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Semi-passive Architecture Facade Design

Pei-Hsien Hsu, and Hong Cing Tung

Graduate Institute of Architecture, National Chiao Tung University, Hsinchu, Taiwan

Abstract: “Making architecture smart” is a key issue for contemporary architecture. Previous research in this direction has been mostly focused on the improvement of control systems insides buildings by making them more intelligent. This research, however, takes a different approach. Rather than focusing on the control systems, this research seeks a breakthrough in the designing of building elements. It proposes a design of architectural façade which incorporates a kinetic mechanism based on smart materials. Through the capability of smart materials in sensing and reaction, a prototype of building façade which has the ability to change dynamically is developed to respond to the changing natural environment and to furthermore affect the performance of architecture and conditions of the built environments (e.g., ventilation, shading and lighting). The proposed design also incorporates an electronic-device-based mechanism and, along with the smart material component, jointly forms a dual actuation system, which aims to equip the façade system with the ability to respond to the environment without consuming power for the majority of time while maintaining the ability to react instantly if required.

Key words: Kinetic building façade, smart façade, double skin façade, smart materials

1. Introduction

Based on case studies at the early stage of research [1], this study proposes a new façade design which can simultaneously control the sunlight intake and ventilation of a building, different from other existing models mostly limited to controlling the intake of sunlight only. In addition, this study proposes a dual system with both energy saving and control capabilities. It consists of a mechanism driven by smart materials which does not rely on electronic devices [2]. The major goal is to develop a dynamic façade module and assembly mechanism based on mechanical movements. Within the developed module design, there is a shading component and windshield component, linked by a designed mechanism. Generally, the two parts are in a fixed relative angle and position, which may be changed in a short time through a clutch mechanism. Based on this design, a special relationship has been created: a complementary relationship between ventilation and sunlight intake. We used shape material alloy (SMA) as an actuator which responds to temperature changes. The transformation of the actuator causes the façade unit to rotate. As the temperature of the environment rises, the rotation angle of the building skin unit increases, and this makes shading element block the daylight effectively (decrease in the amount of sunlight intake) and at the same time widen the gaps between the upper and lower units, increasing the amount of ventilation per unit area of the building surface. Therefore, as the temperature is relatively high, the façade can reduce solar radiation into the interior and increase the amount of ventilation, causing the indoor temperature to be in a relatively comfortable range. Conversely, when the temperature is relatively low, the façade can increase sunlight intake and reduce the amount of ventilation, keeping the interior in a relatively warmer temperature range.

Corresponding author: Pei-Hsien Hsu, Dr., Professor; research area/interest: mixed reality, interaction design, computer-aided architectural design. E-mail: phsu@arch.nctu.edu.tw.

2. Research Method

2.1 Façade Shading System

According to our literature review and case studies, it is found that the most of existing façade designs with dynamic behaviors control the size of opening of the façade to affect both the sunlight and air intake, and there is a proportional and interdependent relationship between the amount of ventilation and the amount of sunlight intake. This proportional relationship results from a change in the size of opening of the façade, corresponding to the change of the natural environment. Such dynamic façade designs, however, lack of positiveness to comfortability of interior of building, and results in low efficiency.

In contrast, the complementary relationship proposed in this study has a relative advantage (Fig. 1). The purpose of façade design is to solve the demand of ventilation and shading at the same time. The two environmental factors do not interfere with each other. In this study, the unit structure of the shading elements and the translucent panels (windshield elements) is linked in a fixed angle. Shading elements are on the outer layer. It blocks the sunlight outside and decreases the indoor solar radiation. Translucent panels are on the inner layer. It controls and adjusts the amount of ventilation. The temperature triggers the actuator, SMA, driving each façade units to achieve the goal of reducing the use of electricity.

Based on the climate in Taiwan, we propose the following four modes and its switching mechanism (Table 1).

From the four modes in Fig. 2, there are three angles between shading panels and Translucent panels, which are:

- Cold-about less than 90 degrees
- Cool and warm-90 degrees
- Hot-about 40 degrees

2.2 Heat Pipe System Applied to the Façade in This Study

In the design of smart building façade units, we need a temperature-driven mechanism. One characteristic of using the smart materials (SMA) as actuator is that,

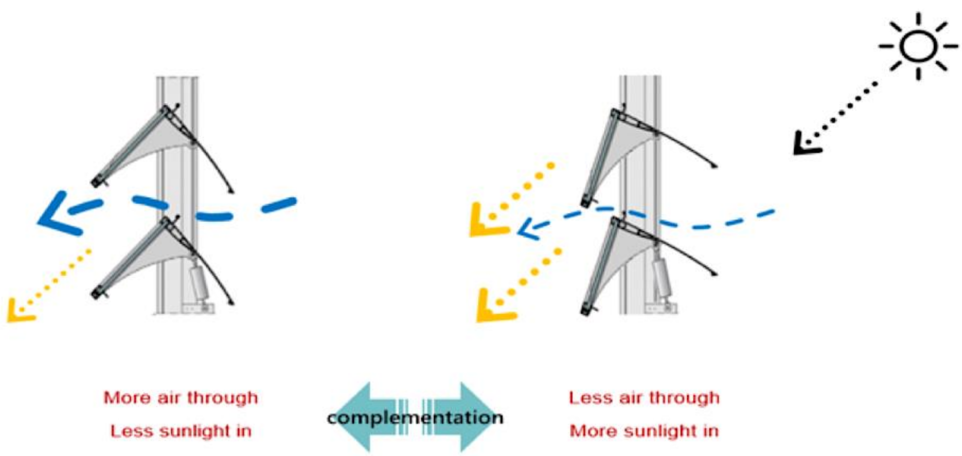

Fig. 1 The design of façade module complementary relationship between the level of sunlight intake and ventilation.

Table 1 four modes of façade unit and switch mechanism.

Modes	Ventilation	Sunlight intake	Solar radiation	Driving force	Linked elements
Cold	Off	Direct sunlight	more	Motor	Separate
Cool	Less	Indirect sunlight	Moderate	SMA	Linked
Warm	More	Indirect sunlight	Less	SMA	Linked
Hot	Off	Indirect sunlight	Less	Motor	Separate

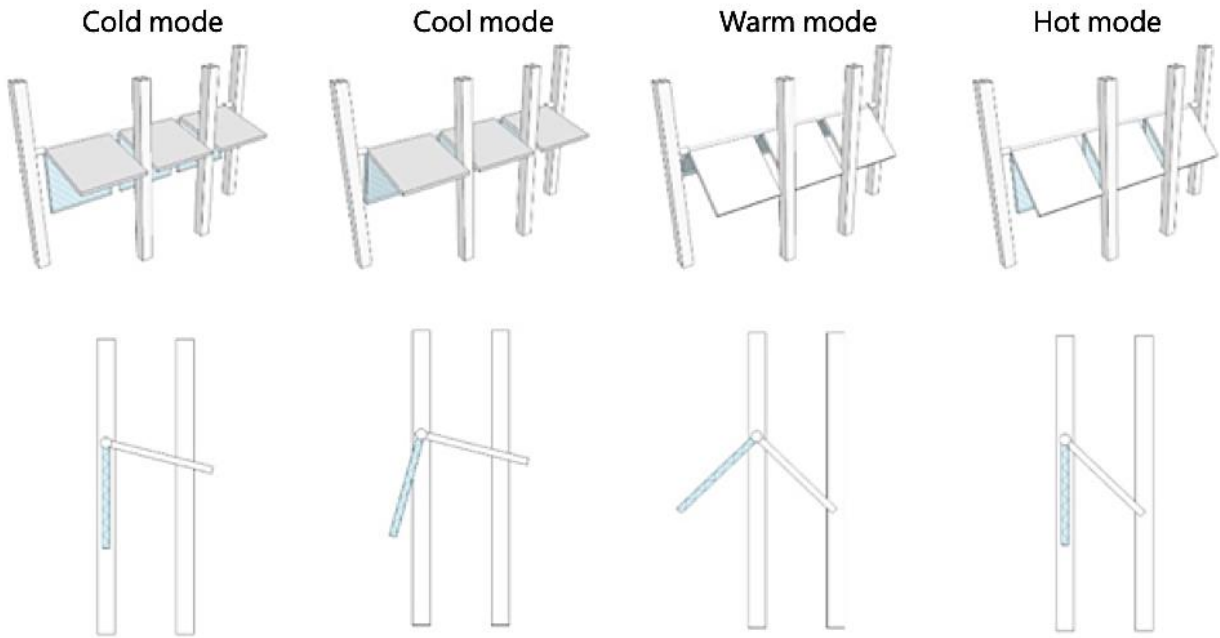

Fig. 2 Four modes of the façade.

there is a gap between the heating transition and the cooling transition, is not the same temperature. In the mechanism design, the smart memory alloy is used as the actuator, but temperature needed to initiate the transition can vary. If the driving temperature of the material is set relatively low, the material can be easily driven. Similarly, the temperature necessary for cooling transition is relatively low, which may cause the reverse temperature state of demand to be difficult to achieve.

Based on this problem, this part of research tried to build a heat accumulative mechanism to enable the shading elements to collect solar thermal energy, to obtain a higher temperature than the outside temperature. Then, heat pipes transfer the collected heat energy to the SMA. As a result, heat conduction is the key point of the problem [3].

In the thermal conduction part, the heat pipe is adopted. The design work that needs to be handled is the combination relationship between the heat pipe and the façade units, while not conflicting with the heat pipe processing. In addition, there is a dynamic mechanism on the façade units, which can rotate to change the angle of the shading elements. The path of the heat pipe needs to be connected to the fixed structure. Therefore, the heat pipe system needs to have elasticity. To face this problem, the heat pipe is connected to an elastic hose rather than rigid like the adjacent heat pipe. The hose position is placed at the rotating shaft of façade units to reduce the hose deformation.

First of all, in the research of heat pipes, the classification of heat pipes can be categorized into the four types by the internal wick structure, which are sinter, groove, fiber and mesh. Among those types, sinter-type is the best, can be placed at arbitrary angle with high thermal conductivity. However, the cost is relatively high. On the other hand, we also study the gravity heat pipe. The gravity heat pipe is a vertical structure. In the heat pipe, cooler end of the pipe is above hot end of the pipe and liquid flows by gravity from top to bottom. Therefore, we only can adopt vertical or tilted ways. The thermal conduction of this type of heat pipe is unidirectional. With its simple structure, convenient processing and relatively low cost, this gravity heat exchange systems are widely used in industrial emission.

In the selection of heat pipes, gravity-type heat pipes are adopted instead of wick-type heat pipes to provide good processing performance. Although the wick-type heat pipe has good performance in thermal conductivity, it is not easy to manufacture, and there is a big limitation in the bending of the heat pipe. Excessive bending will destroy the wick structure and decrease the thermal conductivity. Therefore, it is difficult to integrate building façade design with heat pipe system. Based on such considerations, "gravity heat pipe" is our main option.

2.3 Smart Building Façade Mechanism: Design and Implementation

In the overall design, the heat pipe is arranged on the façade units to absorb the solar energy. In order to match the vapor flow of the heat pipe thermal energy to the blinds, we modified the distance and the number of blinds and then combine it with a gravity heat pipe, by bending it with a manual pipe bender with a minimum diameter of Ø4mm. In production, in order to reduce the weight of smart façade units, the basic structure is almost made by 3D printing. As for shading elements, we design and place the gravity heat pipe on the grooves of façade unit. Because the heat pipe conducts the collected solar energy to the SMA, the SMA spring shrinks and extends as the environmental temperature changes, and then it causes the lower general spring to initiate the overall operation. In the end, the amount of sunlight intake and air intake can be adjusted (Fig. 3).

From the path of thermal conduction in heat pipe system, at the rotating shaft of façade units, we increase the flexibility of the mechanism by connecting the heat pipe and a copper-welded tube with a hose. The SMA spring, enclosed inside the copper tube, will reflect the changes in the received Thermal energy. We fixed two hooks at top and below of structure of unit. The shrink force of SMA spring can be balanced between upper SMA spring and lower general spring.

Fig. 4 explain the façade unit assembly relationship. There are two driving mechanisms in this smart building façade unit, one is from the energy of the transformation of the SMA spring, as explained in 3-2. The other is from the power of the motor. In the part of the motor, we choose stepper motor because rotating angle can be set arbitrarily. The Translucent panels can be turned off by stepper motor, combined with a clutch to achieve keeping the angle unchanged (Fig. 5).

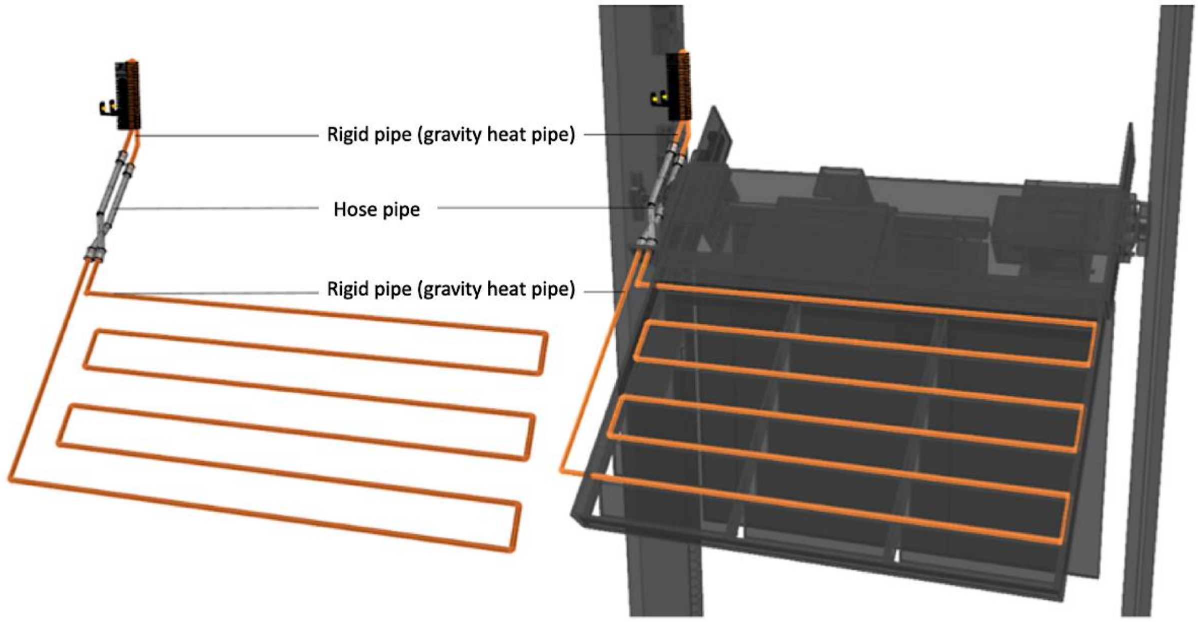

Fig. 3 Heat pipe system configuration and assembly in the smart façade unit.

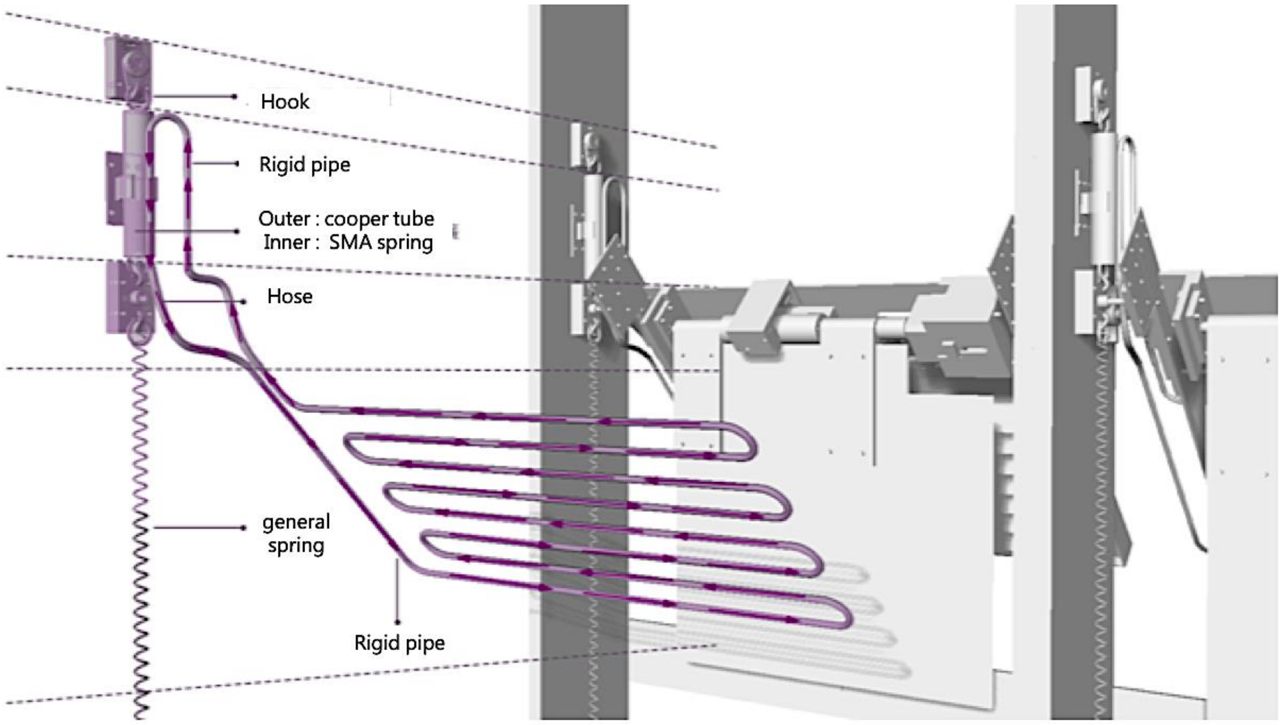

Fig. 4 The thermal flow process in heat pipe system and SMA-driven mechanism in a façade unit.

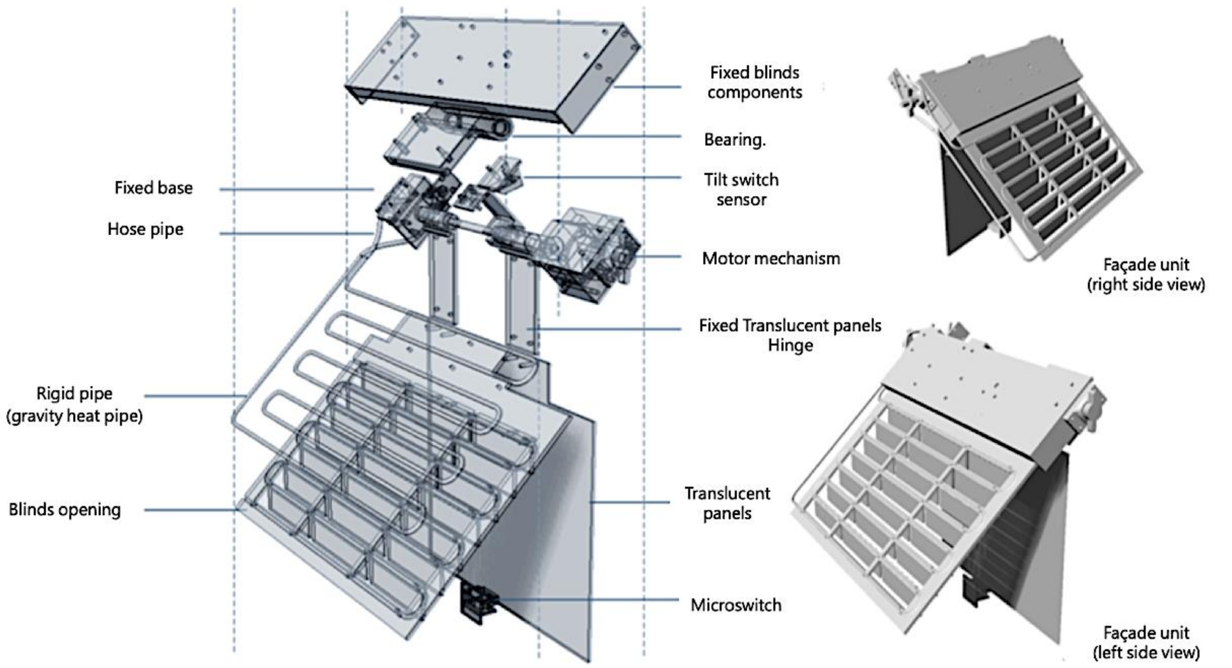

Fig. 5 Exploration diagram of a façade unit assembly.

2.4 Implement Process of Smart Building Façade

In the production of the physical unit, we established a 3D digital model on the computer, and then plan the production of form and simulate the smart building façade with fluid dynamics. Finally, Assembly of the components was produced through 3D printing, and then the various components were assembled together by screws and metal locks (Fig. 6).

In the follow-up, experimental tests on materials and dynamic mechanisms were carried out. The heat pipe system was laid on the façade unit. Also, the façade unit was equipped with motors and other power mechanisms and wire configuration, Finally, a 2×2 movable array unit was built through trial and error. Heating lamps simulated the sunlight temperature to actuate SMA spring (Fig. 7).

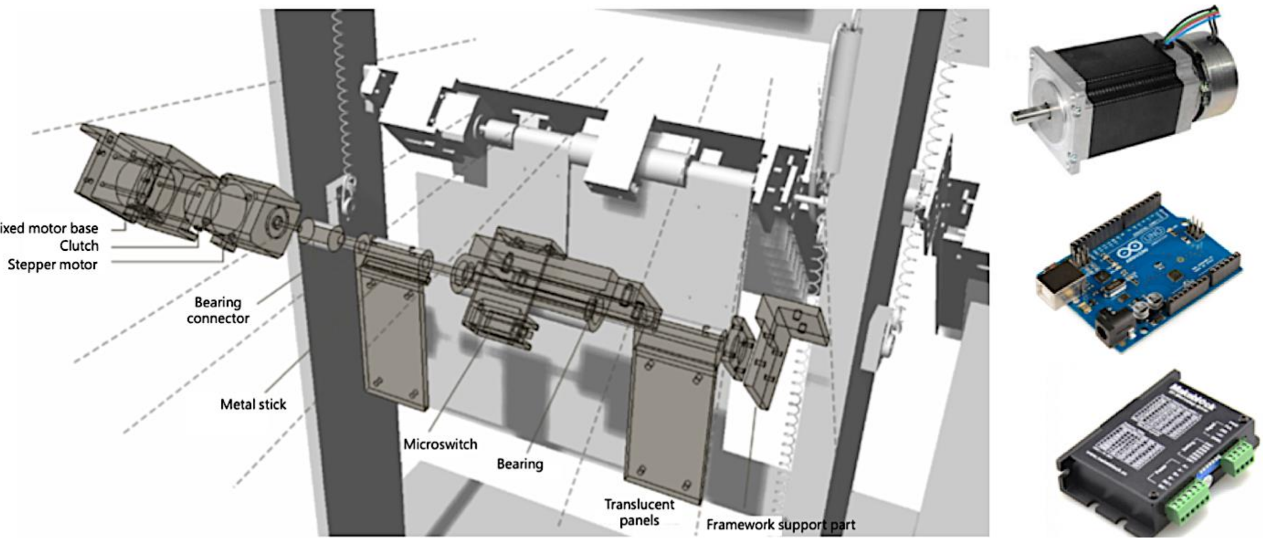

Fig. 6 Exploration diagram of motor-driven mechanism assembly (left) and Electronic equipment used in façade unit, which is stepper motor, microcontroller unit and stepper motor controller (right).

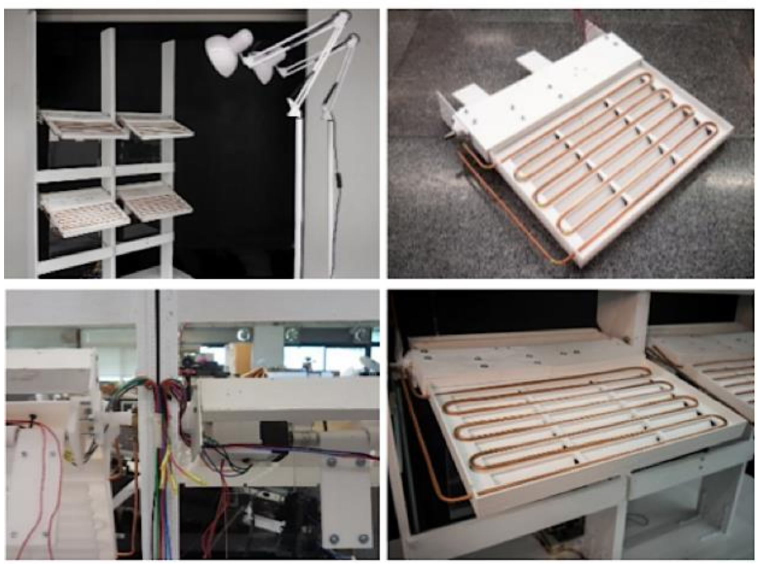

Fig. 7 Simulating the physic model.

3. Computational Fluid Dynamics Analysis Software

We compare the temperature change of the building façade of this research with two common building façade designs by using the computational fluid dynamics (CFD) analysis software (Autodesk CFD Simulation). The two common building façades are the window opening mode and the common double skin façade mode (Fig. 8). In the temperature setting, the simulated outdoor environment was set to 18°C (cool mode) and 28°C (warm mode) as a benchmark for comparison. The wind field was simulated to visually analyze the influence of smart building skin on part air flow [4].

In order to reduce the influence of solar radiation, thermal conduction between the wall and the ground, also, to make the factor of influence the interior temperature as the external building façade, we simulated a 3-storied building in the CFD mutual model framework setting and take the indoor average temperature on the second floor for comparing the results. To elaborate the framework setting, each floor is a cube of the same space, with an opening on the outer wall, allowing wind to enter smoothly. The top of the space on the third floor will be directly exposed to solar radiation so that it would excessively affect its indoor temperature. For this reason, it was not adopted. At the bottom of the first-floor space, the floor will absorb the heat from the surface of the ground because of its lower temperature, and the wall on the leeward side will be affected by a little wind blowing back, so the first floor is not adopted. We only sampled the second-storied space (the darker part of the picture) to calculate the average temperature in the space (Fig. 9).

3.1 Result of Computational Fluid Dynamics Analysis

This study proposes a smart façade method in the natural ventilation condition and warmer condition (28°C). We can know that general window opening type and the common double skin façade type can facilitate lower indoor temperature to improve indoor comfortability (Fig. 10).

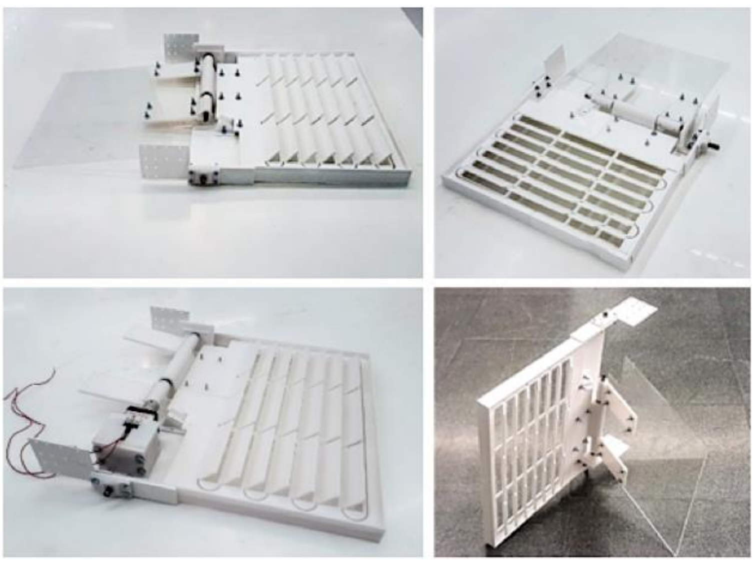

Fig. 8 prototype of smart building façade units.

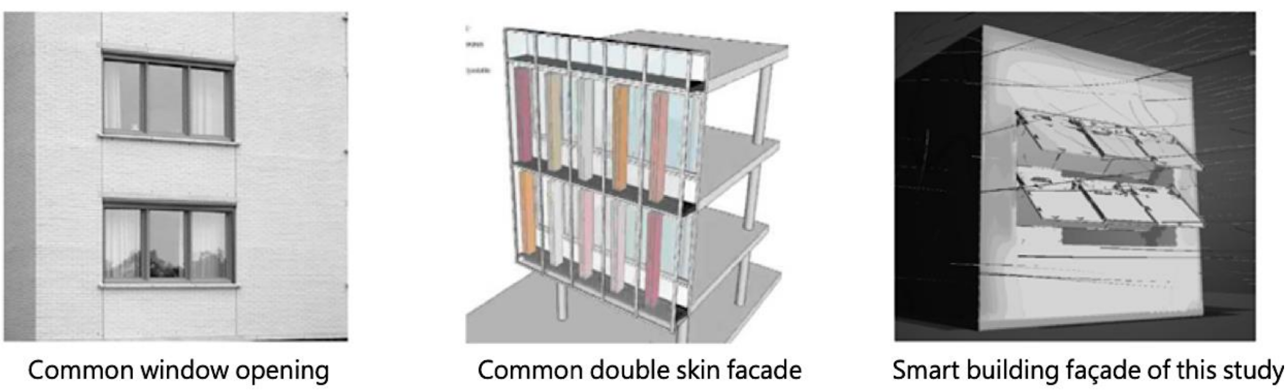

Fig. 9 Diagram of compared models.

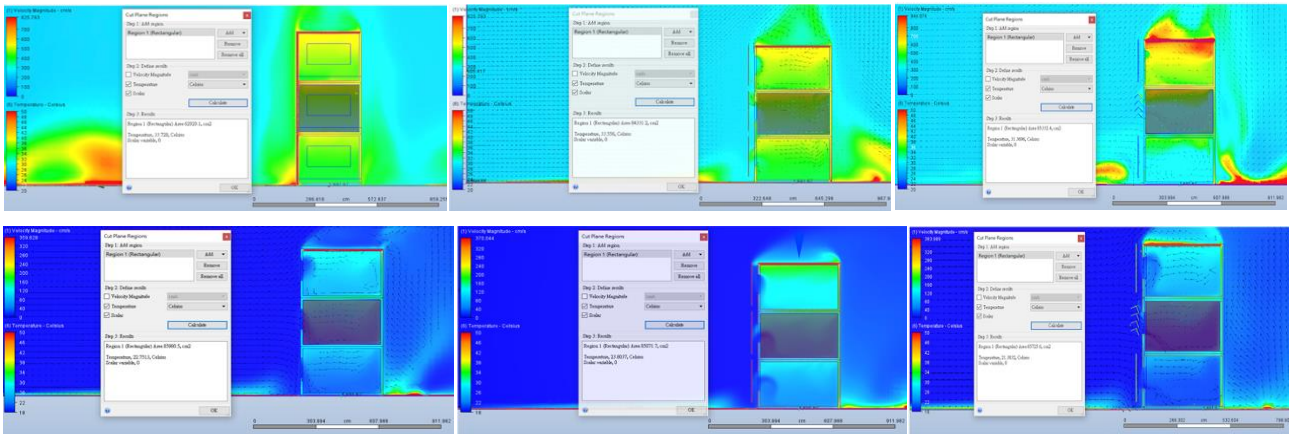

Fig. 10 CFD analysis when outdoor temperature at 18°C (top) and 28°C (below).

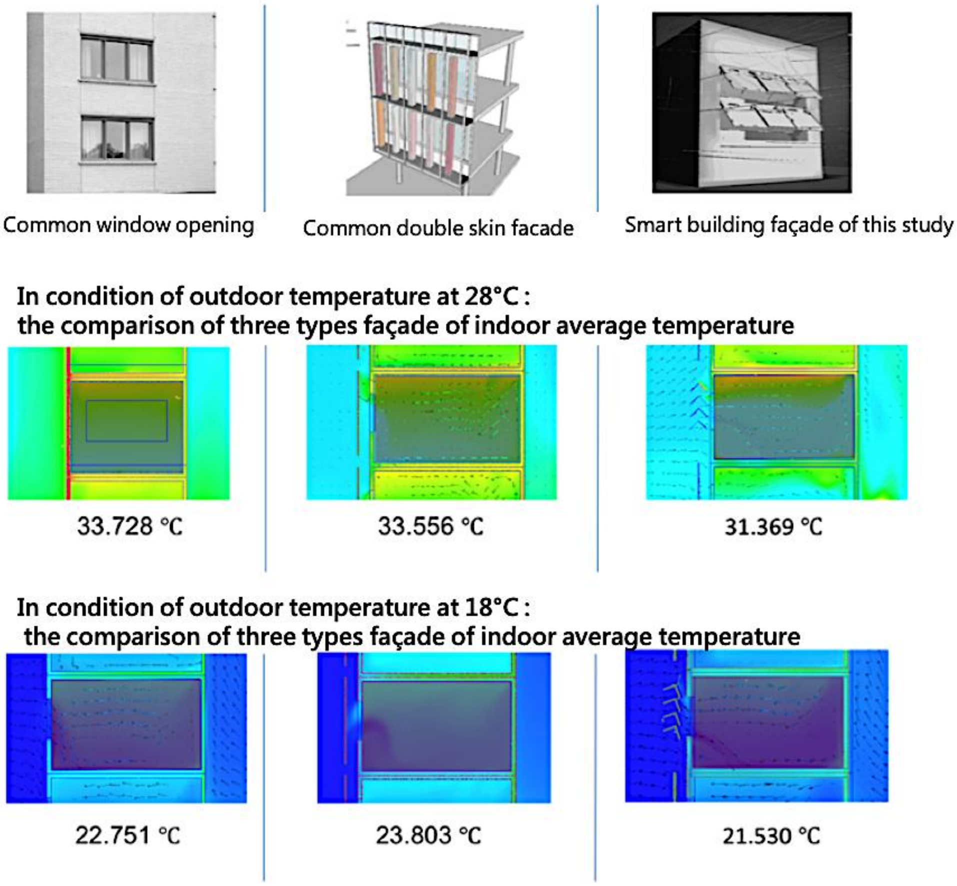

Fig. 11 Comparison of computational fluid dynamics analysis in 18°C and 28°C condition.

This study proposes a smart façade method in the natural ventilation condition and cooler condition (18°C). we can know that general window opening type and the common double skin façade type have no direct help for indoor comfortability and need more follow-up analysis.

4. Conclusion and Future Work

This research proposes a façade design that can control both sunlight intake and ventilation of the building. It has a dual power system and combines the SMA-driven mechanism and electricity-driven mechanism so that this façade skin system consists of energy-saving and control capabilities. Computational fluid dynamics analysis and comparison proves that the smart façade method proposed in this study is indeed helpful for indoor comfort when outdoor temperature at 28°C, but has no significant benefit when outdoor temperature at 18°C.

Through the execution of this study, the module of smart building façade can work. The future research will focus on the following parts:

• understand the relationship between different outdoor and indoor temperature by CFD:

We can simulate the CFD in conditions of temperature with a difference of 1°C, and then observe the change of average indoor temperature. Therefore, we can clearly realize the effect of building façade of this research in different temperature conditions.

• Adjust the CFD mutual model framework settings:

The building façade in this study has the advantage of a shading system to prevent solar radiation directly into the interior. This factor can be added into other comparative models and expected to gain more accurate indoor average temperature.

• Mechanism design and manufacture: Completeness of manufacture and assembling components can be enhanced.

• Connection to the Internet of Things:

The smart building façade can be connected to the Internet of Things platform on the campus in order to send real-time information of the smart façade and can accept commands from the cloud storage to respond. On the concept of smart campus, we can integrate software and hardware network system, and prepare for the cooperation with the building information modeling (BIM).

References

[1] A. De Gracia, A. Castell, L. Navarro, E. Oró and L. F. Cabeza, Numerical modelling of ventilated facades: A review, *Renewable and Sustainable Energy Reviews* 22 (2013) 539-549.

[2] C. Doumpioti, Responsive and autonomous material interfaces, in: *Integration through Computation: Proceedings of the 31st Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)*, 2011.

[3] J. Burry, F. Salim, M. Williams, S. Anton Nielsen, A. Pena de Leon, K. Sharaidin and M. Burry, *Understanding Heat Transfer Performance for Designing Better Facades*, 2013.

[4] M. Coussirat, A. Guardo, E. Jou, E. Egusquiza, E. Cuerva and P. Alavedra, Performance and influence of numerical sub-models on the CFD simulation of free and forced convection in double-glazed ventilated façades, *Energy and Buildings* 40 (2008) (10) 1781-1789.