Challenges in Mixed Methods Research: Data Collection and Assessment of Indoor Air Quality (IAQ) in Low-Income Households

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ABSTRACT

Indoor air pollution is a pressing public health concern, particularly in low-income households where residents are exposed to hazardous compounds and pollutants. However, collecting comprehensive data on indoor air quality (IAQ) in these households poses significant challenges due to limited resources and logistical constraints. This case study investigates the challenges and opportunities encountered in gathering IAQ data from 54 low-income households in Philadelphia, PA, with collaborations involving community and government organizations including an energy authority, a non-profit energy services provider, a neighborhood energy community, household members and academic researchers. Findings reveal key challenges encompassing limited resources, technical limitations, optimal monitor placement, monitoring of specific pollutants, and complexities associated with studying an underserved population. By employing targeted education and community engagement, researchers can overcome these challenges and acquire robust IAQ data. Implications of the study include the development of tailored interventions to enhance IAQ and promote healthier indoor environments in low-income communities. The insights gained contribute to the implementation of specific strategies to mitigate IAQ issues, guiding resource allocation and public health initiatives. This case study highlights the challenges and opportunities in collecting IAQ data from low-income households, emphasizing the importance of addressing these challenges to improve IAQ and well-being in underserved communities.

Keywords: indoor air quality, low-income households, data collection, challenges, opportunities, community engagement.

INTRODUCTION

Americans spend approximately 90 percent of their time indoors, where concentrations of certain pollutants are typically two to five times higher than outdoor levels (E.P.A. 1987). IAQ is crucial for human health and well-being, influenced by a myriad of factors from the outdoor environment to human activities within indoor spaces. Indoor environments contain pollutants frequently associated with vehicular traffic and industrial activities (e.g., smoking, painting, etc.), as well as indoor-specific

pollutants. Common sources in residential settings include paints, aerosol sprays, cleaners, disinfectants, building materials, and furnishings (Norris, Fang et al. 2019). Humans also emit volatile organic compounds (VOCs) through metabolic processes, personal care products, and clothing (Tang, Misztal et al. 2016), as well as particulate matter from activities like cooking (Lunden, Delp et al. 2015) or lighting candles (Petry, Vitale et al. 2014). Moreover, pollutants can accumulate if there is insufficient ventilation and filtration, a situation often exacerbated in older buildings with low airtightness especially in colder environments (Fernández-Agüera, Domínguez-Amarillo et al. 2019).

The urgency for environmental justice in the context of IAQ is highlighted by existing literature (Adamkiewicz, Zota et al. 2011), which shows that low-income households experience substantially poorer indoor air quality due to a combination of factors such as indoor and outdoor sources and activity patterns. Hence, the question of how to promote environmental justice in IAQ management, particularly in marginalized communities, is paramount.

Community involvement through Community-Based Participatory Research (CBPR) methods is crucial for lasting change. However, these methods present specific challenges when applied in low-income households, particularly in the realms of trust and effective communication between researchers and participants (Parker, Israel et al. 2003, Commodore, Wilson et al. 2017). Given the technological limitations, such as limited Wi-Fi access, and the essential but often underexplored issue of establishing a trustful (Israel, Schulz et al. 1998) and respectful participant-researcher relationship, there exists a significant gap in how to effectively conduct IAQ data collection in such settings.

The purpose of this study is to fill this gap by examining the opportunities, challenges, constraints, and risks of collecting household data from the larger community. Our focus includes a particular emphasis on the participant-researcher relationship, exploring the nuances and challenges in establishing and maintaining this vital connection. Our aim is to offer a case study on how to navigate these complex challenges and to highlight the options and workarounds for IAQ data collection in low-income households.

BACKGROUND AND CONTEXT

Air pollution poses a major environmental risk to human health and is a significant contributor to global disease, as stated by the World Health Organization (WHO) (Forouzanfar, Afshin et al. 2016). The average American spends about 90% of their time indoors (E.P.A. 1989) while breathing 10 kilograms of air daily (Samet 1993, Pimentel, Williamson et al. 2008); therefore, the quality of the air that individuals breathe is crucial in their living, working, and recreational environments. Even though outdoor air quality remains a pressing concern, recent research indicates that indoor air contributes close to 90 percent of human exposure to pollution (Ott, Steinemann et al. 2006). This is partially attributable to the influence of outdoor air on indoor

environments, the amount of time spent indoors, and the variety of internal sources in various microenvironments (Jeong, Salehi et al. 2019).

The Environmental Protection Agency (EPA) reports that the average time spent at home is 17 hours per day, compared to 7 hours spent on residential commutes and at work (Hodas, Loh et al. 2016). Paints, aerosol sprays, cleaners, and disinfectants, as well as building materials and furnishings, are common sources of indoor pollution in residential settings (Norris, Fang et al. 2019). Additionally, humans are a significant source of interior pollutants. Some VOC emissions are produced by the human metabolic process, personal care products, and clothing (Tang, Misztal et al. 2016). In 102 residences, (Rudel, Camann et al. 2003) analyzed the levels of volatile organic compounds and other endocrine disruptors and found concentrations of over 30 compounds. Compound concentrations were highest in interior air and dust; inhalation exposure exceeded concentrations in ambient air. The authors concluded that indoor sources of chemicals and sluggish indoor degradation processes resulted in frequent and substantial exposure episodes in residences (Rudel, Dodson et al. 2010). Similarly, (Wallace 2000) identified gas furnaces and burners as the primary indoor source of fine inhalable particles, with indoor concentrations comparable to outdoor air pollution episodes. This research was ultimately motivated by the need to further characterize the extent of indoor emissions in residences where people spend a significant quantity of time.

Mold, ETS, diesel particles, and nitrogen dioxide are among the most prevalent environmental hazards in and around residential areas (Klepeis, Nelson et al. 2001, Squizzato, Masiol et al. 2018). A meta-analysis of 16 cohort and case-control epidemiological studies revealed that mold increases the risk of asthma by 50 percent (Quansah, Jaakkola et al. 2012). In addition, the Institute of Medicine discovered a connection between asthma exacerbations and indoor contaminants such as dust mites, pet allergens, and cockroach/rodent antigen (Asthma, Air et al. 2000). ETS indoors has also been linked to respiratory disease in infants and chronic respiratory issues in adolescents (Berglund, Brunekreef et al. 1992, Flouris, Vardavas et al. 2010). In sum, the existing literature has clearly established a correlation between the built environment and its effects on physical health (Berglund, Brunekreef et al. 1992, Samet 1993).

In the wake of burgeoning green building initiatives, the importance of IAQ has gained renewed attention (Jingguang, Jingya et al. 2022). Adopting environmentally sustainable practices and low-emission materials are viewed as pivotal steps toward mitigating indoor pollution and enhancing well-being (Kumar, Singh et al. 2023, Yang, Zhang et al. 2023). However, while these initiatives offer promising avenues, they are not without challenges. Despite positive findings, challenges in data collection and standardization, exist (Allen, MacNaughton et al. 2015). As well, participant compliance and the control of external variables that could influence IAQ, further complicates the assessment of IAQ in residential buildings.

In the realm of IAQ monitoring, various architectures have been explored beyond Wireless Sensor Networks (WSN) and Internet of Things (IoT) systems (Saini, Dutta et al. 2020). While these alternative approaches offer some advantages, they generally face several limitations. For example, (Wu, Shiledar et al. 2017) focused solely on particulate matter (PM) levels, neglecting other pollutants crucial for comprehensive IAQ assessment. Similarly, studies by (Zampolli, Elmi et al. 2004, Pillai and Veerasingam 2010) made noteworthy attempts at multi-pollutant monitoring but were confined to simulation and controlled lab environments, respectively, questioning their real-world applicability. Additionally, these studies commonly utilized low-cost sensors, raising issues of calibration and overall system performance. (Moreno-Rangel, Sharpe et al. 2018) employed FOOBOT monitors to analyze multiple IAQ parameters but faced challenges in sensor calibration to ensure reliable data. Overall, while these non-WSN and non-IoT architectures promise diversification in IAQ monitoring methods, their limitations in pollutant scope, real-world applicability, and sensor calibration pose substantial challenges.

To conclude, focusing on low-income households currently engaged in weatherization programs offers an exceptionally pertinent context for this IAQ study. These programs inherently aim to improve energy efficiency, often with unintended consequences on IAQ, thereby creating a natural setting for researching the impact of such interventions on indoor air quality (Francisco, Jacobs et al. 2017). These households epitomize the multidimensional vulnerabilities, such as economic constraints and elevated environmental risks, that this study aims to delve into (Wilson, Dixon et al. 2014). Moreover, their voluntary participation in weatherization initiatives suggests a preexisting willingness to allow home-based interventions, which may mitigate some of the trust and data collection challenges frequently encountered in community-based research (Macneill, Dobbin et al. 2016). Essentially, examining low-income households undergoing weatherization not only complements the objectives of this study but also substantiates the need for a nuanced, multi-faceted approach to IAQ research.

METHODOLOGY

In IAQ monitoring projects, objective and subjective data are typically collected together to develop a nuanced understanding of the indoor environment. Subjective data is often collected through surveys, interviews, or other forms of direct communication with individuals in the indoor environment. This type of data is valuable for understanding individuals' perceptions, experiences, and behaviors related to indoor air quality. Examples of subjective data collected in IAQ monitoring projects may include individuals' reports of symptoms or discomfort associated with indoor air quality, their perceptions of indoor air quality, and their behaviors related to indoor air quality, such as ventilation or cleaning practices. There are several means of collecting subjective data associated with IAQ monitoring projects, including in-person surveying, phone surveying, email surveying, and using a third-party agency for surveying. Ultimately, the choice of surveying method will depend on the specific

research question, the characteristics of the population being studied, and the resources available to the researcher.

IAQ monitors are essential tools for collecting data on indoor air quality in various environments. However, the choice of IAQ monitor can impact the quality of the data collected and create challenges or benefits in the data collection process. Specifically, the selection of a specific IAQ monitor can impact the comprehensiveness and accuracy of the data collected, as well as the cost, ease of use, and feasibility of the data collection process. For instance, some IAQ monitors, such as the Awair Element monitor (Awair 2024), only measure a limited range of IAQ parameters. As such, they may not provide a comprehensive assessment of IAQ. Moreover, specific IAQ monitors, such as the IQAir AirVisual Pro monitor (IQAir 2024), can be expensive, especially when multiple units are required to cover a large indoor environment, which can limit the feasibility of using the device for large-scale IAQ data collection projects. Additionally, the ease of use and feasibility of IAQ data collection can be affected by the specific IAQ monitor used. Some IAQ monitors, such as the Awair Element monitor, are easy to set up and do not require special training or expertise, making them accessible to researchers and homeowners alike. Furthermore, the Awair Element monitor provides real-time monitoring of IAQ parameters, allowing for immediate feedback on the quality of the indoor environment. Additionally, the device can be accessed and controlled remotely, allowing researchers to periodically retrieve data from the monitor without needing to be physically close to it, as long as the monitors are connected to a Wi-Fi network and are set up using a smartphone. However, specific IAQ monitors can also create difficulties in the data collection process, such as the need for periodic calibration, which can be time-consuming and require additional equipment and expertise. Furthermore, the accuracy of specific IAQ monitors is highly dependent on their placement within the indoor environment, which needs to be carefully considered to ensure accurate and reliable data collection.

In this study, we employed a mixed-methods approach with a strong emphasis on qualitative data collection to explore the indoor air quality (IAQ) challenges within low-income households. This approach was centered around the deployment of IAQ monitors (IQAir AirVisual Pro and Awair Element) in participant homes and the collection of qualitative feedback through interviews and surveys. It is crucial to clarify that, although we utilized IAQ monitoring devices for data collection, our analysis did not extend to quantitative statistical analysis of the data obtained from these devices. Instead, our focus was on the qualitative insights gained from participant interactions, the subjective perceptions of IAQ, and the practical challenges encountered during the sensor installation and monitoring process. This qualitative emphasis allowed us to capture the nuanced experiences of low-income households with IAQ, highlighting the socio-economic factors influencing IAQ and the potential barriers to implementing and maintaining IAQ interventions.

The collection of subjective data on quality and comfort perception in this case study was done using in-person surveys, phone calls, and online surveys. The well-being of the occupants was assessed by self-reports and questionnaires. For the purpose of

obtaining factual information on indoor air quality, a graduate student, together with delegates from organizations facilitating this project in adopting CBPR methodologies, put IQAir AirVisual Pro and Awair Element monitors in each residence.
PEA, ECA, and Esperanza are among the groups that maintain continuous partnerships with low-income areas in Philadelphia. Their participation in our study was crucial since one of the objectives was to enhance the indoor air quality (IAQ) of these families as part of a comprehensive strategy to address social, economic, and environmental concerns within these communities. Enhancement in this domain for these families can only be achieved if many facets of CBPR are accessible.

These features encompass the presence of resources that contribute to the community's sustainable and enduring welfare, which are mostly provided by these organizations. Additionally, an iterative approach must be adopted that involves making gradual adjustments and gathering input from the community throughout the process. This is also done through these organizations. Lastly, by providing tutoring to the community, we want to integrate knowledge and action on the significance and many elements of Indoor Air Quality (IAQ), and this tutoring is most facilitated by the level of access that these organizations have to our target communities.

This case study explores the complexities and avenues of collecting IAQ data in a Philadelphia-based initiative involving 54 low-income households. The study was executed in partnership with several community and government stakeholders including the Philadelphia Energy Authority (PEA), the Energy Coordination Agency (ECA), Esperanza, a community energy organization, as well as academic researchers from Drexel University. Due to the challenges we faced through the course of the data collection, out of the 54 households targeted, sensors were successfully installed in 11 homes only, and usable data was collected from just five of these installations. These numbers underscore the multi-layered challenges of IAQ data collection in low-income settings, particularly in sustaining the participant-researcher relationship for the successful deployment and retrieval of IAQ monitoring devices.

The low-income status of participants in this research was significant due to the unique challenges and opportunities it presented in collecting indoor air quality (IAQ) data. Low-income households face higher risks of poor IAQ due to economic constraints, elevated environmental risks, and limited access to resources, making them a critical demographic for IAQ studies. Additionally, these households' participation in weatherization programs provided a natural setting to investigate the impact of such interventions on IAQ. The study aimed to develop tailored interventions to improve IAQ and promote healthier indoor environments, highlighting the necessity of a nuanced approach to IAQ research that considers the multidimensional vulnerabilities of low-income communities.

In this study, two types of IAQ sensors were utilized: IQair AirVisual Pro and Awair Element (**Error! Reference source not found.**). The IQair AirVisual Pro sensors are k nown for their high sensitivity in detecting a wide range of pollutants, including PM2.5, VOCs, and CO2, offering a comprehensive IAQ profile. However, they come

at a higher cost and may require professional calibration. Awair Element, on the other hand, is a more budget-friendly option that also measures a variety of pollutants like PM2.5, VOCs, and humidity, but may have a narrower detection range compared to IQair AirVisual Pro. The choice between these two sensors in future projects could depend on the specific research objectives and available resources.

The data collection process began with households applying to PEA's Build to Last project for weatherization services. Eligible applicants were subsequently contacted by ECA to gauge their interest in participating in the IAQ monitoring project and to assess their access to Wi-Fi, which was essential for data collection. Upon confirmation, an appointment was set for the sensor installation, conducted by a Drexel University scholar and an ECA agent. Following the successful setup, the household was asked to complete a respiratory health survey. The sensor retrieval took place at least two weeks post-weatherization. An ECA agent removed the sensor and returned it to the Drexel researcher for data extraction, closing the loop on this intricate, multi-stakeholder data collection process.

Table 1. Comparison of Benefits and Difficulties of IQair and Awair Element Indoor Air Quality Monitors for Research and Home Monitoring.

Difficulties/Benefits	IQair	Awair Element
Expensive	X	
Requires periodic calibration and maintenance	X	X
Accuracy is highly dependent on placement	X	X
Measures a wider range of IAQ parameters	X	
Known for high accuracy and reliability	X	
Stores historical data	X	X
Comes with a mobile app for real-time data monitoring and alerts	X	X
Measures a limited range of IAQ parameters		X
Can be expensive for larger environments		X
Easy to set up and use		X
Can be accessed remotely for data retrieval		X
Has an easy-to-interpret display on the monitor	X	

CHALLENGES AND RECOMMENDATIONS

This section explores the major challenges that we had when collecting data for our IAQ research in low-income households. We provide detailed insights into the various intricacies that emerged from interacting with such particular demography. The core of our future advice is based on our actual experiences, which are derived not from a theoretical perspective but from the real challenges we have encountered and successfully conquered. For instance, the early resistance to participation that we experienced was reduced by tailored education from our partners, demonstrating the significant influence that informed consent and privacy concerns have on participant collaboration.

As we explored the project, it became obvious that creating trust and clear communication channels were of great importance. This was further emphasized when a certain family, initially hesitant due to privacy concerns, actively participated in the

study following our team's relentless and sympathetic efforts to engage them. These examples highlight the importance of our learning process and serve as the foundation for our recommended ways to tackle comparable difficulties.

The collaborative efforts we initiated with community organizations also encountered difficulties, but ultimately proved to be fruitful. We discovered the significance of utilizing established community trust, as demonstrated by the large boost in our project's legitimacy among participants due to the support from an established community-based organization. The knowledge gained from firsthand experiences is what we provide to this section, providing not just suggestions but also a comprehensive approach based on practical encounters and the successful navigation of obstacles in order to accomplish our study goals.

Participants

Data collection in low-income households poses challenges related to participants' factors, including their knowledge, awareness, and willingness to participate. Some of these challenges are described in the following section.The first issue is providing households with accessible and practical information about IAQ. Participants should be made aware of the sources of indoor air pollution, the potential health risks associated with poor IAQ, and strategies to mitigate and improve air quality in their homes. By increasing participants' knowledge and understanding, they can make informed decisions regarding their IAQ.

The second issue stems around concerns over privacy and participants' expectations regarding research activities. Many low-income households have valid concerns about the privacy of their homes and the nature of data collection. Establishing clear protocols that prioritize participant privacy, confidentiality, and informed consent is crucial. Respecting participants' privacy concerns and providing transparent information about data usage can foster trust and increase their willingness to participate. Obtaining informed consent involves providing participants with comprehensive information about the study objectives, procedures, and potential risks and benefits, allowing them to make an informed decision about their participation.

Third, researchers and practitioners have to work towards fostering a sense of ownership and empowerment among participants. By actively involving low-income households in data collection efforts and providing them with the necessary knowledge and resources, participants become partners in addressing IAQ issues. This collaborative approach increases the accuracy and reliability of the collected data and helps tailor interventions to the specific needs of the community.

Engaging participants through education, awareness campaigns, and clear protocols for privacy and informed consent not only enhances the quality of data collection but also contributes to the overall well-being of low-income households. Empowering participants with knowledge and involving them as active stakeholders in the process leads to a more comprehensive understanding of IAQ challenges and more effective interventions to improve air quality and promote healthier living environments.

Collaborators

Collaboration with stakeholders and partners is vital to overcome challenges in the overall project. By collaborating with community organizations, researchers and practitioners can tap into existing networks and resources within the community. These organizations often have established relationships and trust with low-income households, making them valuable intermediaries in recruiting participants and facilitating data collection efforts. Additionally, community organizations can provide insights into the specific needs and concerns of the community, ensuring that data collection efforts are tailored to address their unique IAQ challenges.

Local authorities play a crucial role in supporting data collection initiatives. Engaging with local government agencies and health departments can provide access to expertise, funding opportunities, and regulatory guidance. Collaborating with these authorities not only enhances the credibility and legitimacy of data collection efforts but also facilitates the translation of research findings into actionable policies and interventions.

Collaboration with partners who perform audits and weatherization services, intimately familiar with addressing the unique challenges faced by low-income households, is of great significance. These collaborators can greatly support data collection in low-income neighborhoods. ECAs possess valuable insights into the local culture and community dynamics. They can provide essential assistance, including equipment installations, troubleshooting logistical challenges, and effective communication with participants. Leveraging their expertise enhances the success and efficacy of data collection initiatives.

In addition to community organizations and local authorities, relevant agencies such as environmental health departments, non-profit organizations, and academic institutions can offer valuable resources, expertise, and technical support. These collaborators can contribute to the development of research protocols, provide access to monitoring equipment and laboratories, assist with data analysis, and disseminate findings to a wider audience. By pooling resources and expertise, data collection efforts can become more robust and sustainable.

By engaging with stakeholders and collaborators, data collection efforts can overcome the challenges of limited resources, expertise, and community outreach. Collaboration not only strengthens the credibility and effectiveness of the research but also promotes long-term partnerships that can contribute to sustained improvements in IAQ and the overall well-being of low-income households.

Logistics

Logistical challenges present significant obstacles in data collection regarding IAQ in low-income households. To overcome these challenges, efficient coordination, clear communication channels, and flexibility in scheduling are essential. Streamlining logistics and establishing effective communication protocols can help address challenges related to participants' availability and unreliable infrastructure.

Efficient coordination is key to successful data collection efforts. Coordinating with participants to schedule visits and installations in a timely manner can be complex due to various factors such as participants' availability, conflicting priorities, and limited time windows. Flexibility in scheduling and accommodating participants' needs can help ensure their active participation and reduce barriers to data collection.

Clear communication channels are essential for effective data collection. Providing participants with clear instructions and expectations regarding the data collection process helps minimize misunderstandings and ensures their active engagement. Utilizing multiple communication methods, such as in-person meetings, phone calls, and written instructions, allows for effective and accessible communication with participants.

Streamlining logistics involves identifying and addressing potential challenges related to infrastructure and equipment installation. Unreliable Wi-Fi access and inadequate electrical outlets in households can impede the installation and functioning of monitoring equipment. By assessing the technical requirements in advance and collaborating with participants, alternative solutions can be identified and implemented to ensure data collection can proceed smoothly. This may involve providing portable power sources or utilizing mobile data for transmission in areas with limited internet connectivity.

In addition to efficient coordination and clear communication, flexibility is crucial when navigating the logistical challenges of data collection. Recognizing and accommodating participants' scheduling constraints, providing options for alternative data collection methods, and adapting to the unique circumstances of each household contribute to a more inclusive and effective data collection process.

By streamlining logistics and establishing effective communication protocols, data collection efforts can overcome challenges related to scheduling, participant availability, and infrastructure limitations. These measures enhance the efficiency and accuracy of data collection, ensure higher participant engagement and cooperation, and contribute to the overall success of IAQ research in low-income households.

Lastly, delays in scheduling visits with agencies and funding organizations, as well as delays in survey administration, can significantly impact data collection efforts. These delays may result in extended gaps between the rounds of installations, impeding the overall progress of the project. Establishing efficient communication channels and proactive coordination with relevant entities is vital to minimize delays and ensure timely data collection. Streamlining logistics and adopting effective scheduling strategies help overcome these challenges.

Technical Limitations

Technical limitations pose additional challenges in data collection efforts. To address these challenges, innovative technological solutions can be leveraged. Low-cost sensor networks and mobile applications can mitigate technical limitations, such as limited

infrastructure and resources. Furthermore, specific technical challenges regarding the location of monitors and the monitoring of radon, mold, and other pollutants need to be considered. An important example of these technical issues is the lack of Wi-Fi connections in some of these low-income households. This single issue cut our potential installation destinations in half meaning over 27 our of 54 households that we reached out, did not have a stable and usable Wi-Fi connection for us to install the IAQ monitors.

The location of monitoring equipment can have a significant impact on the accuracy and representativeness of the collected data. For example, the placement of monitors can influence the measurements of CO2, PM2.5, and other pollutants. It is essential to strategically position the monitors within low-income households to ensure that they capture the true IAQ conditions. This requires careful consideration of factors such as air circulation patterns, proximity to pollution sources, and potential obstructions that may affect the measurements. Addressing these challenges involves conducting thorough site assessments and working closely with participants to identify optimal locations for the monitors.

By leveraging innovative technological solutions such as low-cost sensor networks and mobile applications, data collection efforts can address technical limitations related to infrastructure and resources. These solutions offer cost-effective and accessible means to gather IAQ data. Furthermore, securing funding for equipment acquisition and maintenance is crucial to ensure the availability of specialized equipment for monitoring pollutants like radon and mold.

By considering the technical challenges associated with the location of monitors and the monitoring of specific pollutants, data collection efforts can improve the accuracy and comprehensiveness of IAQ data. This knowledge can inform targeted interventions and strategies to mitigate specific IAQ issues in low-income households, leading to healthier and safer indoor environments.

RECOMMENDATIONS

Data collection regarding IAQ in low-income households presents various challenges. To address these challenges, a comprehensive approach is required, encompassing targeted education and awareness campaigns, collaborations with stakeholders, streamlining logistics, and leveraging innovative technological solutions.

In the first aspect, addressing the challenges related to participants, targeted education and awareness campaigns play a crucial role. By implementing these campaigns, low-income households can gain knowledge and understanding of IAQ, potential health risks, and strategies to improve air quality. Additionally, clear protocols for privacy, confidentiality, and informed consent ensure ethical data collection practices. These measures empower participants, fostering their active engagement in data collection efforts.

Collaborations with stakeholders and partners are essential to overcome challenges in data collection. Engaging community organizations, local authorities, and relevant agencies provides valuable assistance and resources. Collaborators contribute expertise, funding, and community outreach, enhancing participants' involvement and data collection efficiency. Strong partnerships and collaborative relationships ensure collective efforts to address IAQ challenges, increase community engagement, and translate research findings into effective interventions.

Logistical challenges present significant obstacles in data collection efforts. Efficient coordination, clear communication channels, and flexibility in scheduling are key to overcoming these challenges. Streamlining logistics and establishing effective communication protocols address issues related to participant availability, conflicting priorities, and infrastructure limitations. By ensuring smooth data collection processes, these measures enhance data quality and participant engagement.

Technical limitations pose additional challenges in data collection efforts. Innovative technological solutions such as low-cost sensor networks and mobile applications can be leveraged to overcome these challenges. Low-cost sensor networks consisting of monitors that either do not need an active internet connection or have their own means of connecting to the internet enable continuous monitoring of IAQ parameters, overcoming infrastructure limitations and financial constraints. Mobile applications allow participants to provide subjective data and complement objective measurements. Securing funding for equipment acquisition and maintenance is crucial to address technical challenges and ensure the availability of specialized equipment for monitoring pollutants such as radon and mold.

By implementing these strategies, data collection efforts can yield comprehensive and accurate information on IAQ in low-income households. This knowledge can inform evidence-based interventions, policies, and practices aimed at improving IAQ and promoting healthier living environments. Furthermore, empowering participants through education, collaborations, efficient logistics, and innovative technology enhances community engagement and fosters long-term sustainability.

Overall, addressing the challenges related to participants, collaborators, logistics, and technical limitations is essential for successful data collection regarding IAQ in low-income households. By adopting a comprehensive approach and implementing these strategies, researchers and practitioners can gather robust data, develop targeted interventions, and contribute to improving IAQ and the overall well-being of low-income communities.

CONCLUSION

Reflecting on the findings and methodologies employed in this research, our study offers critical insights into the challenges of assessing indoor air quality (IAQ) within low-income households, emphasizing a qualitative lens to understand the socio-economic factors and lived experiences affecting IAQ. Through the deployment of

IAQ monitors and direct engagement with households, this research underscores the complex interplay between environmental health and socio-economic status. Our findings highlight the significant barriers low-income households face in achieving healthy indoor environments, from logistical challenges in deploying technology to the broader social determinants of health that exacerbate IAQ issues.

The qualitative feedback from participants provided invaluable insights into the subjective perceptions of IAQ and the efficacy of interventions, reinforcing the importance of community-engaged approaches in environmental health research. This study advocates for policies and interventions that are not only technically feasible but also socially and economically accessible for low-income populations. The emphasis on qualitative methodologies in this research contributes to a deeper understanding of the nuances and complexities involved in IAQ assessment and intervention, offering a foundation for future research to build upon.

In conclusion, this research highlights the critical need for inclusive, multi-faceted strategies to address IAQ in vulnerable communities. By focusing on the qualitative aspects of IAQ challenges and interventions, the study contributes to a more nuanced and comprehensive approach to improving indoor environmental health. Future efforts should continue to prioritize the voices and experiences of those most at risk, leveraging community-based participatory research to design and implement IAQ solutions that are equitable, sustainable, and effective in improving the health and well-being of low-income households.

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