A Study on the Performance Control for Building Façades Applied with Patterns of Hanok Openings

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***Abstract* — This study focuses on window patterns of Hanok, Korean traditional residence, and their effects on building performance and adaptabilities as building skins. The purpose of this study is to investigate the possibility of Hanok patterns as a new type of building façade that satisfy both aesthetic and the efficiency of building space, and to suggest a new method based on Information and Communication Technology (ICT) for optimizing the building performance. For this research, a variety of Korean traditional window patterns were reviewed first, and a typical façade was applied for a comparative analysis in aspect of the effect on the building indoor environment. In addition, this study examines selected façade patterns that could minimize heat loss and make it easy to adjust indoor light environment by changing the intervals. ICT has played an important role as both a controller for the spatial environment and a simulator for evaluating various experimental factors; Wireless Smart Sensor Network (WSSN) and Wireless Fidelity (Wi-Fi) have been utilized for adjusting configuration of the opening patterns, and popular simulation tools like Project Vasari and Green Building Studio (GBS) have been used for verification of the feasibility, investigating relationship between daylighting capability of proposed skins and their energy performance. Finally, building skins satisfying both Korean traditional identity and efficiency of energy performance are suggested and examined in this study.**

Keywords - Hanok; Korean Traditional Window; Opening Patterns; Energy Efficiency; Energy Simulation; Sustainability

I. INTRODUCTION

Modern architecture offers not only aesthetic and user experience but also provides indoor environments that satisfy various requirements, such as visual and thermal comforts. In other words, both design and function should be taken into consideration because contemporary man's demands are going to be greatly diversified. Nowadays, building façades world-wide look very similar without explicitly presenting their identities and tend to focus on simply available form and design. Consistent skins mean that they do not offer any specific characters responding to country, area, and/or building location. This situation causes building users to be uncomfortable in the indoor environment.

Recently, Hanok, which is a Korean traditional residence, has received attention by changing people's awareness because Hanok has its own beauty and is environmentally friendly [1]. Hanok consists of unique structures and components that can accommodate the four seasons of Korean climates. In particular, Hanok window is a more important component than other elements, and it occupies most of the external wall. The Hanok window in this research has been developed as control equipment of external environment that Korean season is hot and humid in the summer and cold and dry in the winter [2]. Figure 1 shows the scheme of this study that Hanok window can be used for new type of façade and increase Energy Efficiency. Hanok window also has a completely distinguished design and tectonic, consisting of a series of wooden ribs and creating unique patterns.

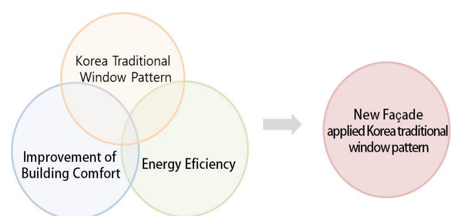


Figure 1. Scheme of the Study

The target of the experiment for this study is a general office building. A comparative study was carried out between an office building with a typical window system and one with Hanok window pattern in the study area of indoor environment and energy efficiency. Indoor environment analysis includes illuminance and insolation and energy efficiency includes fuel consumption, carbon emission quantity, and heating and cooling load [3]. There are details of analysis tools and target factors in Table I.

TABLE I. ANALYSIS TOOLS AND TARGET FACTORS

	Tools	*Factors*
Analysis for Building Performance	Project Vasari, GBS	Fuel Consumption, Carbon Emission Quantity, Heating and Cooling Load
	Autodesk Ecotect, Radiance	Illuminance, Insolation

A simulation was carried out by changing the interval and the scale of Hanok window pattern ribs. Project Vasari and GBS was used to confirm energy efficiency, and indoor environment analysis was simulated by Ecotect and Radiance. An office modeling unit is a basic form provided from the Project Vasari program with code complied construction, located in Seoul, Korea where it has various climatic conditions depending on the four seasons.

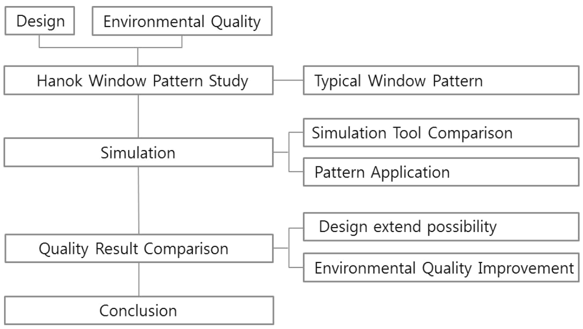


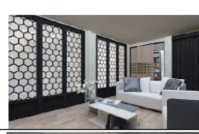
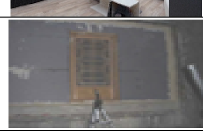
Figure 2. Overall Flow of the Study

Accordingly, this study suggests the architectural skin that is applicable to various climates and also satisfies identical design. Simulation tools were used to prove that the typical Korea window pattern presented in Section II has a positive effect on indoor environment and improves the energy efficiency. ICT such as WSSN and Wi-Fi were applied with window to do a important role as both a controller for the spatial environment and a simulator for evaluating various experimental factors as described in Section III. All data and contents were then integrated to conclude the paper in Section IV. Figure 2 is the flow chart of this study.

II. HANOK-STYLED FAÇADE AND OPENING PATTERNS

Hanok is Korean traditional residence style and is different from western-style housing in structure, space organization, and design [4]. However, previous studies on Hanok façades are limited in that they focused on improving efficiency only or applying design to modern buildings and Table II shows those examples. These studies were mostly related to replacement materials on finishing materials and windows. These existing studies are important, but integrated improvement and eco-friendly design of Hanok and Korean traditional design elements are also important.

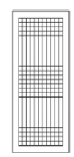
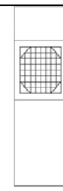
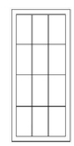
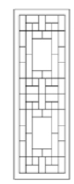
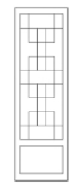
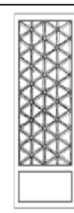
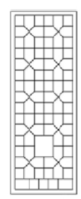
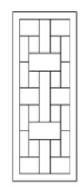
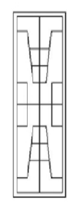
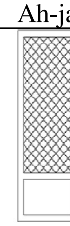
TABLE II. EXAMPLE FOR A STANDARD HANOK DESIGN AND EXPERIMENT FOR BUILDING PERFORMANCE WITH HANOK WINDOWS

Design Alternatives for Hanok Window Patterns		
Experimental Devices for Performance Monitoring		

Therefore, the study of Hanok window is needed with a holistic integrated design approach because it acts as not only a mediator between indoor and outdoor climates, but also serves an alternative to suggest the architectural skin considering Korea identity and energy efficiency. Hanok window physically connects the indoor and outdoor of a building and can be a major influence on the indoor environment such as lighting, heat gain and ventilation. In the design, various window styles can be selected based on client's needs, and this shows a possibility for developing new façade typologies with Hanok patterns.

Hanok window patterns can be configured with different typologies according to climate condition, window location, function, and size. For example, the grid pattern is interlaced by both vertical and horizontal ribs, and formed as intersected rectangular shapes. A window graved in the form of a flower is called Flower-rib window (Kkot-sal-moon in Korean) and many other types also exist such as Wan-ja, Ah-ja, Beaum-sal, Se-sal, Kyo-sal, Ti-sal [5].

TABLE III. KOREAN TRADITIONAL WINDOW PATTERNS

				
Grid	Jeong-ja	Young-ja	Wan-ja	Ah-ja
				
Kkot-sal	Gu-gab	Sut-dea	Gu-ja	Bit-sal

These names are determined by the number of ribs, size, distance between grids, and angle, but the most affective element is a form composed by crossed ribs. These compositions of window grids play an important role as a structural element to support the window and show the beauty of window design. Figure 3 is that grid patterns as a representative typology of Hanok window is not entirely typical in the aspects of vertical and horizontal proportion, but they have a 3.6~6.0cm gap in average between grids and thickness, width, and angle can be changed by grid types.

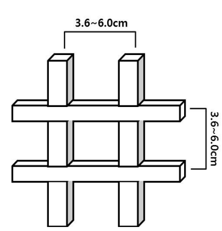


Figure 3. Typical Dimension of the Korean Window Pattern

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The grid pattern, a typical layout of Hanok window pattern was used as the basic form for this study. The number of ribs, size, distance between grids, and angle of grid pattern were adjusted to find the most ideal pattern for energy efficiency and design. The adjusted grid pattern was applied to a general office building and simulated to compare its performance with a typical office building.

III. Analysis For Building Performance Applied With Hanok-Styled Façade

A. Methods and Tools

For this study, Project Vasari, GBS, Ecotect, and Radiance were selected for simulation to compare indoor environment and energy efficiency of the target buildings mentioned on the previous section. Project Vasari uses DOE-2 as an analysis engine based on American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards to input parameters, so it can make relatively accurate results from the simulation. In addition, a Vasari model can produce data in gbXML/IFD format and compute various experimental settings easily by interlocking with GBS; Creating building models and analyzing given problems are executed by Project Vasari, and then GBS performs building energy analysis in this study [6].

For the indoor illuminance, Radiance and Ecotect were used to analyze indoor environment. A lighting research team at Lawrence Berkeley National Laboratory has developed Radiance, which is a program to evaluate lighting performance. This tool uses a ray-tracing logic which starts calculation on the observer's view and investigates complicated phenomenon such as reflection, curve of lighting and diffusion reflection between object surfaces. This program is free for use and can simply be plugged into Ecotect.

Ecotect is developed by Square One Research, Australia, and taken over by Autodesk in 2008. This program can predict the simulation result simply and make the data available for different building performance. This program also can estimate various elements such as sun's radiation, natural lighting, air current, heating, shade and shadow, building heating and cooling load, and so on, allowing designers to use it from the pre-design phase to the design development process. The weather tool and the solar tool are also provided by Ecotect, and make it possible to interpret weather situations and solar movement for loaded building models. Analysis data generated by this tool can easily be exported to various formats for interlocking with more applications [7].

B. Scope and Detail Levels

Since there are no specified guidelines about detail levels of building models for performance evaluation, Level Of Development (LOD) 100 suggested by American Institute of Architects (AIA) has been used for modeling in this study. LOD 100 is known as an equivalent level of the conceptual design in Korea that volume of the building mass and the building type are defined and overall modeling process is established with fundamental building parameters such as area, height, volume, place, axis and so on [8]. In addition, this detail level determines not only a type of the project ordering as suggested by Integrated Project Delivery (IPD) and an initial step for design process with Building Information Modeling (BIM) as well; The AIA documentation, E202TM-2008, includes all the steps of the IPD design process and their detail levels towards BIM [9].

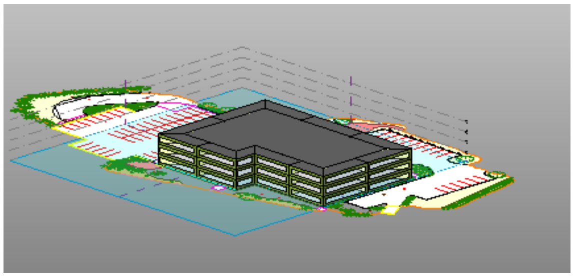


Figure 4. Building Model for Simulation Based on LOD 100

This study has utilized LOD 100 as shown on Figure 4, because the target for the performance evaluation is not for building facility and utilities, but for building façade as an architectural component. Then, building performance focusing on environmental and energy factors has been analyzed with a few alternatives of building skins chosen from both a typical curtain wall and Hanok-styled window patterns for comparison.

C. Settings and Factors

First of all, it is important to set up the climate condition to perform the building performance in aspect of the building skins facing surroundings. The greatest percentage of people on the Earth live in the temperate climate zone along the westerly belt, because this warm area has four clear seasons caused by ideal solar positions normally distributed between 20 to 60 degrees in altitude. Korea is also located in a temperate climate zone in the middle latitude belt, and Seoul, the capital city of Korea, has been selected for analysis, because about 40 percent of the office buildings in Korea are distributed in this city as shown in Table IV.

Most settings for simulation, including weather and climate factors, were extracted from the database supported by official statistics archives such as ASHRAE, and then Ecotect and Project Vasari were utilized to import this information, run simulations and visualize the results on Google Maps directly. Users are able to input standard information about any selected area provided by ASHRAE anytime in this way.

TABLE IV. Distribution of Office buildings by Metropolitan Cities in Korea (2012)

	Seoul (40%)	*Busan (18%)*	*Daegu (14%)*	*Incheon (13%)*	*Gwangju (8%)*	*Daejeon (7%)*
No. of Office	140,987	66,494	49,462	47,654	28,906	28,999

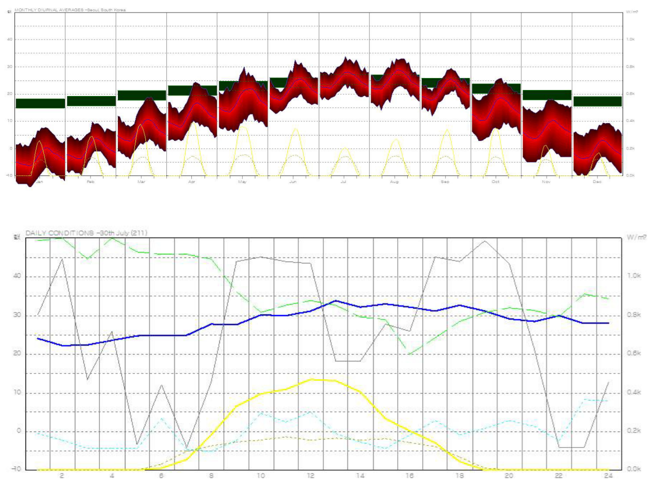


Figure 5. Monthly Climinate Data for Seoul

Figure 5 shows detailed information about the Seoul climate illustrated by the weather tool in Ecotect as an example. It is easily noticed that temperature and isolation are the highest on July 30th and this data can be accepted as Summer data. The building modeling for the standard office is performed by the standard of LOD 100 and then, various types of the building façade including Hanok-styled openings have been applied one by one for the same analysis process repeatedly. Standard office settings used for simulation are shown on Table V, and they include operation hours, lighting equipment schedule, user activity level, and heat gain.

TABLE V. DATA TYPES FOR OFFICE BUILDINGS

Parameters	***Default Values***
Occupancy Schedule	Common Office 8am - 5pm
Lighting/Equipment Schedule	Office lighting 6am - 11pm
People/100 sq. M	3.5
People Activity Level	Standing, Light work, Walking
People Sensible Heat Gain(W/Person)	73
People Latent Heat Gain(W/person)	59
People Sensible Heat Gain(Btu/Person)	250
People Latent Heat Gain(Btu/Person)	200
Lighting Load Density(W/sq. ft.)	1.00
Equipment Load Density(W/sp. Ft.)	1.30
Electrical Equipment Radiant Percentage	0.3
Condition Type	Heated and Cooled
OA L/S Person	10
OA Flow per Area(Cu. M./hr/sq. M)	3.7
Unoccupied Cooling Set point	82

TABLE VI. BUILDING PERFORMANCE FACTORS

Location	Seoul, Korea
Weather Station	555181
Outdoor Temperature	Max:35°c/Min:-14°c
Floor Area	3,721㎡
Exterior Wall Area	1,488㎡
Average Lighting Power	10.87W/㎡
People	130
Exterior Window Ratio	0.24
Electrical Cost	$0.06/kWh
Fuel Cost	$1.21/Therm

D. Data Analysis

This study has suggested four types of grid patterns from the most typical Hanok-styled façade for simulation analyses in Figure 6. The first type has a general scale with a standard rate of proportion between vertical and horizontal ribs [10]. This means that a rate of thickness, width and angle of the crossed components are exactly the same as the traditional form. The second type has prominent vertical ribs instead of the original feature which is adjusted to fit in the typical curtain wall mostly used for current office buildings.

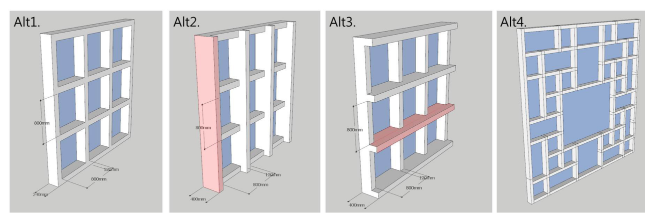


Figure 6. Operational Alternatives for Simulation

The next type has increased in depth for horizontal ribs that can play a role as building louvers. Various rib rates can be selected for both design values and energy efficiencies. The last type shows a combined configuration with both horizontal and vertical ribs that providesmore possibilities for design variation. This type looks very similar to Korean Wan-ja or Sut-dea window patterns as shown in Table III, and it was assumed that the most ideal composition can be found with the analysis procedure suggested in this study.

Table VII summarizes the simulation results generated by GBS and Radiance applications for the above four types. It is found that all cases applied with Hanok opening patterns on the building façade have relatively better scores than the controlled group with a façade type of the general office building. Especially, the annual carbon emissions showed the biggest difference among these, and Hanok-styled façade types seemed relatively helpful for increasing energy efficiency in the aspect of cost. This result emphasizes that the use of Hanok-styled façade may possibly have advantages for both the design creation and the building performance.

E. Proposed Performance Control with ICT

With the above investigation, it turns out that applying Hanok window patterns can increase the effectiveness for indoor environmental quality and energy savings. Furthermore, proposed patterns will possibly be more adaptable to the commercial building façade, if building users can control parameters for the grid patterns conveniently depending on their design preference or any given specific environmental situation.

ICT can play a important role in this sense, and WSSN can be proposed and utilized for adjusting grid intervals and/or component scales of the façade. In addition, WSSN is applicable with mobile devices like smart phone used by most people in daily life. For example, sensors installed onto the building receive signals from smart phones, and then kinetic façade components are operable for controlling their intervals and scales by the preset scenarios with various contexts for optimizing building performance.

WSSN system makes people possible to activate their smart phone applications or computer programs to adjust daylight, and then Wi-Fi signal via TCP/IP arrives to router stack on each window panel as shown on Figure 7. Its transparency and color can be changed through a series of functions by Window Property Controller. Eventually, users can adjust their indoor environment by using WSSN.

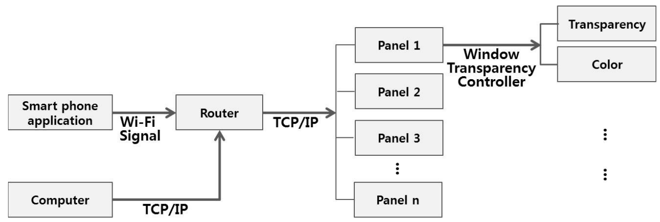
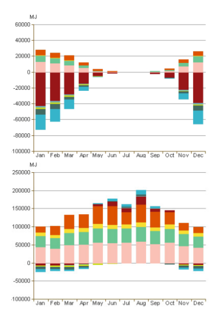
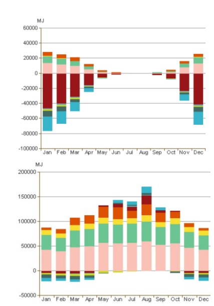
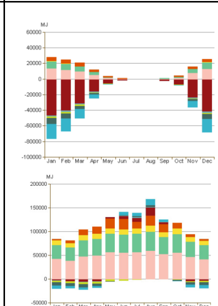
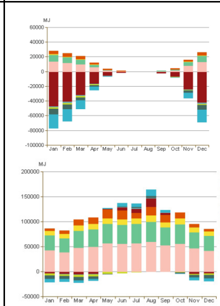
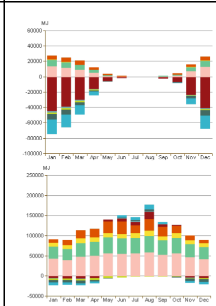
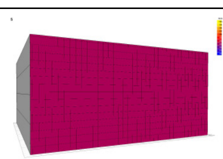
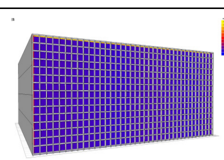
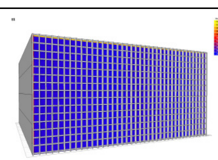
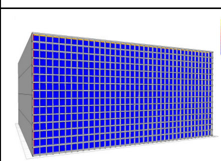
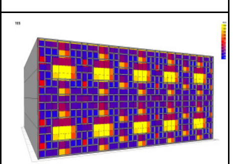


Figure 7. Distribution Diagram of Wireless Smart Sensor Network

TABLE VII. SIMULATION RESULTS

		Control Group	Alt1	Alt2	Alt3	Alt4
Annual Carbon Emissions		129	112	112	109	116
Annual Energy	Use (Electricity: kWh /Fuel:MJ)	555.615 / 597.501	505.753 / 551.923	502.605 /552.556	498.255 /541.729	517.350 /657.167
	Cost ($)	40,103	36,699	36,638	36,149	37,429
Energy use	Fuel (MJ)	697.501	551.822	662.555	641.728	657.167
	Electricity (kWh)	551.162	501.300	498.152	493.813	512.898
Monthly Heating / Cooling Load Misc Equipment Light Fixtures Occupants Window Solar Window Conductive Infiltration Underground Surrounding INT Surroundings Roofs Walls						
Radiation	Direct Radiation Average	675.503	34.5808	34.892	1.063	174.382
	Diffuse Radiation Average	656.262	361.973	322.499	304.592	413.698
	Total Radiation Average	1331.766	396.553	357.391	305.656	588.08
	Simulation Figure					

This research also suggests Polymer Dispersed Liquid Crystal (PDLC) for increasing the indoor environmental performance of Hanok-styled façade. This concept was originally invented by Dr. Edwin Land and has been commercialized since 2003 [11]. The proposed façade system in this paper is composed of the Hanok-styled frames and the responsive window glasses that are usually on the opaque state with only 5% daylight penetration and also convertible to the transparent status passing 70% lights from the outside. These variant situations are made possible by controlling quantity and intensity of the electricity flown on the glasses and signals sent from WSSN based on Wi-Fi and/or Zigbee communication module determine the situation. We are quiet certain that usability of the Hanok-styled façade would be doubled, if ICT such as WSSN and PDLC examined in this paper is successfully integrated.

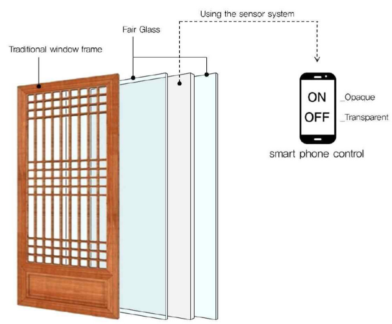


Figure 8. Proposed Performance Control for Hanok-styled Façade

IV. CONCLUSION

The purpose of this study is to investigate characteristics of Hanok opening patterns as the building façade and to prove their energy efficiencies and indoor environmental qualities as important parts of the building performance. With utilizing scientific simulations for various alternatives of the building skins mentioned previously, it was found that Hanok opening patterns may have great advantages to be a type of practical building façade presented worldwide.

For this study, analyses for building performance have been done for selected patterns that may minimize heat loss and make it easy to adjust indoor light environment by changing the intervals. ICT also played an important role as both a controller for the spatial environment and a simulator for evaluating various experimental factors; WSSN has been utilized for adjusting configuration of the opening patterns, and popular simulation tools like Project Vasari and Green Building Studio have been used for verification of the feasibility. The results from the simulations show that Hanok opening patterns can reduce the annual carbon emission from the energy consumption approximately up to 15% in comparison to the generic office buildings, and has the possibility to be used as an alternative for resolving problems related to air pollution. Finally, the building enclosures satisfying both Korean traditional identity and efficiency of the building performance have been suggested as the Hanok-styled façade.

This advanced concept of Hanok-styled façade can be expanded to residential and commercial facilities including office buildings, because it has been proved by simulations that overall energy use and its lifecycle cost are significantly reduced. Future study will include more building components using Hanok-styled elements that make architectural design and fabrication possible to diversify and environmental qualities much higher.

ACKNOWLEDGMENT

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