2010 Census data.

This work was an important first step towards creating a baseline health condition for perceived physical and mental health. Complementing above health survey, this research examines how development patterns create microenvironments that modify both actual and perceived health concerns; in service of this goal, researcher recorded the heat stress index (HSI) and ultrafine particulate (UFP) exposure levels. Based on the survey results, 61.5% (n=72) reported feeling irritable in the summer due to the heat, and 41.9% (n=56) and 42.1% (n=48) of the residents cited summer heat as the cause of changes to their mood and general health, respectively. Approximately 30.8% reported having asthma or another lung disease; while 75.4% (n=89) described owning an air conditioner, only 69.5% (n=82) indicated that they used their air conditioner in the summer months. Four residents cited the cost of electricity as their reason for non-use. The majority, 60.3% (n=70), reported spending less than nine hours a day indoors during the summer months. Importantly, 42.7% of the children (n=50) described using parking lots as a playground; this was followed in frequency by vacant lots, which were used by 35.7% (n=41) of the responding children. The majority of residents reported living within a one-block radius of a vacant building or lot and/or spilled chemicals. There was a greater level of variability in the respondents' self-perception of the outdoor environment; in particular, 56.8% (n=67) reported that greenspace was available to them, and 87.1% felt safe walking in their neighborhood during daylight hours.

3.0 DEVELOPMENT PATTERN

South Cumminsville was developed as an industrial corridor in the 1880s, due to its proximity to water and rail. The combination of light industry and residences allowed workers to live in close proximity to their jobs. Prior to this industrial development, the adjacent waterways of Mill Creek and West Fork Creek created a flood plain; in 1937, flooding destroyed so many businesses and residences that the land use pattern was indefinitely altered. Several flood control projects were subsequently implemented, and the current risk of flooding is significantly lower. However, the community continues to be impacted by small-scale flooding. Beyond the economic, social, and environmental consequences of urban flooding, the chronically wet houses are linked to increased respiratory problems (Reponen et al. 2013).

To investigate the role of the built environment on occupant health, the community development pattern of the study site was analyzed using a Geographical Information System (GIS). The 2015 dataset was made available by the City of Cincinnati's GIS department (CAGIS). Another element of the dataset, the physical attributes of the area's buildings, were available from the Hamilton County Auditor's records. Combining this information allowed the researcher to study development patterns such as land use, land cover, tree canopies, sealant surfaces, street networks, building typology and occupancy, and development density, among others. The intersection of development patterns with related urban systems such as traffic, sewer, and vegetation is also discussed below.

South Cumminsville covers 325.7 acres and is distributed across nine land uses: public service (43.7%), residential (11.47%), institutional (0.3%), mixed-use (0.13%), commercial (1.4%), public utility (1.6%), parks and recreation (7.8%), light industry (11.5%), and vacant (17.4%), as shown in Figure 1. The industrial zoning along the creek lacks vegetation and has a high number of impervious surfaces (roofs and parking lots) that increase the likelihood of flash-flooding. Approximately 42% of the land cover is impervious; it is concentrated near the creek on the east side of the study area (see Figure 1(a)), whereas a majority of the tree canopy (29%) is concentrated on the hillside, away from the creek (see Figure 1(b)). The topographical conditions, including the hills on the west side that slope towards the creek to the east, serve to increase the surface runoff. In addition, the combined sewer overflow (CSO) on the hillside releases surplus water from other areas into South Cumminsville. The result is that the land-use land-cover LULC, tree canopy, topographical conditions, and combined sewer overflow in the floodplain are creating hazardous conditions, resulting in a disproportionately high level of chronic illness in this community.

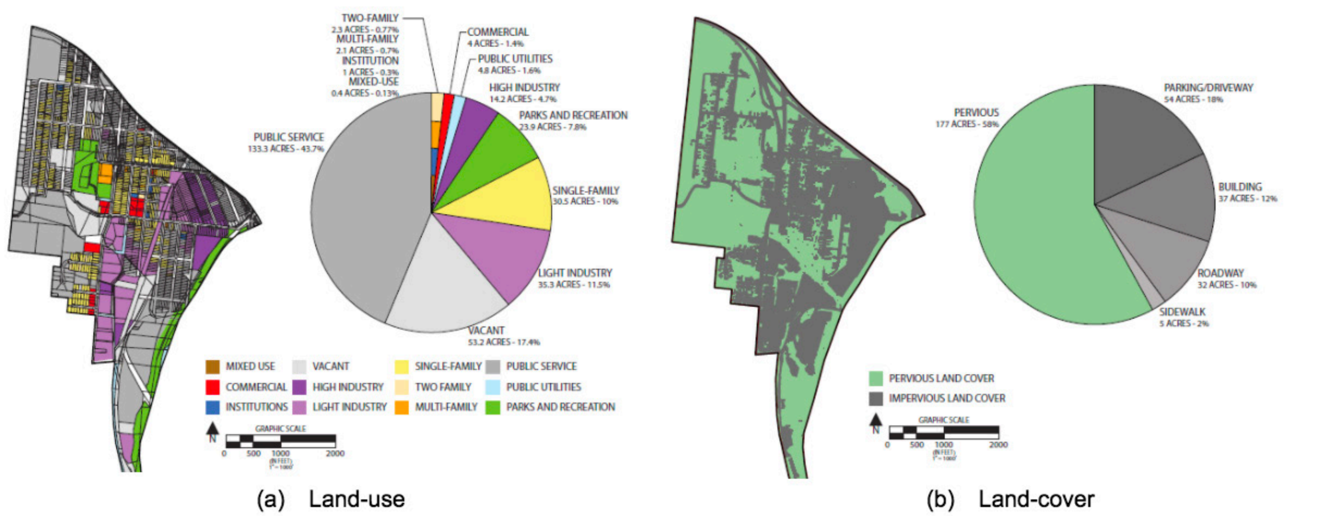

Figure 1. (a) Land-use and (b) Land-cover properties of South Cumminsville, Cincinnati, OH (2015).

3.1 Vacant lots and buildings

At the time of the 2010 Census, there were 422 total housing units, 110 of which were vacant. Fifty of these units were abandoned. Figure 2 illustrates the (a) vacant land, (b) vacant buildings, and (c) building uses in the community. The vacant lot and buildings map is regularly updated in response to foreclosures and demolition. Currently, the majority of independent residential development is located on the north side, on either side of Beekman Street. The south side hosts public housing projects and a few independent residences. The data also indicate that at the time of collection, 54% (n=168) were owner occupied, and 46% (n=144) were occupied by renters. Most residents were children under the age of 20 or middle-aged (45 to 49 for males and 50 to 54 for females).

The east side of Beekman Street, a prominent North-South street, hosts several industrial buildings. To date, approximately 30 sites have been identified as potential brownfields or appropriate for land reuse, including 58 acres of industrial land, three former oil refineries or oil warehouses, 15 acres of city-owned land (including one incinerator), two industrial properties on the city's demolition list, a former gas station adjacent to an elementary school, and other industrial structures used for metalworking, metal plating, chemical manufacturing, oil refining, and printing. One of the most prominent business is a trucking company, which has significantly increased truck traffic in the community.

As might be expected given the proximity of residential areas to vacant lots and industrial spaces, 59% of residents reported living within a ½ block proximity to vacant properties, and 23% lived within a 1 to 3 block radius of the same (11% within one block, 8% within two, and 4% within three). Approximately 7% of the respondents indicated that they did not live close to a vacant property, and 7% reported no knowledge of the topic. At the same time, 51% and 39% of the residents felt that they had “very easy” and “easy” access to greenspace, whereas only 11% indicated that greenspace was either not easy or very difficult to access.

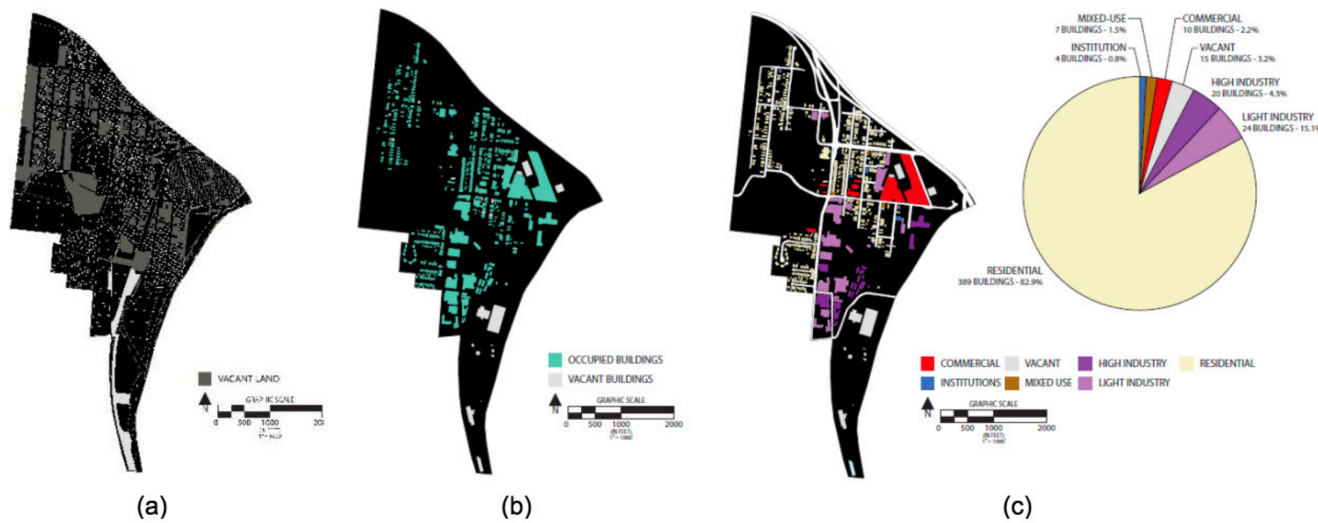

Figure 2: (a) Vacant land, (b) Vacant buildings, and (c) Building use.

3.2 Social Patterns

The use of impervious surfaces (such as parking lots, brownfields, and vacant lots) as playgrounds and areas to gather socially was a very common part of respondents’ daily routine, even though 90% reported easy access to the greenspaces. The majority of children indicated that they walked to the school, and that while doing so, they were on paved surfaces for between 5 and 20 minutes. To walk to school, students must travel along a major thoroughfare (Beekman Street), cross several street junctions (at Elmore St, Dreman St, and Millville Court), and wait near a number of parking lots (at residential, institutional, and commercial locations) at which TRAP levels are high. When not in school, a local non-profit organization, Working In Neighborhood (WIN), hosts a daycare center and uses their parking area for outdoor activities. Similarly, adults and children alike frequently use locally-owned shops, recreational areas, and open spaces along the Beekman corridor as sites for social gatherings. Youths, mostly unemployed, prefer to spend their recreational time in the industrial areas. According to the health survey, more than 60% of the residents reported spending less than nine hours a day indoors during the summer months. Home ownership, use of an air conditioner, and extremely hot indoor conditions during the summer months may all affect such behavior. Staying outside, however, increases exposure to heat stress and air pollution, depending on a resident’s location in the community. Therefore, understanding environmental exposure in terms of both space and time is critical to improving the health quality of the residents of this community. The following section examines environmental exposure in various microenvironments and its association with health stressors.

4.0 HEALTH STRESSORS

As suggested by the National Weather Service, the HSI and UFP exposure (Brandt et al. 2015, Brunst et al. 2015) were recorded as indicators of the heat and asthma-related diseases prevalent in the community. The data were collected on August 12, during the hottest week of 2016; air temperature and relative humidity were above 80°F and 40%, respectively. The second-by-second data were collected by walking around the selected community spaces in two loops; a total of 24 microenvironments were covered (see Figures 3(a) and 3(b)). The first loop was completed in the northern section of the community, where a majority of the single and multi-family residences are located. This area is closer to the freeway and consists of light and heavy industrial use. The data were recorded for a total of 45 minutes, beginning at 11:00 am. The second loop was completed in the southern part of the community, where an elementary school, recreation center, and several public housing projects are located. These neighborhoods are closer to the industrial land use spaces, empty warehouses, and vacant lots. The data were recorded for 15 minutes, beginning at 12:15 pm. Figure 3(c) illustrates the combined loops; the analysis of the recorded data is divided into two categories: space and time.

The HSI was measured using a Kestrel 5400 Heat Stress Meter (NWS 2017). A state-of-the-art portable ultrafine particle (PUFP) meter, developed by researchers at the University of Cincinnati, was used to record particles smaller than 0.1μm that could have a significant impact on respiratory health (Ryan et al. 2015). Currently, UFP levels are not recorded at any of the EPA's monitoring stations; often, particulate matter (PM) is used as a surrogate. Importantly, the lack of location-specific measurements prevents a thorough investigation of how this type of exposure is entangled with development, social, and infrastructure patterns. Without a thorough knowledge of HSI and UFP exposure in low-income communities, future designs for health-promoting environments will be unlikely to achieve their goal.

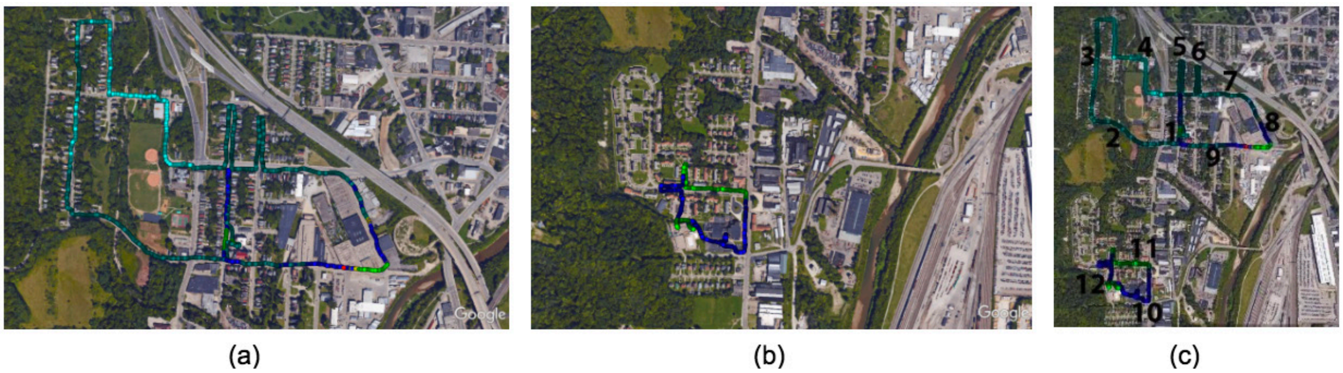

Figure 3: (a) Path traversed in Loop 1, (b) Path traversed in Loop 2, and (c) The combined loops.

4.1 Heat Stress Index

The average HSI on a spatial scale is shown in Figure 4(a). The HSI in 54% (n=13) of the microenvironments fell within the danger zone (104°F to 124°F), according to the heat index scale provided by the National Weather Service (NWS 2017); the remaining 46% (n=11) of the microenvironments were within the extreme caution range (91°F to 103°F). HSI levels in this range can cause heat stroke, dehydration, and exhaustion, the primary causes of heat-related admissions to hospital emergency rooms and heat-related deaths (Hess, Saha, and Luber 2014, Klinenberg 1999, Sheridan and Lin 2014). In the study area, microenvironments such as street intersections, parking lots, and sidewalks along busy streets were all found to fall within the danger zone; such areas have a high percentage of surfaces covered in sealant, are in close proximity to anthropogenic heat (such as traffic), and lack a tree canopy. For example, the intersection of Beekman Street and Millville Court had the highest recorded HSI at 115.78°F, whereas a parking lot near the elementary school and public housing, almost empty at the time of data collection, was at just above 108°F. The HSI values along the sidewalks close to parking lots and industrial areas, and along streets with frequent traffic, were also high (i.e., within the range of 104°F to 108°F).

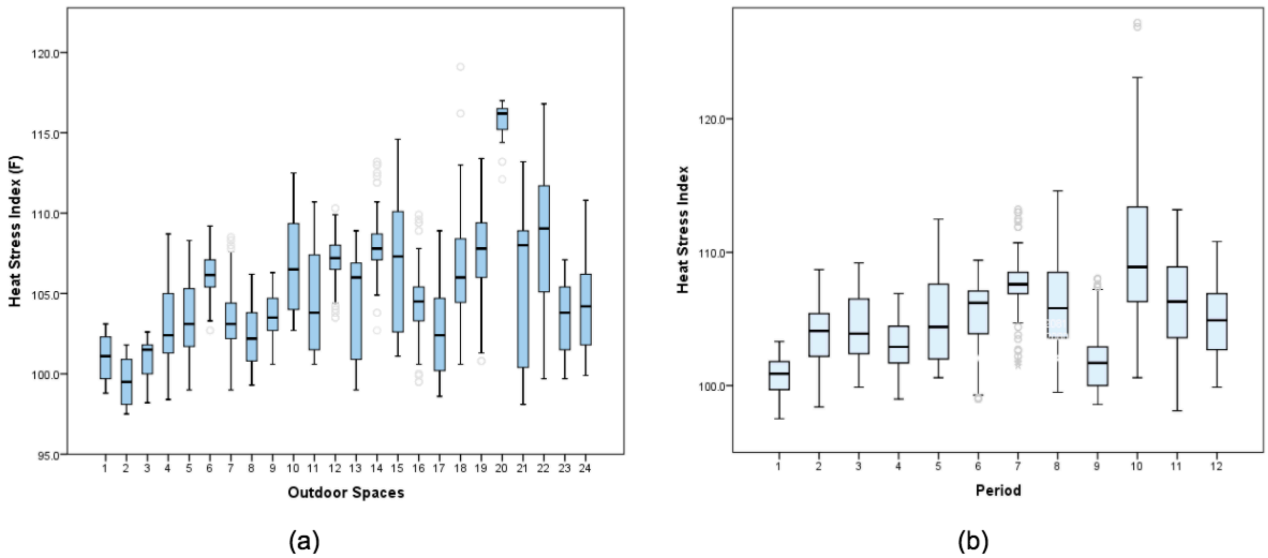

Figure 4: Heat stress indices: (a) Spatial distribution of HSI, and (b) Temporal distribution of HSI, averaged over 5-minute intervals *(Outdoor Spaces - 1: Parking lot at WIN, 2: Dreman Avenue (WIN-Beekman), 3: Intersection of Beekman and Dreman, 4: Dreman Avenue (green zone), 5: Cass Avenue (single-family residential zone), 6: Hoffner Avenue (single-family residential zone), 7: Heron Avenue (green zone), 8: Powers Street (single-family residential zone), 9: Sylvan Avenue (next to playground), 10: Intersection of Beekman and Elmore, 11: Llewellyn Avenue (single-family residential zone near freeway), 12: Borden Street (single-family residential zone near freeway), 13: Elmore Street, 14: Dirr Street (in industrial zone), 15: Dreman Avenue (in industrial zone between Dirr and Dawson), 16: Dreman Avenue (single-family residential zone between Dawson and Llewelyn), 17: Llewellyn Avenue (residential zone, near parking lot), 18: Parking lot of elementary school, 19: Beekman Street, 20: Intersection of Beekman and Millville Court, 21: Parking lot of a public housing project on Bellevue Street, 22: Millville Court, 23: Parking lot of a recreation center, 24: Playground between a recreation center and the elementary school).*

It was also observed that a transition space between land use and land cover on the same sidewalk showed major variations in HSI. A sidewalk on Dreman Avenue that transitioned from an industrial zone (Outdoor Space 15) to a residential zone located near industry (Outdoor Space 16) and then to a residential zone away from any industrial zones showed average HSI changes from 106.97°F to 104.4°F to 98.81°F, respectively. Mature tree canopies in the residential zone likely contributed to this change, making a strong case for shaded sidewalks. At the same time, the sidewalk on Dreman Avenue that runs along a playground where shading is minimal showed an HSI of 103.01°F.

The average HSI values along a temporal scale are presented in Figure 4(b). It was observed that 70% of residents' time-averaged HSI exposure estimated in five minute increments (described herein as Periods) fell within the danger zone, and 30% were within the extreme caution range. The highest HSI (109.74°F) was recorded during Period 10, which covered most of the school's parking lot and part of Beekman Street. This period also showed the maximum amount of variation in HSI values, as the locations in which the data were recorded changed from the center of a parking lot, to a shaded space near buildings, to shade under a tree. Period 7, which was recorded along the Elmore Street sidewalk, had an HSI value of 107.65°F; this area was closer to industry and the freeway, and the tree canopy cover was minimal. This period indicated only a minimum of variation between the high and low HSI values, making extended periods of walking a concern. Also, Elmore is a busy street, and traffic affects the HSI values of sidewalks and intersections. Similarly, sidewalks without any tree canopy in industrial land use areas like parts of Dreman Avenue (Period 9) tend to have higher HSI values (Dreman Avenue had a value of 105.91°F) than do sidewalks in high-canopy areas (in this study, 102.08°F).

4.2 Ultrafine particulate exposure

The UFP concentration varied by both space and time (see Figure 5). Figure 5(a) shows the spatial variations in UFP exposure. The highest values were recorded at the intersection of Beekman and Millville (34,751 particles/cm3); this was followed closely by the sidewalk along Dirr Street (34,677 particles/cm3). The lowest UFP exposure (7,633 particles/cm3) was recorded along the sidewalk of Powers Street. Thus, the average UFP concentrations among the 24 microenvironments varied up to 78%. Such variations may have occurred due to traffic exposure, as this can instantly cause a spike in exposure levels. Therefore, the data presented in Figure 5(b) was averaged at five minute intervals. The parking lots (Period 10) and sidewalks along the major streets (Period 7) were the most susceptible to high pollution exposure. Street intersections were the microenvironments most susceptible to short-term exposure, such as what was observed at the intersection of Beekman and Millville Court (Periods 11 and 12). Areas near public housing, such as parking lots and sidewalks, were also among the spaces with the highest UFP concentrations.

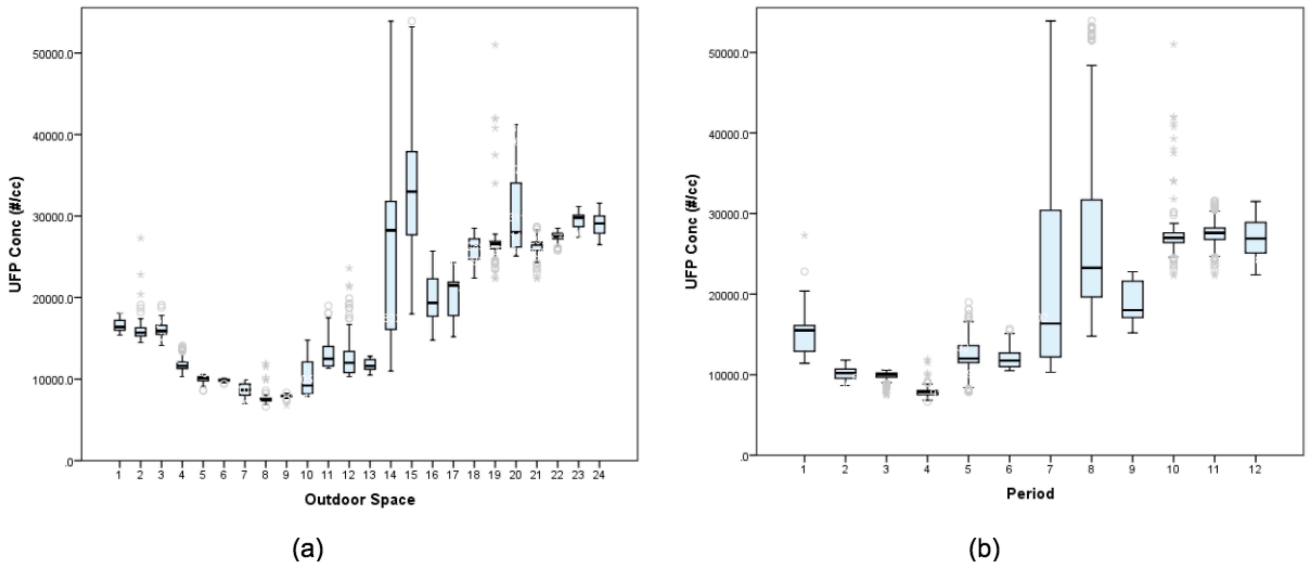

Figure 5: Ultrafine particulate exposure. (a) Spatial distribution of UFP concentrations, and (b) Temporal distribution of UFP concentrations averaged over 5-minute intervals.

Distance from the freeway also affected the collected UFP exposure values, due to migrating pollution; areas within 500 feet of the throughway were the most affected (Ryan et al. 2005). In this research, however, the UFP concentrations were recorded during off-peak hours, and consequently, no such influence was observed. For example, sidewalks on Llewellyn (Outdoor Space 11) and Borden (Outdoor Space 12) located within 500 feet of the freeway actually had lower UFP concentrations than other microenvironments. However, the minimum UFP concentrations observed within the range of 10,000 to 15,000 particles/cm3 represented the effects of indirect pollution, since there was no traffic at the time of recording. One possible reason for this could be that UFP tend to be very light in weight and can stay in the air for up to 30 days before settling down. In such cases, UFP movement depends upon wind direction and speed. Consequently, it can be difficult to predict its actual contribution and thus was not attempted in this research. UPF concentrations during rush hour were higher than during non-peak hours, which was as expected; this finding also agrees with the literature (Ryan et al. 2005, Brunst et al. 2015), emphasizing the role of urban transportation systems in microclimatic conditions and their health impacts.

Vegetation plays an important role in reducing UFP concentration. Sidewalks along Cass, Hoffner, Herron, and Powers Street (Periods 2 through 6) are located in the greenest part of the community, distant from the freeway; consequently, they showed lower UFP exposure levels than the sidewalks along Beekman, Elmore, and Dreman Street (Periods 7 through 9), which are closer to the freeway and serve as major streets for through traffic. Existing land uses such as light and heavy industry are major UFP contributors because of the resulting truck traffic. The lack of vegetation and minimal freeway buffer were evident in the high concentration levels recorded. For example, a sidewalk on Dreman Avenue that runs east-west through the community and connects an industrial area on the west side with residential spaces to the east showed a mean UFP concentration of 37,847 particles/cm3 near the industrial areas; this was reduced to 11,909 particles/cm3 near the residential neighborhoods, where the tree canopy is denser.

DISCUSSION

The heat-related mortality rate in the US has decreased in the last decade, due to improved access to air conditioning, better forecasting, and a general increase in preparedness. However, heat-related mental health impacts and certain long-term illnesses are on the rise, and extreme heat remains a prominent public health threat (CDC); the built environment plays a significant role in this. The health survey report examined in this research and a cross sectional HSI and UFP exposure confirmed this in the study area. It is undeniable that a long-term investigation of the relationships among the physical attributes of the built environment and health outcomes is needed; however, the above analysis presents a preliminary results of the combined effects of development patterns, urban infrastructure systems, and socioeconomic factors on microenvironments.

There are several questions that must be answered as the city continues to search for ways to improve the environment.

These include: How can the pilot data regarding the health survey and environmental exposure be used to inform the design process? What type of designs provide hope for improved health in the community? Could resident-led changes be engaged to develop small-scale ventures using a bottom-up urbanism approach? And, How to integrate small-scale projects in holistic plan? Importantly, how to avoid gentrification as nearly half of the current residents are renters.

The evidences presented in this research provides crucial context-specific information that can be used to design and redesign the built environment in ways that stimulate improved living conditions and minimize health-related disparities in economically deprived communities. Health surveys and community science projects can provide support for resident-led changes geared towards lowering the public health burden caused by land reuse and brownfields. A survey instrument developed to document current health and place-based issues would provide an evidence-based platform for requesting changes to policies and funding for projects. Finally, this research's analysis of existing development patterns and processes and on-site environmental data offer meaningful opportunities for infill development and resident-led bottom-up urbanism projects that will include urban greening.

CONCLUSION

The findings of a study conducted during an extreme heat event are presented here to understand urban landscapes and the built environment's relationship to heat and asthma-related illnesses, as reported in an earlier health survey.

Urban landscape and the built environment: Existing urban development patterns with a high percentage of sealant surfaces (42%) and tree canopies (29%) are creating a wide variety of microenvironments in the low-income community examined in this research. It was observed that an uneven distribution of tree canopies located very high on a hillside and far from the industrial areas is creating a significant gradient in overall environmental exposure. Also, the presence of industry and the resulting heavy track traffic is a major source of anthropogenic heat and air pollution. Finally, close proximity to the freeway further intensifies this type of exposure.

Environmental exposure in microclimates: The heat and air pollution varied across space and time. Among the 24 microenvironments in the study community, 54% had HSI values in the danger zone (104°F to124°F); the remaining 46% had HSI values within the extreme caution zone (91°F to103°F), per the scale provided by the National Weather Service. The high HSI values were complemented by UFP exposure, particularly in industrial zones, at street intersections, and in parking lots. HSI values based on an average five minute walk among these microclimates showed that 70% of the time, residents would be in the danger zone and 30% of the time they would be in the extreme caution zone during extreme heat events. The UFP exposure based on averaged five minute walk varied from 7,633 to 34,751 particles/cm3, between high-canopy streets and low-canopy streets with greater traffic exposure.

Environmental exposure and mental health: The outdoor spaces commonly used for social gatherings and children's playgrounds, such as parking lots and spaces near street intersections, had high HSI values and health-damaging environments that could result in heat-related irritation and mood swings. The evidence presented in this study provides clues to understanding how and why reported heat-related mental health issues (irritation, mood swings, and negative perceptions of health) are emerging in the community. A need for long-term data is evident if the relationships among the built environment and negative mental health outcomes are to be fully explored.

Demographics and microclimates: The demographic parameters of gender, race, age, and home occupancy were all found to be significantly associated with negative health outcomes, as was argued in the health survey. The evidence presented in this research are useful in understanding how microclimatic environmental exposure may affect health outcomes, and highlight potential directions for future research.

ACKNOWLEDGEMENT

Author wishes to acknowledge Dr. Jim Lockey, Enmont LLC for providing PUFP meter for this study. Thanks to the "Project Cool It" team consisting Cincinnati's Office of Environments and Sustainability, the Cincinnati Department of Health, TRC Companies, Millennium Energy, Shrewsberry and Associates, and INNOVATIONS on the Community Research and Program Evaluation, a program in the Division of Behavioral Medicine and Clinical Psychology at Cincinnati Children's' Hospital Medical Center. Also, thanks to Stephen Diko, a doctoral student with the School of Planning and Alan Bossman, undergraduate student in the School of Architecture and Interior Design at the University of Cincinnati for their help with GIS maps. The support from the community and WIN is much appreciated.

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