International Journal on Advanced Science Engineering Information Technology

Vol.12 (2022) No. 2
ISSN: 2088-5334

The Effect of Different Specifications of Passive Spaces on Residents' Satisfaction in Adjoining Spaces within a Hot Dry Climate

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***Abstract*— Passive spaces are a passive design strategy that aims to reduce energy consumption and increase user satisfaction in buildings. One example of passive space is the air shaft. The air shaft is a vertical void within the building from the ground level to the roof level, and it provides the building with natural ventilation and daylight, especially in deep-plan buildings. However, the function of the air shaft is questioned due to its impacts on residents' needs. This study assesses the effects of air shaft specifications on residents' satisfaction with the indoor environment quality of air shafts and adjoining spaces. Survey questionnaires were distributed to residents of apartment buildings. The results proved that air shafts have a significant negative impact on residents' satisfaction. The findings of cross-tabulation analysis illustrate a significant relationship between the air shafts' specifications and the residents' answers. The analysis also showed that the air shafts that are closed from the bottom and include A\C outdoor units have a more negative impact on the thermal environment and air quality. Regarding the air shaft areas, the small areas have a high negative response regarding bad smell, the view, visual and acoustic privacy, and thermal environment. From the indoor environment quality perspective, this study emphasizes the need to consider the impact of air shaft design on a building's performance and residents' satisfaction. The results of this study are expected to contribute to the development of future passive spaces design.**

***Keywords*— Passive space; air shaft; indoor environment quality; residents' satisfaction; residential buildings.**

Manuscript received 18 May 2021; revised 20 Aug. 2021; accepted 26 Nov. 2021. Date of publication 30 Apr. 2022.

I. INTRODUCTION

There has been a consistently growing body of research on Sustainability within the field of building design. The research is quite widespread [1], with many being multidisciplinary. These disciplines include architecture [2]–[6], and engineering fields such as mechanical [7], electrical [8]–[10], and structural. As a result of the multidisciplinary nature, sustainable building design research will unavoidably include the users of buildings and the performance [1], [3].

In many countries, sustainable buildings have increased rapidly, for example, in the United States, Europe[11], and many countries in Asia [10]. This increase is because sustainable building design has been demonstrated to improve overall building performance [12], occupant well-being [13]–[16], and the environmental effect of a building's life cycle [17]. These positive impacts are in line with the way [18] described the term 'sustainable building' as "a systematic effort to create, sustain, and accelerate changes in practice, technology, and behavior to reduce building-related environmental impacts while creating places that are healthier and more satisfying for people". One of the strategies of sustainable design is the use of passive spaces. These can increase the residents' satisfaction and reduce environmental impacts on the indoor environment quality by relying on natural resources, such as natural ventilation and daylight [19].

A. Passive Space

Passive spaces have advanced specifications that help the space adapt dynamically to user habits, the building's function, and climate. The physical environment of a passive space and surrounding areas can improve a building's physical environment. It can also reduce energy consumption and increase user satisfaction [20], [21]. There are different types of passive space, as shown in Table 1 [22].

TABLE I
PASSIVE SPACES CATEGORIES

Passive Space	Space type
Courtyard space	Enclosed courtyard, half-enclosed courtyard, overhead space, outdoor platform
Atrium Space	One-direction atrium, two-direction atrium, three-direction atrium, four-direction atrium
Well space	Ventilation wall, underground wind tunnel, wind tower, light well, air shaft
Interface Space	Double layer space, sunspace, porch space

This study focuses on air shafts as an example of passive spaces. The air shaft is a vertical shaft that is carefully implemented in buildings as a design solution to provide daylight and natural ventilation for interior spaces [19]. The air shaft has been widely implemented in buildings to overcome the issue of building depths to provide daylight and natural ventilation to central spaces, as shown in Fig. 1 [19], [21], [23], [24].

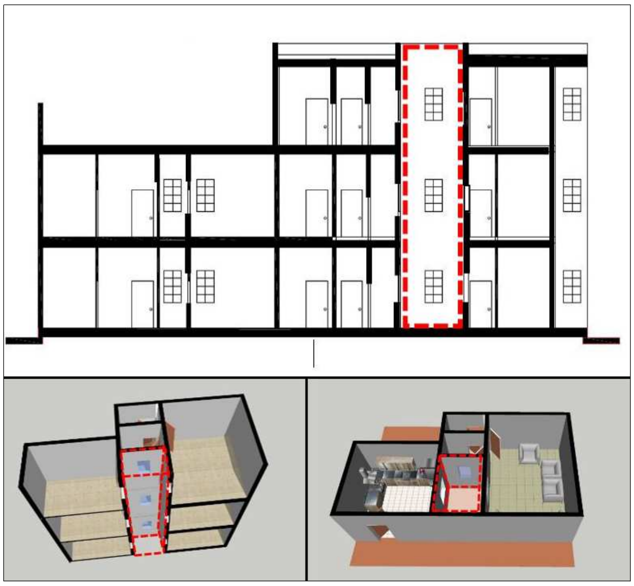

Fig. 1 An example of an air shaft in the building

Authors in some previous studies [25], [21], [26] reported that air shafts have other functions besides providing daylight and natural ventilation, such as a service core as shown in Fig. 2 to install plumbing lines (PL) and outdoor air conditioner (AC) units. Also, the air shafts are referenced by different names, such as light well [26], light shaft [27], ventilation shaft [28], and meenware [21].

B. Indoor Environment Quality (IEQ)

Many studies have proven that indoor environments are used much more than outdoor environments [29]. As a result, it is critical to thoroughly study the aspects affecting indoor environmental quality (IEQ)[30], [31]. IEQ is not only concerned with the environment but also with the psychological and physiological effects of the indoor environment on the human body, such as the health, satisfaction, productivity, and well-being of the people who live in a building's interior spaces [32], which the authors in [33] claimed were not adequately studied. That argument asserted that the phenomena of IEQ are more complex than a cursory examination of its primary parameters. Hence, in addition to the impact of IEQ on psychology and physiology, studies also explore the effects of thermal comfort [34], acoustics [35], [34], visual comfort [36] ,and indoor air quality [37], [38] on buildings' occupants. Additionally, it has been demonstrated that the only way to attain a better and healthier environment and increased tenant satisfaction is to create high-quality indoor environments.

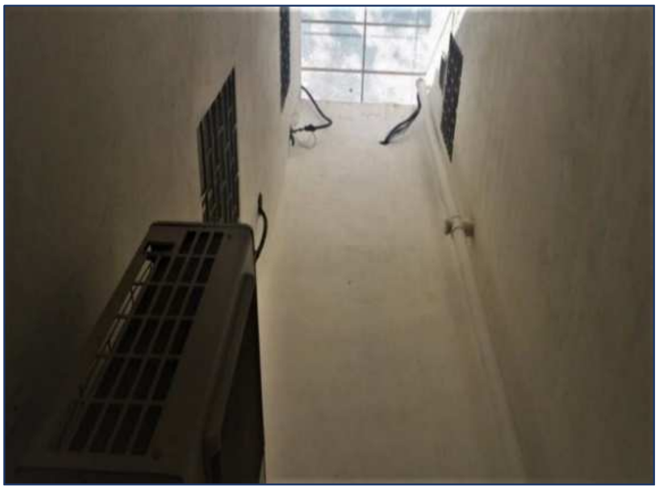

Fig. 2 Installing plumbing lines and outdoor air conditioner units inside the air shaft

C. The Relationship Between Buildings, Passive Space and IEQ

Various studies have regularly and widely identified passive spaces as the most effective economic strategies for realizing sustainable buildings. However, regarding verifying this critical claim on passive design as a robust strategy, such a line of research is in its infancy. Moreover, the existing test methods and verification conclusions regarding passive design do not constitute sufficient scientific validation. As a response, a new logical framework was introduced [22], which could be appropriately adopted to assess the performances of buildings' spaces. The study further developed a multi-criteria approach in validating and optimizing the influence of passive spaces on buildings. The method was from the perspectives of IEQ and occupants' satisfaction. To assess the building environment quality, four parameters were used as fieldwork physical environment tests. They included indoor thermal condition, lighting, indoor air quality, and acoustics data in the operating phase. The study also developed assessment indicators to test satisfaction. The tool evaluated the occupants' satisfaction with the overall building's environment and space efficiency. Within the context of the relationship between buildings and people on the one hand and buildings and the environment, on the other hand, a comprehensive assessment model was developed [22] for a comfort and satisfaction matrix. The matrix is utilized to display the regulation capacity of a building's environmental performance in the passive space. To validate the multi-criteria approach that was developed earlier, an in-depth fieldwork survey was conducted. The survey had selected six types of passive courtyard spaces in a cold climate. Results from the survey revealed the level of the environmental performance of each case building. The results highlighted the existing optimized possibilities for passive space and the whole building in design and renovation phases.

II. Material and Methods

For IEQ assessments, the field measurements and feedback from building occupants are considered the main methods to collect data in this type of study. The questionnaires are one of the most cost-effective and efficient methods of obtaining the data. According to Robson [39], the survey method is one strategy for getting consistent and steady data collection from a specified group. This method was used in this study because of the number of buildings covering the entire city. In addition, this study focuses on the residents' satisfaction with the indoor environment quality of air shafts and adjoining spaces. The online questionnaire survey was the most appropriate method, as it allowed for the most convenient and cost-effective contact with respondents.

The questionnaires were distributed randomly to 100 households in various apartment buildings in Makkah. The response rate was 53% and covered most parts of Makkah, including central, north, south, east, and west. The data were collected within a timeframe from January 2019 to June 2019. The questionnaire only targeted the adult household members, who spent the longest time inside their units to complete the questionnaire. The questionnaire includes a brief description of the air shaft, the point of answer as a guide, and questions relating to the air shaft specifications and its impact on residents' satisfaction, as shown in Tables 2&3. The scope of the effects of air shafts on the indoor environment was determined based on the negative impacts of air shafts on residents in the previous studies [21], [26].

TABLE II
THE QUESTIONS REGARDING AIR SHAFT SPECIFICATION

Design Parameter	Type
Air shafts type	Residential (living room, bedroom) Service (kitchen, bathroom, storage) Combined (residential and service)
Air shaft area	Less than 5 m^2 5 m^2 to 7 m^2 8 m^2 to 12 m^2
Air shaft top (roof)	Open Closed
Air shaft bottom (floor)	Open Closed
Ari shaft usage	Natural ventilation Daylight Installing plumbing lines Installing outdoor A/C units.

The multi-site approach to buildings assures that each building's unique context and setting results in unique viewpoints for end-users, likely to result in a significant deal of diversity of opinions and justifications. The study's range of buildings has been constrained by various characteristics, including height, location, and age, to provide a coherent and comparable data collection.

TABLE III
THE SCOPE OF THE QUESTIONS IN INDOOR ENVIRONMENT QUALITY

Parameter	Element
Visual environment	The view from the window to outside Visual privacy
Air quality	Residents' suffocation Different types of smells
Thermal environment	An increase in air temperature An increase in relative humidity
Acoustic environment	Sound privacy

The analyses that are used in this study are descriptive analysis and cross-tabulation analysis. The descriptive analysis described the residents' satisfaction with the indoor environment quality in air shafts and adjoining spaces. At the same time, cross-tabulation analysis was used to achieve the study's aim, which is to determine the relationship between the air shafts' specifications and the residents' satisfaction with indoor environment quality in air shafts and adjoining spaces shown in Fig. 3. These were performed using software from IBM Statistical Package for the Social Sciences (SPSS 20).

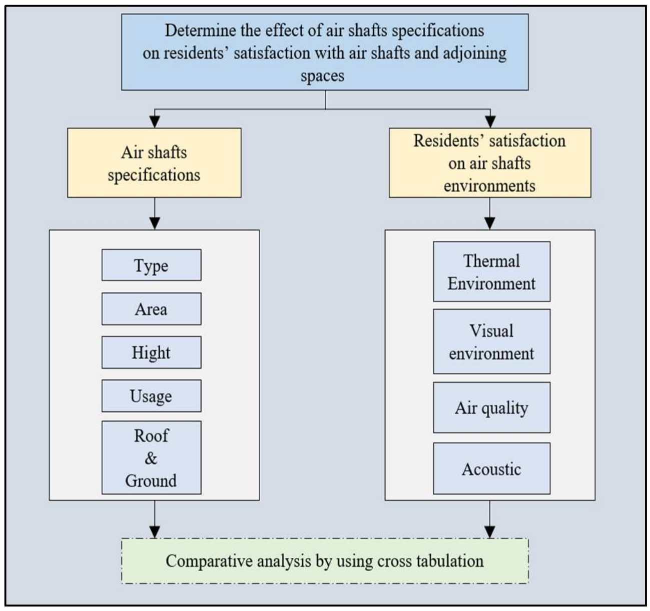

Fig. 3 Research framework

III. Results and Discussion

A. Air Shafts Specifications

There are six questions regarding the air shaft specification: type, area, height, design, and usage, as shown in Fig. 4. There were three types of air shafts. The first one is the residential type, which is opened in different living rooms, dining rooms, bedrooms, and guest rooms.

The second type was the service air shaft, which opened on service spaces such as kitchens and bathrooms. The last type is the combined air shaft that opens to the rooms and services spaces simultaneously. As for the areas of the air shafts, there was significant variation, as they ranged from 1 square meter to 12 square meters.

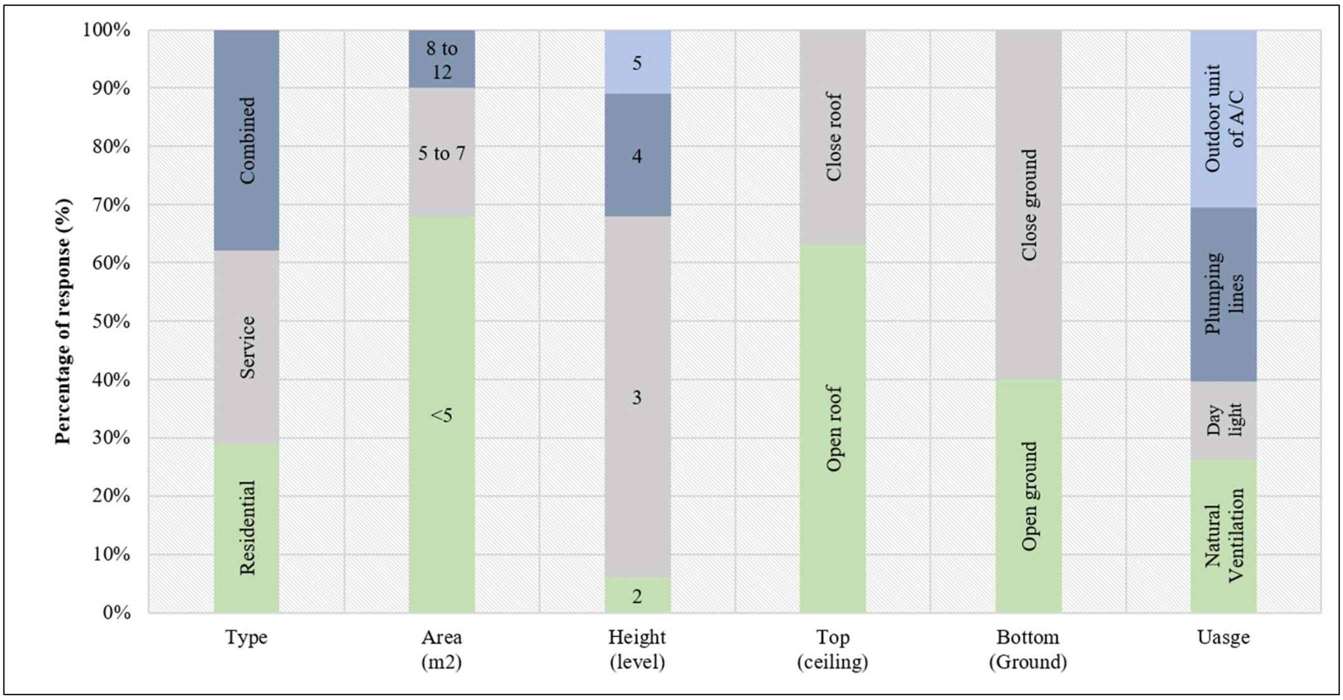

Fig. 4 Air shafts specifications

As for the height of the air shafts, the height was according to the height of the building, and there was no increase above the roof, such as wind catchers or wind towers. The buildings were low-rise and ranged from two floors to five floors. Concerning the top of the air shafts, some air shafts were closed from the top, and the others were opened to the sky. Also, the bottoms of the air shafts were closed, and the others were opened to the level of parking lots or the basement. The last question was about the use and function of the air shafts in the building. There were four uses for air shafts. The first usage was to provide natural ventilation. The second usage was natural lighting for the surrounding spaces. The third usage was as a place to install plumping lines. The fourth usage was as a place to installing outdoor air conditioner units. In general, the answers in this part showed a difference between the specifications of the air shafts, which contributes to studying the most significant possible number of different variables and comparing them in terms of their impact on residents' satisfaction by using cross-tabulations.

B. Impact of the Air Shafts on Residents' Satisfaction with Indoor Environment Quality in Air Shafts and Adjoining Spaces

1) Visual Environment:

Four parameters were adopted to assess the residents' satisfaction with the visual environment Fig. 5. The first parameter estimates the residents' satisfaction with the amount of sunlight that enters the apartment through air shafts. The responses reveal that there is no overall satisfaction regarding the amount of sunlight that enters the apartment. In detail, only 7.8% of total responses feel very satisfied with the amount of sunlight, and 17.6% were satisfied. The result also shows that 37.7% of the residents considered the amount of sunlight as neutral. Whereas 23.5% of respondents were unsatisfied and 13.7% were very unsatisfied. Eliciting from these results, only 1/4 of the household feels satisfied with the amount of sunlight in their apartment, while 3/4 of other households feel either neutral or unsatisfied. Given that most people spend most of their time indoors, it is critical to design the interior to maximize daily natural light with daylight; the best visual comfort for humans is realized. It has a beneficial effect on the human psyche, and people exposed to this light during the day tend to be more relaxed and pleasant [32].

The second parameter assesses the residents' satisfaction with sunlight brightness during the daytime. The result shows that 45.1% of the respondents were very satisfied, followed by 33.3% satisfied, 19.6% neutral, while the remaining 2% were unsatisfied. This high satisfaction from the residents about the sunlight brightness in adjoining spaces for air shafts was due to indirect sunlight inside air shafts. Based on the results, there is a need to study the brightness of sunlight in air shafts and adjoining spaces to enhance visual comfort. Therefore, future studies in this aspect should use field measurements and simulation software.

The third parameter assesses the residents' satisfaction with the external view through the windows of spaces adjoining air shafts. The data analysis reveals that only 2% of respondents were very satisfied, 3.9% were satisfied, and 7.8 had a neutral feeling with the view toward the air shaft. In contrast, 11.8% were unsatisfied, and, surprisingly, 74.5% of the responses were very unsatisfied with the external views.

These results reveal an urgent need to improve the visual elements of the air shaft because most answers feel unsatisfied with the exterior view no connection with the natural environment. According to BREEAM [40] and LEED [41], the external view is essential for improving visual comfort. The last parameter assesses the residents' satisfaction with visual privacy. The results indicate that 51% of responses were very satisfied, 23.5% were satisfied, 21.6% were neutral, 2% were unsatisfied, and only 2% were very unsatisfied. Although most respondents feel satisfied with the air shaft's visual privacy, it is important to conduct a deeper investigation to identify the defects that influence the unsatisfied respondents because visual privacy may be required for cultural, religious, personal, or psychological reasons [42]. At the end of this part, it is essential to develop the air shaft design to improve the visual environment, which will achieve the residents' satisfaction and comfort.

2) Air Quality:

This study assessed the air quality using five parameters based on a five-point frequency measurement scale ranging from never to always to extract residents' feelings, as shown in Fig. 5. There are four parameters on the smells which were smelled in the air shafts and adjoining spaces. The first parameter is dust smell. The analysis shows that 11.8% of the respondents never smelled dust smells, 13.7% rarely smelled dust smells, whereas 27.5 % sometimes smelled dust smells, 27.5% often smelled dust smells, and 19.6% of respondents always smelled dust smells. The presence of dust inside the air shafts may cause bacteria and germs to appear inside buildings which lead to cause different diseases [43]. The second parameter was the cooking smells, where 21.6% of the respondents said they never smelled cooking smells, 13.7% rarely smelled cooking smells, 15.4% sometimes smelled cooking smells.

In comparison, 25.5% often smelled cooking smells, and 23.5% always smelled cooking smells. As sown in the results, around 86.3% of the residents smelled cooking smells from the air shaft and adjoining spaces. Cooking in the home may be a significant source of smell, pollution, and particle matter inside [44]. Therefore, the residents should use different solutions such as range hoods or ceiling exhaust fans to remove the smells outside the houses.

The third parameter was measuring sewer smells. The analysis shows that 36.3% of respondents 'never smelled sewer smells', 17.6% rarely smelled sewer smells, 7.8% sometimes smelled sewer smells, 15.7% often smelled sewer smells, and. 23.5 % always smelled sewer smells. The presence of a sewer smell indicates a malfunction in the sewage system, which may be due to the water leakage inside the air shafts. Sewer drain leak may create significant difficulties for sewage system operation and management, including smells concerns produced by hydrogen sulfide (H_2S) and the explosion danger posed by methane (CH_4) [45].

The fourth parameter measured musty smells where 19.6% of the respondents indicated that they were never smelled musty smells, 17% rarely smelled musty smells, 15.7% sometimes smelled musty smells, 21.6 % often smelled musty odors, and 25.5% respondents always smelled musty smells.

The potential sources of musty smells that affect indoor air may include bird droppings, tobacco products, and paints [46]. The last parameter was used to indicate the feeling of suffocation when residents opened the windows. The analysis shows that 15.7% of the respondents never felt they were suffocating, 13.7% rarely felt they were suffocating, 33.33% sometimes felt they were suffocating. In comparison, 25.5% often felt suffocated, and 11.8% felt suffocated when they opened the air shaft windows. Although residents open the windows for natural ventilation, they feel suffocated. This feeling may be due to the presence of different smells. It may also be due to the design of the air shafts, as some of them are closed from the bottom and top and have a small area. As a result, the trapped, heated air inside the enclosed air shafts would cause suffocation and headaches in the residents [47]. In general, the residents were dissatisfaction with the indoor air environment. For that, there is a need to study the different indoor air quality parameters to determine the different levels of each parameter by using the data logger instruments in the field measurements and determine if they have a relationship with the sick buildings syndrome (SBS) or not [48].

3) Thermal Environment:

Relative humidity and air temperature are part of the indicators used to assess the thermal environment. This study adopted two parameters to evaluate the residents' feelings of relative humidity and air temperature. Regarding relative humidity, 28% never felt any increase, 18% rarely felt increase, and 30% felt sometimes increasing. In comparison, 18% often felt an increase, and 6% of the respondents always felt an increase Fig. 5. 14% of respondents never felt an increase, and the same percentage also rarely felt an increase in air temperature. 34% of the respondents sometimes felt increases, while 18% often felt increases, and 20% always felt increases in air temperature. The findings showed an increase in air temperature and relative humidity based on the resident's answers. This increase may lead to affect the thermal comfort of residents in adjoining spaces [32].

4) Acoustic Environment:

The acoustic environment, as shown in Fig.5, examined residents' sounds privacy or speech privacy. The results showed that 11.8% of respondents never heard any sounds from their neighbors, 19% rarely heard sounds, 35.8% sometimes heard sounds, while 21.6% often heard sounds from their neighbors, and only 11.8% of the respondents always heard sounds from their neighbors. In general, the loud sounds might be heard but difficult to understand, while the normal sounds could be just audible but not understandable. To improve sound privacy at air shafts, as part of the architectural design of buildings, the consideration of sound privacy is addressed by selecting acceptable values of the weighted apparent sound reduction index R'_w or the sound level difference D_{nT} in all directions to adjoining flats, as applicable. The sounds privacy is a multifaceted concept. It is not solely dependent on the insulating properties of the partitions but also on several other considerations. The ambient noise level at the listener's location is the most important of these factors to consider [49].

C. Impact of the Air Shafts' Specifications on Residents' Satisfaction with the Indoor Environment Quality

1) Visual Environment

The first impact of air shafts specification is air shaft types. As shown in Fig. 6, the service type significantly impacts the residents' visual privacy. The respondents indicated that the windows in the service type have less visual privacy than other air shaft types. In detail, 47.1% of respondents feel a

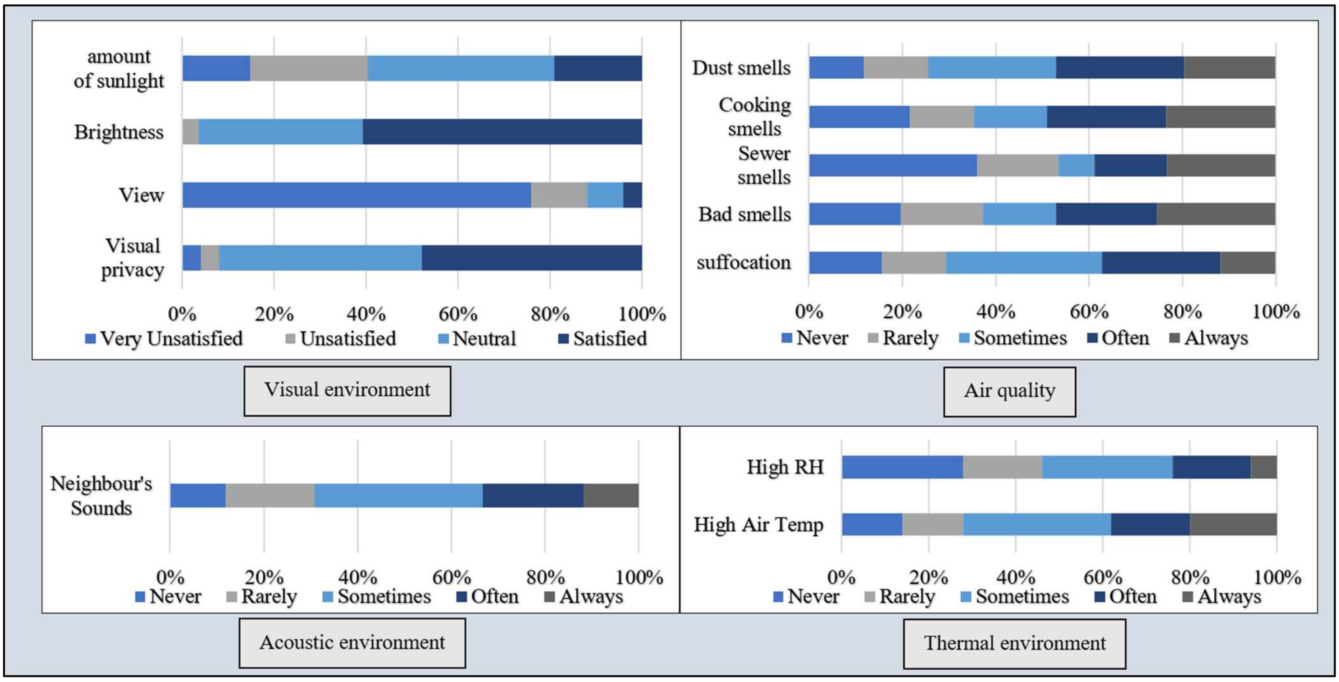

Fig. 5 The percentage of responses on residents' satisfaction with indoor environment quality in air shafts and adjoining Spaces

Strong impact and 52.9% of respondents feel a very strong negative impact on their privacy by neighbors. The residential type shows various impacts on visual privacy. The negative impact ranged from slight with 23.5% of responses to very strong with 53.3%. The percentage was 16.5% of answers for the medium impact, while for strong influence, it was 6.7% of responses. Therefore, it can be stated that the residential type impacts the visual privacy of the residents.

Regarding the combined type, only 5% of responses showed it does not impact visual privacy. In addition, 5% of responses feel a slight negative impact on their privacy. 25% feel medium impacts, 20% feel a strong impact, while 25% of respondents indicate that they feel a very strong impact from their neighbors on their visual privacy. In general, there is a relationship between the types of air shafts and visual privacy. The impact was notable in the service and residential types because the family members spent most of their time in the living room and kitchens.

The second relationship between the air shafts specifications and the visual environment was areas with visual privacy. The areas that were less than 5 m^2 had medium to very strong negative impacts on visual privacy. 63% of the respondents revealed a very strong impact, followed by 26.3% of the respondents indicating a strong impact, while the last option of medium effect had only 10.5% of the responses. For the areas from 5 m^2 to 7 m^2, only 4% of respondents chose 'no effect'.

The remaining responses were for the negative impact from 'slight' to very 'strong.' The highest percentage of responses was for the option 'very strong' with 44%. In contrast, the second highest was 28% for 'medium strong', and the third-highest of 20% was for 'strong.' The last option in this regard was 'slight impact' with only 4% of responses. For the areas that stated from 8m^2 to 12 m^2, only 2% of responses showed no effect. The rest of the results showed a negative impact that varied from 'slight' to very 'strong.'. The option 'very strong' had the highest negative impact with 45%, followed by 'strong' option with 25%, 'medium strong' with 21.2%, and 'slight impact' with 2% of responses. From these findings, it can be stated that the air shafts less than 5 m^2 have the most impact on residents' visual privacy. Therefore, it is recommended to consider increasing air shaft areas to protect the residents' privacy.

The third impact is the impact of air shaft types on the views. The impact of air shaft types on the views was examined using a residents' satisfaction scale. The highest responses were for 'very unsatisfied' for all types of air shafts by assessing the view of air shafts. The highest percentage of negative impact responses was 76% in service air shafts, 66.7% for residential type, and 45% for combined type.

The fourth relationship was the air shaft areas with the view. The respondents were unsatisfied with the views of all the various air shaft areas. The results indicate that the highest percentage of very unsatisfied respondents is for large air shaft areas, whereas 87.5 % of the very unsatisfied responses were for areas of 8m^2 to 12m^2. The second-highest percentage of 73.3% was for areas less than 5 m2. For areas of 5 m^2 to 7 m^2, only 4% of responses were very satisfied. The highest percentage of answers for the option 'very unsatisfied' was 68%. Based on the analysis findings of cross-tabulation, the view to the outside was unsatisfactory for the residents in all different types and areas of air shafts. These findings are expected since the air shafts do not have any access to the outdoor environment, which means the view from the window to the outside will be opened to walls or windows. Also, the air shafts do not include any element of natural landscaping, such as plants and water bodies. The air shafts as passive space may benefit from further using landscape to improve the indoor environment in general, such as the use of landscape in the courtyards [50].

2) *Air Quality*

This section summarizes the main findings of cross-tabulation of indoor air environment parameters and the

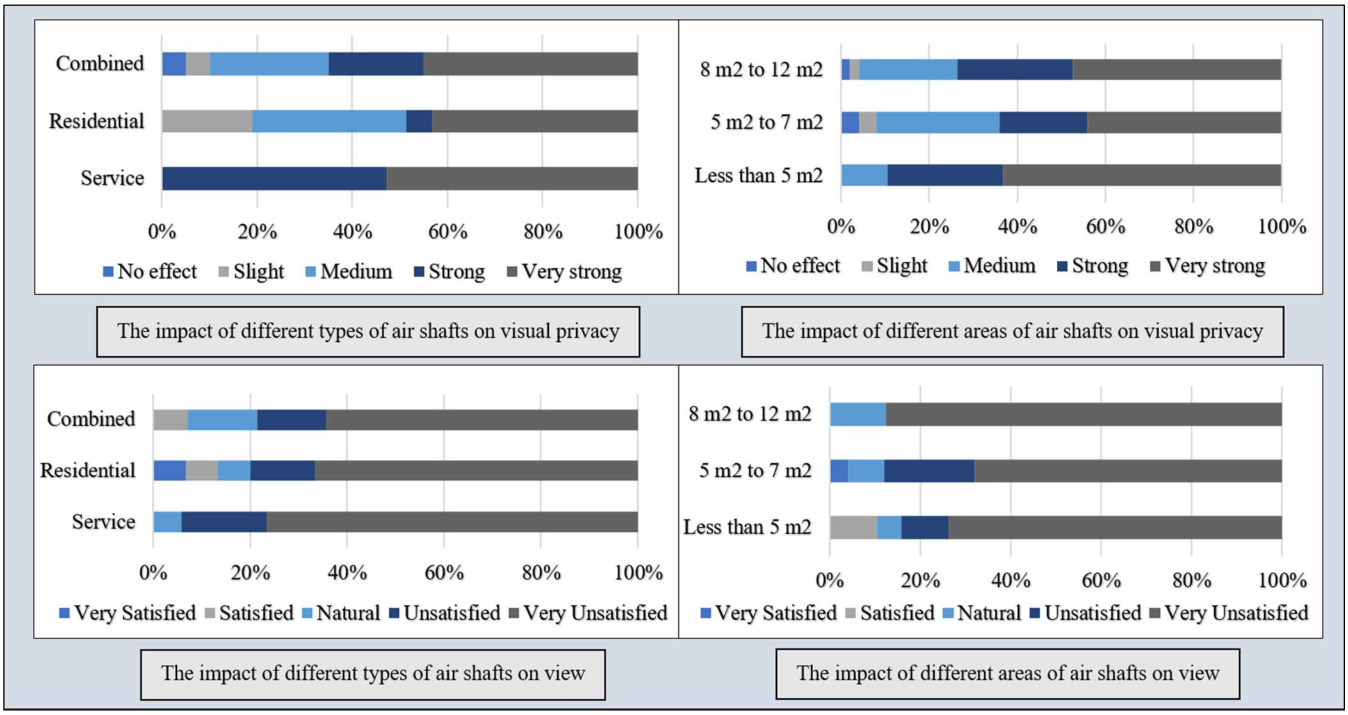

Fig. 6 The impact of the air shafts' specifications on residents' satisfaction with the visual environment in air shafts and adjoining Spaces

different specifications of air shafts. The first relationship was between the air shaft types and residents' suffocation. As seen in Fig.7, the residential type had the minimum impact on residents' suffocation. 52.9% of responses showed no suffocation impact, while 47.1% showed adverse impacts from the 'slight' to 'very strong' suffocation impact. In the combined type, 35% of responses did not show any impact, while 65% indicated a 'slight' to 'very strong' positive impact. In the service air type, 93.3% of responses showed the suffocation impact on residents, from a 'slight' to 'very strong', while 6.7% of responses showed no suffocation impact.

The second impact of air shaft types was on the bad smells. As shown in Fig. 7, 46% of responses chose 'no smell', while 53.4% chose 'slight' to 'very strong' bad smell in residential type. With the combined type, 25% of responses showed 'no smell', while 75% showed bad smells from 'slight' to 'very strong' smell. 17.6% of respondents did not smell any bad smell with the service type, while the highest percentage was for the 'slight' to 'very strong' smell with 82.4%. The service type had the worst relationship with the bad smells. Also, the combined type was not far from the performance of the service type, but it was slight better because of having a higher percentage of positive responses. The third impact of air shaft types was on the emission of sewage smells.

This part analyses the performance of different types of air shafts with sewage smells. Regarding the residential type, around 60% of responses chose 'no sewage smell' while the remaining percentage showed that approximately 40% of responses were 'slight' to 'very strong'.

The highest responses for the combined type were for sewage smell from 'slight' to 'very strong' with 70%. The remaining percentage was for 'no sewage smell' with 30%. The sewage smell responses were as high as 94.1% in the service type, from 'slight' to 'very strong' sewage smell. On the other hand, 5.9% of respondents chose 'no sewage smell'. As shown in Fig. 7, these numbers confirm the negative impact of service and combined types on the indoor air environment.

The last impact of air shaft types on the indoor air environment was on the cooking smells. The residential type responses showed that 66.7% of respondents chose 'no cooking smell', while the remaining 33.3% showed cooking from 'slight' to 'strong' Fig. 7. The combined type responses were 25% for the 'no cooling smell'. The remaining percentage of responses for the combined type was 75% for the cooking. Smell from 'slight' to 'very strong'. 93.1% chose 'slight' to 'very strong' cooking smell in service type. The remaining percentage was for the option, 'no cooling smell', with 5.9%. As shown in the findings of air shaft types, the worst type was the service type. It was clear that separating rooms and service spaces in one air shaft reduces the possibility of residents suffocating due to smells from services spaces such as kitchens and bathrooms.

The second specification of air shafts that had a relationship with the indoor air environment is the design of air shaft bottoms. Regarding the opened bottoms of air shafts, the highest percentage of responses were for the answer 'no dust smell', which is 61.3%. The remaining percentage showed the existence of dust smell from 'slight' to 'medium', with 38.7% of responses. In air shafts with a closed bottom, 87.1% of responses chose dust smell from 'slight' to 'strong' dust smell. The remaining percentage for 'no dust smell' was 12.9%.

In summary, the difference in the performance between opened bottoms and closed bottoms of air shafts can be attributed to a number of factors. Firstly, there was no gathering of dirt and dust in the opened bottoms. Secondly, the air movement in the opened bottoms air shafts was better than the closed bottoms because the opened bottoms allow the air to flow from inside and outside the air shafts, increasing the air change rates. [27].

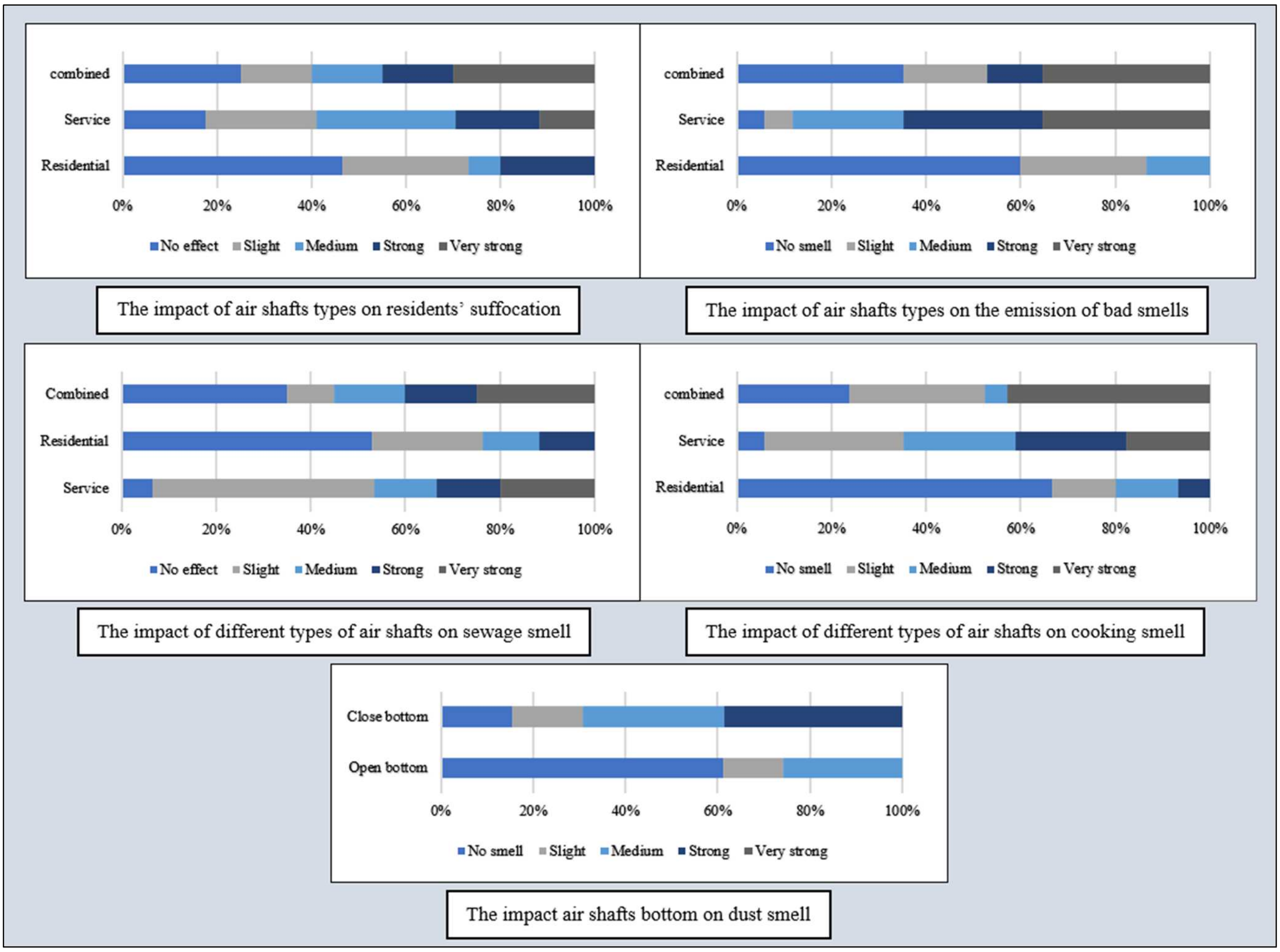

Fig. 7 The impact of the air shafts' specifications on residents' satisfaction with air quality in air shafts and adjoining Spaces

3) Thermal Environment

The first relationship between the air shafts specification and the thermal environment was the area of air shafts which has a strong impact. The air shafts with areas less than 5 m^2, all responses showed increases in air temperature, with 47.4% of respondents choosing 'moderately hot.' Following that was the option 'slightly hot' and 'very hot' with 21.1%. The choice of 'extremely hot' was chosen by 10.5%. For the RH, 5.3% of responses did not show any increase. The remaining percentage of 94.7% showed a rise in RH with the 'extremely high' option chosen by 31.6% of respondents and the same percentage for 'moderately high.' 21.5% of responses showed a 'very high' increase in RH. The last option of 'slightly hot' was chosen by 10.5% of respondents. Regarding the air shafts with areas from 5 m^2 to 7 m^2, 32% of responses were for 'not hot at all, while the remaining responses of 68% showed an increase in air temperature. 32% of responses were for 'moderately high' in air temperature. The second highest percentage was for responses regarding air temperature increase, 24% was for 'slightly high.' A minor percentage of responses was for 'extremely high' and' very high' with 8% and 4% ,respectively. Regarding RH, 96% of responses showed a rise in the RH, while the remaining percentage responses of 4% did not increase RH. The responses choosing the options, 'slightly high' and 'moderately high', were the highest at 32% each. The responses that chose 'very high' and 'extremely high' had 16% each. For the air shafts with areas from 8 m^2 to 12 m^2, 37.5% of responses showed no increase in the air temperature. On the other hand, the responses that showed a rise in air temperature were 62.5%. The option most chosen reflected the increase in air temperature was 'extremely hot' with 37.5%. The remaining percentage of around 25% of responses was for the last option, 'very hot.' In the case of RH, 25% of responses showed no rise, while 65% of responses showed an increase in RH from 'slight' to 'extreme.' The highest percentage of responses was 37% for 'extremely high', while 25% chose 'very hot. In summary and as expected, a significant increase in air temperature and RH was observed when the areas of air shafts decreased. On the other hand, the air temperature and RH decreased when the areas increased, as shown in Fig. 8.

The second impact of air shafts on the thermal environment was the air shaft's bottom. For the air shafts that are opened at the bottom, 38.1% of responses showed no increase in air temperature, while 61.9 of responses indicated a rise in air temperature. The highest percentage of responses for the rise in air temperature question was 28.6%, who chose 'moderately hot'. The second option of 'very hot' was selected by 14.3% of responses, 8% of 'extremely hot' responses, and 4.8% for 'slightly hot.' Regarding the RH, 9.5% of responses did not increase, while 90.5% showed an increase from 'slight' to 'extremely'. The breakdown is 38.1% for 'slightly high' and 23.8% for 'moderately high.' Only 19%

of responses were for ‘extremely high’ and 9.5% for ‘very high’. For the air shafts with a closed bottom, the highest percentage of responses was 90.7% which was for the increase in air temperature from ‘slight’ to ‘extremely’ hot. The highest rate of responses was 35.5% for the option ‘moderately hot’, followed by 29% of responses for ‘slightly hot.’ For the remaining responses, 12.9% chose the options ‘very hot’ and ‘extremely hot’. From the responses, 9.7% did not show any increase in air temperature. There was a very high increase regarding the RH, as reflected by 93.5% of responses, while 6.5% did not show any increase. Four options measured the increase in RH. The highest options were ‘slightly high’ and ‘extremely high’, with 32.2% of responses each. The third option of ‘very high’ got 22.6% of responses, while the fourth option of ‘moderately high’ got 6.5%. The last impact of air shafts on the thermal environment was using air shafts as the place for Installing A\C outdoor fan unit inside air shafts. The first part is the air shafts with the A\C outdoor unit. The responses in this aspect showed a decrease in responses choosing the option ‘not hot at all’ with only 4.8% of responses. The remaining percentage was for the increase in air temperature from ‘slight’ to ‘extreme.’ The highest percentage of responses of 47.6%, was for the option ‘moderately hot’, and the second-highest, 19%, was for each of the two options, ‘very hot’ and ‘extremely hot.’ The option ‘slightly hot’ had 9.5 % of responses. Regarding questions on RH, 90.3% of responses were for an increase in relative humidity. The highest percentage of 29% of responses showed that the increase in RH was ‘extremely high.’ The second-highest percentage of 25.8% was responses and chose the option ‘moderately high.’ That was followed by 19.4% of responses selecting the option ‘slightly hot’, while only 16.1% chose the ‘very high’ option. The second part is the use of air shafts without an A\C outdoor unit. The answers regarding this question showed 32.3% saying ‘not hot at all’, and 67.7% of responses showed an increase in air temperature from ‘slight’ to ‘extreme.’ The air temperature was ‘slightly hot’ by 25.8% of respondents, and ‘moderately hot’ by 22.6% respondents. The remaining percentage of 9.7% was for each of the two options, ‘very hot’ and ‘extremely hot.’ The question on RH showed 4.8% of responses did not have any increase in RH. Responses showing increases in relative humidity were from 95.2% of the respondents. The options ‘high’ and ‘moderately high’ recorded 33.3%. The options ‘slightly hot’ and ‘very hot’ were chosen by 19% of respondents. 9.7% of the responses chose ‘extremely hot’. The thermal performance of air shafts with A\C outdoor fan units was worse than other air shafts without A\C outdoor fan units. The responses showed that 67.7% of air shafts without A\C outdoor fan units increased air temperature from ‘slight’ to ‘extremely’, while the air shafts with A\C outdoor fan units had a rise in air temperature; by 95.2% of respondents.

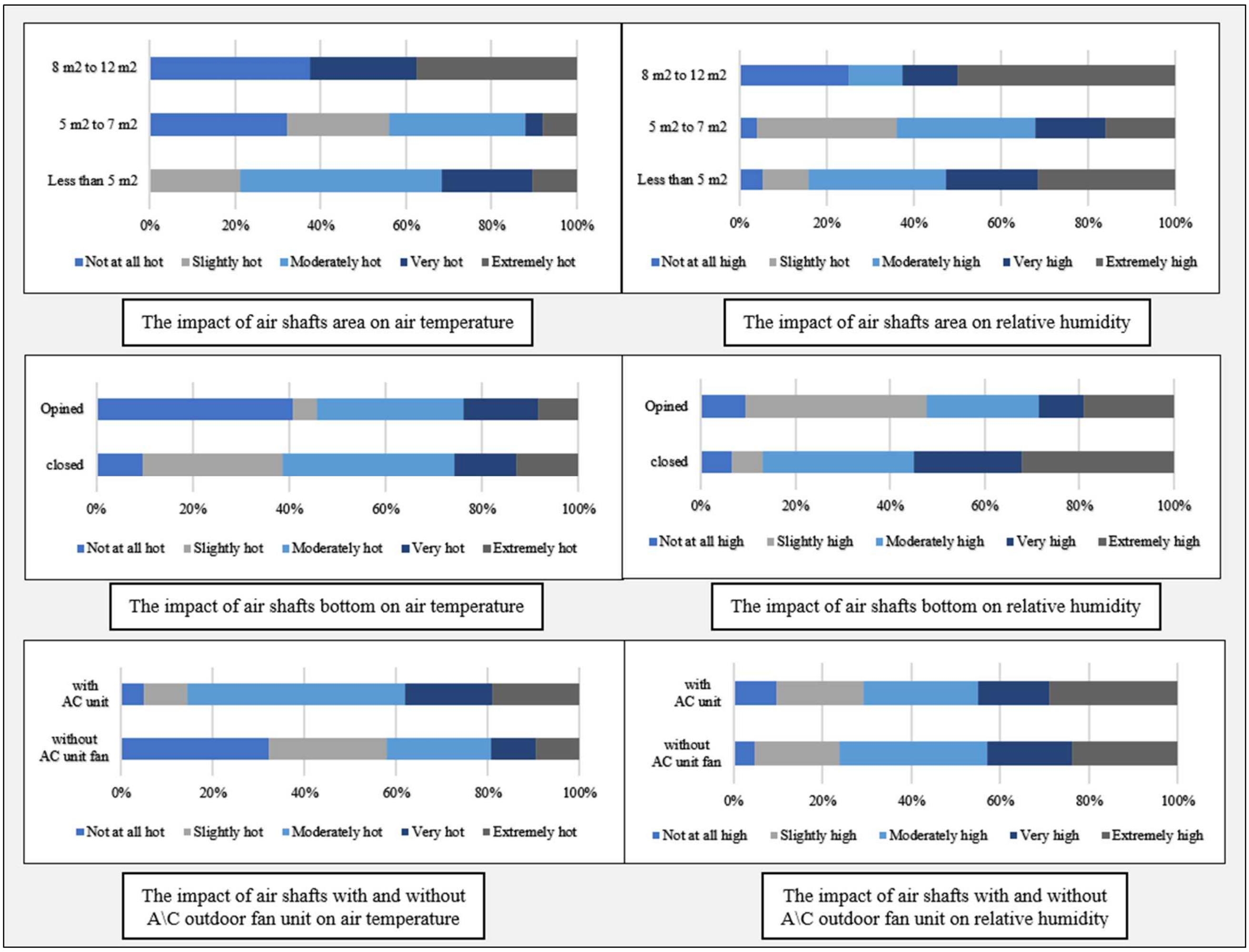

Fig. 8 The impact of the air shafts’ specifications on residents’ satisfaction with the thermal environment in air shafts and adjoining Spaces

In summary, the high percentage of residents' dissatisfaction was in the air shafts with a small area closed from the bottom and sometimes closed from the top. In addition, the findings also agree with the results reported by [26]; the use of the air shafts as a place to installing the outdoor units of A/C inside air shafts caused a rise in air temperature and affected the resident's satisfaction. Responses showing increases in relative humidity were from 95.2% of the respondents. The options 'high' and 'moderately high' recorded 33.3%. The options 'slightly hot' and 'very hot' were chosen by 19% of respondents. 9.7% of the responses chose 'extremely hot'. The thermal performance of air shafts with A\C outdoor fan units was worse than other air shafts without A\C outdoor fan units. The responses showed that 67.7% of air shafts without A\C outdoor fan unit had an increase in air temperature from 'slight' to 'extremely', while the air shafts with A\C outdoor fan unit had a rise in air temperature; by 95.2% of respondents. In summary, the high percentage of residents' dissatisfaction was in the air shafts with a small area closed from the bottom and sometimes closed from the top. In addition, the findings also agree with the results reported by [26]. The air shafts to install the outdoor units of A/C inside air shafts caused a rise in air temperature and affected the resident's satisfaction.

4) Acoustic Environment

In this part, the types of air shafts also have an impact on neighbors' voices. The results showed that neighbors' voices mainly were very high for all types of air shafts. For the residential air shaft, 6.7% of responses indicated that there were no sounds from neighbors. The remaining answer is 93.3% for the sounds from neighbors that ranged from 'slight' to 'strong sounds.' 40% of the responses were 'strong sounds', 33.3 % for 'medium sounds', and 20% for 'slight sounds.' The highest percentage of answers for the service air shaft was for 'no sounds', with 23.5% of responses as shown in Fig. 9. The remaining percentage of responses was for 'very strong sounds' with 17.6%, 'slight sounds' with 17.6%, and 'strong sounds' with 17.6%. For the combined air shafts, 5% of responses chose 'no sounds from neighbors.' The remaining 95% of responses ranged from 'slight sounds' to 'very strong sounds.' Out of that, 20% was for 'slight sounds' and 'strong sounds', and 15% was for 'very strong sounds.

The areas of air shafts also impact the privacy of the residents, as shown in Fig. 9. The performance of small area air shafts in terms of hearing neighbors' voices was better than air shafts of bigger areas. The shafts with areas less than $5m^2$ had the highest percentage of responses for 'no sound' with 15.8%. The remaining 84.2% of responses were for the existence of neighbor's sounds ranging from 'slight' to 'strong sounds.' 47.4% of responses reported 'medium sounds' from neighbors, 31.6% reported 'slight sounds', and 5.3% reported 'strong sounds'. For air shafts with areas from $5m^2$ to $7m^2$, 12% of responses chose 'no sound'. The remaining reactions for hearing sounds from neighbors ranged from 'slight' to 'very strong sounds.' 40% of responses reported 'strong sounds', 20% reported 'medium sounds', 16% reported 'slight sounds', and 12% reported 'very strong.' For air shafts with areas from $8m^2$ to $12m^2$, all responses showed the existence of neighbors' sounds ranging from 'medium' to 'very strong sounds.' 50% of responses chose 'medium sounds', 37.5% chose 'very strong sounds', and 12.5% chose 'strong sounds. Overall, the study of the effect of different types and areas of air shafts on sound privacy is inconclusive. Therefore, future research should seek to address the issue of sound privacy by using the proposed method in this study [49].

IV. Conclusion

This paper has presented the findings of a study of air shafts as a passive space within 53 residential buildings in a hot, dry climate in Saudi Arabia by using the questionnaire. Based on the questionnaire, a comparison of results was made by using cross-tabulation analysis. The analysis adds information to the questionnaire results on the visual environment, air quality, thermal environment, and acoustic environment towards air shafts design parameters. It was found that visual privacy, the view from the windows to outside, and daylight amount were found most dissatisfying aspects of the visual environment of air shafts and adjoining areas. Regarding the air quality, the types and the roof and ground of air shafts had the most negative answers on residents' satisfaction with the smells of sewage, dust, and cooking. On the aspect of the thermal environment, the results showed that residents were not satisfied due to the increases in the temperatures in all the types of air shafts regardless of the usages, areas, and heights. That was also because of the negative use of the air shafts. For example, they are installing the outdoor A\C units inside the air shaft and closing the tops and bottoms of the air shaft, as reflected in some answers. The acoustic environment also had negative responses regarding the resident's satisfaction.

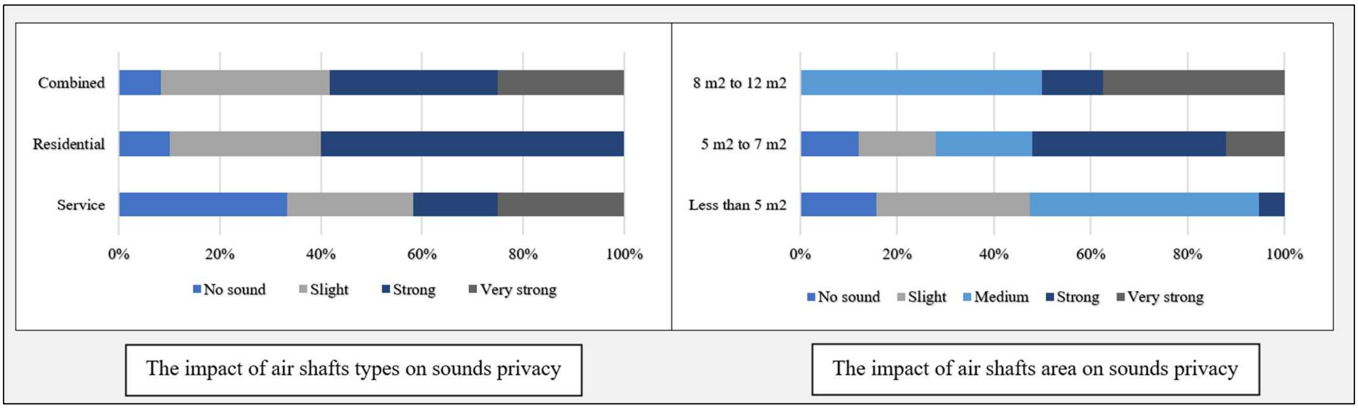

Fig. 9 The impact of the air shafts' specifications on residents' satisfaction with air quality in air shafts and adjoining Spaces

The neighbors sometimes heard other neighbors through the small air shafts. It is almost certain that further research and action relating to air shafts design improve the residents' satisfaction with the buildings while also improving buildings performance by providing the buildings with natural ventilation and daylight, which contribute to saving energy. Additionally, the study's findings aid in not only identifying issues that cause disruptions in building performance and avoid faults or building deterioration and allow for the avoidance of defects or building environment deterioration. By identifying potential for improvement at all stages of the building process and the linkages between the environment and behavior of owners, users, and designers, the study contributes significantly to the Saudi Arabia building industry. Nevertheless, further investigation on the relationship between indoor environmental quality parameters and passive spaces design by using field measurements or simulation tools may be interesting to perform.

ACKNOWLEDGMENT

The authors thank the Deanship of Scientific Research and Prince Khalid Al-Faisal Chair for Developing Makkah Al-Mukarramah and the Holy Places at Umm Al-Qura University (project: DSRUQU.PKC-42-11) for the financial and logistical supports.

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