【カテゴリーⅠ】

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PASSIVE DESIGN SEEN FROM SPATIAL OPENNESS AND AIRFLOW IN CONTEMPORARY TUBE HOUSES OF HO CHI MINH CITY, VIETNAM

ベトナム・ホーチミンの現代のチューブハウスにおける空間の開放性と風環境からみたパッシブデザイン

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This study aims to shed light on the correlation between spatial composition and indoor airflow as a passive design used in contemporary tube houses in Ho Chi Minh City (HCMC), Vietnam. In this constraint housing typology due to rapid urbanization, the study clarifies patterns of the living room and bedroom for their architectural and environmental characteristics such as room placement, spatial openness, airflow area and wind path. By revealing variable combinations between spatial openness and airflow in terms of rooms pattern and houses pattern, the finding clarifies diverse design methods responding to the environment in the contemporary tropical city.

Keywords: *Spatial Composition, Openness, Wind environment, Tube House, Passive Design, Ho Chi Minh City*
空間構成、開放性、風環境、チューブハウス、パッシブデザイン、ホーチミン

1. Introduction

1.1 Background and purpose

In the hot and humid climate of Vietnam, climate-responsive building solutions, routed in the way of the culture characterized by strong community connections and traditional lifestyles close to nature, are essential. Although heavily influenced by different cultures, transformations and adaptations through several periods of colonization, the spatial planning of Vietnamese housing has always tried to keep its unique traits. These are the characteristics of open structure, the organic connection to the natural environment and the capacity for self-adaptation to the climate conditions[i]. Recently, these unique characteristics are going under constant modification in the urban situation of Ho Chi Minh City (HCMC), the densest city in Vietnam and one of the largest urban metropolis in Southeast Asia. As a recently developed metropolis, with fast-constructed urbanization via the economic boom with waves of scholars returned from abroad, HCMC has fostered its own architectural identity. The identity inspired by modernism features an interplay of voids and enclosures that provides composite articulation for louvers and porosity blocks on the building facades[ii]. These spatial compositions belong not only to the architecture of public buildings and institutions but also evolved, transformed and continuously reinvented to be a part of the urban housing design in this city[iii]. Among all the typologies of urban housing in HCMC, the tube house is a fascinating example of street houses, which existed since the 15th century and has been retrofitted to adapt to different periods of urban development since the Doi Moi policy in 1986. However, despite being the most popular type of housing in HCMC[iv], the contemporary tube house is a challenge for architects in terms of preserving a comfortable environment for urban dwellers and reducing energy consumption. Hence, this context of high urban density and high impact of heat islands in HCMC intrigue interest to understand the contribution of housing design to enhancing the living condition of urban dwellers. This study aims to investigate how the design of tube houses in the contemporary era, with its unique characteristic of spatial composition, could provide alternative solutions using the climate-responsive approach.

Besides, in the previous research on contemporary Vietnamese houses[4], the authors investigated the light and wind environment of living spaces. The previous results clarify their composite characteristics of space and environment. However, how the

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composite characteristics of these environmental factors might vary in different living spaces of the housing planning, such as the bedrooms and living rooms with different time usage and environmental conditions are not clarified yet. Also, for contemporary urban houses like the tube house, the passive design strategy is a challenge to be considered within the living condition of HCMC. Further, the outcome could contribute to the design of contemporary tube house typology and offer different approaches to integrating passive solutions that enhance the dwelling environment in Vietnam.

1.2 Past studies and relevancy

For the analysis methods focusing on passive design in detached houses seen from spatial composition, in addition to the continuity of previous research on contemporary Vietnamese houses[4)], the following authors' past studies mainly provide a base used in this research. Matsumoto[5)] clarified the intentionality towards environmental design in Yoshimura's housing works through the interpretations of spatial composition as a thermal and airflow design. Fujiwara[6)] highlighted the integrations and confrontations inherent in the window composition of the seaward villas. These researches give significant references for the analysis methods in this study, especially for the opening ratio and wind path. Besides, concerning past research on Vietnamese tube houses, researchers developed several directions considering the typology, spatial organization and environmental assessment. Firstly, the focus was to determine the conservation requirements for the traditional typology of Vietnamese architecture, such as the study from To[7)]. Secondly, several studies focused on comparing traditional and modern typologies. To[8)] clarified the transformation of the traditional type to the modern type under the influence of rapid urbanization after the 1986 Reform. Nguyen[9)] analyzed a large sample of tube houses via different urban development periods to determine the Isovist of green space ratio within the change in structure and organization. Thirdly, according to the recent rise of interest in reducing energy consumption in housing design, there was a new wave of research on sustainable design strategies to understand the tendency of reinventing tube house typology. For instance, Nguyen[10)] focused on improving energy efficiency in tube houses via a survey on occupants' awareness. While Dang[11)] took another approach through the comfort perception of urban dwellers based on the simultaneous influences of temperature and airflow by combining questionnaires and on-site measurements to justify the acceptable rate of wind velocity to enhance the indoor environment. Despite these previous researches contributing to clarifying the diverse fields covering the broad topics of Vietnamese tube houses, the relationships in the spatial and environmental characteristics through a scientific approach have not been investigated yet.

Also, on a broader scale of adaptation from the traditional to modern housing design in Asia, several researchers are interested in spatial composition as a part of the climate-responsive design in the tropical climate. As lessons learned from the vernacular architecture, Dahniar[12)] studied the composition of open veranda during different historical periods as a climatic control device maintaining social life and identity of Indonesia's social interactions. Ichikawa[13)] was interested in the layout of the terraces as an extended semi-outdoor space between houses in the dense village of the Philippines for social gatherings and private uses with taking advantage of the natural wind flow. Le[14)] studied the flexibility and potential for expansion of the building envelope from traditional street houses to high-rise apartments, focusing on ensuring natural ventilation for cooling in Vietnam. These previous researches contributed to the quest to apply the passive design strategy to building elements for contemporary housing in the tropical climate.

By considering the above methods and positioning this study from the past studies, this research clarifies the combinational characteristics of space and environment by simulating the indoor airflow of the rooms with different functions and investigating how these spaces are open to the outdoors in the contemporary tube houses which is a critical urban house typology in Vietnam. The findings from this study would provide helpful insights for future practices to improve urban housing. Further, the outcome will contribute to finding solutions to enhance the quality of living according to sustainable design trends, especially in tropical cities.

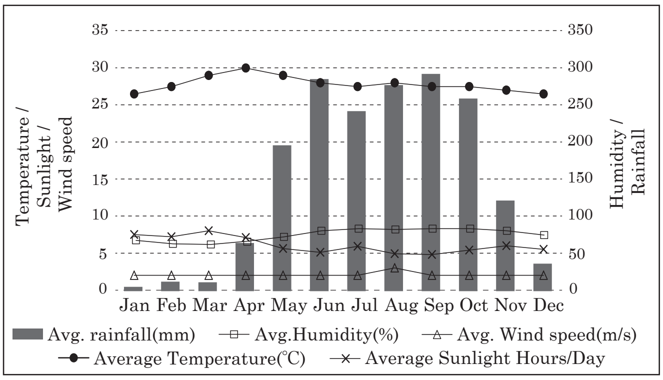
2. Methodology

2.1 The environmental condition of HCMC

The environment of HCMC is characterized by a tropical climate with key features such as high temperature, high humidity and long sunlight hours across most time of the year (see Fig.1). Besides, the rapid urban expansion and the influence of climate change are accelerating the vulnerability of the living condition of urban dwellings, resulting in an unsatisfactory indoor environment and increasing the use of air conditioning by households to reduce discomfort during the hottest month. Considering these data, the simulation conducted in the following chapters of this research is set in April, which is at the end of the dry seasons, coinciding with the period of highest temperature and long sunlight hours while the precipitation stays among the lowest and wind speed is average with high humidity. In addition, reports on the use of air conditioning during this month stand at the highest during the period of daily activities[v)].

2.2 Case studies of contemporary tube house in HCMC

Tube houses are traditionally known as the urban townhouse, which evolved from the rural housing type into an indigenous urban context, initially with a narrow front for shops[vi)] and the houses expanded longitudinally to accommodate housing functions inside the street block. After the Reform in 1986, tube houses became the most dominant type in the urban



*Source https://www.weather-atlas.com/en/vietnam/ho-chi-minh-city-climate
*Data are collected from average temperature, average rainfall, average humidity, average wind speed, average daylight/ sunshine hours and combined.

Fig.1 Climate condition of Ho Chi Minh city

Tab.1 List of case studies

No.	House	Year	Architect	Status
1	White House	2010	H.a	a
2	NA House	2011	Nature Arch Studio	a
3	Stacking green	2011	VTN Architects, SDA, NISHIZAWAARCHITECTS	a + b
4	Anh House	2013	S+Na Architects	b
5	Binh Thanh House	2013	VTN Architects, SDA, NISHIZAWAARCHITECTS	a + b
6	Folding Wall House	2013	Nha Dan Architects	a
7	3×10 House	2014	DD concept	a
8	B House	2014	i.House Archi. & Cons.	a
9	The Gills	2014	Cong Sinh Architects	a
10	Thong House	2014	NISHIZAWAARCHITECTS	b
11	Vegan House	2014	Block Architects	a
12	Breeze House	2015	Mel Schenck	b
13	HEM House	2015	Sanuki Daisuke Architects (SDA)	b
14	House 304	2015	KIENTRUC O	a
15	Kaleidoscope	2015	Cong Sinh Architects	a
16	Micro Town House 4×8m	2015	MM++ Architects	a + b
17	Saigon House	2015	a21 studio	a
18	Townhouse with a Folding-up Shutter	2015	MM++ Architects	a + b
19	Wasp House	2015	Tropical Space	a
20	Bamboo House	2016	VTN Architects	a
21	Lee&Tee House	2016	Block Architects	a
22	Nha Cua Tien	2016	23o5 Studio	a
23	Quiin House	2016	23o5 Studio	a
24	Zen House	2016	H.a	a
25	/ House	2017	Time Architects	a
26	// House	2017	Time Architects	a
27	Backyard House	2017	AD+studio	a
28	D House	2017	KIENTRUC O	a
29	Giabinh.House	2018	AD9 Architects	a
30	House for a Daughter	2018	Khuon Studio	a
31	Lantern House	2018	atelier NgNg	a
32	Lien Thong House	2018	6717 Studio	a
33	The Rough House	2018	NELO DÉCOR	a
34	ZAKK and MB'S House	2018	Sawadeesign	a
35	Breathing House	2019	VTN Architects	a
36	Ha House	2019	VTN Architects	a
37	k59 home& atelier	2019	k59 atelier	a
38	MM Tropical Suburd Townhouse	2019	MM++ Architects	a + b
39	Pattern House	2019	MM++ Architects	a + b
40	Tan Phu House	2019	k59 atelier	a
41	V House	2019	AD9 Architects	a
42	VOM House	2019	Sanuki Daisuke Architects (SDA)	b
43	VY ANH House	2019	Khuon Studio	a
44	Floating Nest	2020	atelier NgNg	a
45	HL House	2020	Chi.Arch	a
46	T House	2020	Acspace	a
47	THD House	2020	AD9 Architects	a

*a = Vietnamese local architect, b = foreign architect based in HCMC, a + b = local and foreign collaboration

area due to their low-cost construction that can adapt to rapid urbanization[vii], the influence of western living standards and a recent rise in awareness of building design incorporated the idea of sustainability. The tube house's features are characterized by a long and narrow form and segmented arrangement, usually built on one to two storeys above ground with several voids across the length of the building to maximize the porosity and provide enough natural light and airflow for all the rooms. However, since the mass production of tube houses between 1999-2009, land coverage in HCMC can go up to 80-100% in a residential neighbourhood of core districts[viii] and the original features also transformed with more storeys and shorter lengths due to the packed urban settings. These conditions make it extremely difficult to ensure a comfortable environment for all rooms and affect the dwellers' living conditions. Based on this context, this study analyses the tube houses designed after the mass production period, focusing on the relationship between airflow and spatial openness. Forty-seven case studies are selected from the architectural medium as the contemporary tube houses in HCMC[ix]. They are built from 2010 onward (Tab.1), having three to six stories above ground, a depth-to-length ratio of two or more and only the narrow side of the house facing the road.

2.3 Structure of the analysis

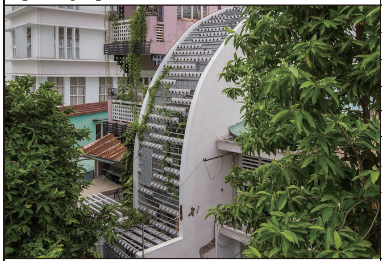
The analysis is structured in three steps corresponding to chapters 3, 4 and 5. Firstly, chapter 3 focuses on the space where the main activities of urban dwellers occur during the daytime and nighttime. The analysis extracts living rooms and bedrooms in each case study as the targeted functional room. It examines how to open up these spaces to the outdoor environment in terms of spatial composition via examination of room placement and spatial openness. Secondly, chapter 4 analyzes the potential of wind path and continuity of air movement within these rooms by using the simulations of indoor airflow during the dry season. Finally, chapter 5 illustrates the variations of combinational patterns of spatial composition and airflow in each room. Further, the intentionality toward the passive design of each house inheriting the spatial openness and tendencies of airflow is clarified. These analysis methods are shown through an analysis example illustrated in Fig.2.

3. Spatial composition by room placement and spatial openness

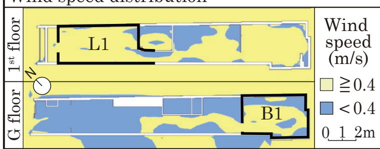
3.1 Room placement

The study extracted the living rooms and bedrooms as the target for analysis. The data collection retrieved 49 living rooms and 124 bedrooms from the 47 case studies. As shown in Tab.2 and Tab.3, case studies with one living room (45/47) and multiple bedrooms (45/47) are a majority. Then, the living rooms and bedrooms are investigated in terms of room placement in Tab.4 and Tab.5. The analysis examines their position on the building side, their level at the building height, and the orientation of their windows.

No.43 VY ANH House
(photograph of Khuon Studio, 2019)



Wind speed distribution



Chapter 5 Spatial composition & airflow			
Room No.	L1	B1	Bedroom Open group
Room pattern	Ⓓ ii	Ⓑ iv	b

Chapter 3 Spatial Composition		
Room placement		
Room No.	L1	B1
Side	Street	Back
Level	Middle	Low
Orientation	W	E
Spatial openness		
Open surface No.	L1-1	B1-1
Window size	3.0 m²	3.8 m²
Window/wall ratio	39%	39%
Attached elements	Open	None
Composite opening ratio	SS	LS
Configuration pattern	④ Multiple ・S	② Single ・S
Chapter 4 Airflow		
Room No.	L1	B1
Airflow area	Wide	Wide
Wind path	ii	iv
Indoor air movement	Presence	None

Fig.2 Analysis example

Tab.2 Number of living room

Number of room per house	One 1	Multiple 2
Number of houses	45	2
Total number of rooms		49

Tab.3 Number of bedroom

Number of room per house	One 1	Multiple 2	3	4	5	6	7
Number of houses	2	24	13	7	0	0	1
Total number of rooms							124

Tab.4 Placement of living room

Level \ Side	Street (18)				Middle (2)		Back (3)				Across (26)	
Top (0)	0				0		0				0	
	N	S	E	W	N-S	E-W	N	S	E	W	N-S	E-W
	0	0	0	0	0	0	0	0	0	0	0	0
Middle (19)	10				0		2				7	
	N	S	E	W	N-S	E-W	N	S	E	W	N-S	E-W
	3	3	1	3	0	0	1	0	0	1	7	0
Ground (30)	8				2		1				19	
	N	S	E	W	N-S	E-W	N	S	E	W	N-S	E-W
	4	1	1	2	0	2	0	0	1	0	9	11

Tab.5 Placement of bedroom

Level \ Side	Street (55)				Middle (12)		Back (51)				Across (6)	
Top (21)	8				2		10				1	
	N	S	E	W	N-S	E-W	N	S	E	W	N-S	E-W
	4	1	1	2	0	2	1	4	3	2	1	0
Middle (94)	47				10		32				5	
	N	S	E	W	N-S	E-W	N	S	E	W	N-S	E-W
	8	20	8	11	2	8	7	9	12	4	5	0
Ground (9)	0				0		9				0	
	N	S	E	W	N-S	E-W	N	S	E	W	N-S	E-W
	0	0	0	0	0	0	4	2	3	0	0	0

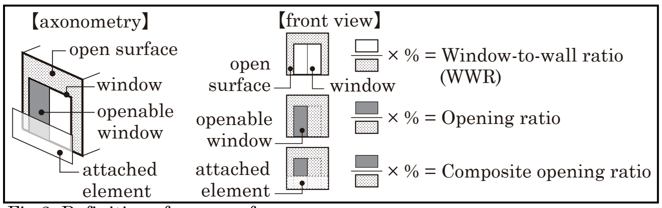


Fig 3. Definition of open surface

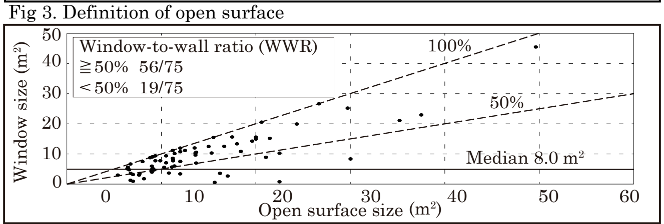


Fig.4 Window size and WWR of living room

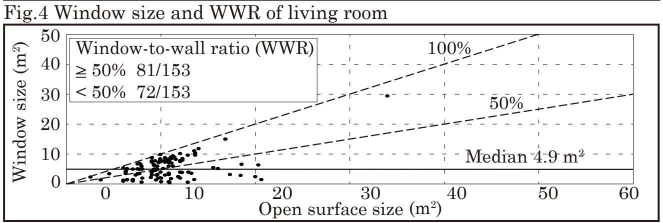


Fig.5 Window size and WWR of bedroom

As a result, all the living rooms are lifted from the street level and located on the ground floor (30/49) or middle floors (19/49). Concerning their position on the building sides, the majority of the rooms is facing either the street side or the backside of the building (26/49). Both situations are mostly with the south orientation. Concerning their level at the building height, about 80% of the bedrooms are on the middle level (94/124). In this case, the placements are mostly on the street side (55/124) and backside (51/124). Also, these placements are toward only one side of the building. Regarding the orientation of windows, the most common is the south in cases of rooms on the street side and the east in cases of rooms on the backside (21/55 and 18/51).

3.2 Spatial openness

The spatial openness of living rooms and bedrooms is analysed considering the open surface, which is the combined characteristics of windows in terms of the window's size and the structure of layers using attached elements such as louver, porosity blocks or planters. Firstly, the analysis extracts the open surface from all the living rooms and bedrooms. It is defined as illustrated in Fig.3, which is the wall consisting of the window facing the outside air. The collection counts 75 open surfaces in the living rooms and 153 in the bedrooms. In Fig.4 and Fig.5, the medians for window size[x)] are found to be 8m^2 for windows in the living room and 4.9m^2 for the one in the bedroom. Regarding these open surfaces' size, the window-to-wall ratio (WWR) was also examined (see Fig.3). The majority of open surfaces show more than 50% of WWR, which are from 56 living rooms and 81 bedrooms. This result indicates a tendency for both types of rooms to have large windows to provide natural light.

Secondly, the attached elements, which are installed parallelly outside the windows, were classified by the characteristics of open or closed (Tab.6). The majority of these elements are the open type in both living rooms and bedrooms (22/75 and 67/153), which always allow light and air to flow through, such as porous blocks or nets. Then, the ratio between the openable window and to open surface is defined as the opening ratio. Also, the ratio between the openable window's area, excluding the area blocked by attached elements, was defined as the composite opening ratio (see Fig.3). For each open surface, the above ratios are calculated, and the combinations of these two are classified as the pattern of composite opening considered in each living room and bedroom. As shown in Fig.6 and Fig.7, the medians of the opening ratio are 50% in the living rooms and 33% in the bedrooms. The medians of the composite opening ratio are 27% and 15%, respectively, indicating that the attached elements halve the openness overall in both room types. In addition, the majority of the composite opening patterns are LL and SS in both room types. For instance, 28/75 and 26/75 are found in living rooms, while 55/153 and 54/153 are in bedrooms, respectively.

Finally, combinations of the composite opening pattern and the presence of attached elements were examined and classified into four configuration patterns in terms of opening surface (Tab.7). In both living rooms and bedrooms, the majority of combinations are the type of layers using attached elements. Also, the most common configuration pattern of opening surface is ④ Multiple layers・S (31/75 for the living room and 63/153 for the bedroom). However, in the case of the living rooms, ① Single layer・L also has an almost equal number (28/75). This configuration is a Large and Single opening surface facing the outdoor air without any attached element. In the case of the bedrooms, there is a similar quantity of the configuration ③ Multiple layers・L (37/153). This configuration is also a Large opening surface, but there are Multiple openings using layers of attached elements. These results suggest a confrontation between the spatial openness and the layers of the outer surface of the windows.

4. Wind environment by airflow area and wind path

4.1 Settings of wind simulation for airflow

The natural airflow in the rooms was investigated by Computational Fluid Dynamics (CFD) and used climate data from WEADAC[xi] with the settings for the simulation model detailed in Fig.8. The average wind condition in April[xii] (cf. Chapter 2.1) was defined as the input values for the analysis model according to the most significant period concerning activities in each type of room. The wind speed was calculated from the hourly average of the chosen period in each room type, at 4.0 m/s and 1.7 m/s, for the living rooms and bedrooms, respectively. The wind direction was South-South-East, found in both room types[xiii]. The targeted building was modelled with some considerations in spatial forms, such as including stairs, and built-in furniture. Also, all the windows and doors are open considering a condition for the maximum potential of natural airflow. The surrounding buildings were modelled as an assumed urban environment of medium-rise and high-density conditions, with simple building shapes without eaves[xiv]. A setback of 0.5m between buildings on the sides and at the back are defined for all surrounding buildings, taking into account the rapid urbanization of HCMC[xv].

4.2 Airflow area

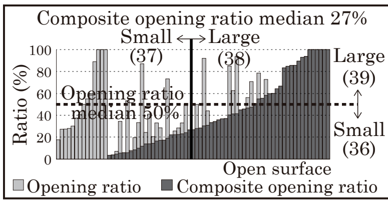
For both room types, a distribution plan of wind speed defined at the height of 0.5m from the floor level is set to show the behavior of natural airflow inside the rooms according to human height. Then, the ratios between the airflow area to the floor area in each room were calculated, by defining the range of wind speed for airflow area from 0.4 m/s and faster, which is the range of airflow people could feel[xvi]. As shown in Fig.9 and Fig.10, the medians of airflow area ratio are 74% in the living rooms and 25% in the bedrooms, indicating that strong velocity in the living rooms tends to cover a large airflow area, while it tends to be limited in the bedrooms.

4.3 Wind path

Next, the analysis examines the shape of the airflow area in

Tab.6 Types of attached element

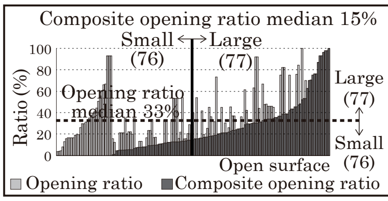
Open (22,67)					Open-close (4,1)	Close (15,33)
Louver (5,15)	Porous block (4,26)	Net (8,11)	Planter (5,5)	Low wall (0,10)	Door	High wall



Composite opening pattern

Opening ratio \ Composite opening ratio	Large	Small
Large	LL 28/75	LS 11/75
Small	SL 10/75	SS 26/75

Fig.6 Composite opening pattern of living room's open surface



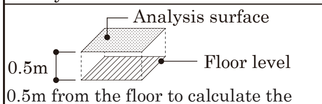
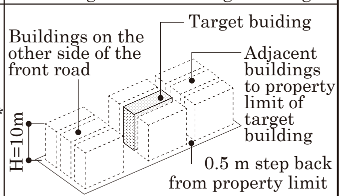
Composite opening pattern

Opening ratio \ Composite opening ratio	Large	Small
Large	LL 55/153	LS 22/153
Small	SL 22/153	SS 54/153

Fig.7 Composite opening pattern of bedroom's open surface

Tab.7 Configuration patterns of open surface

Attached element	None (34,53)				Presence (41,100)			
Composite opening pattern	LL (19,23)	SL (9,17)	LS (0,1)	SS (6,12)	LL (9,32)	SL (1,5)	LS (11,21)	SS (20,42)
Configuration pattern of opening surface	①Single・L (28,40)		②Single・S (6,13)		③Multiple・L (10,37)		④Multiple・S (31,63)	

Software (STREAM ver.2021.1)	Climate (WEADAC)
Turbulence model: Standard k-ε Boundary cond.: All surfaces smooth. Root block: -Standard length is x,y,z=1m -Limit width: x,y,z=0.01m -Surface roughness classification: III -Power index:α=0.2	Location：HCMC, Vietnam Season: April Living room: Time: 17:00 - 20:00*, Orientation: S-S-E, Wind speed: 4.0m/s Bedroom: Time: 0:00 - 5:00*, Orientation: S-S-E, Wind speed: 1.7m/s
Analysis surface	Modelling of surrounding buildings
 0.5m from the floor to calculate the wind speed relative to human height**	 Surrounding buildings are modeled as simple shape without eaves.
Modelling of target building	
All openings (doors, windows, skylight) are open. Include stairs and built-in furniture. Not include vegetations.	

*The time for simulation in living room and bed room are chosen according to the period when these rooms are most used during the day.
**The height correspond to the posture of sitting and lying on bed.

Fig.8 Settings of simulation for airflow

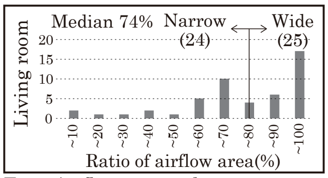


Fig.9 Airflow area in living room

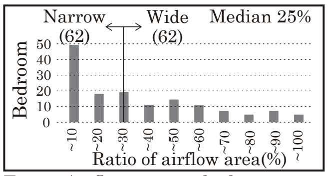


Fig.10 Airflow area in bedroom

Tab.8 Wind path

Wind path	Presence of wind path: In depth direction: With side direction (i)	Presence of wind path: In depth direction: No side direction (ii)	Presence of wind path: In transverse direction (iii)	None (iv)
Living room	4/49 (4)	24/49 (14)	4/49 (4)	17/49
Bedroom	1/124 (1)	36/124 (31)	10/124 (10)	77/124

Tab.6, 7 Note: The numbers indicate the quantity of rooms (living room, bedroom), in which contains the type of attached element.
Tab.8 Note: The numbers in ( ) indicate the quantity of rooms which have the wind path continuing to the adjacent indoor space.

each room, called the wind path, which is an airflow area crossing between adjacents and opposites walls. Further, the presence and the shape of wind path, considering factors such as the depth or the direction, characterize the wind paths into four types, as illustrated in Tab.8. In the case of the living rooms, the majority (32/49) have a wind path, while in the case of bedrooms, it is only about 40% (47/124). This result shows a difference in the tendency of wind path between the two room types. Regarding the directions of wind path, in the case it existed a wind path, results show the highest quantity in the depth direction with no side direction (24/49 for living rooms and 36/124 for bedrooms). Especially in the living rooms, wind paths in transverse directions are limited. Furthermore, the wind path continuing to the adjacent indoor space was examined (see Tab.8 note). In the case of the bedroom with the presence of wind path (i, ii, iii), the result shows that 90% (42/47) have this continuous airflow crossing in the indoor spaces through the internal opening on the wall. This result indicates that the spatial connection between different indoor spaces would create airflow between spaces, even though these room types tend to locate at the end of long narrow buildings.

5. Passive design seen from spatial openness and airflow

This final chapter examines the correlation between the spatial openness and the indoor airflow in the living rooms and bedrooms, which are results from the previous chapters, investigating variations in terms of the passive design for each house.

5.1 Combination of open pattern and wind path in each room

First of all, in the configuration pattern of the opening surface, the [Single] layer with no attached element and the [Large] composite opening ratio could be understood as the components promoting spatial openness. Hence, a combination of these components in windows was examined in all room types and classified into four open patterns. Further, the combination of these open patterns and the wind path is considered the room

Tab.9 Combinations of open pattern and wind path

Room no.	Side	Level	N	S	E	W	Airflow area (%) Ratio		Avg.	Continuity	Wind path	Open pattern
25-L1	S	M	①	①	-	-	91	W	96	○	i (2,0)	Ⓐ Single layer・Large pattern (22,31)
8-L1	S	M	-	-	①	④	100	W		○		
5-L2	A	M	①	①	-	-	94	W	87	-	ii (9,12)	
5-L1	A	M	①	①	-	-	95	W		-		
4-L1	S	G	①	-	-	-	67	N		-		
18-L1	S	G	④	①	-	-	69	N		○		
42-L1	S	G	④	①	-	-	73	N		○		
17-L1	M	G	-	①	-	-	100	W		○		
22-L1	A	G	-	-	④	①	93	W		-		
31-L1	S	M	-	-	-	①	94	W		○		
38-L1	A	G	-	-	-	①	98	W		○		
4-B2	S	M	①	①	-	-	50	W	54	-		
4-B4	A	M	①	①	-	-	80	W		-		
36-B2	S	M	①	-	-	-	26	N		○		
1-B1	S	M	①	-	-	-	55	W		○		
42-B1	S	T	③	②	-	-	35	W		○		
25-B3	S	M	-	①	-	-	75	W		○		
6-B2	S	M	-	①	-	-	48	W		○		
11-B1	S	M	-	①	-	-	42	W		○		
15-B1	S	M	-	-	①	①	36	W		○		
38-B3	B	T	-	-	-	①	88	W		○		
15-B2	B	M	-	-	-	①	30	W		○		
38-B2	B	M	-	-	-	①	84	W		○		
36-L1	S	G	①	-	-	④	55	N	62	○	iii (2,5)	
30-L1	A	G	①	-	-	-	69	N		○		
1-B2	S	M	①	-	-	-	55	W	56	○		
18-B2	S	M	-	①	-	-	48	W		○		
28-B2	A	M	-	①	-	-	63	W		○		
33-B2	B	M	-	①	-	-	64	W		○		
33-B3	B	T	-	-	①	-	51	W		○		
37-L1	S	G	①	①	-	-	39	N	60	-	iv (9,14)	
11-L1	A	G	①	④	-	-	66	N		-		
47-L1	A	G	①	④	-	-	64	N		-		
2-L1	A	G	④	①	-	-	60	N		-		
9-L1	S	M	④	①	-	-	59	N		-		
46-L1	A	G	-	-	①	④	81	W		-		
24-L1	A	G	-	-	-	①	50	N		-		
26-L1	A	G	-	-	-	①	62	N		-		
29-L1	S	G	-	-	-	①	61	N		-		
41-B1	B	M	①	-	-	④	0	N	25	-		
6-B3	B	M	①	-	-	-	16	N		-		
33-B1	S	M	①	-	-	-	16	N		-		
17-B1	S	T	④	①	-	-	14	N		-		
6-B4	S	M	-	①	-	-	27	N		-		
27-B2	S	M	-	①	-	-	96	W		-		
21-B1	S	M	-	①	-	-	28	W		-		
27-B1	S	M	-	①	-	-	0	N		-		
28-B1	S	M	-	①	-	-	31	W		-		
15-B3	S	M	-	-	①	①	35	W		-		
23-B2	B	M	-	-	①	-	63	W		-		
8-B2	B	M	-	-	④	①	7	N		-		
45-B3	B	M	-	-	-	①	12	N		-		
22-B2	S	T	-	-	-	①	2	N		-		
6-L1	A	G	④	②	-	-	94	W	94	○	i (1,0)	Ⓑ Single layer pattern (4,9)
39-L1	A	G	④	②	-	-	88	W	88	-	ii (1,2)	
42-B2	B	T	②	①	-	-	51	W	28	○		
38-B1	S	M	-	-	②	-	6	N		○		
28-L1	S	M	-	②	②	-	8	N	32	-	iv (2,7)	
16-L1	A	M	-	②	-	-	55	N		-		
36-B3	S	M	②	-	②	②	10	N	24	-		
41-B3	B	T	④	-	-	②	42	W		-		
46-B3	S	M	-	-	②	-	11	N		-		
32-B1	B	M	-	-	②	-	0	N		-		
46-B1	S	M	-	-	②	-	9	N		-		
8-B1	B	M	-	-	④	②	26	W		-		
43-B1	B	G	-	-	-	②	70	W		-		
12-L1	A	G	③	①	-	-	98	W	82	○	ii (10,8)	Ⓒ Large pattern (10,35)
17-L2	S	M	③	④	-	-	100	W		○		
1-L1	A	M	③	④	-	-	94	W		-		
3-L1	A	M	④	③	-	-	74	W		-		
20-L1	A	M	④	③	-	-	87	W		-		
21-L1	A	G	④	③	-	-	71	N		-		
35-L1	S	M	-	③	-	-	58	N		○		
15-L1	A	G	-	-	①	③	77	W		-		
19-L1	S	G	-	-	③	-	82	W		○		
40-L1	S	M	-	-	③	-	82	W		○		
10-B2	S	M	①	③	-	-	98	W	58	-		
12-B1	S	M	①	③	-	-	43	W		○		
12-B4	B	M	③	①	-	-	30	W		○		
5-B3	A	T	③	③	-	-	55	W		-		
20-B2	A	M	③	-	-	-	73	W		○		
1-B3	B	T	-	③	-	-	86	W		○		
39-B2	S	M	-	③	-	-	28	W		○		
41-B2	S	T	-	-	③	-	50	W		○		
39-B3	B	M	③	-	-	-	21	N	21	○	iii (0,1)	
4-B3	B	M	①	③	-	-	0	N	12	-	iv (0,26)	
20-B1	A	M	③	-	-	-	16	N		-		
39-B4	B	T	③	-	-	-	0	N		-		
12-B3	B	M	③	-	-	-	33	W		-		
5-B2	S	M	③	-	-	-	41	W		-		
12-B2	B	M	③	-	-	-	0	N		-		
3-B1	B	G	③	-	-	-	0	N		-		
10-B1	S	M	③	-	-	-	8	N		-		
30-B1	S	M	③	-	-	-	0	N		-		
3-B2	A	M	④	③	-	-	0	N		-		
2-B2	S	M	-	③	-	-	0	N		-		
16-B2	S	M	-	③	-	-	6	N		-		
35-B2	S	M	-	③	-	-	7	N		-		
2-B1	S	M	-	③	-	-	50	W		-		
5-B1	B	G	-	③	-	-	27	W		-		
16-B1	S	M	-	③	-	-	4	N		-		
34-B1	S	M	-	③	-	-	0	N		-		
35-B1	S	M	-	③	-	-	15	N		-		
19-B2	S	M	-	-	③	④	0	N		-		
8-B3	S	T	-	-	①	③	9	N		-		
19-B1	S	M	-	-	③	④	11	N		-		
15-B7	B	T	-	-	③	-	28	W		-		
13-B1	B	G	-	-	③	-	10	N		-		
45-B1	S	M	-	-	③	-	25	N		-		
15-B5	B	M	-	-	-	③	31	W		-		
29-B3	B	T	-	-	-	③	0	N		-		
14-L1	B	G	-	-	④	-	93	W	93	○	i (1,1)	Ⓓ Multi layer・Small pattern (13,49)
36-B1	B	M	-	④	-	④	83	W	83	○		
27-L1	B	M	④	-	-	-	88	W	95	○		
10-L1	A	G	-	④	-	-	98	W		○		
23-L1	S	G	-	-	-	④	97	W		○		
43-L1	S	M	-	-	-	④	95	W		○		
13-B2	B	M	④	-	④	-	48	W		○		
18-B4	M	T	④	-	-	-	27	W		○		
25-B4	M	T	④	-	-	-	56	W	55	○	ii (4,14)	
11-B2	S	T	④	-	-	-	62	W		○		
21-B2	B	M	④	-	-	-	27	W		-		
25-B2	M	M	④	-	-	-	46	W		○		
4-B1	B	G	④	-	–	-	40	W		○		
15-B6	M	M	-	-	④	-	44	W		○		
7-B2	S	M	-	-	④	-	91	W		○		
7-B1	S	M	-	-	④	-	91	W		○		
22-B1	M	M	-	-	④	-	31	W		○		
44-B3	S	M	-	-	-	④	52	W		○		
40-B2	M	M	-	-	-	④	81	W		○		
44-B2	S	M	-	-	-	④	73	W		○		
33-L1	M	G	-	-	④	-	66	N	65	○	iii (2,4)	
32-L1	A	G	-	-	-	④	64	N		○		
30-B2	S	T	④	-	-	-	24	N	43	○		
6-B1	B	G	④	-	-	-	60	W		○		
37-B3	B	M	-	④	④	-	37	W		○		
37-B2	B	M	-	④	④	-	51	W		○		
13-L1	S	M	④	-	④	-	6	N	41	-	iv (6,30)	
34-L1	A	M	-	④	-	-	24	N		-		
7-L1	A	G	-	-	④	-	99	W		-		
41-L1	A	G	-	-	④	-	61	N		-		
44-L1	A	G	-	-	-	④	38	N		-		
45-L1	B	M	-	-	-	④	16	N		-		
9-B3	M	M	④	-	-	-	0	N	11	-		
18-B3	M	M	④	-	-	-	0	N		-		
47-B2	B	M	④	-	-	-	3	N		-		
18-B1	M	M	④	-	-	-	0	N		-		
39-B1	B	G	④	-	-	-	0	N		-		
37-B1	B	M	-	④	④	-	38	W		-		
9-B2	B	M	-	④	-	-	0	N		-		
17-B2	B	T	-	④	-	-	16	N		-		
24-B2	M	M	-	④	-	-	0	N		-		
9-B1	B	M	-	④	-	-	0	N		-		
24-B1	M	M	-	④	-	-	0	N		-		
25-B1	M	M	-	④	-	-	0	N		-		
47-B1	S	T	-	④	-	-	8	N		-		
15-B4	M	M	-	-	④	-	22	N		-		
31-B3	B	M	-	-	④	-	8	N		-		
26-B2	B	M	-	-	④	-	0	N		-		
29-B2	S	M	-	-	④	-	0	N		-		
45-B2	S	M	-	-	④	-	15	N		-		
23-B1	B	G	-	-	④	-	67	W		-		
26-B1	B	M	-	-	④	-	0	N		-		
29-B1	B	G	-	-	④	-	0	N		-		
31-B1	B	M	-	-	④	-	9	N		-		
46-B4	B	T	-	-	-	④	21	N		-		
14-B2	S	M	-	-	-	④	20	N		-		
31-B2	S	M	-	-	-	④	14	N		-		
32-B2	S	M	-	-	-	④	4	N		-		
46-B2	B	M	-	-	-	④	25	N		-		
14-B1	S	M	-	-	-	④	30	W		-		
40-B1	B	M	-	-	-	④	19	N		-		
44-B1	S	M	-	-	-	④	0	N		-		

Notes

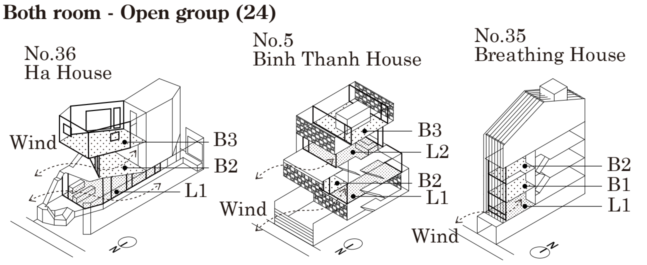
[Side]
S : Street
M : Middle
B : Back
A : Across

[Level]
T : Top
M : Middle
G : Ground

[Airflow area]
N : Narrow
W : Wide

*Configuration patterns of open surface are ①, ②, ③, ④ from Tab.7
* Continuity of air movement, resulted from Tab.8 as
○ presence of continuity
- no continuity

Both room - Open group (24)



a Each room has wind path (14)

No.	Project name	Pattern	Direction
1	White House	Ⓒii/ⒶiiⒶiiiⒸii	NS
4	Anh House	Ⓐii/ⒹiiⒶiiⒸivⒶii	-
5	Binh Thanh House	ⒶiiⒶii/ⒸivⒸivⒸii	NS
6	Folding Wall House	Ⓑi/ⒹiiiⒶiiⒶivⒶiv	NS
12	Breeze House	Ⓒii/ⒸiiⒸivⒸivⒸii	NS
15	Kaleidoscope	Ⓒii/ⒶiiⒶiiⒶivⒸivⒸivⒹiiⒹiv	EW
20	Bamboo House	Ⓒii/ⒸivⒸii	-
21	Lee&Tee House	Ⓒii/ⒶivⒹii	NS
22	Nha Cua Tien	Ⓐii/ⒹiiⒶiv	EW
30	House for a Daughter	Ⓐiii/ⒸivⒹiii	N
36	Ha House	Ⓐiii/ⒹiⒶiiⒷiv	-
38	MM Tropical Suburb Town House	Ⓐii/ⒷiiⒶiiⒶii	-
39	Pattern House	Ⓑii/ⒹivⒸiiⒸiiiⒸiv	NS
42	VOM House	Ⓐii/ⒶiiⒷii	NS

b Living rooms have wind path (5)

No.	Project name	Pattern	Direction
3	Stacking green	Ⓒii/ⒸivⒸiv	NS
8	B House	Ⓐi/ⒷivⒶivⒸiv	EW
17	Saigon House	ⒶiiⒸii/ⒶivⒹiv	NS
19	Wasp House	Ⓒii/ⒸivⒸiv	-
35	Breathing House	Ⓒii/ⒸivⒸiv	S

c Bedrooms have wind path (2)

No.	Project name	Pattern	Direction
11	Vegan House	Ⓐiv/ⒶiiⒹii	NS
28	D House	Ⓑiv/ⒶivⒶiii	-

d Each room has no wind path (3)

No.	Project name	Pattern	Direction
2	NA House	Ⓐiv/ⒸivⒸiv	-
16	Micro Town House 4×8m	Ⓑiv/ⒸivⒸiv	S
46	T House	Ⓐiv/ⒷivⒹivⒷivⒹiv	EW

Living room - Open group (10)

a Each room has wind path (3)

No.	Project name	Pattern	Direction
18	Townhouse with a Folding-Up Shutter	Ⓐii/ⒹivⒶiiiⒹivⒹii	NS
25	/ House	Ⓐi/ⒹivⒹiiⒶiiⒹii	NS
40	Tan Phu House	Ⓒii/ⒹivⒹii	-

b Living rooms have wind path (1)

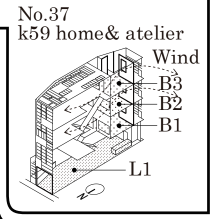
No.	Project name	Pattern	Direction
31	Lantern House	Ⓐii/ⒹivⒹivⒹiv	-

c Bedrooms have wind path (1)

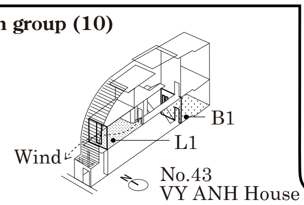
No.	Project name	Pattern	Direction
37	k59 home& atelier	Ⓐiv/ⒹivⒹiiiⒹiii	-

d Each room has no wind path (5)

No.	Project name	Pattern	Direction
9	The Gills	Ⓐiv/ⒹivⒹivⒹiv	NS
24	Zen House	Ⓐiv/ⒹivⒹiv	-
26	// house	Ⓐiv/ⒹivⒹiv	-
29	Giabinh.House	Ⓐiv/ⒹivⒹivⒸiv	-
47	THD House	Ⓐiv/ⒹivⒹiv	NS



Bedroom - Open group (10)



a Each room has wind path (2)

No.	Project name	Pattern	Direction
10	Thong House	Ⓓii/ⒸivⒸii	-
33	The Rough House	Ⓓiii/ⒶivⒶiiiⒶiii	-

b Living rooms have wind path (4)

No.	Project name	Pattern	Direction
23	Quiin House	Ⓓii/ⒹivⒶiv	-
27	Backyard House	Ⓓii/ⒶivⒶiv	-
32	Lien Thong House	Ⓓiii/ⒷivⒹiv	-
43	VY ANH House	Ⓓii/Ⓑiv	W

c Bedrooms have wind path (2)

No.	Project name	Pattern	Direction
13	HEM House	Ⓓiv/ⒸivⒹii	NE
41	V House	Ⓓiv/ⒶivⒸiiⒷiv	-

d Each room has no wind path (2)

No.	Project name	Pattern	Direction
34	ZAKK and MB'S House	Ⓓiv/Ⓒiv	S
45	HL House	Ⓓiv/ⒸivⒹivⒶiv	-

Both room - Close group (3)

b Living room have wind path (1)

No.	Project name	Pattern	Direction
14	House 304	Ⓓi/ⒹivⒹiv	-

c Bedroom have wind path (2)

No.	Project name	Pattern	Direction
7	3×10 House	Ⓓiv/ⒹiiⒹii	E
44	Floating Nest	Ⓓiv/ⒹivⒹiiⒹii	W

Legend
1 — Case study No.; White House — Project name; Living room Ⓒii / Bedroom ⒶiiⒶiiiⒸii — Combination of patterns in ascending order; NS — Same direction of open surface in the living room and bedroom

Fig.11 Correlation of spatial openness and airflow in each house

patterns (as shown in Tab.9). As a result, patterns Ⓐ, Ⓑ, Ⓒ include many [Single] layer and [Large] composite opening ratios, and they tend to be open to the outdoor. Among them, Ⓐ Single layer・Large pattern has the same quantity of components as [Single] layer and [Large] composite opening ratio, and they mainly have a simple form of a large window area without attached elements, which are found a majority in the living room (22/49). On the other hand, Ⓑ Single layer pattern has more [Single] layer than [Large] composite opening ratio, and Ⓒ Large pattern has more [Large] composite opening ratio than [Single] layer. In both living rooms and bedrooms, the quantity of room patterns is the smallest in the Ⓑ Single layer (4/49, 9/124), and the quantity in the Ⓒ Large pattern (10/49, 35/124) is more than twice Ⓑ. From this result, it could be that when one of the components promoting openness is dominant, the tendency of spatial openness is to increase the window size while adjusting by layers of the attached element, rather than making a small window without any attached element. This tendency leads to enhancing the composite characteristic of the windows.

In addition, in the case of the Ⓒ Large pattern, only ii consists of a combination with the wind path in the depth direction, and this pattern corresponds to all living rooms. In these cases, the orientation of the open surface is majority on the opposite sides, like N-S, which is along with the input wind direction in simulation, and the wind path continuing to the adjacent indoor space is also the majority. From this result, it could be that the placement of the open surface and the continuity of airflow between the indoor spaces are related. This relationship tends to enhance the airflow across the depth direction while including the composite characteristic of the windows using attached elements. In the case of Ⓓ Multi layer・Small pattern, all the open surfaces are ④ Multiple・S. This is the tendency of the open pattern to be closed to the outdoors. More than 30% of each room type corresponds to this classification (13/49 and 49/124).

Furthermore, the average airflow area in the room pattern shows that the wind area in both room types becomes smaller, ranging from i to iv, where the wind path decreases in the depth direction. In the living rooms, this attenuation from i to iv is similar regardless of the open patterns. On the other hand, for the bedrooms without wind path (wind path iv), the mean value of the airflow area ratio of Ⓐ and Ⓑ is more than twice that of Ⓒ and Ⓓ. This result suggests that the adjusting by layers of the attached elements causes significant effects on the airflow area.

5.2 Correlation of spatial openness and airflow in each house

Furthermore, the combination of room patterns and wind paths was examined in each of the case studies of tube houses (Fig.11). The distribution of the room patterns was classified into the open-oriented pattern (Ⓐ, Ⓑ, Ⓒ) and the close-oriented pattern (Ⓓ). By assembling these patterns, four groups of living rooms-bedrooms are defined: the Both rooms - Open group, in which living rooms and bedrooms have the majority of Ⓐ, Ⓑ, Ⓒ; the Living room - Open group, in which only the living room has a majority of Ⓐ, Ⓑ, Ⓒ; the Bedroom - Open group, in which only the bedrooms have a majority of Ⓐ, Ⓑ, Ⓒ; and the Both rooms - Close group, in which living rooms and bedrooms have only Ⓓ. As a result, Both rooms - Open group is the most common, while Both rooms - Closed group is the least common. Also, the quantity of Living room - Open group and Bedroom - Open group are equal.

In each group, regarding the combination with wind path, [a] is the majority for Both rooms - Open group. Among the case studies, No.36 has different room patterns ranging from Ⓐ, Ⓑ, Ⓓ with all types of wind paths ranging from i to iv. This combination contains the most variation in spatial openness and airflow. Besides, No.5 has only Ⓐ in the living room and only Ⓒ in the bedroom, though this is in the same category. From this result, it could be that both of these tube houses have large windows but adjust them using either a single layer or multiple layers of attached elements depending on the function of the rooms. This tendency allows the winds to flow across the space in each room. On the other hand, the majority of case studies in [b] have only the open pattern Ⓒ. Also, in all the rooms, while there is a homogeneity of having open patterns with large windows, the wind paths are different according to the function of the rooms. Besides, in the Living room - Open group, the proportion of wind path [d] increases, and these living rooms all have large windows, but the area of wind path is limited. On the other hand, in the Bedroom - Open group, the category [b], which is Living room has wind path, is the most common. For instance, in the case of No.43, the living room is connected to the corridor leading to the staircase with skylight[xvii], creating a wind path.

6. Conclusion

This research examined the contemporary Vietnamese tube houses in HCMC. By analyzing the spatial composition of the living rooms and bedrooms in terms of room placement and windows' characteristics, and further defining the patterns in which they open up to the outdoors as spatial openness. Then by correlating these patterns with the potential of the indoor wind environment via simulation analysis in terms of airflow area and wind path, the results clarify some tendentious characteristics of passive design in terms of spatial openness and airflow.

Firstly, the analysis of the rooms' placement showed different tendencies according to the room types in both the horizontal and vertical arrangements. Examining the spatial openness by the window size and layers of attached elements, the results illustrated that both room types have mostly the opening surface consisting of Multiple layers and Small opening combined. However, there was a confrontation between openness and layers of attached elements. Secondly, the simulation analysis of the indoor airflow considering a significant wind condition during the hottest season resulted that the living rooms tend to have larger airflow areas and wind paths mainly crossing in the depth direction, while these movements of airflow tend to be limited in the bedrooms. Finally, the correlation between spatial openness and airflow, considering all room types and all case studies of tube houses, was examined. The classification of room patterns showed a tendency to increase the windows' size and to adjust it by using the attached elements when one of the elements promoting openness was predominant.

Furthermore, the combination of room patterns and wind path was examined in all case studies. The majority showed in the group where both rooms are mainly open-oriented, while each room mostly has a wind path. On the other hand, about 40% of the case studies limited these open-oriented room patterns to either the living rooms or the bedrooms. These combinations create diverse relationships between the houses' living environments and the outdoors and would suggest various possibilities in passive design using airflow for HCMC contemporary tube houses.

These findings clarify the variations of the passive design approach concerning spatial openness and indoor airflow, which present the opportunity to address the current challenges of urbanization and enhance the living environment for urban dwellers in HCMC. Hence, it would showcase the diversity of solutions integrating a passive approach from local architects to find solutions working with spatial composition and airflow to enhance the dweller's living conditions and preserve the inherited knowledge and cultural identity of southern Vietnamese architecture. Though several tendencies of correlation between spatial openness and airflow are found in this research, it is clear that not all of them can be applied to the diverse climate regions in Vietnam. Further investigations are needed to explore the richness in terms of climate-responsible solutions for Vietnamese housing. Also, this research scope only focuses on the significant typology of tube houses within the most recent period to demonstrate the diversity of approaches that integrate design methods responding to the environment in contemporary Vietnamese architecture, especially in HCMC. The insight collected from this study is beneficial for future research on housing in tropical climates like HCMC, which gain knowledge from passive design principles to respond to environmental threats and uncertainties. Finally, this paper is an improved study of the research[17),18)] on contemporary tube houses in HCMC by further modifications.

Notes

i) In reference 1), the authors clarify how the devices found in vernacular dwellings of three distinctive regions in Vietnam adapt to the local climate conditions and ensure comfort for its inhabitant.

ii) In reference 2), Schenck identifies the vernacular modernism style of southern region architecture through terms such as articulation (relationship of in and out through openings and protrusions in the facade) and brise-soleil (sun-blocking elements and ventilation screens) with a high level of complexity for the quest of harmony.

iii) Being relatively young, architecture in HCMC doesn't have many traditional-style buildings except community halls, religious buildings and the colonial style of French institutions. Hence, in reference 2), it is assumed that the development of urban dwellings in HCMC is inspired by these styles fusing past patterns and local climate adaptation.

iv) According to Reference 3), the most dominant type of HCMC urban settlement is the row houses, mostly built between 1999 to 2009. This category is called "tube house", concerning self-constructed units for the low and middle-income population.

v) Following the report on the rise in electricity consumption for HCMC from Vietnam Electricity (EVNHCMC) between 2017 to 2019, the increase in energy consumption reached 36.43% in 2020 compared to the previous year. The majority was due to the increase in the use of air-conditioning. Data retrieved from https://www.plo.vn/do-thi/dien-luc-tphcm-ly-giai-hoa-don-tien-dien-tang-cao-904947, (accessed 2022.3.25)

vi) According to reference 8), the settlement of rural housing typology developed with a front shop to sell products in the popularized urban areas. The feudal government started to tax the size of the front width, which led to the form of a tube house that extended toward the inward of the street blocks while keeping the front facade as narrow as possible.

vii) According to reference 8), the period between traditional and modern tube houses is separated by the Reform of 1986. This reform is considered to be the urbanization period of this typology.

viii) According to the report on Vietnamese urban dwelling stock and typology. Data retrieved from https://www.unhabitat.org/viet-nam-housing-sector-profile, (accessed 2022.4.6)

ix) In Vietnam, there are not yet professional magazines that continuously publish architectural works. Considering this situation, the case studies in this research are selected from ArchDaily (https://www.archdaily.com). This would be regarded as a leading database of worldwide contemporary architecture with enough information and continuous publication introduced via texts, drawings and photographs. By collecting articles from this database of tube houses built after 2010 in HCMC, 47 case studies were selected to provide the necessary materials for the analysis.

x) In this research, the window also contains a glazing door and hole as openings, disregarding being fixed or openable.

xi) WEADAC is a program that generates weather data from 3726 locations worldwide for heat load calculations, which are supplied by the MetDS (https://www.metds.co.jp). The procedure for compilation of the weather data files is explained in reference 15).

xii) The hourly average wind speed, wind direction and temperature in April are shown in the table below, also the selected periods for simulation in the bedrooms (0:00 to 5:00) and living rooms (17:00-20:00). Within these periods, all openings are considered to be open in the simulated model. Also, the WEADAC database is used to obtain the hourly average, while the yearly average data in Fig.1 is collected from a different source.

Hour	0	1	2	3	4	5	6	7	8	9	10	11
T	26.4	26.2	26	25.9	25.9	25.8	26.1	26.9	28.2	29.7	31.2	32.5
WD	7	7	7	7	7	7	6	6	7	7	7	7
WV	2	2	2	2	1	1	1	1	1	2	2	2
Hour	12	13	14	15	16	17	18	19	20	21	22	23
T	33.3	33.6	33.4	32.9	32.2	31.2	30.1	28.9	28.1	27.4	27	26.6
WD	7	7	7	7	7	7	7	7	7	7	7	7
WV	3	3	3	3	4	4	4	4	4	3	3	3

T = Dry-bulb temperature (degree C)
WD = Wind direction (1-16) (East=4, South=8, West=12, North=16)
WV = Wind velocity (m/s)

xiii) Average values of wind speed and wind direction during the selected periods for each room type are applied.

xiv) In addition to the surrounding building models as an assumed urban environment of middle-rise and high-dense situation, the surface roughness classification is selected, taking into account effects for wider areas as continuous building blocks with a middle-rise and high density.

xv) The local regulation allows housing owners to build directly on the property limit with exterior walls touching neighbors. If having windows, the setback is regulated at a minimum of 2 meters (Article 178 of the Civil Code 2015) [from https://www.luatvietnam.vn/dan-su/bo-luat-dan-su-nam-2015-101333-d1.html (accessed on 2022.09.01) (in Vietnamese)]. Besides, according to the National Standard TCVN 9411:2012 for adjacent housings[from https://www.vanbanphapluat.co/tcvn-9411-2012-nha-o-lien-ke-tieu-chuan-thiet-ke (accessed on 2022.09.01) (in Vietnamese)], design standard 6.4.3 mentioned that if the street block adjacent is still not constructed, even if the distance between 2 houses is less than 2 meters, the owner can install openings if there is no complaint. In current practices, tube houses are built with high density based on these regulations and neighborhood negotiations. Hence, for the simulation model settings in this research, considering the situation when urban street blocks are filled up and only the minimum distance is kept to allow the installation of an exhaust fan between adjacent houses, a distance of 0.5m is set as their general situation.

xvi) In reference 16), 0.35m/s is used as a lower threshold of wind speed to investigate the thermal comfort in a hot temperature condition. By referring to this value, it is simplified to be 0.4m/s in this research simulation as the lowest threshold for wind speed.

xvii) Among 47 case studies, 32 cases contain skylights which can open above the staircases.

References

1) Anh-Tuan Nguyen, Quoc-Bao Tran, Duc-Quang Tran, Sigrid Reitera: An investigation on climate responsive design strategies of vernacular housing in Vietnam, Building and Environment, Vol.46, No.10, pp.2088-2106, 2011.10 (DOI: https://doi.org/10.1016/j.buildenv.2011.04.019)

2) Mel Schenck, Alexandre Garel: Southern Vietnamese Modernist Architecture: Mid-Century Vernacular Modernism, Lightning Source UK Ltd., 2020

3) Ducksu Seo, Youngsang Kwon: In-Migration and Housing Choice in Ho Chi Minh City: Toward Sustainable Housing Development in Vietnam, Sustainability, 9 (10), 1738, 2017 (DOI: https://doi.org/10.3390/su9101738)

4) Yui Hasegawa, Ryo Murata, Yen-Khang Nguyen-Tran: Wind and Light Environment of In-space of Living Space in Contemporary Houses in Ho Chi Minh City, Journal of Architecture and Planning (Transactions of AIJ), Vol. 85, No. 772, pp.1173-1181, 2020.6 (in Japanese) 長谷川由依 , 村田涼 , グエントランイェンカン : ホーチミンの現代住宅作品におけるリビングの居場所の構成と風・光環境 , 日本建築学会計画系論文集 , 第 85 巻 , 第 772 号 , pp.1173-1181, 2020.6 (DOI: https://doi.org/10.3130/aija.85.1173)

5) Yoshie Matsumoto, Ryo Murata, Yui Hasegawa, Kisa Fujiwara: The Intentionality towards Environmental Design in terms of Spatial Composition in Junzo Yoshimura's Houses, Journal of Architecture and Planning (Transactions of AIJ), Vol.83, No.845, pp.397-404, 2018.3 (in Japanese) 松元良枝、村田涼 , 長谷川由依、藤原起沙 : 吉村順三の住宅作品における主空間の構成からみた環境制御の志向性 , 日本建築学会計画系論文集 , 第 83 巻 , 第 845 号 , pp.397-404, 2018.3 (DOI: https://doi.org/10.3130/aija.83.397)

6) Kisa Fujiwara, Fuki Sato, Ryo Murata, Kazuhiro Yuasa, Koichi Yasuda: Utilization of Seaward Views and Cross Ventilation in Contemporary Japanese Villas, Journal of Architecture and Planning (Transactions of AIJ), Vol.81, No.722, pp.851-858, 2016.4 (in Japanese) 藤原 紀沙 , 佐藤 芙紀 , 村田 涼 , 湯淺 和博 , 安田 幸一 : 現代日本の別荘における海に臨む室の眺望と通風 , 日本建築学会計画系論文集 , 第 81 巻 , 第 722 号, pp. 851-858, 2016.4 (DOI: https://doi.org/10.3130/aija.81.851)

7) Kien To: Conservation Pressing Task and New Documentation of old Tube Houses in Hanoi Old Quarter through the case of No.47 Hang Bac Street House, Journal of Architecture and Planning (Transactions of

AIJ), Vol.73, No.624, pp. 457-463, 2008.2 (DOI: https://doi.org/10.3130/aija.73.457)

8) Kien To: "Tube House" and "Neo Tube House" in Hanoi: A Comparative Study on Identity and Typology, Journal of Asian Architecture and Building Engineering, Vol.7, No.2, pp.255-262, 2008.11 (DOI: https://doi.org/10.3130/jaabe.7.255)

9) Phuong-Thao Nguyen, Julien Dewancker Bart: A Comparative Study on the Visibility Relation of Vietnam Traditional and Contemporary Tube House Plans, WIT Transactions on Ecology and The Environment, Vol.226, pp.207-218, 2017 (DOI: https://doi.org/10.2495/SDP170181)

10) Phan-Anh Nguyen, Regina Bokel, Andy van den Dobbelsteen: Improving Energy Efficiency in Vietnamese Tube Houses. A survey of Sustainable Challenges and Potentials, Smart and Sustainable Built Environment, Vol.8, No.5, pp.366-390, 2019 (DOI: https://doi.org/10.1108/SASBE-01-2018-0002)

11) Thanh-Hung Dang, Adrian Pitts: Simultaneous Influences of Temperature and Airflow on Comfort Perceptions in Residential Buildings in Vietnam, Proceedings of the 35th Conference on Passive and Low Energy Architecture (PLEA), Vol.2, pp.1269-1274, 2020

12) Dahniar, Shoichiro Sendai: The Formation of the "Open Veranda" ("Emper Terbuka") in Friedrich Silaban's Private House Projects, Journal of Architecture and Planning (Transactions of AIJ), Vol. 86, No.785, pp.2021-2031, 2021.7 (DOI: https://doi.org/10.3130/aija.86.2021)

13) Takanori Ichikawa, Hideaki Wagatsuma, Nobuhiro Suzuki: A survey of Layout of the Terraces for Comfortable Wind Flow and Various Uses in the High Density Village on a Sea of Palawan Island in the Philippines, Journal of Architecture and Planning, Vol.69, No. 580, pp.73-78, 2004.6 (in Japanese) 市川 尚紀 , 我妻 秀亮 , 鈴木 信宏 : 季節・時刻別の風と快適な生活行為に対する海上テラスの配置構成の調査 : フィリピン・パラワン島の高密度海上集落を対象として , 日本建築学会計画系論文集 , 第 69 巻 , 第 580 号, pp. 73-78, 2004.6 (DOI: https://doi.org/10.3130/aija.69.73_2)

14) Thi-Hong-Na Le, Jin-Ho Park, Minjung Cho: Lessons from Vietnamese Urban Street Houses for Contemporary High-rise Housing, Open House International, Vol.38, No.2, pp.31-46, 2013.6 (DOI: https://doi.org/10.1108/OHI-02-2013-B0004)

15) Hiroshi Akasaka, Soichiro Kuroki, Yoshinobu Arai: Weather Data for Design and Average Heat Load Calculation at any Location in the World. Part 1- Compilation of Montly Weather Data Files including more than 3700 stations in the World, Journal of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, No. 45, pp.25-34, 1991.2 (in Japanese) 赤坂裕、黒木小一郎、荒井良延：世 界 の 任 意 地 点 に お け る設 計 お よ び 平 均 熱 負 荷 計 算 のた めの気象 デー タに関す る研究 , 第 1 報ー世界 3700 地 点余の月統計気象データファイルの作成、空気調和・衛生工学会論文集、No. 45, pp.25-34, 1991.2 (DOI: https://doi.org/10.18948/shase.16.45_25)

16) Oura Risa, Miyamoto Seichi: Study on the Range of Wind Speed to be the Thermal Comfort in Thermally Neutral to Hot Environment, Proceedings of the 39th Symposium on Human-Environment System, pp.125-128, 2015.11 (in Japanese) 大浦理沙 , 宮本征 一 : 温熱的中立な環境下から暑熱環境下における温熱的に 快適となる風速の範囲に関する研究 , 人間 - 生活環境系シンポジウム報告集 , pp.125-128, 2015.11

17) Ban Tomoka, Ueyama Mizuho, Murata Ryo, Yen-Khang Nguyen-Tran: Spatial Openness and Wind Environment of Contemporary Houses in Ho Chi Minh City (1), Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, History and Design of Architecture, pp.91-92, 2022.9 (in Japanese) 坂朋香 , 上山瑞穂 , 村田涼 , グエントランイェンカン : ホーチミンの現代住宅作品における居室の開放性と風環境 (1), 日本建築学会大会学術講演梗概集 , 建築歴史・意匠 , pp.91- 92, 2022.9

18) Ueyama Mizuho, Murata Ryo, Yen-Khang Nguyen-Tran, Ban Tomoka: Spatial Openness and Wind Environment of Contemporary Houses in Ho Chi Minh City (2), Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, History and Design of Architecture, pp.93-94, 2022.9 (in Japanese) 上山瑞穂 , 村田涼 , グエントランイェンカン , 坂朋香 : ホーチミンの現代住宅作品における居室の開放性と風環境 (2), 日本建築学会大会学術講演梗概集 , 建築歴史・意匠 , pp.93- 94, 2022.9

和文要約

本研究は、高温多湿な気候の下、近年、経済発展により高密中層という同質的な住宅地が急速に広がるベトナムのホーチミンにおいて、都市住宅の型として現代も広く用いられているチューブハウスに着目し、生活の場をどのように屋外に開き、自然の風をいかに享受するのかというパッシブデザインの特徴の一端を明らかにすることを目的としている。そこで、リビングと寝室という２種類の居室に着目し、これらの現代住宅にみられる空間の開放性と風環境の関係性を検討している。そこで､全 47 件の対象事例からリビング（49 個）、寝室（124 個）を抽出し、まず、これらの居室の空間構成を、平面的・断面的な配置、窓の大きさ、ルーバーなどの付加要素を加味したレイヤー状の複合的な開放性から検討した。さらに、乾期の自然通風の性状をシミュレーションにより模擬的に検証し、各居室の通風領域と通風経路について検討した。そして、各居室の開放性と通風経路の組合せから居室パタンを導き、さらに、これらの各住宅における組合せを検討することにより、４種の系に属する事例群を見出した。リビングと寝室がいずれも開放系の該当数が最も多くみられ、また、その過半はいずれの居室にも通風経路が発生している。一方、リビングと寝室の開き方に差異をつくる事例も全体の約４割が該当し、この内、リビングのみが開放系の場合には、いずれの居室にも通風経路なしの割合が増え、寝室のみが開放系の場合には、リビングのみに通風経路ありの割合が増えるという傾向がみられた。

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