THE SPATIAL COMPOSITION OF EARTH, WIND AND FIRE SYSTEM IN ELDERLY HOUSING

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ABSTRACT

The Earth Wind and Fire (EWF) system is a natural air-conditioning system integrating geo-thermal energy, wind energy, solar energy and heat recycle system. Its excellent utilization of natural resources promises high energy efficiency and good air quality. Moreover, the strong connection to natural elements also has great potential of spatial quality and pleasure of nature. This paper is based on the theories of the EWF system, and referred to similar systems to try to produce a series of rules for spatial composition of residential complex which applies the EWF system. The final results offer practical principles that can be used for architectural design for architects, and it reveals the potential to further explore the spatial qualities of this system in other type of buildings.

KEYWORDS: *architecture, natural air-conditioning, residential building, spatial composition.*

I.INTRODUCTION

The Earth Wind and Fire system (EWF) is an integrated air-conditioning system researched and verified by Dr. B. Bronsema. As shown in Figure 1, the system is mainly composed of Climate cascade, Solar chimney and Ventec roof, and it utilizes geo-thermal energy, solar energy and wind energy for ventilation, heating and cooling. Moreover, residual heat is recycled and stored in underground water reservoir, which further improves its energy efficiency. Compared with existing HVAC system, it has higher energy efficiency [1]. In certain cases, it can exceed the level set by EU regulation 1253/2014 by a factor of 10[11].

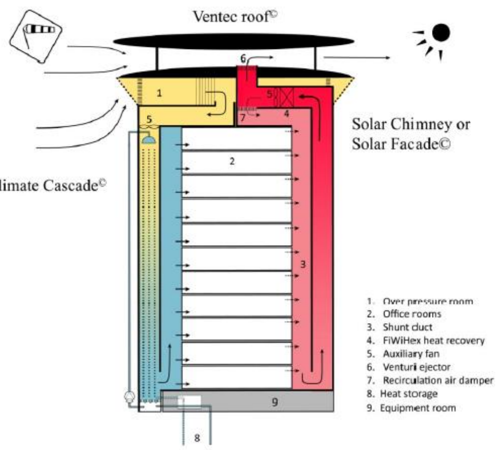

Figure 1: the principles of EWF system

Source: Ben Bronsema,2013

The Climate cascade, Solar chimney and Ventec roof are so dominant in architectural composition that it gives the architect a role to use climate elements for architectural expression, and a building will become a climate machine [1]. Although Bronsema has proven the technical feasibility and superiority of this system, the architectural variations of this system are still underdeveloped. Till now, there is only one project(Breezing Hotel, Amsterdam) under construction and a few other projects researched by architects and students. The research has involved office, hotel, and also housing [1][2][3].

In architecture, communal space plays an important role in community life, especially for elderly people whose movability is limited. The movability restriction makes the urban facilities less accessible for the elderly people. As a result, the elderly spend 75% of their time inside their dwelling units [4]. To correspond to that need, a typical elderly housing, there are activity rooms, reading rooms and other shared facilities as communal space to encourage interaction and reduce social isolation [5].

The indoor environment for communal space can be further improved by means of EWF. People still complain about the indoor environment for air quality, the cold draught, fan noise, and Sick Building Syndrome[3]. Moreover, they lose connection to the nature in a mechanically ventilated building. The EWF can help to increase the energy efficiency, improve thermal comfort and also reconnect residents and nature. For architects, it's potential to explore its spatial variations and qualities to further explore the application of this system in elderly housings.

II. METHODS

The goal of the paper is to experiment applying EWF system in elderly housing, which involves both architectural and technical requirements. To research that, literature reviews and form study will be the main methods.

Literature of EWF theories regarding will be studied to figure out the technical requirements. Besides, literatures related to EWF and corresponding technologies, such as solar chimney, will be studied to broaden the theoretical framework. In architectural aspects, the program for elderly housing and its spatial requirements will be studied. Combining these 2 parts, a series of rules can be created to be used for future architectural design.

To research whether a composition is good, form study will be carried out, and analytical section perspective drawing is chosen as the tool to assess the spatial qualities. The richness of space is subjective, which can only be assessed by the observers' feeling. Since there is not enough time to assess it based on a larger group questionnaire, the researcher will assess it by architectural common sense, which might lead to inaccuracy. By revealing the spatial qualities of these compositions, it will be clear what the better solution is.

III. RULES FOR EWF COMPOSITION

The EWF system's requirements involve the dimension of different components and the area it can ventilate. The elderly housings' requirements involve the dimension of the living units and communal space, and their corresponding needs for both ventilation and experience. Afterwards, the rules of ventilation should also be discussed.

3.1 EWF components and requirements

The EWF system consists of 3 main components, including the climate cascade, solar chimney and main body, and they have different spatial requirements regarding performance.

The climate cascade usually has the form of a tower, and it needs to meet certain dimension. According to the physical test by Bronsema, a climate cascade with 1000x1000x6000mm can provide nominal air exchange rate of $1800m^3.h^{-1}$ [1]. Although the climate cascade needs height to exchange heat, it should not be more than 6 floors. The Energy efficiency will decrease from 21 at 4 floors to 8 at 20 floors[1]. To promise the efficiency, the height of the climate cascade should be limited. When the climate cascade is higher than 6 floors (approximately 20.4m), subdivision is needed and each part should be equipped with extra sprayer.

The form of solar chimney is usually a flat tower, and it has both requirements for dimension, location and direction. According to the physical test by Ben, a solar chimney with 2000x250x11000mm can provide nominal air exchange rate of $1800m^3.h^{-1}$ with air velocity of 1m/s, which promises an air exchange rate of $1800m^3.h^{-1}$ [1]. The dimension of the solar chimney (facade) also contributes to its efficiency. Both height and width can help to increase the amount of air it can extract [1]. In other words, the higher and wider the solar chimney is, the more efficient it is. To maximize the efficiency of harvesting solar energy, the solar chimney should face south to get maximal sun light, while facing south-west or south-east can also provide more than 93% of the maximum sun radiation per year [1]. Due to the same reason, the solar chimney should be placed at the south of the building, and it should be as little shaded as possible in the context.

The main body (including rooms and communal space) are the ventilated space and it needed to follow the rule of ventilation path. At building scale, the rooms and communal space should be connected together to enable the EWF system. As shown in Figure 2, Series connection and parallel connection are the 2 main airways of organizing ventilation. In series ventilation, the quantity of air is the same in the path. In parallel, the total quantity of air is equal to the sum of amount of air from different branches.

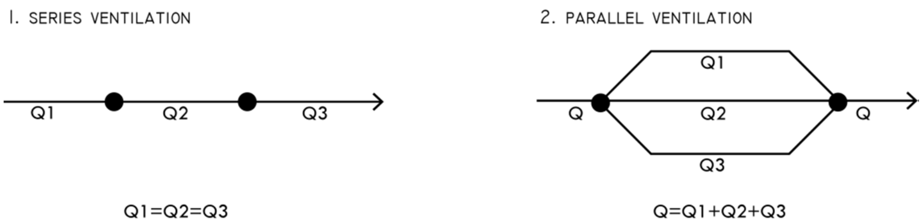

Figure 2: Ventilation modes

3.2 Program of elderly housing

For elderly housing, living units and communal space are the main components of the system, which has specific ventilation and dimension requirements.

Living units are individual rooms separated from each other. According to previous research, the elderly housing in the Netherlands for self-standing living is $60\text{-}80m^2$ [9][10]. Although there are other variations of floorplan, this basic unit can be used. To make the spatial composition more clear, an 8mx8mx3.4m ($64m^2$) box is chosen for the form study. Based on case studies of existing elderly housing projects, 50 is assumed to be the number for living units.

Communal space includes halls, libraries, common rooms, and other collective functions serving the users. They are usually larger and interconnected. Compared with regular dwelling units, the floor area for communal space can be quite varied in different building, since the program can be different. Nowadays, different functions are integrated into traditional housing typology to increase interaction, and so will I do in my research. To make the research more handy, 8mx8m is assumed to be the basic unit for communal space, following the modular of living units. Not sure how much area exactly is needed, since the typology itself will also be new.

The ventilation requirements are determined by the functions, which determine the size needed for the climate cascade and the solar chimney. For dwelling, a minimal ventilation rate of 1.08m3/h/m2 (0.3L/s/m2) is needed, while 2.12m3/h/ m2 (0.6L/s/m2) is needed for other communal functions, such as commercial area or library [8]. If it's sports space, such as gym, it can reach 8.64m3/h/ m2 (2.4L/s/m2).

3.3 Spatial composition rules

Based on the rules and data in 3.1 and 3.2, now it's possible to calculate the necessary ventilation rate and corresponding dimension of different spatial components. Linear estimation will made here as a simplified way to calculate the dimension of climate cascade and solar chimney, which is not exactly as CFD simulation. Since the form study is conceptual, this is acceptable.

$$Q = S * n * k$$

Q: total ventilation rate (m^3/h)
S: floor area (m^2)
n: number of units
k: minimal ventilation rate($m^3/h/m^2$)

Known that dwelling has floor area of 64 m^2, and we need 50 of them with a minimal ventilation rate of $1.08m^3/h/m^2$, Q1= $64m^2$x50x1.08=$3456m^3/h$. Knowing that the communal space has the same area, with a ventilation rate of $2.12m^3/h/\ m^2$, Q1= 2.12 m^2x50x1.08=6784 m^3/h. Q=Q1+Q2= $102403456m^3/h$. Considering the climate cascade in the test was $1m^2$ large and supply 1800 m^3/h, 5.68 m^2 large one can meet the needs, which needs a section to be 2.5mx2.5m.

Similar calculation can be applied to the solar chimney. Since the depth of solar chimney doesn't affect amount of exhausted air, and the height is unknown, the same height is assumed. A solar chimney of 5.69m wide will be needed for this form study.

It can be seen that the dimension of the solar chimney and climate cascade are quite small, compared with the dimension of a living unit. In real design, the architectural aspects are usually more dominant in determining size of these components. To make these 2 components spatial and easy for form study, a standard dimension of 8mx8m is assumed, which is the same as a dwelling unit. However, it should be kept in mind that their dimension can be reduced if needed.

3.4 Ventilation rules

Since the residential building is ventilated by EWF, it has to follow the basic rules of ventilation. To figure out the rules to follow, the system is separately analyzed by communal and living units, which promises good indoor environment for individuals and the effectiveness of the whole system.

Communal space is usually continuous in a building, and it connects all the other rooms. When the communal space is continuous, it easily forms a ventilation pipe, with which series ventilation is more efficient. When there are separated communal spaces, it is more suitable to choose parallel ventilation system to organize the building.

Rooms are the basic units for housing. Compared with communal space, rooms are more isolated and closed. They are usually the end points of the ventilation route, which makes it vital for the ventilation design. They can only be connected to the communal space or be connected in a parallel ventilation system by ducts, since resident won't accept the exhausted air from other rooms. Figure 3 shows the 3 modes of air supply for rooms in a EWF system from spatial perspective—Cross ventilation, single-sided ventilation, and ducted ventilation. Type 1 and type 2 are typical natural ventilation modes, and duct system is simply mechanical system. Buoyancy effect (which is the other way of natural ventilation) is excluded here, because of the small size of a living unit.

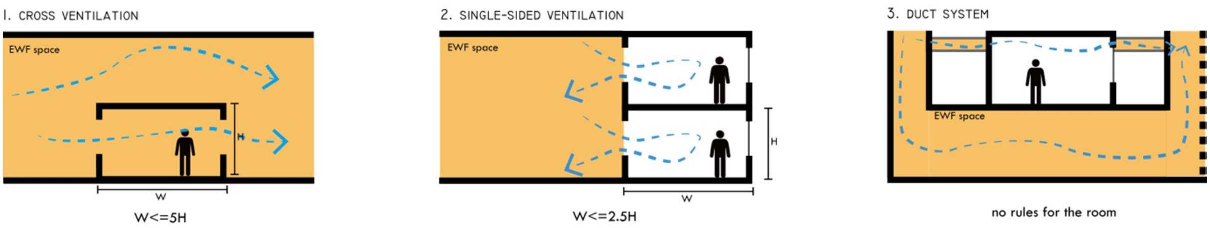

Figure 3: modes of room ventilation in EWF system

Based on existing research of natural ventilation, rooms with natural ventilation modes (Cross ventilation and single-sided ventilation) have to follow minimum dimension requirements to effectively ventilate the room. In cross ventilation, the width of the room should be less than 5 times the height. For single-sided ventilation, the width of the room should be less than 2.5 times the height

Natural ventilation modes also provide more exposure to the communal space, which is vital in dwelling. Since the EWF ventilated space still allows natural wind and its variation in velocity, temperature and humidity, it provides a filtered nature. It has been proven that occupants who have greater access to controls (e.g. those close to a window) report less discomfort than those who have less access (e.g. away from the window) [7]. Therefore, the living units should have at least one side facing outside space(nature) or EWF space.

IV. SPATIAL VARIATIONS

In the experiment, 20 different compositions are created. As shown in Figure 4, they have quite various spatial qualities and they can form different typologies.

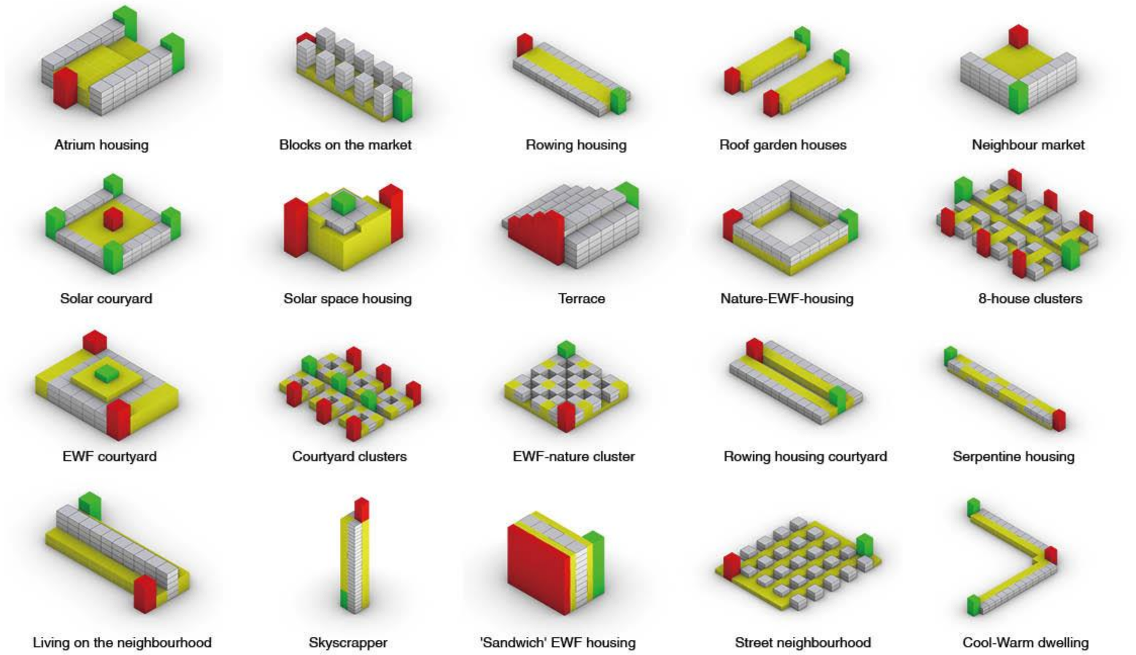

Figure 4: Spatial composition experiments

Although they have quite different form, their spatial qualities and ventilation modes have similarity. They can be concluded into 3 types of ventilation modes for the rooms, corresponding to 3 kinds of compositions at building scale with different spatial qualities, as shown in Figure 5.

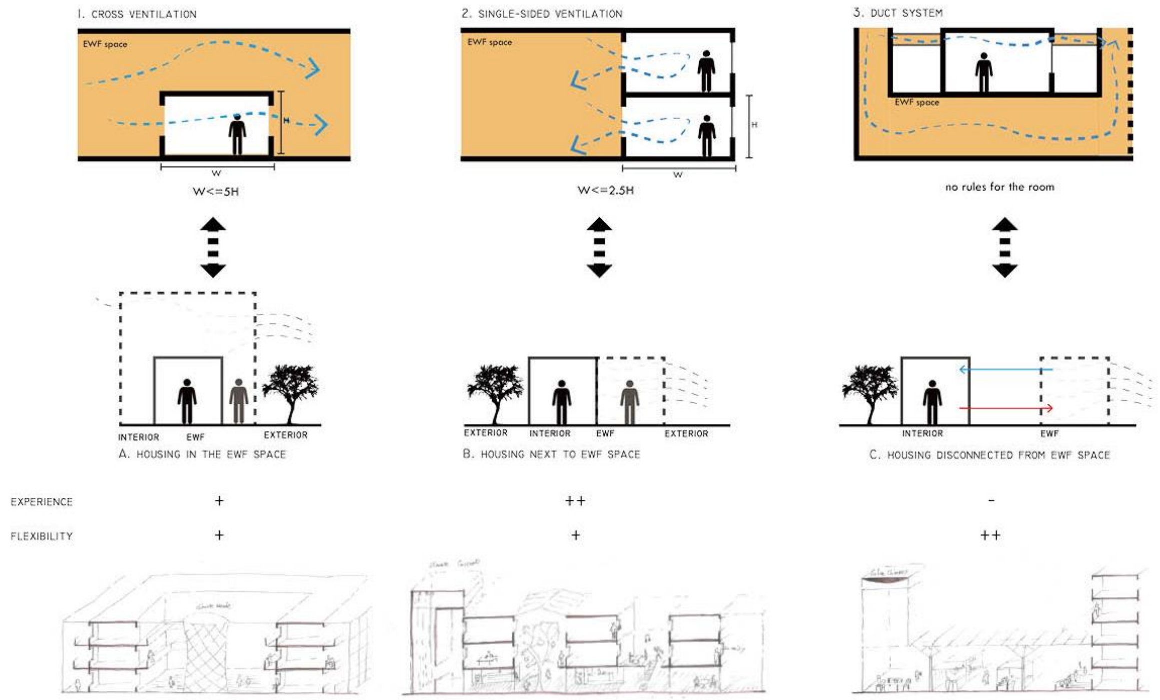

Figure 5: modes of ventilation

The first room ventilation type is cross ventilation, and the building type is housing in the EWF space. In this type, the living units are located in a larger EWF ventilated space. Rooms simply follow natural ventilation rule of cross ventilation. With such a compact composition, residual heat can be well recycled, which promises high energy efficiency. The users can enjoy the atrium ventilated by EWF system, which is quite good. Since residents lose direct access to outside, the experience is sacrificed to some extent.

The second room ventilation type is single-sided ventilation, and the building type is housing next to the EWF space. Residents are free to choose their connection to either exterior space or EWF space, which enriches their spatial experience. According to the schema, it can be seen that EWF system can provide the spatial qualities of an improved atrium with good thermal comfort condition. This alternative space enables people to control their indoor climate as easy and direct as outside, which is its advantage. Meanwhile, opening to outside for sure will lower the energy performance of the building.

The third room ventilation type is ducted ventilation, and the building type is housing disconnected to the EWF space. Similar to all the mechanically ventilated buildings, the rooms can be composed just based on their function requirements, regardless of the ventilation issue. It only needs one inlet and one outlet for the room, and a pipe for ventilation. Its minimal dimension provides lots of flexibility or spatial design. On the other hand, this disconnection gives residents less access the EWF communal space. The easy experience of sheltered natural space is gone. Therefore, it contributes little to the experience, but it still helps to improve energy performance.

The EWF open space is superior to deucedly ventilated space for elderly users. Firstly, it's a more simple and direct way to control climate. Elderly people are gradually losing control to their daily life, and this usually leads to psychological depression and physical danger. Simply opening the window to access to fresh air and enjoy sun light and breezing also follows our instinct. For elderly people, the simplicity enables them to use it without any problem, and it helps them to establish their control to their daily life.

Secondly, EWF space provides an experience of half natural experience. EWF is an air-conditioning system with variations. The light intensity, temperature, air velocity, and humidity still correspond to the exterior circumstance. These factors make this space more closely related to the world. The essence of changing and protection is actually the essence of our earth. The earth, our mother planet, utilizes all the energy from the sun, storing it the massive earth, and transport the energy by wind. Earth, wind and fire might be more than just a system, but a nutshell of the natural system.

V. CONCLUSIONS

The climate cascade and solar chimney are mostly restricted spatial components in the EWF system, especially the solar chimney. However, it doesn't influence the building composition a lot, thanks to their relatively small size. The main body composing of communal space and living units can be organized in 3 different ways, corresponding to their ways of ventilation

The 3 types of EWF ventilation reveal different qualities, and it’s proven that using EWF as an extra option is the best choice for experience. It’s similar to the quality of atrium, but it provides better climate control. People can easily enjoy sun light and natural wind without worrying rain for being too hot. When the spatial requirements are not met, duct system can always solve ventilation problem at the end.

If we want to realize the spatial qualities of EWF atrium, it has some spatial restrictions. In housing design, each unit should have at least one side facing EWF space. Since another side should face exterior space, and at least 2 sides are needed for structural use, the density is restricted. High density apartment housing with only one side facing outside are not suitable to provide the spatial quality of EWF, but they can still benefit from the energy efficiency and thermal comfort of this system.

This research reveals the potential of spatial qualities of EWF system in elderly housing, and the restrictions of spatial typologies it can be applied. There is still quite a lot freedom to compose the building with different functions. Since this research focuses on elderly housing, the typology experimented were focused on low-density housing. There are still more potential types to be explored in other kind of housing and functions.

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