A Study of Environmental Sustainability Hidden in the Traditional Korean Residences through Computational Analysis Tool

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Submitted towards the fulfillment of the requirements for the Doctor of Architecture Degree.

School of Architecture
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We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in fulfillment as a Doctorate Project for the degree of Doctor of Architecture in the School of Architecture, University of Hawai`i at Mānoa.

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"Lord, You raise me up…. To more than I can be."

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This research extracts the environmental design responses of the traditional Korean residences through a holistic computational analysis tool referred to as Ecotect. Ecotect is used to generate intersections with design analysis and perform various environmental solutions. Three traditional Korean residences - *Yeongyeongdang*, *Unjoru,* and *Chusagotaek* during the *Joseon* dynasty (AD1392~1910) of Korea are tested. Furthermore, Ecotect is used to demonstrate the environmental design response in detail with parameters such as shadows, shading, solar analysis, wind flow, and thermal performance. Taking into consideration the social and cultural impact of the *Joseon* dynasty, the performances of the various design solutions are analyzed, explaining the impact that different building elements have on energy consumption. The relationships are represented in the form of statistical relations and interactive data charts.

This research will also: (i) introduce methodologies to the holistic buildings' energy performance, (ii) implement the aforementioned method in analyzing the three traditional Korean residences, (iii) view three traditional residences' range of environmental design responses through computational analysis, (iv) deal in depth the environmental design responses that enhance the thermal comfort in the traditional residences, (v) and lastly, make suggestions based on the outcome of this study for future research.

1. INTRODUCTION

1.1. Background

In 1996, Intergovernmental Panel on Climatic Change (IPCC) confirmed that rise in carbon dioxide level in the atmosphere had contributed in global warming, and the architects were forced to scrutinize the environmental factors in building designs (Jones and Ando 1998). The considerations for the environmental design responses emphasized new movement in building analysis using energy programs, which included orientation, natural ventilation, daylight, solar control, and thermal capacity. Theses environmental design responses lead to enhancing its energy programs performances for the hundreds of building designs (Crawley, et al. 2005). Human comfort and energy conservation is the major functional considerations in building performances and dwellings. The important elements to provide energy efficient design principles, to improve comfort levels to occupants, and to reduce energy consumption are the building and room orientation, the size and shading of windows, the roof and wall insulation, the use of thermal mass, the cross ventilation, the landscaping, and energy-efficient appliances (Development and Land Use 2000).

Nature always has been regarded as an important consideration in Korean residential architecture. The traditional Korean architecture never attempted to resist or compete with the natural environment, but attempted to harmonize its structures with the natural surroundings. In the popular scheme, residences were most often arranged in a compound at the foot of a mountain or in a valley (Yoon 1974). Ordinarily, traditional Korean residences utilized locally available materials, but the layout of the traditional Korea residences showed various relationships with the surroundings. Case in point, the Korean residences make efficient use of natural ventilation, daylight, solar control, and thermal capacity.

Through many studies conducted, experts are predicting that aforementioned elements in the traditional Korean residence will conserve energy for the contemporary architecture. These studies demonstrated how to extract the environmental design characteristics of the traditional Korean residence to lead the building systems and to improve the comfort levels in the residences. This investigation, however, integrates the impacts of building components and the environmental design responses in a holistic approach through a computational analysis tool.

1.1.1. Statement of Existing Knowledge

Many scholars and professors have tried to investigate the traditional architecture characteristics after the Japanese occupation (1910-1945) and the Korean War (1961). Korea had to face many confrontations throughout its history such as Mongolian war (1231), *Imjin* war (1592-1598), Japanese Invasion (1592-1598), and Japanese occupation (1910~1945). During such wars, the Japanese and Mongolians took many Korean treasuries and destroyed them. During the *Imjin* war, the Japanese soldiers even tried to change Korean history. After the Japanese occupation, the traditional Korean architecture had been broken, and consequently, the Korean architecture became westernized at a dramatic speed. Korean architecture since, has continued to change into westernized modern styles without any consideration for its own culture and history.

There have not been many analytic studies about the traditional Korean residences with the modern paradigm. Efforts have been made to find reputable examples of the environmental factors for contemporary architecture but it has been in vain to find correlation between the traditional residences and the environmental factors through the modern scientific paradigm. In the past, before democracy in Korea, the social hierarchy had discriminated professionals like carpenters, and their social status restricted them from recording any data, namely drawings and literary documents. Therefore, only the existing architectures and the foundations of demolished buildings reveal the images of the traditional architectural characteristics. The following books were reviewed for this thesis paper.

> Inaji, T. and Virgilio, P.(ed). "*The garden as an architecture; Form and Spirit in the gardens of Japan, China, and Korea.*" Japan: Kodansha International, (Inaji and Virgilio 1998). Toshiro Inaji is a professor emeritus in the Department of Design of Tokyo National University of Fine Arts and Music. He introduced the traditional garden styles and the architects of Japan, China, and Korea. Pamela Virgilio earned a Master in Fine Arts in environmental

design from Tokyo National University of Fine Arts and Music under Toshiro Inaji. They introduced three national architectures and gardens in English. They have contributed by introducing traditional Korean residents and the geographical terminologies in English.

ZU, Nam-Chul. "*Yeongyeongdang.*" Seoul, Korea: Iljinsa, (N. Zu 2003). Nam-Chul Zu is a professor in the School of Architecture at Korea University. He has published many books related to traditional Korean architectures in various topics. His book, entitled '*Yeongyeongdang'*, includes the drawings of the buildings and describes the difference between the original drawings and the current building. However, his argument is based on the original drawings and historical background as opposed to this research, which will focus on the environmental factors using Ecotect software.

SHIN, Young-Hoon. "*Hanok*," Seoul, Korea: Haeamsa, (Sin 2005). Young-Hoon Shin had repaired the Korean national treasures from 1962 to 1999. He has had a lot of field experience and knowledge of the traditional Korean architecture, and he published many books reflecting his experience. His book, 'Hanok', the traditional Korean architecture, explains the general concepts concerning the environmental factors.

HUR, Nahmkeon, Lee, Myungsung, and YANG Sungin. "Numerical Simulation of Ventilation in the Storage Hall of *Tripitaka Koreana* at *Haein* Temple in Case of Building Rearrangement." Seoul, Korea: *Journal of the Society of Air-Conditioning And Refrigerating Engineers Of Korea*, 2007; 379-385. (Hur, Lee and Yang 2007). This research proposes the ventilation strategy for adding an auxiliary traditional Korean style building in *haeinsa* temple. The *haeinsa* temple, built in 802, has been preserving 81,258 wooden printing blocks of the Buddhist Scriptures since 1398. Numerical results from Computational Fluid Dynamics (CFD) compare the conditions of the temple after the extra building has been added. This investigation introduces the ventilation strategy of the traditional Korean architecture using the computational software CFD. This research focuses on the Flow analysis of the building in the mechanical engineering department at Sogang University in Seoul, Korea.

Abaza, Hussein Fuad. "*An Integrated Design and Control Strategy for Energy Efficient Buildings*," Doctorate Thesis, Virginia: Virginia Polytechnic Instituted and State University, (Abaza 2002). Hussein Fuad Abaza proposes a holistic evaluation model that assists architects and designers in producing buildings with low energy consumption. This evaluation model was tested and used to support new ventilation strategies for the Beliveau House in Blacksburg, Virginia through the energy simulation software EnergyPlus[1]. This paper also suggests new direct and indirect ventilation control strategies to reduce cooling load to improve comfort for Beliveau House in Blacksburg. The scope of the study is from the simulation software, which process the strategies for the contemporary Beliveau residence.

1.1.2. Problem statement

With the rapid development of building technologies, architects have made remarkable contributions to our built environment since the Industrial Revolution (1780s). In return, however, the serious consumption of natural resources, the pollution from the use of the technologies, and the loss of vernacular architecture has been the hidden cost of our current environment. They inflict grievous harm to the environment, threatening to degrade our future habitat with current global warming and lack of architectural identity.

Vernacular architecture employs locally available resources to address the needs

[1] EnergyPlus models heating, cooling, lighting, ventilating, and other energy flows as well as water in buildings. EnegrgyPlus originally based on the most popular features and capabilities of BLAST and DOE-2. EnergyPlus includes innovative simulation capabilities such as time steps of less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, water use, natural ventilation, and photovoltaic systems (U.S. Department of Energy 2008).

according to geographical characteristics, and evolves to satisfy the environmental, cultural, and historical requirements in which the architecture exists. In this context, this research starts from the hypothesis that the Traditional Korean Architecture developed its own methods to achieve the best outcome from its limited technological advances and nature. The goal of this work is to extract the environmental design responses of the traditional Korean residences through the holistic computational analysis.

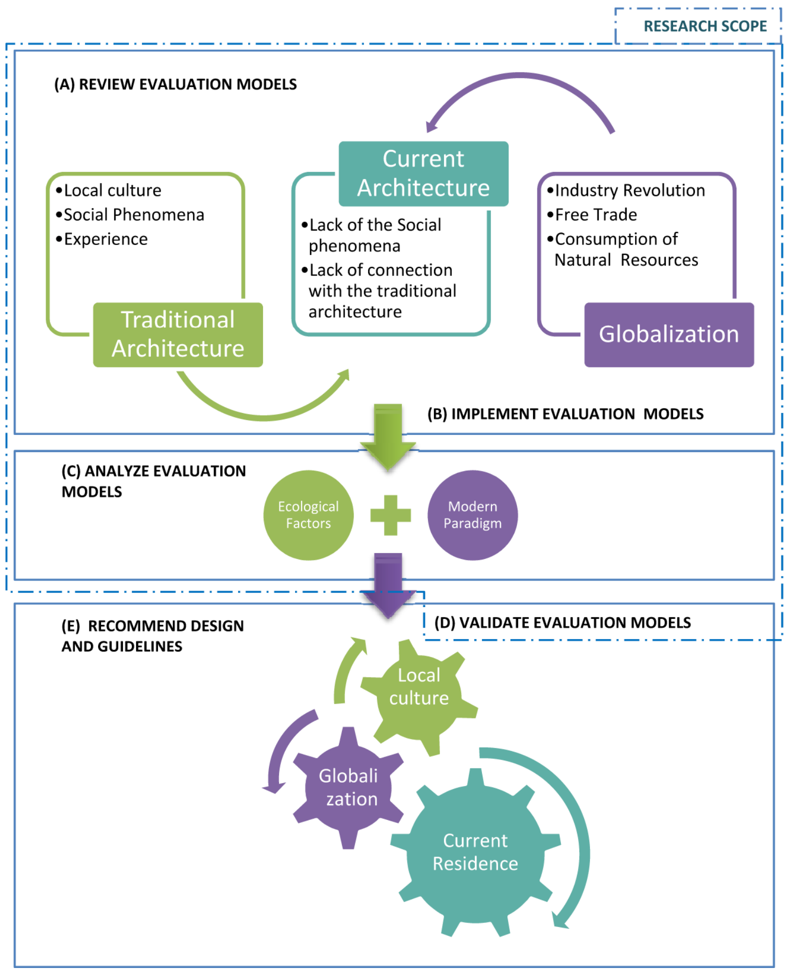


Figure 1-1 Overall Thesis Statement

1.2. Scope of Research

Through data collection, analysis, simulation, and evaluation, this research provides an analysis of the building performances. This research involves proposing a building evaluation model, testing, and redefining these evaluation models in *Yeongyeongdang*, *Unjoru,* and *Chusagotaek.*

The proposed building evaluation models are composed of four major components.

First, the component is CAD interface that transfers the building geometry to the energy simulation software.

Second, a solution generator (Ecotect) integrates the energy simulation with building components. Ecotect also inputs of the building base plan and building components, which were the subjects of the evaluation. The Ecotect Output is a matrix of complete design analysis.

Third, a simulation generator feeds energy simulation with the matrix of the alternative solution to simulate them and export their results to the fourth component, known as data analysis generator. The data analysis generator conducts the analysis to derive relations between the design and their effect on energy consumption and comfort.

The research also involves testing and implementation of the building evaluation model. *Yeongyeongdang*, *Unjoru*, and *Chusagotaek* were used as case studies to test the evaluation models.

Finally, the research redefines what holistic approach is by integrating the ecological characteristics such as solar analysis, natural ventilation, thermal performance, and others.

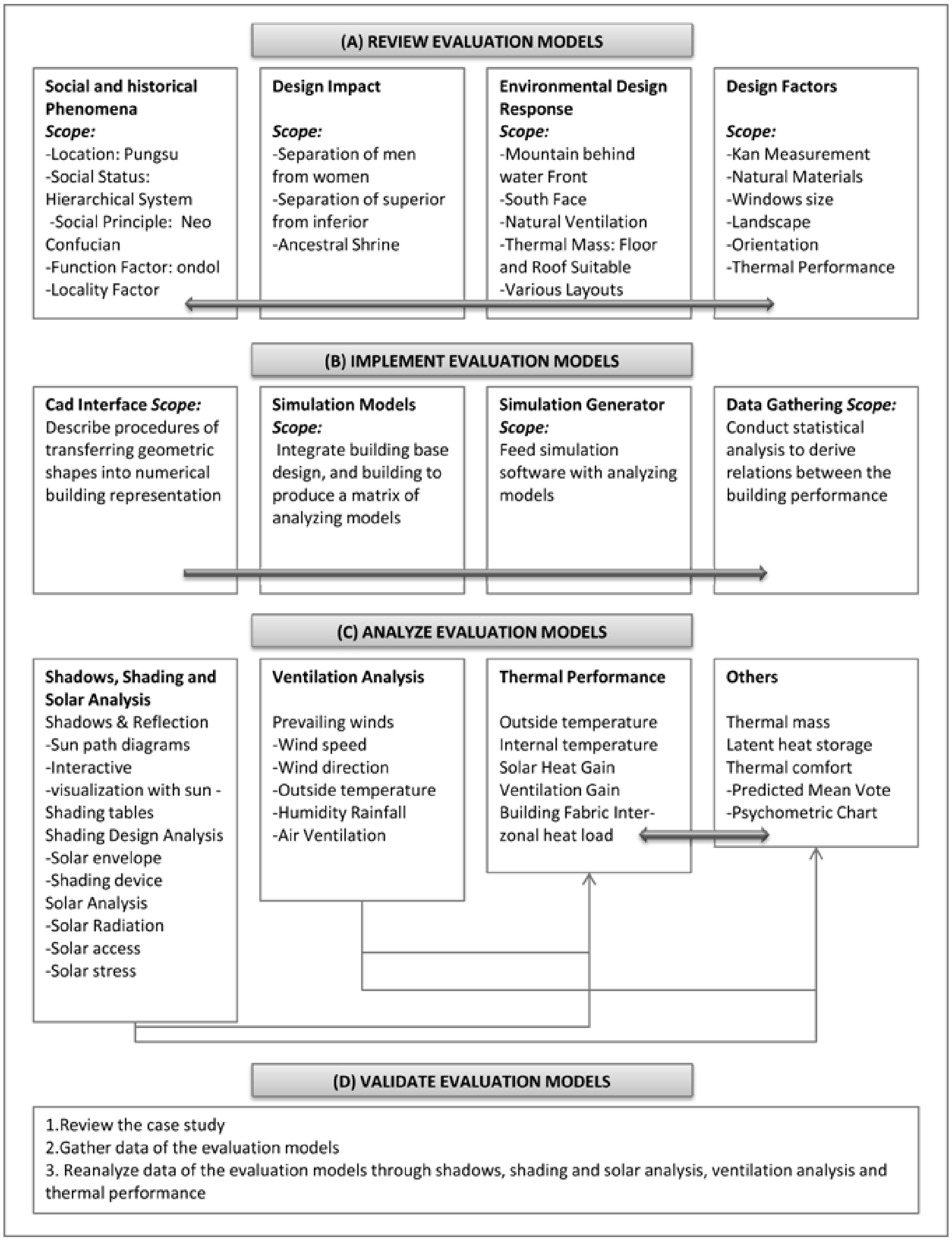


Figure 1-2 Overall Research Scope

1.2.1. Research Objectives

The principal objectives of the study are to find the hidden environmental design responses through evaluation of building solar analysis, natural ventilation, and thermal performance of evaluation models. The models in *Yeongyeongdang*, *Unjoru*, and *Chusagotaek* will be tested, simulated, and evaluated. The objectives of this study are to analyze the usage of Korean traditional space using *Yeongyeongdang*, *Unjoru,* and

Chusagotaek as models, and utilize the results of the models to further explore the energy saving potentials and methods to enhance design qualities.

The analyses of this study will have the following objectives:

- ✓ Analyze and systematically re-arrange the apparently unclear and non-systematic features in the expression of the traditional spatial concepts which appear in the traditional residence.
- ✓ Extract the environmental design responses of the traditional Korean residences based on the simulation energy tool as a modern paradigm.
- ✓ Analyze the relationships between the interior and exterior space of the upper class residence of Korea's last *Joseon* dynasty and human dimensions based on their life styles of the era.

1.2.2. Research Methodology

This research starts from gathering data from books and studies published in both Korean and in English. The evaluation models are applied on the basic drawings and the building materials found in Korean resources, and the analysis method using Ecotect is referenced to materials in English.

This methodology involves analyzing a building evaluation models that acts as a central agent between a Base Analysis Generator and Alternative Design Analysis Tool, which consists of a solution generator, a simulation generator, and a data analysis generator. The evaluation model was used to identify general design of traditional Korean residence for using the shadows, shading and solar analysis, wind flow, and the thermal performance. More information or methodology is presented in Chapter 2.

1.3. Research limitations

Since the research involves multi-disciplinary subjects, there are limitations and restrictions raised through the research. Although the computational analysis tool (Ecotect) was thoroughly tested and calibrated, some technical limitations arose which required co-operation between the researcher and Ecotect help support to overcome. A more thorough description of these difficulties is discussed later in chapter two.

1.4. Organization of Dissertation

The dissertation is presented in seven chapters covering background information stating the problem, explaining the development of the evaluation method, introducing the three traditional Korean residence - *Yeongyeongdang*, *Unjoru* and *Chusagotaek*, evaluating these residences, and lastly comparing the evaluation models.

Chapter One: Introduction

Chapter one offers background information, presents the problem statement, and identifies the primary objective.

Chapter two: Methodology

Chapter two discusses the concept, components, and procedures using a holistic building evaluation tool referred to as Ecotect. It describes the steps of developing an AutoCAD interface, which extracts building formation from CAD drawings, prepares for the analysis of models, and make three dimension models in the simulation software, Ecotect. This chapter also discusses the means and methods used to extract statistical relationships generated by the models results.

Chapter three: Yeongyeongdang – Test Model I

Chapter three introduces the first of three selected model, *Yeongyeongdang*, which is analyzed for its environmental factors, and calibrated the simulation results. Evaluation model is then used to explore the contribution of controlled shadows, shading, solar analysis, wind flow, and the thermal performance, and to derive a holistic view of building performance.

Chapter four: Unjoru – Test Model II

Chapter four introduces *Unjoru*, which is the second evaluation model. Unlike *Yeongyeongdang*, *Unjoru* had been occupied by the founder's family. It is located on the steep valley that represents the traditional Korean architecture concept. This chapter analysis will follow the same method used for *Yeongyeongdang*.

Chapter five: Chusagotaek – Test Model III

Chapter five introduces *Chusagotaek*, which is the last evaluation model. It is located on the steep valley like *Chusagotaek*, and fortunately, it was preserved very well. This chapter analysis to be followed the means and the method of the other previous evaluation models.

Chapter six: Comparison

Chapter six compares the three evaluation models: *Yeongyeongdang*, *Unjoru,* and *Chusagotaek*. First, this chapter analyzes the performance and calibrates the previous simulation results. Second, this chapter compares the evaluation models to explore the contribution of controlled shadows, shading, solar analysis, wind flow, and the thermal performance. Finally, this considers the holistic view of comparison of building performances.

Chapter seven: Discussion

Chapter seven summarizes the research results, and suggest future research that maybe come out of this research.

2. METHODOLOGY

This research starts from gathering data from books and studies published in mostly Korean language and in English language. The evaluation models are applied on the basic drawings and the building exteriors, materials found in Korean resources, and the analysis method is referenced material in English.

This methodology involves analyzing building evaluation models that act as a central agent between a Base Analysis Generator, AutoCAD, and Alternative Design Analysis Tool that consists of a solution generator, a simulation generator, and a data analysis generator. The evaluation model was used to identify general design of traditional Korean residence for using the shadows, shading and solar analysis, wind flow, and the thermal performance.

2.1. Basic Scheme Generator

The basic scheme tool, AutoCAD, generates an initial plan, and Ecotect simulates the initial plan for energy simulation analysis. These methodologies are explained as follows;

2.1.1. Generating Initial Plan

The analysis starts from building geometric Ecotect models with AutoCAD, which allows precise detail in size and shape. First, building parameters are described in the AutoCAD 2007, which used to transfer building information as a bitmap file, which feeds the necessary data to Ecotect.

Ecotect software requires initial building data, which includes location criteria, materials properties, and weather data. Both building configuration and building components description form the initial building design.

2.1.2. Simulating the Building Energy Performance

The Ecotect software is used to simulate the building energy performance including the shadows, shading and solar analysis, wind flow and thermal performance. Ecotect was selected for its capability of simulating heat transfer though the building envelope, solar radiation heat gain, natural ventilation, predictive mean radiant temperature, moisture transfer, and comfort parameters. Ecotect also supports the other simulation software as WINAIR4 (CFD), Energyplus, ESP-r, and Radiance / Daysim.

2.2. Filed Study

The filed study in November 2007 defines the existing drawing same as the information from books or internet web site, which gives the ambiguous information of the plans and site circumstances. The filed study implements the evaluation models, which are clear the drawing and the condition of preservation.

2.3. Calibrate and Standardize Simulation Results

To validate the evaluation models, the interaction among the shadows, shading and solar analysis, the wind flow and thermal performance, the research divided into three main analysis parts.

First, the analysis represents shadows, shading and solar analysis. Shadows includes the sunlight shadows and reflection, sun path diagram, visualization with sun shading tables, Shading shows the solar envelope, and the Solar analysis provide the solar radiation, solar access and solar stress. Second, the ventilation analysis provides the wind speed, direction, outside temperature, humidity rainfall and air ventilation on the two dimensions plan. Third, the final would be the thermal performance, which interacted the previous analysis, presents outside temperature, internal temperature, solar heat gain and loose, ventilation gain and loose, building fabric including insulation value, and inter zonal heat load.

2.4. Comparison Energy Simulation Tools

Wide varieties of building energy simulation programs have been developed and enhanced and are in use throughout the building energy community. This section is an overview of a report, which provides up-to-date comparison of the features and capabilities of twenty major building energy simulation programs. The comparison is based on information provided by the program developers in the following categories: general modeling features; zone loads; building envelope and daylighting and solar; infiltration, ventilation and multizone airflow;

renewable energy systems; electrical systems and equipment; HVAC systems.

2.4.1. Introduction

Over the past 50 years, literally hundreds of building energy programs have been developed, enhanced and are in use (Crawley, et al. 2005). The core tools in the building energy field are the whole-building energy simulation programs that provide users with key building performance indicators such as energy use and demand, temperature, humidity, and costs. During that time, a number of comparative surveys of energy programs have been published, ranging from comprehensive surveys of building energy simulation programs to reviews of single topics such as daylighting tools or energy auditing. This section provides a small excerpt from a much longer report which compares the features of twenty major building energy simulation programs: BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS. The developers of these programs provided initial detailed information about their tools. This report by Crawley, Hand, Kummert, and Griffith (2005) includes more information of detailed references for the surveys mentioned above as well as for the 20 tools. The detailed report is available on the web (Crawley, et al. 2005).

2.4.2. Summary

This report does not attempt to deal with whether the tools would support analysis over the lifetime of the project—from design through construction into operation and maintenance. Several program developers also indicated that they plan to make the simulation inputs available to users for download in the near future. There is also the issue of trust—do the tools really perform the capabilities indicated, and which level of effort by the user is involved? How detailed is the model behind a tick in the table? For open source tools, everyone can check the model and adapt it.

2.4.3. Abbreviations in the Tables

X feature or capability available and in common use

P feature or capability partially implemented

O optional feature or capability

R optional feature or capability for research use

E feature or capability requires domain expertise

I feature or capability with difficult to obtain input

Table 1 General Modeling Features	BLAST	Bsim	DOE-2.1E	Ecotect	Ener-Win	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA IES	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Full Geometric Description																		
Walls , roofs, floors	X	X	X	X		X	X	X		X	X			P		X	X	
Windows, skylights, doors, and external shading							X	X		X						X	X	
Multi-sided polygons		X	X	X	P		X	X	X		X	X	X			X		
Import building geometry from CAD Programs		X		X			X	X	X	P		X	X	X		X	X	X
Export building geometry to CAD Programs				X			X		X				X			X	X	
Import/export model to other simulation programs				X			X		X									
Number of surfaces, systems, and equipment unlimited		X		X			X	X	X	X	XX	X	X	X		X	X	X

Table 2-1 Contrasting the Capabilities of Building Energy Performance Simulation Programs (Crawley, et al. 2005)

Table 2 ***Building Envelope, Daylighting and Solar***	BLAST	BSim	DOE-2.1E	Ecotect	Ener-Win	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Solar analysis																		
Beam solar radiation reflection from outside and inside window reveals		X		X			X											X
Solar gain through blinds accounts for different transmittances for sky and ground diffuse solar							X						X			X		X
Creation of optimized shading devices				X														
Shading surface transmittance	X		P	X			X	X					X			X		
Shading device scheduling	X	X	P	X			X	X			X	X	X	P	X	X	X	X
User-specified shading control		X	P	X			X		X		X	X	X			X	X	X
Bi-directional shading devices		P					X		X			X	X			X	X	X
Shading of sky IR by obstructions			X		X		X	X					X			X		X
Advanced fenestration																		
Controllable window blinds		X	X	X			X	X	X		X	X	X		X	X		X
Between-glass shads and blinds			X	X			X	X	X			X	X			X		X
Electronchromic glazing				X			X	X	X			X						E
Thermochromic glazing				X					X			X			I			E
Datasets of window types		P	P	X			P	X	P	X	X	X	X			X	P	X
Movable storm windows				X			X		X			X	X			X		X
Bi-directional shading devices							X		X			X	X			X	X	X
Window blind model				X			X	X	X		X		X					X
User-specified daylighting control		X		X			X		X		X	X	X			X	X	X
Window gas fill as single gas or gas mixture				X			X		X				X			X		X
Daylighting illumination and controls																		
Interior illumination from windows and skylights		X	X	X	X	X	X	X	X		X	X	X			X	X	
Stepped or dimming electric lighting controls		X	X		X	X	X	X	X		X	X	X			X	X	X
Glare simulation and control			X	P			X	X	X				X			X		
Radiosity interior light interreflection calculation							X		X			X	X			X		
Daylight illuminace maps		X		X			X		X				X			X		
Daylighting shelves				X	X		X		X				X			X		
Tubular daylighting devices							X		X				X					

Table 2-2 Contrasting the Capabilities of Building Energy Performance Simulation Programs (Crawley, et al. 2005)

Continue Table 2 ***Building Envelope, Daylighting and Solar***	BLAST	BSim	DOE-2.1E	Ecotect	Ener-Win	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Movable/transparent insulation	X	X	X				X		X		X	X	X		P			X
Zone surface temperatures	X	X	P	X	X		X	X	X			X	X	X	X	X	X	X
Airflow windows				X			X		X			O	X	X	X	X		X
Surface conduction																		
1-dimension	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2 and 3 dimension							X		R1			O						
Ground heat transfer																		
ASHRAE simple method																		X
1 dimension	P	X	P	X	X	X	X	X	X	X	X	X	X	X	X	X	P	O
Variable thermophysical properties				X					I			X		X				
Phase change materials									I			O		R	X			E

Table 2-3 Contrasting the Capabilities of Building Energy Performance Simulation Programs (Crawley, et al. 2005)

Table 3 ***Infiltration, Ventilation, Room Air and Multizone Airflow***	BLAST	BSim	DOE-2.1E	Ecotect	Ener-Win	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Single zone infiltration	X	X	X	X		X	X	X		X	X		X	X	X	X	X	X
Automatic calculation of wind pressure coefficients		X					X						X		X	X		
Natural ventilation (pressure, buoyancy driven)		X					X	X	X				X	X	X	X		O
Multizone airflow (via pressure network model)		X					X		X				X		X	X		O

Table 2-4 Contrasting the Capabilities of Building Energy Performance Simulation Programs (Crawley, et al. 2005)

Table 4 Climate Data Availability	BLAST	BSim	DOE-2.1E	Ecotect	Ener-Win	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA IES	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Weather data provided																		
With the program	X	X		X	X	X	X	X	X	X		X	X	P		X	X	X
Separately downloadable		X		X	X		X	X	X	X		X	X			X	X	X
Generate hourly data from monthly averages				X	X								X				X	X
Estimate diffuse radiation from global radiation			X		X		X						X			X		X
Weather data processing and editing	X		X	X	X	X	X	X	X					X		X		X

Table 2-5 Contrasting the Capabilities of Building Energy (Crawley, et al. 2005)

Table 5 Results Reporting	BLAST	BSim	DOE-2.1E	Ecotect	Ener-Win	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA IES	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Standard reports	X		X	X	X	X	X	X	X	X		X	X		X	X	X	X
User-defined reports	X	X		X		X	X	X	X	X		X	X	X	X		P	X
User-selectable report format																		
Comma-separated value				X	X	X	X	X	X				X		X		X	
Text		X		X			X	X	X	X	X	X	X	X	X		X	X
Word										X		X	X			X	X	
Tab-separated value		P		X			X	X	X				X		X	X	X	X
HTML		X		X			X	X	P				X				P	
Graph				X		X		X	X	X	X	X	X	X		X	P	X
Statistics									X				X					X
Load, system, and plant variables reportable at time step with daily, monthly, and animal aggregation	X	X	X		X	X	X	X	X	X	X	X	X	X		X		X

Table 2-6 Contrasting the Capabilities of Building Energy Performance Simulation Programs (Crawley, et al. 2005)

2.5. Selective Energy Software

2.5.1. Ecotect

The selective software for the environmental analysis is Ecotect. This list below provides the Ecotect particular reasons (Marsh and Raines 2007);

- ✓ Highly visual and interactive building design and analysis tool, covering the widest range of analysis features, including; solar, thermal, energy, lighting, acoustics, regulations, resource use and cost aspects.
- ✓ Fully interactive OpenGL model and integrated analysis visualization.
- ✓ Interactively view shadows, sun penetration, reflections and more.
- ✓ Analyses the effects of overshadowing using; sun-path diagrams; shadow profiles for any date/time range; shadow highlighting, sorting and animation.
- ✓ Solar exposure calculations for optimizing passive solar design techniques, photovoltaic collection and solar access rights.
- ✓ Natural and artificial light level calculations together with daylight factor and vertical sky component analysis.
- ✓ Hourly internal temperatures as well as the graphical analysis of thermal mass effects, fabric, ventilation and solar gains.
- ✓ Thermal and spatial comfort prediction throughout the year.
- ✓ Part-L compliance testing featuring full Elemental, Target U-Value, Whole Building and Carbon Emission methods.
- ✓ Prevailing wind data graphically displayed as part of a model.
- ✓ Export to a range of other focused analysis tools such as the RADIANCE Lighting Simulation Software for incredibly realistic Radiosity-based lighting simulation as well as EnergyPlus, ESP-r and HTB2 for detailed thermal simulation and analysis.

Ecotect (Focus features for this paper);

- ✓ Modeling & visualization
- ✓ Shadows, shading and solar analysis
- ✓ Wind flow and ventilation
- ✓ Thermal performance-Hourly internal temperatures, heat gain and loose,

Thermal and spatial comfort prediction throughout the year.

Experimental Focus Date:

- ✓ January 13: The Coldest Date
- ✓ May 6: Summer Start
- ✓ June 21: The Summer Solstice/ Sun at its highest noon altitude and the Longest Light Date
- ✓ July 23: The Hottest Date
- ✓ August 23: Summer End
- ✓ December 23: The Winter Solstice/ Sun at its lowest noon altitude and the Shortest light Date (Korea National Heritage Online 2000)

2.5.1.1. Modeling

After making the floor plan in the AutoCAD 2007, the converted bitmap file can be loaded in the analysis graph, and the background Bitmap dialog controls in Ecotect the display of a scaled Bitmap that can be used to trace over plans in the model.

Then, the building model is made in the Ecotect. A Ecotect model is simply 3d model, a way of encoding a set of information so that it can be interpreted by a computer program or analyzed for us in a mathematical algorithm (Andrew 2008). All building rooms and elements must belong to zone, which is to define the floors, walls, ceiling or windows within each zone (Figure 2-1).

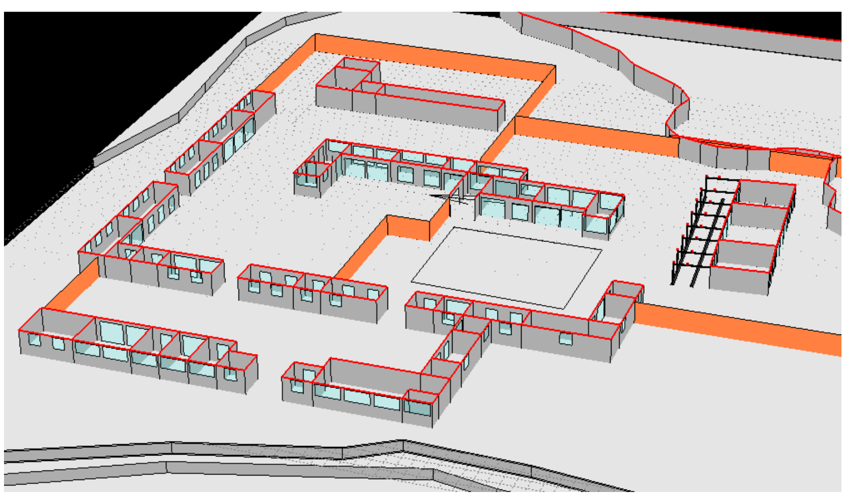


Figure 2-1 Three Dimensional Model of *Yeongyeongdang* in Ecotect

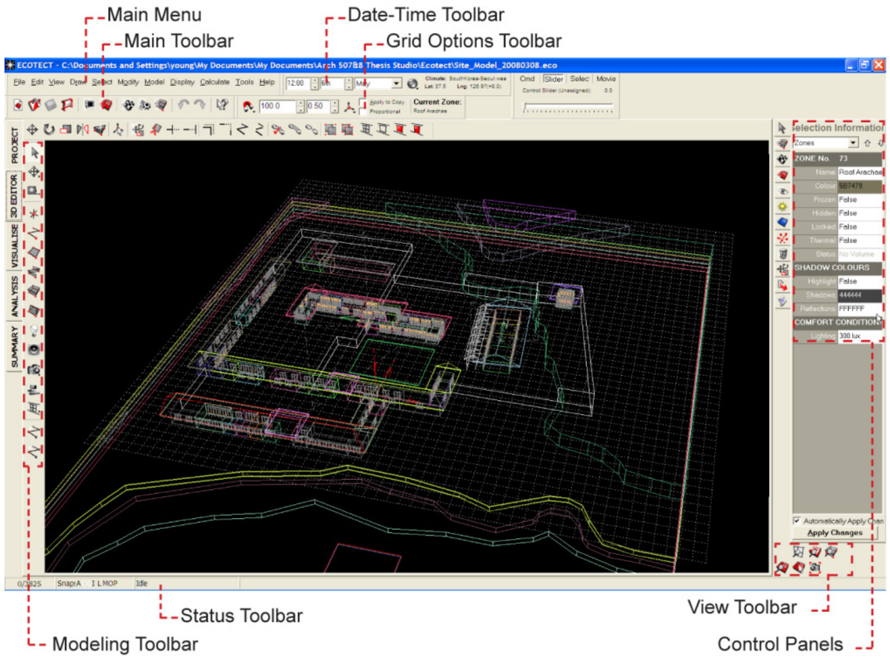


Figure 2-2 Ecotect User Interface

Ecotect comprises of the Main menu used for file management with other editable tool bar like modeling, status, date-time, grid options, and view toolbar with a couple more features (Figure 2-2). The control panels also are very helpful to manage materials, zone, display settings, visualization, shadow, analysis grid and export manger. The main toolbar the modeling toolbar are usually used to make model.

For Modeling Fundamentals, the following Ecotect tutorials website is available to learn making modeling; http://www.squ1.com/archive/ecotect/tutorials/tutorials.htm.

2.5.1.2. Material Assignments

It is always a good procedure to assign the materials first before we start Ecotect modeling; otherwise one ends up in selecting each object in the model and then assign its particular material, which is a tedious process.

All objects in the Ecotect model can be assigned two different materials, referred to as their 'primary' and 'alternate' materials. When an object is initially created its default alternate material is the same as the primary material. The effect of selecting a different alternate material depends on the element type of the object. For objects such as walls, roofs, floors, and ceilings, the alternate material is used whenever the object overlaps another object belonging to the external surface of another zone. For windows, doors, panels, voids, appliances, lights and speakers the alternate material is used only when the object is activated.

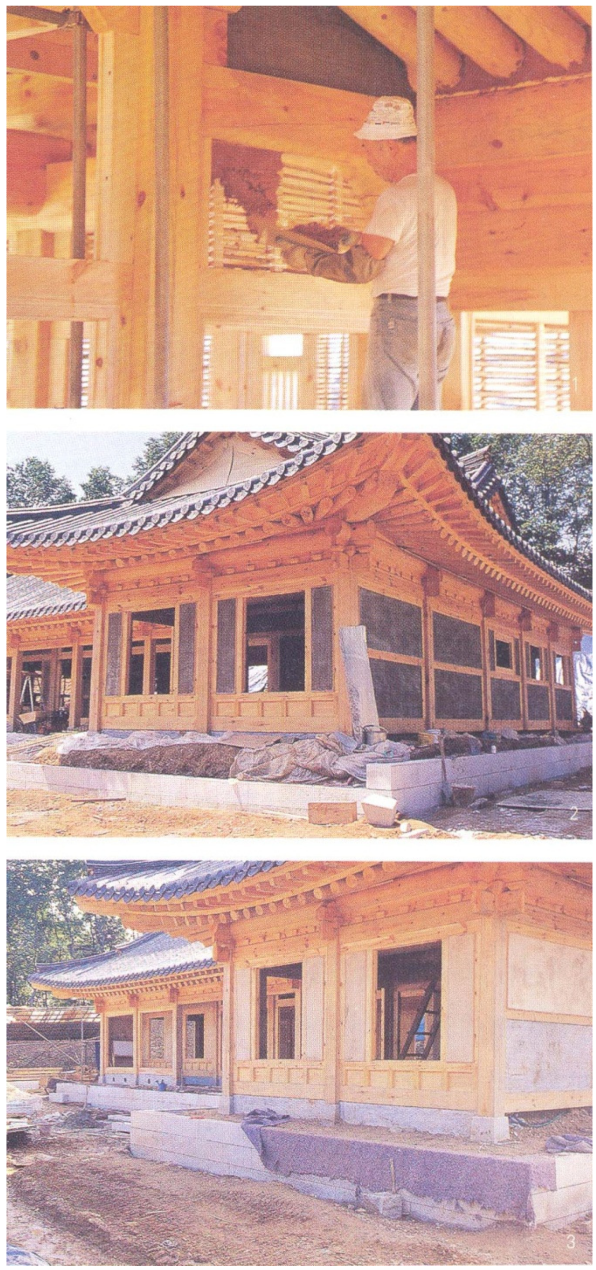


Figure 2-3 The traditional residence wall process. (D. K. Kim 2004)

The walls of the traditional Korean residence were made of the wood or soil with rice straw that provides the insulation (Figure 2-3). In this research, the wall U-values, which is measured as the rate of heat flow in watts through per square meter of a structure when there is a temperature difference across the structure of 1 degree, assumes 1.77 W/m^2K that is same as 206mm brick + veneer value. The specific admittance represents its ability to exchange heat with the environment when subjected to cyclic variations in temperature. It is dependent upon a number of material properties, most notably density, thermal capacity and the thermal conductivity of the first 100mm (Ecotect 2007). The specific admittance measures 2.20W/m^2K. The thermal lag and Decrement are used for the thermal mass. The thicker and more resistive the material, the longer it will take for heat waves to pass through. The reduction in cyclical temperature on the inside surface compared to the outside surface is known and the decrement. A material with a decrement value of 0.5 that experiences a 20-degree diurnal variation in external surface temperature would experience only a 10-degree variation in internal surface temperature (Ecotect 2007). In the solar absorption, Ecotect assumes that if a material is assigned a transparency of 0.5, then 50% of the incident radiation is assumed to pass through. This research assumes that the solar absorption is 0.5 (Table 2-7).

The roof thermal properties assumes the 19mm Asphalt + 150mm Aerated Concrete Slab, but the roof of the traditional residence must be higher value of the thermal performance because the roof is very thicker such as the roof top garden (Figure 2-4) (Table 2-9).

The windows U-value assumes higher than the others glass due to the traditional windows are made by oilpaper. The windows were made two layers in rooms of *Yeongyeongdang*, and the oilpaper can keep the heat energy more than the glass (Figure 2-5) (Table 2-10).

The floor ondol system utilizes the heat of smoke from an enclosed furnace in rooms called pang. The floors of the heated rooms were constructed of a layer of thin ondol stone slabs laid upon the thicker stoner risers, covered a thick layer of clay and put a top layer of vanished paper The stone radiates heat to the floor, warming the room from the furnace that is usually located in the kitchen. The heat from furnace also is used to cook for dish. Radiant heat and convection were also applied. In the past, a wood fire was used as the heat source (Figure 2-6) (Figure 2-7) (Figure 2-8). The value of the floor cannot be measured in Ecotect, and this research assumes same as the material, 150mm Concrete Slab on Ground + 4 Exp. Edges but the value of the ondol floor must be higher than its value (Table 2-10). The traditional Korean residence combines with the ondol floor and the wooden floor without the heating. The combination of two different floors makes to be activated separately in the winter and summer, and light and night.

Figure 2-4 Roof construction, it provide the roof thickness about 30 centimeter ((D. K. Kim 2004)

Figure 2-5 Yeongyeongdang Windows, the inside windows are sliding type and outside windows are swing door.

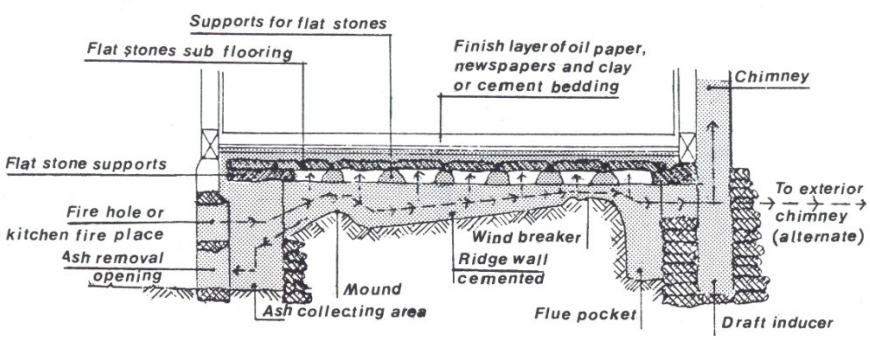


Figure 2-6 Schematic section of floor heating system, called *ondol* (S. Y. Park 1992)

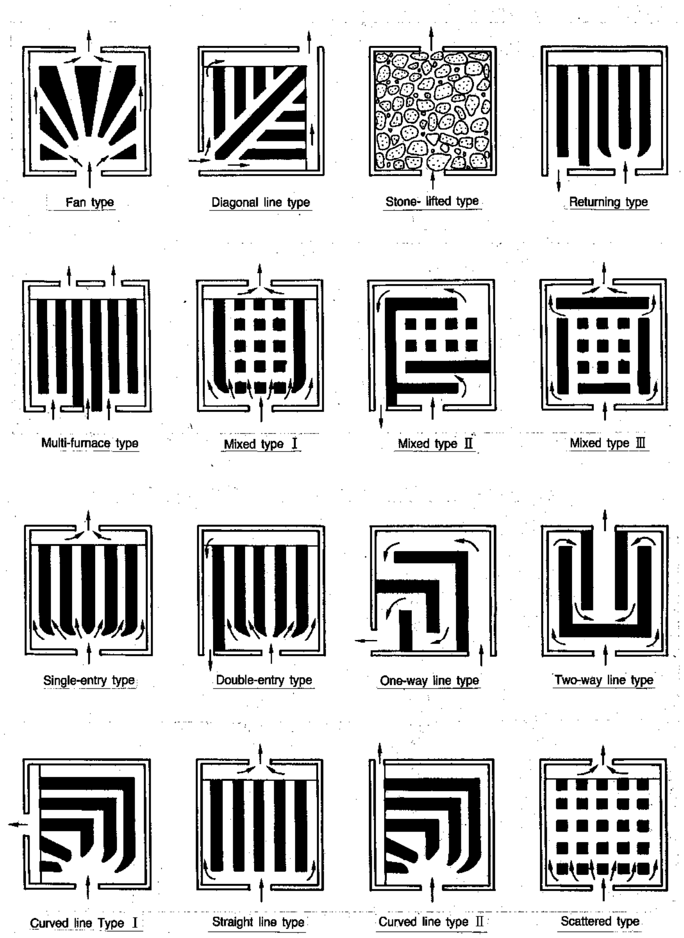


Figure 2-7 Types of *koroes* (ridge stone) (Yeo and Jung n.d.).

Figure 2-8 *Ondol* furnace places in unjoru (left) and chusagotaek (right).

Single Leaf Construction	U	Y	Lag	Decr	Abs
1mm Framed Galvanised Iron	5.66	5.20	0.00	1.00	0.30
12mm Framed Fibroboard or Gyprockk	5.16	4.96	0.30	1.00	0.40
20mm Framed Weatherboard	3.00	3.00	0.40	1.00	0.45
75mm Concrete Panel Precast	4.28	4.90	1.90	0.91	0.62
75mm Panel + 13mm Dense Plaster	3.88	4.78	2.00	0.89	0.62
75mm Panel + 10mm Gyprockk	3.65	4.72	2.00	0.88	0.62
110mm Brick Single	3.30	4.20	3.00	0.87	0.70
110mm Brick + 13mm Dense Plaster	2.70	4.10	3.00	0.84	0.70
110mm Brick + 10mm Gyprockk	2.60	4.00	3.00	0.83	0.70
150mm Aerated Concrete Block	1.28	2.28	7.10	0.54	0.60
150mm Aerated + 13mm Dense Plaster	1.00	2.00	7.00	0.51	0.60
150mm Aerated + 10mm Gyprockk	0.95	2.00	7.00	0.50	0.60
150mm Concrete Dense Cast In-situ	3.48	5.20	4.00	0.70	0.60
150mm In-situ + 13mm Dense Plaster	3.00	5.05	4.10	0.68	0.60
150mm In-situ + 10mm Gyprockk	2.96	5.00	4.10	0.67	0.60
200mm Concrete Blockwork	2.10	2.60	6.50	0.36	0.60
200mm Blockwork + 13mm Dense Plaster	1.80	2.48	6.80	0.35	0.60
200mm Blockwork + 10mm Gyprockk	1.70	2.47	6.80	0.35	0.60
230mm Brick Header	2.30	4.70	6.10	0.54	0.70
220mm Brick + 13mm Dense Plaster	2.10	4.50	6.50	0.49	0.70
230mm Brick + 10mm Gyprockk	1.90	4.50	6.50	0.47	0.70
250mm Concrete Dense Cast In-situ	2.84	5.20	5.80	0.52	0.65
250mm In-situ + 13mm Dense Plaster	2.66	5.00	6.00	0.50	0.65
250mm In-situ + 10mm Gyprockk	2.50	4.92	6.00	0.49	0.65
Tested Wall Value	1.77	2.20	4.00	0.77	0.70

Table 2-7 Wall thermal properties: this list contains U-values (U: W/m²K), specific admittance (Y: W/m²K), thermal lag (Lag: hrs), decrement (Decr: 0-1) and solar absorption (Abs: 0-1) (Ecotect 2007).

Cavity Construction	U	Y	Lag	Decr	Abs
2 x 1mm Galv. Iron + 100mm Gap	2.86	2.34	0.3	1	0.3
2 x 1mm Galv. Iron + Gap + 50mm Insulation	0.63	0.9	0.7	0.99	0.3
2 x 12mm Fibroboard or Gyprock + 100mm Gap	2.2	2.2	0.3	1	0.4
2 x 12mm Gyprock + Gap + 50mm Insulation	0.6	0.9	0.7	0.98	0.4
2 x 12mm Gyprock + Gap + Foil + 50mm Insul.	0.53	0.9	0.7	0.89	0.4
12mm Weatherbd + 100mm Gap + Gyprockk	2.08	2.48	0.8	0.98	0.4
12mm Weatherbd + Gap + Foil + Gyprockk	1.7	2.05	0.8	0.96	0.4
12mm Weatherbd + Gap + 50mm Insul. + Gyprockk	0.52	0.9	1.2	0.94	0.4
260mm Brick Veneer	1.77	2.2	3.5	0.77	0.7
260mm BkVeneer + Foil on Gyprockk	1.36	1.7	3.7	0.75	0.7
260mm BkVeneer + Foil Between Studs	0.66	1.1	4.1	0.71	0.7
270mm BkVeneer + 50mm Insulation	0.51	0.9	4.3	0.69	0.7
270mm BkVeneer + Foil + 50mm Insulation	0.34	0.9	4.3	0.69	0.7
270mm BkVeneer + Foil + 100mm Insulation	0.29	0.41	4.3	0.68	0.7
270mm Cavity Brick	1.88	4.4	7.7	0.44	0.7

270mm Cavity + 13mm Dense Plaster	1.72	4.22	7.8	0.41	0.7
270mm Cavity + 10mm Gyprockk	1.58	4	7.8	0.4	0.7
270mm Cavity + 50mm Insul. + 10mm Gyprockk	0.47	4.7	9.2	0.32	0.7

Table 2-8 Wall thermal properties: this list contains U-values (U: W/m²K), specific admittance (Y: W/m²K), thermal lag (Lag: hrs), decrement (Decr: 0-1) and solar absorption (Abs: 0-1) (Ecotect 2007).

Roof Construction	U	Y	Lag	Decr	Abs
1mm Angled Metal Decking	7.14	7.1	0	1	0.5
1mm Metal + Attic + Gyprockk	2.54	2.6	0.3	1	0.5
1mm Metal + Attic + 50mm Insulation + Gyprockk	0.55	1	0.7	0.95	0.5
1mm Metal + Attic + 100mm Insulation + Gyprockk	0.44	0.88	0.9	0.9	0.5
10mm Angled Clay Tiles	3.1	3.1	0.2	1	0.6
10mm Tiles + Attic + Gyprockk	2.6	2.64	0.5	1	0.6
10mm Tiles + Foil + Attic + Gyprockk	1.82	2	0.5	0.95	0.6
10mm Tiles + Attic + 50mm Insulation + Gyprockk	0.61	1	1.5	0.91	0.6
10mm Tiles + Attic + 100mm Insulation + Gyprockk	0.35	0.88	1.8	0.88	0.6
19mm Asphalt + 150mm Concrete Slab	2.8	5.9	8	0.4	0.9
25mm Pebbles + Asphalt + 150mm Slab	2.5	4.35	7	0.34	0.7
19mm Asphalt + 150mm Aerated Concrete Slab	0.88	2.3	7	0.58	0.9
25mm Pebbles + Asphalt + 150mm Aerated Slab	0.66	4.21	6.2	0.31	0.7
Tested Roof	0.896	2.3	7	0.58	0.9

Table 2-9 Roof thermal properties: this list contains U-values (U: W/m²K), specific admittance (Y: W/m²K), thermal lag (Lag: hrs), decrement (Decr: 0-1) and solar absorption (Abs: 0-1) (Ecotect 2007).

Floor Construction	U	Y	Lag	Decr	Abs
Suspended Timber Floor	2.16	2	0.7	0.99	--
Suspended Timber Floor + Carpet Thin	1.43	1.5	0.8	0.94	--
Suspended Timber Floor + Carpet Thick	1.24	1.3	0.8	0.93	--
100mm Concrete Slab Suspended	2.56	4.2	4	0.7	--
100mm Concrete Slab on Ground + 4 Exp. Edges	1.1	6	4	0.32	--
100mm Concrete Slab on Ground + 2 Exp. Edges	1.07	6	4	0.32	--
100mm Concrete Slab on Ground + Carpet Thin	0.92	6	4.2	0.31	--
100mm Concrete Slab on Ground + Carpet Thick	0.9	6	4.2	0.31	--
150mm CSOG + 4 Exp. Edges	0.88	6	4.6	0.3	--
150mm CSOG + 2 Exp. Edges	0.45	6	4.6	0.3	--
150mm CSOG + Carpet Thin	0.72	6	4.6	0.28	--
150mm CSOG + Carpet Thick	0.71	6	4.6	0.28	--
150mm CSOG + 25mm Insul. + 4 Exp. Edges	0.21	6	4.6	0.18	--
150mm CSOG + 25mm Insul. + 2 Exp. Edges	0.2	6	4.6	0.18	--
Tested Floor	0.88	6	4.6	0.3	

Table 2-10 Floor thermal properties: this list contains U-values (U: W/m²K), specific admittance (Y: W/m²K), thermal lag (Lag: hrs), decrement (Decr: 0-1) and solar absorption (Abs: 0-1) (Ecotect 2007).

Window Glazing	U	Y	SC	AG Lt	AG Hvy	RI	Trans
3mm Clear Float	5.98	6	1	0.66	0.51	1.74	0.94
6mm Clear Float + Wood Frame	5	5	0.92	0.64	0.47	1.74	0.86
6mm Clear Float + Tinted Film + WF	5	5	0.71	0.53	0.41	1.74	0.6
6mm Clear Float + Reflective Film + WF	5	5	0.51	0.29	0.23	1.74	0.6
6mm Clear Float + Tinted Reflective Film + WF	5	5	0.49	0.26	0.23	1.74	0.41
6mm Clear Float + Metal Frame	6	6	0.95	0.64	0.47	1.74	0.88
6mm Clear Float + Tinted Film + MF	6	6	0.74	0.53	0.41	1.74	0.62
6mm Clear Float + Reflective Film + MF	6	6	0.55	0.29	0.23	1.74	0.61
6mm Clear Float + Tinted Reflective Film + MF	6	6	0.52	0.26	0.23	1.74	0.42
6-10mm Body Tinted Glass + WF	5	5	0.45	0.47	0.38	1.74	0.58
6-10mm Reflecting Glass + WF	5	5	0.43	0.33	0.27	1.74	0.55
6-10mm Heat Absorbing Glass + WF	5	5	0.65	0.64	0.47	1.74	0.78
6-10mm Body Tinted Glass + MF	6	6	0.48	0.47	0.38	1.74	0.59
6-10mm Reflecting Glass + MF	6	6	0.46	0.33	0.27	1.74	0.56
6-10mm Heat Absorbing Glass + WF	6	6	0.67	0.64	0.47	1.74	0.79
6mm Acrylic Clear Sheet	4.5	5	0.98	0.64	0.47	1	0.84
1.5mm PVC Acrylic Clear Sheet	6.2	6	0.84	0.66	0.51	1	0.77
0.75mm Polyester Corrugated Sheet Frosted	6	6	0.63	0.45	0.39	1	0.52
4.6mm Clear Polycarbonate Sheet	4.5	5	0.92	0.65	0.49	1	0.81
6mm Clear Float Angled Roof Glazing	6.6	6.6	0.92	0.64	0.47	1.74	0.94
6mm Opal Acrylic Skylight	3.8	3.8	0.67	0.62	0.44	1	0.69
Tasted Glazing	2.8	2.8	0.45	0.47	0.38	1.76	0.85

Table 2-11 Window Glazing thermal properties: this list contains U-values (U: W/m²K), specific admittance (Y: W/m²K), thermal lag (Lag: hrs), decrement (Decr: 0-1) and solar absorption (Abs: 0-1) (Ecotect 2007).

2.5.1.3. Shadows, Shading and Solar Analysis

Shadows, Shading and Solar Analysis offer the greatest opportunity for incorporating the traditional Korean residential features. This analysis could observe the use of natural energy flows as the primary means of harvesting solar energy. It also provides dates on space heating, cooling load avoidance, natural ventilation and natural light. Ecotect provides three big functions in this research; Shadows & Reflections Analysis, Shading Design and Incident Solar Radiation.

2.5.1.3.1. Shadow & Reflections Analysis

First, Shadows & Reflections Analysis is an important aspect of the analysis. Through the Ecotect analysis, the display of Daily Sun Path, Annual Sun Path tool, and

Sun Path Diagrams provides to observe quickly the layout and structure related the environmental factors as soon as to accomplish an Ecotect models. The sun position in the sky varies continually during the day and changes seasonally in the year. It is also very location dependant, so it is critical to know the latitude and longitude of the site (squ1.org 2007). Sun path diagrams are a convenient way of representing annual changes in the path of the sun through the sky within a single two dimensions diagram. Ecotect provides various sun path diagrams: Spherical Projection, Equidistant Projection, Stereographic Projection, BRE Sun-Pat Indicator, Orthographic Projection and Waldram Diagram (Figure 2-9). Spherical Projection, Equidistant Projection, Stereographic Projection, BRE Sun-Path Indicator are all polar projections, displaying the sun-path and overshadowing information on a circular diagram with concentric circles representing altitude angles. The different projections vary in how they calculate the radius of points on the circle from their altitude. Orthographic Projection and Waldram Diagram are used in primarily in the US and display the same information as a 2D graph using essentially cylindrical projection with azimuth as the X axis and altitude in the Y axis (Ecotect 2007).

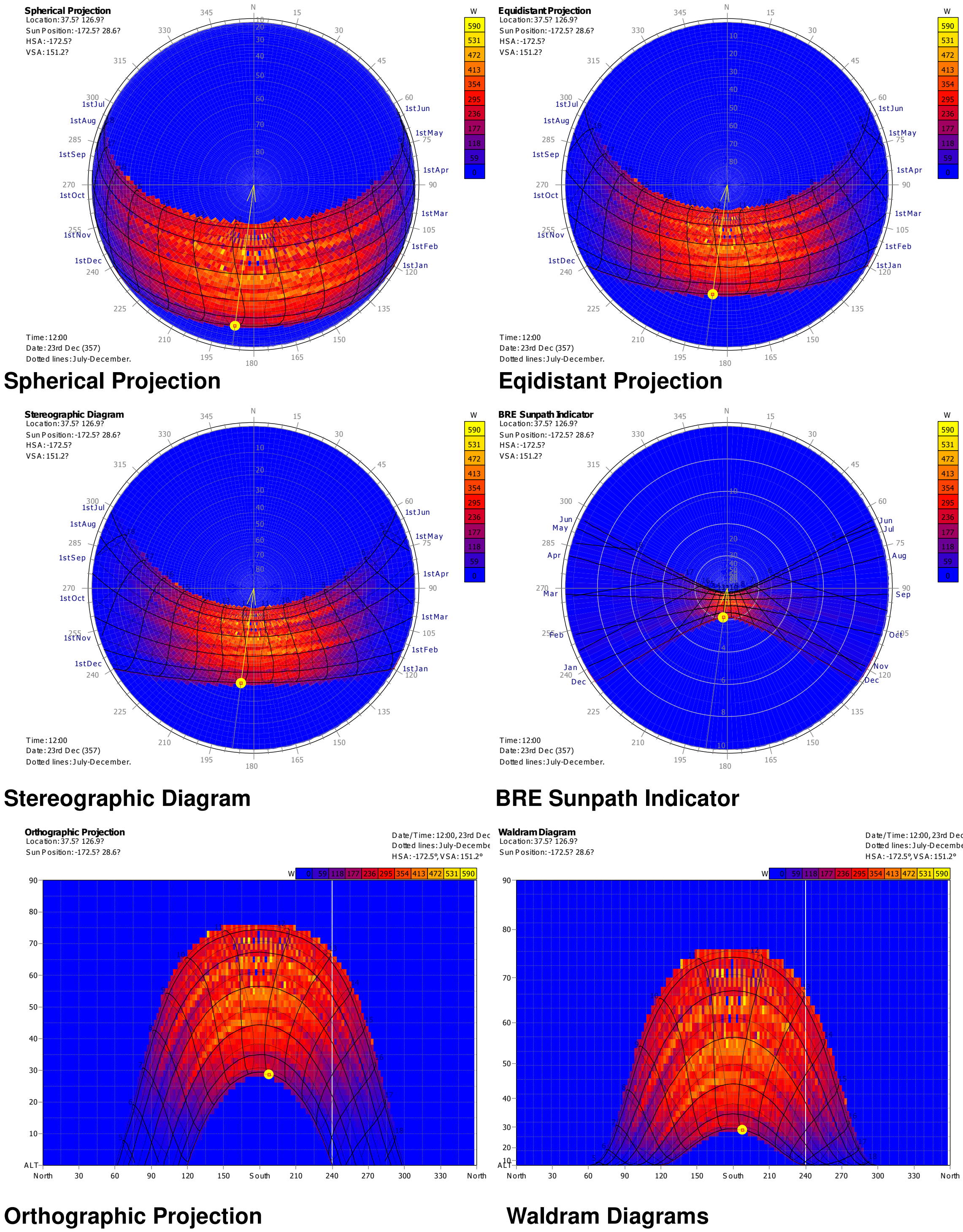


Figure 2-9 Various sun path diagram from Ecotect, April 1st 12:00 Sun Position, Location 37.5°, 126.9°, South Korea.

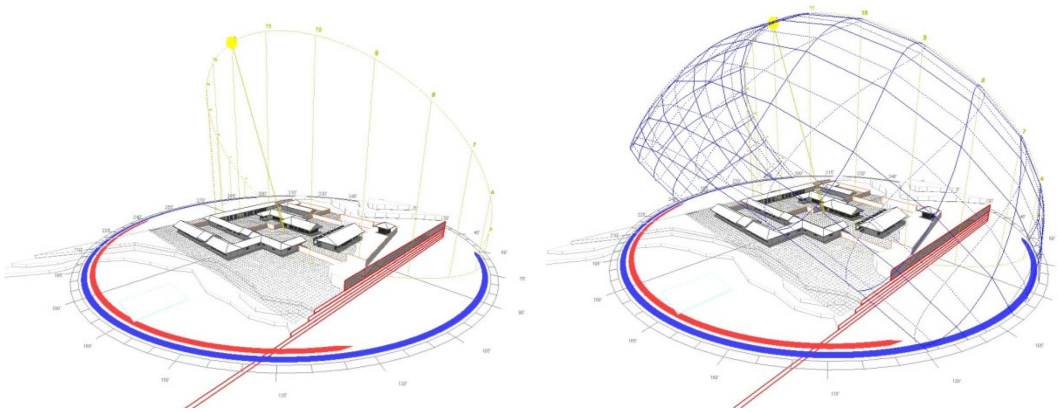


Figure 2-10 Yeongyeongdang daily sunpath diagram (left) and the monthly sunpath diagram (right), and display the position and path of the sun relative to the model at any date, time and location, and monthly paths in the entire year.

2.5.1.3.2. Shading Design Analysis

Second, Shading Design Analysis that generates the Optimized Shading Device to shade the currently selected window object, the Project Solar Shading Potential to visualize clearly, which part of an obstruction or shading device is the most important. Sun path diagram also provide outside shading design. The shading design wizard in Ecotect provides *Yeongyeongdang* through the process of shading requirements (Ecotect 2007). One of very useful function of this Wizard is to generate automatically the exact shading shape perfectly to shade a window for and specified period.

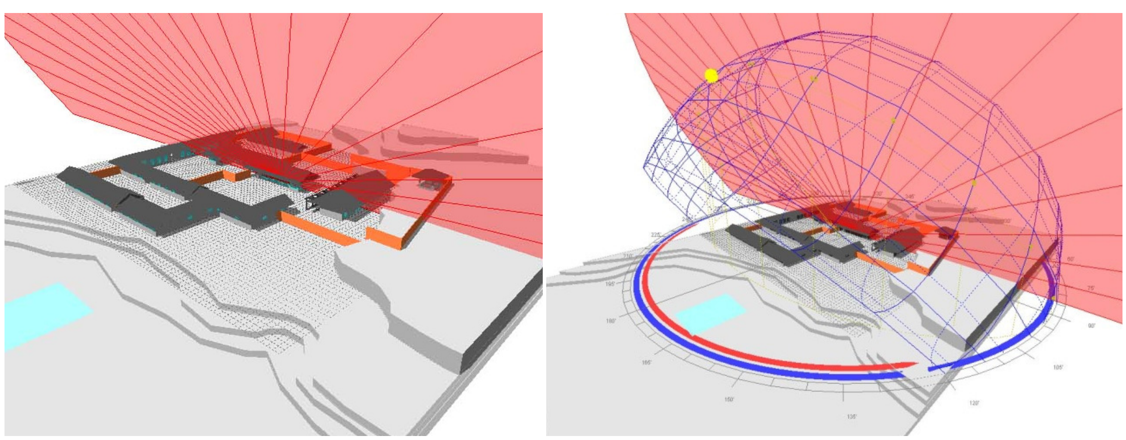


Figure 2-11 Shading design shape (left) and shading design shape with sun path diagram, *Yeongyeongdang* on May 6th.

2.5.1.3.3. Solar Analysis

Lastly, Incident Solar Radiation refers to the wide spectrum radiant energy from the Sun, which strikes an object or surface. Excessive solar exposure is one of the main causes of summer overheating in buildings. However, it is also one of the most effective sources of natural energy available in winter. Thus, Shading systems and the analysis of solar gains are linked with the solar access and incident solar radiation (squ1.com 2007).

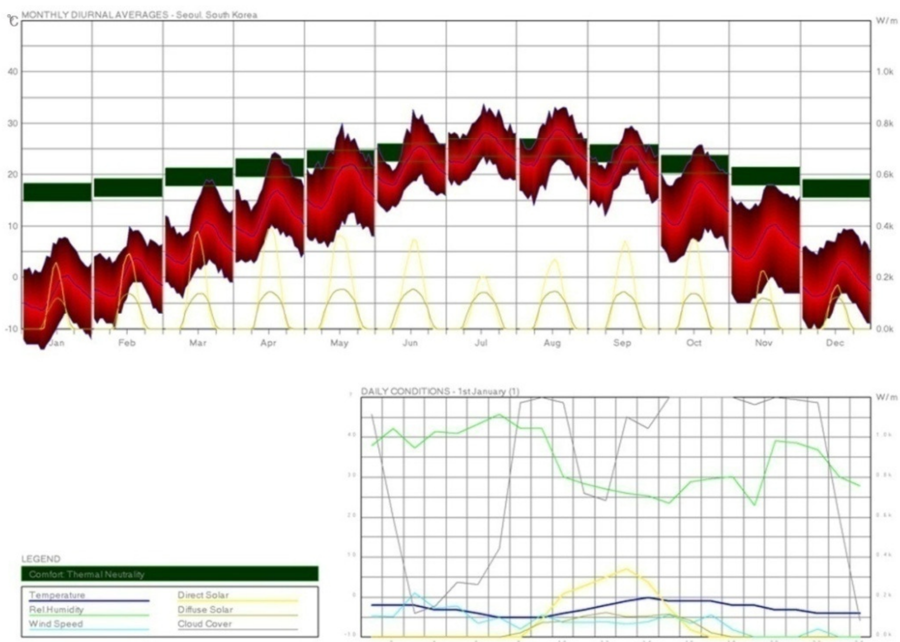


Figure 2-12 Monthly diurnal averages in Seoul, South Korea, it shows the outside temperature and solar amount, wind speed and humidity

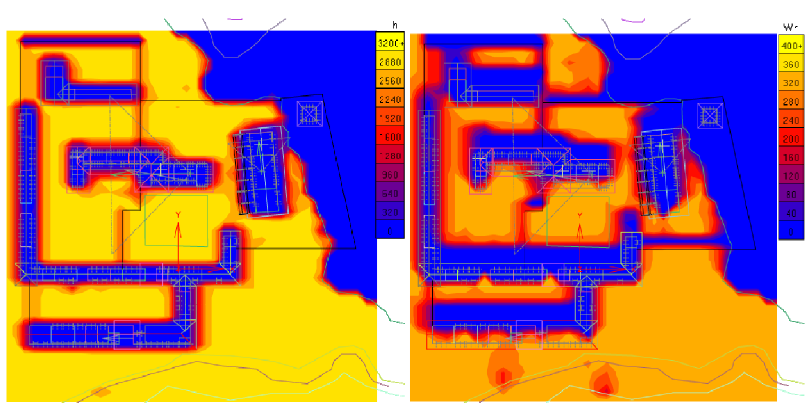


Figure 2-13 Yeongyeongdang Total Direct Radiation, summer solstice, June 21st (left) and winter solstice, Dec 23(right)

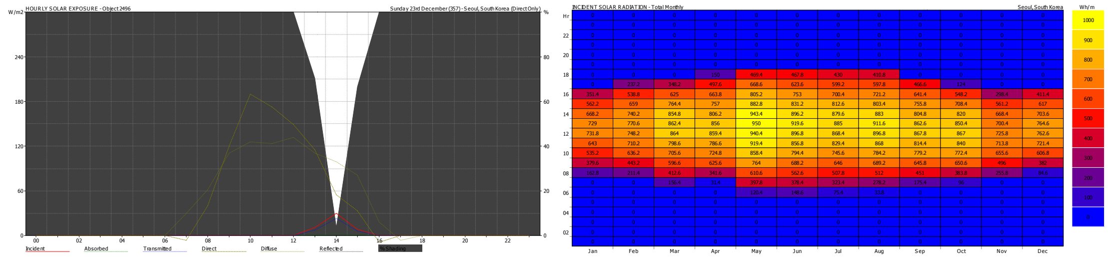


Figure 2-14 Solar access, hourly solar gains for single day in an anbang window (left), Monthly average hourly gains of anbang over whole year (right)

2.5.1.4. Wind Flow

The prevailing winds in Ecotect can overlay wind speed and direction directly on top of the models, making it especially relevant to natural ventilation and wind shelter strategies. This data can also show temperature, humidity and rainfall, over any date and time range. Otherwise, Ecotect does not provide Computational Fluid Dynamics (CFD) itself. Theoretically, its model can be exported directly to CFD tools such as NIST-FDS, Fluent and WinAir4, and then after the calculations in those tools, it is possible to import results back into Ecotect for display within the feature of the original model (Figure 2-16). I had tried many times, but it has never worked and the results provide wrong data. In the Ecotect forum on the web, there has not been anyone with the success to get the CFD result like the image hosted on the Ecotect web site (Figure 2-16).

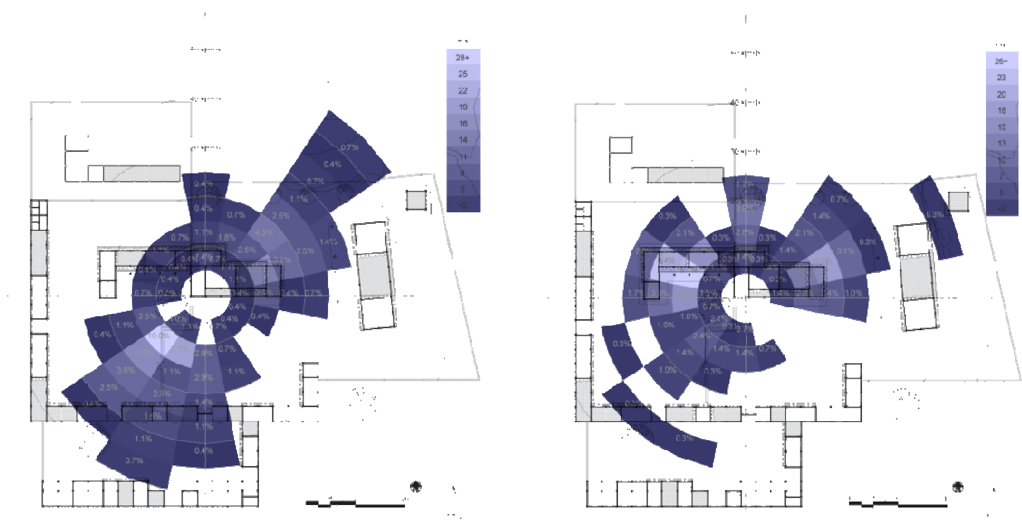


Figure 2-15 Prevailing Winds, Wind Frequency (Hrs), *Yeongyeongdang*, time: 10:00 ~14:00, summer: 1st June ~ 31st August (left), winter 1st December ~ 28th February (right)

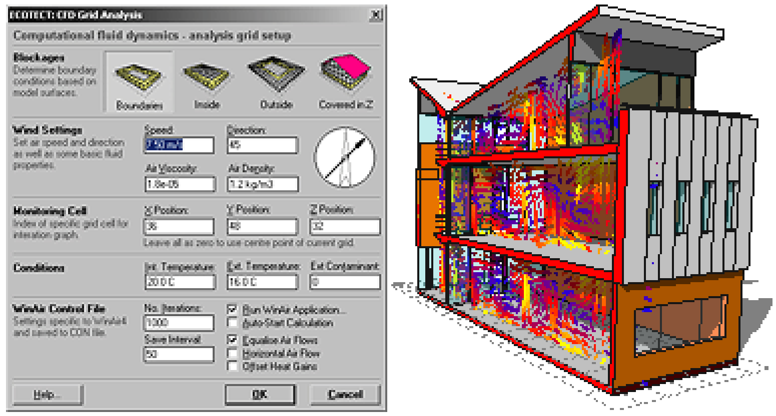


Figure 2-16 In the Ecotect web site, they introduce the model file to export to Computational Fluid Dynamics (CFD) and import from the tools (squ1.com 2007)

2.5.1.5. Thermal Performance

Thermal performance is related to materials, windows and doors sizes, height, length, temperature, orientation, and many other factors. The Chartered Institute of Building Services Engineers (CIBSE) Admittance Method determines internal temperatures and heat loads in Ecotect. This thermal algorithm is very flexible and has no restrictions on building geometry or the number of thermal zones that can be simultaneously analyzed. The internal temperature of any building will always tend towards the local mean outdoor temperature. Any fluctuations in outside temperature or solar load will cause the internal air temperature to fluctuate in a similar way, though delayed and dampened somewhat by thermal capacitance and resistance within the building fabric. When the total of all heat losses become equal to the total of all gains, then internal temperatures stabilize (Ecotect 2007).

In the Admittance Method, the temperature and load calculations are two separate processes. First, the magnitude of potential heat gains and losses acting on the building are calculated for each hour of each day, from which average daily load factors can be determined. Variations in the instantaneous load factor against each daily average can then be used to determine that the relative thermal stress each zone is subject to each hour of the day. Second, a next calculation is performed to determine the absolute heating and cooling loads. Given inside and outside temperatures for each zone, fabric, ventilation and infiltration loads can be accurately determined along with solar and internal loads. Whilst in summary it is a simplified method, the Admittance Method encapsulates the effects of conductive heat flow through building fabric, infiltration and ventilation through openings, direct solar gains through transparent materials, indirect solar gains through opaque elements, internal heat gains from equipment, lights and people and the effects of inter-zonal heat flow (Ecotect 2007). Thermal performance of Ecotect evaluates the thermal comfort of human beings that is governed by many physiological mechanisms of the body and varies from person to person. In any particular thermal environment, it is difficult to get more than 50 per cent of the people affected to agree that the conditions are comfortable (McMullan and Seeley 2007). The principal factors affecting thermal comfort can be conveniently considered in the following sections: Personal variables included activity, age, clothing, and gender; and Physical Variables included air temperature, air movement, surface temperatures, and humidity.

2.5.2. Predicted Mean Vote

2.5.2.1. Introduction

This application is an implementation of ISO 7730-1933(E) for calculating the Predicted Mean Vote (PMV) and PPD (Predicted Percentage Dissatisfied) indices and specifies acceptable conditions for thermal comfort. PMV is based on heat balance equations for the human body and is an index that predicts the mean vote of a large group of people on a 7-point thermal sensation scale. The PMV predicts the mean value of the votes of a large group of people on the ISO thermal sensation scale (+3=hot; +2=warm; +1=slightly warm; 0=neutral; -1=slightly cool;-2=cool;-3=cold). The PPD predicts the percentage of a large group of people likely to feel ‘too warm’ or ‘too cool’. The indices are exactly as described by Fanger (1970). A draft rating index is provided in the standard as an equation involving air temperature, air velocity and turbulence intensity. It is applicable to mainly sedentary people wearing light clothing with a whole-body thermal sensation close to neutral(Introduction to thermal comfort standards and to the proposed new Version of EN ISO 7730, K C Parsons, Loughborough University, UK).

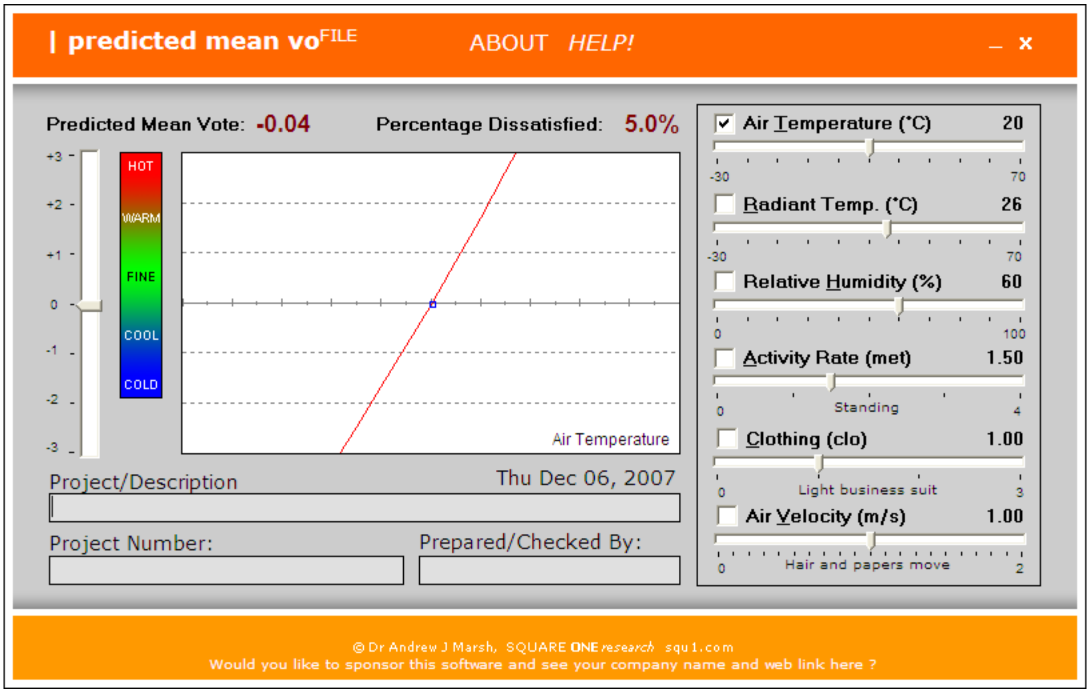


Figure 2-17 Predicted Mean Vote by Ecotect

2.1.1.1. Human Comfort

This application also implements ISO 7730-1993(E) for calculating the Predicted Mean Vote (PMV). PMV is based on heat balance equations for the human body and is an index that predicts the mean vote of a large group of people on a 7-point thermal sensation scale. This scale reads from -3(feeling cold) to +3 (feeling hot). When you click the Human Comfort button, PMV values are overlaid over the chart, allowing for the interactive manipulation of various factors affecting PMV.

2.1.1.2. Thermal Comfort Concepts

The calculation of PMV is based on the parameters; Air Temperature, Relative Humidity, Radiant Temperature, Air Velocity, Activity Rate, and Clothing level.

2.1.1.2.1. Activity Rate

Activity rate combines two factors metabolic rate and external work. Metabolic rate is the rate at which energy is produced by the body, measured in W/m^2 of body surface area. 1 metabolic unit (1met) equals 58 W/㎡ which is the energy produced per unit surface area of a seated person at rest. External work refers to that part of the metabolic rate delivered to the environment with levels of activity over and above the base seated rate.

Energy production in the body takes place continuously through the metabolic processes, which oxidize food into energy. This energy is partly converted into external mechanical work while the rest is released as internal body heat. For most activities, the energy used in working is negligible, increasing to about 20% for heavy manual labor.

	Activity Heat output (male): W	**Heat output (female): W**
Sleeping	70	60
Seated	115	98
Light work	150	128
Medium work	265	225
Heavy work	440	374

Table 2-12 Typical heat outputs of human bodies are the above chart

2.1.1.2.2. Clothing Level

Clothing Level refers to the amount and type of clothing as well as the ratio of exposed/unexposed skin areas. This affects the rate of heat loss by the body. This ranges from nude (0.00) through business suits (1.0 – 1.5) to full Arctic furs (3.0).

The amount of clothing worn has a significant effect on heat flow around the body. This is because it has insulation by reducing both radiant and convective losses/gains. The effect of clothes is so great that they allow us to survive in conditions ranging from -20°C in the snow to more than 40°C in a desert.

The radioactive and convective effects do not vary significantly with the amount or type of fabric worn; this clothing is classified according to its insulation value. The unit normally used for measuring clothing's insulation is the **Clo** unit, but the more technical unit is m^2K/W (1 Clo = 0.155 m^2K/W). The Clo scale is designed so that a naked person has a Clo value of 0.0 and someone wearing a typical business suit has a Clo value of 1.0. An overall Clo value can be calculated for a person's dress by simply taking the Clo value for each individual garment worn and simply adding them together (squ1.org 2007).

2.5.3. Psychometric Chart

The Psychometric chart provides a graphic representation of the state or condition of the air at any particular time. The chart relates temperature along the horizontal scale to moisture content along the vertical scale. These tools are a critical in all forms of bio-climatic design and comfort analysis so it is worthwhile becoming reasonably familiar (Ecotect 2007).

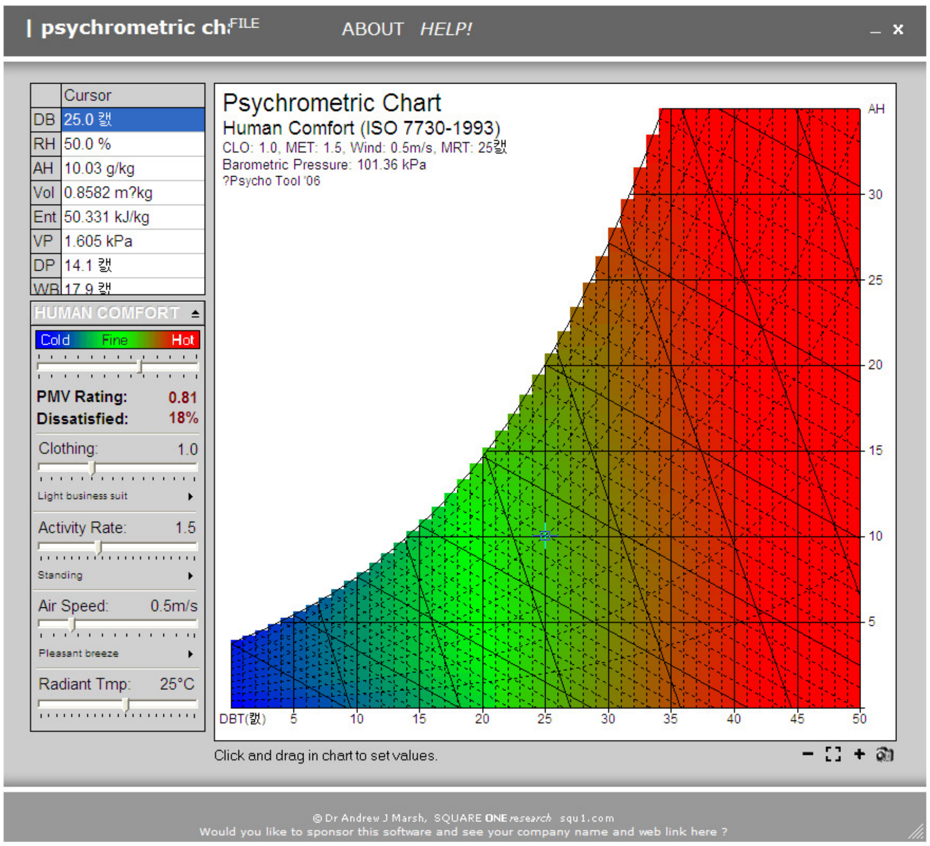


Figure 2-18 Psychometric Chart by Ecotect

The amount of moisture vapor in the air varies quite significantly under different conditions. When the air is hot, it can contain a large amount of moisture vapor, sometimes as much as 5% by volume (University of Connecticut n.d.). When it is cold, its capacity to hold the moisture as a vapor is reduced. When the temperature of warm air begins to fall, the vapor also cools and, if cooling continues, will eventually condense into tiny moisture droplets. In the atmosphere this results in the formation of clouds and eventually rain, whilst it is more commonly manifest as condensation running down the outside of a glass of iced water.

The Psychometric Chart contains the features; Dry-Bulb temperature (DB), Wet-Bulb temperature (WB), Relative Humidity (RH), Vapor Pressure (VP), Specific Volume (VOL), Air Enthalpy (Ent), Humidity ratio of moist, and Dew-point temperature. When condensation is beginning to occur, the air is said to be saturated and cannot hold any more moisture, the point of 100% relative humidity (University of Connecticut n.d.). For a given amount of humidity, the temperature along the X-axis at which this occurs is called the saturation point. The dew point for each temperature in the Psychometric Chart above is therefore represented by the inner curved boundary. This is because the air simply cannot exist at a state above and to the left of this line. If the air is cooled beyond its dew point, excess vapor is lost as condensation.

3. *YEONGYEONGDANG* - TEST MODEL I

3.1. Introduction

Yeongyeongdang condenses the history of the traditional Korean residences with the Korean history over the century. *Yeongyeongdang* also represents the traditional Korean residences, that has developed its own method for achieving the best outcome with given requirements with nature and limited technological advantages. During the *Joseon* dynasty (1392 ~ 1910) of Korea, the basic design and the layout of the Korean residence had been developed in the strong consideration of the historical circumstances and social environment of the country. Especially when *Yeongyeongdang* was built in the 19th century, social status was getting more important factor in the composition of every traditional Korean residence. The Confucian principles underpinning the hierarchical social system had a tremendous influence on the basic design and layout of the traditional Korean residence. The neo-Confucianism, with its emphasis on moral duties, was established as the dominant philosophy where ancestor worshipping became the core practice of people's spiritual life. Several generations of an extended family lived together under the charge of the family patriarch. Social hierarchy was maintained within the extended family, as within the broader community, by Confucian principles. Accordingly, the separation of men from women and of superior from inferior, and the need for an ancestral shrine became fundamental elements in the composition of the traditional Korean residence (Inaji and Virgilio 1998). The factor shows that the Traditional Korean Architecture, *Yeongyeongdang*, was built on a very strict layout and formal composition in order to represent a rigid hierarchical social system required in the 19th century. It leads to question that how *Yeongyeongdang* would accommodate various environmental needs within its building design governed by the given social and cultural structure. With the help of a computation application (Ecotect), the paper provides the evidence that *Yeongyeongdang* incorporated the environmental design responses into its design with administering the shadows, shading and solar analysis; wind flow and airflow; and thermal performance.

This research in this chapter mainly tests and demonstrates the selective building, *Yeongyeongdang*, using one of buildings energy efficient analytical software, Ecotect.

Ecotect is easily formulated to work in three dimensions for the energy efficient and the thermal performances. The investigation starts to analyze and systematically to re-arrange the apparently vague and non-systematic features in the expression of the traditional spatial concepts, which appear in *Yeongyeongdang*. Second, the investigation extracts the environmental expressive characteristics of the *Yeongyeongdang* based on the tendency of a contemporary paradigm using the energy simulation software. Lastly, this research analyzes and defines the relationships between the social, cultural impacts and the environmental consideration in the upper class residence of Korean *Joseon* dynasty based on their life styles in *Yeongyeongdang.*

3.2. History

Yeongyeongdang were built in the *Changdeokgung* Palace after the model of Korean gentry's houses in 1828. *Changdeokgung* Palace is one of the "Five Grand Palaces" built by the kings of the *Joseon* Dynasty and it is located on east of *Gyeongbok* Palace, the main royal palace. Construction of *changdeokgung* Palace began in 1405, and completed in 1412 during the reign of King *Taejong*. King *Sejo* of *Joseon* expanded the palace grounds by about 500,000 square meters. Most Palaces had been destroyed during the Japanese invasion in 1592, the *Injo* Political Revolt against *Kwanghaegun* in 1623, and the occupation by the *Qing* dynasty of China, French, and the United States. Korea's last king, King *Sunjong* lived in Seoul until his death in 1926. The main buildings of *Gyeongbok* Palace, which was built on flatland, followed a strict layout placing them on a straight axis from South to North. However, the buildings and pavilions of *Changdeokgung* were constructed on the base of mountain, positioned more naturally, took the geographical features of the mountain slope into consideration (Cultural Heritage Administration 1996).

In his book “The Garden as Architecture,” Inaji (1998) introduces five basic factors that influence the form of the residential environment: location, social status, social mores, function, and locality. The location factor is based on the geomantic principles of *pungsu* in Korean (*fengshui* in Chinese), social status factor is influenced by the traditional hierarchical class system, social mores factor comes from Confucian principles, function factor includes the *ondol* system of heating, and locality factor is related to the dwelling's locale. The selective composition, *Yeongyeongdang* is also represented those five factors, and is preserved well for analyzing the data (squ1.com 2007) (Inaji and Virgilio 1998).

It is made of 99 *kan*[2] and *Yeongyeongdang* was built inside the palace to show the King how typical master's resident looked like (N. Zu 2003). In this respect, all the buildings are important artifacts that relate ancient Korean housing, architecture and life history. *Yeongyeongdang* comprises of four distinctive places: men's quarters, women and children's quarters, servants and service quarters. Men's quarters has public space and business space (Figure 3-1).

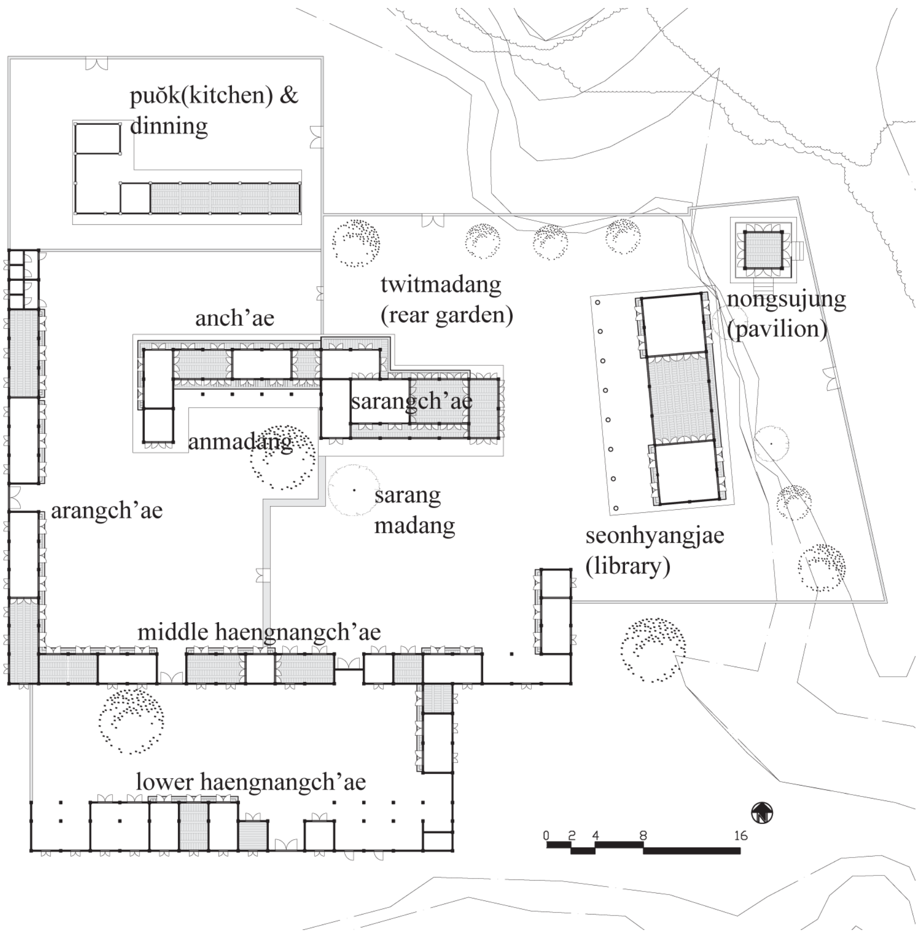


Figure 3-1 Yeongyeongdang Site Plan

[2]*Kan* measurement is equal to the width of the span between columns. The width of the span varies, and the basic unit of measurement used in traditional Korean residence.

According to the social mores, spatial composition of *Yeongyeongdang* can be prioritized as below.

1. Men's quarters: *sarangchae* (master quarter), *sarangmadang* (garden in front of master quarter), s*eonhyangjae* (library), *nongsujung* (pavilion)
2. Women and children's quarters: *anchae*(family's living quarter), *anmadang*(garden in front of *anchae*), *arangchae*(children and lesser women's quarter)
3. Servant's quarters: middle and lower *haengnangchae*(long, narrow building used to accommodate lesser family and servants)
4. Service quarters: *bueok* (kitchen) and dining area

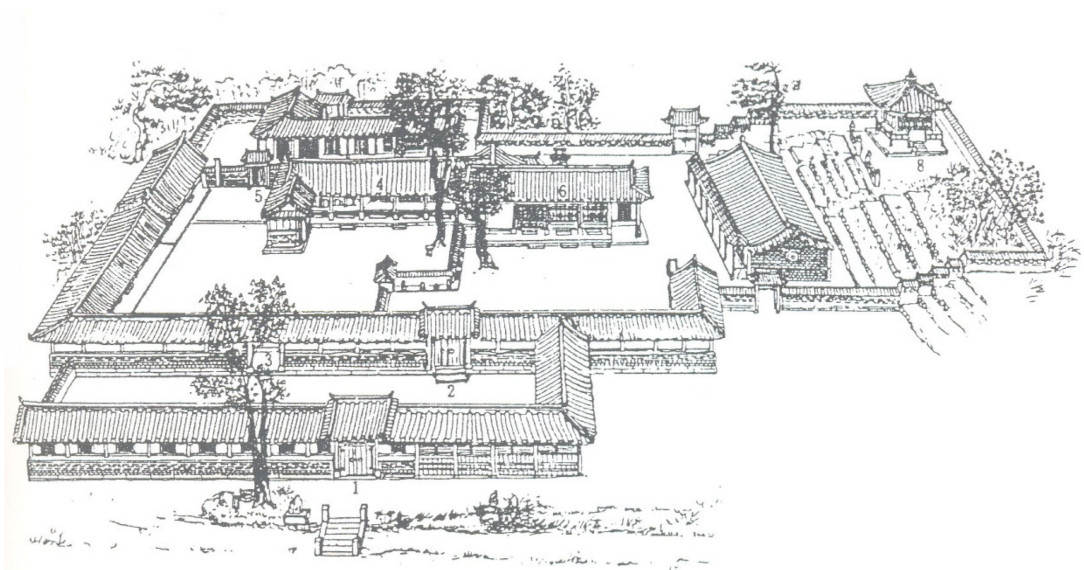


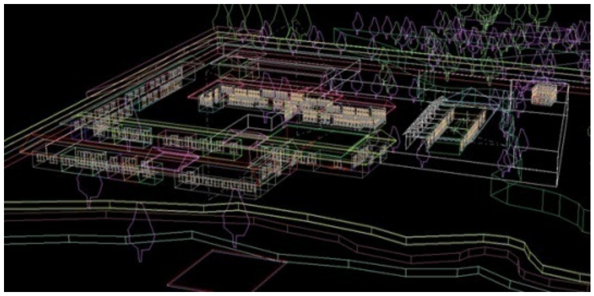
Figure 3-2 Yeongyeongdang Bird View (Yu 2002)

3.3. Methodology

The analysis starts from building geometric models of *Yeongyeongdang* with AutoCAD, which allows precise detail in size. Based upon the models, the design factors and the environmental factors of *Yeongyeongdang* are redefined in the contemporary paradigm. The design factors include building layout, windows position and size, landscape, overhang, building distance, orientation, material selection, human comfort, and thermal performance. The environmental factors include water and rain, wind and airflow, sunlight, micro and macroclimate, temperature, energy, consumer goods, and on-site natural resources (J. Kim 2000). The environmental factors embedded in *Yeongyeongdang* are compared to the design factors. With this comparison, architectural principles that sustain the environmental advantages in *Yeongyeongdang* are reviewed.

In Ecotect, the model of *Yeongyeongdang* is formatted on the grid that allows size changes (Figure 3-3). Because of the difference between the original plan and existing building plan, the drawings are made according to existing building size and position, and then the layout angle is changed to simulate the original building plan. After each space of buildings, called zone, are perfectly enclosed and assigned with correct materials, the analysis of the lighting, thermal, and acoustic is performed based upon the geographic and meteorological data regarding the site of *Yeongyeongdang*.

Ecotect is a highly visual and interactive building design and analysis tool, covering the widest range of analysis features including solar, thermal, energy, lighting, acoustics, regulations and so on (Figure 3-3) (squ1.org 2007). It is employed for analyzing shadows, shading & solar influence, thermal performance, heat gain & loss, spatial comfort, ventilation and daylight & sunlight. Ecotect uses a system of inter-object relationships to assist with this. Based upon the plan of a zone, Ecotect automatically extrudes the corresponding walls and a ceiling. This is useful for modifying the nodes in the plan object. It keeps track of all related walls, ceilings and any added windows (squ1.org 2007).



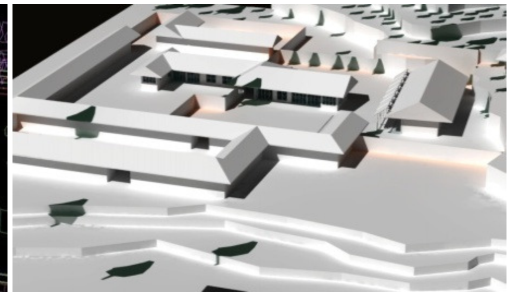


Figure 3-3 Ecotect Modeling **Figure 3-4 Rendering by Radiance**

Experiments are focused on summer and winter of Korea, which require secondary needs to maintain environmental comfort in a building:

- ✓ January 13 - the coldest date
- ✓ May 6 - the start of summer
- ✓ June 21 the summer solstice: Sun at its highest noon altitude
- ✓ July 23-the hottest date
- ✓ August 23 -the end of summer
- ✓ December 23 - the winter solstice: Sun at its lowest noon altitude. (Korea National Heritage Online 2000) (squ1.org 2007)

3.4. *Yeongyeongdang* investigation

Unlike the traditional Korean residence, existing building orientation of *Yeongyeongdang* is tilted fifteen degrees towards the west from exact south. There are some statements to agree with changing the axis of *Yeongyeongdang* in the past period.

In Korea, usually solar glazing should be oriented the south. South facing facade offers the best results of both winter heating and summer shading. If the residence is occupied mainly at nighttime, the 15degree west of south is better for afternoon activity. However, during exiting sunlight, Korean, who mainly engage in agriculture, has woken up early and went to bed early at the time. Therefore, most of the traditional residence including *Unjoru* and *Chusagotaek* had been built slightly east of south to consider the activity during the light.

Figure 3-5 The bigger pond called aeryeonji using for amusement before *Yeongyeongdang* (left), and the small pond using for function before *Yeongyeongdang* (right)

After pass by Main Palace, *Yeongyeongdang* is located on the west side of *Changdeokgung* and the corner of the Secret Garden of *Changdeokgung*. There are two square ponds before passing *Yeongyeongdang*, and after walking two ponds, one called *aeryeonji*, *Yeongyeongdang* is faced on the mountainside rather than faced open space toward the pond (Figure 3-5). This orientation is different from the regular concept of traditional residence, *pungsu*, because the regular adopted principle of the traditional residence indicates that the front of house should be open to the pond for considering prospect, sunlight and wind flow. The existing *Yeongyeongdang* layout ignores one of favorable principle that is the "Prospect" that refers to a panoramic vista unobstructed by an artificial framing element or the type of view. Seldom had the traditional Korean residence changed the south face layout, but the "Prospect" or "Borrowed Scenery" could make to change it. Unlike the tradition Korean architecture, the traditional Japanese architecture distinguished the 'Prospect" and "Borrowed Scenery". The Borrowed Scenery in Japan is an artificial garden of limited area that is set against a feature of a distant natural scene, but the Korean garden is based on the uncultivated that provide more open view, which leads to consider surrounding.

Korean Architectures follow a strict theory, "mountain behind and river in front" and the architecture face south based on the principles of *pungsu*. Due to several reconstructions resulted from many rebellions and conflagration, and changing layouts during the Japanese occupation, current *Yeongyeongdang* is different from its original plan (J.-D. Choi 2005) (N. Zu 2003). The existence of these different layouts of Y*eongyeongdang* provides a difficulty to perform the analysis on *Yeongyeongdang*. In order to decide a research object between the original layout and the current layout, the original layout is compared to the current layout using Ecotect according to various environmental factors.

The Daylight Analysis in the Ecotect provides the decision of the layout, which one should be used for analyzing the environmental factor. The daylight levels are not time dependant and it represent a worst-case design condition base on a sunless cloudy or uniform sky distribution. Daylight Factor (DF) indicates percentage of outdoor light under overcast skies that is available indoors, and the daylight reaching a particular point inside a room is made up of three principle components, which are Sky component (SC), Externally Reflected Component (ERC), and Internally Reflected Component (IRC). The Sky Component (SC) is the light received directly from the sky, the Externally Reflected Component (ERC) is the light received directly by reflection form buildings and landscape outside the room. Internally Reflected Component (IRC) is the light received from surfaces inside the room (McMullan and Seeley 2007).

Ecotect assumes the Design Sky Illumination maximized 8500 lox. Daylight usually enters a building by means of oilpaper windows or doors, but these windows or doors also transmit heat, which is related with the thermal performance. The amount of daylight provides the decision of lighting as well as the cooling energy. The provision of natural lighting in a contemporary residence needs to be considered together with factors of artificial lighting, heating, ventilation and sound control.

The result from Daylight Analysis (Figure 3-6) shows that the original layout and existing layout proof to compare which one is better the Daylight Factors (DF) including the Externally Reflect Light, and the Internally Reflect Light. Both of the Internally Reflected Lights of the Original Layout and Existing layout are less than 1 %, meaning that both of the layouts are not affected by Internally Reflected Lights. This is due to the design of long hangover. On the other hands, the Externally Reflected Light is very strong so the unnecessary heat during summer maybe transmit into the building easily. In case of the tilted layout of the existing *Yeongyeongdang*, both south front facing building and east facing building layout could have the Externally Reflected Light. However, unnecessarily in the corner of building such as between *sarangchae* and *anchae*, the northwest of *anbang* and the west south of Kitchen, the light spreads out irregularly and reflects strongly, and the light also makes the heat gain in the summer. In the original layout facing exact south, the externally reflected light spreads out evenly. In the current layout, it is difficult to plan the overhang length that protects strong light during the hot summer. The overhang of the faced west or east of south creates longer distance between wall and sun altitude. Otherwise, the longer overhang is good in rain season, but it makes shading a lot in all seasons. The daylight analysis of Ecotect shows that the original layout is environmentally superior to the current layout. It leads us to take the original layout of *Yeongyeongdang* as our research object rather than the current building.

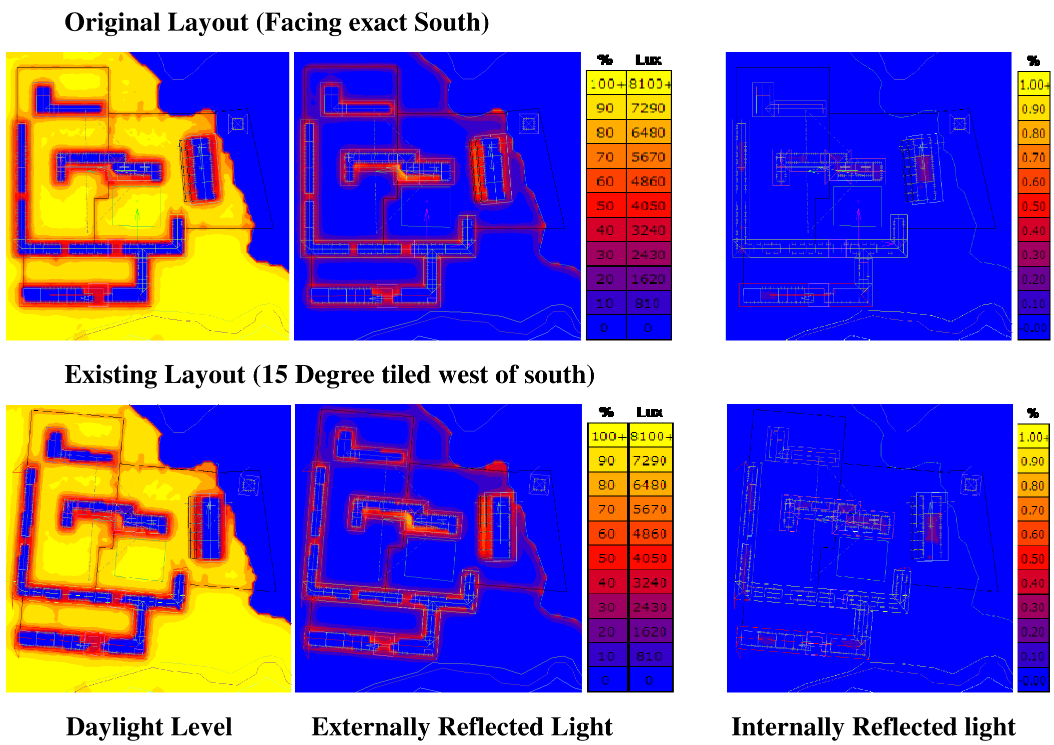


Figure 3-6 Daylight Analysis

3.4.1. Shadows, Shading and Solar Analysis

Shadows, Shading and Solar Analysis offer the greatest opportunity for incorporating *Yeongyeongdang* features. This analysis could be done by observing the use of natural energy flows as the primary means of harvesting solar energy. It also provides the space heating, cooling load avoidance, natural ventilation and natural light.

Ecotect provides three big functions in *Yeongyeongdang* analysis; Shadows & Reflections Analysis, Shading Design and Incident Solar Radiation.

First, Shadows & Reflections Analysis is an important aspect of *Yeongyeongdang* analysis. Through the Ecotect analysis, the display of Daily Sun Path, Annual Sun Path tool, Sun Path Diagrams provides quick layout and structure related the environmental factors as soon as to accomplish an Ecotect model of Y*eongyeongdang*. The sun position in the sky varies continually during the day and changes seasonally in the year. In addition, the position of the sun is highly dependent on the location of the site, which means that the latitude and longitude of the site becomes the very ciritical point (squ1.org 2007). Sun path diagrams are a convenient way of representing annual changes in the path of the sun through the sky within a single two dimensions diagram (Figure 3-7).

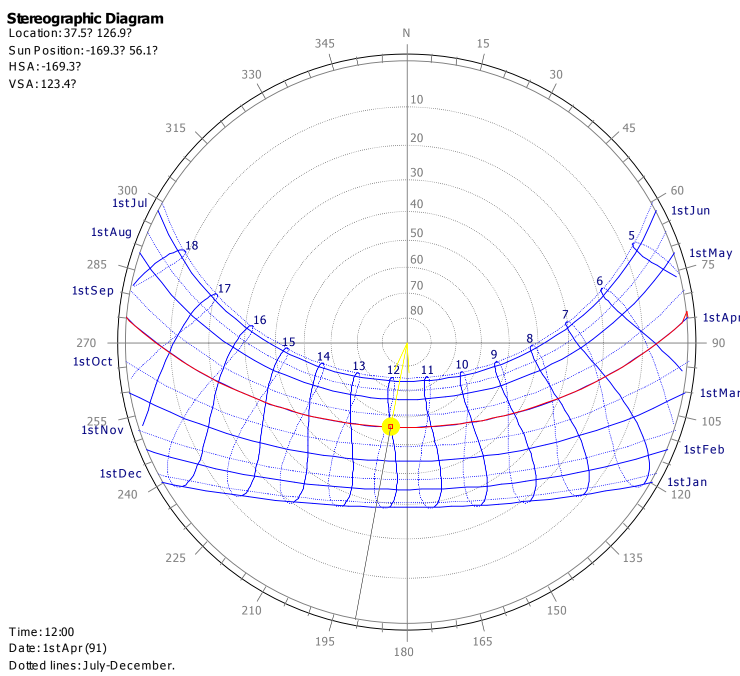


Figure 3-7 Stereographic Diagram, April 1st 12:00 Sun Position, Location 37.5°, 126.9°, South Korea

Ecotect provides various sun path diagrams: Spherical Projection, Equidistant Projection, Stereographic Projection, BRE Sun-Pat Indicator, Orthographic Projection and Waldram Diagram. Spherical Projection, Equidistant Projection, Stereographic Projection, BRE Sun-Path Indicator are all polar projections, displaying the sun-path and overshadowing information on a circular diagram with concentric circles representing altitude angles (Figure 3-8). The different projections vary in how they calculate the radius of points on the circle from their altitude. Orthographic Projection and Waldram Diagram used in primarily the US is to display the same information as a 2D graph using essentially cylindrical projection with azimuth as the X-axis and altitude in the Y axis (Ecotect 2007).

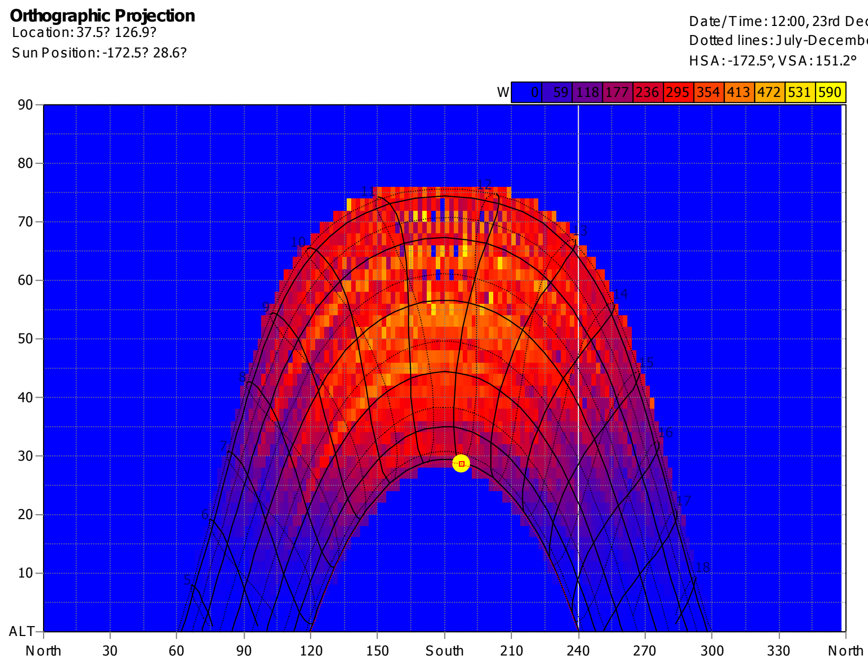


Figure 3-8 Waldram Diagram with Solar Stress, South Korea

Second, Shading Design Analysis that generates the Optimized Shading Device to shade the currently selected window object, the Project Solar Shading Potential to visualize clearly, which part of an obstruction or shading device is the most important. Sun path diagram also provide outside shading design. The shading design wizard in Ecotect provides *Yeongyeongdang* through the process of shading requirements (Ecotect 2007). One of very useful function of this Wizard in Ecotect is to generate automatically the exact shading shape perfectly to shade a window for and specified period.

Lastly, one of Solar Analysis function, Incident Solar Radiation refers to the wide spectrum radiant energy from the Sun, which strikes an object or surface of an object. Excessive solar exposure is one of the main causes of summer overheating in buildings.

However, it is also one of the most effective sources of natural energy available in winter. Thus, Shading systems and the analysis of solar gains are linked with the solar access and incident solar radiation (squ1.com 2007). Through the incident solar radiation in Ecotect, the roof shade all of buildings one of hot summer dates, June 21, and the sunlight, which can be the radiant energy, can penetrate to the buildings. The total direct radiation shows the sunlight valuable amount in the specific day. The summer sunlight, 3200-Watt[3] hour, emits more than ten times of the winter sunlight, 320-Watt hour, which can penetrate inside building, and avoiding the stronger summer sunlight put forward better design solution in the traditional residence *Yeongyeongdang*.

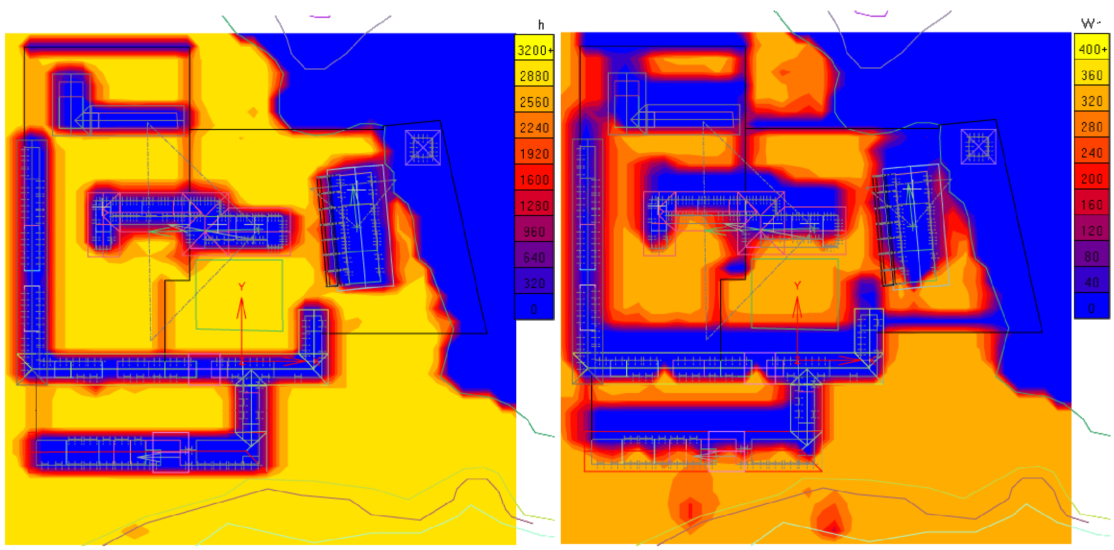


Figure 3-9 Total Direct Radiation, summer solstice, June 21st (left) and winter solstice, Dec 23(right)

3.4.1.1. Protecting the Strong Sunlight in the Summer

In the summer, solar analysis tests how the roof eaves protect, and provides sunlight during the winter. Daily Sun Path and Annual Sun Path Display in the Shadow Settings panel, Ecotect, are set to shadow on the special day and time (Figure 3-10). The Shading Design Wizard extrudes objects for solar envelope that crates reference lines and planes to test or interrupt buildings heights (Figure 3-11).

[3] The power required to produce energy at the rate of 1 joule per second. Commonly used to specify size for light bulbs, furnaces, air conditioners, and other heat producers. 1W=3.412Btu/h joule: Newton-meter, or a force of 1 Newton (1N) acting through a distance of 1meter. In terms of heat, a joule is 1/4.184 of the amount of heat required to raise 1 gram of water by 1℃ (McMullan and Seeley 2007).

The measured value takes off the ambiguous when and how the eaves' length was decided. The summer starts from May 6th to August 23rd. The sun's altitude is at its highest at noon, June 21st, and at it's lowest on August 23rd during the summer. On the last day of summer and the lowest altitude sun during the summer, which is august 23rd, at 10 AM, this sun will hit the tip of the roof on the side, and it creates angel that is always at 56.6 degree every year (Figure 3-11 and Figure 3-12). At this angle 56.6 degree, it creates shading towards the house that encloses the whole house creating friendly or cooler atmosphere inside. The eaves angle of the main building is at same angel 56.6 degree at 10 AM or 1:30 PM, azimuth 45.7° and at 2 PM, azimuth 134.3° (Figure 3-11). Azimuth represents the horizontal angle of the sun relative to true north. This angle is always positive in a clockwise direction from north, and is usually given in the range 0° < azimuth < 180° (squ1.org 2007). Altitude represents the vertical angle the sun makes with the horizontal ground plane. It is given as an angle in the range 0° < alt < 90°.

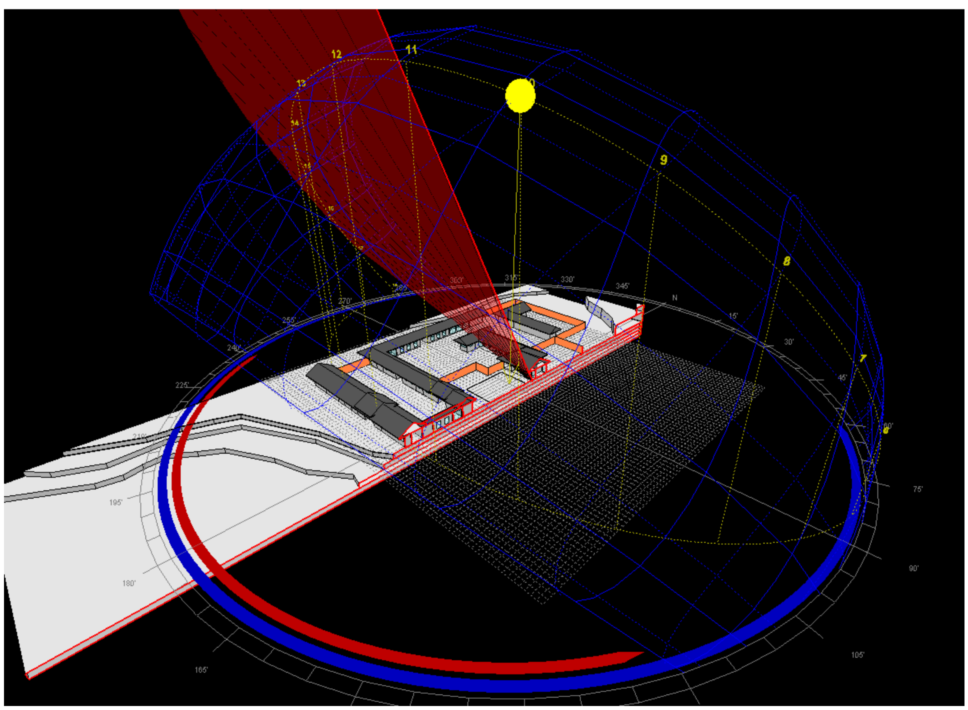


Figure 3-10 Sarangbang Daily and Annual Sun Path Analysis with Extrude Sunlight for Solar Envelope on August 23rd, Summer Solstice

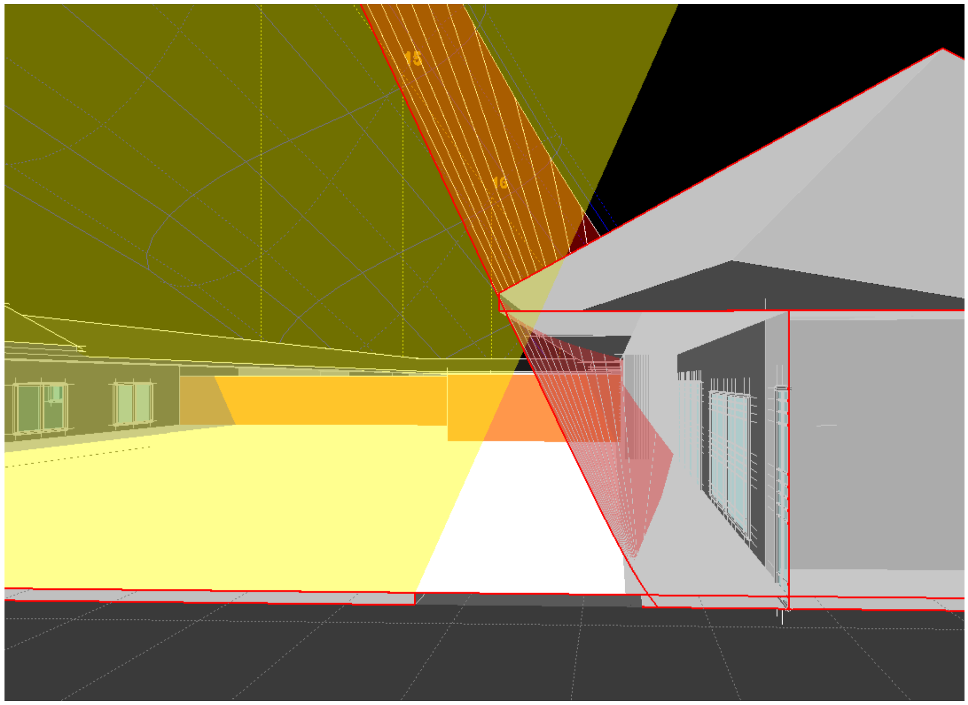


Figure 3-11 Sarangbang Section of Daily and Annual Sun Path Analysis with Extrude Sunlight for Solar Envelope on August 23rd, Summer Solstice

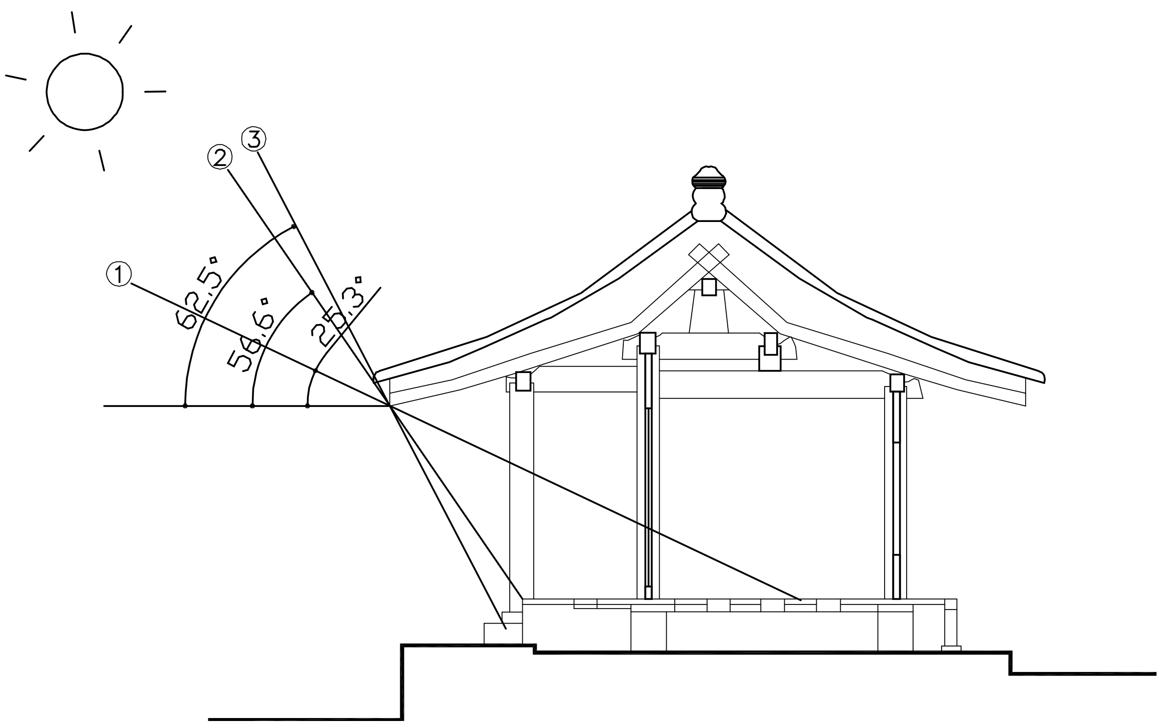


Figure 3-12 Sarangchae sunlight angle section, 1. Winter solstice, 23rd December, 10 o'clock 2.August 23rd Sunlight Angle, 10 o'clock 3.Summer Solstice, 23rd July, 10 o'clock

The zones are tested in the following rooms: *anbang* (master women's room), *antaechong* (women's living room), *konnobang* (women and children's room), Middle Room, *sarangbang* (master men's room), *sarangtaechong* (master men's living room), *numaru* (reception room), library bang, *haengnangbang* (servant's room), *arangbang* (children room), *seonhyangjae* (library room) (Figure 3-13). In the Hourly Heat Gains of the Ecotect Thermal Calculation, the more hourly heat gaining rooms, which unnecessarily can get heat a room in the summer, are ordered these following rooms; *anbang* > *numaru* > *sarangtaechong* > *antaechong* > *arangbang* > Middle Room > *haengnangbang* > *konnobang* > s*eonhyangjae* > *sarangbang* (Figure 3-14,Figure 3-15,Figure 3-16,Table 3-1).

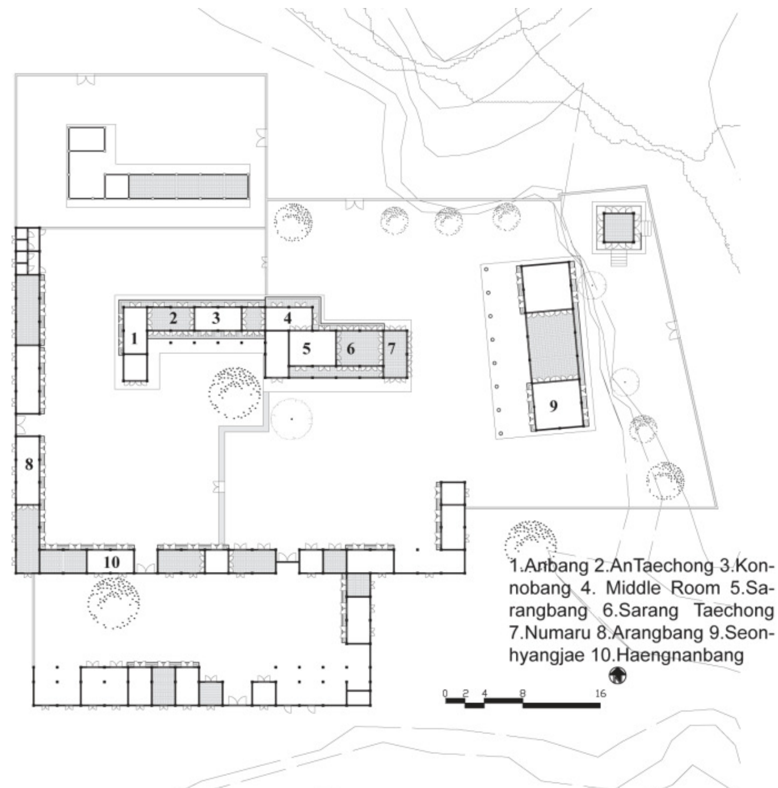


Figure 3-13 Selected Thermal Analytic Rooms

The test dates in the summer are on June 21st, the summer start, and July 23rd, the hottest date, to August 23rd, the summer end. On June 21st and July 23rd, the *anbang* room has numerous heat gain that increases the Percentage Dissatisfied. The numerous heat gain hours in the dates are after 2 o'clock in June 21st and 3 o'clock in July 23rd, because the oil-papered windows open toward the west (Figure 3-14, Figure 3-15). The *anbang* roof eaves are not enough longer to protect the evening sunlight, because the solar altitude is lower than the roof eaves. The solar altitude of July 23rd is up to 43.3 degree[4] after 2 o'clock, and the *anbang* gains heat more and more because the roof eaves angle is over 58.8 degree, which is not protect the strong evening sunlight after 1 o'clock. The second bigger heat gain place is the *numaru*, which the men's meeting place (Figure 3-14, Figure 3-15). In the July 23rd (Figure 3-15), the solar heat gain shows that *numaru* has numerous heat gain. The *numaru* is located in the east part of the master's building, which can have heat gain in the morning time. The *antaechong* and *sarangtaechong*, which are the room for daily activity without any *ondol* heating in the winter, are the next bigger heat gain place, because there are bigger heat gain windows that provide heat gain as well as heat loose. Lastly, the other rooms, which are used to sleep night, have almost equal numerical value of heat gain.

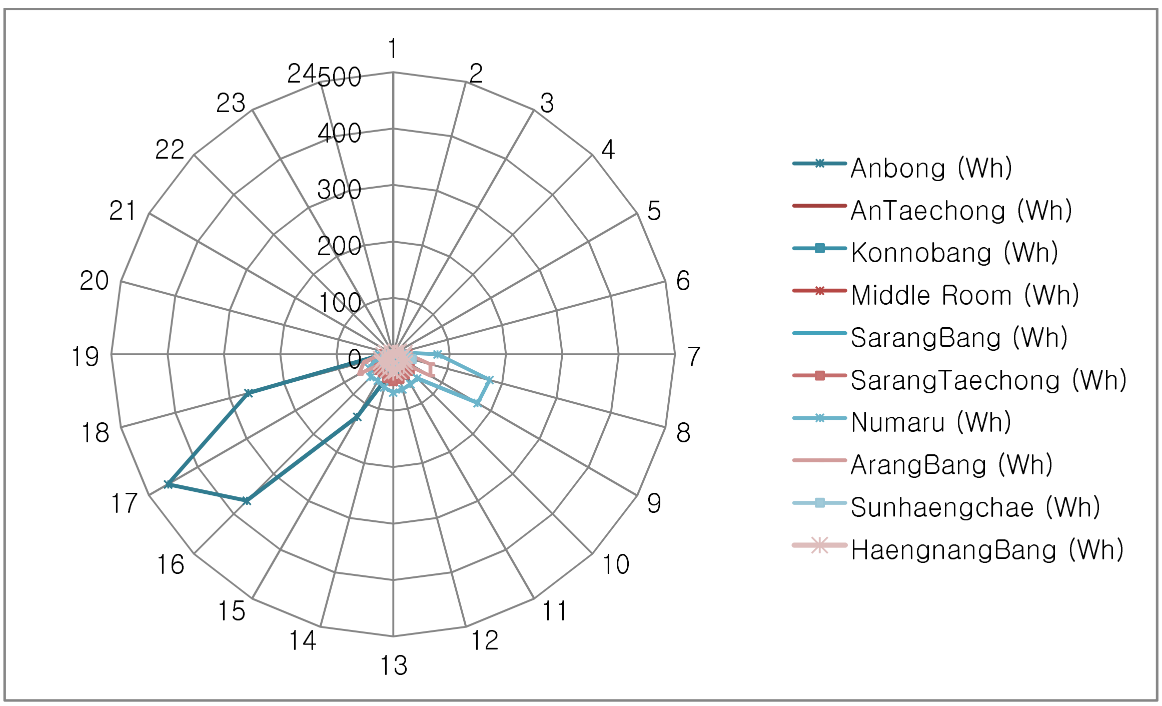


Figure 3-14 Solar Hourly Gains, June 21, the summer solstice

[4] See also Appendix A. Tabulated Daily Solar Data.

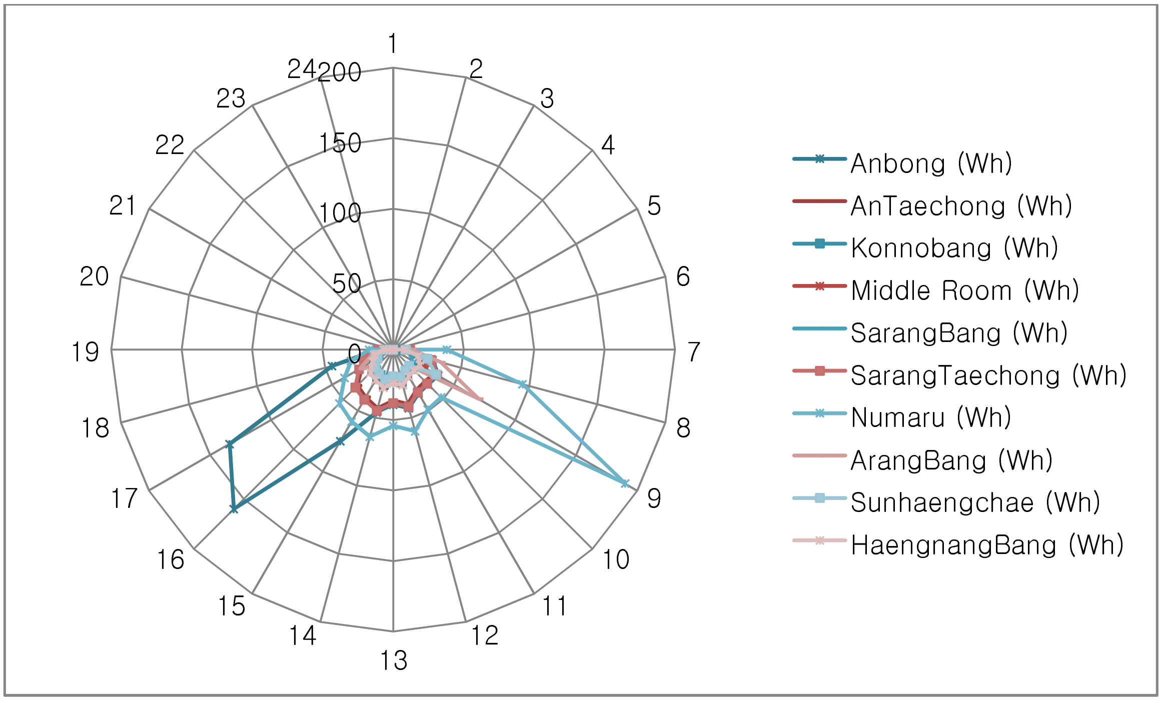


Figure 3-15 Solar Hourly Gains, July 23rd, the hottest date

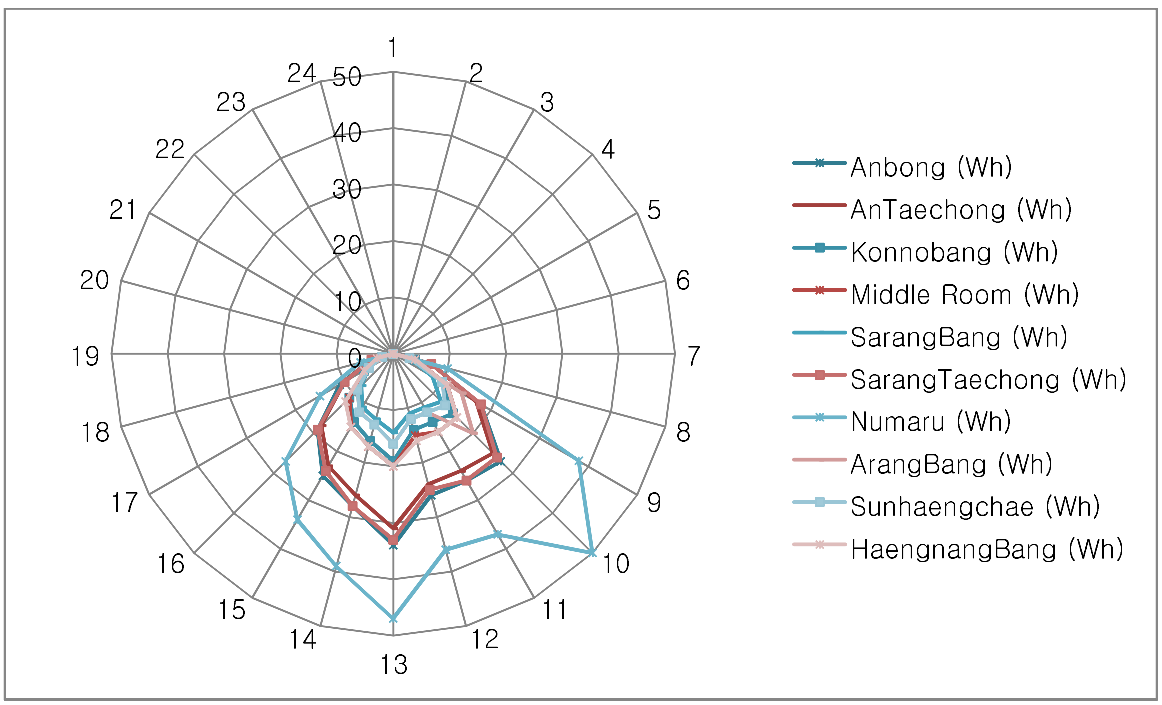
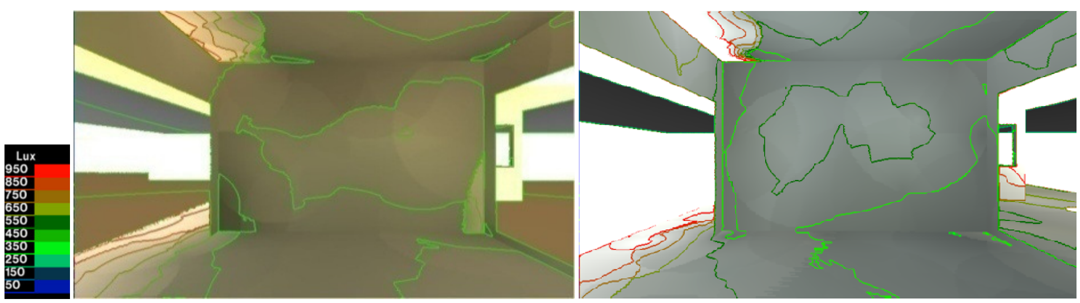


Figure 3-16 Solar Hourly Gains, August 23rd, the end of summer

3.4.1.2. Daylight Factor Analysis using the Radiance[5]

During the summer, the eaves perfectly enclose the strong sunlight. Otherwise, the inside must be darken because there is no sunlight penetration (Shin 2000). When it was built, there was no electrical light source, but the inside building is not very dark according to the simulation from Ecotect and Radiance software. After finishing *Yeongyeongdang* model and setting camera view, Ecotect can export the model to Radiance, that provide the daylight level and daylight factor in the three dimension views (Figure 3-17). The assumption is that the Madang, garden, collar. *Madang* was used for drying the rice and red pepper, and save crop (Shin 2000) (Inaji and Virgilio 1998). The *madang* is white in color. When Madang color is changed to white from its regular ground yellow soiled color, the test result showed different. When *madang* is white, the sunlight reflects smoothly inside more than 50lux in every nook and corner.



1) Regular Ground 2) White Ground

Figure 3-17 Sarangbang Daylight Difference in August 23rd. reading activity possible

3.4.1.3. Penetrating the Sunlight into each Rooms evenly in the Winter

In the winter, the basic natural processes that are used in solar energy are the thermal energy flows associated with radiation, conduction, and convection. When sunlight strikes a building, the building materials can reflect, transmit, or absorb the solar radiation. Additionally, the heat produced by the sun causes air movement that can be predictable in designed spaces. These basic responses to solar heat lead to layout

[5] Address quantitative and qualitative lighting and daylight issues quickly and easily, using the Radiance lighting simulation and rendering software directly from within AutoCAD and Ecotect. Radiance offers unparalleled accuracy, especially in daylighting computations (Lawrence Berkeley National Laboratory 2002).

elements, material choices and placements that can provide heating and cooling effects in a residence. Excessive solar exposure is one of the main causes of summer overheating, but it is also one of the most effective sources of natural energy in winter. In the summer, there is no excessive solar energy, because the roof eaves perfectly make shading in all of rooms.

In the Hourly Heat Gains of the Ecotect Thermal Calculation, the more hourly heat gaining rooms, which necessarily can get heat a room in the winter, are ordered these following rooms; *numaru* ＞ *sarangtaechong* ＞ *antaechong* ＞ *sarangbang* ＞ *konnobang* ＞ *anbang* ＞ *haengnangbang* ＞ *arangbang* > s*eonhyangjae* ＞ Middle Room (Figure 3-18,Figure 3-19 ,Figure 3-20). The Solar Hourly Heat Gain for *Yeongyeongdang* (Table 3-1) provides that at the morning time between 9 o'clock and 11 o'clock the sunlight is stronger than any other times during the winter. Therefore, if the room has the east of south facing windows more, or has placed on the east part of building, the sunlight heat gain is higher than any other directions of buildings such as the west of south or the north. On June 21st, the summer solstice date, *numaru* has 973 watt[6] heat gain in a day, and on December 23rd, *numaru* has 1256 Watt heat gain in a day. There are several critical reasons for having bigger number in the winter. First, the sun altitude is lower in the winter than in the summer (Figure 3-12). Through the sunlight analysis, in case of the south facing windows, the sunlight penetrates to the rooms more than half of floor, which is so much bigger than nothing is penetration during the summer. On the other hands, the *numaru* has many windows, which can lose the heat easily. Comparing the *numaru* with *sarangbang* shows that numaru has more numerous values, and the number during the summer is higher than *sarangbang*. The data shows that the numaru can gain the heat easily necessarily during the winter and unnecessarily during the summer. *Anbang*, which is place on the west of the building, has the third heat gain room among the analyzing rooms. The amount of heat gain in the *anbang* is mostly afternoon during the winter. Through the result of heat gain of *anbang*, the women

[6] The power required to produce energy at the rate of 1 joule per second. It commonly used to specify size for light bulbs, furnaces, air conditioners, and other heat producers. 1W=3.412Btu/h One joule is the Newton-meter, or a force of 1 Newton (1N) acting through a distance of 1meter. In terms of heat, a joule is 1/4.184 of the amount of heat required to raise 1 gram of water by 1℃ (McMullan and Seeley 2007). A human climbing a flight of stairs is doing work at a rate of about 200 watts (Stein and Reynoldsd 2000).

master room, *anbang*, is able to save energy in the night.

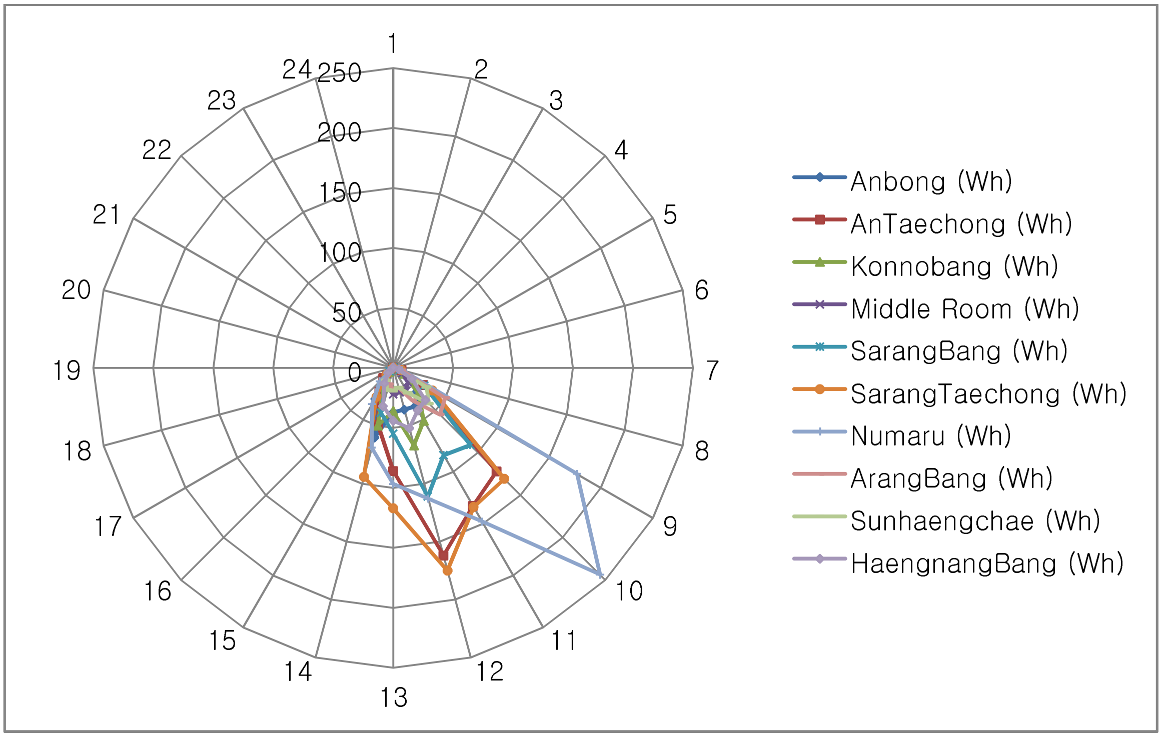


Figure 3-18 Solar Hourly Gains, January 13th, the coldest date

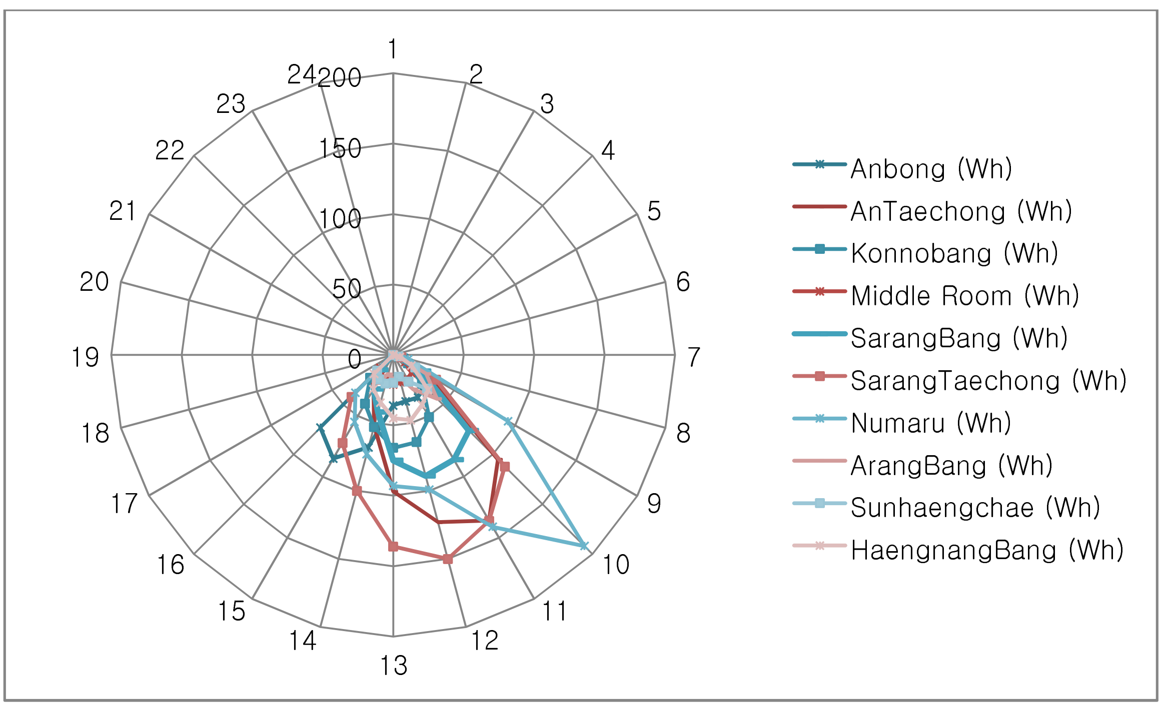


Figure 3-19 Solar Hourly Gains, December 23rd, the winter solstice

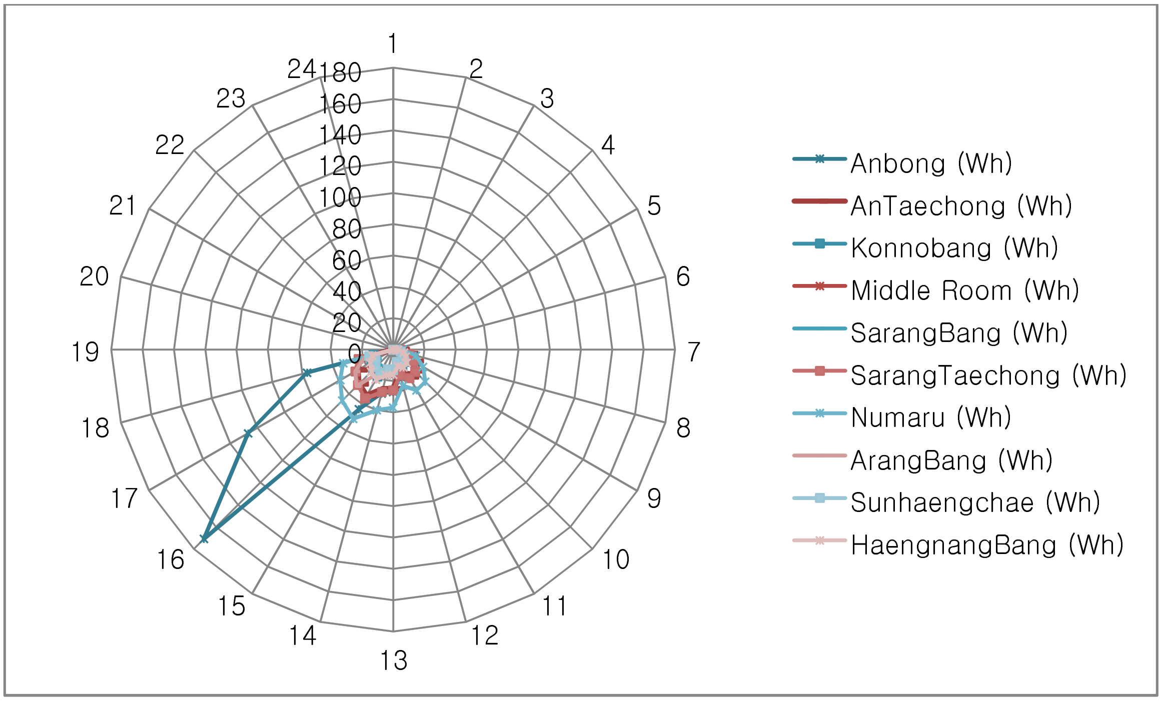


Figure 3-20 Solar Hourly Gains, May 6th

Zone	Solar Hourly Heat Gains									
	Anbong (㎡)	AnTaechong (㎡)	Konnobang (㎡)	Middle Room (㎡)	SarangBang (㎡)	SarangTaechong (㎡)	Numaru (㎡)	ArangBang (㎡)	Sunhaengchae (㎡)	HaengnangBang (㎡)
Total Surface Area:	64.34	61.14	60.56	58.08	81.434	81.434	64.56	81.6	130.776	60.02
	525%	531%	515%	499%	449%	449%	549%	466%	363%	490%
Total Exposed Area:	25.08	27.291	25.52	23.197	21.63	27.414	29.28	35.04	35.158	29.52
	205%	237%	217%	199%	119%	151%	249%	200%	98%	241%
Total South Window:	0	7.08	4.395	3	6.092	7.788	3	0	0	2
	0%	62%	37%	26%	34%	43%	26%	0%	0%	16%
Total Window Area:	6.32	14.16	8.395	9	8.092	14.868	14.93	13.8	67	9.2
	52%	123%	71%	77%	45%	82%	127%	79%	67%	75%
Total Conductance (AU)(W/㎡K):	61	62	54	50	47	64	74	76	87	62
Total Admittance (AY)(W/㎡K):	187	172	168	164	229	233	187	232	392	168
Response Factor:	2.91	2.65	2.95	3.08	4.4	3.39	2.43	2.87	4.01	2.6

HOUR	Anbong (Wh)	AnTaechong (Wh)	Konnobang (Wh)	Middle Room (Wh)	SarangBang (Wh)	SarangTaechong (Wh)	Numaru (Wh)	ArangBang (Wh)	Sunhaengchae (Wh)	HaengnangBang (Wh)
13th January										
7	6	7	3	4	6	7	8	7	3	5
8	16	29	10	9	30	38	177	50	32	18
9	28	122	30	17	91	131	244	55	42	38
10	37	133	51	22	84	134	148	31	24	41
11	36	162	67	21	111	175	113	17	17	52
12	37	86	36	22	55	117	97	18	19	44
13	60	49	50	17	39	94	69	14	19	33
14	30	23	15	14	12	28	35	12	12	15
15	2	12	5	8	4	8	16	4	5	6
TOTAL	**252**	**623**	**267**	**134**	**432**	**732**	**907**	**208**	**173**	**252**
6th May										
6	5	4	3	3	2	5	6	2	2	3
7	11	10	6	6	5	11	15	5	5	7
8	16	15	9	9	7	15	22	7	7	9
9	21	19	11	12	9	20	29	10	10	12
10	21	20	12	13	9	21	30	10	10	13
11	18	16	10	10	8	17	24	8	8	11
12	27	25	15	16	11	26	37	13	13	16
13	29	26	16	17	12	28	40	13	13	17
14	44	34	20	22	16	36	51	17	17	22
15	171	31	18	19	14	32	46	33	16	20
16	107	26	16	17	12	28	39	28	13	17
17	57	22	13	14	10	23	33	19	16	14
TOTAL	**527**	**248**	**149**	**158**	**115**	**262**	**372**	**165**	**130**	**161**
21st June										
5	10	9	6	8	4	9	13	10	4	8
6	24	25	13	22	10	26	79	27	20	18
7	29	27	16	27	12	28	177	68	34	17
8	35	33	19	24	15	34	173	76	17	21
9	43	40	24	26	19	42	60	20	20	26
10	44	40	24	26	19	42	61	21	21	26
11	46	43	26	27	20	45	64	22	22	28
12	49	46	27	29	21	48	68	23	23	30
13	44	41	24	26	19	43	61	21	21	26
14	128	36	21	23	17	38	54	18	18	23
15	367	38	23	24	18	40	57	20	20	25
16	461	33	20	21	15	35	49	70	17	22
17	266	22	13	14	10	23	32	54	11	15
18	17	15	14	12	7	18	25	20	8	10
TOTAL	**1563**	**448**	**270**	**309**	**206**	**471**	**973**	**470**	**256**	**295**
23rd July										
6	11	12	6	10	5	12	38	13	9	8
7	29	27	16	23	12	28	95	35	25	18
8	37	34	20	27	16	36	190	70	35	22
9	35	32	19	20	15	34	48	16	16	21
10	36	33	20	21	15	35	49	17	17	22
11	43	40	24	26	19	42	60	20	20	26
12	39	36	22	23	17	38	54	19	19	24
13	46	43	26	27	20	45	64	22	22	28
14	75	39	23	25	18	41	59	20	20	25
15	160	36	21	23	17	38	54	18	18	23
16	134	26	16	17	12	28	40	27	13	17
17	45	22	12	14	10	22	31	16	13	14
18	11	11	6	6	5	11	17	3	5	7
TOTAL	**701**	**391**	**231**	**262**	**181**	**410**	**799**	**296**	**232**	**255**
23rd August										
7	7	7	4	4	3	7	10	3	3	4
8	18	17	10	11	8	18	38	14	10	11
9	27	25	15	16	12	26	50	20	13	16
10	26	24	14	16	11	26	37	12	12	16
11	26	24	14	15	11	25	36	12	12	16
12	34	31	19	20	14	33	47	16	16	20
13	28	26	16	17	12	28	39	13	13	17
14	25	23	14	15	11	24	34	12	12	15
15	19	18	11	11	8	19	27	9	9	12
16	11	10	6	6	5	10	15	5	5	6
17	4	4	2	3	2	4	6	2	2	3
TOTAL	**225**	**209**	**125**	**134**	**97**	**220**	**339**	**118**	**107**	**136**
23rd December										
7	8	7	4	5	3	6	11	3	4	5
8	17	30	12	10	23	35	94	27	18	15
9	31	105	29	18	76	112	192	44	34	35
10	35	136	51	20	86	136	141	28	22	41
11	34	123	64	20	89	150	99	16	16	48
12	36	97	66	21	75	136	93	17	20	45
13	68	52	53	18	42	100	73	14	21	35
14	85	28	40	16	28	72	55	23	20	28
15	73	21	23	13	15	42	38	20	16	19
TOTAL	**699**	**889**	**516**	**327**	**572**	**1094**	**1256**	**351**	**319**	**460**
	Anbong	**AnTaechong**	**Konnobang**	**Middle Room**	**SarangBang**	**SarangTaechong**	**Numaru**	**ArangBang**	**Sunhaengchae**	**HaengnangBang**

Table 3-1 Solar Hourly Heat Gain for *Yeongyeongdang*

3.4.2. Cooling Strategies: Wind Flow and Air Flow

Human comfort within residence is primarily controlled by four major factors: air temperature, mean radiant temperature, humidity and airflow. Each can have a dominating effect, and these factors affect human comfort including clothing and activity (Fairey 1994). The Psychometric Chart provides a graphic representation of the state of condition of the air and moisture related with comfort zone at any particular time. The chart relates temperature along the horizontal scale to moisture content along the vertical scale (Ecotect 2007). The Psychometric Chart shows that the Natural ventilation, High-Mass Cooling, High mass Cooing with Night Ventilation and Evaporative Cooling affect the Passive cooling design to extend the comfort zone (Figure 3-21). Ventilation increasing air motion across the skin can greatly increase the tolerance for higher temperature and humidity levels. According to the research by P.O. Fanger, the human comfort can be maintained at 27.8℃(82℉) and 100 percent relative humidity as long as air velocities of 1.53m/s(300 feet per minute) across the skin are maintained. Most good ceiling fans will produce this 1.53 m/s degree of air motion. At lower relative humilities (50 percent and below) much higher temperatures (up to 32℃(90℉)) are comfortable at this air velocity (Fanger 1970).

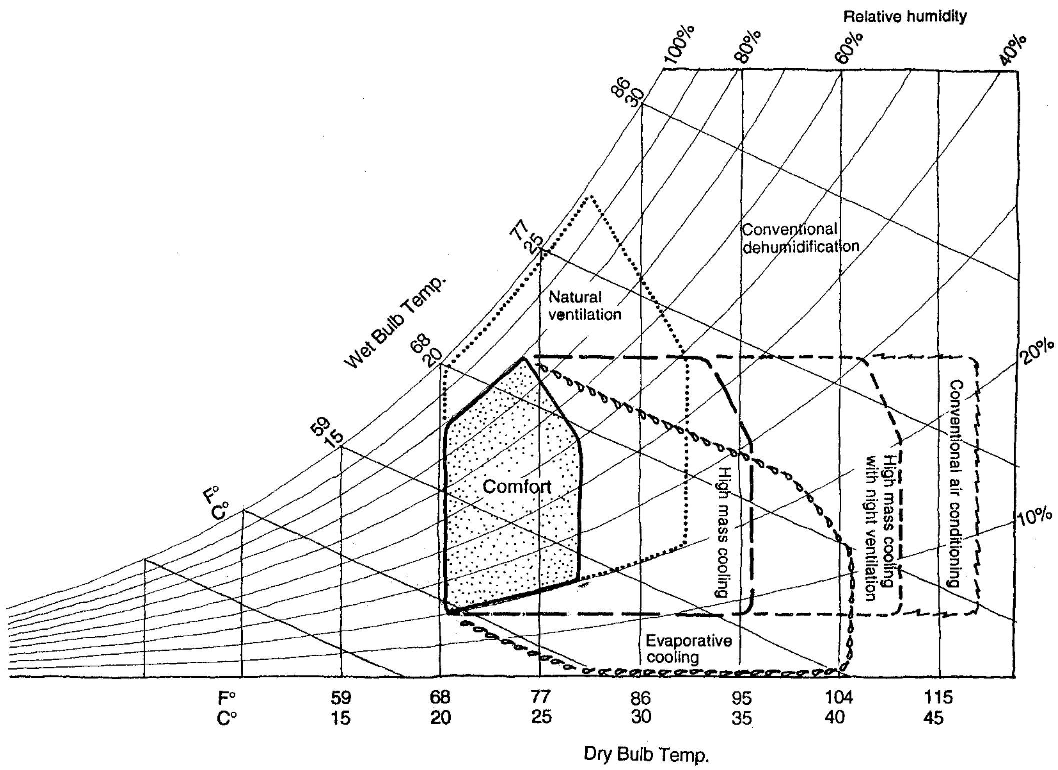


Figure 3-21 Psychometric Chart shows that the Natural Ventilation increases the comfort zone, Passive Cooling design strategies (Stein and Reynoldsd 2000)

3.4.2.1. Summer

There are two cooling strategies, which dominate the *Yeongyeongdang*. First, one of strategies is Natural Ventilation, which is cross ventilations driven by wind and accomplished with windows. It relies on narrow plans with large ventilation openings on either side. Second, the other strategy is High-mass Cooling, which is for warm, dry summers, when the extremes of hot days are tempered by the still cool thermal mass, thicker roof and the floor by underground. Cool nights then slowly drain away the heat that such mass accumulates during the day. The roof has the advantage of radiating to the cold night sky.

In the summer, the Seoul wind flows average 2.4m/s and the minimum of airflow is the 0.7m/s up to few days according to the Korea Meteorological Administration recording from 1961 to 1980 (Korea Meteorological Adiministration 2006). If the 2.4m/s airflow constantly affects *Yeongyeongdang*, during summer, there is enough cooling for human comfort. The traditional sliding door of *Yeongyeongdang* can be opened 100% of the window-installed space, unlike the modern glass door (Figure 3-22) (D.-K. Kim 2000).

Figure 3-22 100% open possible oiled-paper windows in *sarangbang*, after opening the windows of half installed windows area, all windows hang over the ceiling or the roof eaves.

During the summer, the open door offers enough air inside. Additionally, for the wind flow from the southwest in the summer, the building layout was so well suited to the each room (Figure 3-23). Ecotect shows the prevailing winds, which is able to display in the 3D model. Ecotect prevailing winds displays the wind speed, frequency and the direction. In the prevailing winds, the wind flows 35% of the total wind from east of north to the building in the morning (6:00~10:00), and 40% of the total wind from west of south trough the building during the day (10:00~6:00PM) (Figure 3-31). Diurnal airflow in the valley cools also down the temperature during the summer. Diurnal airflow during the day moves the wind from the low valley to the high valley using the different temperature and pressure. The layout also is considered the wind flow well during the summer. The wind flows from the southwest to the women's quarter, placed on the west, which stays backward, and men's quarter, place on the east, which stays frontward. Therefore, the women's quarter dose not interrupt the wind to the men's quarter. The layout is very suitable to be effected by the wind flow.

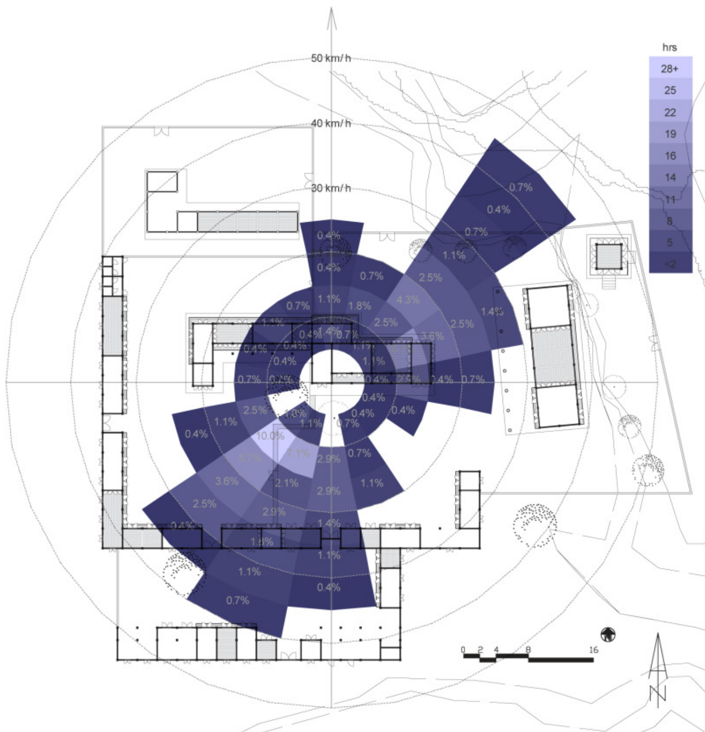


Figure 3-23 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: summer, 1st June ~ 31st August. Time: 10:00 ~14:00

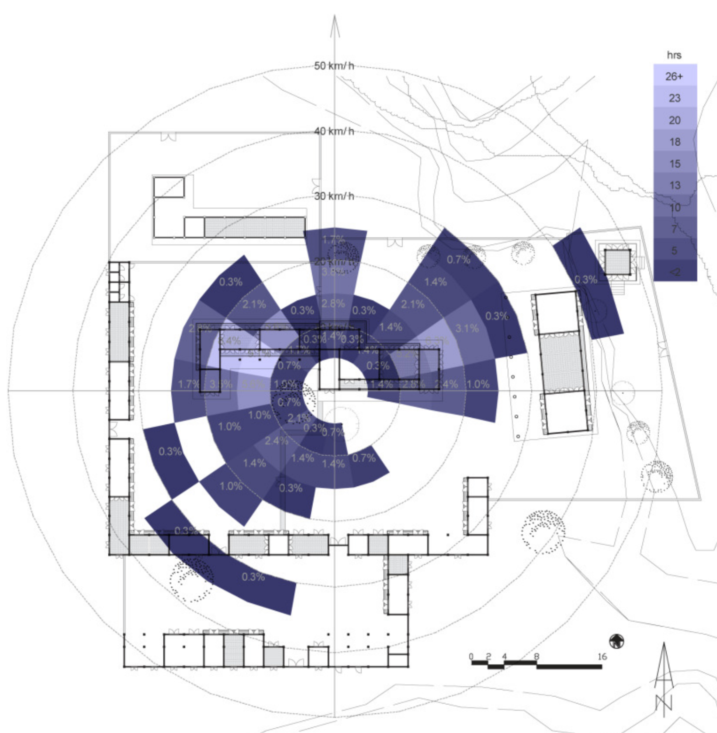


Figure 3-24 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: winter, 1st December ~ 28th February. Time: 10:00 ~14:00

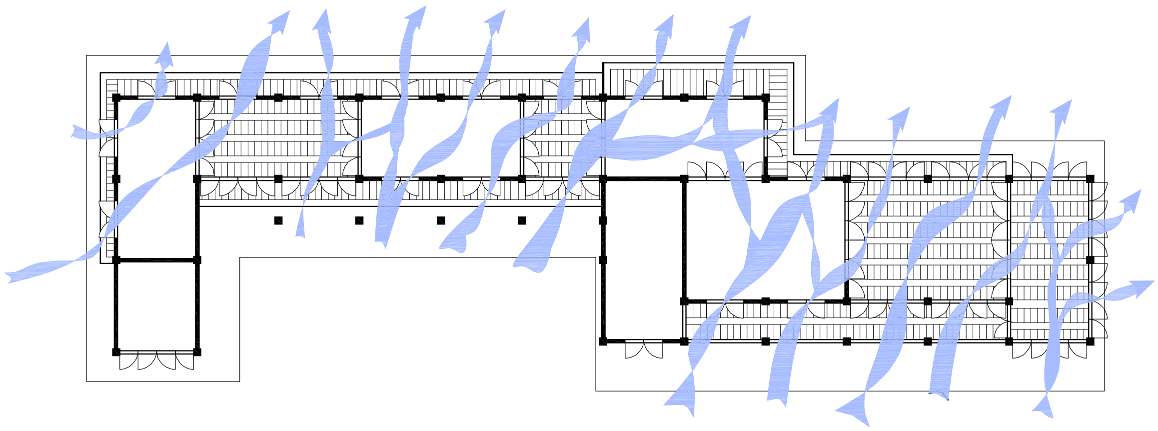


Figure 3-25 Natural Ventilation in a master's Building. Room location allows heat to vent from West of south to east of north.

Besides the wind consideration, *seonhyangjae*, library, is tilted toward the southwest, towards the bottom floor of Numaru (Figure 3-26, Figure 3-26, Figure 3-28). *Numaru* is a special reception room in the *sarangchae*, master's quarters. The *sarangchae* raises about 70 centimeters higher than other closed rooms. The gap between the Numaru floor and the ground provides the wind flow towards *seonhyangjae* without interruption (Figure 3-26). The *seonhyangjae* faces tilted west of south, and in summer, the sunshine strikes the building at sunset. An additional roof structure was installed at the outside of the building to prevent strong sunshine from penetrating into the room, and it adds an oil-papered blind on the bottom of roof eaves (Korea National Heritage Online 2000). During sunset on august 23, from 2:00 to 5:30, an additional roof structure doses not enclose perfectly the strong sunlight, but after putting oil-papered blind on Ecotect model, it covers perfectly the sunlight (Figure 3-26). Ecotect offers the prevailing wind data that visualize the wind flow. Otherwise, *arangbang*, servant's room, opens windows toward the north or west, which does not affect the wind like the main master building in the day. Social status factor, which is influenced by the traditional hierarchical class system, decides the room function. The servants usually work outside during the day, and they used usually the rooms in the night. In the night, the prevailing winds flow from East of north, the wind direction is toward the *haengnangbang* (servant's room), and then the *haengnangbang* can cool down in the night.

Figure 3-26 ***Numaru*** **and** ***Seonhyangjae*** **Figure 3-27** ***Seonhyangjae***

Figure 3-28 ***Seonhyangjae***

3.4.2.2. Winter

In the winter, the replication of the mountain-like wraps in traditional Korean residence behind the north protects against the strong wind during the winter. *Yeongyeongdang* is enclosed by mountain from east higher hill to west lower hill trough north hill. The Ecotect prevailing winds provide that the winter winds flow from the west or east of north to the building (Figure 3-24).

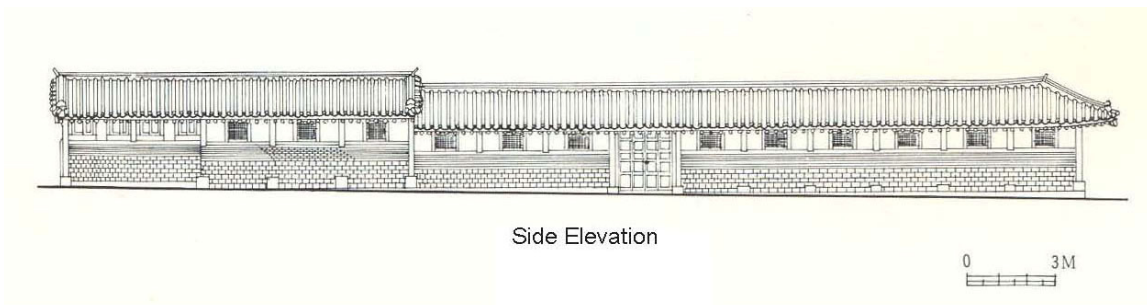


Figure 3-29 West Elevation of the *Yeongyeongdang* site

The windows on the north facing or the windward windows in the winter are smaller than the south facing windows (Figure 3-29). The sizes of east facing windows are about 790mm x 790mm, but the other south facing windows size is 2235mm x 1770mm that is more than twice. The north facing windows size for living rooms (*maru* or *taechong)* is 1118mm x 1465mm for maru, and it is 1118mm x 1225mm for rooms.

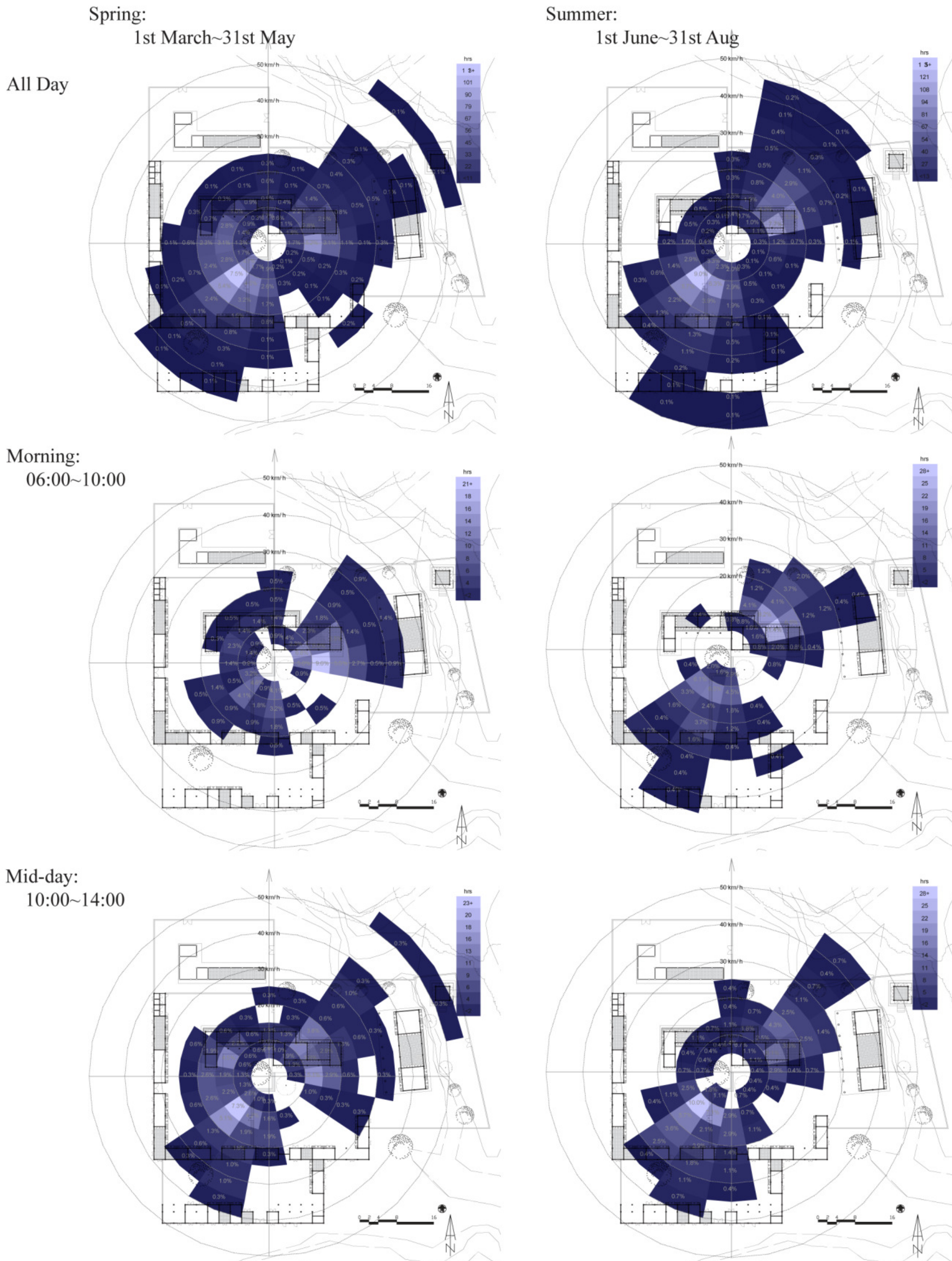


Figure 3-30 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: spring and summer, morning to mid-day

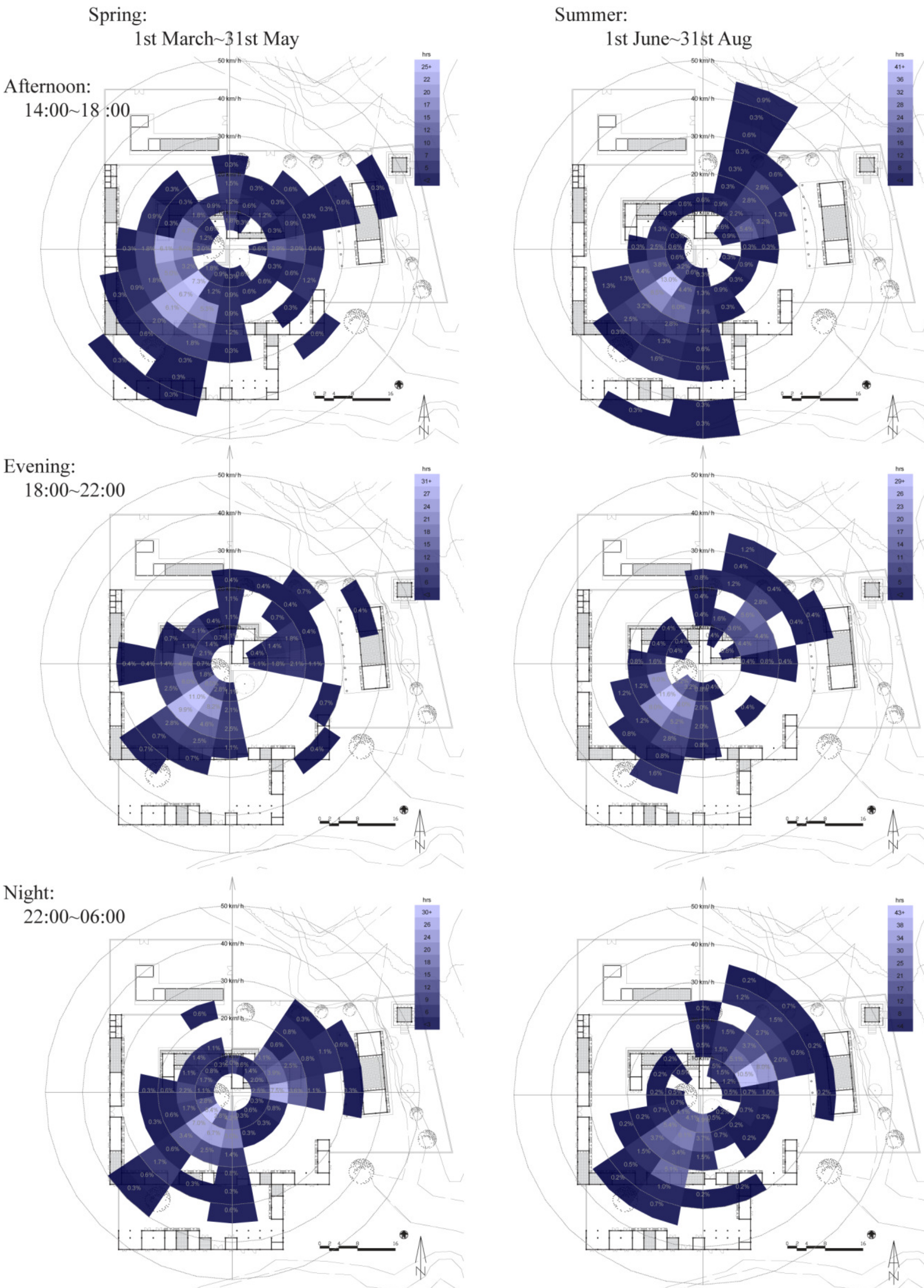


Figure 3-31 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: spring and summer, evening to night

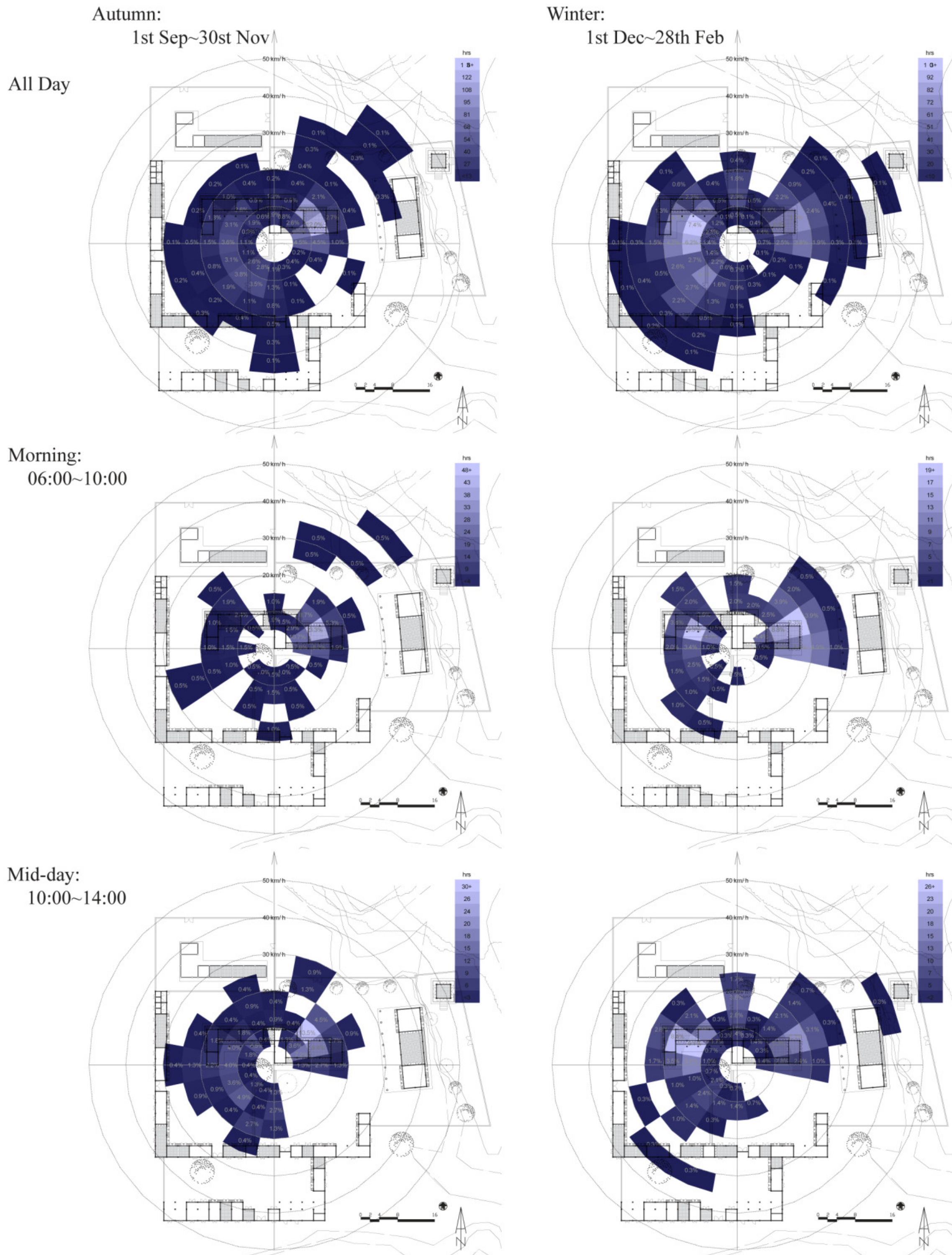


Figure 3-32 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: autumn and winter, morning to mid-day

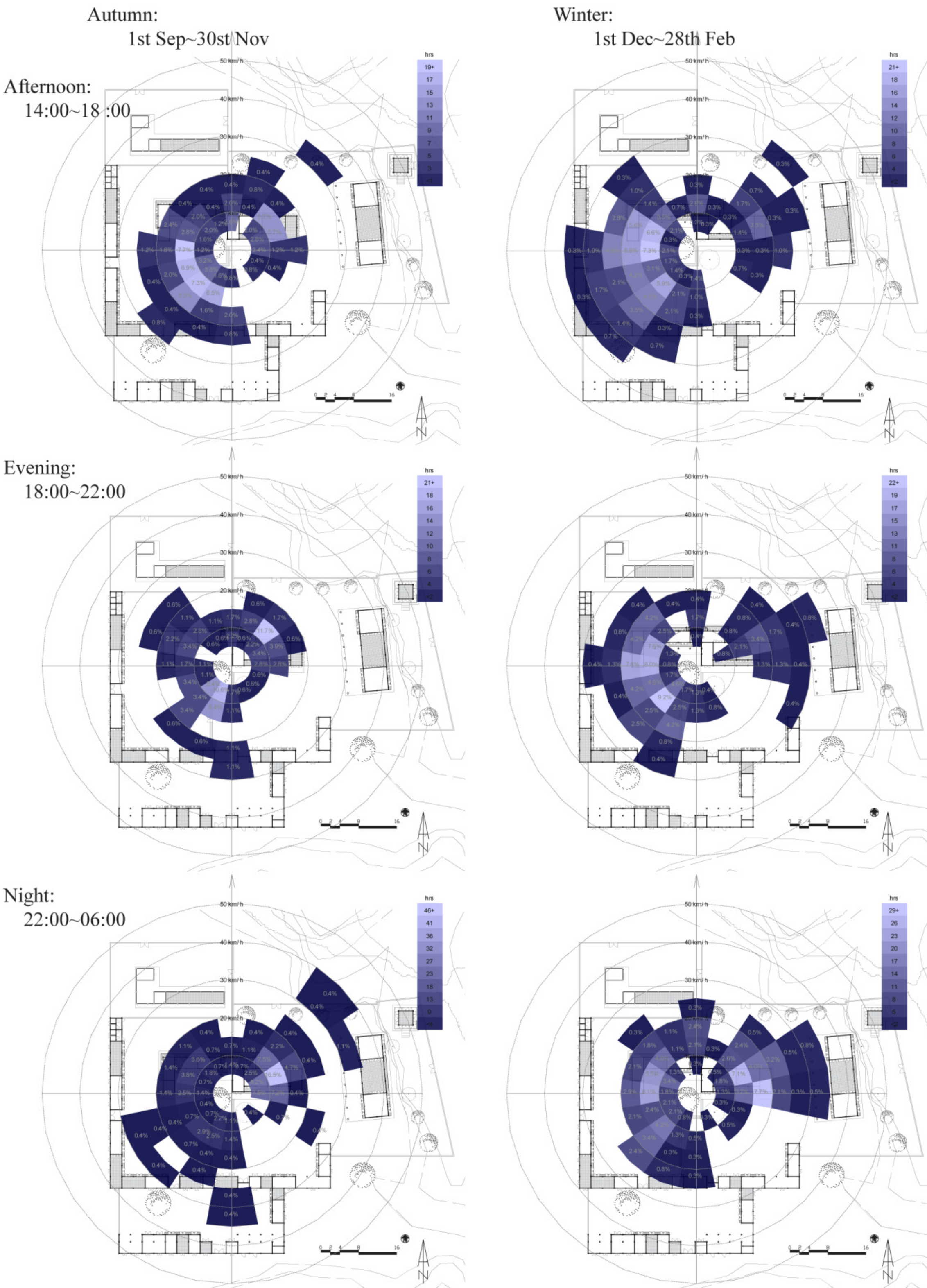


Figure 3-33 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: autumn and winter, evening to night

3.4.3. Thermal Performance

Thermal performance is related to materials, windows and doors sizes, height, length, temperature, orientation, and many other factors. The Chartered Institute of Building Services Engineers (CIBSE) Admittance Method determines internal temperatures and heat loads in Ecotect. This thermal algorithm is very flexible and has no restrictions on building geometry or the number of thermal zones that can be simultaneously analyzed. The internal temperature of any building will always tend towards the local mean outdoor temperature. Any fluctuations in outside temperature or solar load will cause the internal air temperature to fluctuate in a similar way, though delayed and dampened somewhat by thermal capacitance and resistance within the building fabric. When the total of all heat losses become equal to the total of all gains, then internal temperatures stabilize (Ecotect 2007).

In the Admittance Method, the temperature and load calculations are two separate processes. First, the magnitude of potential heat gains and losses acting on the building are calculated for each hour of each day, from which average daily load factors can be determined. Variations in the instantaneous load factor against each daily average can then be used to determine that the relative thermal stress each zone is subject to each hour of the day (Ecotect 2007). Second, a next calculation is performed to determine the absolute heating and cooling loads. Given inside and outside temperatures for each zone, fabric, ventilation and infiltration loads can be accurately determined along with solar and internal loads. Whilst in summary it is a simplified method, the Admittance Method encapsulates the effects of conductive heat flow through building fabric, infiltration and ventilation through openings, direct solar gains through transparent materials, indirect solar gains through opaque elements, internal heat gains from equipment, lights and people and the effects of inter-zonal heat flow (Ecotect 2007). Thermal performance of Ecotect evaluates the thermal comfort of human beings that is governed by many physiological mechanisms of the body and varies from person to person. In any particular thermal environment, it is difficult to get more than 50 per cent of the people affected to agree that the conditions are comfortable (McMullan and Seeley 2007). The principal factors affecting thermal comfort can be conveniently considered in the following sections: Personal variables included activity, age, clothing, and gender; and

Physical Variables included air temperature, air movement, surface temperatures, and humidity.

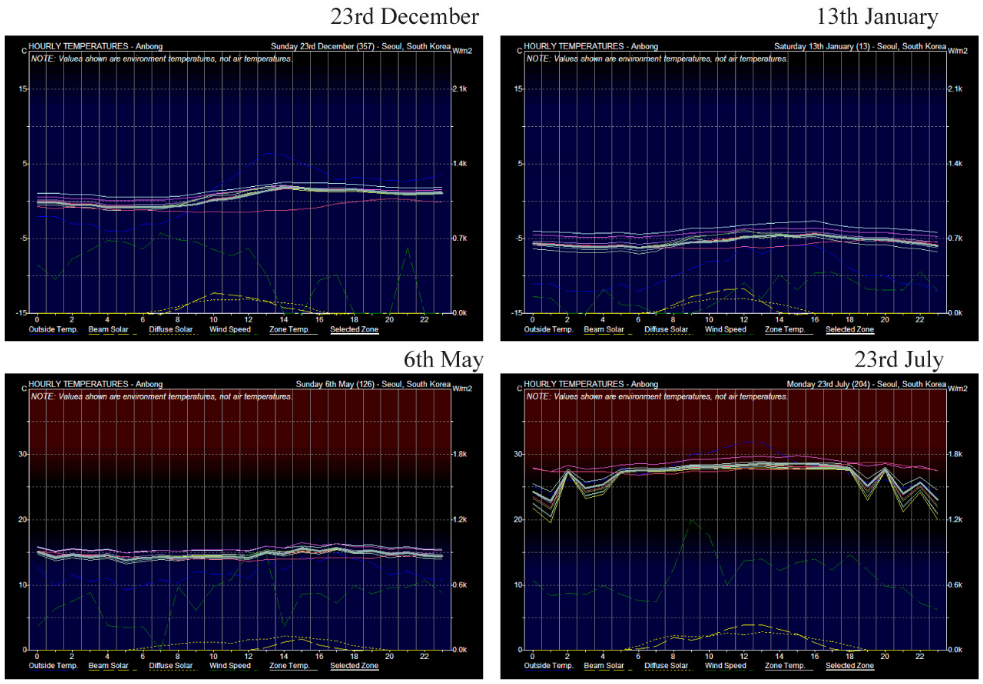


Figure 3-34 Thermal Performance, master building, Ecotect Thermal Analysis shows the Hourly Temperature Profile with the cold zone, blue part, and the hot zone, red part (Ecotect: 2007)

The evaluation of thermal performance of Ecotect chooses many different zones of *Yeongyeongdang*: master men's and women's rooms, library room, servants' rooms. The zones are tested in the following rooms: *anbang* (master women's room), *antaechong* (women's *maru*), *konnobang* (women and children's room), Middle Room, *sarangbang* (master men's room), *sarangtaechong* (master men's *maru*), *numaru* (reception room), library bang, *haengnangbang* (servant's room), *arangbang* (children room), s*eonhyangjae* (library room) (Figure 3-35).

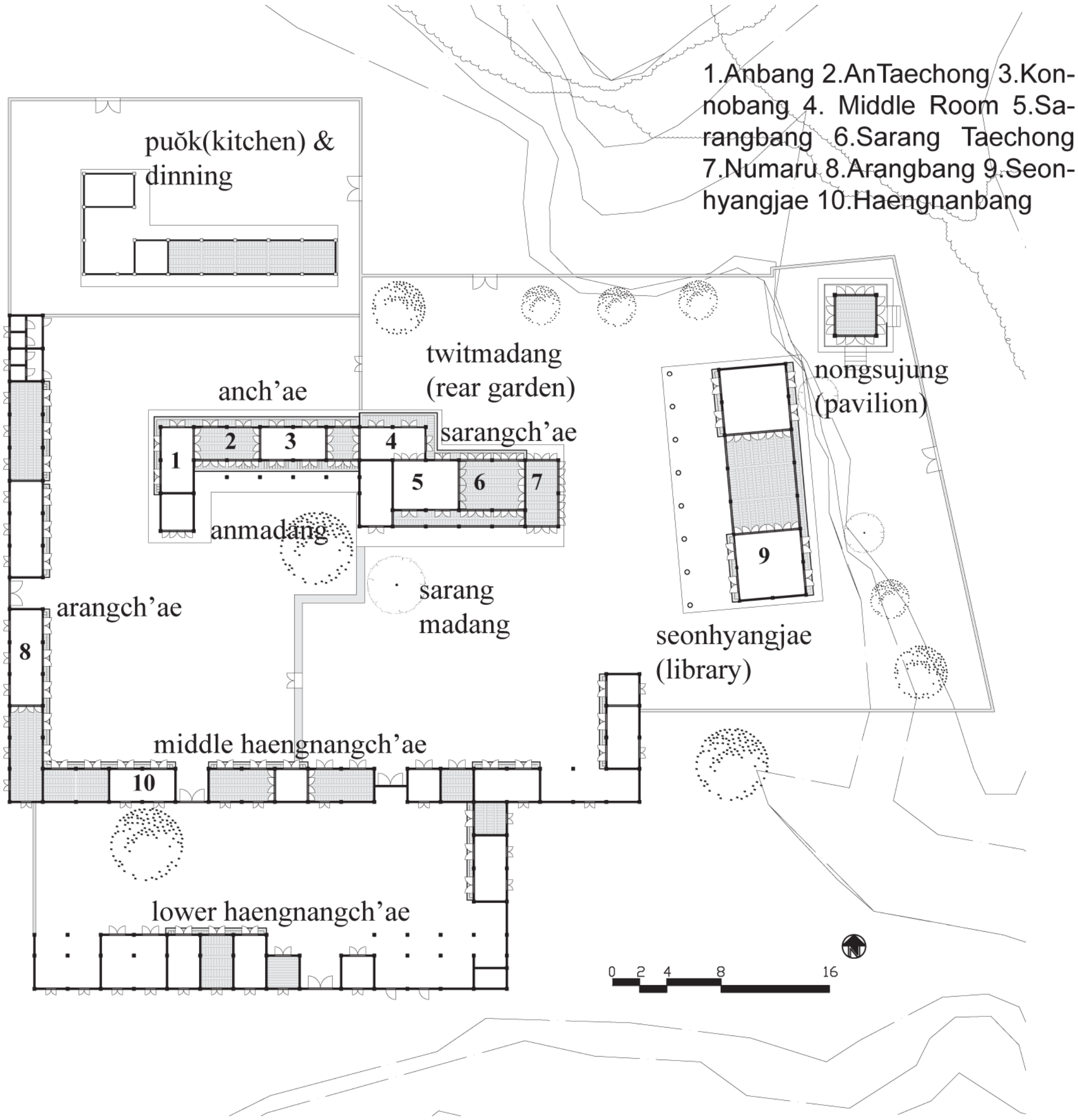


Figure 3-35 Selected Thermal Analytic Rooms

Zone	Anba ng	Antae chong	Konn oban g	Middl e Room	Saran gbang	Saran gtaec hong	Numa ru	Arang bang	Sunh aengc hae	Haen gnan gBan g
	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)
Total Floor Area(㎡):	12.25	11.52	11.76	11.64	18.13	18.13	18.13	17.52	36.01	12.25
Total Surface Area(㎡):	64.34	61.14	60.56	58.08	81.43	81.43	81.43	81.6	130.8	60.02
	525%	531%	515%	499%	449%	449%	449%	466%	363%	490%
Total Exposed Area(㎡):	25.08	27.29	25.52	23.20	21.63	27.42	27.42	35.04	35.16	29.52
	205%	237%	217%	199%	119%	151%	151%	200%	98%	241%
Total South Window(㎡):	0	7.08	4.395	3	6.092	7.788	7.788	0	0	2
	0%	62%	37%	26%	34%	43%	43%	0%	0%	16%
Total Window Area(㎡):	6.32	14.16	8.395	9	8.092	14.87	14.87	13.8	67	9.2
	52%	123%	71%	77%	45%	82%	82%	79%	67%	75%
Total Conductance (AU)(W/㎡ K):	61	62	54	50	47	64	64	76	87	62
Total Admittance (AY)(W/㎡ K):	187	172	168	164	229	233	233	232	392	168
Response Factor:	2.91	2.65	2.95	3.08	4.4	3.39	3.39	2.87	4.01	2.6

Table 3-2 ***Yeongyeongdang*** **Area and Environmental Factors Calculation**

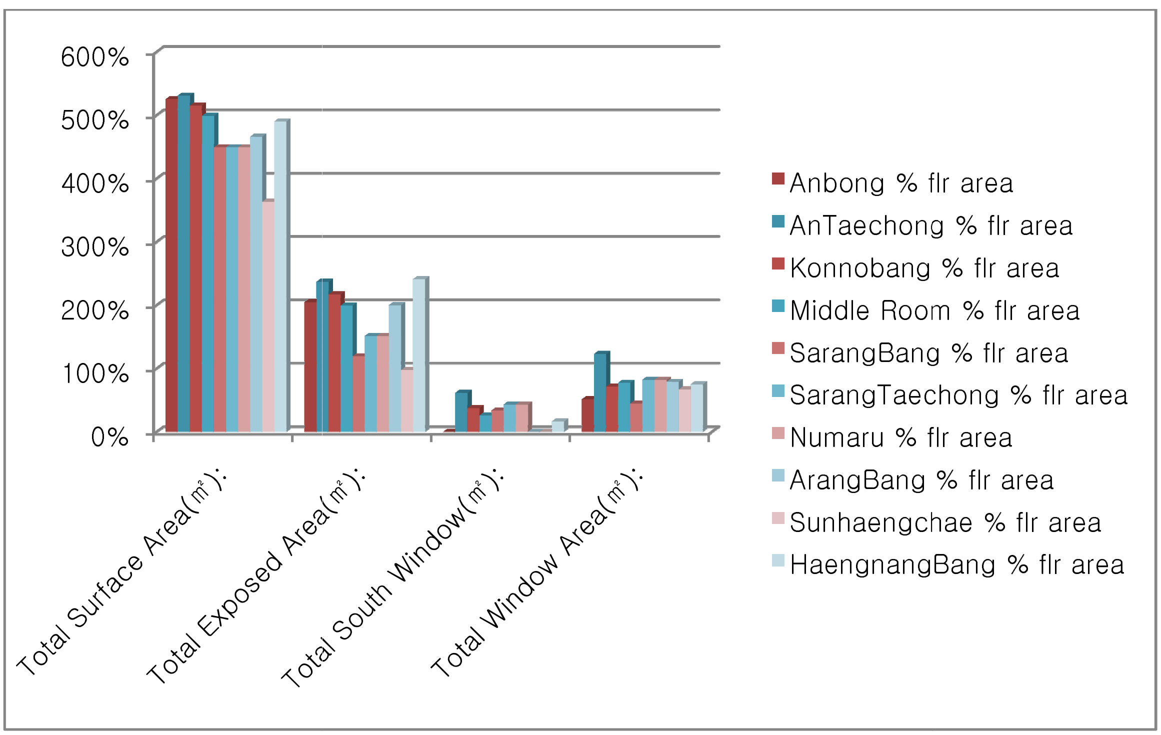


Figure 3-36 Percentage of Total are, this chart provides that the window area in ***Yeongyeongdang*** **is very bigger than contemporary residence**

3.4.3.1. Summer

In the summer, the hottest date is the July 23rd after two days of the summer solstice, at which the sun position is highest. The outside average temperature is the 27.5℃, and the range is from 23.5℃ at 24 o'clock to 31.8℃ at 1o'clock. The priority comfortable rooms, the cooling rooms, are ordered these following rooms; *numaru* ﹥ *antaechong* ﹥ Middle Room ﹥ *konnobang* ﹥ *haengnangbang* ﹥ *sarangtaechong* ﹥ *arangbang* ﹥ *anbang* ﹥ *sarangbang* ﹥ s*eonhyangjae*. The worst temperature in the s*eonhyangjae* is 29℃ at 1 o'clock. The percentage dissatisfied is 29.7% and the PMV is the 1.08 of the maximum hot point 3. The conditional factors are these following values: Relative Humidity 82%, Activity Rate 1.50met (standing), Clothing 0.50clo (Trousers and shirt), and Air Velocity 1.90m/s. While, when air velocity changes 0 m/s from 1.9m/s, the percentage dissatisfied would change 54.4% from 29.7% (Table 3-3). The result of analysis provides that *Yeongyeongdang* is not only satisfied with the thermal comfort in the summer. It also proofs that the air velocity is important factor. The *Yeongyeongdang* total window area of the total floor area excesses not only enough open over 50%, the *antaechong* case is 123% ,and the s*arangtaechong* and Numaru are 92% windows area of the total floor area. The window is also very flexibly moveable, and can open 100% of windows installation (Figure 3-22).

	Air Velocity (0 m/s)	Air Velocity (1.9 m/s)	
Air Temperature (℃) = 14	29	29	July 23rd
Radiant Temperature (℃)	23	23	
Relative Humidity (%)	82	82	Source by Korea Meteorological Administration, the average humidity from 1961 to 1990.
Activity Rate (met)	1.50	1.50	Standing
Clothing (clo)	1.00	1.00	Light Business Suit
Percentage Dissatisfied	54.4 %	29.7 %	

Table 3-3 Predicted Mean Vote, this table shows that if the air velocity is suitable well, the percentage dissatisfied changes from 54.5% to 29.7%.

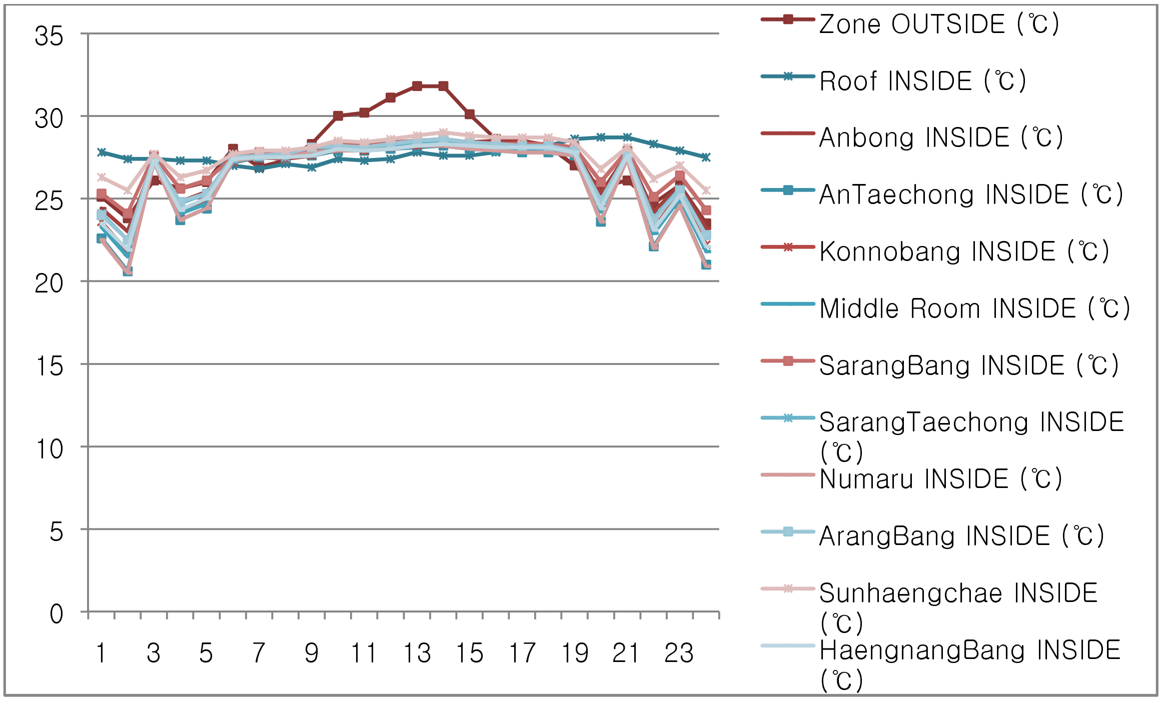


Figure 3-37 Hourly Temperature, July 23rd

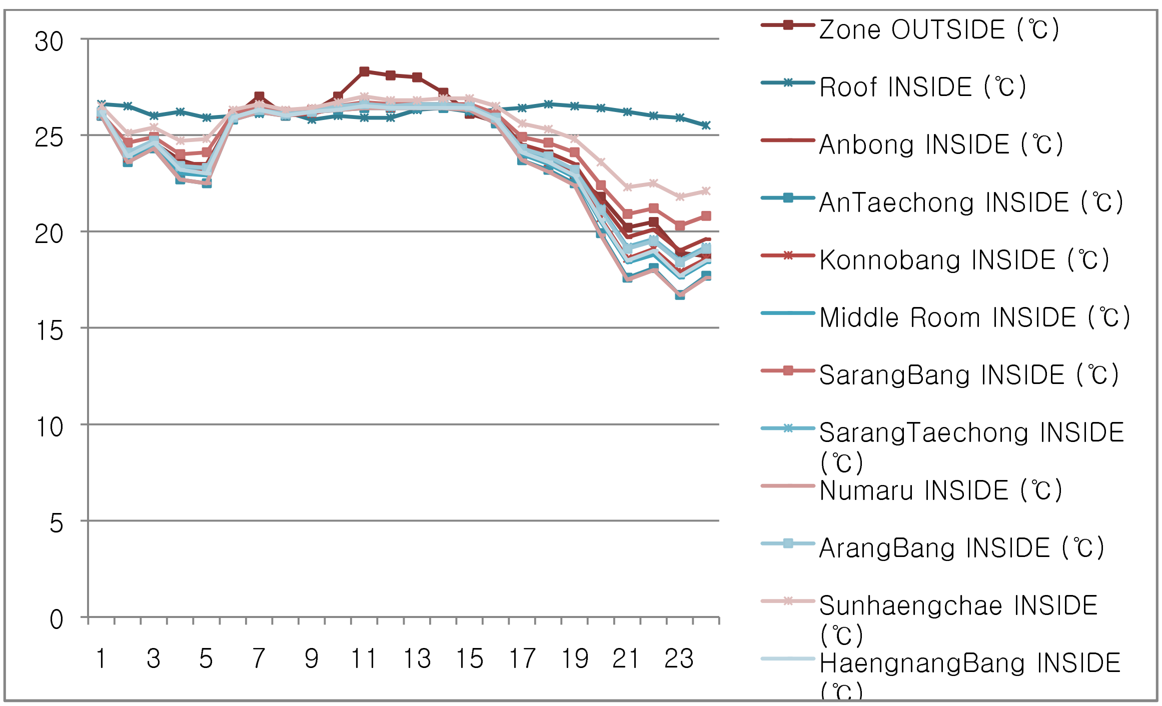


Figure 3-38 Hourly Temperature, August 23rd

3.4.3.2. Winter

In the winter, the better inside thermal comfort in Seoul, Korea definably should be warm temperature inside and keep the lasting warm energy. On January 13, the coldest date, the priority comfortable rooms are ordered these following rooms; s*arangbang* 〉*seonhyangjae* 〉 *arangbang* 〉 *haengnangbang* 〉 s*arangtaechong* 〉 *konnobang* 〉 *anbang* 〉 Middle Room 〉 *antaechong* 〉 *numaru*. The Middle Room, one of the coldest room, located in the north part of *sarangbang* manipulates that the *sarangbang* is the best condition, although the *sarangbang* has a higher total admittance (AY)(W/㎡K), which represents its ability to absorb and release heat energy and defines its dynamic response to cyclic fluctuations in temperature conditions. *Sarangbang* is the biggest size of room, approximately 18.13㎡, and the biggest exposed area, 21.63㎡, but the exposed window area is 8㎡, 45% of the total floor area, which is the smallest size comparing the other rooms(Table 3-2). Sarangbang ensures to keep the heat gain and to reduce the cooling energy from outside due to the maru in front to of sarangbang, which is enclosed by oiled-paper windows, and Middle Room, which is located on the backside of *sarangbang*. The hierarchal social status factors also contribute that the *sarangbang* is the most comfortable room. While, hieratically the *anbang* represents the second biggest measured room after *sarangbang* in the second emphasized important quarter, but the *anbang* condition is worse than *arangbang*, and *konnobang*. The *anbang* window area is only 52%, which is good to save energy, but there is no the total south window. The less south window size causes the less solar heat gain that leads to the worse condition, and the bigger north side windows can have the northwest winter wind. The social mores factor comes from Confucian principles as well as the privacy cause not to have the south windows in anbang. Comparing the metabolic heat output between male and female explains that female needs more the amount of heat[7]. This thermal analysis of Ecotect does not provide the ondol system, and the ondol heat discharge cannot be measured in currently preserved *Yeongyeongdang*. There is the biggest chimney behind the *anbang* structure, and then the speculations of the chimney position provide that the furnace, which placed near *anbang*, made further amount of heat

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[7] See also Chapter 2. Human Comfort

energy to *anbang*.

Seonhyangjae is the second best condition; even though it has the highest total admittance, 392 W/㎡K , and none of total south window. The smallest total exposed area, which is 35.158㎡ 98% of total floor area, protects loosing heat. *Numaru* (reception room in the summer) is the worst's situation in the winter, because the window area is the highest proportion compared any other rooms approximately 14.868 ㎡, 82 % total window area of total floor area. The window area, the surface area, and the south window area of *numaru* is same as the *sarangtaechong*, but the *sarangtaechong* has higher temperature because of the position in middle of *sarangbang* and *numaru*. Most of rooms provide higher temperature than *maru* place, which has no ondol system. There are three reasons, which lead to make *numaru* worse condition in the winter. First, the window surface areas are bigger. Second, there is no ceiling in the *maru*, and lastly, total exposed area is bigger. In this result, *numaru* was designed for summer activity and open space receiving visitors. Its wooden floor is constructed a step higher than that of all the other rooms with the sub floor space left open for ventilation, and the walls on three sides consisting of doors that swing up leaving the room open to the outside.

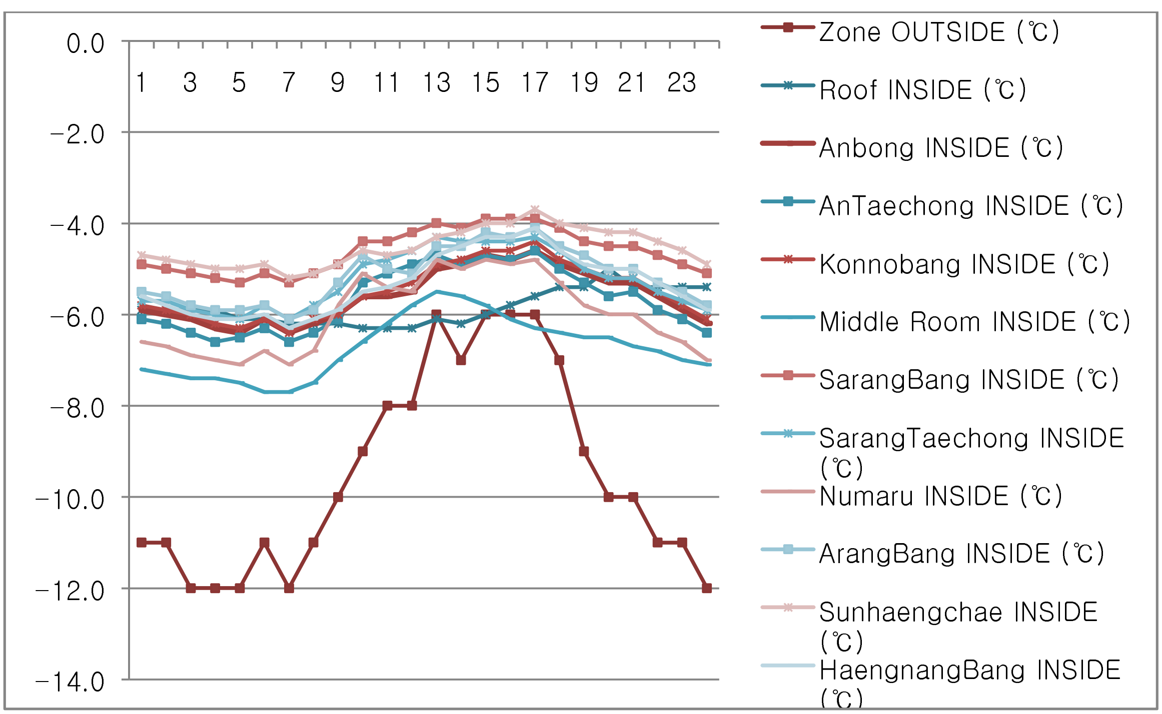


Figure 3-39 Hourly Temperatures, 13th January

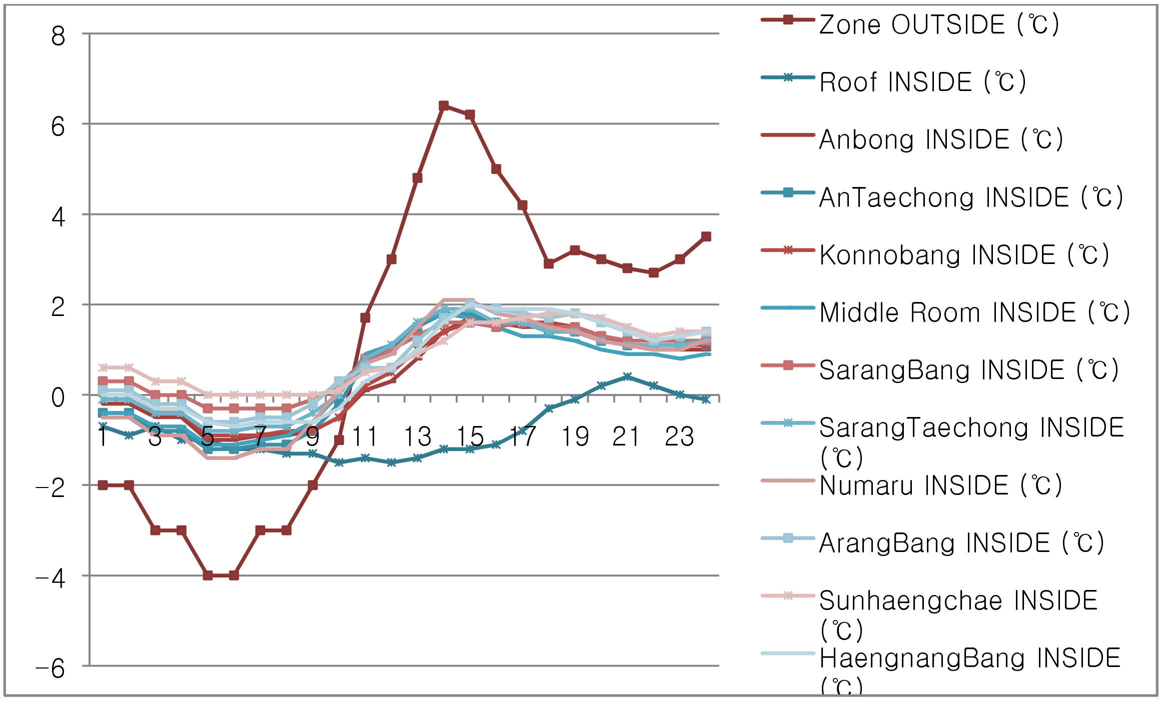


Figure 3-40 Hourly Temperature, 23rd December

3.4.3.3. Spring and autumn

In the May 6th, which starts suddenly to change the weather point from the spring to the summer, the average temperature is 14.6 ℃, and the range is from the 14℃ to the 16℃ in all of rooms in Yeongyeongdang. The dissatisfied percentage at the 14℃ air temperature point to the dissatisfied percentage at 33% in Predicted Mean Vote (PMV)[8] software offered by SQUARE One research, and the dissatisfied percentage at16℃ is 19.2% (Table 3-4). In any particular thermal environment, it is difficult to get more than 50 per cent of the people affected to agree that the conditions are comfortable (McMullan, 2007). In the date, the thermal comfort is mostly satisfied, but one could feel little cold for sleeping. If the clothing level is changed, the percentage satisfied should be changed.

	The lowest temperature	The highest temperature	
Air Temperature (℃) = 14	14	16	May 6th
Radiant Temperature (℃)	23	23	
Relative Humidity (%)	70	70	Source by Korea Meteorological Administration, the average humidity from 1961 to 1990.
Activity Rate (met)	1.50	1.50	Standing
Clothing (clo)	1.00	1.00	Light Business Suit
Air Velocity (m/s)	1.00	1.00	
Predicted Mean Vote	-1.48	-0.83	-3 too cold, +3hot
Percentage Dissatisfied	33.0 %	19.2 %	

Table 3-4 May 6th Predicted Mean Vote (PMV)

8 The Predicted Mean Vote (PMV) is based on heat balance equations for the human body and is an index that predicts the mean vote of a large group of people. This application supported by Ecotect implements ISO 7730-1993 (E) for calculating human comfort.

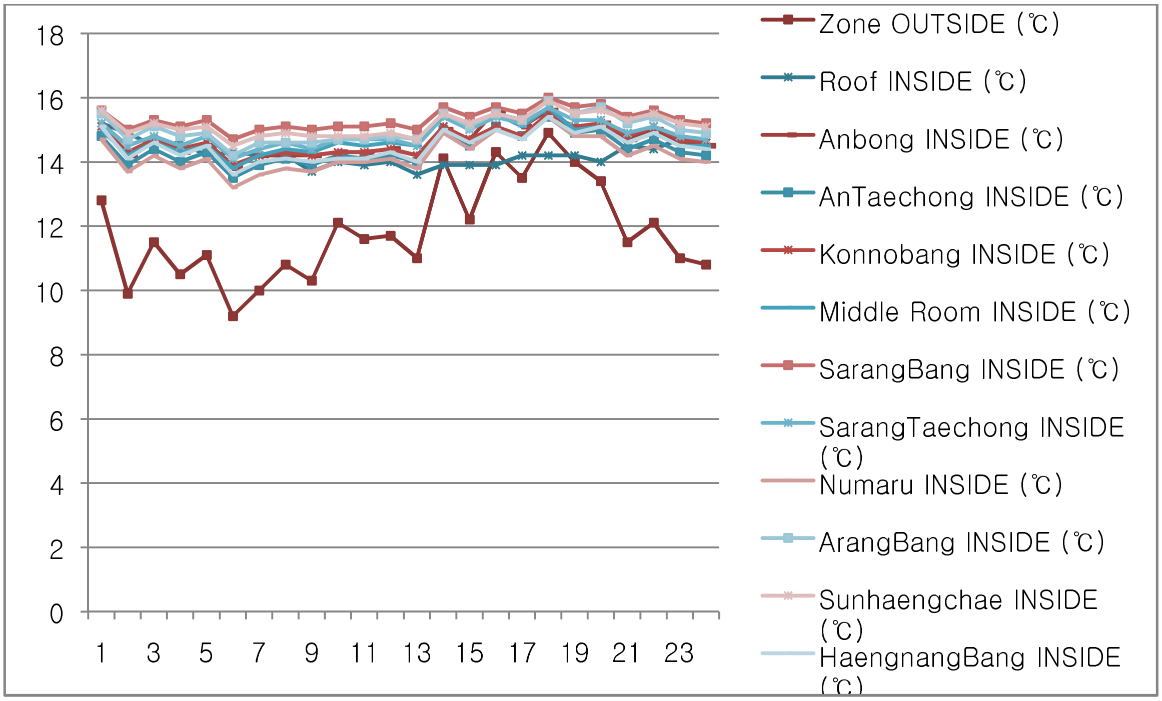


Figure 3-41 Hourly Temperature, May 6th

3.4.3.4. Other elements to decide *Yeongyeongdang* layout

Most materials are environmentally friendly and flexible. The *Yeongyeongdang* employed the *kan* measurement, which is equal to the width of the span between columns. The width of the span varies in length from 1.8 meters to 2.8 meters. It is the basic unit of measurement used in the traditional Korean residence. The modular measure depends on the local environment and the social hierarchy. They used not only the fine and straight trees, but they also used bent tree for building. This saved labor fee and preserved trees. Different Kan measurements are used by various conditions of buildings. One by one *k*an is used for pavilion. 3, 4, 5 *Kan* of front of building by 1, 2 *kan* of side used in a commoner's house, *minga*. 4 *kan* of front of building is used sleeping room in the palace. 5 *kan* of front of building used in school lecture hall, or royal palace. The *kan* measurement of *Yeongyeongdang* used 2,445 mm for X.Y axes, and the whole layout was strictly followed on the axes.

3.4.3.5. Thermal Mass: Roof and ondol

The ondol system utilizes the heat of smoke from an enclosed furnace. Excess heat from the furnace passes through flues located beneath the floor to a chimney at the other end of the room or rooms. The furnace is most commonly located in the kitchen, and it heats the rooms. The ondol system does not create any pollution or dust since the smoke pass through the flues to heat the pang and ventilate through an external chimney (Shin 2000). The roof is very thick, almost over thirty centimeters, which can preserve the heat in the light and keep the heat from *ondol*. The ondol system and the thicker roof are the thermal mass, which controls the heating and cooling in different seasons[9].

3.4.3.6. Oiled-paper

The oiled-paper used for sliding doors preserve the thermo energy and allows the fresh air to circulate inside. For the experiment data of oil-paper and the red soil regarding the U-Value (W/㎡.k), solar absorption and reflectance, the approximate quantity were used with similar materials. In this result, during the spring, summer, and autumn, the thermal performance is within the comfort zone. The satisfy degrees order that man's masters' quarter is first, the women's quarter is second, the south pace servant quarter is third, and the west quarter is last. U Value indicates Thermal Transmittance (BTU/[hr x ft^2 x ℉] or W/㎡.k), Measure of heat transferred through a building assembly Reciprocal of total R Value – (1/U). The higher the U value goes the greater the insulation value increases (McMullan and Seeley 2007) .

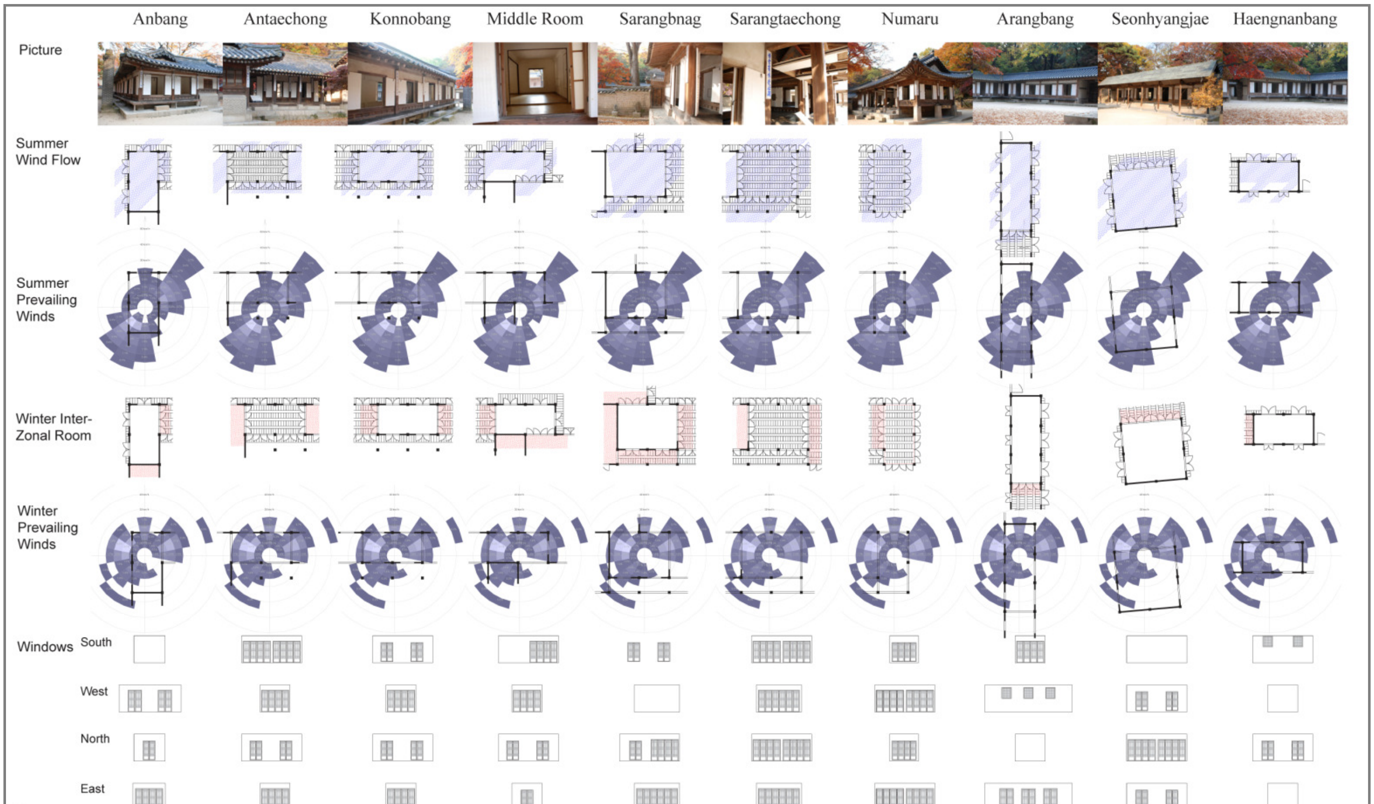
[9] See also Chapter 2

3.5. Summary

The modeling and visualization result of *Yeongyeongdang* through Ecotect software defines how *Yeongyeongdang* controls sunlight and daylight, shading, wind flow, and the thermal performance. The eaves length encloses the sunlight during the summer from May 6th to August 23rd, and the additional roof with oiled-paper blinds in the *seonhyangjae*, which faces west, perfectly prevents strong sunshine at sunset. The eaves of each building sufficiently were considered the sunlight and shading, and the eaves design was not focused only the summer solstice. The focus date was the summer end date, August 23, which is the last hottest day. The radiance classifies how much the white garden supply the daylight inside room. The prevailing wind helps to look at Yeongyeongdang layout well. However, the current Ecotect application does not support the various detailed material properties available for vernacular architecture such as the Korean oilpaper and the red soil wall.

In the thermal performance, the priority rooms define different order using by the different seasons, then in the winter season, the order are these following rooms: *seonhyangjae* > *sarangbang* > *arangbang* > *haengnangbang* > *sarangtaechong* > *konnobang* > anbang > Middle Room > *antaechong* > *numaru*. In the summer, the priority rooms, which are cooler rooms, are these following rooms: *numaru* > *antaechong* > Middle Room > *konnobang* > *haengnangbang* > *sarangtaechong* > *arangbang* > *anbang* > *sarangbang* > *seonhyangjae*. These orders are satisfied with the rooms function, but anbang was not very good condition comparing other rooms, because its room emphasizes the privacy and the social mores rather than the environmental condition.

In this research, Ecotect, the environmental analysis tool, sheds some lights on our understanding of the environmental principles embedded in the original design of *Yeongyeongdang*. Ecotect was employed for realizing *Yeongyeongdang* on the broad range of simulation, and analyzing its functions required for maximizing environmental values by data. The outcomes from the analysis provide that this traditional Korean Architecture, *Yeongyeongdang*, was built with incorporating various ecological factors into its basic design and layout, which are heavily influenced by social and cultural structure. It confirms that as the traditional Korean architecture, *Yeongyeongdang* satisfies the environmental, cultural and historical requirements in which the architecture exists (Shin 2000).



		Anbang	Antaechong	Konnobang	Middle Room	Sarangbnag	Sarangtaechong	Numaru	Arangbang	Seonhyangjae	Haengnanbang
Area											
Total Floor Area(m²):		12.25	11.52	11.76	11.64	18.13	18.13	18.13	17.52	36.01	12.25
Total Surface Area(m²):		64.34	61.14	60.56	58.08	81.434	81.434	81.434	81.6	130.776	60.02
		525%	531%	515%	499%	449%	449%	449%	466%	363%	490%
Total Exposed Area(m²):		25.08	27.291	25.52	23.197	21.63	27.414	27.414	35.04	35.158	29.52
		205%	237%	217%	199%	119%	151%	151%	200%	98%	241%
Total South Window(m²):		0	7.08	4.395	3	6.092	7.788	7.788	0	0	2
		0%	62%	37%	26%	34%	43%	43%	0%	0%	16%
Total Window Area(m²):		6.32	14.16	8.395	9	8.092	14.868	14.868	13.8	67	9.2
		52%	123%	71%	77%	45%	82%	82%	79%	67%	75%
Priority Room In Summer		8	2	4	3	9	6	1	7	10	5
Building Fabric	6-May	-7,464	-8,154	-6,618	-6,330	-5,834	-8,454	-9,830	-8,888	-8,159	-7,538
	21-Jun	375	19	89	91	1,269	10	142	711	200	98
	23-Jul	2,626	2,626	2,252	2,129	1,958	2,716	3,208	3,373	2,922	2,578
	23-Aug	644	638	570	530	491	659	776	852	763	655
Solar Heat Gain	6-May	525	248	147	158	115	260	371	166	131	161
	21-Jun	1,563	448	279	308	206	472	974	469	255	296
	23-Jul	703	392	231	261	180	411	799	296	233	255
	23-Aug	226	210	124	133	97	220	338	118	108	136
Ventila-tion Gain	6-May	-2,145	-2,013	-2,055	-2,034	-3,167	-3,167	-2,059	-2,984	-4,239	-2,140
	21-Jun	-16	-15	-16	-16	-24	-24	-16	-23	-33	-16
	23-Jul	714	670	684	677	1,054	1,054	685	993	1,411	712
	23-Aug	138	129	132	130	203	203	132	191	272	137
Internal Loads		1,470	1,382	1,411	1,397	2,176	2,176	1,411	2,045	2,905	1,470
Inter-zonal Loads	6-May	-363	-74	-274	38	-1,022	-409	66	-302	-529	-200
	21-Jun	-894	-645	-800	-405	-2,321	-1,042	-601	-1,119	-1,636	-779
	23-Jul	-1,345	-1,131	-1,269	-1,046	-2,376	-1,935	-1,062	-1,782	-2,600	-1,268
	23-Aug	-1,247	-968	-1,170	-886	-2,310	-1,758	-872	-1,597	-2,357	-1,134
Priority Room in Winter		7	9	6	8	2	5	10	3	1	4
Building Fabric	23-Dec	-21,843	-23,184	-19,205	-18,313	-16,819	-23,976	-27,812	-26,654	-23,779	-21,691
	13-Jan	-34,897	-37,245	-30,676	-29,258	-26,897	-38,555	-44,720	-42,249	-37,914	-34,726
Solar Heat Gain	23-Dec	387	598	342	142	437	789	796	193	171	271
	13-Jan	252	623	267	133	432	731	909	207	173	252
Ventilation Gain	23-Dec	-5,635	-5,288	-5,398	-5,343	-8,322	-8,322	-5,410	-7,839	-11,137	-5,623
	13-Jan	-8,105	-7,605	-7,763	-7,684	-11,969	-11,969	-7,781	-11,274	-16,017	-8,087
Internal Loads		1,470	1,382	1,411	1,397	2,176	2,176	1,411	2,045	2,905	1,470
Inter-zonal Loads	23-Dec	934	856	838	1,003	956	1,307	947	1,253	1,696	891
	13-Jan	1,242	1,426	1,211	1,599	1,109	1,907	1,609	1,844	2,520	1,357

Table 3-5 *Yeongyeongdang* Summary of the Environmental Analysis

3.6. Drawings

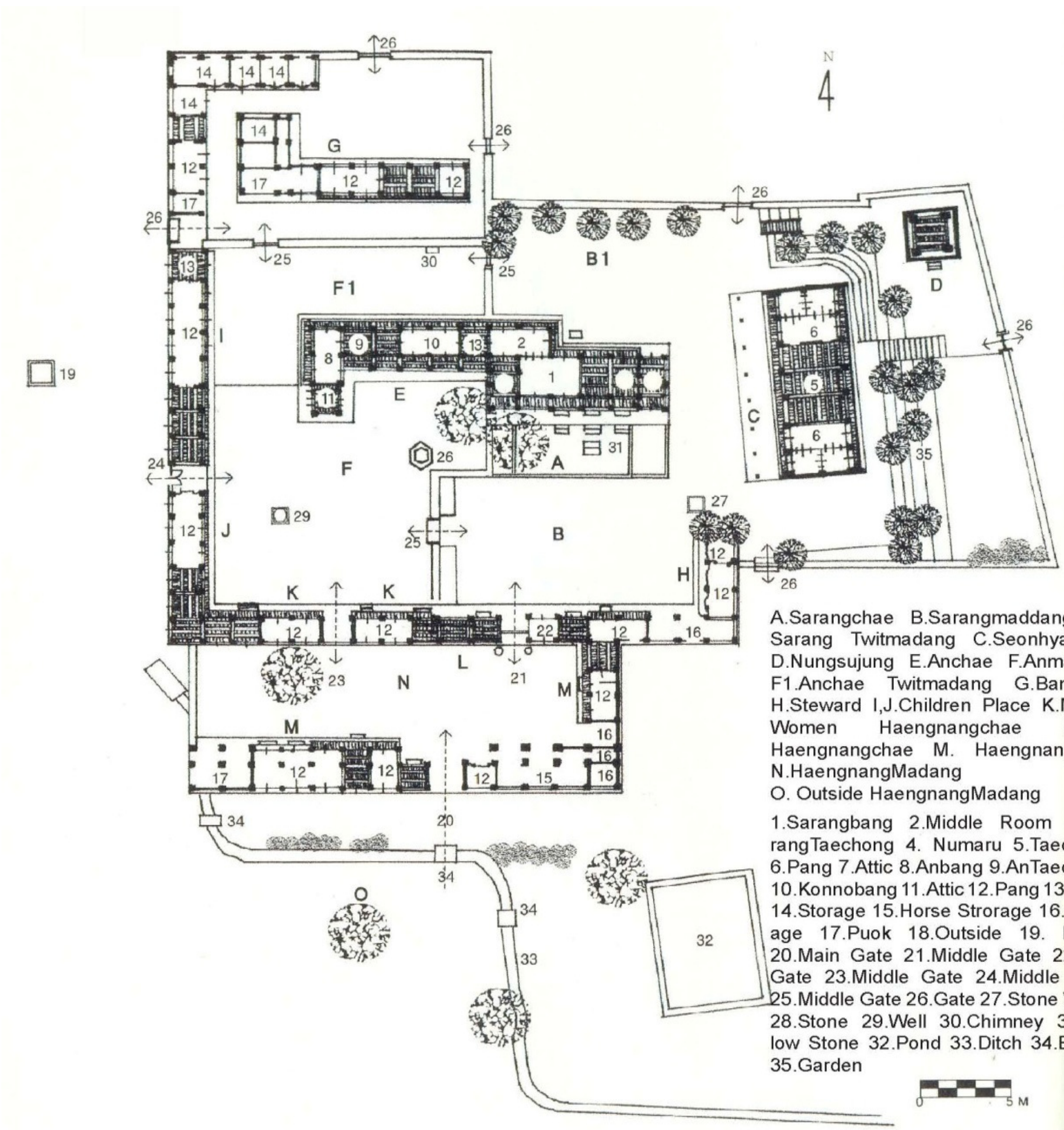


Figure 3-42 Site Layout (Original Plan) (N. Zu 2003)

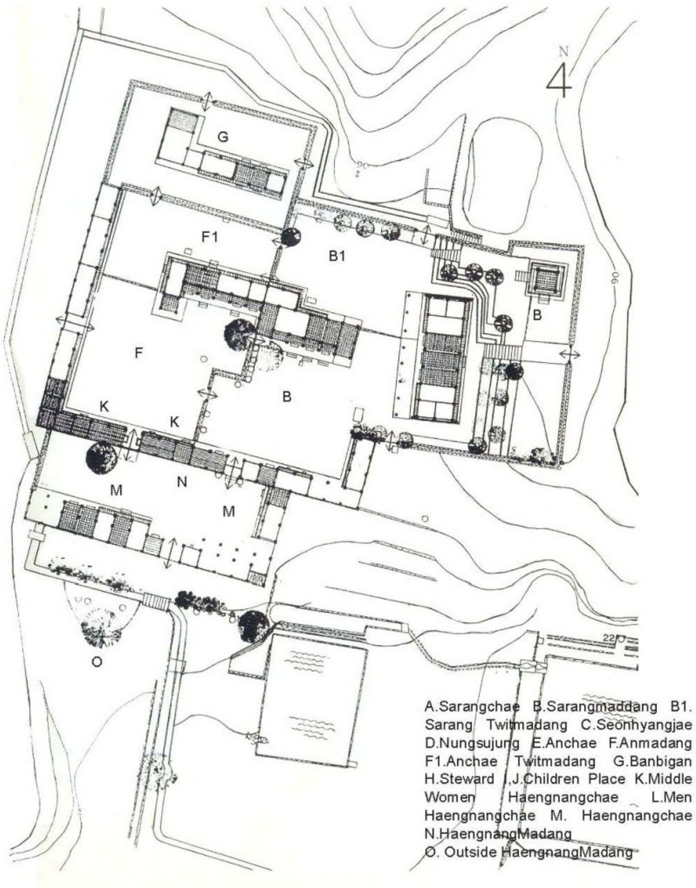


Figure 3-43 Existing Plan (N. Zu 2003)

Figure 3-44 Original Plan in 1826~1830 (J.-D. Choi 2005) (An and Yu 2005)

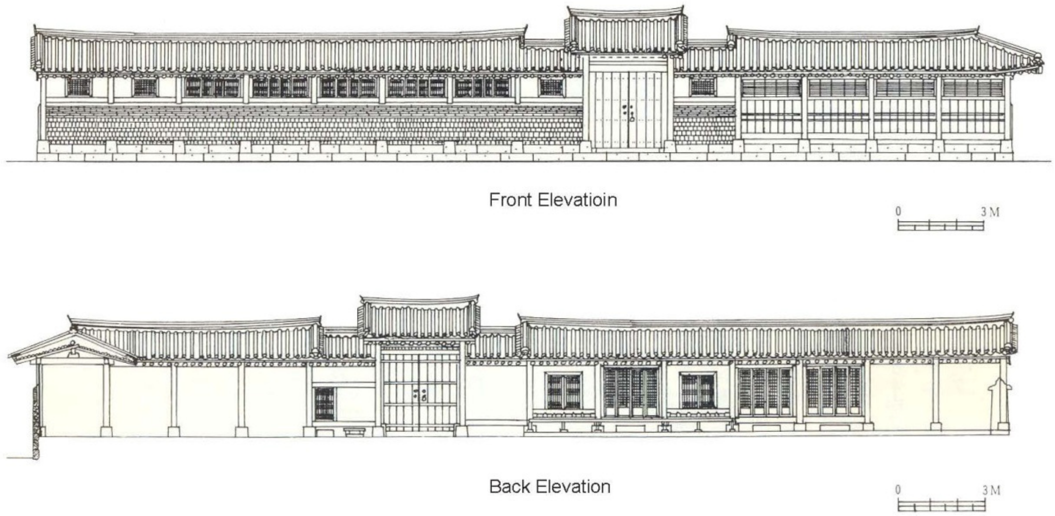


Figure 3-45 Haengnangchae Elevation (N. Zu 2003)

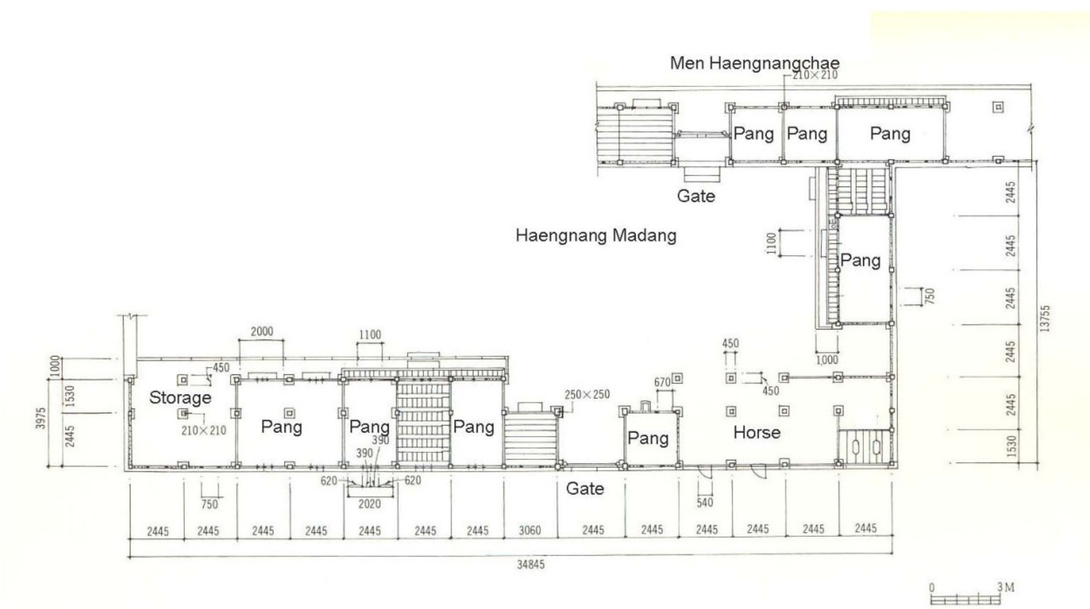


Figure 3-46 Haengnangchae Floor Plan (N. Zu 2003)

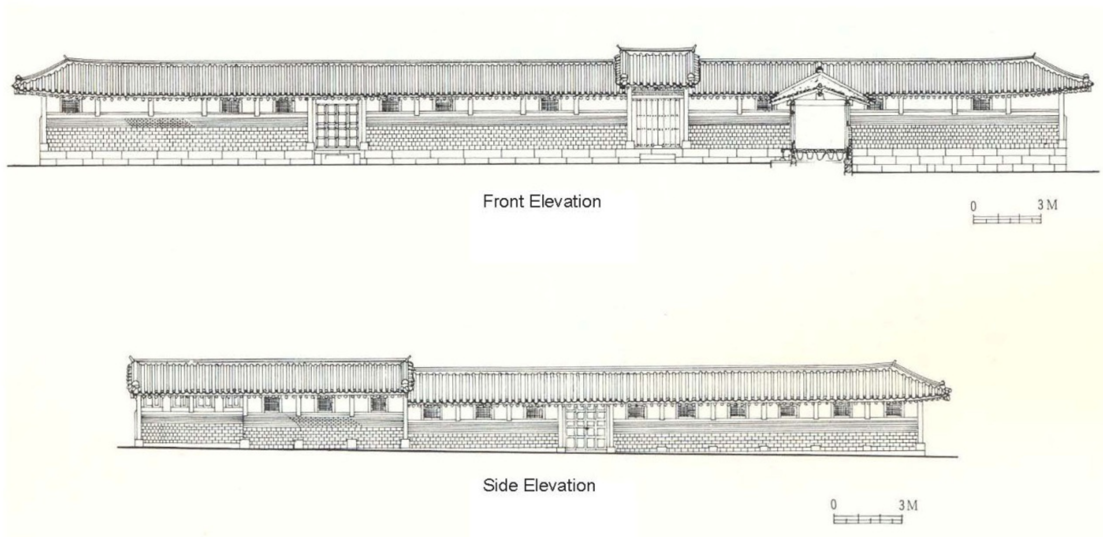


Figure 3-47 Middle Haengnangchae Elevation (N. Zu 2003)

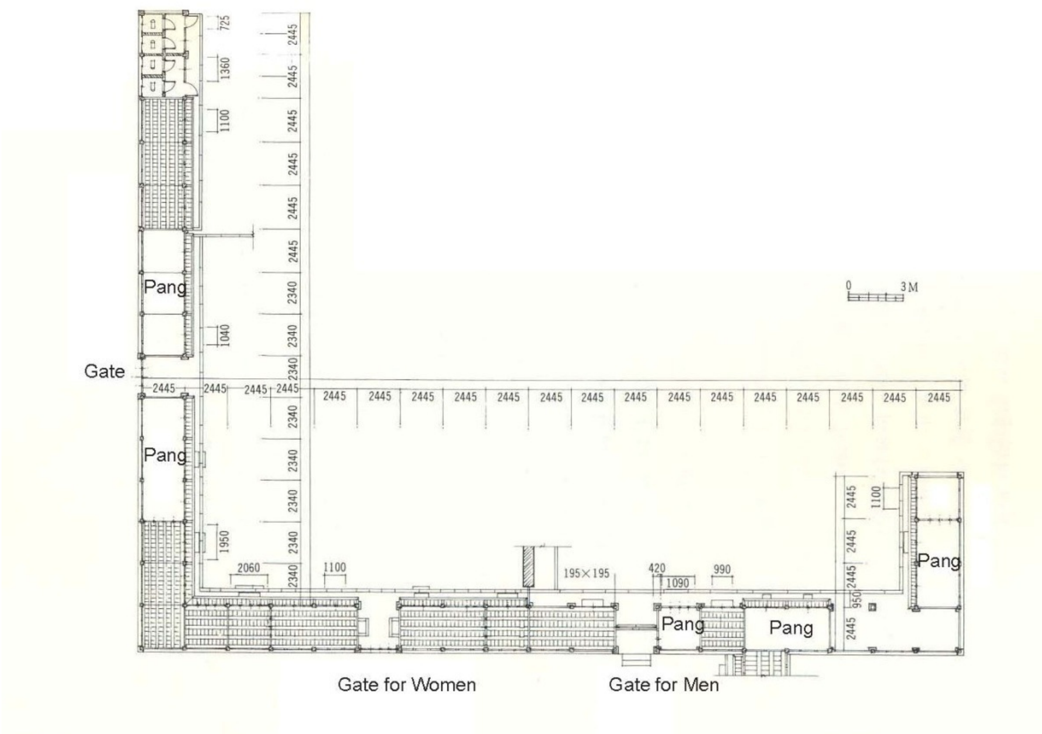


Figure 3-48 Middle Haengnangchae Floor Plan (N. Zu 2003)

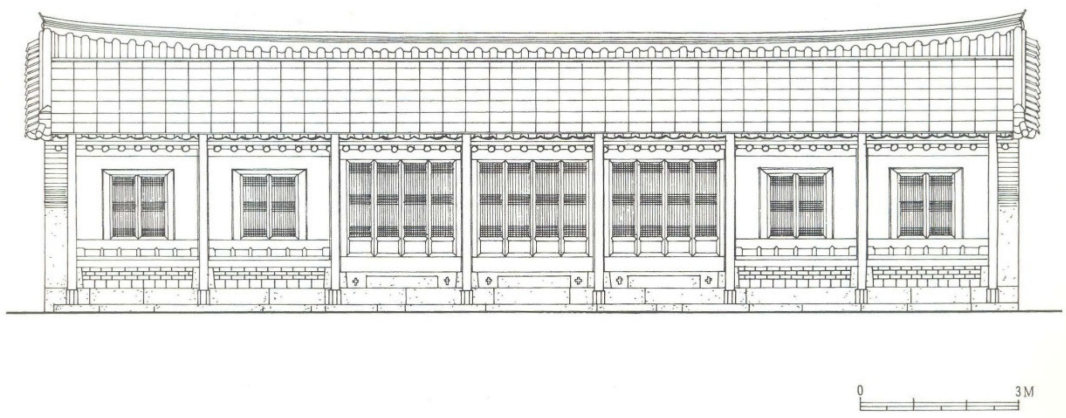


Figure 3-49 Seonhyangjae Elevation (N. Zu 2003)

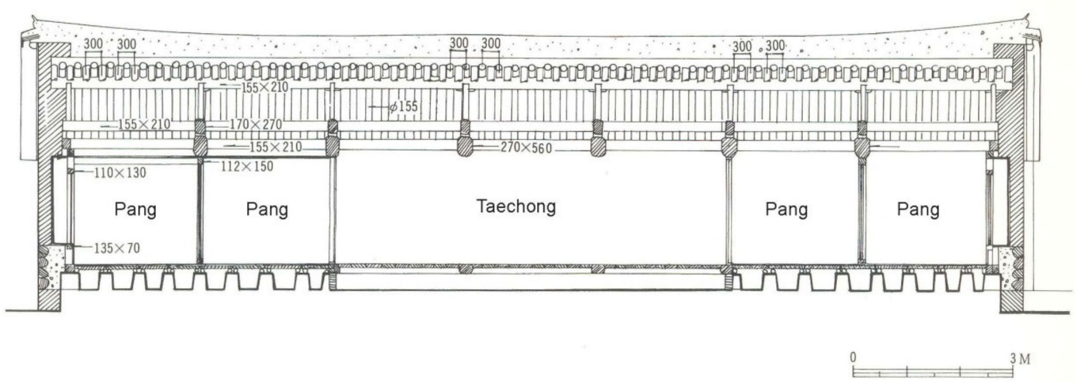


Figure 3-50 Seonhyangjae Section (N. Zu 2003)

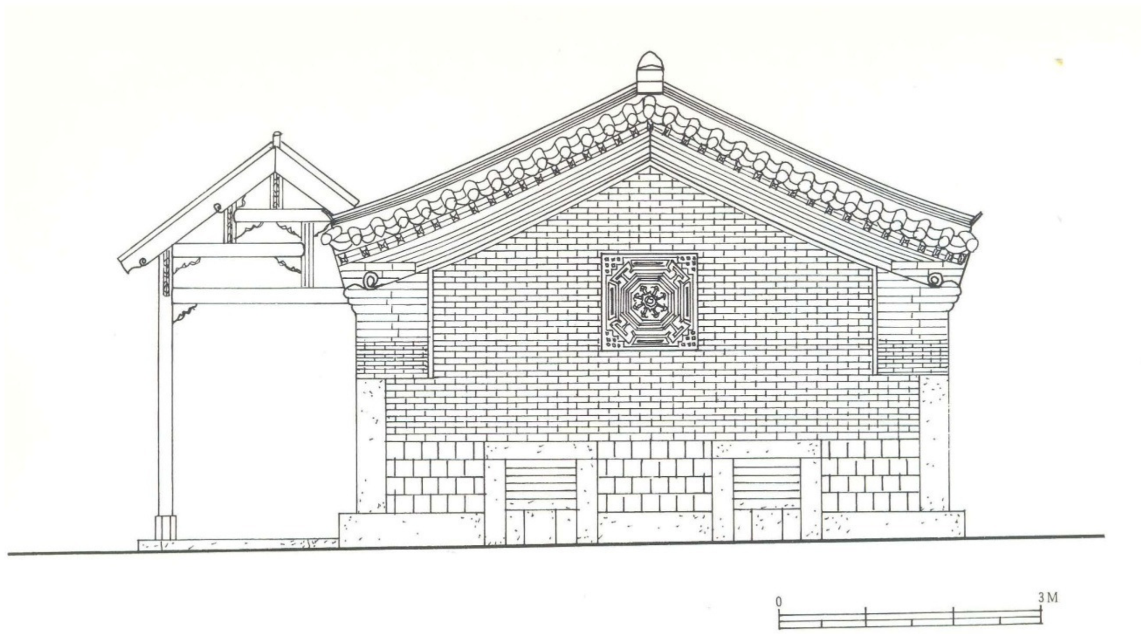


Figure 3-51 Seonhyangjae Right Elevation (N. Zu 2003)

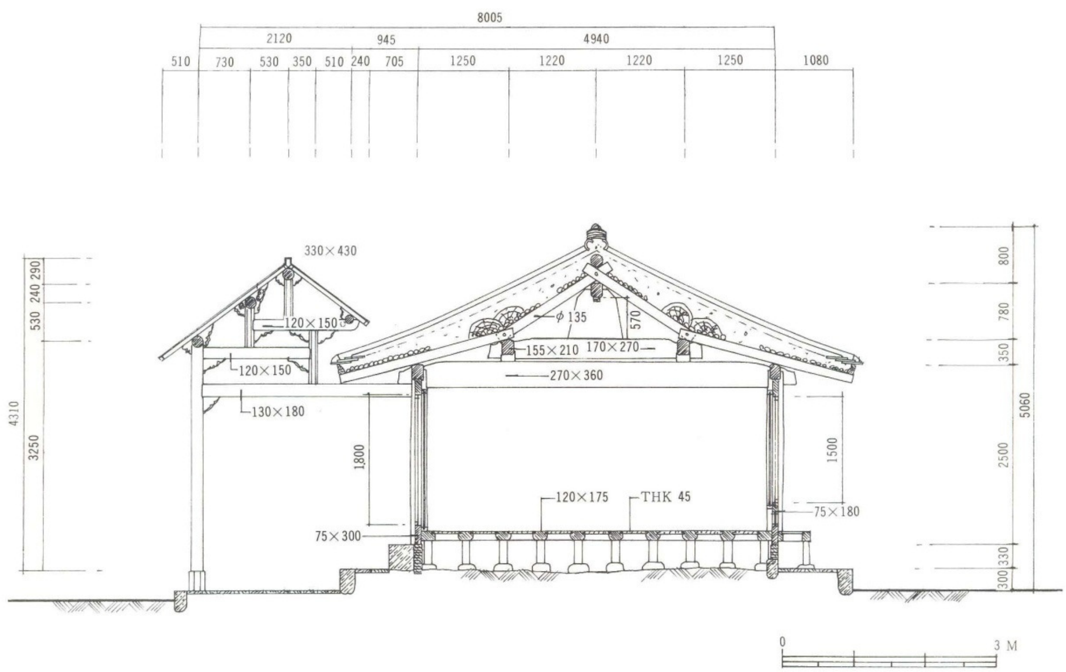


Figure 3-52 Seonhyangjae Cross Section (N. Zu 2003)

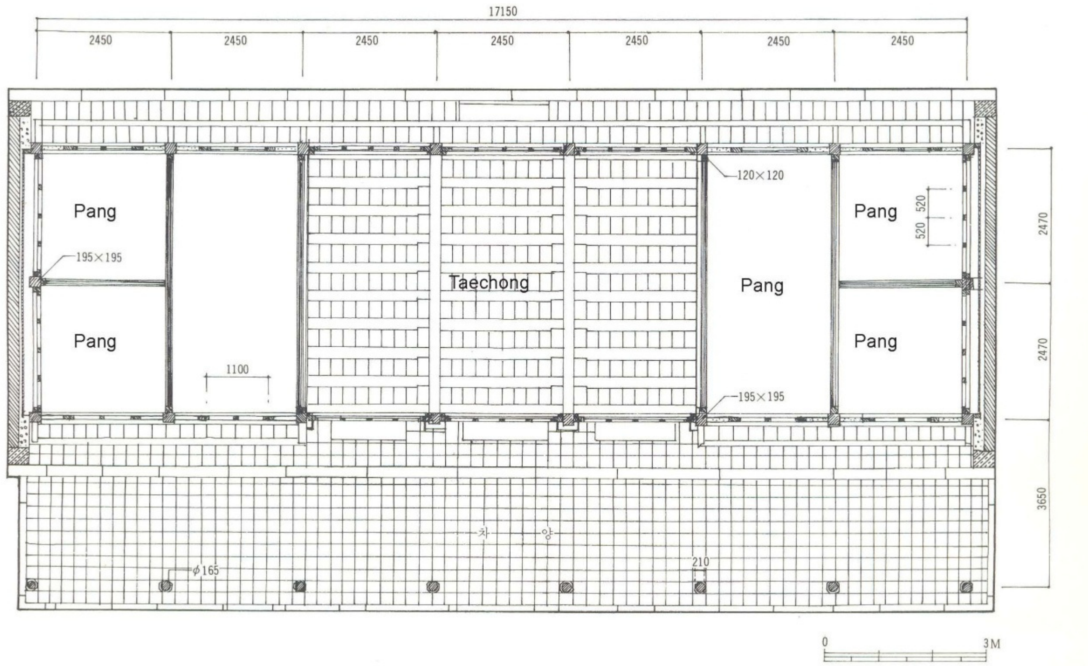


Figure 3-53 *Seonhyangjae* Floor Plan (N. Zu 2003)

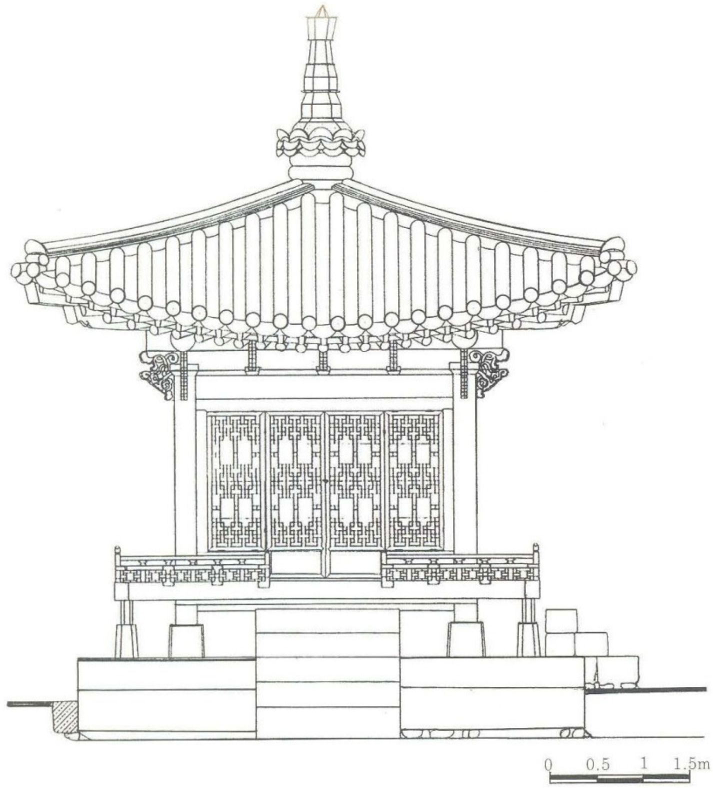


Figure 3-54 ***Nungsujung*** **Front Elevation (N. Zu 2003)**

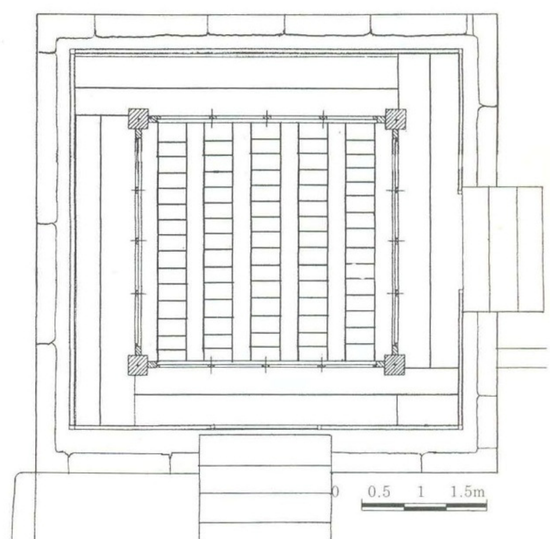


Figure 3-55 ***Nungsujung*** **Floor Plan (N. Zu 2003)**

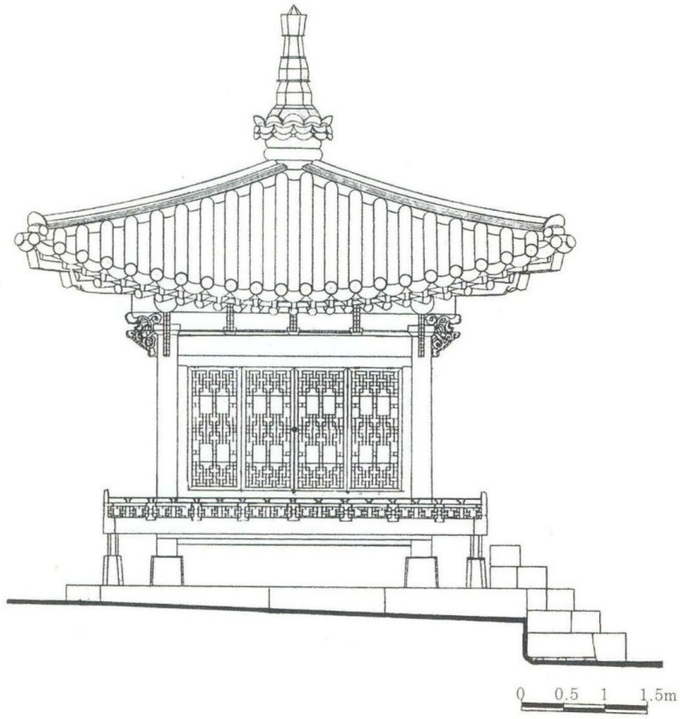


Figure 3-56 ***Nungsujung*** **Side Elevation (N. Zu 2003)**

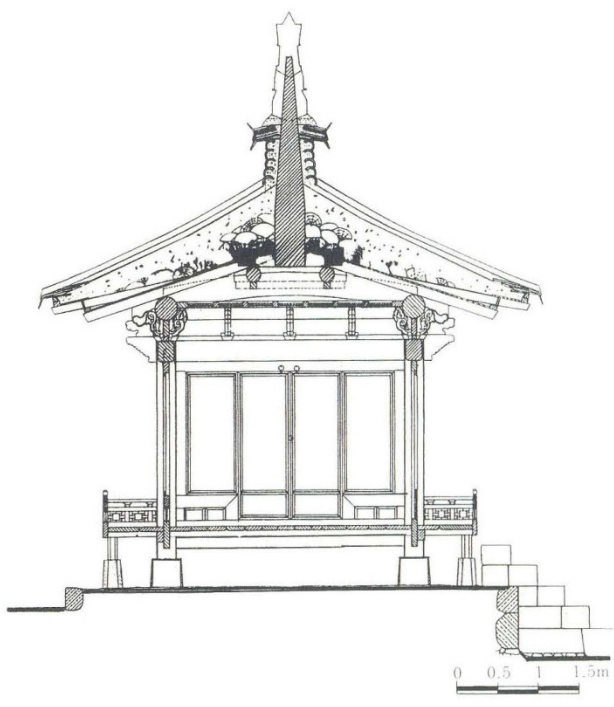


Figure 3-57 ***Nungsujung*** **Section (N. Zu 2003)**

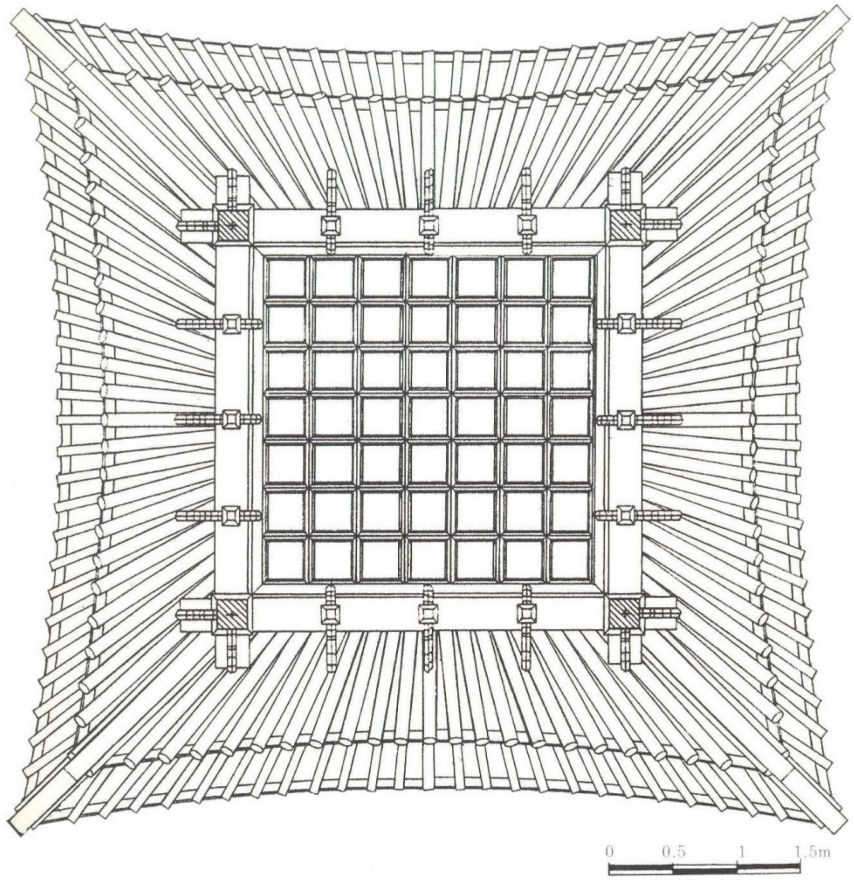


Figure 3-58 *Nungsujung* Ceiling Plan (N. Zu 2003)

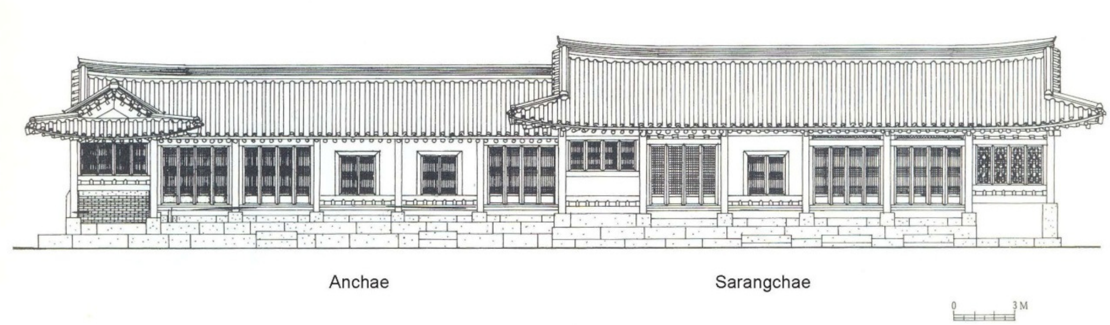


Figure 3-59 ***Anchae*****,** ***Sarangchae*** **Front Elevation (N. Zu 2003)**

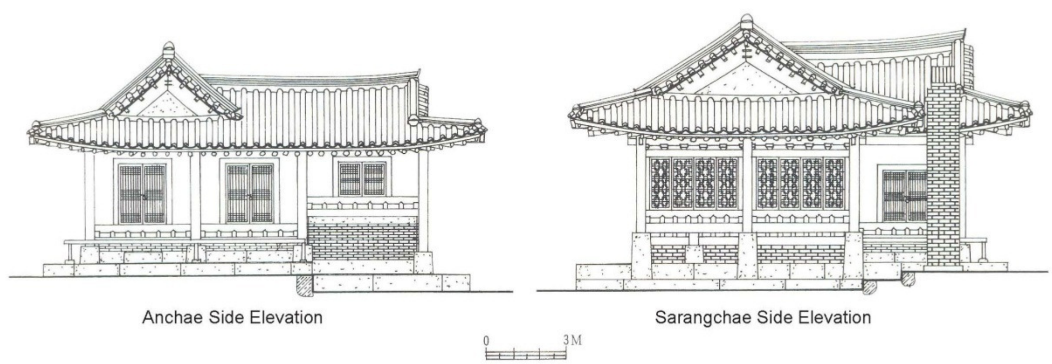


Figure 3-60 ***Anchae*****,** ***Sarangchae*** **Side Elevation (N. Zu 2003)**

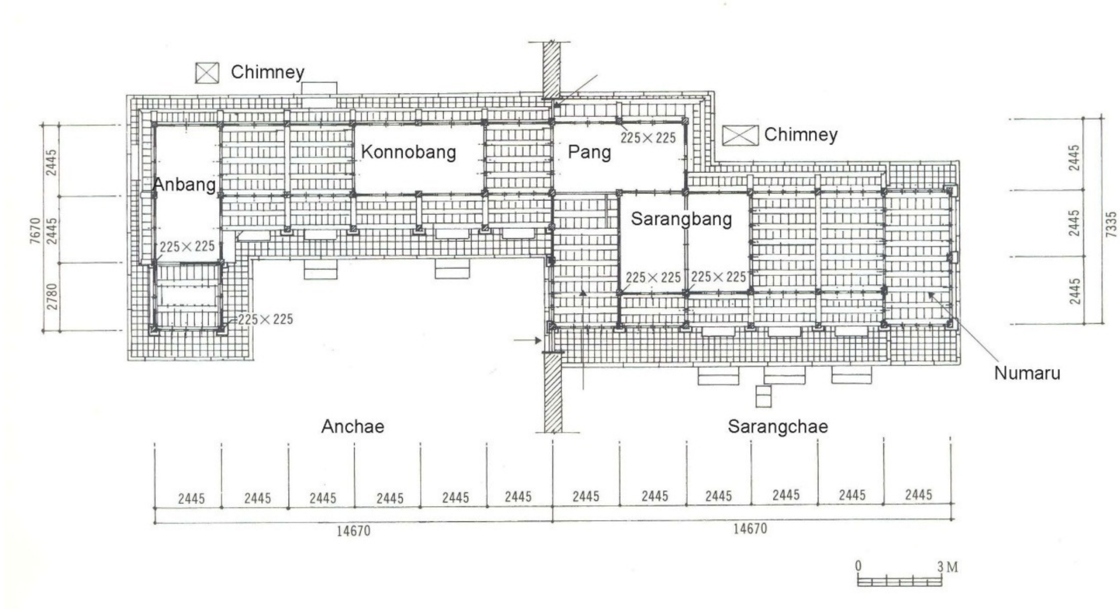


Figure 3-61 *Anchae*, *Sarangchae* Floor Plan (N. Zu 2003)

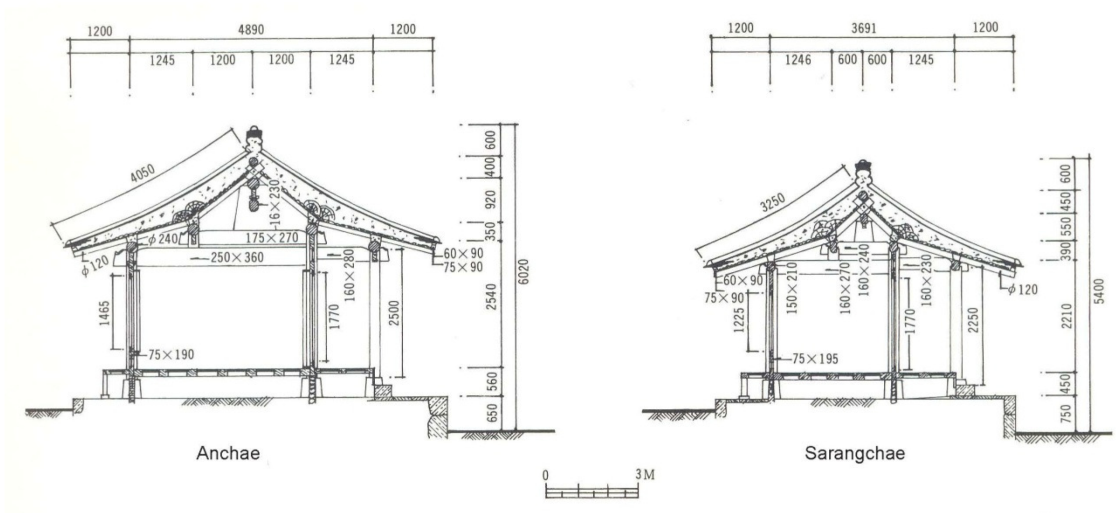


Figure 3-62 *Anchae*, *Sarangchae* Section (N. Zu 2003)

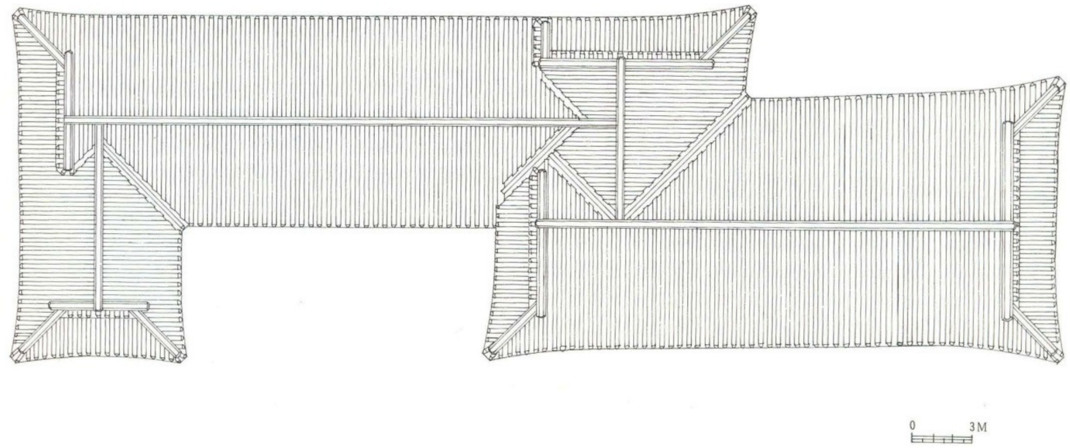


Figure 3-63 ***Anchae*****,** ***Sarangchae*** **Roof Plan (N. Zu 2003)**

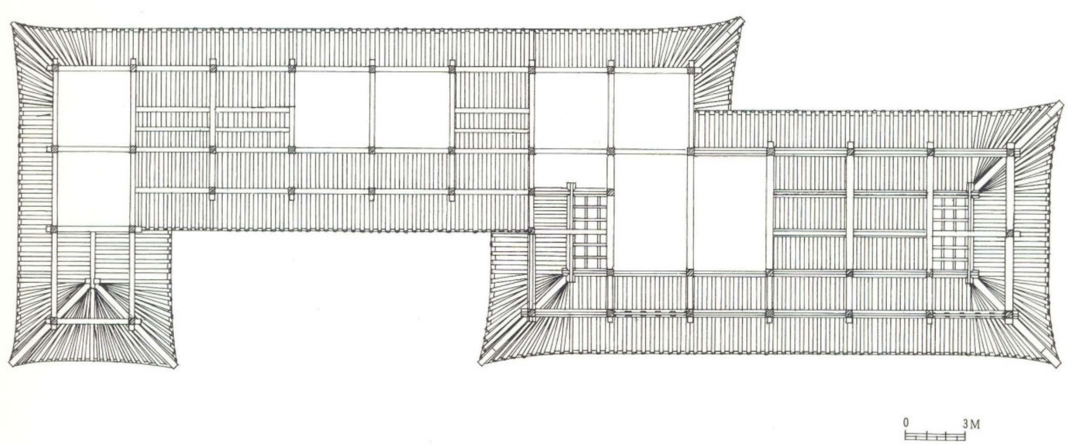


Figure 3-64 ***Anchae*****,** ***Sarangchae*** **Ceiling Plan (N. Zu 2003)**

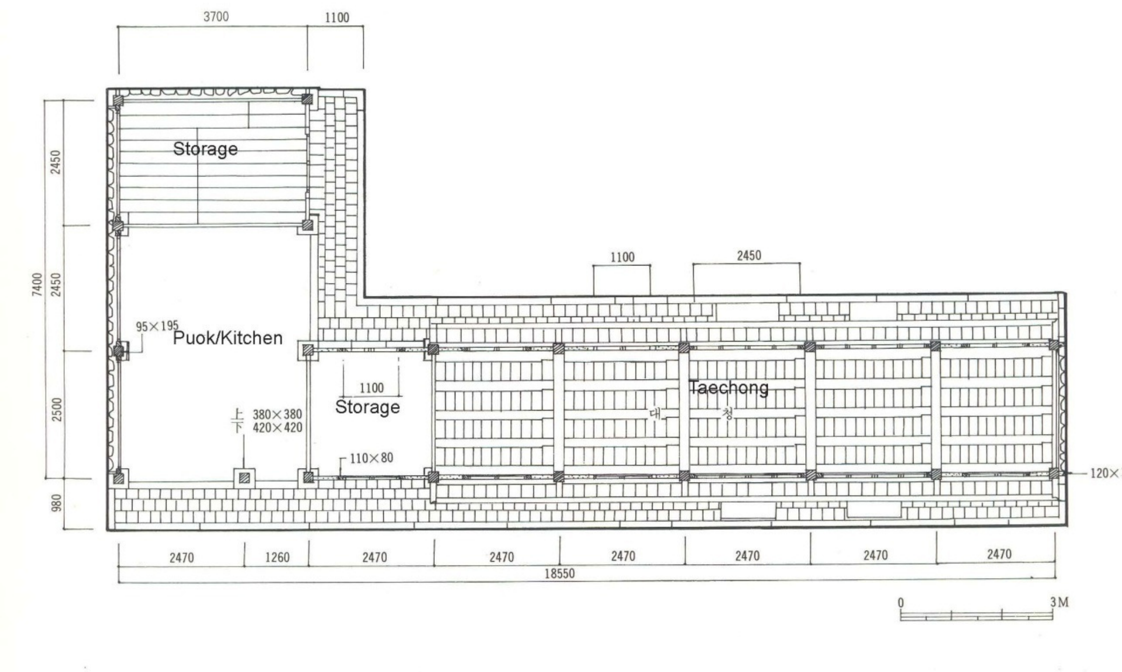


Figure 3-65 *Banbingan*/ Kitchen & Dinning Floor Plan (N. Zu 2003)

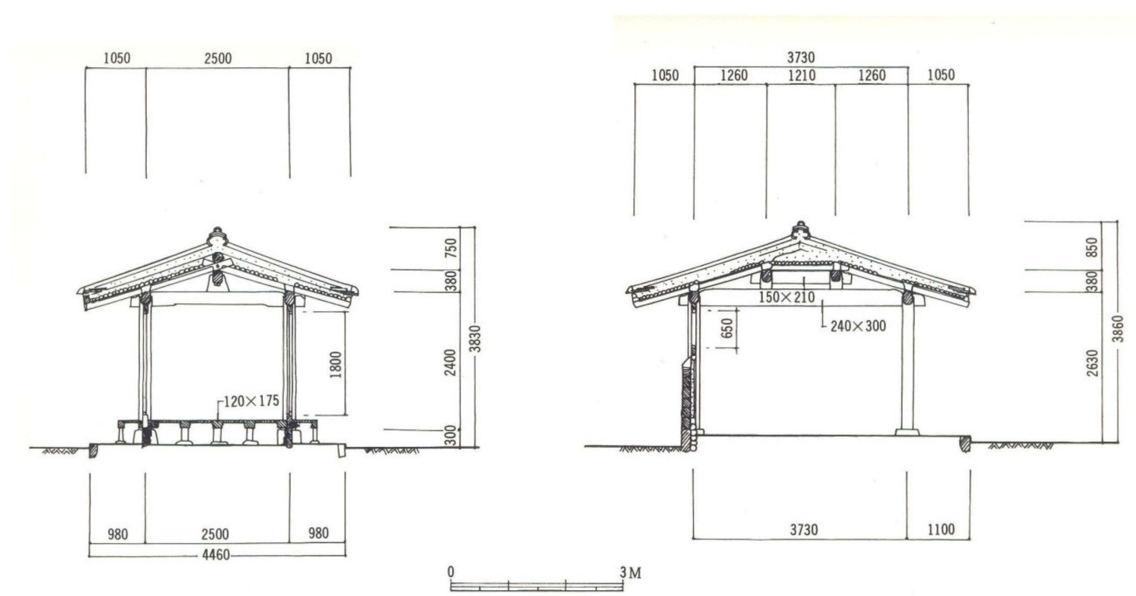


Figure 3-66 *Banbingan*/Kitchen & Dinning Section (N. Zu 2003)

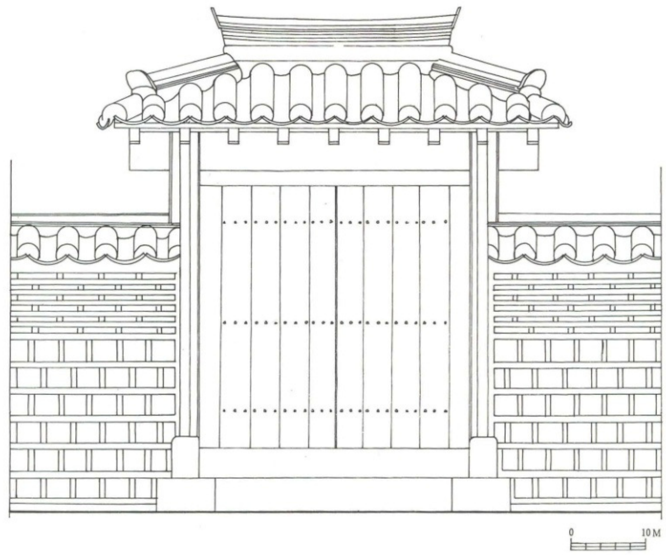


Figure 3-67 Side Gate Elevation (N. Zu 2003)

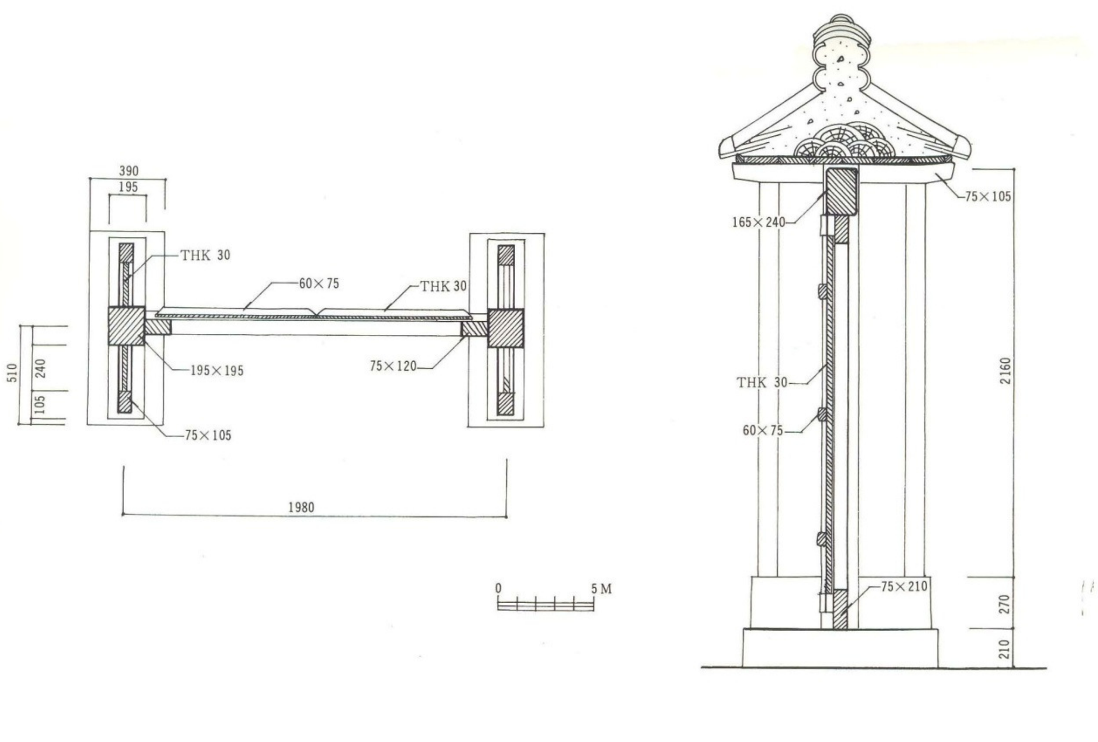


Figure 3-68 Side Gate Section (N. Zu 2003)

4. *UNJORU* - TEST MODEL II

4.1. Introduction

Unjoru, another selective project, represented one of good example of the traditional upper level residence, which has adoption of pungsu idea and reflection of the same age social tendency where exists in southern part of Korea. This chapter affords how the *Unjoru* reflects not only the social impact and cultural impact, but also mainly focus on the environmental analysis. Unlike the previous analyzing residence, *Yeongyeongdang*, *Unjoru* has different neighborhood condition and built on the different surrounding geographical conditional site, which is located on the slope site unlike *Yeongyeongdang*, which is located on the flat site. Most of the traditional residence in Korea has been built on the low mountains and hills. Therefore, the *Unjoru* can show the normal traditional design living more than the *Yeongyeongdang* analysis.

In this chapter, the analysis of *Unjoru* makes more deeply digging how the Korean ancestor live with the environmental factors and how the upper class level live around the late 18th century to the early 19th century. The different geographical characteristics in the different area environment within Korea also had decided the residence's layouts and appear different compositions. *Unjoru* layout specially emphasizes the Confucian principles, which was established as the dominant philosophy where ancestor worshipping became the core practice of people's spiritual. It shows that the separation of men from women, and the need for an ancestral shrine became fundamental elements in the composition of the traditional Korean residence. This chapter provides the evidence that *Unjoru* incorporated the environmental design responses into its design with administering the shadows, shading, solar analysis, wind flow, and thermal performance.

4.2. History

Unjoru as the representative residence building of the west southern part of Korea is the building built in 1776 (the 52nd year under King *Yeongjo* of *Joseon* period), and it is typical of upper-class residences of the *Joseon* Dynasty and is rarely found in *Honam* area, the west southern part of Korea. *Unjoru* was built by Yu Eui-ju who had been born in *Andong*, *Gyeongsangnamdo*, the east southern part of Korea, and worked as the town country headman, major local governors, and a national architect in charge in the west southern part of Korea (N.-C. Zu 2003). Therefore, the east southern Korean residence style showed in the west southern part of Korea. Yu Eui-ju architectural experience might assist that the *Unjoru* had very good condition of environmental design responses, and leaded to the east southern architectural style in the west southern part of Korea at the time. The west southern style separates the man quarter and women quarter in the different each structure, but the west southern style composed two different quarters in the same structure, like the *Chusagotaek*. Various household goods and relics remain here.

In terms of *pungsu* idea, *Unjoru*, the name of the house, means "the house hidden in clouds like birds" and "an eminent house in which birds flying in clouds live." There is a passage "Clouds go up from a gorge unconsciously and birds get tired of flying and return their nests. Literally, "*Un*" means cloud, "*jo*" means bird, and "*ru*" means nest. The tested rooms are 55 *kan* remains built and is composed of Sarangchae, Anchae, a servant quarters and a family shrine. The house sits in what, according to the theory of pungsu, a geomantic theory, is considered one of the three best sites in the southern part of Korea (Korea National Heritage Online 2000). Total 55 kan remain wooden house comprises main house, men's quarters, and the servants' quarters on both sides of the gate, the rooms of which are arranged in a straight line. T-shaped, men's quarters is unique in structure because it has a big kitchen, which it generally does not have, and because of the raised wooden-floor with rail encircled the whole wing. Main house, which is shaped like the letter 'ㅁ', one of Korean alphabet[10] is located on the right of the men's quarters. It comprises an inner wooden-floor hall on the center and two rooms on the sides. Two-compartment the servants' quarters on both sides of the gate, is shaped like 'ㅡ', one of Korean alphabet. One compartment is a room and the other is an attic. A family shrine is in the northeastern sector. Structurally, there are no brackets, which are used in all of structure of *Unjoru*, and it has a half-gabled, half-hipped roof.

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[10] Korean Consonant letters: ㄱ ㄲ ㄴ ㄷ ㄸ ㄹ ㅁ ㅂ ㅃ ㅅ ㅆ ㅈ ㅉ ㅊ ㅋ ㅌ ㅍ ㅎ
Korean Vowel Letters: ㅏ ㅐ ㅑ ㅒ ㅓ ㅔ ㅕ ㅖ ㅗ ㅘ ㅙ ㅚ ㅛ ㅜ ㅝ ㅞ ㅟ ㅠ ㅡ ㅢ ㅣ
The Korean alphabets are used to express the Korean residences layout.

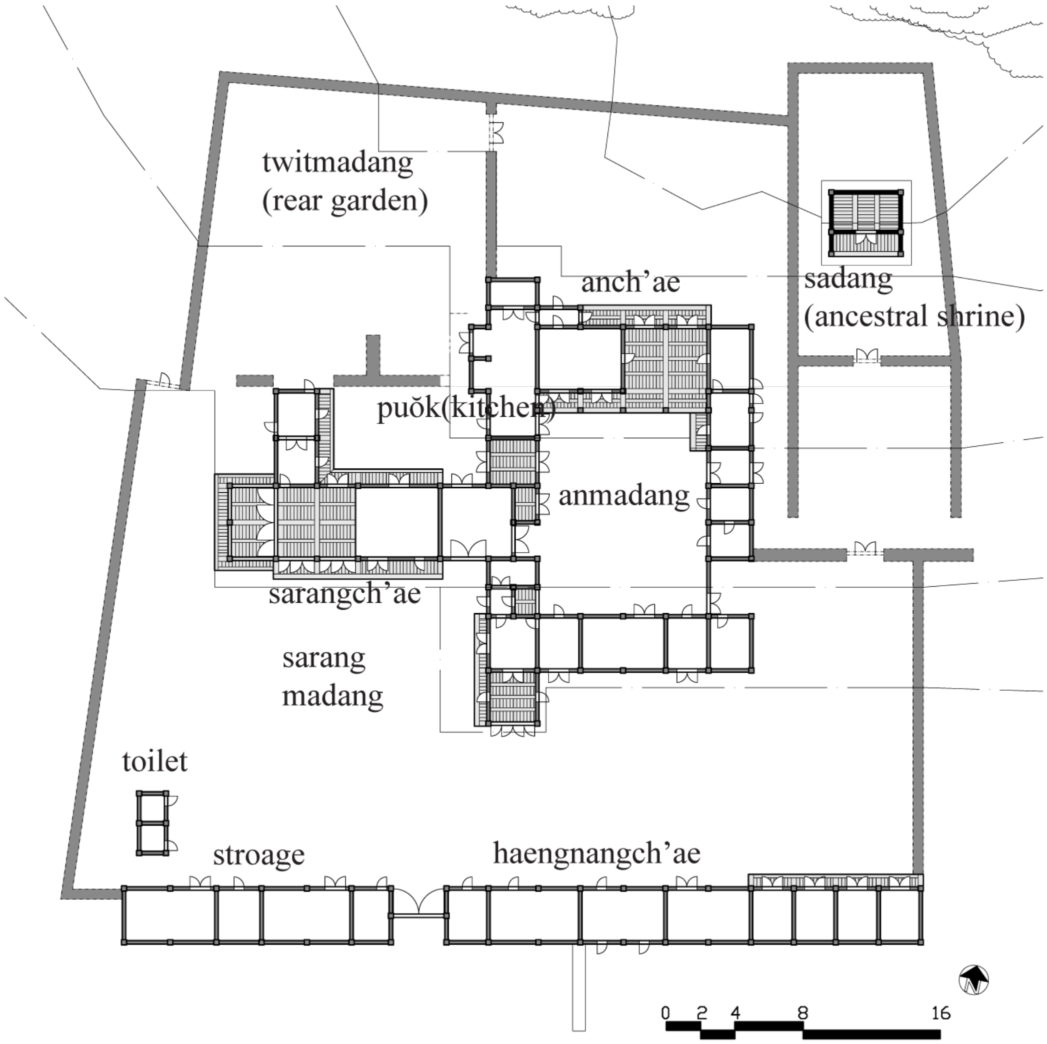


Figure 4-1 *Unjoru* Site Plan

Spatial composition of *Unjoru* can be prioritized as below.

1. Men's quarters: *sarangchae* (master quarter), *sarangmadang* (garden in front of master quarter)
2. Women and children's quarters: *anchae* (family's living quarter), *anmadang* (garden in front of *anchae*)
3. Servant's quarters: *haengnangchae*(long, narrow building used to accommodate lesser family and servants)
4. Service quarters: *bueok* (kitchen) in the middle of building, between Women and Men quarters.

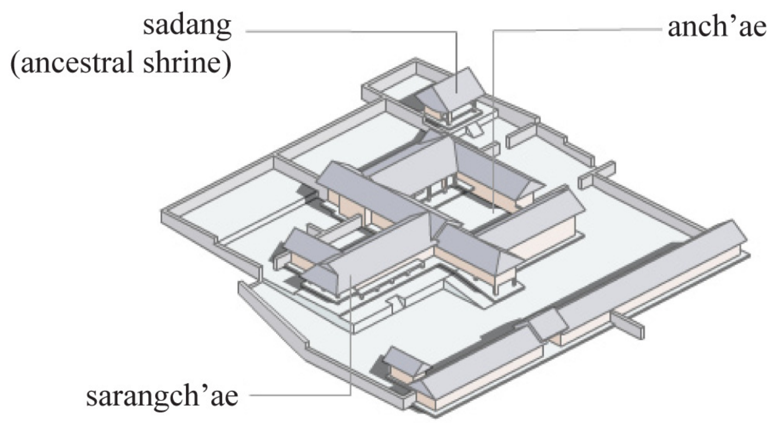


Figure 4-2 *Unjoru* Bird View (Korea Culture & Content Agency 2003)

4.3. Methodology

The analysis starts from building geometric models of *Unjoru* with AutoCAD, which allows precise detail in size. Based upon the models, the design factors and the environmental factors of *Unjoru* are redefined in the contemporary paradigm. The design factors include building layout, windows position and size, landscape, overhang, building distance, orientation, material selection, human comfort, and thermal performance.

In Ecotect, the model of *Unjoru* is formatted on the grid that allows size changes (Figure 4-3). After each space of buildings, called zone, are perfectly enclosed and assigned with correct materials, the analysis of the lighting, thermal, and acoustic is performed based upon the geographic and meteorological data regarding the site of *Unjoru*.

Ecotect is a highly visual and interactive building design and analysis tool, covering the widest range of analysis features including solar, thermal, energy, lighting, acoustics, regulations and so on (squ1.org 2007). It is employed for analyzing shadows, shading & solar influence, thermal performance, heat gain & loss, spatial comfort, ventilation and daylight & sunlight. Ecotect uses a system of inter-object relationships to assist with this. Based upon the plan of a zone, Ecotect automatically extrudes the corresponding walls and a ceiling. This is useful for modifying the nodes in the plan object. It keeps track of all related walls, ceilings and any added windows (squ1.org 2007).

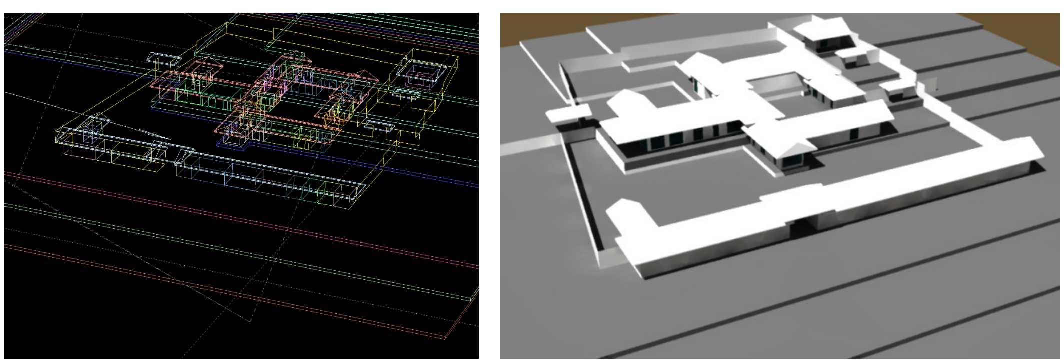


Figure 4-3 Ecotect Modeling (left), and Rendering by Radiance (Right)

Experiments are focused on summer and winter of Korea, which require secondary needs to maintain environmental comfort in a building:

- ✓ January 13 - the coldest date
- ✓ May 6 - the start of summer
- ✓ June 21-the summer solstice: Sun at its highest noon altitude
- ✓ July 23-the hottest date
- ✓ August 23 -the end of summer
- ✓ December 23 - the winter solstice: Sun at its lowest noon altitude. (Korea National Heritage Online 2000, squ1.com 2007)

4.4. *Unjoru* investigation

Like most of the traditional Korean residences, *Unjoru* building orientation is faced the south and tiled the east about 8 degree. In Korea, usually solar glazing should be oriented the south. This orientation offers the best results of both winter heating and summer shading. If the residence is used mainly at night, the 15degree west of south is better for afternoon activity. However, during exiting sunlight, Korean, who mainly engage in agriculture, has woken up early and went to bed early at the time. Therefore, most of the traditional residence including *Unjoru* and *Chusagotaek* had been built slightly east of south.

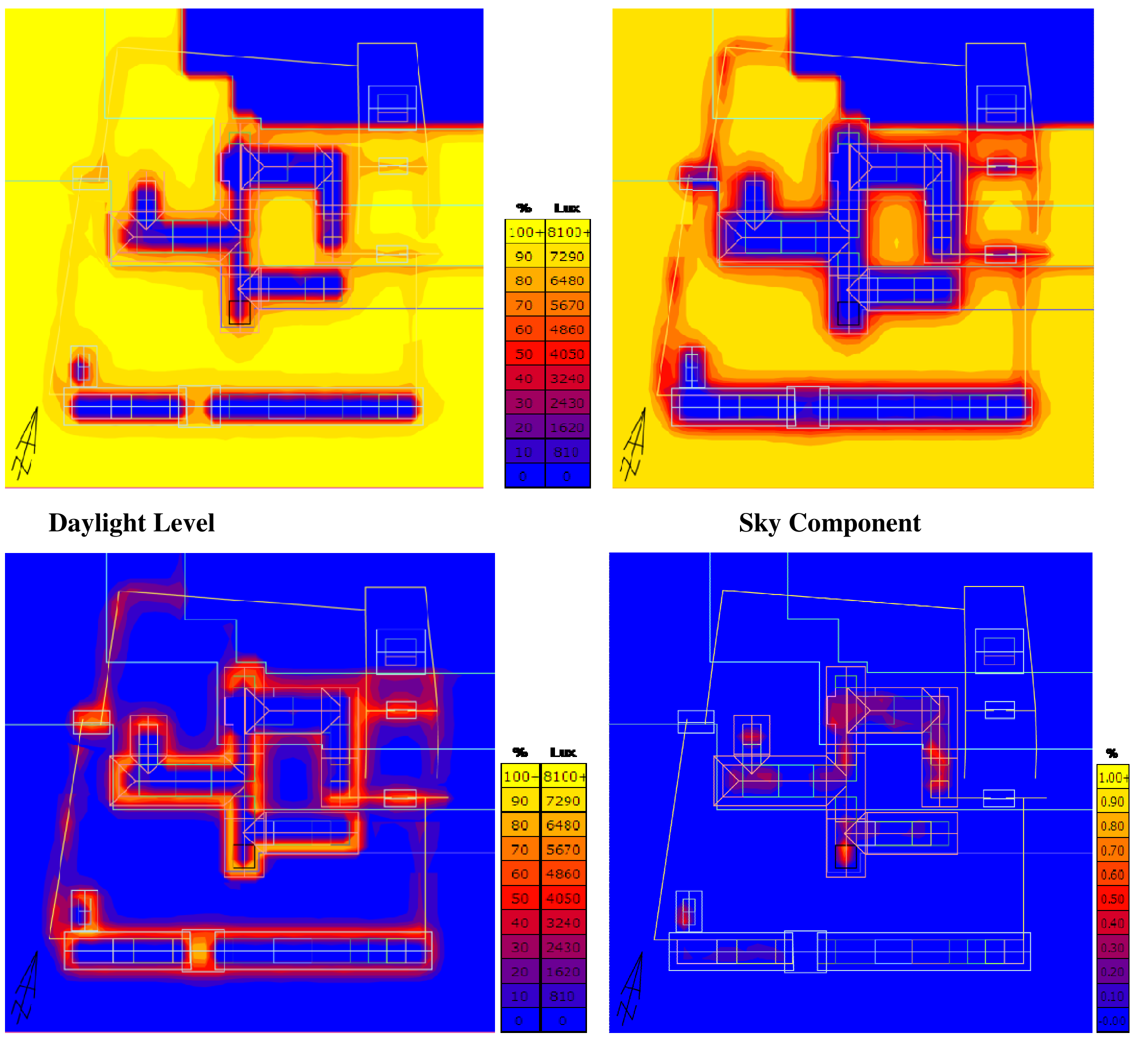
Unjoru follows the theory, "mountain behind and river in front" and the architecture face south based on the principles of *pungsu*. However, there is no river in front of building, and it does not seem to follow the theory. Therefore, they made the artificial pond. Unjoru, the name of the house, means "the house hidden in clouds like birds" and "an eminent house in which birds flying in clouds live." Byoung-Ju Lee, who is a cousin with *Unjoru* owner, and lives one block down from *Unjoru*, interviewed on 2nd November, 2007, that the bird needs water, and then they made a pond in front of house to satisfy the legend (B.-J. Lee 2007).

Figure 4-4 A pond in front of *Unjoru*

The Daylight Analysis in the Ecotect provides the decision of the layout, which one should be used for analyzing the environmental factor. The daylight levels are not time dependant and it represent a worst-case design condition base on a sunless cloudy or uniform sky distribution. Daylight Factor (DF) indicates percentage of outdoor light under overcast skies that is available indoors, and the daylight reaching a particular point inside a room is made up of three principle components, which are Sky component (SC), Externally Reflected Component (ERC), and Internally Reflected Component (IRC). The Sky Component (SC) is the light received directly from the sky, the Externally Reflected Component (ERC) is the light received directly by reflection form buildings and landscape outside the room. Internally Reflected Component (IRC) is the light received from surfaces inside the room (McMullan and Seeley 2007).

Ecotect assumes the Design Sky Illumination maximized 8500 lux. Daylight usually enters a building by means of oilpaper windows or doors, but these windows or doors also transmit heat, which is related with the thermal performance. The amount of daylight provides the decision of lighting as well as the cooling energy. The provision of natural lighting in a residence needs to be considered together with factors of artificial lighting, heating, ventilation and sound control.

The outcome from Daylight Analysis (Figure 4-5) shows the Daylight Factors (DF) including the Externally Reflect light, and the Internally Reflect light. The internally reflected lights are less than 1 % that does not involve enough light to inside of buildings, because of the design of long hangover. On the other hands, the externally reflected light is very strong that transmit the unnecessary heat in the summer, but the externally reflected light spreads out evenly.



Daylight Level **Sky Component**

Externally Reflected Light **Internally Reflected light**

Figure 4-5 Daylight Analysis

4.4.1. Shadows, Shading and Solar Analysis

Shadows, Shading and Solar Analysis offer the greatest opportunity for incorporating *Unjoru* features. This analysis could observe use of natural energy flows as the primary means of harvesting solar energy. It also provides the space heating, cooling load avoidance, natural ventilation and natural light. Ecotect provides three big functions in *Unjoru* analysis; Shadows & Reflections Analysis, Shading Design and Incident Solar Radiation.

First, Shadows & Reflections Analysis is an important aspect of *Unjoru* analysis. Through the Ecotect analysis, the display of Daily Sun Path, Annual Sun Path tool, and Sun Path Diagrams provides to observe quickly the layout and structure as soon as to accomplish an Ecotect model of *Unjoru*. The sun position in the sky varies continually during the day and changes seasonally in the year. It is also very location dependant, so it is critical to know the latitude and longitude of the site (squ1.org 2007).

Second, Shading Design Analysis that generates the Optimized Shading Device to shade the currently selected window object, the Project Solar Shading Potential to visualize clearly, which part of an obstruction or shading device is the most important. Sun path diagram also provide outside shading design. The shading design wizard in Ecotect provides *Unjoru* through the process of shading requirements (Ecotect 2007). One very useful function of this Wizard is to generate automatically the exact shading shape perfectly to shade a window for and specified period.

Lastly, Incident Solar Radiation refers to the wide spectrum radiant energy from the Sun, which strikes an object or surface. Excessive solar exposure is one of the main causes of summer overheating in buildings. However, it is also one of the most effective sources of natural energy available in winter. Thus, Shading systems and the analysis of solar gains are linked with the solar access and incident solar radiation (squ1.com 2007). Trough the incident solar radiation in Ecotect, the roof shade all of buildings one of hot summer dates, June 21, and the sunlight, which can be the radiant energy, can penetrate to the buildings. The total direct radiation shows the sunlight valuable amount in the specific day. The summer sunlight, 3200-Watt hour, emits more than ten times of the winter sunlight, 320-Watt hour, which can penetrate inside building, and avoiding the stronger summer sunlight put forward better design solution in the traditional residence *Unjoru*.

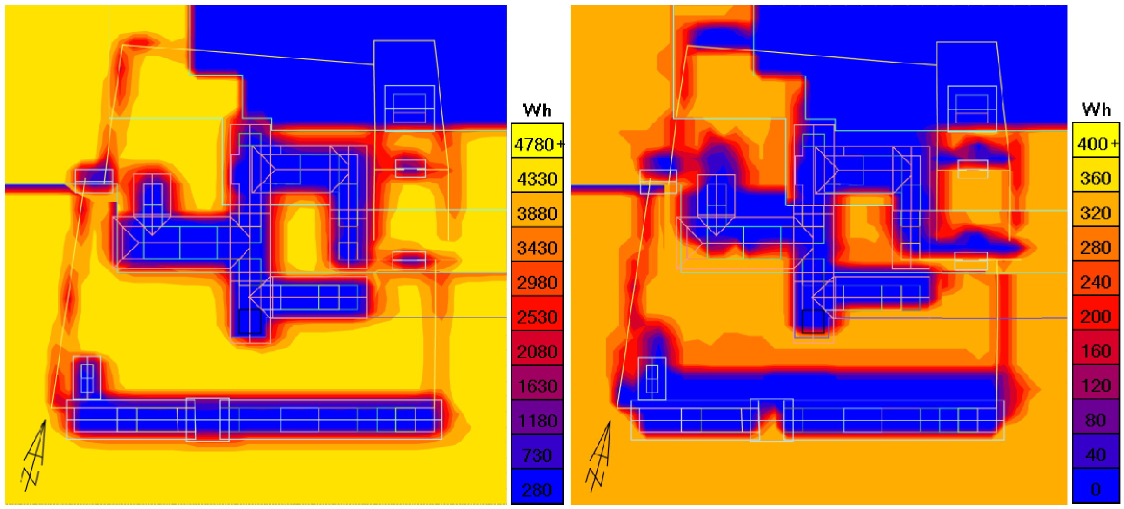


Figure 4-6 Total Direct Radiation, summer solstice, June 21st (left) and winter solstice, Dec 23(right)

4.4.1.1. Protecting the Strong Sunlight in the Summer

In the summer, solar analysis tests how the roof eaves protect, and provides sunlight during the winter. Daily Sun Path and Annual Sun Path Display in the Shadow Settings panel, Ecotect, are set to shadow on the special day and time. The Shading Design Wizard extrudes objects for solar envelope that crates reference lines and planes to test or interrupt buildings heights (Figure 4-7~Figure 4-10).

The *Unjoru* eaves are satisfied with the summer dates from May 6th to August 23rd. The sun's altitude[11] is at its highest at noon, July 21, and at its lowest on August 23rd during the summer. On the last day of summer and the lowest altitude sun during the summer, which is august 23rd, at 10 AM and about 1:30, this sun will hit the tip of the roof on the side, and it creates angel that is always at 56.6 degree every year (Figure 4-7~Figure 4-11). At this angle 56.6 degree, it creates shading towards the house that encloses the whole house creating friendly or cooler atmosphere inside. One of Ecotect tool, Shading Design, shows that the eaves protect direct sunlight both sarangbang and anbang on August 23rd. The eaves angle of the main building is at same angel 56.6

[11] Altitude represents the vertical angle the sun makes with the horizontal ground plane. It is given as an angle in the range 0° < alt < 90° (squ1.org 2007).

degree at 10 AM or 1:30 PM, azimuth[12] 45.7° and at 2 PM, azimuth 134.3° (Figure 4-9). In the winter, the sunlight can penetrate to inside room about half of room's floor on December 23rd, the winter solstice (Figure 4-11).

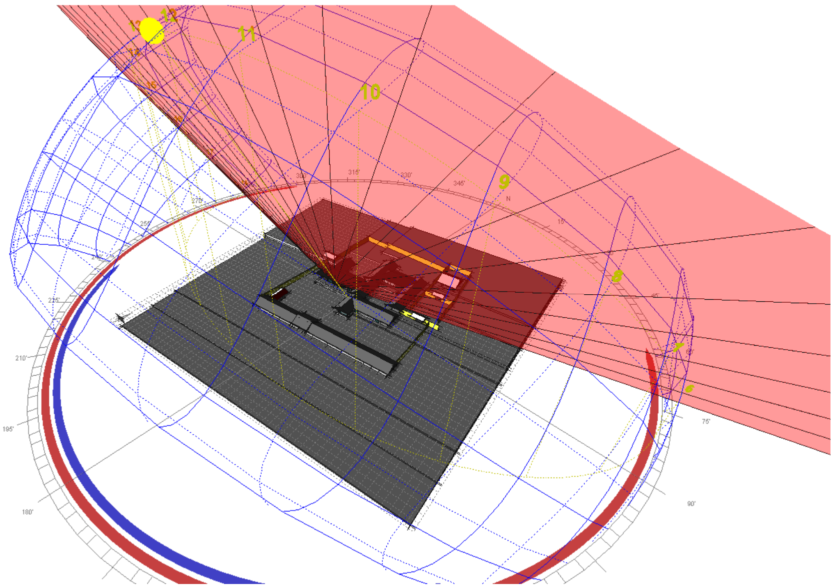


Figure 4-7 Daily and Annual Sun Path Analysis with Extrude Sunlight in Shading Design

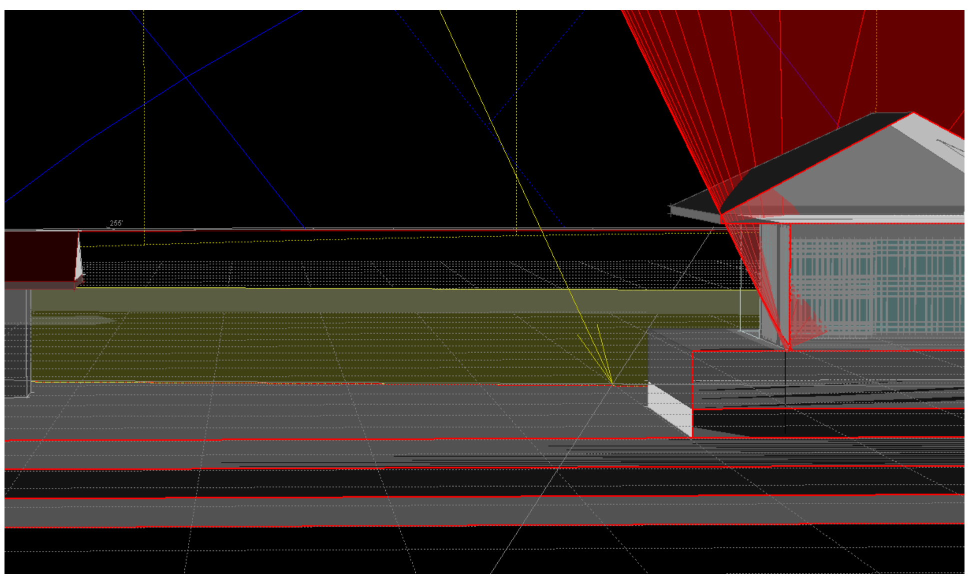


Figure 4-8 Extrude Sunlight for Analyzing shading and shadow, *Sarangbang* on August 23rd, the end of Summer

[12] Azimuth represents the horizontal angle of the sun relative to true north. This angle is always positive in a clockwise direction from north, and is usually given in the range 0° < azimuth < 180°.

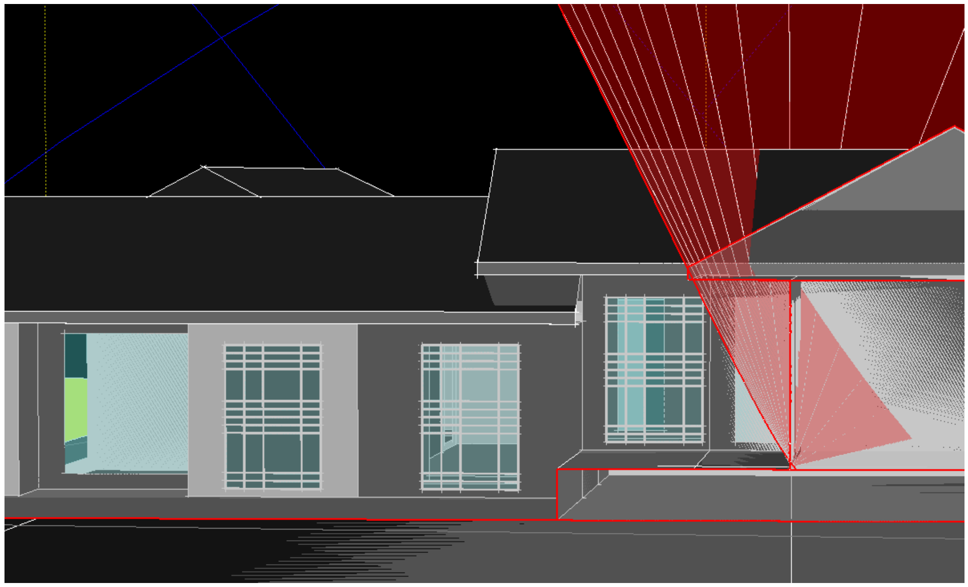


Figure 4-9 Extrude Sunlight for Analyzing shading and shadow, *anbang taechong* on August 23rd, the end of Summer

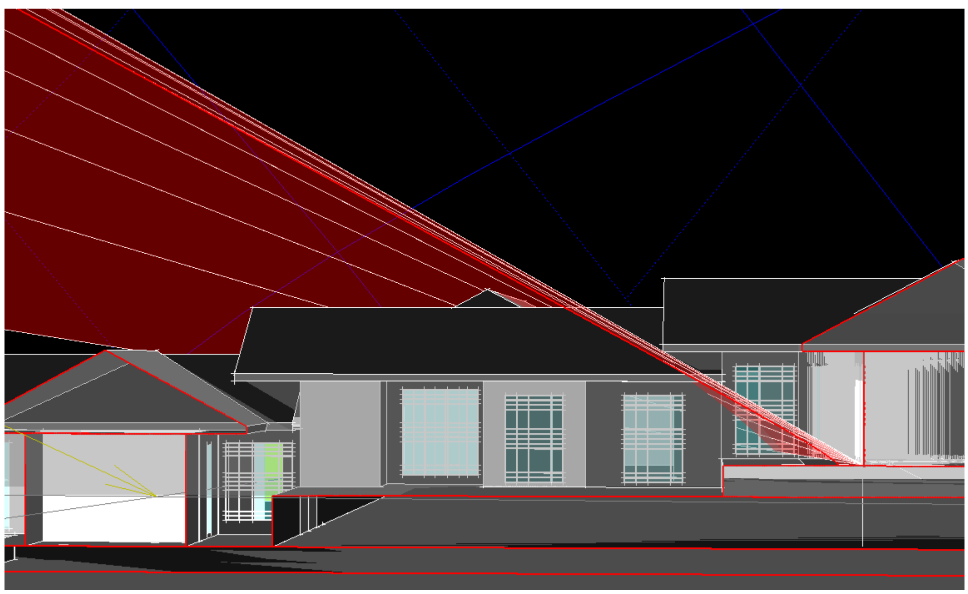


Figure 4-10 Sunlight for Analyzing shading and shadow, *anbang taechong* on December 23rd, the winter solstice

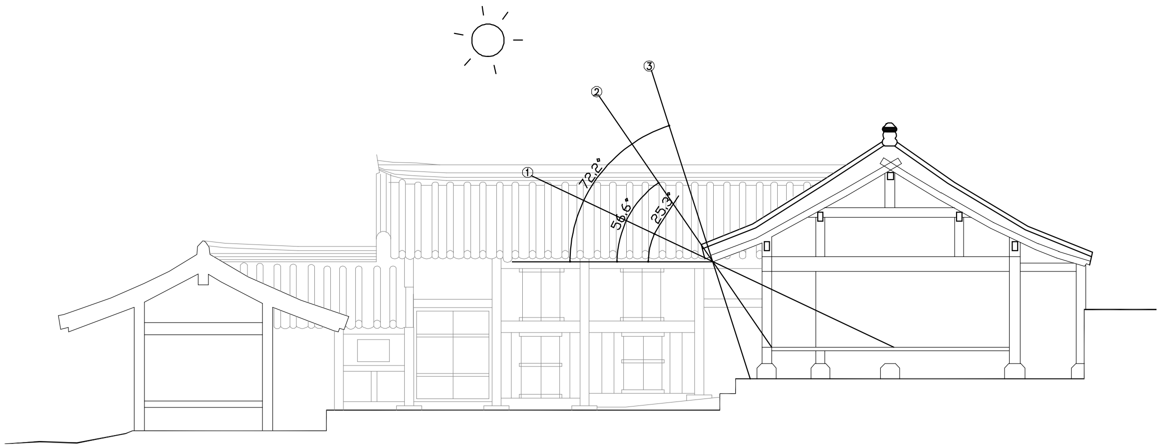


Figure 4-11 *Anbang* sunlight angle section, 1. Winter solstice, 23rd December, 10 o'clock 2.August 23rd Sunlight Angle, 10 o'clock 3.Summer Solstice, 23rd July, Noon

In the Hourly Heat Gains of the Ecotect Thermal Calculation, the more hourly heat gaining rooms, which unnecessarily can get heat a room in the summer, are ordered these following rooms; *sarangtaechong* > *sarangbang* > *anbang* > small *sarangtaechong* > women *konnobang* > small *sarangbang* > men *konnobang* (Figure 4-13, Figure 4-14 and Figure 4-15).

The zones are tested in the following rooms: *sarangtaechong* (master men's *maru*), *sarangbang* (master men's room), men *konnobang* (children's room), small *sarangtaechong*, *anbang* (master women's room), women *konnobang* (women and children's room) (Figure 4-12). This test of *Unjoru* excepts the antaechong unlike *Yeongyeongdang* and *Chusagotaek*, because unlike the other buildings in *Unjoru* opens front side without windows. The test dates in the summer are on June 21st, the summer start, July 23rd, the summer solstice, August 23rd, the summer end. On June 21st and July 23rd, the *anbang* room has numerous heat gain that increases the Percentage Dissatisfied.

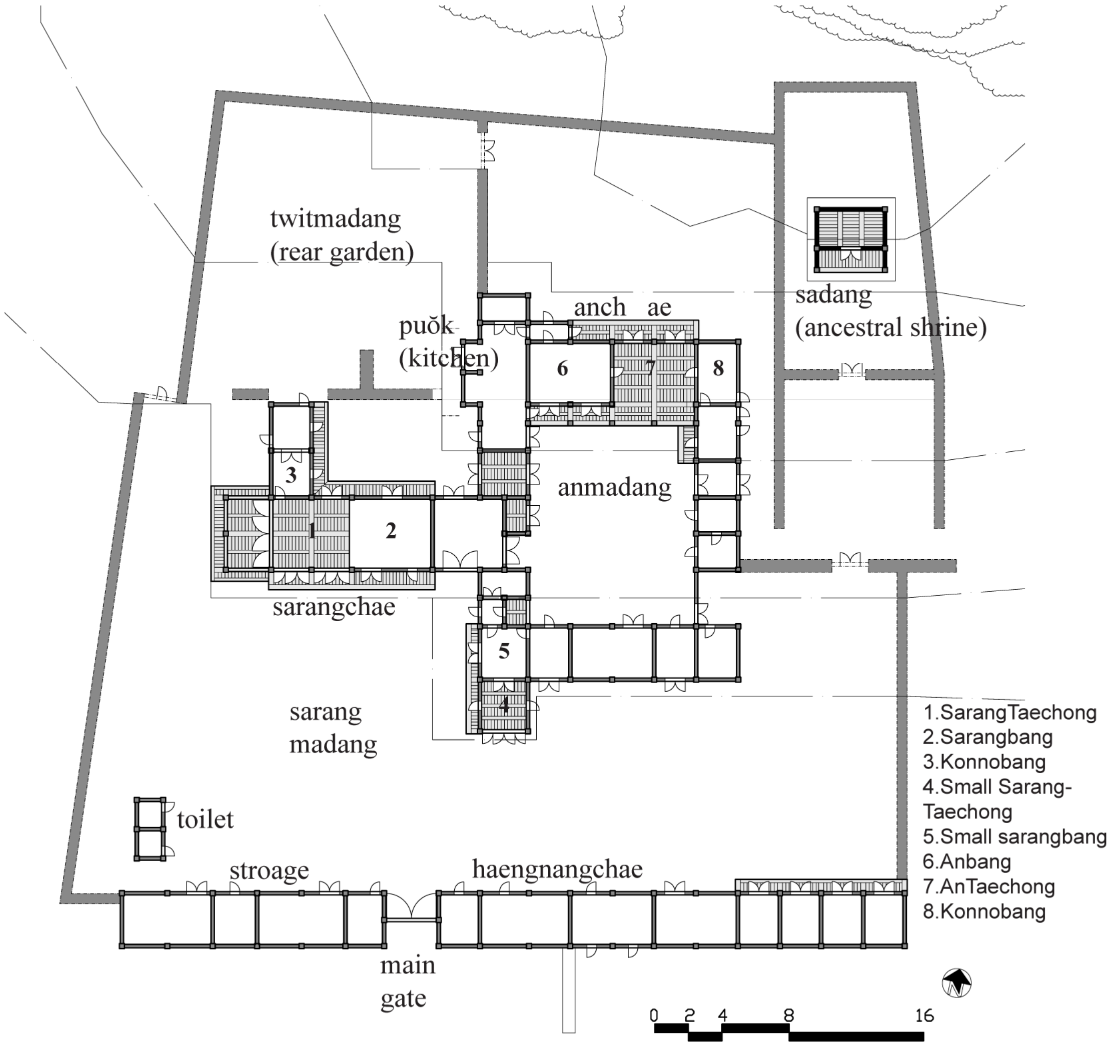


Figure 4-12 Selected Thermal Analytic Rooms

Men's place, sarangchae, has heat gain more than women's place, *anchae*. Hierarchically, men's places open to the south and have enough windows to get sunlight. *Sarangtaechong* has heat gain more than any other rooms. Especially, the taechong has more heat gain than any other bang. *Sarangtaechong* has 33.3% south exposed windows of the total floor area, which is the most south exposed windows than any other rooms. After one enters the main gate of the *Unjoru*, immediately one can see the *sarangtaechong*, the living room for men. The *sarangtaechong* is almost 100 % opening space on two sides, west and south, and the opening windows assists to view outside easily and have the heat gain. The second most heat gained room reports the sarangbang next by the *sarangtaechong*. *Sarangbang* also has mainly south open windows that can get the solar heat gain. The room is sleeping room, which has *ondol*, the heating floor system. Therefore, the sarangbang has smaller windows, and other rooms, *sarangbang* and the middle gate zone, enclose it to assist to keep the heat energy in the winter. In the summer, some part of *sarangbang* windows connecting *sarangtaechong* can be moveable, and then it helps to cool down *sarangbang*.

Anbang and women's *konnobang* get the solar heat gain not very much like *sarangbang* and *sarangtaechong*, but continually those rooms get the heat gain that provides to carry the sunlight during the day. Even though, the *anbang* and *konnobang*, which are enclosed by the west kitchen and the east storage, are placed on the corner of anchae. The proper sunlight carries those rooms. In the winter, all of rooms receive the sunlight evenly from morning to afternoon. Women konnobang at 9 o'clock has little more heat gain. The cause of east window in women *konnobang* makes more solar heat gain at 9 o'clock. The different level between the backside rooms, anbang, *antaechong* and women *konnobang*; and the front storage leads to outcome the social mores coming from Confucian that makes women separating from men.

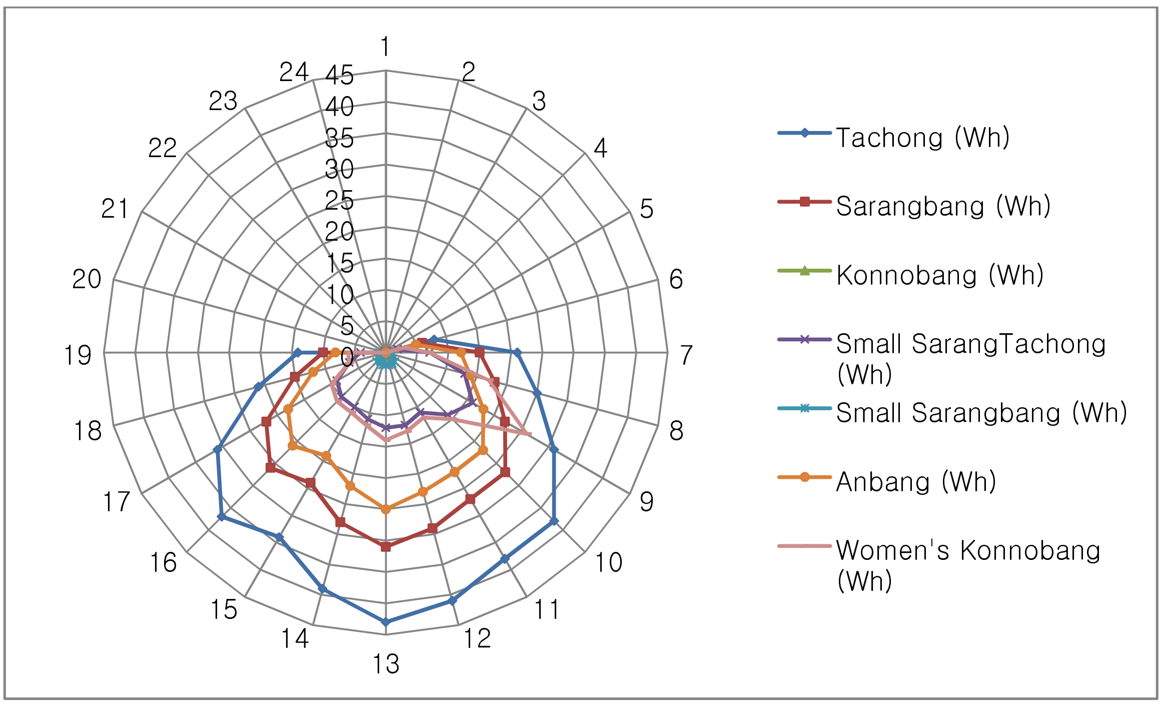


Figure 4-13 Solar Hourly Gains, June 21, the summer solstice

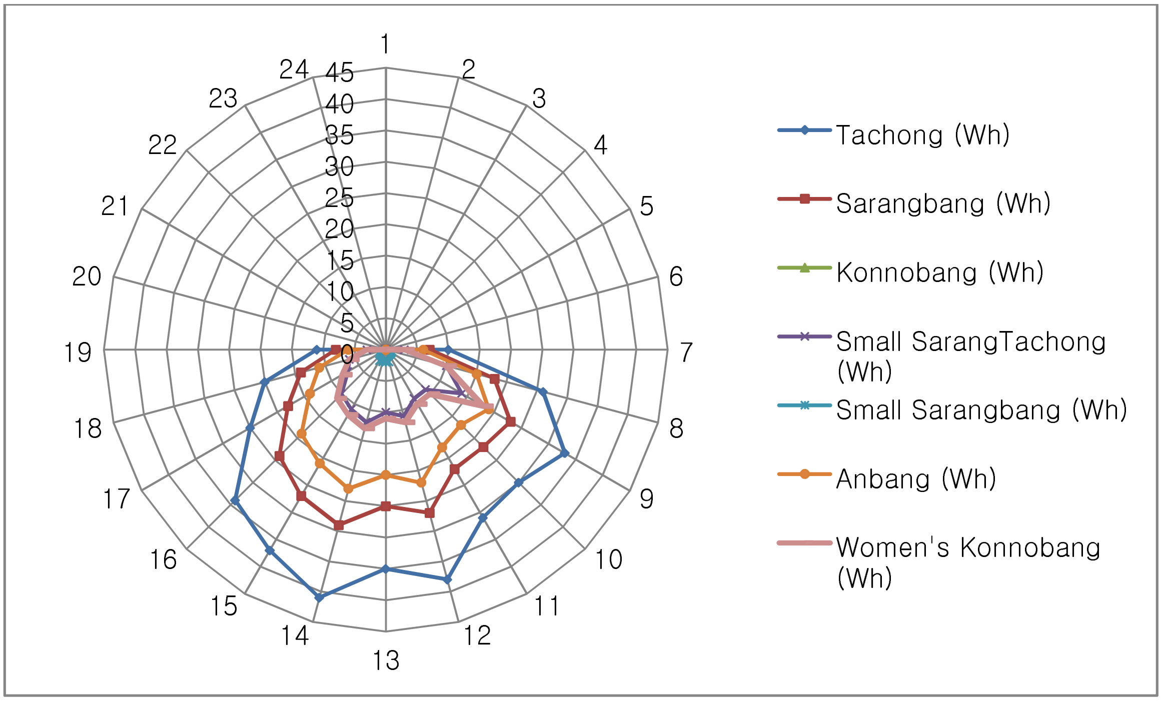


Figure 4-14 Solar Hourly Gains, July 23rd, the hottest date

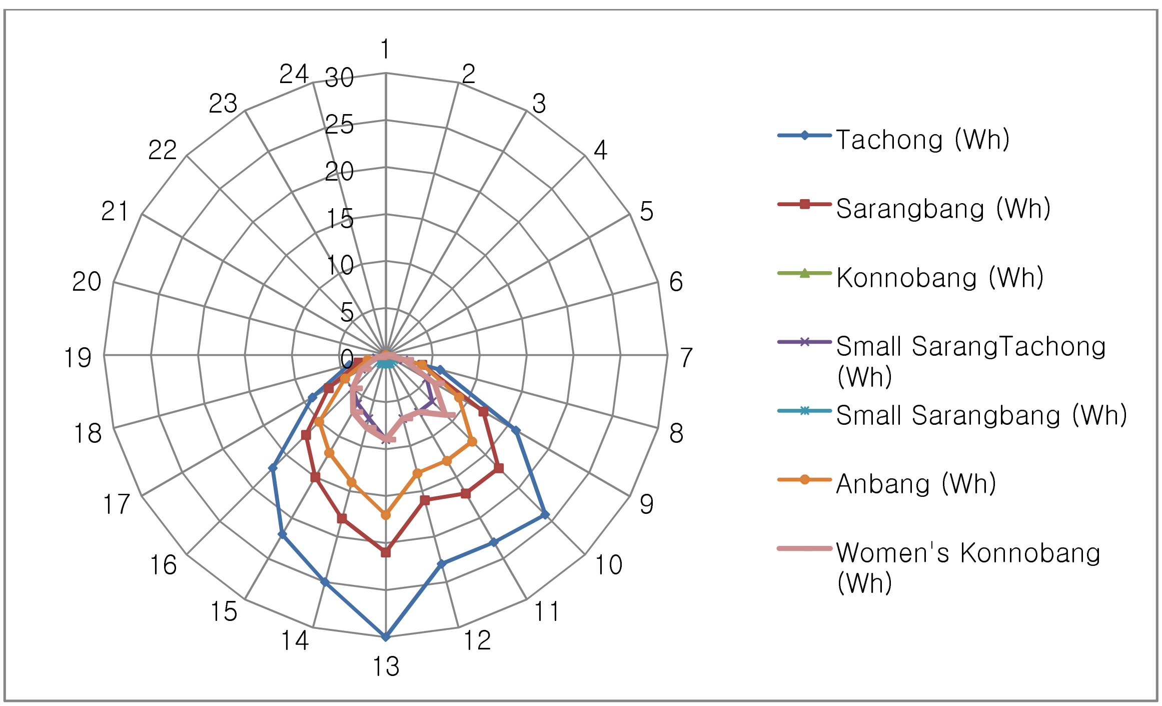


Figure 4-15 Solar Hourly Gains, August 23rd, the end of summer

4.4.1.2. Penetrating the Sunlight into each Rooms evenly in the Winter

In the winter, the basic natural processes that are used in solar energy are the thermal energy flows associated with radiation, conduction, and convection. When sunlight strikes a building, the building materials can reflect, transmit, or absorb the solar radiation. Additionally, the heat produced by the sun causes air movement that can be predictable in designed spaces. These basic responses to solar heat lead to layout elements, material choices and placements that can provide heating and cooling effects in a residence. Excessive solar exposure is one of the main causes of summer overheating, but it is also one of the most effective sources of natural energy in winter.

In the Hourly Heat Gains of the Ecotect Thermal Calculation, the more hourly heat gaining rooms, which necessarily can get heat a room in the winter, are ordered these following rooms; *sarangtaechong* > *anbang* > *sarangbang* > women *konnobang* > small *sarangtaechong* > small *sarangbang* > men *konnobang* (Figure 4-16, Figure 4-17 and Figure 4-18).

Sarangtaechong and *saranbang* have the solar heat gain continually during the light. It is free to release to penestrate the solar heat into the rooms that basically open the front and backside. Anbang also has the slar heat gain allmost amount of *sarangbang*, even though the anbang is the corner of left behide in anchae, women quarter. While, the amount of heat gain increases between 10 to 11 o'clock in ther morning, and during that time, anbang have the solar heat gain directly from the solar (Figure 4-10). After 11:30 AM, the sun passes over the kicthen roof , in middle of the buidling, and then the anbang has the indirect solar heat gain. Women's *konnobang* also have the solar gain, evnen it is in the corner of building, anchae. The solar heat gan of anbang affects differently everytimes. Women konnobang's windows open to maily west and east, and the west windows are twice bigger than the east windows, therfore afternon konnobang has more solar heat gain, which provides to remain the heat in the night. Small *sarangtaechong* in front of main gate was faced south and opens the front side, but the amount of the heat gain reports smaller than any other tested rooms. The reasons of the smaller heat gains are several reasons. First, small sarangtaechong is smaller than other rooms, and the room is placed on the one meter post, which reduces the Externally Reflected Light. Second, the deep roof eaves in small sarangbang of which the windows mainly open to the south, protects the strong sunlight. Through the shadows, shading and sunlight analysis shows how the pat of hierarchical isolation outcomes in the anchae. The different level and variety windows direction solves the problem.

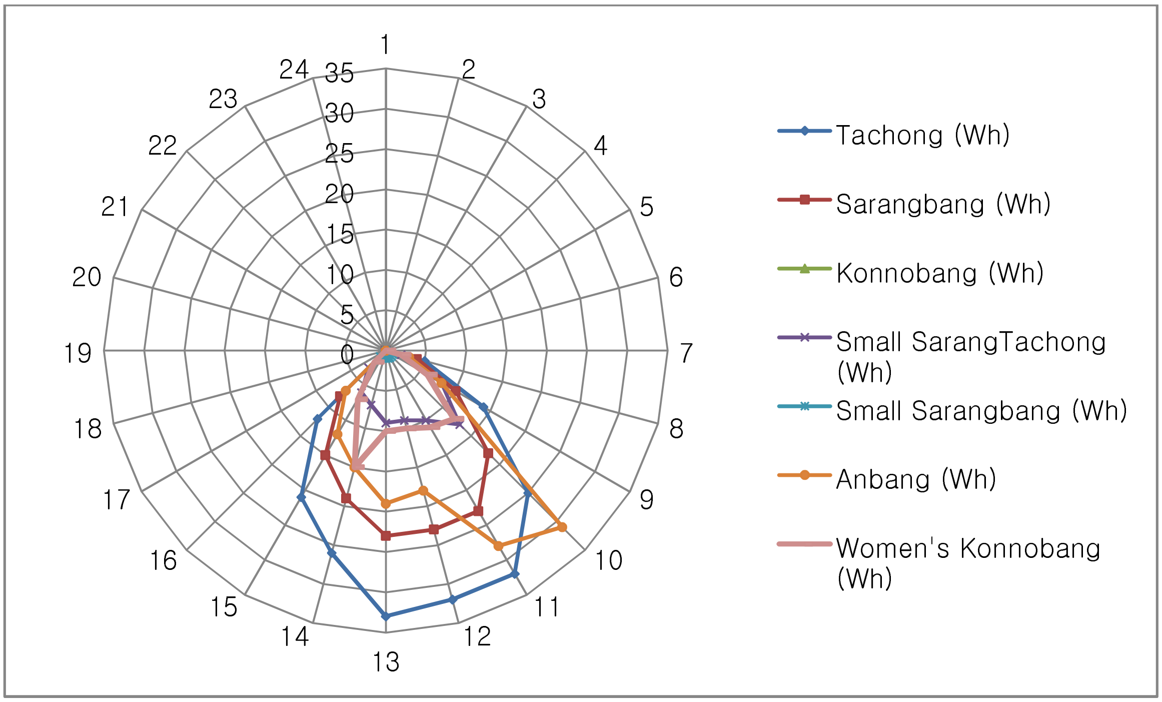


Figure 4-16 Solar Hourly Gains, January 13th, the coldest date

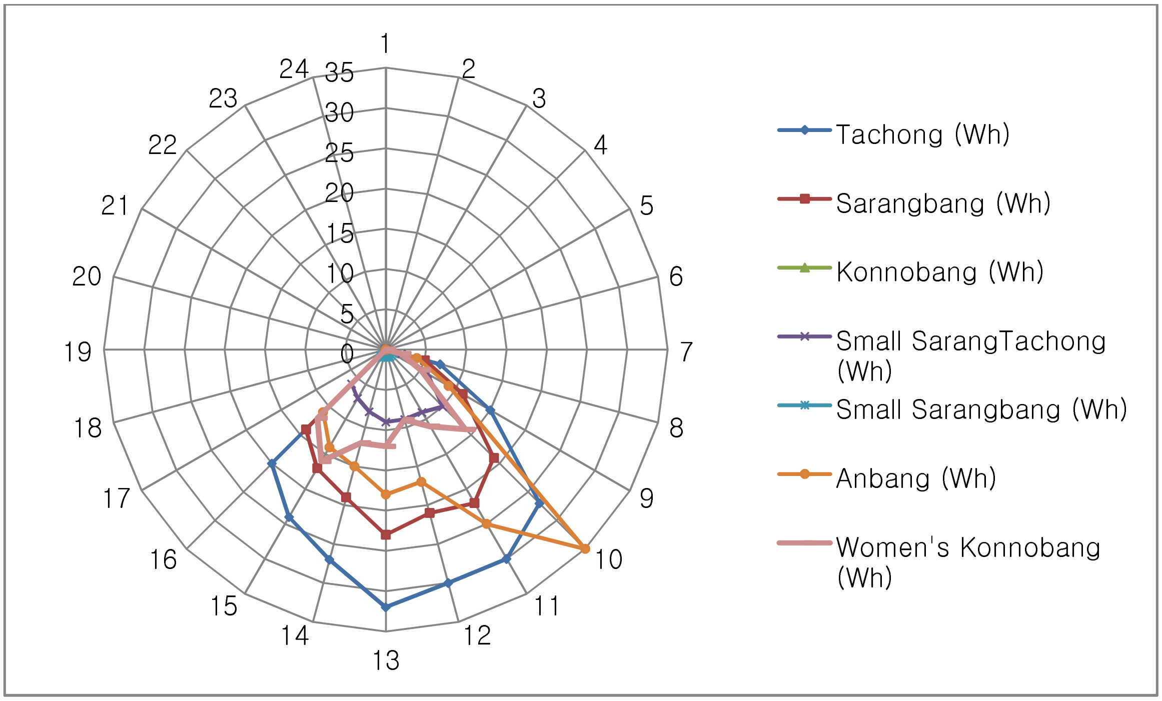


Figure 4-17 Solar Hourly Gains, December 23rd, the winter solstice

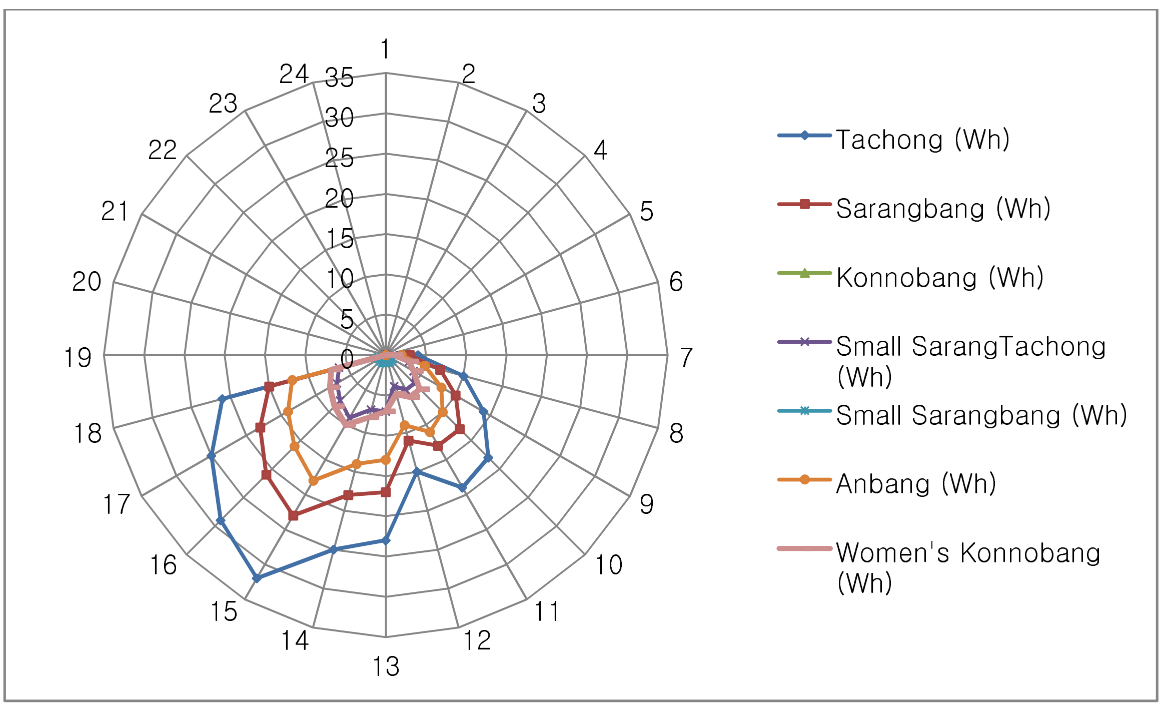


Figure 4-18 Solar Hourly Gains, May 6th

Solar Hourly Heat Gains for unjoru

Zone	Tachong (㎡)	Sarangbang (㎡)	Konnobang (㎡)	Sm-SarangTachong (㎡)	Sm-Sarangbang (㎡)	Anbang (㎡)	Women's Konnobang (㎡)
Total Surface Area:	80.63	80.87	36.68	44.02	44.56	78.49	46.08
	395.1%	394.7%	538.0%	496%	493%	405%	495%
Total Exposed Area:	36.24	41.58	19.96	19.85	12.87	51.37	31.35
	177.6%	202.9%	293.0%	224.0%	142.0%	228%	337%
Total South Window:	6.80	2.93	0.00	5.51	0.00	4.32	0.00
	33.3%	14.3%	0.0%	62.0%	0.0%	23%	0%
Total Window Area:	8.96	5.09	1.80	7.69	1.80	5.40	1.98
	43.9%	24.8%	4.9%	86.0%	16.0%	29%	21%
Total Conductance (AU)(W/㎡K):	60.00	66.00	28.00	31.00	15.00	82.00	52.00
Total Admittance (AY)(W/㎡K):	242.00	231.00	99.00	123.00	122.00	225.00	128.00
Response Factor:	3.69	3.62	3.31	3.67	6.66	2.61	2.39

HOUR	Tachong (Wh)	Sarangbang (Wh)	Konnobang (Wh)	Sm-SarangTachong (Wh)	Sm-Sarangbang (Wh)	Anbang (Wh)	Women's Konnobang (Wh)
13th January							
7	5	4	0	2	0	3	2
8	14	10	0	8	1	8	6
9	25	18	0	13	1	31	12
10	32	23	0	10	1	28	11
11	32	23	0	9	1	18	10
12	33	23	0	9	1	19	10
13	26	19	0	7	1	15	15
14	21	15	0	6	1	12	7
15	12	8	0	3	1	7	2
TOTAL	**200**	**143**	**0**	**67**	**8**	**141**	**75**
6th May							
6	4	3	0	1	0	2	1
7	10	7	0	3	0	5	3
8	14	10	0	4	1	8	4
9	18	13	0	5	1	10	6
10	19	13	0	5	1	11	6
11	15	11	0	4	1	9	5
12	23	17	0	7	1	13	7
13	25	18	0	7	1	14	8
14	32	23	0	9	1	18	10
15	29	21	0	8	1	16	9
16	25	18	0	7	1	14	8
17	21	15	0	6	1	12	7
TOTAL	**235**	**169**	**0**	**66**	**10**	**132**	**74**
21st June							
5	8	6	0	2	0	5	3
6	21	15	0	7	1	12	7
7	25	18	0	13	1	14	17
8	31	22	0	16	1	18	26
9	38	27	0	14	2	22	15
10	38	27	0	11	2	22	12
11	41	29	0	12	2	23	13
12	43	31	0	12	2	25	14
13	39	28	0	11	2	22	12
14	34	24	0	10	1	19	11
15	37	26	0	10	2	21	11
16	31	22	0	9	1	18	10
17	21	15	0	6	1	12	6
18	14	10	0	4	1	8	6
TOTAL	**421**	**300**	**0**	**137**	**19**	**241**	**163**
23rd July							
6	10	7	0	3	0	6	3
7	26	18	0	10	1	15	10
8	33	23	0	14	1	19	18
9	30	22	0	9	1	17	10
10	31	22	0	9	1	18	10
11	38	27	0	11	2	22	12
12	35	25	0	10	2	20	11
13	41	29	0	12	2	23	13
14	37	27	0	11	2	21	12
15	34	24	0	10	1	19	11
16	25	18	0	7	1	14	8
17	20	14	0	6	1	11	6
18	11	8	0	3	0	6	3
TOTAL	**371**	**264**	**0**	**115**	**15**	**211**	**127**
23rd August							
7	6	4	0	2	0	4	2
8	16	12	0	5	1	9	6
9	24	17	0	7	1	13	9
10	23	17	0	7	1	13	7
11	23	16	0	7	1	13	7
12	30	21	0	9	1	17	9
13	25	18	0	7	1	14	8
14	22	15	0	6	1	12	7
15	17	12	0	5	1	10	5
16	9	7	0	3	0	5	3
17	4	3	0	1	0	2	1
TOTAL	**199**	**142**	**0**	**59**	**8**	**112**	**64**
23rd December							
7	7	5	0	2	0	4	2
8	15	11	0	6	1	9	5
9	27	19	0	10	1	35	14
10	30	22	0	9	1	25	11
11	30	21	0	9	1	17	9
12	32	23	0	9	1	18	12
13	27	19	0	8	1	15	12
14	24	17	0	7	1	14	16
15	20	14	0	6	1	11	12
TOTAL	**488**	**348**	**0**	**147**	**19**	**303**	**181**
	Tachong	**Sarangbang**	**Konnobang**	**Sm-SarangTachong**	**Sm-Sarangbang**	**Anbang**	**Women's Konnobang**

Table 4-1 Solar Hourly Heat Gain for *Unjoru*

4.4.2. Cooling Strategies: Wind Flow and Air Flow

Human comfort within residence is primarily controlled by four major factors: air temperature, mean radiant temperature, humidity and airflow. Each can have a dominating effect. There are factors, which affect human comfort including clothing and activity (Fairey 1994). The Psychometric Chart provides a graphic representation of the state of condition of the air and moisture related with comfort zone at any particular time. The chart relates temperature along the horizontal scale to moisture content along the vertical scale (Ecotect 2007).

4.4.2.1. Summer

There are two cooling strategies, which dominate the *Unjoru*. First, one of strategies is Natural Ventilation, which is cross ventilations driven by wind and accomplished with windows. It relies on narrow plans with large ventilation openings on either side. Second, the other strategy is High-mass Cooling, which is for warm, dry summers, when the extremes of hot days are tempered by the still cool thermal mass, thicker roof. Cool nights then slowly drain away the heat that such mass accumulates during the day. The roof has the advantage of radiating to the cold night sky (McMullan and Seeley 2007).

In the summer, the Seoul wind flows average 2.4m/s and the minimum of airflow is the 0.7m/s up to few days according to the Korea Meteorological Administration recording from 1961 to 1980 (Korea Meteorological Adiministration 2006). If the 2.4m/s airflow constantly affects *Unjoru*, during summer, there is enough cooling for human comfort. The traditional sliding door of *Unjoru* can be opened 100% of the window-installed space, unlike the modern glass door (D.-K. Kim 2000). During the summer, the open door offers enough air inside. Additionally, for the wind flow from the southwest in the summer, the building layout was so well suited to the each room. Ecotect shows the prevailing winds, which is able to display in the 3D model. Ecotect prevailing winds displays the wind speed, frequency and the direction. In the prevailing winds, the wind flows 35% of the total wind from east of north to the building in the morning (6:00~10:00), and 40% of the total wind from west of south trough the building during the day (10:00~6:00PM) (Figure 4-19). Diurnal airflow in the valley cools also down the temperature during the summer. The wind flows from the southwest to the women's quarter, placed on the west, which stays backward, and men's quarter, place on the east, which stays frontward.

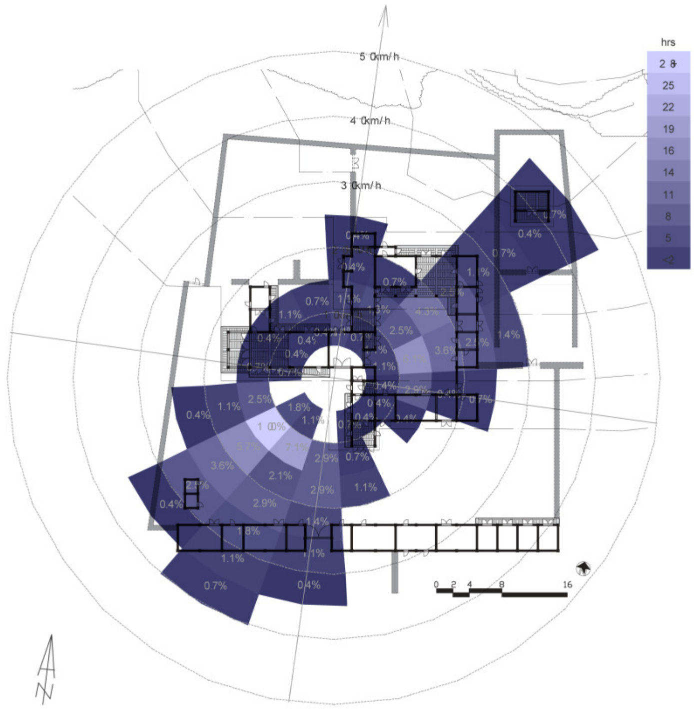


Figure 4-19 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: summer, 1st June ~ 31st August. Time: 10:00 ~14:00

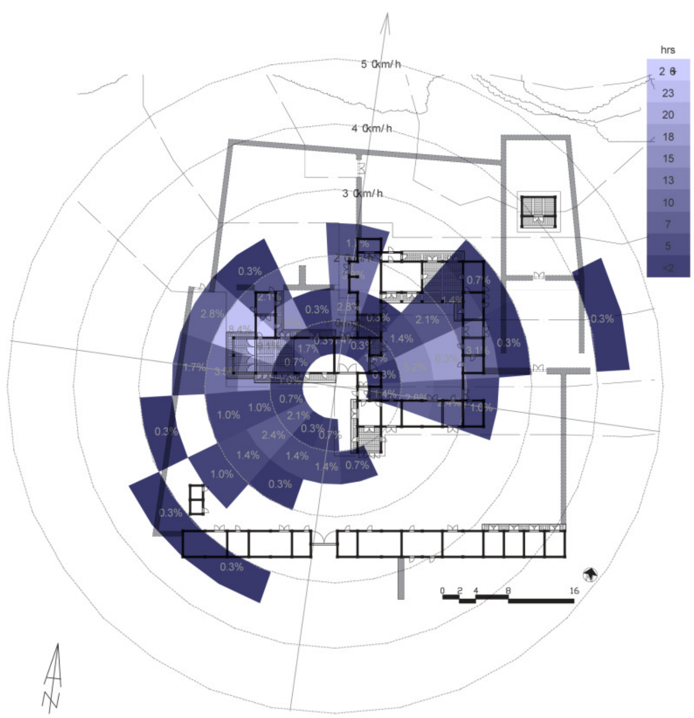


Figure 4-20 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: winter, 1st December ~ 28th February. Time: 10:00 ~14:00

4.4.2.2. Winter

In the winter, the replication of the mountain-like wraps in traditional Korean architecture behind the north protects against the strong wind during the winter. *Unjoru* is enclosed by mountain from east hill to west hill trough north hill. The Ecotect prevailing winds provide that the winter winds flow from the west or east of north to the building (Figure 4-20). In addition, the windows on the north face or the windward windows are almost not installed for protecting the cold wind in the winter.

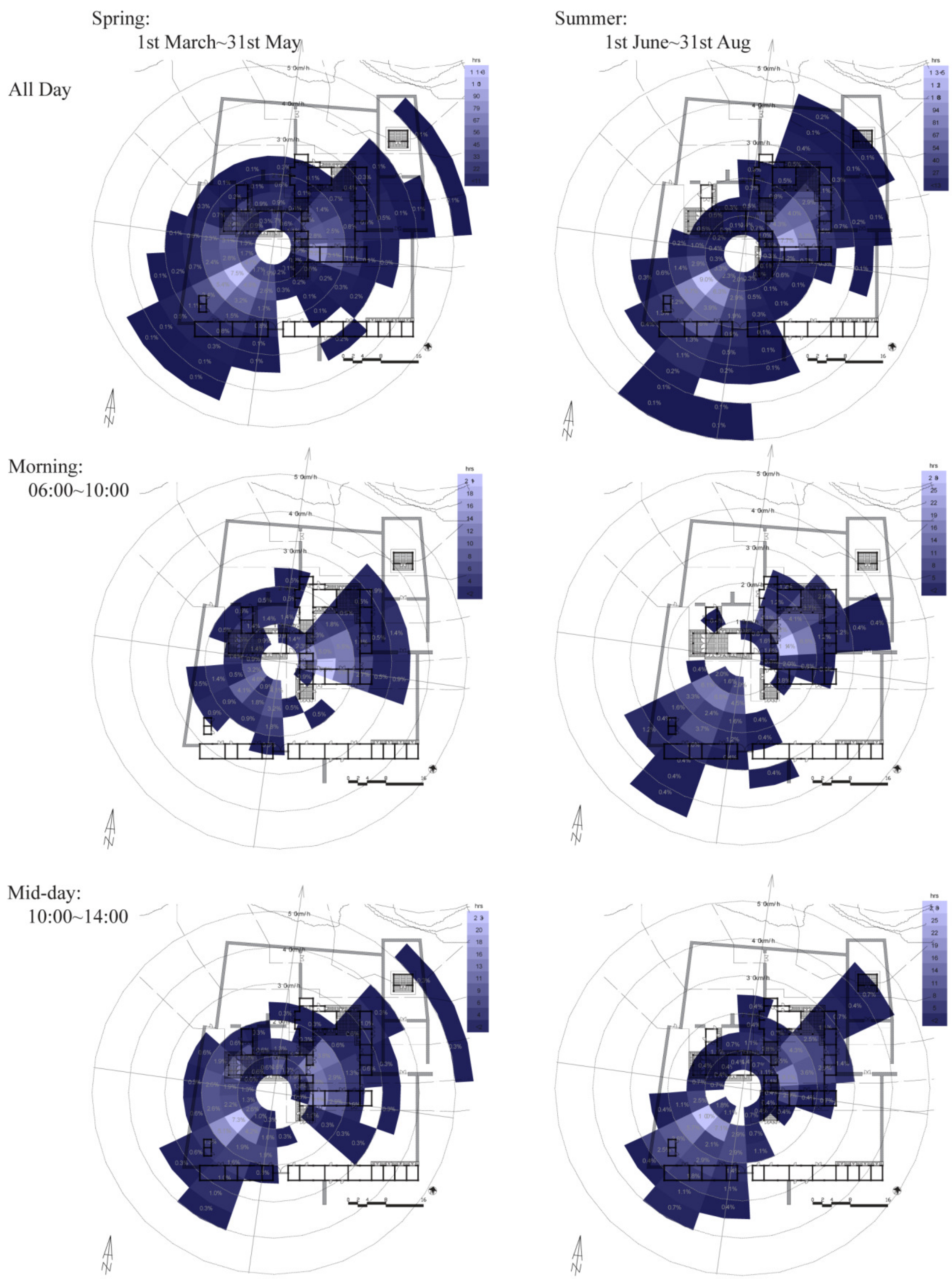


Figure 4-21 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: spring and summer, morning to mid-day

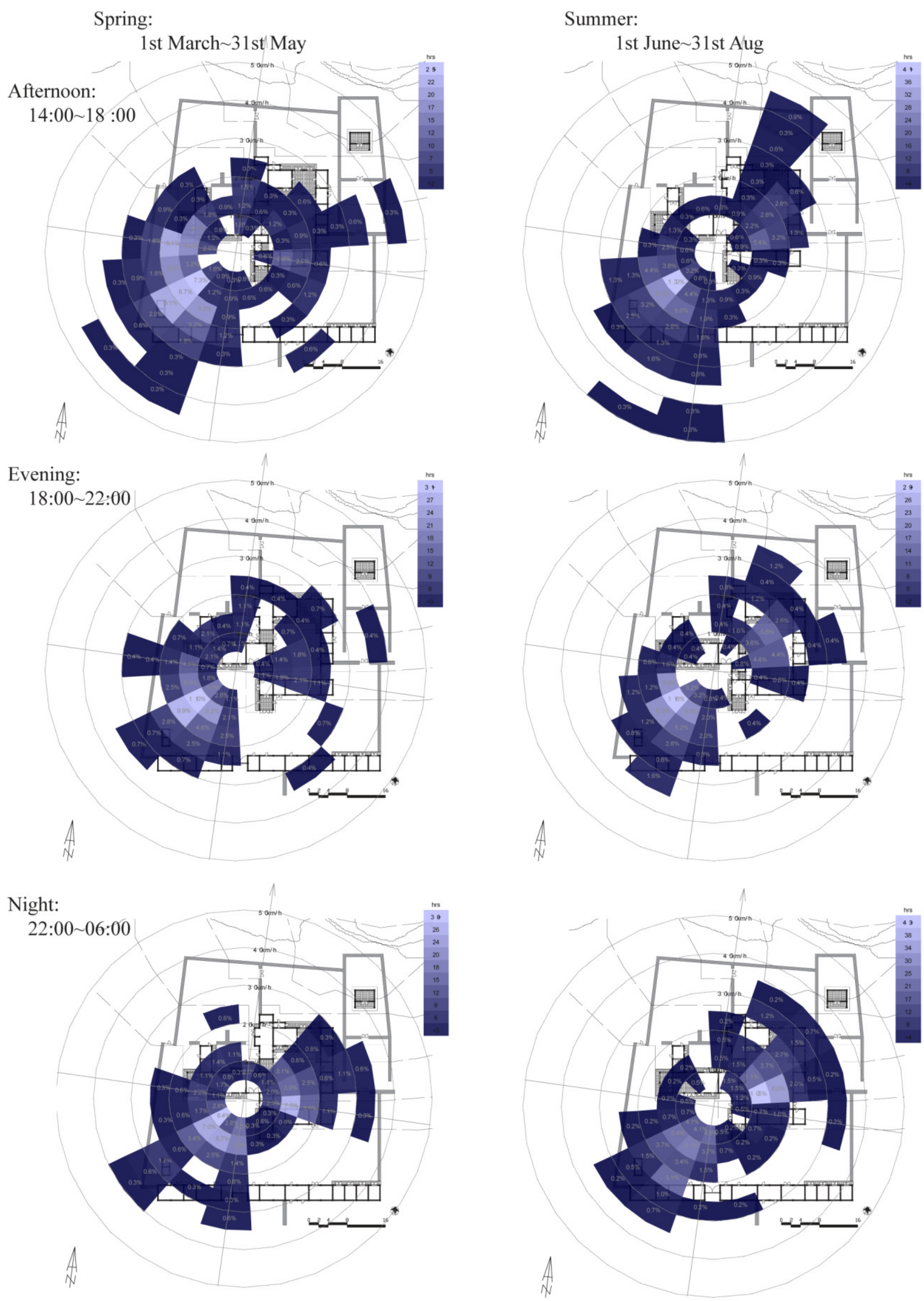


Figure 4-22 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: spring and summer, evening to night

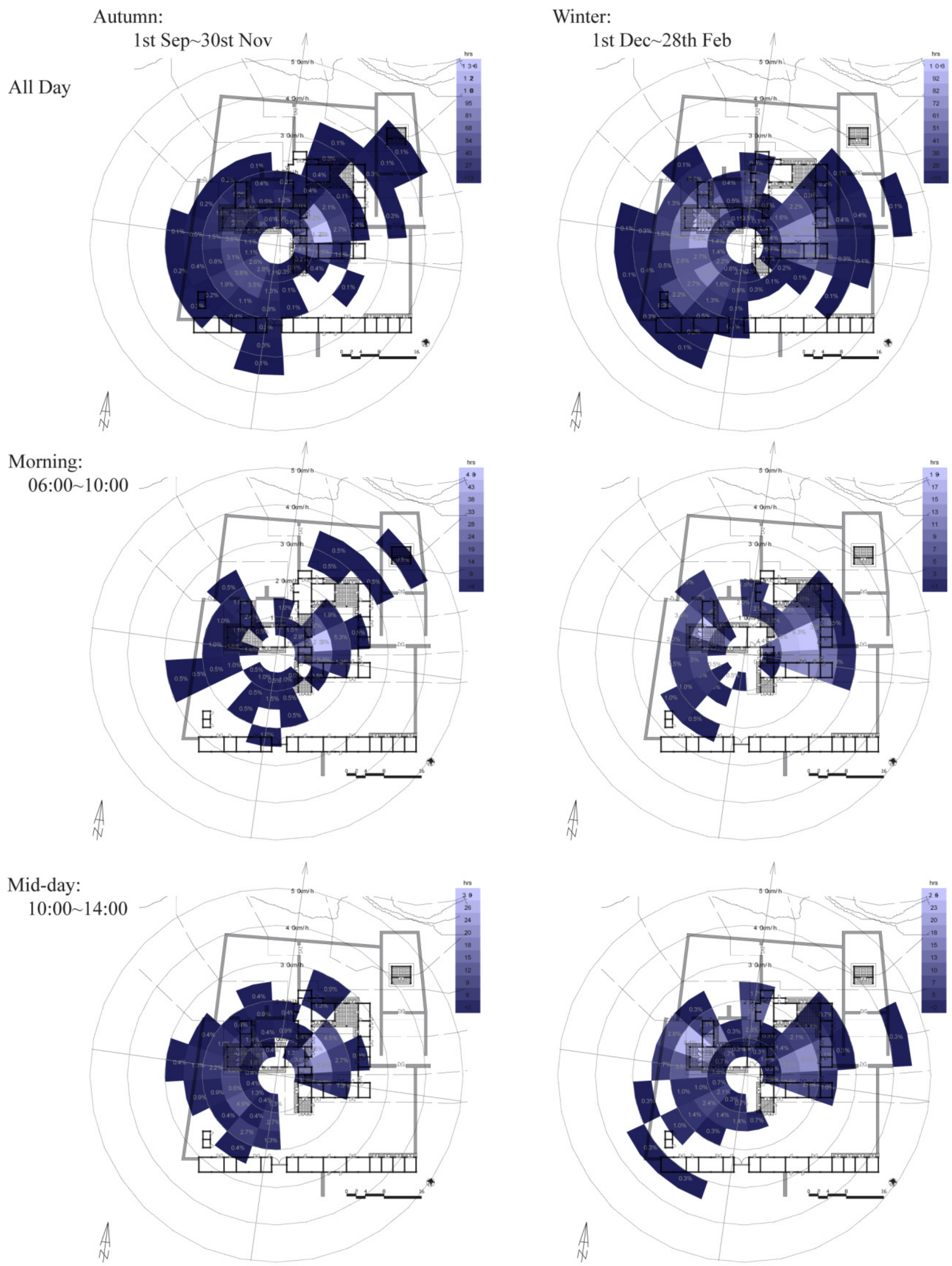


Figure 4-23 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: autumn and winter, morning to mid-day

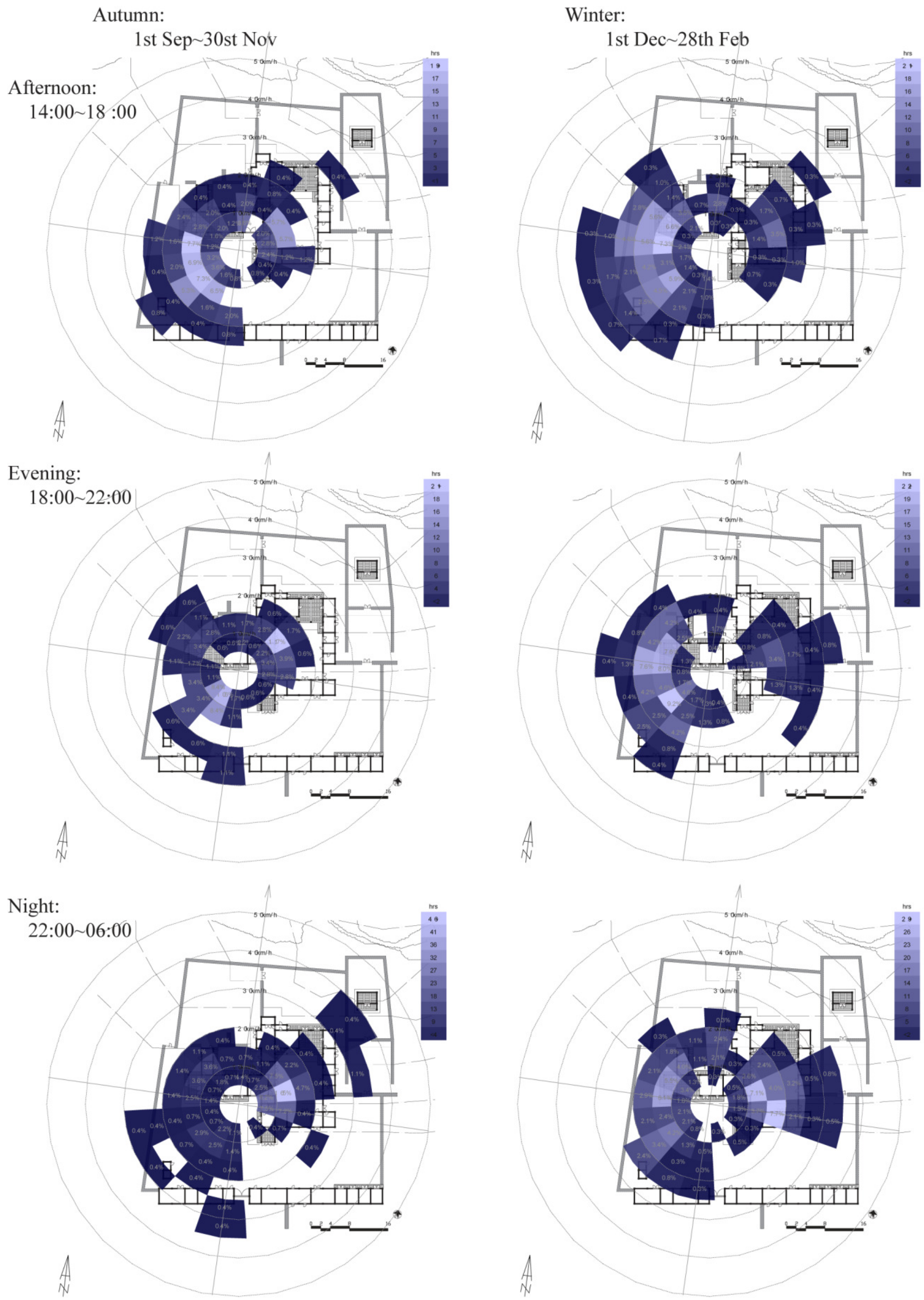


Figure 4-24 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: autumn and winter, evening to night

4.4.3. Thermal Performance

Thermal performance is related to materials, windows and doors sizes, height, length, temperature, orientation, and many other factors. The Chartered Institute of Building Services Engineers (CIBSE) Admittance Method determines internal temperatures and heat loads. This thermal algorithm is very flexible and has no restrictions on building geometry or the number of thermal zones that can be simultaneously analyzed. The internal temperature of any building will always tend towards the local mean outdoor temperature. Any fluctuations in outside temperature or solar load will cause the internal air temperature to fluctuate in a similar way, though delayed and dampened somewhat by thermal capacitance and resistance within the building fabric. When the total of all heat losses become equal to the total of all gains, then internal temperatures stabilize (Ecotect 2007).

Thermal performance of Ecotect evaluates the thermal comfort of human beings that is governed by many physiological mechanisms of the body and varies from person to person. In any particular thermal environment, it is difficult to get more than 50 per cent of the people affected to agree that the conditions are comfortable (McMullan and Seeley 2007). The principal factors affecting thermal comfort can be conveniently considered in the following sections: Personal variables included activity, age, clothing, and gender; and Physical Variables included air temperature, air movement, surface temperatures, and humidity.

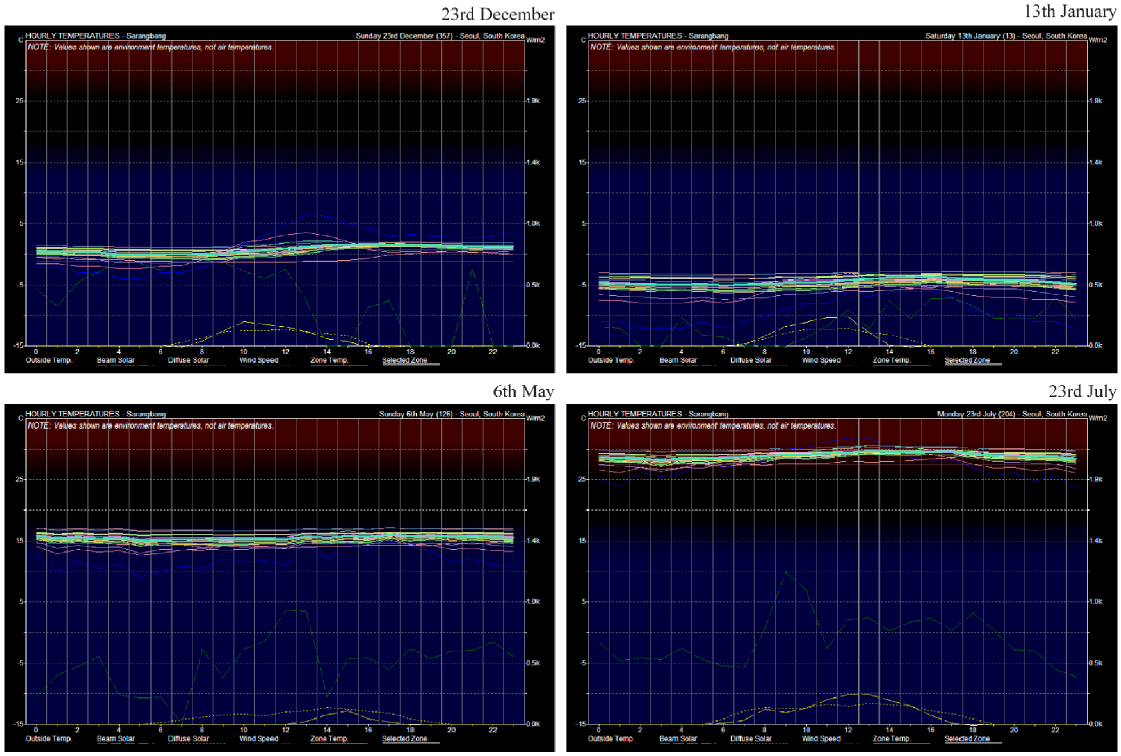


Figure 4-25 Thermal Performance, Ecotect Thermal Analysis shows the Hourly Temperature Profile with the cold zone, blue part, and the hot zone, red part (Ecotect: 2007)

The zones are tested in the following rooms: *sarangtaechong* (master men's *maru*), women *konnobang* (women and children's room), *sarangbang* (master men's room), small *sarangtaechong*, small sarangbang, anbang (master women's room), women *konnobang* (women and children's room) (Figure 4-12). The test dates in the summer are on June 21st, the summer start, July 23rd, the summer solstice, August 23rd, the summer end. On June 21st and July 23rd, the *anbang* room has numerous heat gain that increases the Percentage Dissatisfied.

Zone	Taechong	Sarangbang	Konnobang	Small Taechong	Small Sa_bang	Anbang	Women Konnobang
	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)
Total Floor Area(㎡):	20.41	20.49	6.82	8.88	9.04	19.38	9.31
Total Surface Area(㎡):	80.63	80.87	36.68	44.02	44.56	78.49	46.08
	395%	395%	538%	496%	493%	405%	495%
Total Exposed Area(㎡):	36.24	41.58	19.96	19.85	12.87	51.37	31.35
	178%	203%	293%	224%	142%	228%	337%
Total South Window(㎡):	6.80	2.93	0.00	2.76	0.00	4.32	0.00
	33%	14%	0%	31%	0%	23%	0%
Total Window Area(㎡):	8.96	5.09	0.00	43.00	0.72	5.40	1.98
	33%	25%	0%	0%	8%	23%	0%
Total Conductance (AU)(W/㎡ K):	60.00	66.00	28.00	31.00	15.00	82.00	52.00
Total Admittance (AY)(W/㎡ K):	242.00	231.00	99.00	123.00	122.00	225.00	128.00
Response Factor:	3.69	3.62	3.31	3.67	6.66	2.61	2.39

Table 4-2 *Unjoru* Area and Environmental Factors Calculation

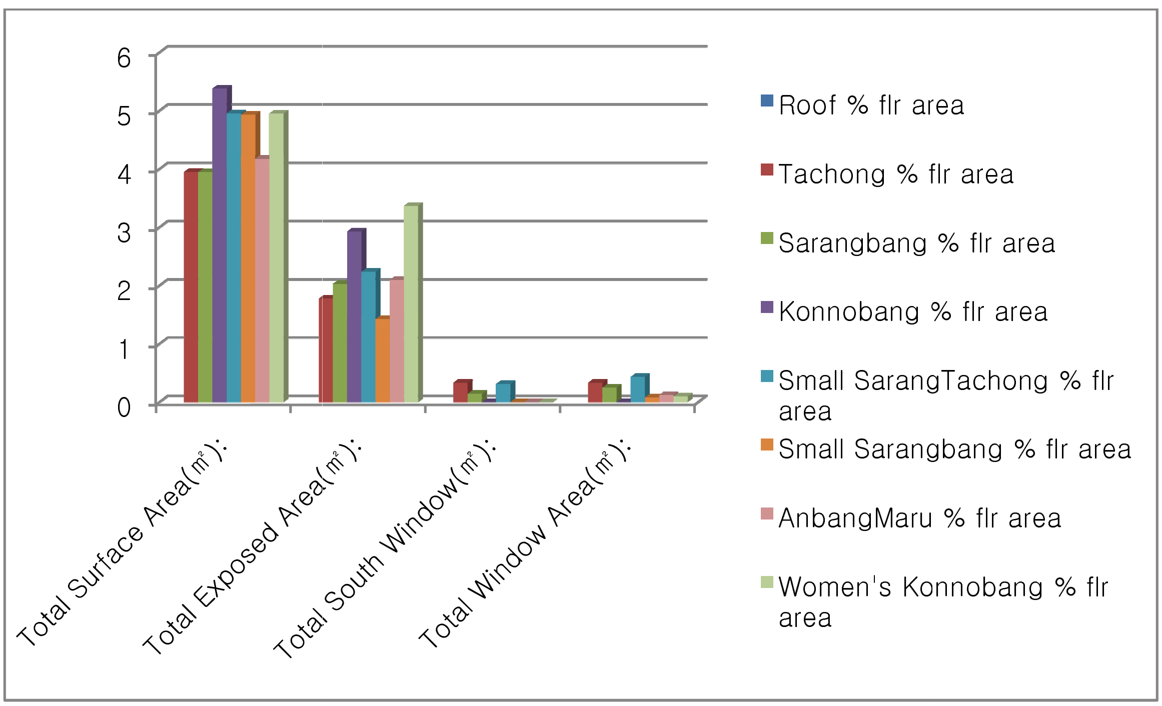


Figure 4-26 Percentage of Total area

4.4.3.1. Summer

In the summer, the hottest date is the July 23rd after two days of the summer solstice, at which the sun position is highest. The outside average temperature is the 27.5℃, and the range is from 23.5℃ at 24 o'clock to 31.8℃ at 1o'clock. The priority comfortable rooms, the cooling rooms, are ordered these following rooms; small *sarangtaechong* >*sarangtaechong* > women *konnobang* > *anbang* > *sarangbang* > men *konnobang* >small *sarangbang*.

Ecotect reports the small sarangtaechong the best comfortable rooms, which is the lowest temperature in summer. Small sarangtaechong is in front of the main gate. As soon as one enters the *Unjoru*, one could see the small sarangtaechong. It's south side is covered whole oil-papered windows, and the west and east sides have small windows.

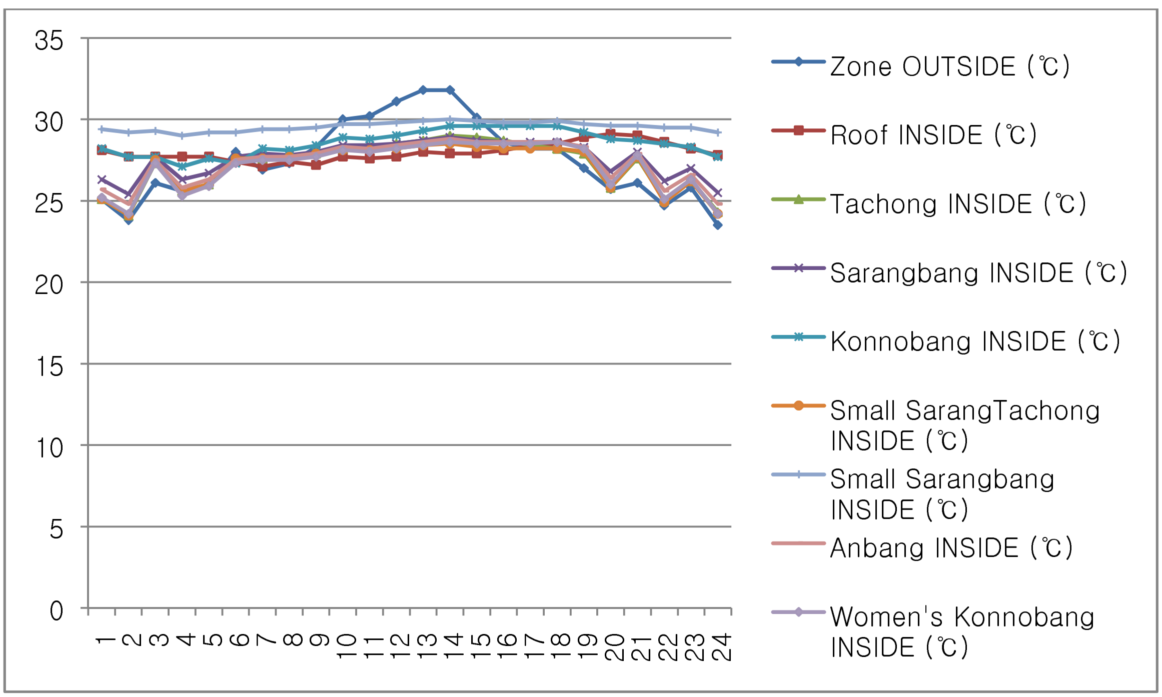


Figure 4-27 Hourly Temperature, July 23rd

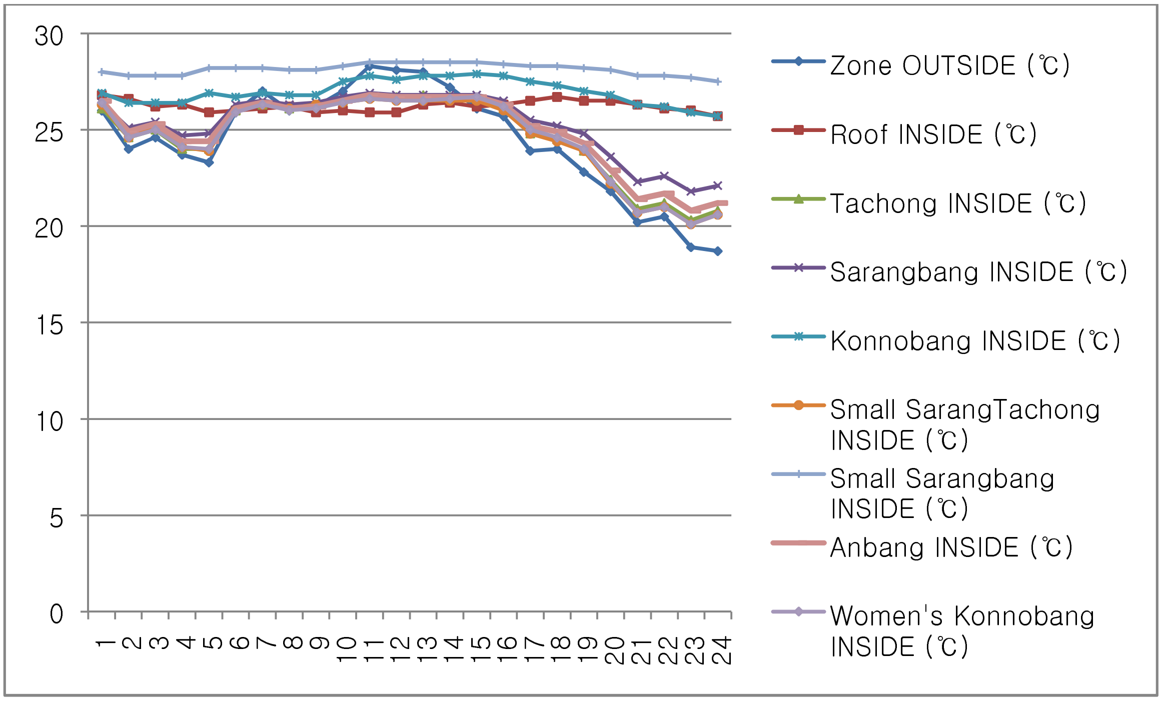


Figure 4-28 Hourly Temperature, August 23rd

4.4.3.2. Winter

In the winter, the better inside thermal comfort in Seoul, Korea definably should be warm temperature inside and keep the lasting warm energy. On January 13, the coldest date, the priority comfortable rooms are ordered these following rooms; small *sarangbang* > *anbang* > *sarangbang* > *sarangtaechong* > women *konnobang* > small *sarangtaechong* > men *konnobang*. Small sarangbang is the most comfortable room, which is the warmest room in the winter. Small sarangbang is placed behind the small sarangtaechong, which is paced on the south and has enough solar heat gain in the winter. The room is the smallest exposed room about 12.87㎡, 142% of the total surface area. Additionally, the most of rooms in the traditional residence have two sides exposed windows on the front and backside. The solar heat gain of small sarangtaechong penetrates to the sarangbang, and the small sarangtaechong embodies the buffer zone that provide to carry the winds from outside in summer and to preserve the heat gain in winter. The next warmer room reports anbang, which is master women room. Even though anbang is placed on the corner of the west of anchae, the anbang condition is very good condition. In this analysis, there is no considering installing the ondol system, of which the furnace is placed in the kitchen next by anbang that can have more benefit the heating system. The result of Ecotect analysis provides that the anbang is very good condition of living. The reason of the good condition in anbang is to be in middle of the other zones such as kitchen, antaechong and maru. The other zones transmit the heat to anbang and preserve the heat from anbang. The backside hill also provides to keep the anbang heat in winter, and there are no north side windows directly from outside. There are small maru between anbang and north hill. The analysis reports sarangbang to be next good condition in winter, because sarangbang also is surrounded by other rooms such sarangtaechong and middle gate. Otherwise, sarangbang condition is worse than small sarangbang and anbang, because sarangbang has more total exposed area and total surface area. The next worse rooms are the men and women konnobang and taechong. There is no heating system like ondol in taechong, and those rooms have bigger windows and exposed to outside. Usually those rooms enclose the heating rooms, bangs, such as sarangbang and anbang. The konnobang for second generation also have worse situation, because the rooms do not have the south windows and isolate the corner of any other rooms. Trough the analysis in winter, the report proves that each rooms emphasize their own function and the order of important rooms.

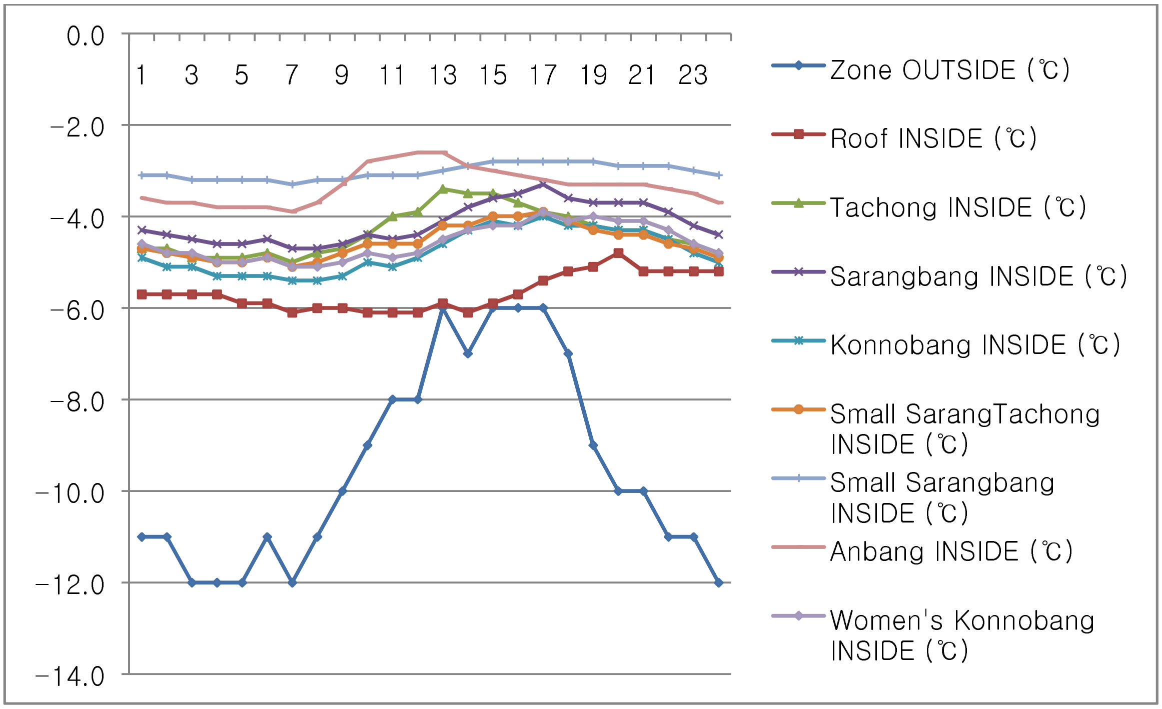


Figure 4-29 Hourly Temperatures, 13th January

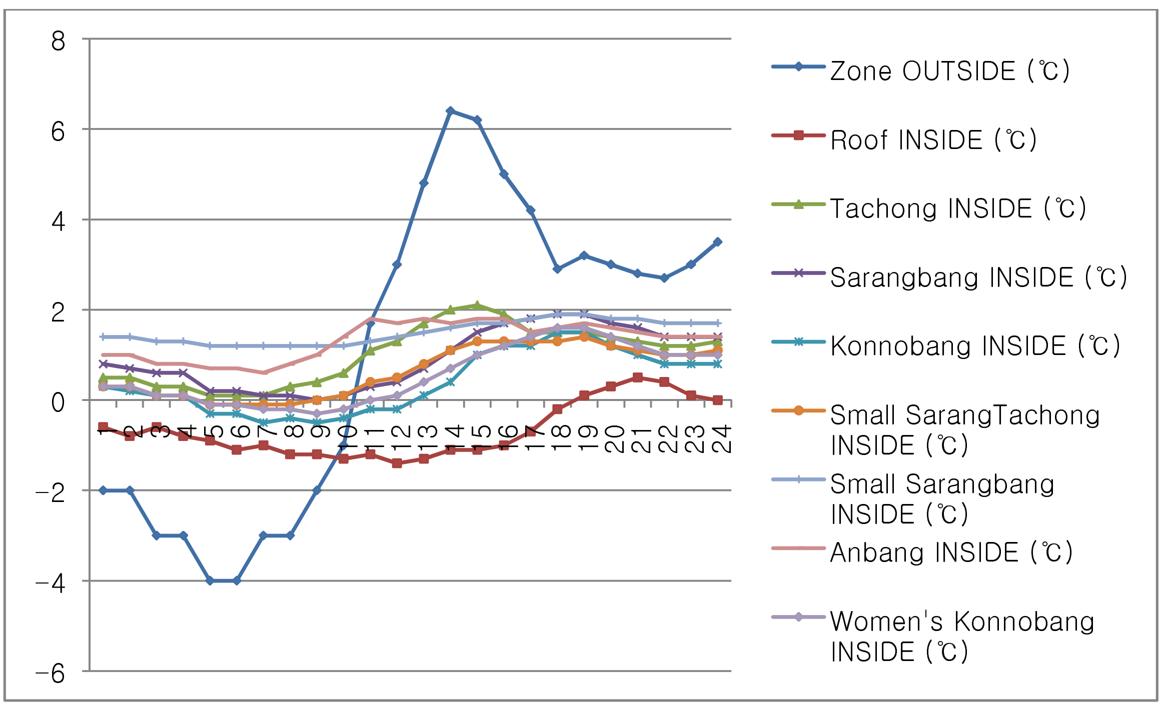


Figure 4-30 Hourly Temperatures, 23rd December

4.4.3.3. Spring and Autumn

In the May 6th, which starts to change the weather point to the summer, the average temperature is 14.6 ℃, and the range is from the 14℃ to the 16℃ in all of rooms in Yeongyeongdang. The dissatisfied percentage at the 14℃ air temperature point to 33% in Predicted Mean Vote(PMV)[13] software offered by SQUARE One research, and the dissatisfied percentage at16℃ is 19.2% (Table 4-3). In any particular thermal environment, it is difficult to get more than 50 per cent of the people affected to agree that the conditions are comfortable (McMullan, 2007). In the date, the thermal comfort is mostly satisfied, but one could feel little cold for sleeping. If the clothing level is changed, the percentage dissatisfied should be changed.

	The lowest temperature	The highest temperature	
Air Temperature (℃)	14	16	May 6th
Radiant Temperature (℃)	23	23	
Relative Humidity (%)	70	70	Source by Korea Meteorological Administration, the average humidity from 1961 to 1990.
Activity Rate (met)	1.5	1.5	Standing
Clothing (clo)	1	1	Light Business Suit
Air Velocity (m/s)	1	1	
Predicted Mean Vote	-1.48	-0.83	-3 too cold, +3hot
Percentage Dissatisfied	33.00%	19.20%	

Table 4-3 May 6th Predicted Mean Vote (PMV)

[13] See also Chapter 2 Predicted Mean Vote Section

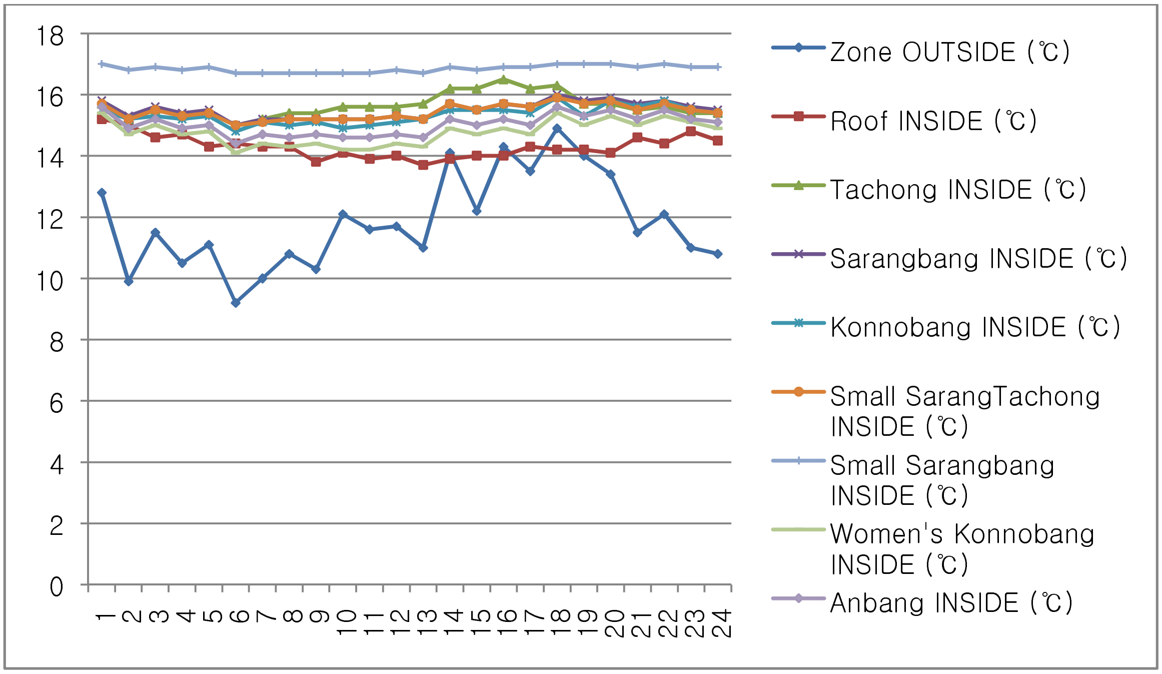


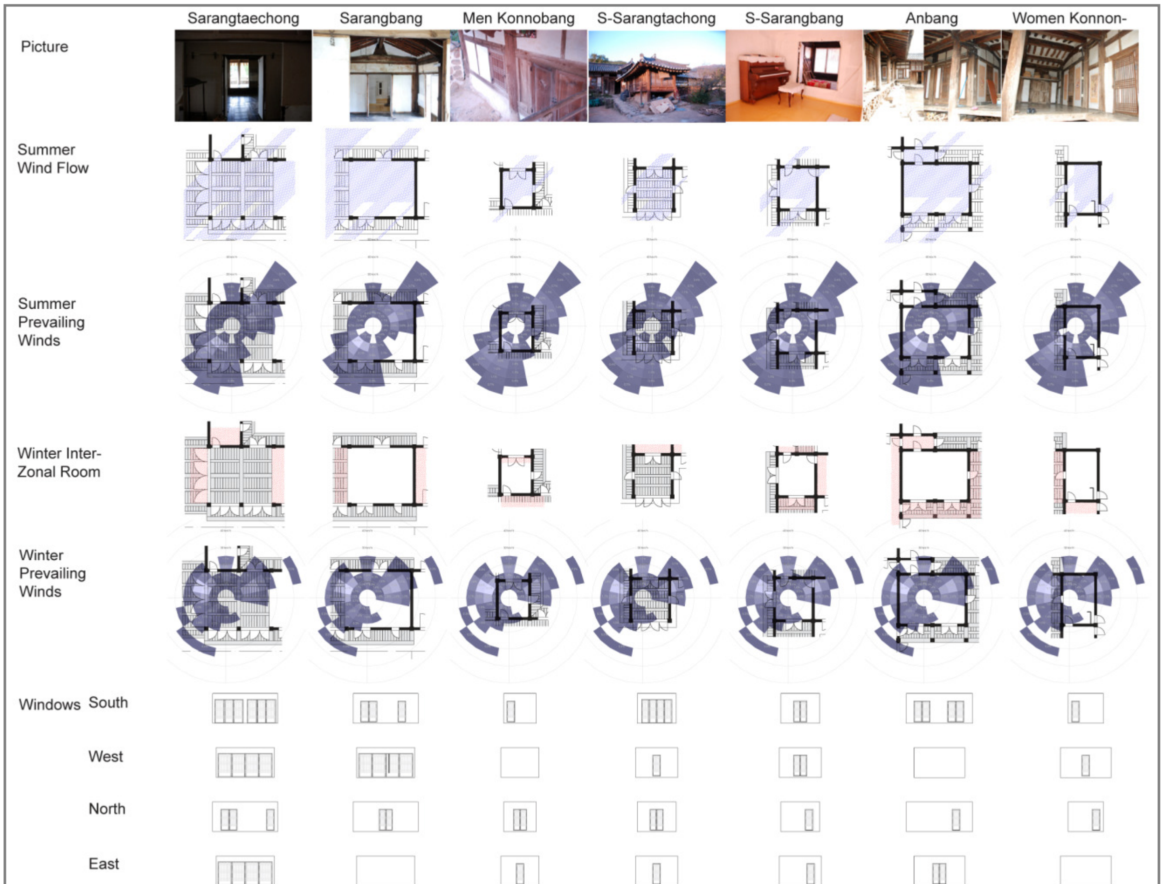
Figure 4-31 Hourly Temperature, May 6th

4.5. Summary

The *Unjoru* research trough Ecotect software manly divide three big analyses to control sunlight and daylight, shading, wind flow, and the thermal performance. Those factors are related and linked together. In this chapter analyzing the *Unjoru*, the main idea of sunlight protects the strong sunlight in the summer until august 23rd same as *Yeongyeongdang*.

During the summer, the open door offers enough air inside. Additionally, for the wind flow from the southwest in the summer, the building layout was so well suited to the each room. The southern part of windows in sarangchae and anchae provides the wind flow from the southwest in the summer. Ecotect shows the prevailing winds' direction and amount, which is able to display in the 3D model. In addition, the windows on the north face or the windward windows are almost installed small windows for protecting the cold wind in the winter

The priority comfortable rooms, the cooling rooms, in summer are ordered these following rooms; small *sarangtaechong* >*sarangtaechong* > women *konnobang* > *anbang* > *sarangbang* > men *konnobang* >small *sarangbang*. In the thermal performance, the priority rooms define different order using by the different seasons, then in the winter season, the order are these following rooms: small *sarangbang* > *anbang* > *sarangbang* > *sarangtaechong* > women *konnobang* > small *sarangtaechong* > men *konnobang*. These orders are satisfied with the rooms function in the summer. In the winter the inside temperature in the all of rooms are independent on the outside temperature, even though there is no ondol system, thermal heating system.



		Sarangtaechong	Sarangbang	Men Konnobang	S-Sarangtachong	S-Sarangbang	Anbang	Women Konnon-
Area								
Total Floor Area(m^2):		20.41	20.49	6.82	8.88	9.04	19.38	9.31
Total Surface Area(m^2):		80.63	80.87	36.68	44.02	44.56	78.49	46.08
		395%	395%	538%	496%	493%	405%	495%
Total Exposed Area(m^2):		36.24	41.58	19.96	19.85	12.87	51.37	31.35
		178%	203%	293%	224%	142%	228%	337%
Total South Window(m^2):		6.80	2.93	0.00	2.76	0.00	4.32	0.00
		33.3%	14.3%	0.0%	31.0%	0.0%	23.0%	0.0%
Total Window Area(m^2):		8.96	5.09	0.00	43.00	0.72	5.40	1.98
		33.3%	24.8%	0.0%		8.0%	23.0%	0.0%
Priority Room In Summer		2	5	6	1	7	4	3
Building Fabric	6-May	-6,352	-6,511	-2,520	-3,201	-1,180	-8,257	-5,204
	21-Jun	13	108	243	116	72	187	214
	23-Jul	2,126	2,264	1,022	1,126	447	2,965	1,936
	23-Aug	591	584	272	281	115	783	515
Solar Heat Gain	6-May	236	168	0	67	10	134	74
	21-Jun	422	300	0	137	18	240	162
	23-Jul	371	264	0	115	16	211	127
	23-Aug	199	142	0	58	9	113	65
Ventilation Gain	6-May	-3,268	-3,281	-1,094	-11	-967	-3,015	-1,491
	21-Jun	-25	-25	-8	-16	-9	-23	-11
	23-Jul	1,088	1,092	364	474	313	1,004	496
	23-Aug	210	210	70	91	63	193	96
Internal Loads		2,449	2,459	818	1,066	1,084	2,263	1,117
Inter-zonal Loads	6-May	1,199	-123	-119	-5,395	-1,808	93	27
	21-Jun	1,217	4	-42	-405	-612	201	51
	23-Jul	1,057	-105	-42	-8,784	-4,214	41	-4
	23-Aug	1,142	-140	-97	-8,136	-4,029	29	-2
Priority Room in Winter		4	3	7	6	1	2	5
Building Fabric	23-Dec	-18,226	-18,968	-7,844	-9,368	-3,587	-24,487	-15,667
	13-Jan	-29,304	-30,218	-12,274	-14,926	-5,663	-38,788	-24,722
Solar Heat Gain	23-Dec	212	151	0	65	9	148	94
	13-Jan	199	142	0	67	9	141	75
Ventilation Gain	23-Dec	-8,587	-8,621	-2,874	-3,742	-2,570	-7,922	-3,917
	13-Jan	-12,350	-12,398	-4,134	-5,382	-3,820	-11,393	-5,634
Internal Loads		2,449	2,459	818	1,066	1,084	2,263	1,117
Inter-zonal Loads	23-Dec	744	-217	33	6,258	1,472	-114	-59
	13-Jan	1,274	-161	-135	9,207	2,051	124	62

Table 4-4 *Unjoru* Summary of the Environmental Analysis

4.6. Drawings

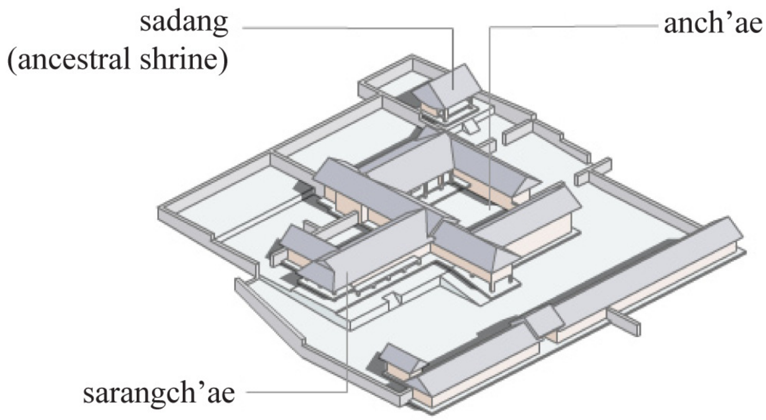


Figure 4-32 Isometric View (Korea Culture & Content Agency 2003)

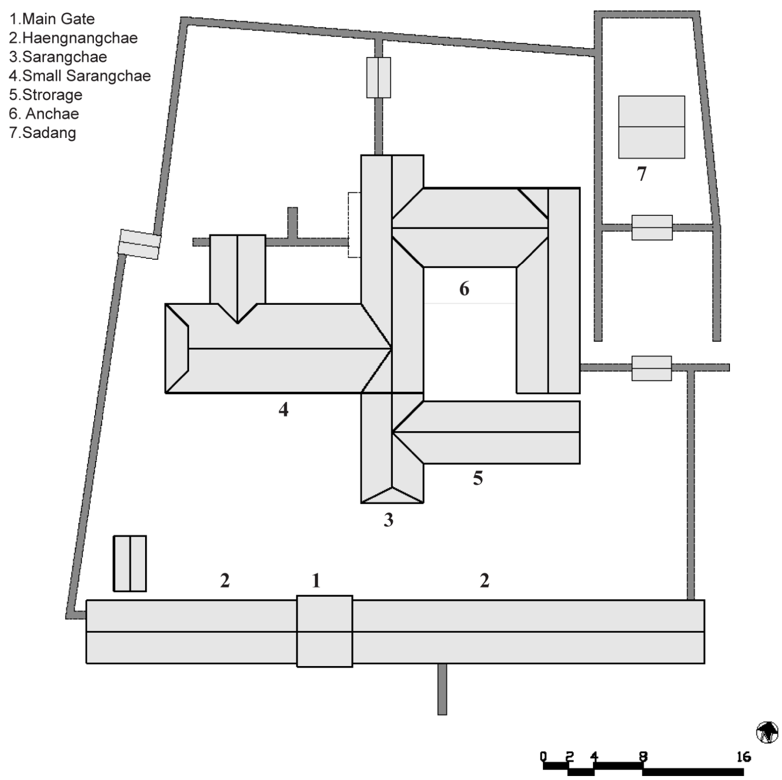
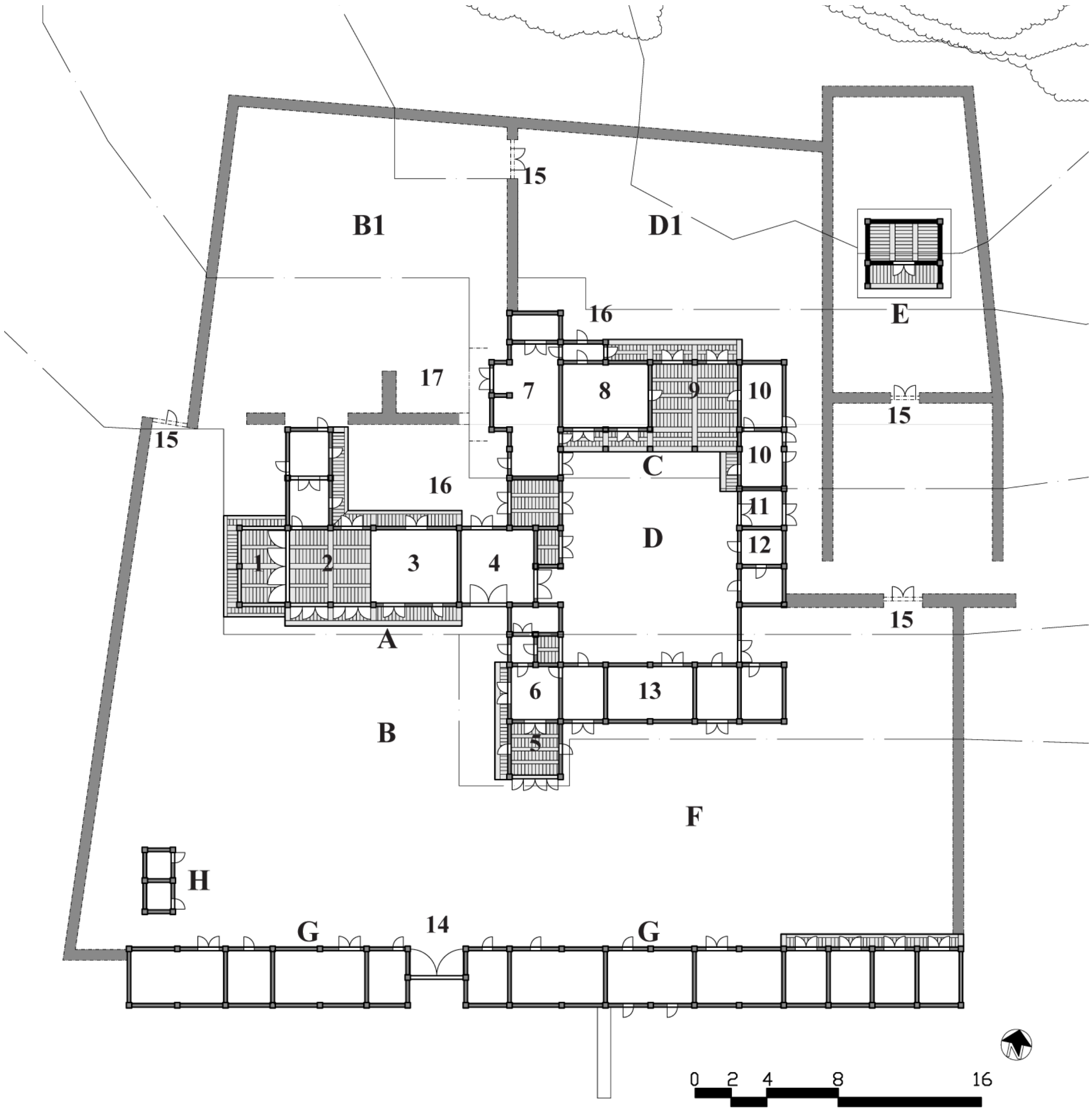


Figure 4-33 Roof Plan



A.Sarangchae B.Sarangmaddang B1. Sarang Twitmadang C.Anchae D.Anmadang D1.Anchae Twit-madang E.Sadang(ancestral shrine) F.Madang G.Haengnangchae H. Toliet

1.Numaru 2.SarangTaechong 3.Sarang-bang 4. Inner Gate 5.Small SarangTaechong 6.Small sarangbang 7.Puok 8.Anbang 9.AnTaechong 10.Konnobang 11.Innner Gate 12.Attic 13.Storage 14.Main Gate 15.Middle Gate 16.Chimney 17.Pond

Figure 4-34 Site Layout

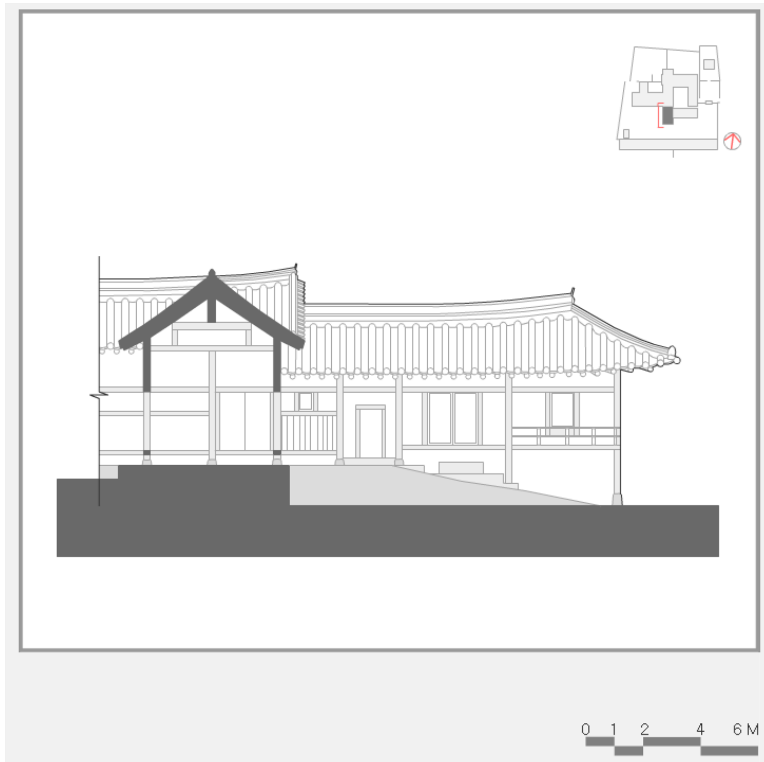


Figure 4-35 East Elevation of Small *Sarangchae* (Korea Culture & Content Agency 2003)

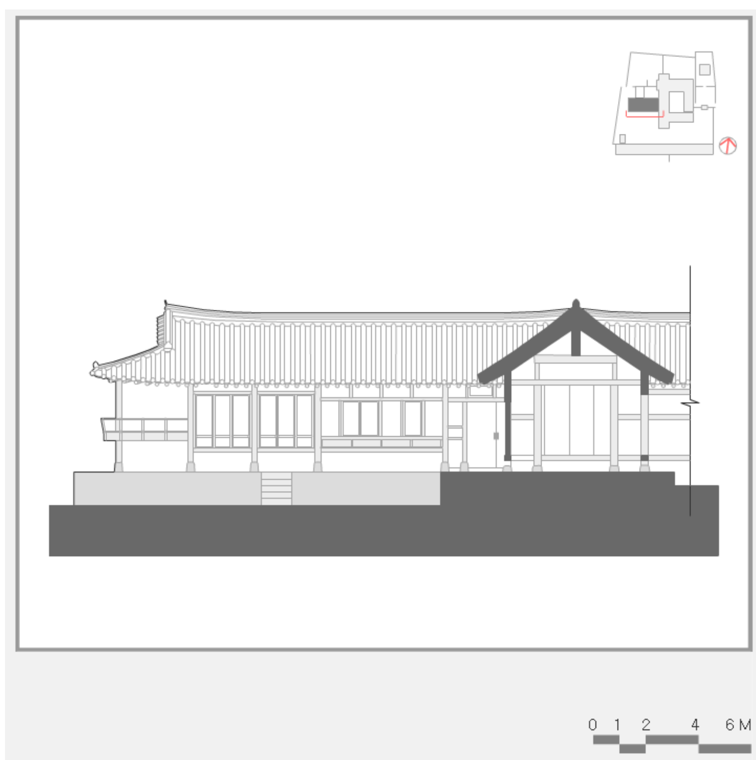


Figure 4-36 South Elevation of *Sarangchae* (Korea Culture & Content Agency 2003)

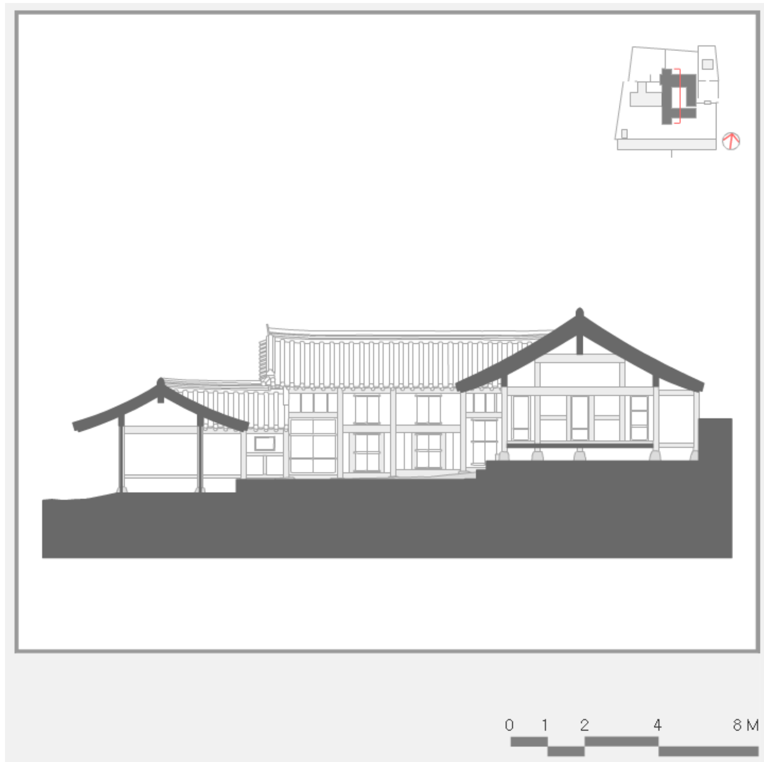


Figure 4-37 Section (Korea Culture & Content Agency 2003)

5. *CHUSAGOTAEK* - TEST MODEL III

5.1. Introduction

Chusagotaek, the other selective project, represented one of good example of the traditional upper level residence, which has adoption of *pungsu* idea and reflection of the same age social tendency where exists in southern part of Korea. This chapter affords how the *Unjoru* reflects not only the social impact and cultural impact, but also mainly focus on the environmental analysis. Unlike the previous analyzing residence, *Yeongyeongdang* and *Unjoru*, *Chusagotaek* has different neighborhood condition and built on the different surrounding geographical conditional site, which is located on the slope site unlike *Yeongyeongdang*, which is located on the flat site. Most of the traditional residence in Korea has been built on the low mountains and hills. Therefore, the *Chusagotaek* also can show the normal traditional design living more than the *Yeongyeongdang* analysis.

In this chapter, the analysis of *Chusagotaek* makes more deeply digging how the Korean ancestor live with the environmental factors and how the upper class level live around the late 18^{th} century to the early 19^{th} century. The different geographical characteristics in the different area environment within Korea also had decided the residence's layouts and appear different compositions. *Chusagotaek* layout specially emphasizes the Confucian principles, which was established as the dominant philosophy where ancestor worshipping became the core practice of people's spiritual. It shows that the separation of men from women, and the need for an ancestral shrine became fundamental elements in the composition of the traditional Korean residence. *Chusagotaek* provides the late *Joseon* period upper level classes residence more than Unjoru, because in the late *Joseon* period, the anchae and sarangchae were built totally separate without continuing building. Ecotect, the paper provides the evidence that *Chusagotaek* incorporated the ecological factors into its design with administering the shadows, shading and solar analysis; wind flow and airflow; and thermal performance.

5.2. History

Chusagotaek is located at *Yongung-ri*, *Sinam-myeon*, *Yeson-eup*, where is in middle of the west part of Korea before 1758, and it was renovated in 1977. This house is built it originally 53 kan, but only 20 kan is remained. The servants' area and the service area were located outside, but those buildings are not remained. *Chusagotaek* was rebuilt using the other house structure, which was one of biggest house in Seoul. This house is where Kim Jeong-Hui was born. Chusa Kim Jeong-Hui's is one of the greatest philosophers, political leader, and artists at the end of *Joseon* Dynasty. *Chusa* means the pseudonym of Kim Jeong-Hui. It has been told that Kim Han-sin, who was great grandfather of Kim Jeong-Hui, built it. There is an anchae in the west, a sarangchae on the lower plane in the east. The anchae has a 6 *kan* taechong, a 2 kan *anbang*, a *konnobang* have their veranda respectively. The Kitchen's closet is a garret. The building manager, Park Sewng-Hae, said that the kitchen was located outside of *Chusagotaek*, because the wife of the great grandfather of Kim Jeong-Hui was a king's daughter and she did not cook (S.-H. Park 2007).

The sarangchae is facing the south 'ㄱ'shaped. There is a one kan ondol in the south, a 2kan ondol in the east, a taechong and a maru. A stone column inscribed '*seoknyeon'* by Kim Jeong-hui was erected on the terracing stones (Figure 5-1). They measured the time of day by using the shadow of the column. The stylobate of the anchae and the sarangchae were made by the long terracing stones. Corner stones were laid on it. The house is '八' (eight in Chinese) shaped roof, whose eaves are single. The furnace of the sarangchae is declined on the plane. With the *Chusagotaek* at the center, on the right there is a grave where Kim Han-sin and his wife, *Hwasunongju*, who was the king's family, were buried together, and next to the grave there is a monumental gate, which commemorates on exemplary wife at the that time. White pine tree, which is Natural Monument No. 106 stands next to the gate. On the left of the *Chusagotaek*, there is Chusa Kim Jeong-hui's grave, and on the back of it there is a temple named *Hwaamsa*. There are also a number of stones, which have Chusa's writings (Yesan County 2007).

Figure 5-1 A stone column inscribed 'seoknyeon' by Kim Jeong-hui was erected in the small garden.

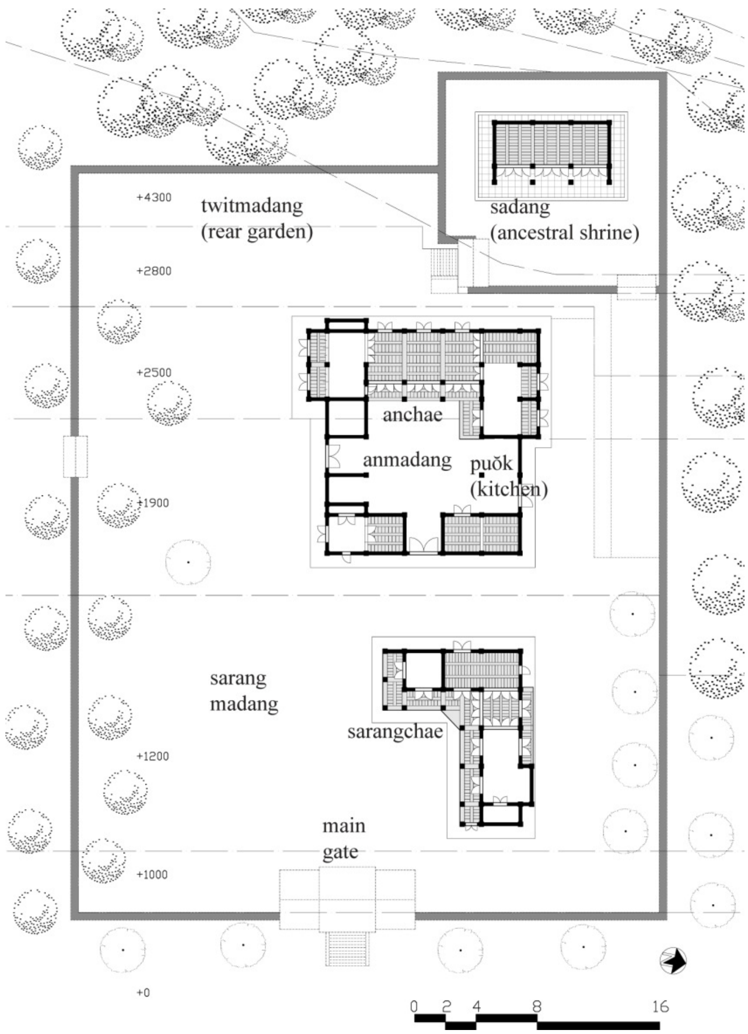


Figure 5-2 *Chusagotaek* Site Plan

Spatial composition of *Chusagotaek* can be prioritized as below.

1. Men's quarters: *sarangchae* (master quarter), *sarangmadang* (garden in front of master quarter), *seonhyangjae* (library), *nongsujung* (pavilion)
2. Women and children's quarters: *anchae* (family's living quarter), *anmadang* (garden in front of *anchae*), *arangchae* (children and lesser women's quarter)
3. Servant's quarters: not remained
4. Service quarters: *bueok* (kitchen) in the anchae quarters, but originally it was located outside and not remained

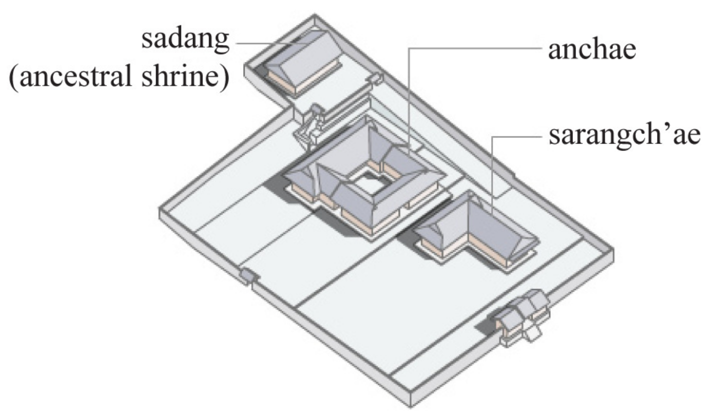


Figure 5-3 *Chusagotaek* Bird View (Korea Culture & Content Agency 2003)

5.3. Methodology

This analysis of *Chusagotaek* had been processed same as *Yeongyeongdang* and *Unjoru*. The analysis starts from building geometric models of *Chusagotaek* with AutoCAD, which allows precise detail in size. Based upon the models, the design factors and the environmental factors of *Chusagotaek* are redefined in the contemporary paradigm. The design factors include building layout, windows position and size, landscape, overhang, building distance, orientation, material selection, human comfort, and thermal performance.

In Ecotect, the model of *Chusagotaek* is formatted on the grid that allows size changes (Figure 5-4). After each space of buildings, called zone, are perfectly enclosed and assigned with correct materials, the analysis of the lighting, thermal, and acoustic is performed based upon the geographic and meteorological data regarding the site of *Chusagotaek*.

Ecotect is a highly visual and interactive building design and analysis tool, covering the widest range of analysis features including solar, thermal, energy, lighting, acoustics, regulations and so on (squ1.org 2007). It is employed for analyzing shadows, shading & solar influence, thermal performance, heat gain & loss, spatial comfort, ventilation and daylight & sunlight. Ecotect uses a system of inter-object relationships to assist with this. Based upon the plan of a zone, Ecotect automatically extrudes the corresponding walls and a ceiling. This is useful for modifying the nodes in the plan object. It keeps track of all related walls, ceilings and any added windows (squ1.org 2007).

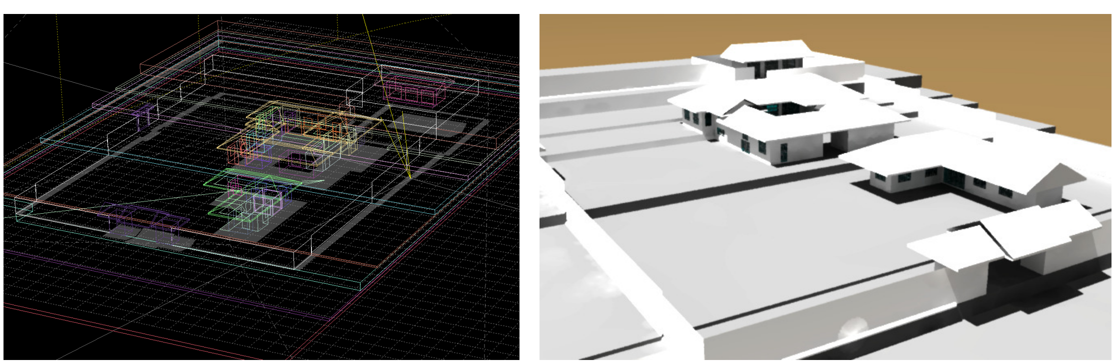


Figure 5-4 Ecotect Modeling (left), and Rendering by Radiance (Right)

Experiments are focused on summer and winter of Korea, which require secondary needs to maintain environmental comfort in a building:

- ✓ January 13 - the coldest date
- ✓ May 6 - the start of summer
- ✓ June 21-the summer solstice: Sun at its highest noon altitude
- ✓ July 23-the hottest date
- ✓ August 23 -the end of summer
- ✓ December 23 - the winter solstice: Sun at its lowest noon altitude. (Korea National Heritage Online 2000, squ1.com 2007)

5.4. *Chusagotaek* investigation

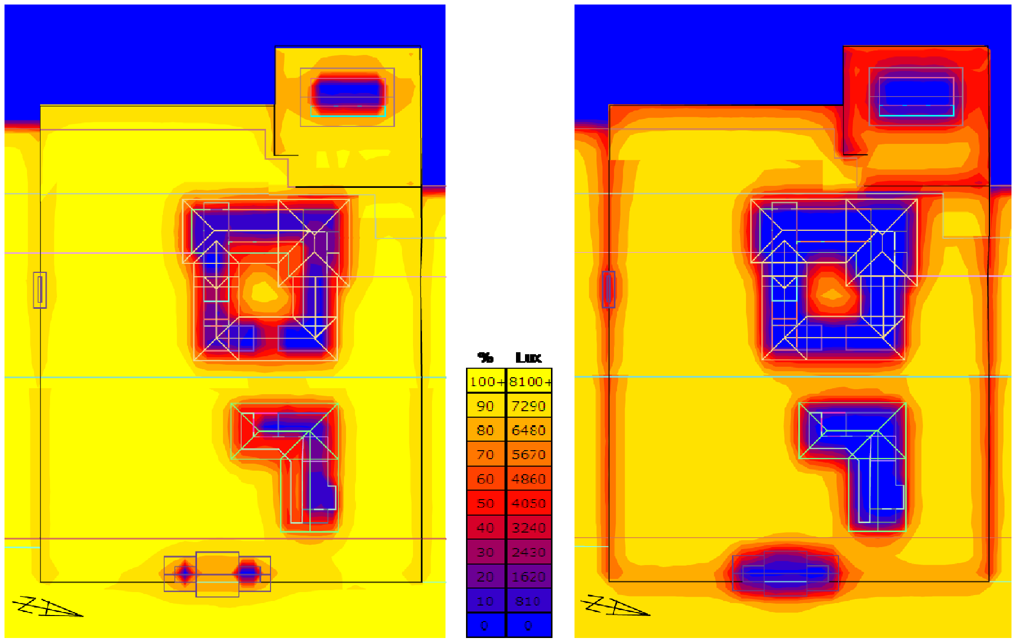
Like the traditional Korean residence, *Chusagotaek* building orientation is faced the south and tiled the east about 12 degree. Otherwise, Unjoru building orientation is faced the 8 degree east of south. In Korea, usually solar glazing should be oriented the south. This orientation offers the best results of both winter heating and summer shading. The main owner was one of famous scholar, Chusa Kim Jeong-hui studed or painted early. Therefore, it is better design solution that the *Chusagotaek* must be built slightly east of south. .

Chusagotaek also follows the theory like the other traditional buildings, “mountain behind and river in front” and the architecture face south based on the principles of *pungsu*. However, there is no river or any bigger water place in front of building, and it does not seem to follow the theory but in front of *Chusagotaek*, there is a small pond. The pond is very small, which does not seem to support the pungsu theory, but the pond could be a small gesture of symbolizing the *pungsu* theory. However in front of *Chusagotaek* structure are almost empty, the sunlight spread out to the building very well without interruption of the front view. *Yeongyeongdang* and *Unjoru* have the main gate on the southern part of buildings, and those buildings are faced toward south. *Unjoru* has the main gate on the eastern part of buildings, and the building is faced toward south for considering the daylight.

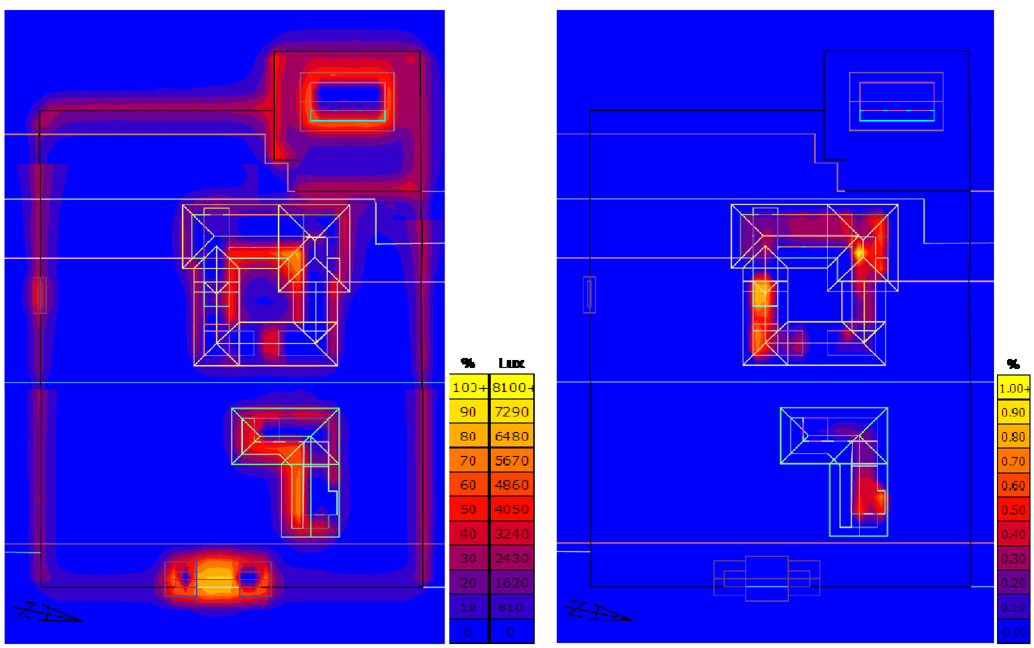
The Daylight Analysis in the Ecotect provides the decision of the layout, which one should be used for analyzing the environmental factor. The daylight levels are not time dependant and it represent a worst-case design condition base on a sunless cloudy or uniform sky distribution.

Ecotect assumes the Design Sky Illumination maximized 8500 lux. Daylight usually enters a building by means of oilpaper windows or doors, but these windows or doors also transmit heat, which is related with the thermal performance. The amount of daylight provides the decision of lighting as well as the cooling energy. The provision of natural lighting in a residence needs to be considered together with factors of artificial lighting, heating, ventilation and sound control.

The result from Daylight Analysis (Figure 5-5) shows the Daylight Factors (DF) including the Externally Reflect light, and the Internally Reflect light. The internally reflected lights in *anbang* and *sarangbang* are stronger than in *Yeongyeongdang* and *Unjoru*, but the daylight factor is still not very strong. On the other hands, the externally reflected light is very strong that transmit the unnecessary heat in the summer, but the externally reflected light spreads out evenly in anchae and sarangbang. Even though, the anbang and women's *konnobang* are located in the west of north, the Externally Reflect light spreads out to the corner of buildings. The differ level of the anchae site leads to the sunlight to spread out to the corner. The *anbang*, *antaechong*, and a *konnobang* are placed on the higher site level than the other servant's rooms called *haengnangbang,* and kitchen.



Daylight Level **Sky Component**



Externally Reflected Light **Internally Reflected light**

Figure 5-5 Daylight Analysis

5.4.1. Shadows, Shading and Solar Analysis

Shadows, Shading and Solar Analysis offer the greatest opportunity for incorporating *Chusagotaek* features. This analysis could monitor use of natural energy flows as the primary means of harvesting solar energy. It also provides the space heating, cooling load avoidance, natural ventilation and natural light. Ecotect provides three big functions in *Chusagotaek* analysis; Shadows & Reflections Analysis, Shading Design and Incident Solar Radiation.

Trough the incident solar radiation in Ecotect, the roof shade all of buildings one of hot summer dates, June 21, and the sunlight, which can be the radiant energy, can penetrate to the buildings. The total direct radiation shows the sunlight valuable amount in the specific day. The summer sunlight, 3200-Watt hour, emits more than ten times of the winter sunlight, 320-Watt hour, which can penetrate inside building, and avoiding the stronger summer sunlight put forward better design solution in the traditional residence *Chusagotaek*.

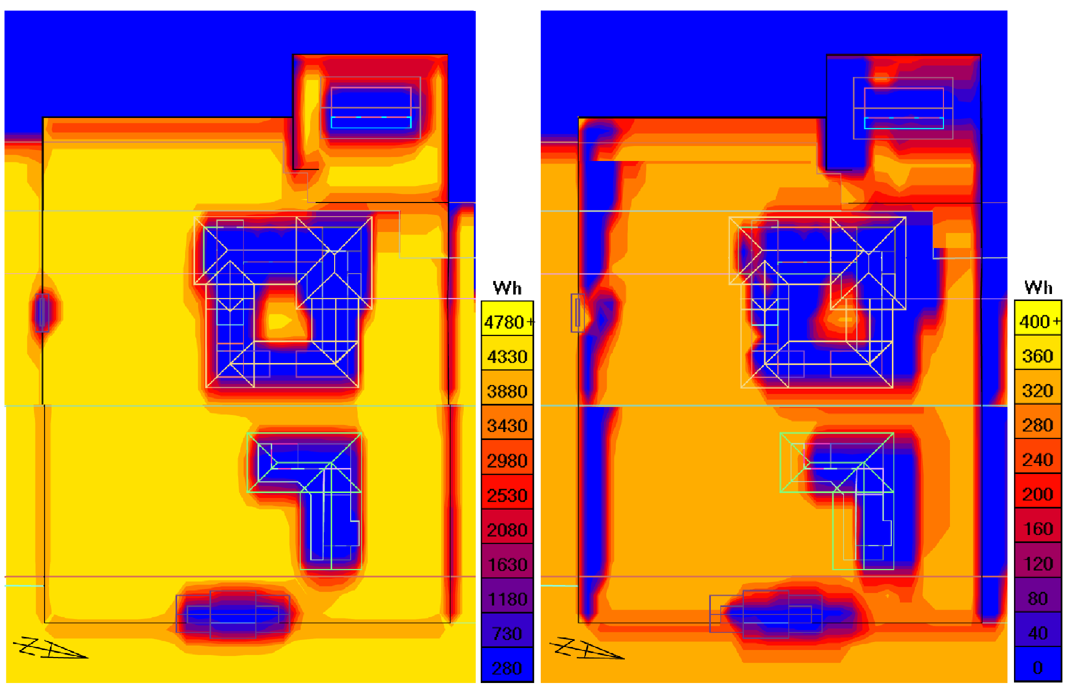


Figure 5-6 Total Direct Radiation of solar analysis, summer solstice, June 21st (left) and winter solstice, Dec 23(right)

5.4.1.1. Protecting the Strong Sunlight in the Summer

In the summer, solar analysis tests how the roof eaves protect, and provides sunlight during the winter. Daily Sun Path and Annual Sun Path Display in the Shadow Settings panel, Ecotect, are set to shadow on the special day and time. The Shading Design Wizard extrudes objects for solar envelope that crates reference lines and planes to test or interrupt buildings heights (Figure 5-9~Figure 5-14). The *sarangbang* eaves in *Chusagotaek* are shorter than any other sarangbang in *Yeongyeongdang* and *Unjoru*. Usually the sarangbang eaves in the other buildings perfectly protect sunlight as far as the maru in front of *sarangbang* in August 23rd, and the *sarangbang* eaves in *Chusagotaek* protects the sunlight to *sarangbang* but not to the maru in front of sarangbang. It means that sarangbang has more sunlight, and has more heat gain from outside. Unlike, *Yeongyeongdang* and *Unjoru*, *Chusagotaek* has small garden in front of the *sarangbang*. The garden could gradually reduce the heat energy. Otherwise, there are a stone, inscribed '*seoknyeo'*, meaning the year stone in a literal translation, in front of the small garden. The stone had used for measuring time, and then there should not be tree behind the stone (N.-C. Zu 2003). I think the garden was different shape, for example, there were only lawn, small sculpture, or small pond.

Figure 5-7 Chusagotaek has small garden in front of the sarangbang, unlike *Yeongyeongdang* and *Unjoru*

On the other hands, the anbang eaves are satisfied with the summer dates from May 6th to August 23rd. On the last day of summer and the lowest altitude[14] sun during the summer, which is august 23rd, at 10 AM and about 1:30, this sun also will hit the tip of the roof on the side, and it creates angel that is always at 56.6 degree every year (Figure 5-8). At this angle 56.6 degree, it creates shading towards the house that encloses the whole house creating friendly or cooler atmosphere inside.

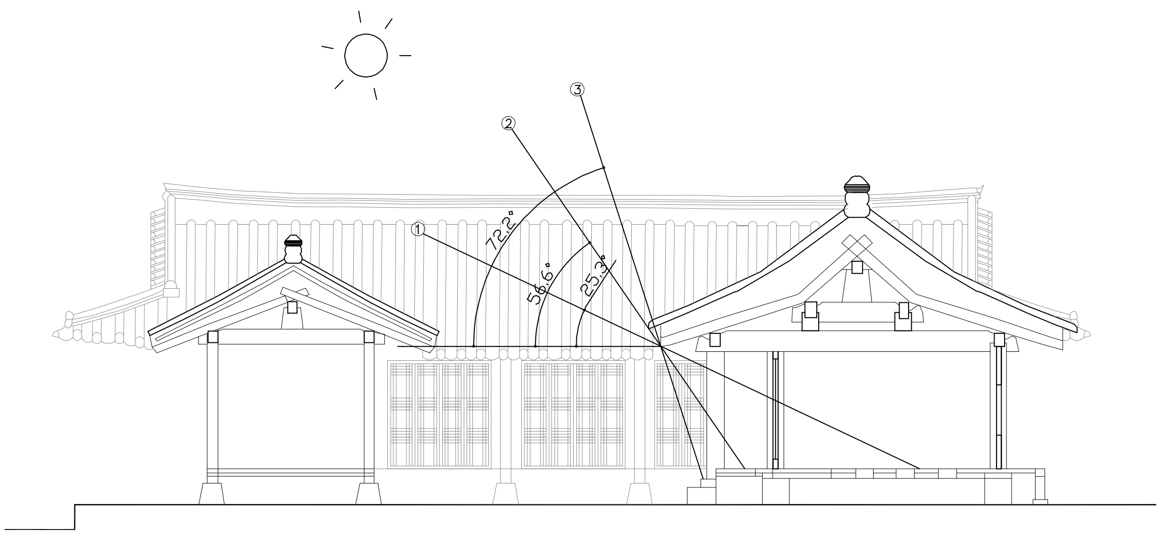


Figure 5-8 *Anbang* sunlight angle section, 1. Winter solstice, 23rd December, 10 o'clock 2.August 23rd Sunlight Angle, 10 o'clock 3.Summer Solstice, 23rd July, Noon

[14] Azimuth represents the horizontal angle of the sun relative to true north. This angle is always positive in a clockwise direction from north, and is usually given in the range 0° < azimuth < 180° (squ1.org 2007). Altitude represents the vertical angle the sun makes with the horizontal ground plane. It is given as an angle in the range 0° < alt < 90°. In the winter, the sunlight can penetrate to inside room about half of room's floor on December 23rd, the winter solstice.

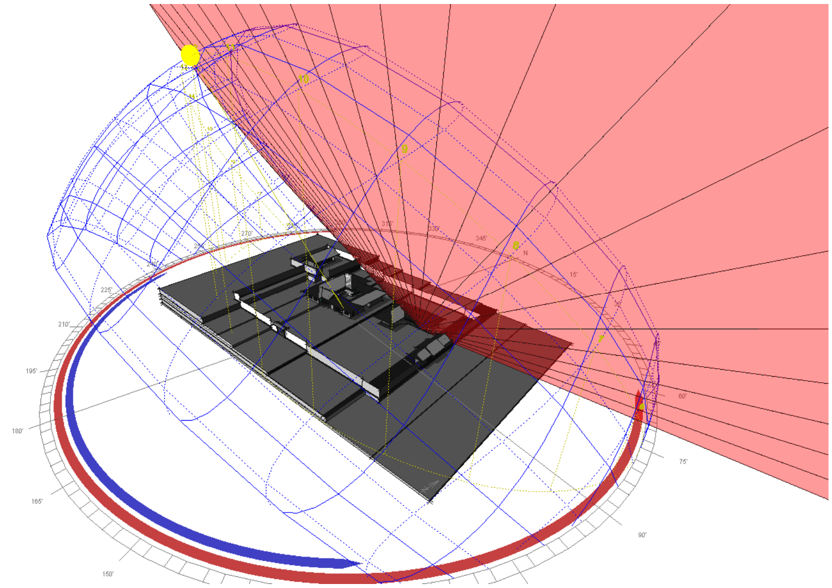


Figure 5-9 Daily and Annual Sun Path Analysis with Extrude Sunlight in Shading Design

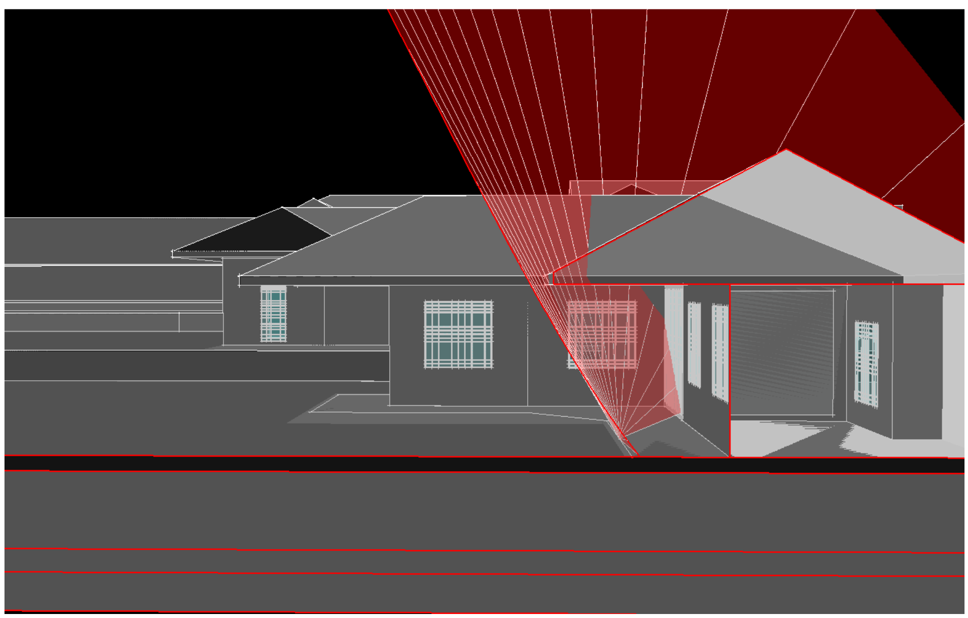


Figure 5-10 Extrude Sunlight for Analyzing shading and shadow, *Sarangbang* on August 23rd, the end of Summer

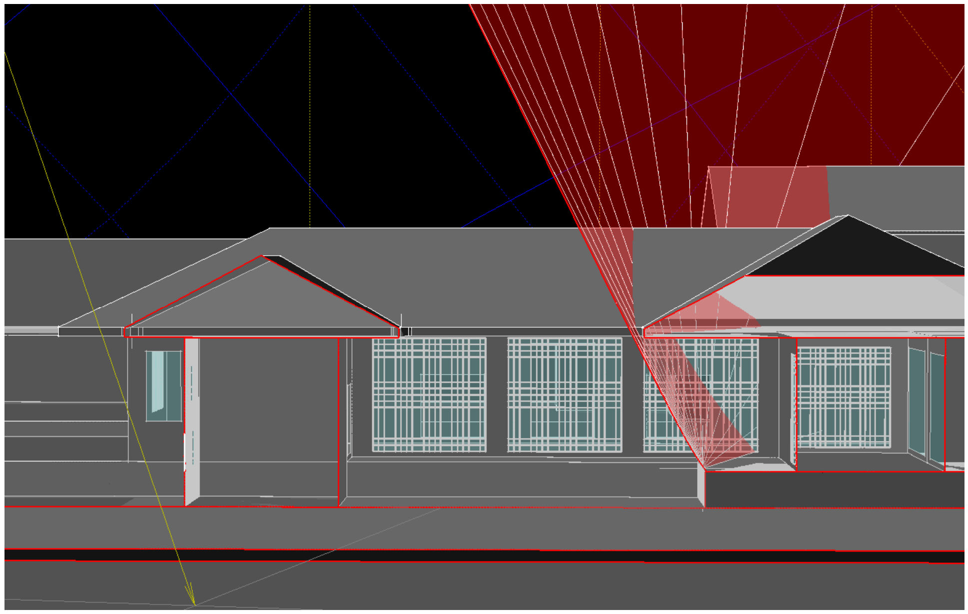


Figure 5-11 Extrude Sunlight Section for Analyzing shading and shadow, *anbang taechong* on August 23rd, the end of Summer

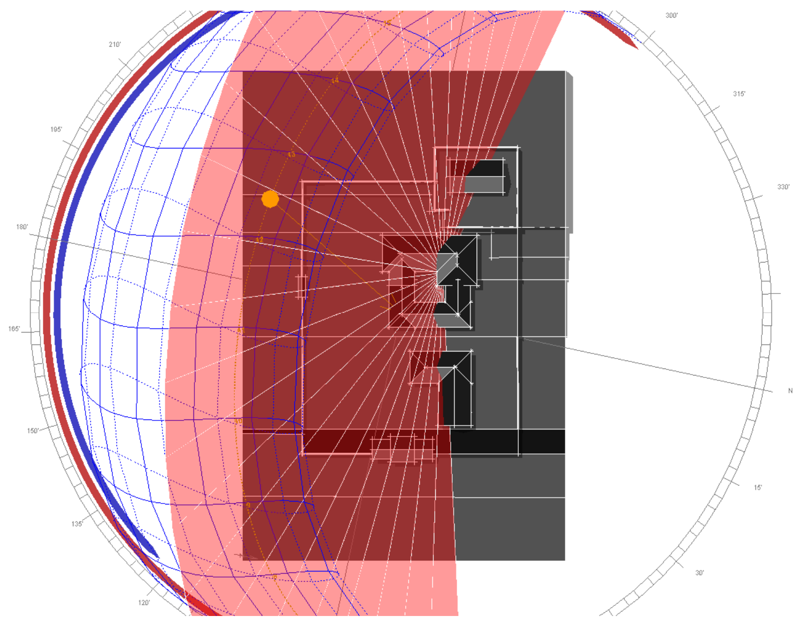


Figure 5-12 Extrude Sunlight Floor Plan for Analyzing shading and shadow, *anbang taechong* on August 23rd, the end of Summer

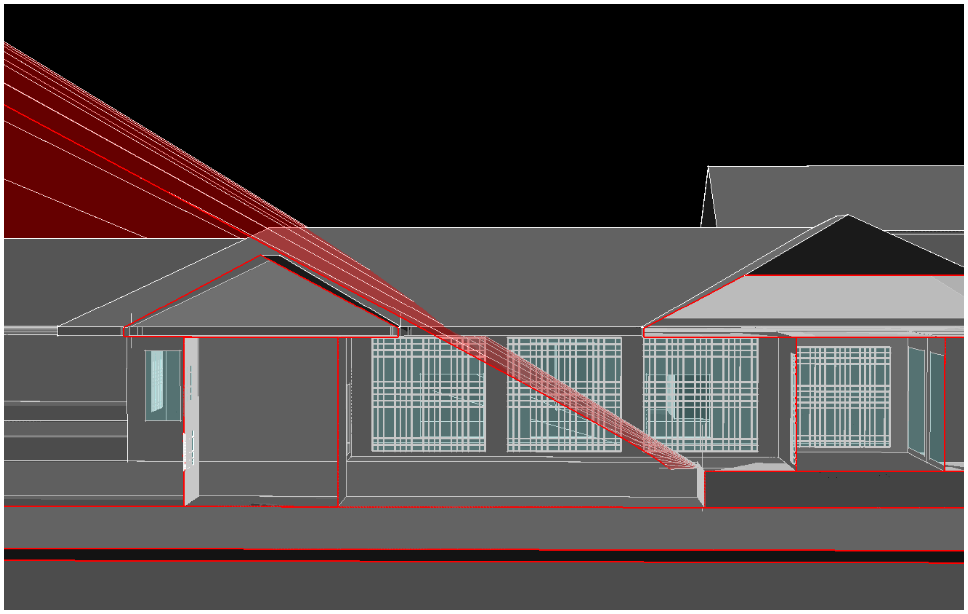


Figure 5-13 Sunlight Section for Analyzing shading and shadow, *anbang taechong* on December 23rd, the winter solstice

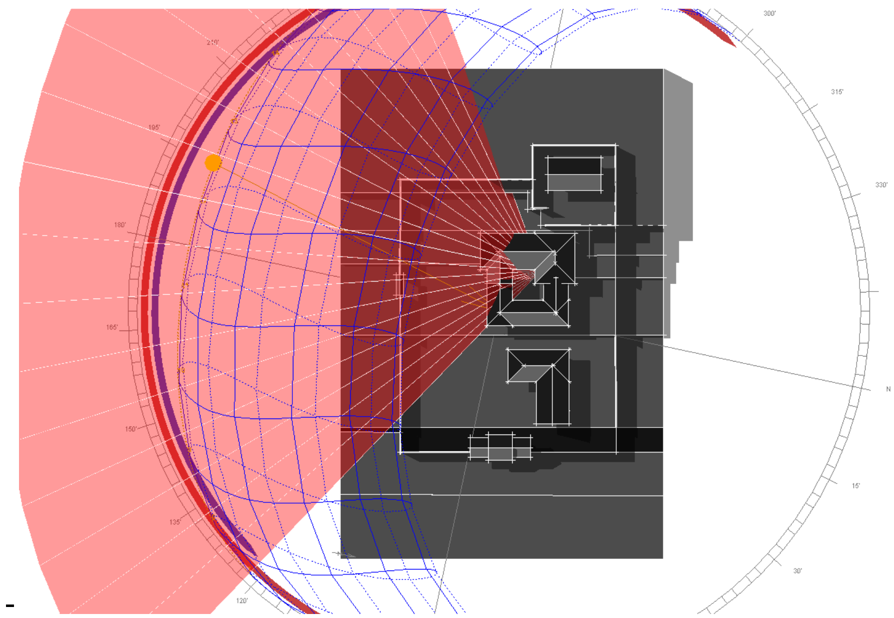


Figure 5-14 Sunlight Floor Plan for Analyzing shading and shadow, *anbang taechong* on December 23rd, the winter solstice

In the Hourly Heat Gains of the Ecotect Thermal Calculation, the more hourly heat gaining rooms, which unnecessarily can get heat a room in the summer, are ordered these following rooms; *antaechong* 〉 women *konnobang* 〉 *anbang* > *sarangtaechong* 〉*sarangbang* 〉 men *konnobang* (Figure 5-16~Figure 5-18).

The zones are tested in the following rooms: *sarangtaechong* (master men's *maru*), *sarangbang* (master men's room), men *konnobang* (master men's *maru*), *antaechong* (women's *maru*), *anbang* (master women's room), and women *konnobang* (women and children's room) (Figure 5-15). The test dates in the summer are on June 21st, the summer start, July 23rd, the summer solstice, August 23rd, the summer end.

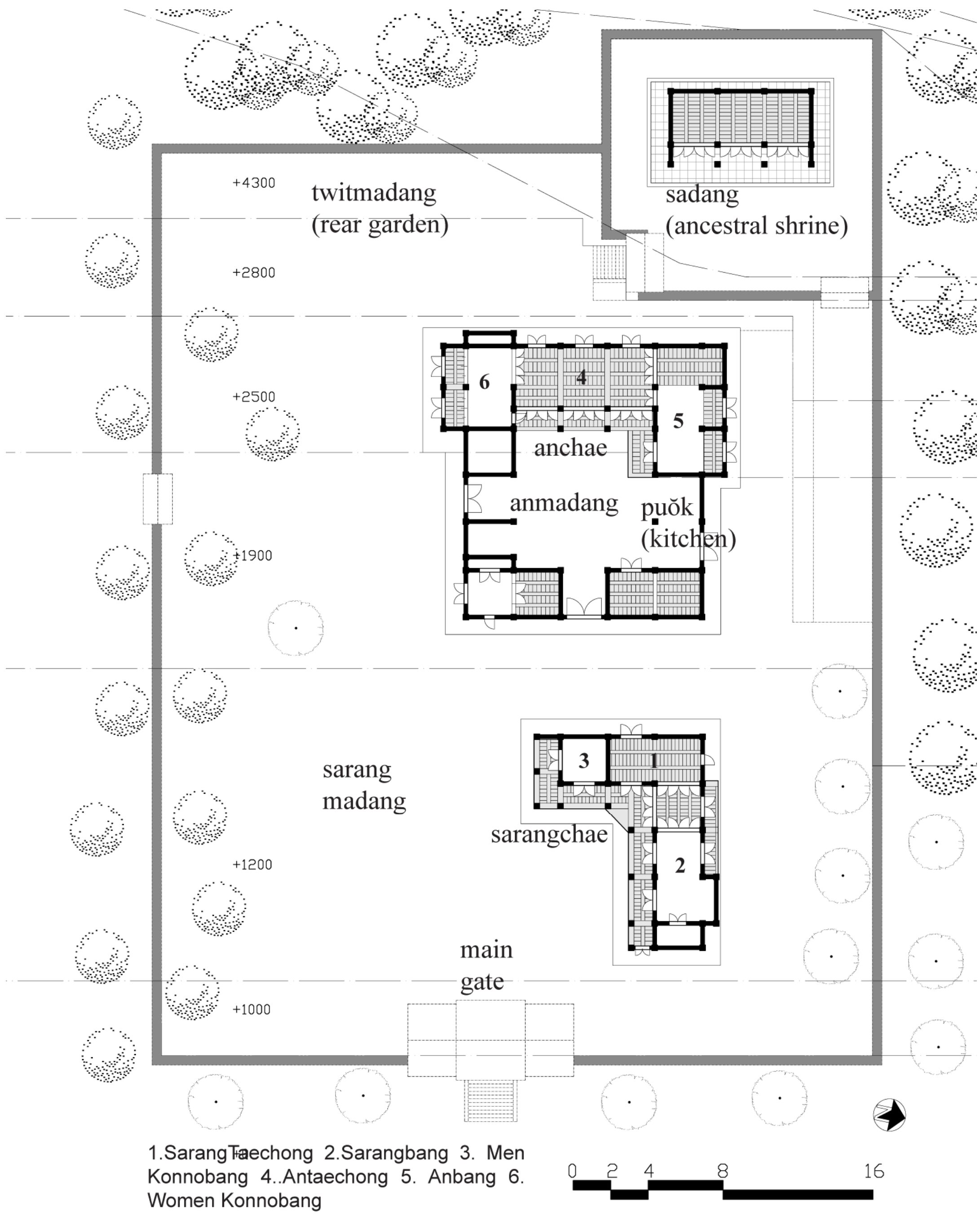


Figure 5-15 Selected Thermal Analytic Rooms

On June 21st and July 23rd, the *antaechong* has numerous heat gain that can increase the Percentage Dissatisfied, because there are many big windows about 67% of the floor area without the total south window (Figure 5-16, Figure 5-18). Otherwise, many windows in antaechong sustain to increase the ventilation heat loose. If the rooms avoid the strong sunlight, the heat gain does not affect the comfort temperature. On June 21st and July 23rd, between 3 o’clock and 5o’clock afternoon the heat gain is very higher than any other times, because there are three bigger windows on the west of *antaechong*. The west windows in *antaechong* makes to heat the room, but also it increase daylight to the anbang and *antaechong*, which is located in the corner of anchae. The women’s *konnobang* and *anbang*, in which are women’s quarter, are the next heat gain rooms, and even though the *anchae* is shaped exclusive form, ‘ㅁ”. The solar heat gain spreads out properly to each room in *anchae*. The outcome of the exclusive form, which could be interrupting the sunlight and closing the outside view, could find the different levels of rooms in the anchae. The *antaechong*, *anbang* and women *konnobang* raise up more than kitchen and servant’s area about one meter higher, which could also explain heroically distinguishing between master and servant.

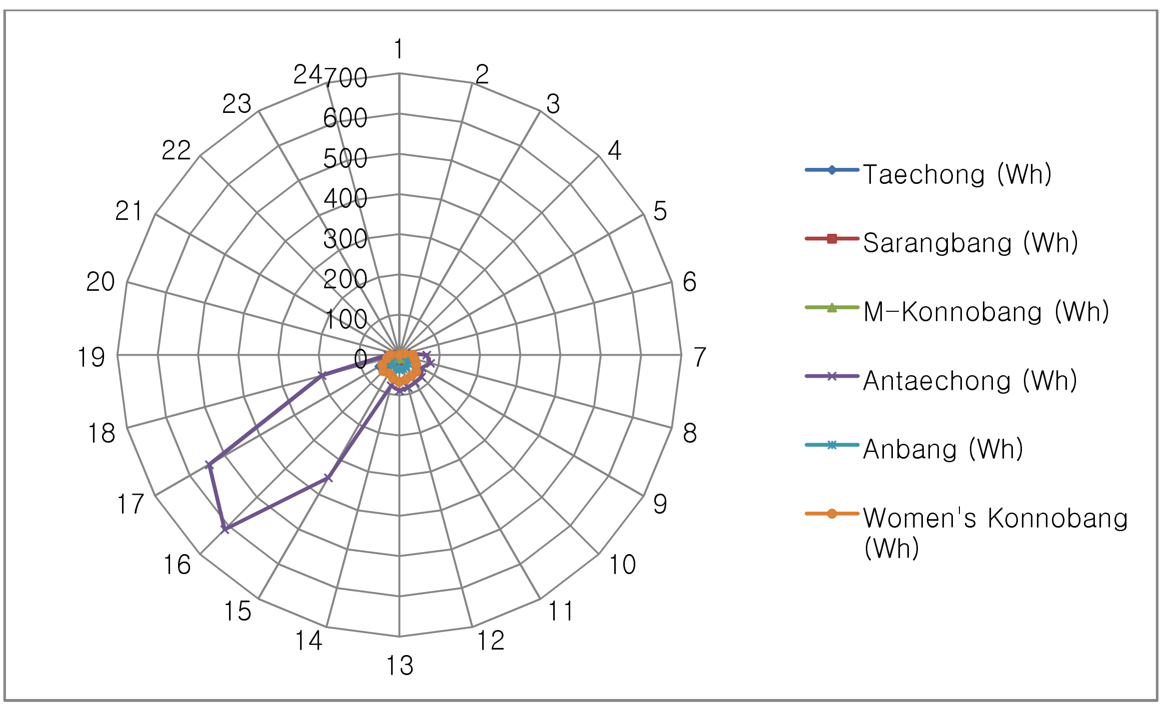


Figure 5-16 Solar Hourly Gains, June 21, the summer solstice

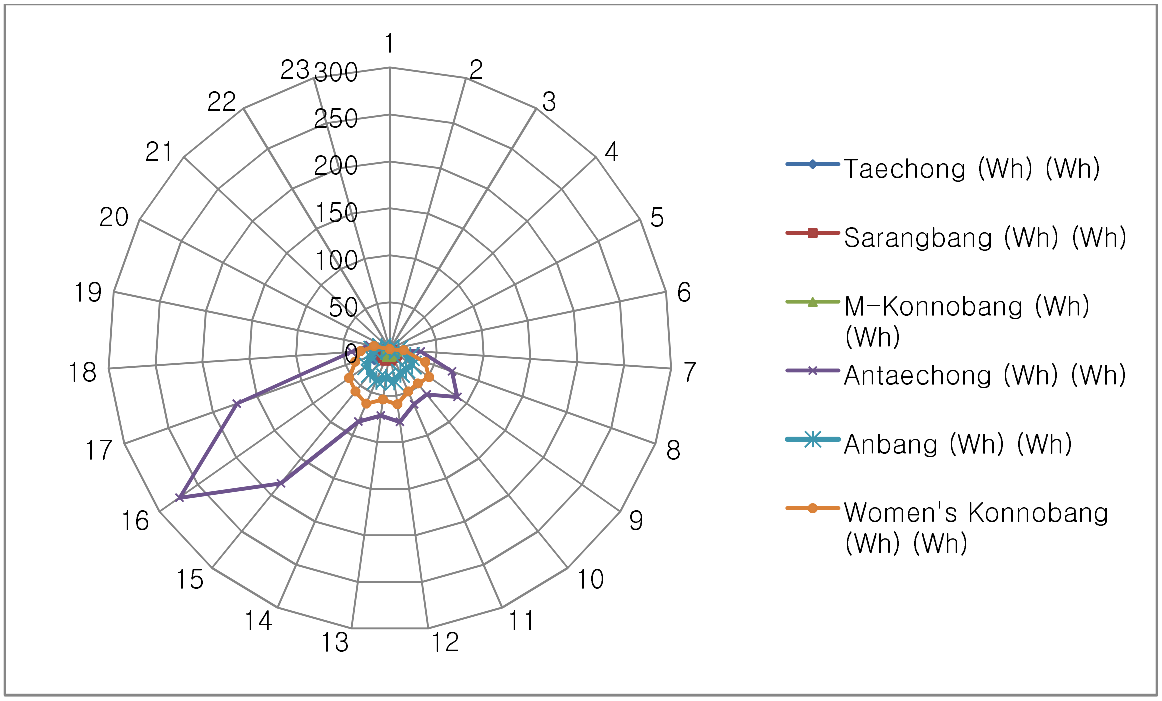


Figure 5-17 Solar Hourly Gains, July 23rd, the hottest date

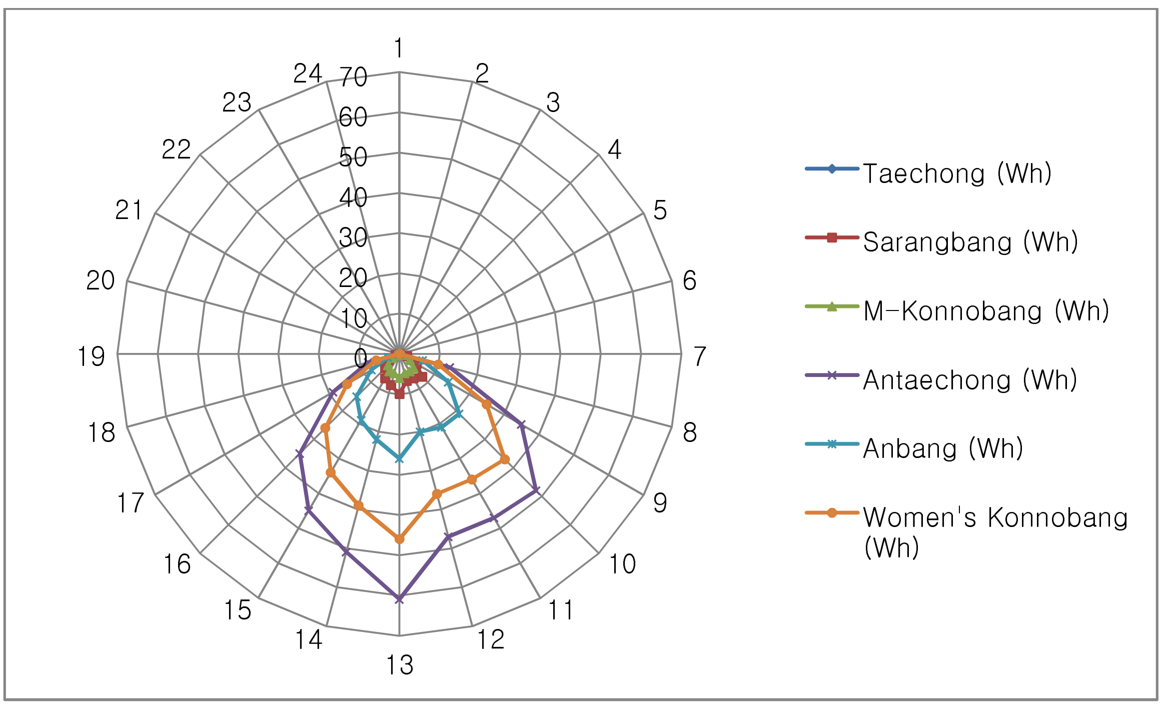


Figure 5-18 Solar Hourly Gains, August 23rd, the end of summer

In the August 23rd, the end of summer, the Solar Hourly Gains affect equally from 9 AM to 4 PM, because the sunlight altitude is getting lower and the sunlight closes to the rooms more and more after the day. In the August 23rd, *antaechong*, *anbang*, and *antaechong* has still higher solar heat gains.

Chusagotaek also almost perfectly enclose the strong sunlight. There are several sustainability strategies, which can be remarkable mention to outcome the hierarchy impact of the design limitation. First, the axis to 12 degree west of south with the reasonable west windows provides enough light and ventilation heat loose. Second, the different ground level assists the open view, and approximately receives the sunlight.

5.4.1.2. Penetrating the Sunlight into each Rooms evenly in the Winter

In the winter, the basic natural processes that are used in solar energy are the thermal energy flows associated with radiation, conduction, and convection. When sunlight strikes a building, the building materials can reflect, transmit, or absorb the solar radiation. Additionally, the heat produced by the sun causes air movement that can be predictable in designed spaces. These basic responses to solar heat lead to layout elements, material choices and placements that can provide heating and cooling effects in a residence. Excessive solar exposure is one of the main causes of summer overheating, but it is also one of the most effective sources of natural energy in winter.

In the winter, solar analysis provides how long sunlight penetrates inside of anchae. The anchae has a 6 kan *taechong*, a 2 kan anbang, a *konnobang*, a kitchen, and several furnaces in the 'ㅁ' shaped, which seems some part not to have enough sunlight. The *anbang*, *antaechong*, and a *konnobang* are placed on the higher site level than the other servant's rooms called *haengnangbang,* and kitchen. Otherwise, in the Hourly Heat Gains of the Ecotect Thermal Calculation, the more hourly heat gaining rooms, which necessarily can get heat a room in the winter, are ordered these following rooms; *antaechong* ＞ women *konnobang* ＞ *anbang* ＞ *sarangbang* ＞ men *konnobang* ＞ *sarangtaechong* (Figure 5-19, Figure 5-20).

In January 13th and December 23rd, the solar heat gains shows that *anbang* and *antaechong* are higher position, even though the rooms are in corner of *anchae*. In the winter, the solar altitude is lower than any other seasons. Therefore, the sunlight can penetrate to rooms more than any other seasons, if there are enough windows but it can affect ventilation loose too. The *antaechong* has the peak of the sun heat gain at 2 o'clock, which is the sunlight to penetrate to the west window of *antaechong*. Women's *konnobang* is located on the southern part of the anchae. the outside windows of *konnobang* has two windows place installed, of which one is the regular oiled-paper windows, and the other outside windows are made by only wood without the oiled-paper. The outside windows made by wood are faced by the outside *madang*. Therefore, the outside windows' function emphasizes the privacy as well the wind protection in the winter. Anbang and *sarangbang* have the heat gains more morning time, because the sunlight blocks with the west part of buildings, *antaechong* and *sarangtaechong*.

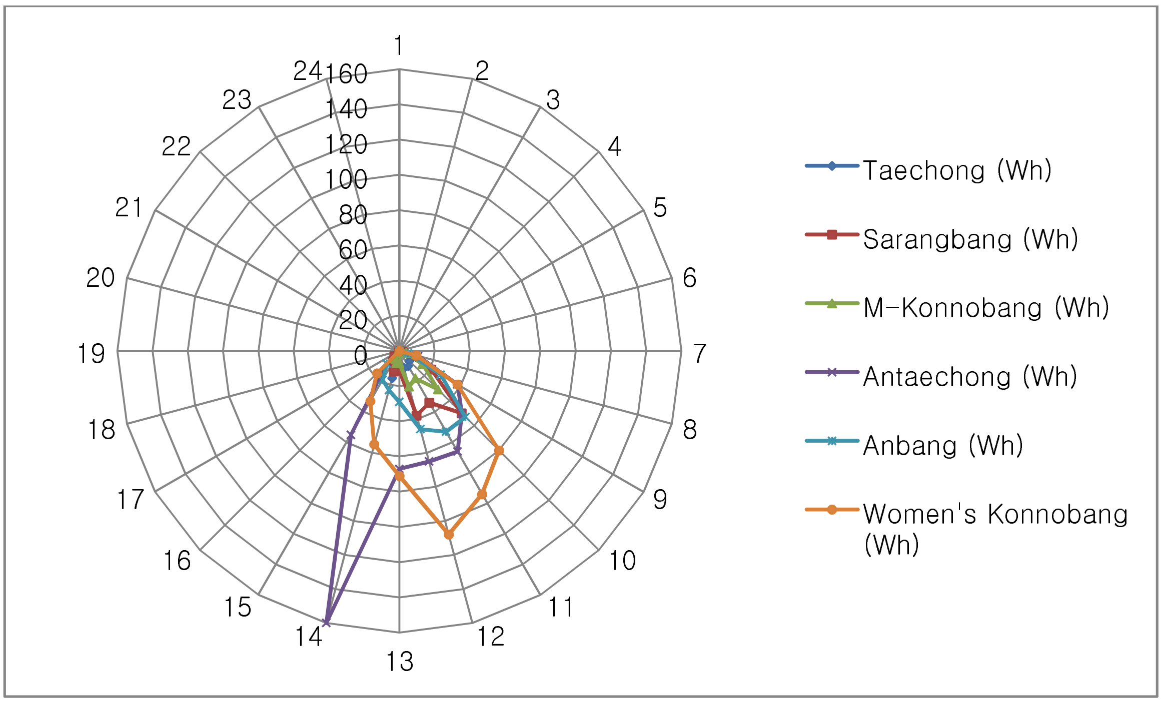


Figure 5-19 Solar Hourly Gains, January 13th, the coldest date

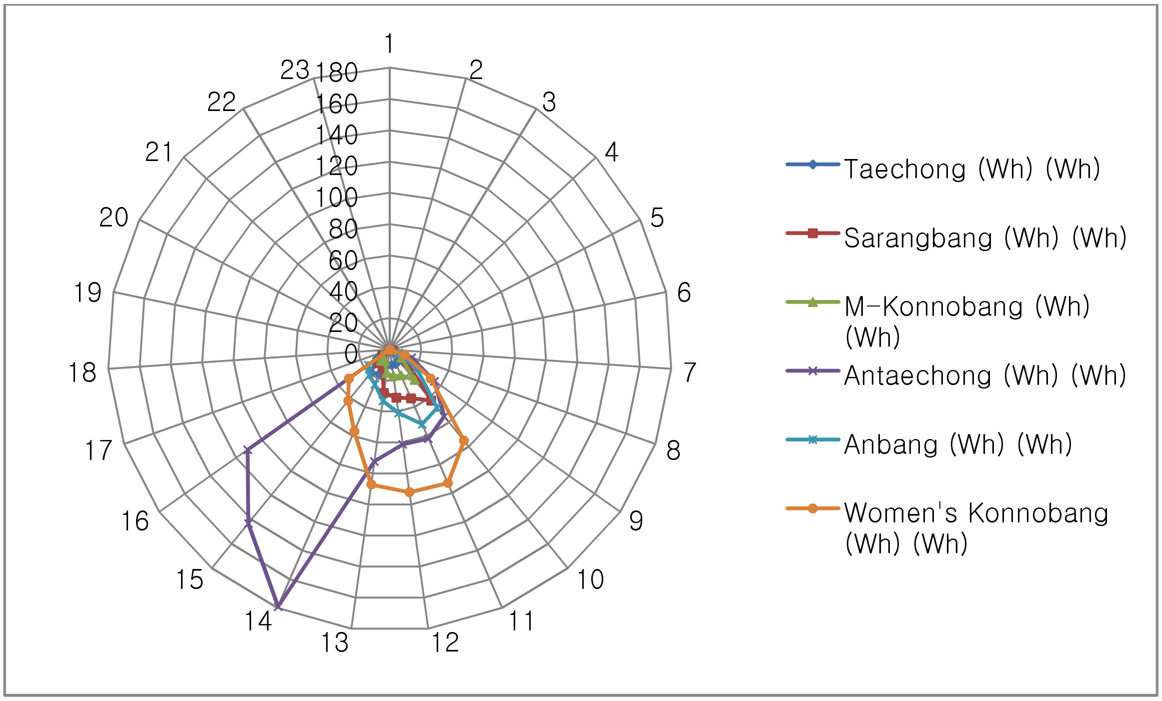


Figure 5-20 Solar Hourly Gains, December 23rd, the winter solstice

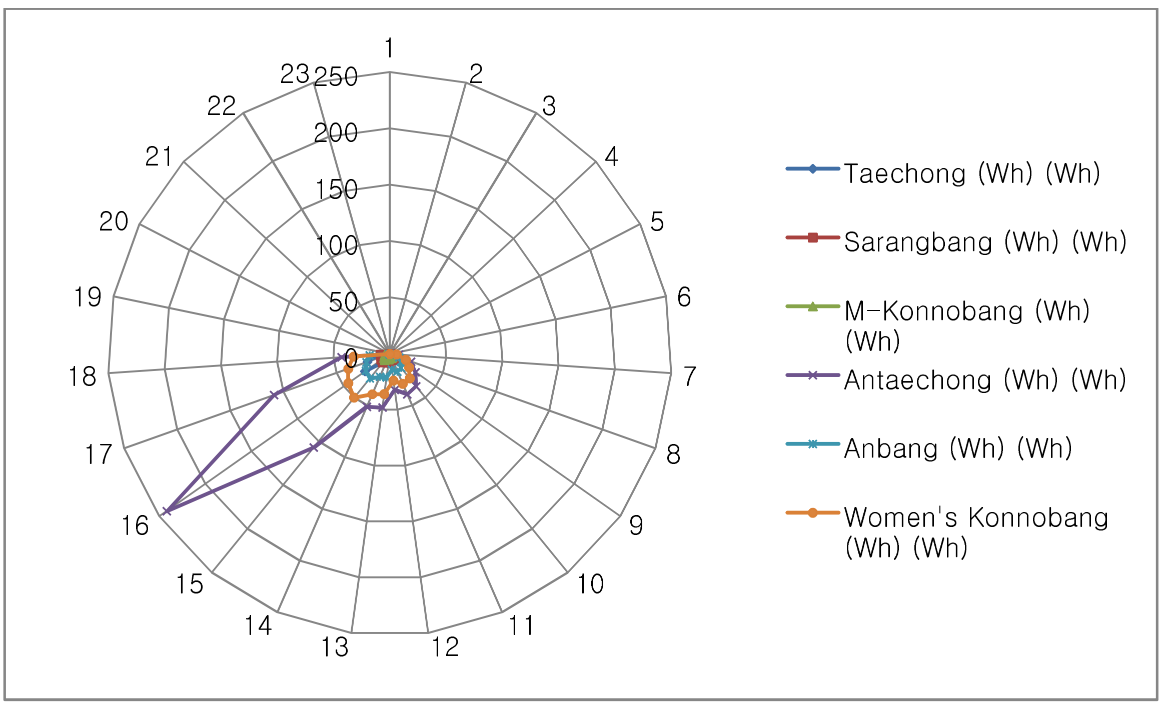


Figure 5-21 Solar Hourly Gains, May 6th

Zone	Solar Hourly Heat Gains					
	Taechong (㎡)	Sarangbang (㎡)	M-Konnobang (㎡)	Antaechong (㎡)	Anbang (㎡)	Women's Konnobang (㎡)
Total Surface Area:	58.51	66.03	34.38	98.60	54.06	53.46
	464%	447%	553%	390%	475%	471%
Total Exposed Area:	34.83	39.93	22.73	67.68	36.33	30.90
	276%	270%	366%	267%	319%	272%
Total South Window:	0.00	2.88	1.44	0.00	2.16	6.48
	0%	20%	23%	0%	19%	57%
Total Window Area:	4.32	4.32	2.88	17.04	11.88	11.16
	34%	29%	46%	67%	104%	98%
Total Conductance (AU)(W/㎡K):	55.00	62	38	126	66	67
Total Admittance (AY)(W/㎡K):	163.00	186	93	301	155	167
Response Factor:	2.82	2.84	2.38	2.29	2.25	2.41

HOUR	Taechong (Wh)	Sarangbang (Wh)	M-Konnobang (Wh)	Antaechong (Wh)	Anbang (Wh)	Women's Konnobang (Wh)
13th January						
7	3	2	4	11	5	10
8	8	21	15	38	27	38
9	8	50	31	50	53	80
10	10	34	18	66	53	94
11	10	38	21	65	46	108
12	11	11	7	67	29	71
13	16	12	7	160	23	55
14	8	7	5	55	19	33
15	3	4	2	10	10	18
TOTAL	**77**	**179**	**110**	**522**	**265**	**507**
6th May						
7	1	1	1	8	4	6
8	3	3	2	20	9	15
9	4	4	3	28	12	21
10	6	6	4	37	16	28
11	6	6	4	39	17	29
12	5	5	3	32	14	24
13	8	8	5	48	21	36
14	8	8	5	51	22	39
15	10	10	7	107	28	50
16	27	9	6	242	26	45
17	21	8	5	109	22	39
18	10	8	4	43	18	32
TOTAL	**109**	**76**	**49**	**764**	**209**	**364**
21st June						
5	3	3	3	17	7	13
6	7	7	9	68	19	33
7	8	8	5	80	22	39
8	10	10	7	64	28	48
9	12	12	8	78	34	59
10	12	12	8	79	34	60
11	13	13	9	84	36	63
12	14	14	9	89	38	67
13	12	12	8	79	34	60
14	11	11	7	353	30	53
15	36	12	8	614	32	57
16	57	10	7	545	28	49
17	43	13	4	199	18	32
18	10	7	3	29	12	22
TOTAL	**248**	**144**	**95**	**2378**	**372**	**655**
23rd July						
7	3	3	4	33	9	15
8	8	8	8	70	23	40
9	10	10	7	88	29	51
10	10	10	7	62	27	47
11	10	10	7	64	28	49
12	12	12	8	78	34	59
13	11	11	7	71	31	54
14	13	13	9	84	36	63
15	12	12	8	184	33	58
16	20	11	7	274	30	53
17	20	8	5	173	22	39
18	9	7	4	41	18	31
19	2	3	2	22	9	17
TOTAL	**140**	**118**	**83**	**1244**	**329**	**576**
23rd August						
7	2	2	1	13	6	10
8	5	5	3	35	14	25
9	8	8	5	48	21	37
10	7	7	5	47	21	36
11	7	7	5	47	20	36
12	10	10	6	61	26	46
13	8	8	5	51	22	39
14	7	7	5	45	19	34
15	5	5	4	35	15	26
16	3	3	2	19	8	15
17	1	1	1	8	3	6
TOTAL	**63**	**63**	**42**	**409**	**175**	**310**
23rd December						
8	2	2	0	15	6	10
9	6	13	9	35	21	32
10	9	42	25	55	48	75
11	10	34	18	62	52	93
12	10	31	17	61	41	92
13	10	28	15	72	33	87
14	17	12	8	179	24	57
15	19	11	9	143	21	42
16	10	6	6	111	17	32
TOTAL	**93**	**179**	**107**	**733**	**263**	**520**
	Taechong	**Sarangbang**	**M-Konnobang**	**Antaechong**	**Anbang**	**Women's Konnobang**

Table 5-1 Solar Hourly Heat Gain for *Chusagotaek*

5.4.2. Cooling Strategies: Wind Flow and Air Flow

Human comfort within residence is primarily controlled by four major factors: air temperature, mean radiant temperature, humidity and airflow. Each can have a dominating effect. There are factors, which affect human comfort including clothing and activity (Fairey 1994).

There are two cooling strategies, which dominate the *Chusagotaek*. First, one of strategies is Natural Ventilation, which is cross ventilations driven by wind and accomplished with windows. It relies on narrow plans with large ventilation openings on either side. Second, the other strategy is High-mass Cooling, which is for warm, dry summers, when the extremes of hot days are tempered by the still cool thermal mass, thicker roof. Cool nights then slowly drain away the heat that such mass accumulates during the day. The roof has the advantage of radiating to the cold night sky.

In the summer, the Seoul wind flows average 2.4m/s and the minimum of airflow is the 0.7m/s up to few days according to the Korea Meteorological Administration recording from 1961 to 1980. If the 2.4m/s airflow constantly affects *Chusagotaek*, during summer, there is enough cooling for human comfort. The traditional sliding door of *Chusagotaek* can be opened 100% of the window-installed space, unlike the modern glass door (D.-K. Kim 2000). During the summer, the open door offers enough air inside. Additionally, for the wind flow from the southwest in the summer, the building layout was so well suited to the each room. Ecotect shows the prevailing winds, which is able to display in the 3D model. Ecotect prevailing winds displays the wind speed, frequency and the direction. In the prevailing winds, the wind flows 35% of the total wind from east of north to the building in the morning (6:00~10:00), and 40% of the total wind from west of south trough the building during the day (10:00~6:00PM) (Figure 5-22, Figure 5-24, Figure 5-25). Diurnal airflow in the valley cools also down the temperature during the summer. The wind flows from the southwest to the women's quarter, placed on the west, which stays backward, and men's quarter, place on the east, which stays frontward.

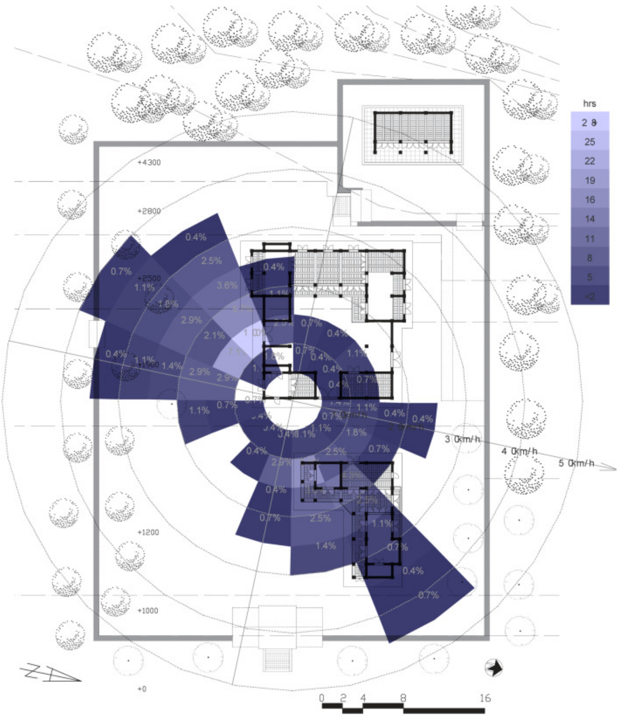


Figure 5-22 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: summer, 1st June ~ 31st August. Time: 10:00 ~14:00

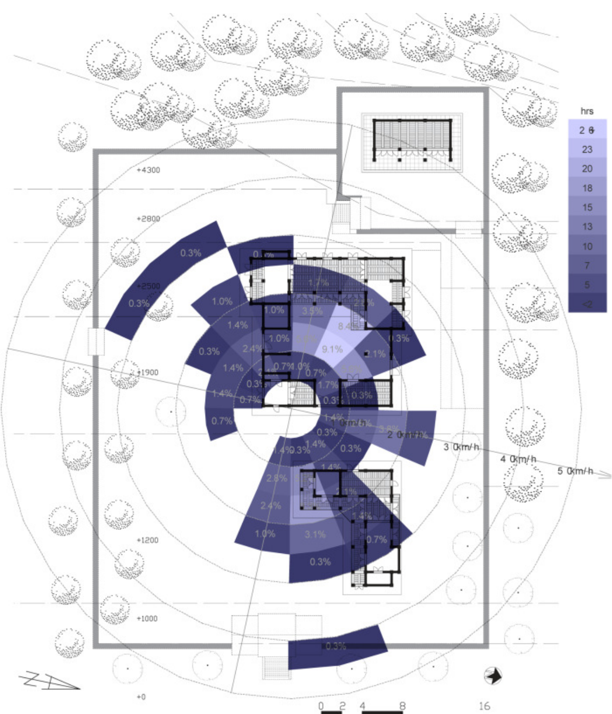


Figure 5-23 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: winter, 1st December ~ 28th February. Time: 10:00 ~14:00

In the winter, the replication of the mountain-like wraps in traditional Korean architecture behind the north protects against the strong wind during the winter. *Chusagotaek* is enclosed by mountain from east higher hill to west lower hill trough north hill. The Ecotect prevailing winds provide that the winter winds flow from the west or east of north to the building. In addition, the windows on the north pace or the windward windows in the winter are smaller than the south pace.

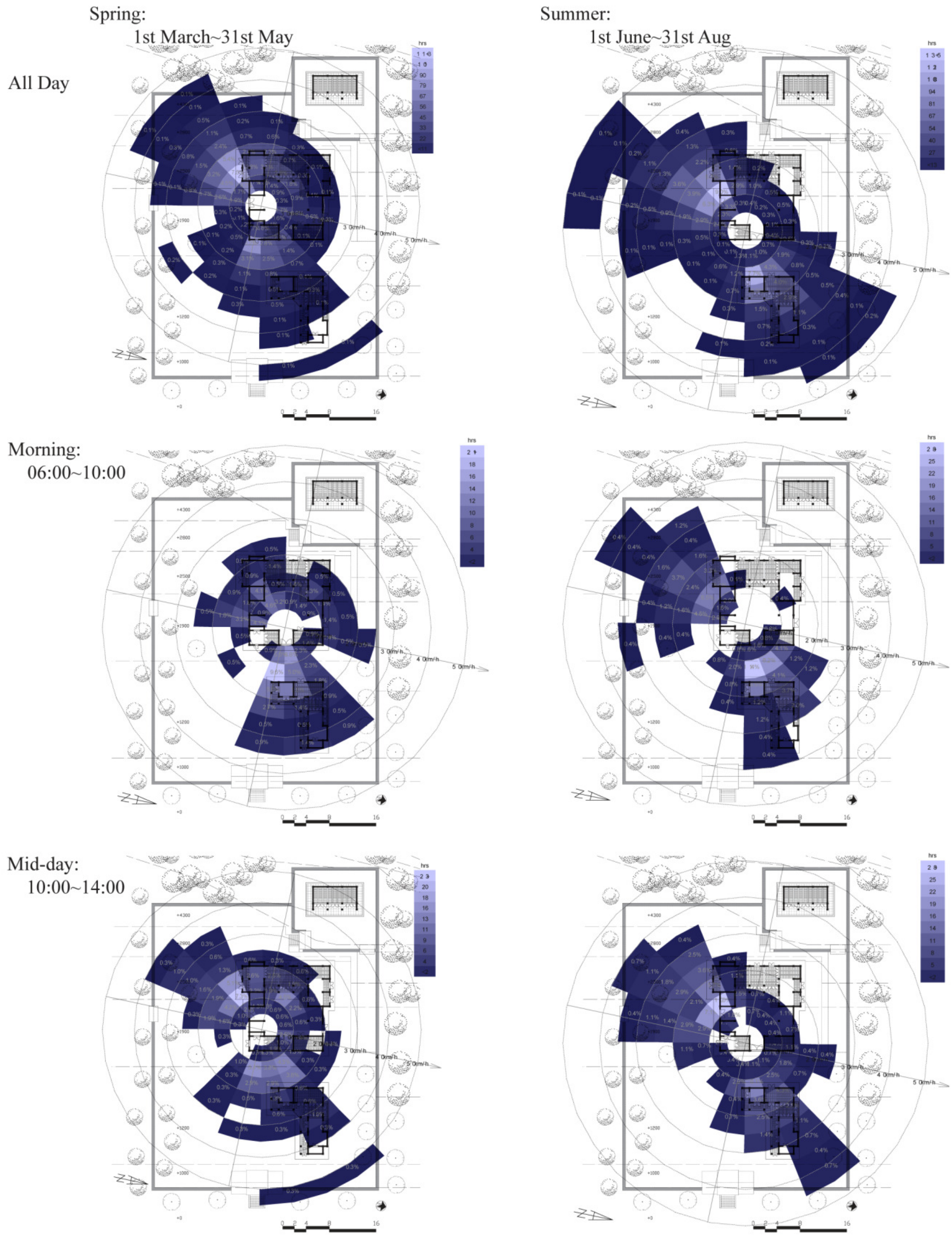


Figure 5-24 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: spring and summer, morning to mid-day

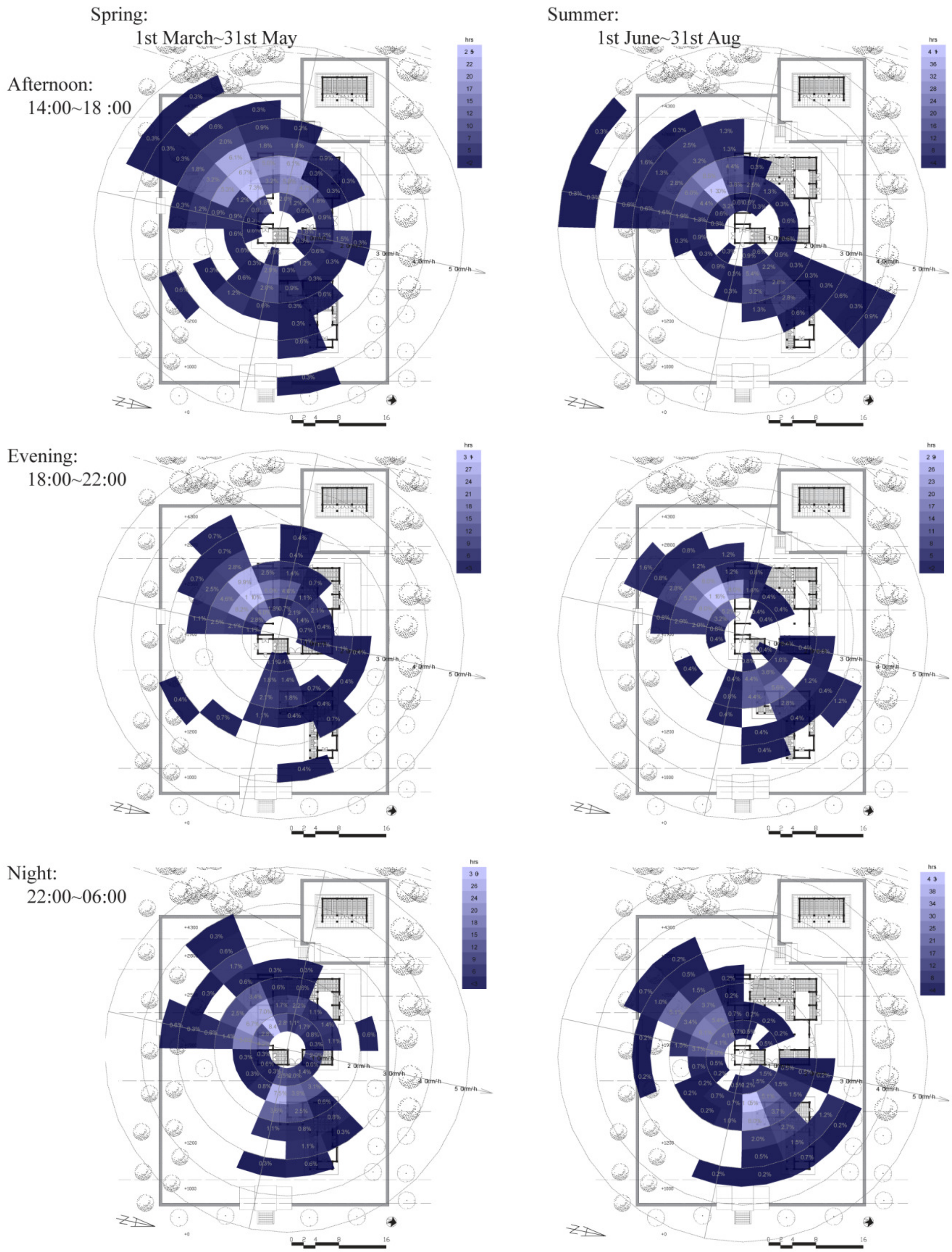


Figure 5-25 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: spring and summer, evening to night

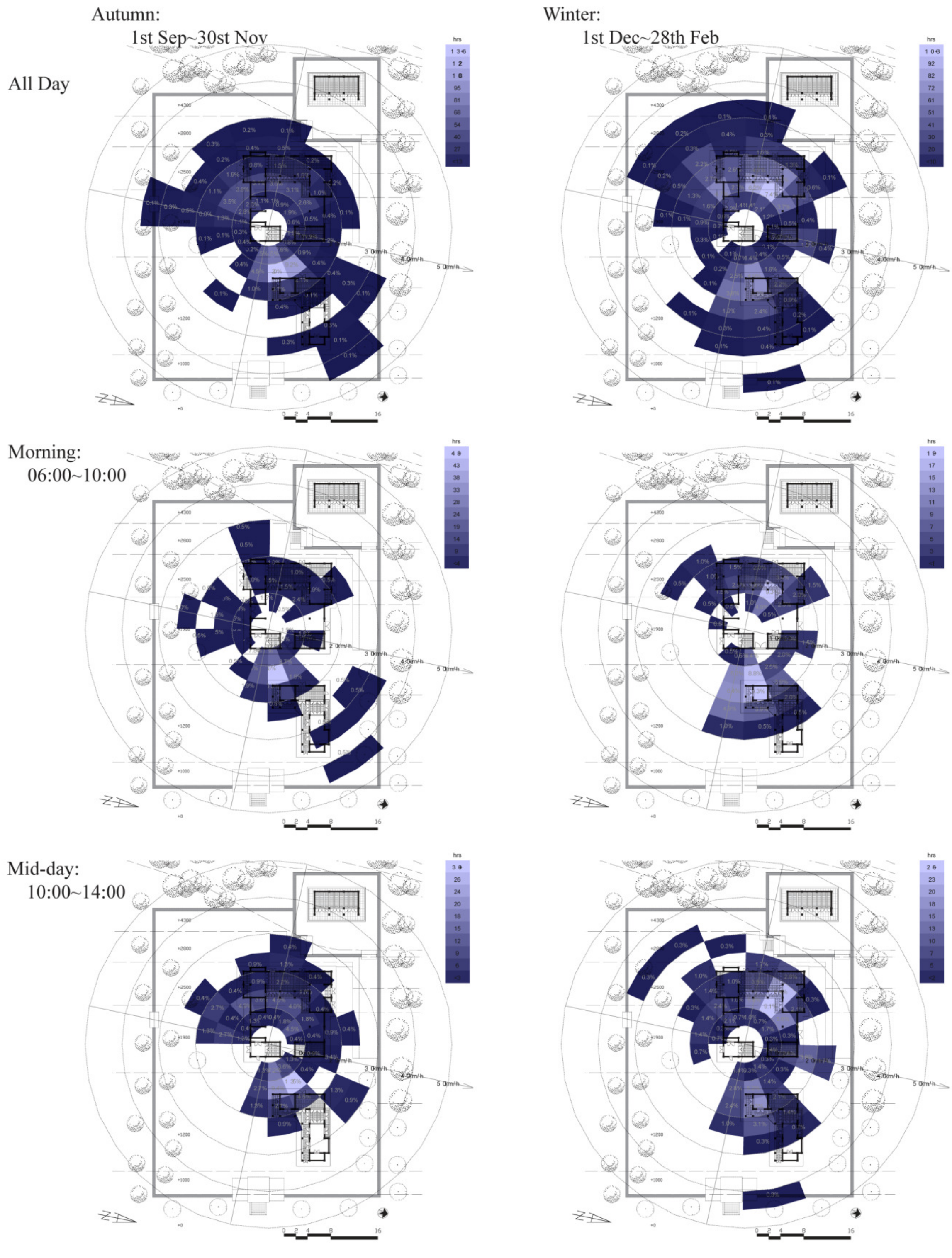


Figure 5-26 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: autumn and winter, morning to mid-day

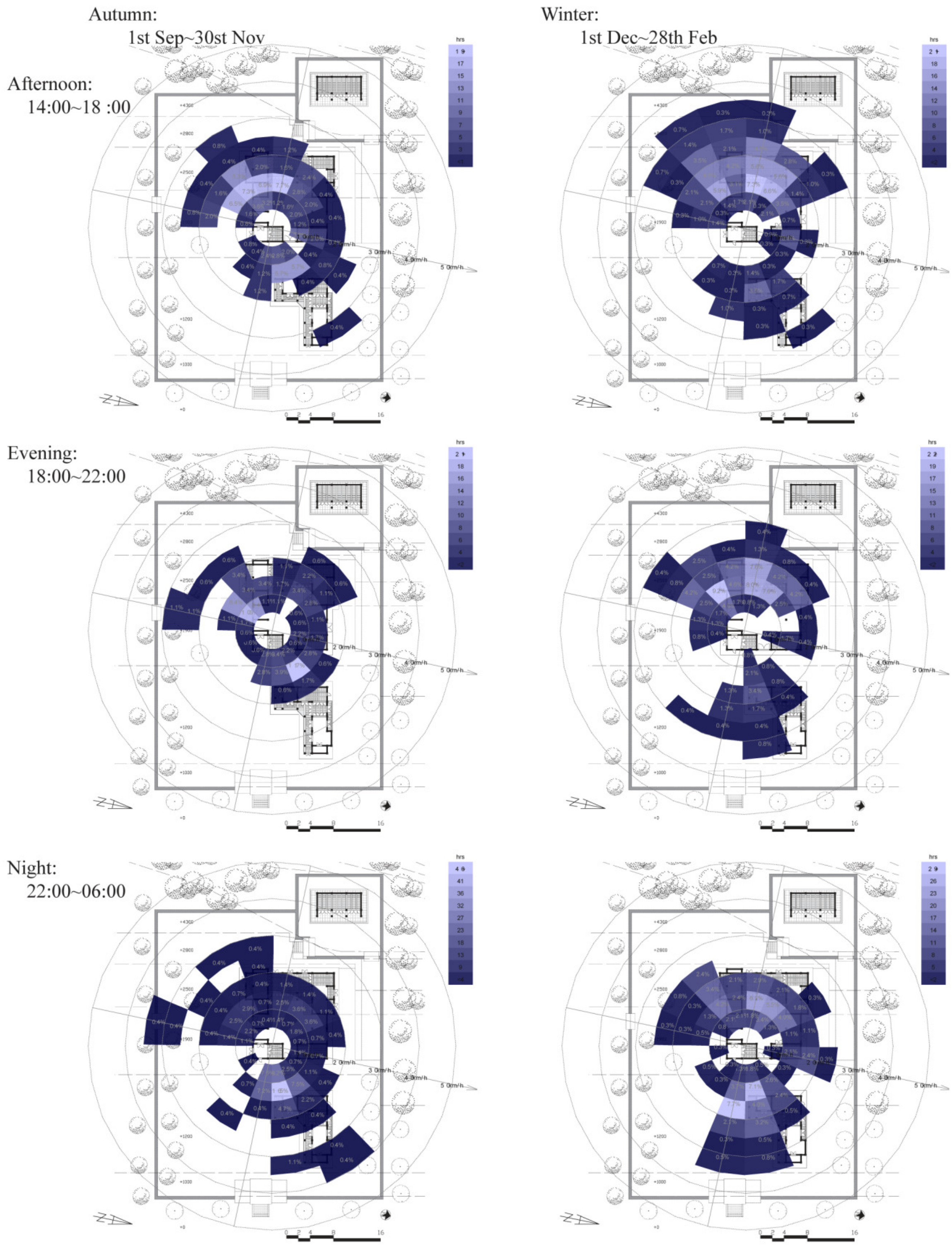


Figure 5-27 Prevailing Winds, Wind Frequency (Hrs). Seoul, South Korea. Date: autumn and winter, evening to night

5.4.3. Thermal Performance

Thermal performance is related to materials, windows and doors sizes, height, length, temperature, orientation, and many other factors. The Chartered Institute of Building Services Engineers (CIBSE) Admittance Method determines internal temperatures and heat loads. This thermal algorithm is very flexible and has no restrictions on building geometry or the number of thermal zones that can be simultaneously analyzed. The internal temperature of any building will always tend towards the local mean outdoor temperature. Any fluctuations in outside temperature or solar load will cause the internal air temperature to fluctuate in a similar way, though delayed and dampened somewhat by thermal capacitance and resistance within the building fabric. When the total of all heat losses become equal to the total of all gains, then internal temperatures stabilize (Ecotect 2007).

The principal factors affecting thermal comfort can be conveniently considered in the following sections: Personal variables included activity, age, clothing, and gender; and Physical Variables included air temperature, air movement, surface temperatures, and humidity.

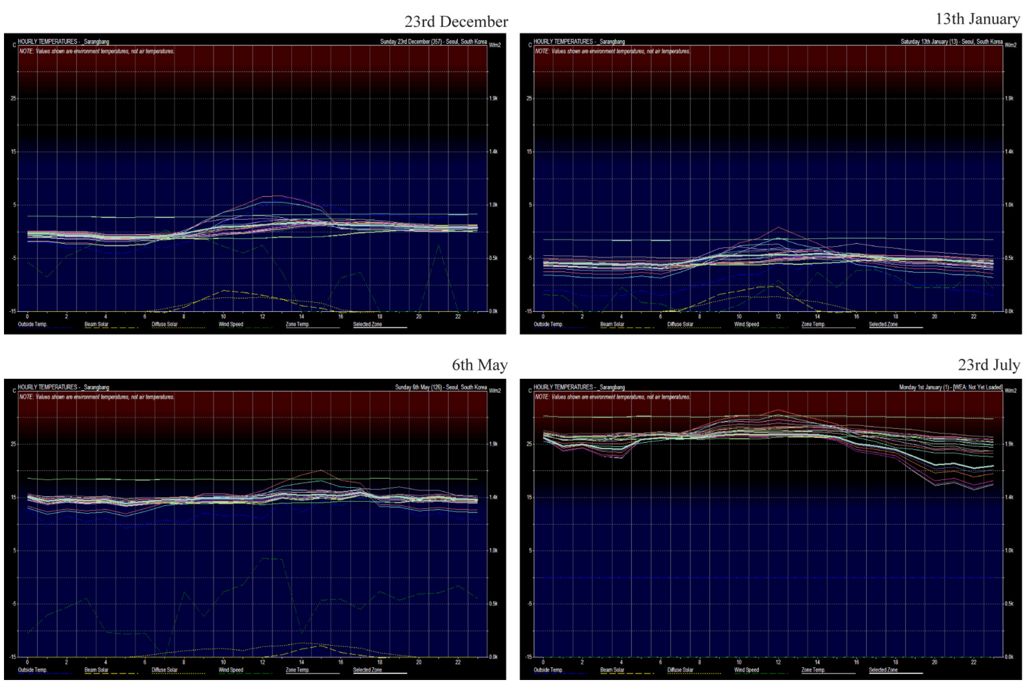


Figure 5-28 Thermal Performance, Ecotect Thermal Analysis shows the Hourly Temperature Profile with the cold zone, blue part, and the hot zone, red part (Ecotect: 2007)

The zones are tested in the following rooms: *sarangtaechong* (master men's *maru*), *sarangbang* (master men's room), men *konnobang* (children's room), *antaechong* (women's *maru*), *anbang* (master women's room), and women *konnobang* (women and children's room) (Figure 5-30). The test dates in the summer are on June 21st, the summer start, July 23rd, the summer solstice, August 23rd, the summer end.

Zone	Roof Sarangbang	Roof Anchae	Taechong	Sarangbang	M-Konnobang	Antaechong	Anbang	Women's Konnobang
	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)
Total Floor Area(㎡):	106.36	240.86	12.60	14.77	6.22	25.31	11.39	11.34
Total Surface Area(㎡):	249.19	613.24	58.51	66.03	34.38	98.60	54.06	53.46
	234%	255%	464%	447%	553%	390%	475%	471%
Total Exposed Area(㎡):	185.05	470.91	34.83	39.93	22.73	67.68	36.33	30.90
	174%	196%	276%	270%	366%	267%	319%	272%
Total South Window(㎡):	0.00	0.00	0.00	2.88	1.44	0.00	2.16	6.48
	0%	0%	0%	20%	23%	0%	19%	57%
Total Window Area(㎡):	0.00	0.00	4.32	4.32	2.88	17.04	11.88	11.16
	0%	0%	34%	29%	46%	67%	104%	98%
Total Conductance (AU)(W/㎡ K):	670.00	1639.00	55.00	62.00	38.00	126.00	66.00	67.00
Total Admittance (AY)(W/㎡ K):	764.00	1869.00	163.00	186.00	93.00	301.00	155.00	167.00
Response Factor:	1.14	1.14	2.82	2.84	2.38	2.29	2.25	2.41

Table 5-2 *Chusagotaek* Area and Environmental Factors Calculation

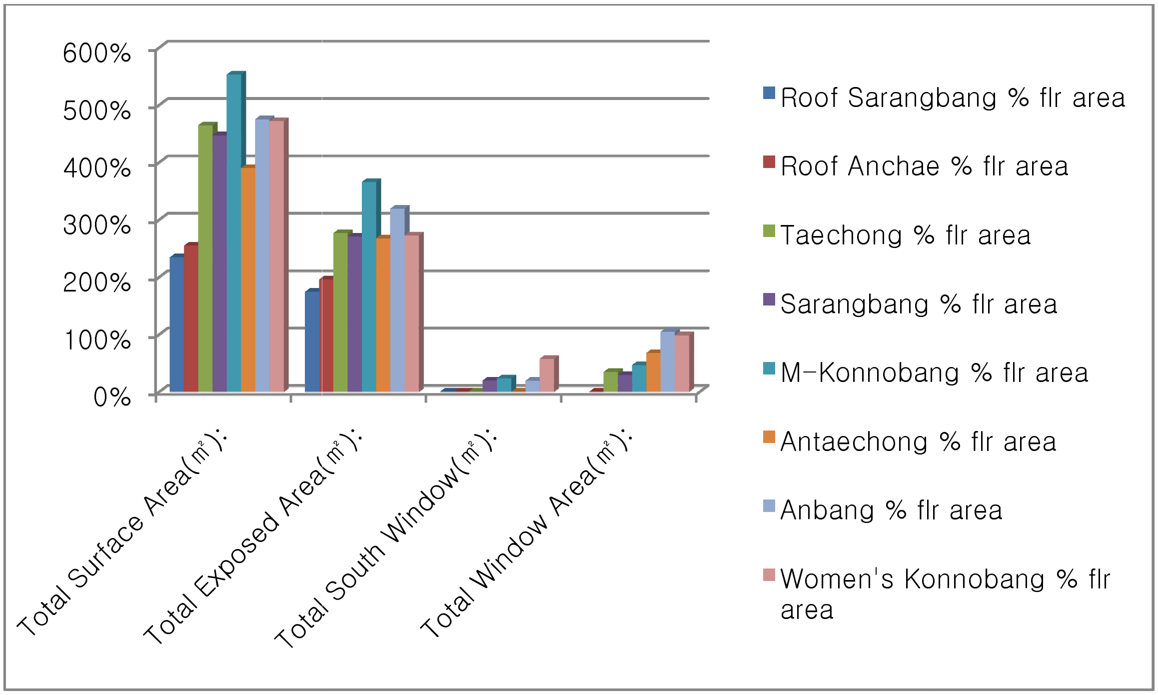


Figure 5-29 Percentage of Total area

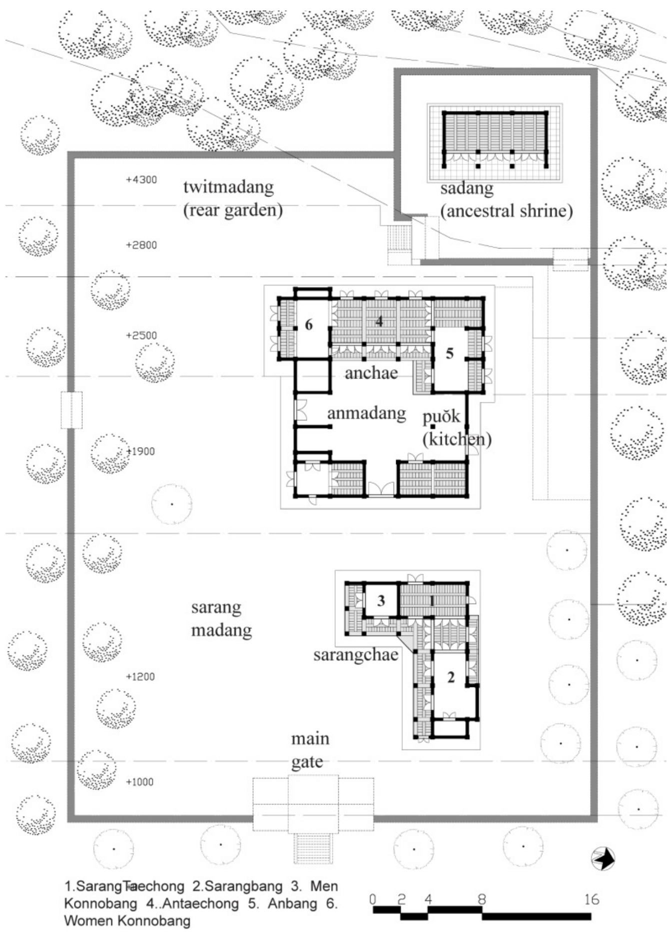


Figure 5-30 Thermal Analytic Rooms

5.4.3.1. Summer

In the summer, the hottest date is the July 23rd, the hottest date, at which the sun position is highest. The outside average temperature is the 27.5℃, and the range is from 23.5℃ at 24 o'clock to 31.8℃ at 1o'clock. The priority comfortable rooms, the cooling rooms, in the summer are ordered these following rooms; *anbang* > women *konnobang* > men *konnobang* > *antaechong* > *taechong* > *sarangbang*. *Anbang* and women *konnobang* are reported most comfortable rooms, which are cooler than any other rooms. These rooms have the windows on the each side, south and north that can produce the enough ventilation. The wind flows from the east of south to west of north in the winter. Therefore, the opening of anbang and *konnobang* does not interrupt to flow the wind, which makes more comfortable in those rooms. On the other hands, the *sarangbang*, men *konnobang* and *sarangtaechong* are reported worse than the rooms of anchae. Total part of *sarangbang* is little lower satisfied, but some part of *sarangbang* can affect the wind very well like upper *sarangbang* part near *sarangtaechong*, because there are many openings in the *sarangtaechong*. Once there are more windows on the west part of *sarangtaechong*, the air winds flow very well. The element of reducing windows on the west part of *sarangtaechong* emphasizes the women privacy and it represents the Confucian theory, which must distinguish between men and women. The worst temperature in the anbang is 28℃ at 2 o'clock on July 23rd. The percentage dissatisfied is 15.4% and the PMV is the 0.70 of the maximum hot point 3 (Figure 5-31). The conditional factors are these following values: Relative Humidity 82%, Activity Rate 1.50met (standing), Clothing 0.50clo (Trousers and shirt), and Air Velocity 1.90m/s. While, when air velocity changes 0 m/s from 1.9m/s, the percentage dissatisfied would change 40.9% from 15.4%. The result of analysis provides that *Chusagotaek* is not only very satisfied with the thermal comfort in the summer. It also proofs that the air velocity is important factor. The *Chusagotaek* total window area of the total floor area is from 29% in *sarangbang*, to 104% in *anbang*. The window is also very flexibly moveable, and can open 100% of windows installation. It makes not to interrupt the wind flow.

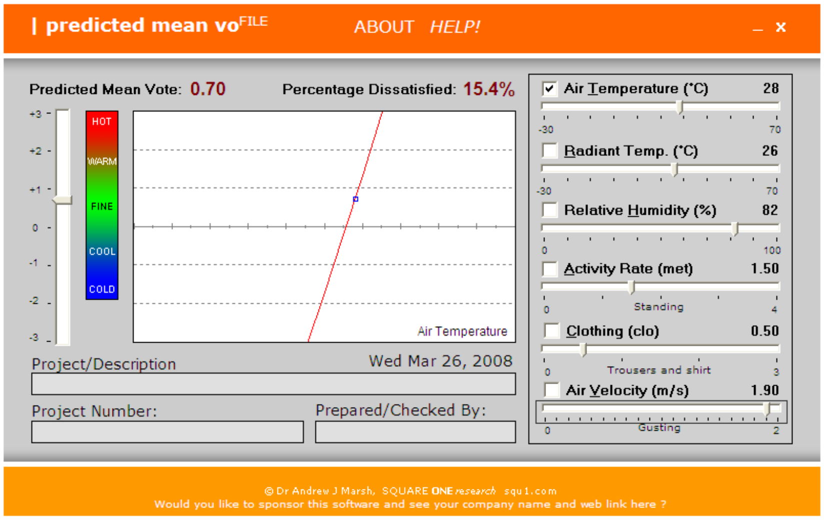


Figure 5-31 The percentage dissatisfied is 15.4 % (84.6% satisfied) and the PMV is the 0.70 of the maximum hot point 3, in anbang, the hottest day, July 23rd. This result provides that all rooms are satisfied in the summer.

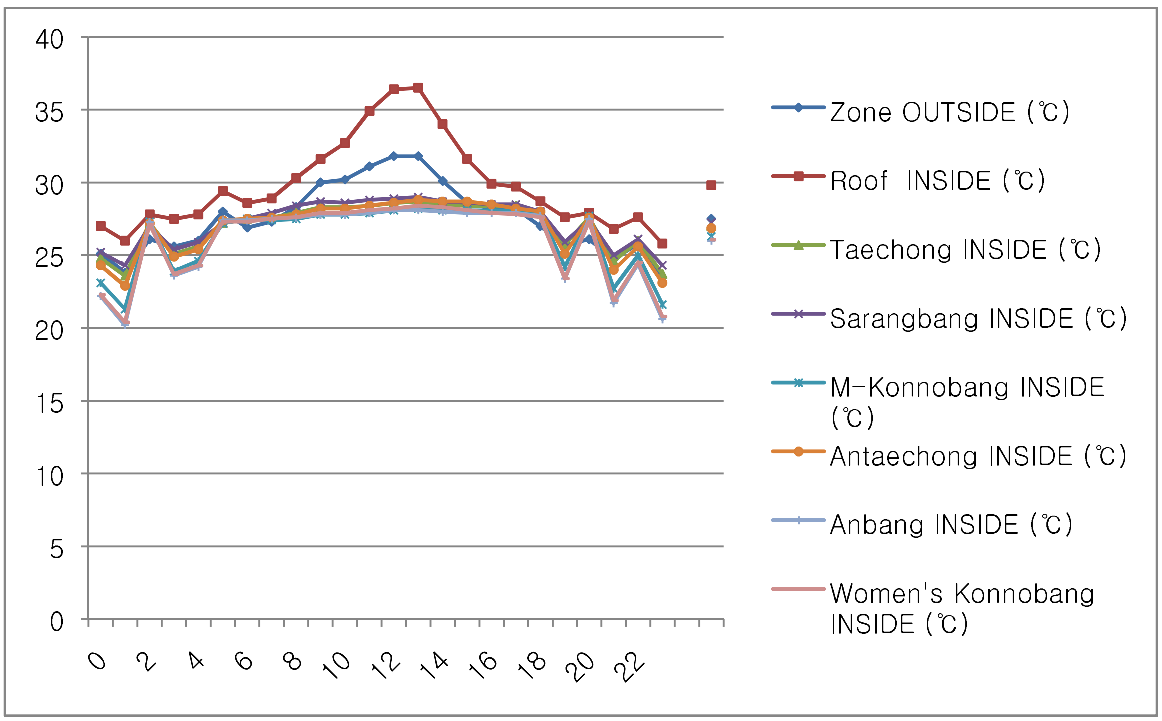


Figure 5-32 Hourly Temperature, July 23rd

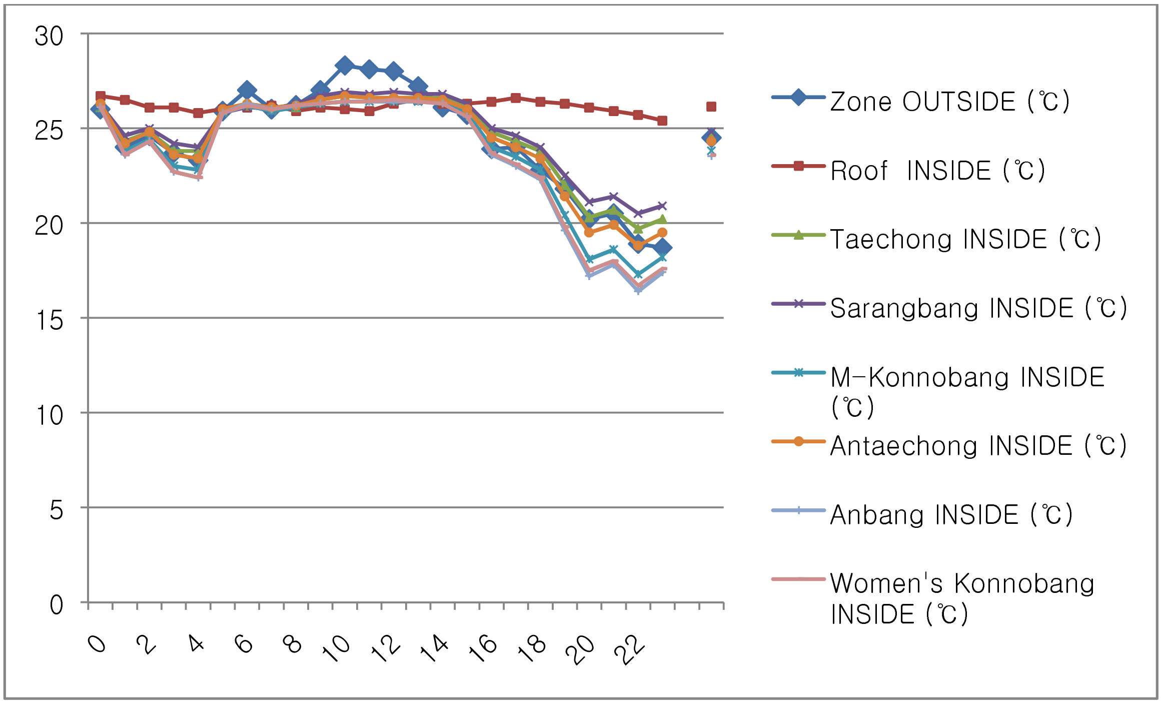


Figure 5-33 Hourly Temperature, August 23rd

5.4.3.2. Winter

In the winter, the better inside thermal comfort in Seoul, Korea definably should be warm temperature inside and keep the lasting warm energy. On January 13, the coldest date, the priority comfortable rooms are ordered these following rooms; *sarangbang* 〉 men *konnobang* 〉 *sarangtaechong* 〉 *anbang* 〉 women *konnobang* 〉 men *konnobang* 〉 *antaechong*. *Sarangbang* and men *konnobang* are reported most comfortable room, which are warmer than any other rooms. These rooms have less windows area percentage of the total floor area and more south window percentage than any other rooms (Table 5-2). The south windows generate more heat gain, and make more satisfied room in the winter. *Anbang* and women *konnobang* are reported worse comfortable room, which are colder than any other rooms, but those rooms does not change the temperature affected by outside temperature. Those rooms are enclosed by the other rooms, or by the second layer zone. Between outside madang and these rooms are some small rooms enclosed by windows that provide to protect strong wind, and reduce the heat loose. There are a buffer zone like the closet and maru on the south and west side, the *taechong* on the north side, and a kitchen on the east side in the women *konnobang*. There are a buffer zone like *maru* on the north and west, and a kitchen on the east side in the *anbang*. All side rooms in *anbang* and women *konnobang* has protected by the other zones and rooms, which can control the opening during hot day.

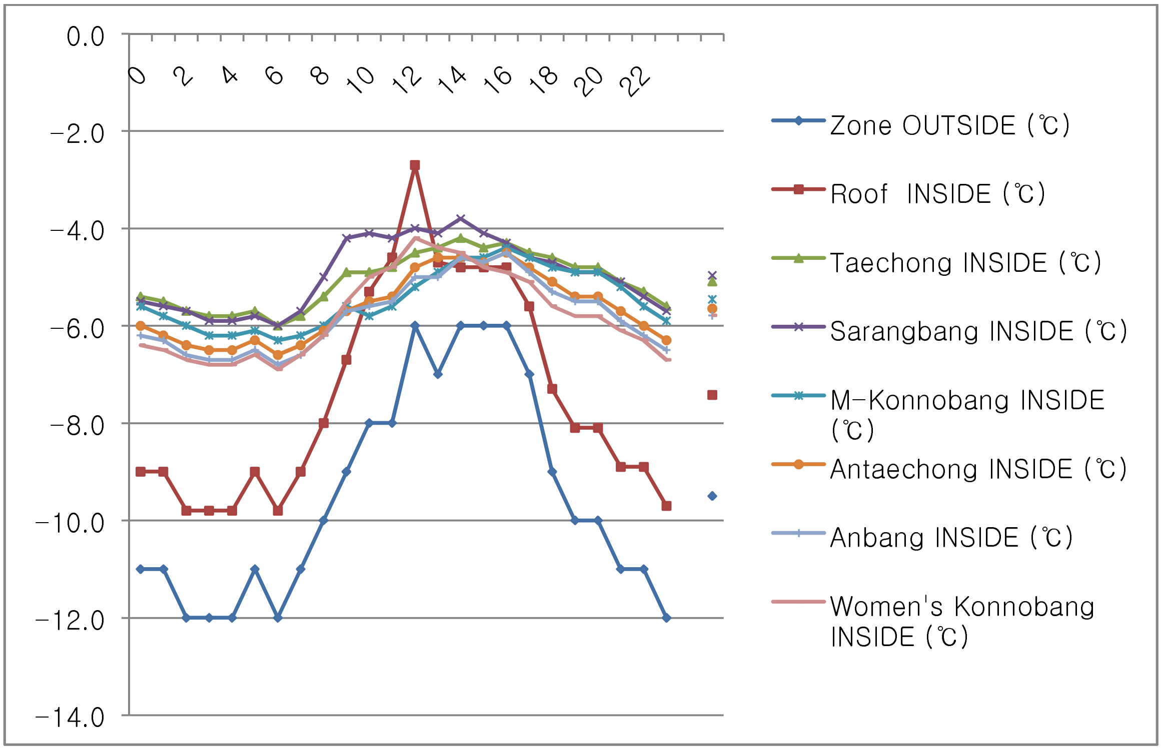


Figure 5-34 Hourly Temperatures, 13th January

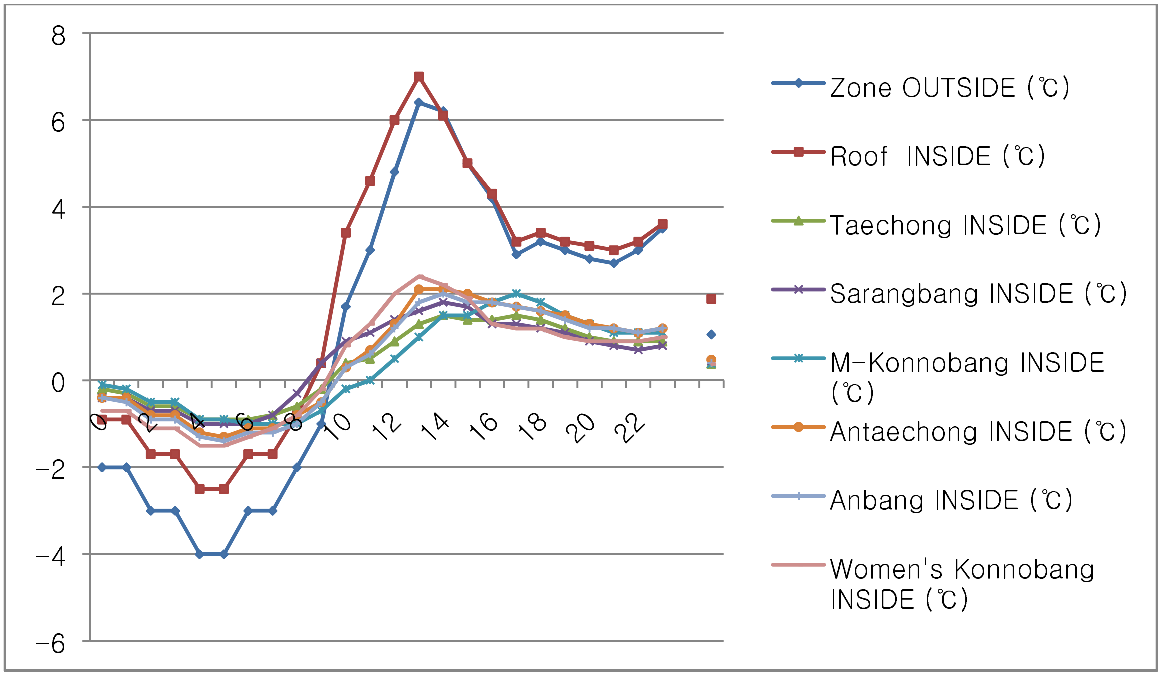


Figure 5-35 Hourly Temperatures, 23rd December

5.4.3.3. Spring and Autumn

In the May 6th, which starts to change the weather point to the summer, the average temperature is 14.6 ℃, and the range is from the 14℃ to the 16℃ in all of rooms in *Yeongyeongdang*. The dissatisfied percentage at the 14℃ air temperature point to 33% in Predicted Mean Vote(PMV) software offered by SQUARE One research, and the dissatisfied percentage at16℃ is 19.2% (see. Chapter3. Predicted Mean Vote). In any particular thermal environment, it is difficult to get more than 50 per cent of the people affected to agree that the conditions are comfortable (McMullan, 2007). In the date, the thermal comfort is mostly satisfied, but one could feel little cold for sleeping. If the clothing level is changed, the percentage dissatisfied should be changed.

	The lowest temperature	The highest temperature	
Air Temperature (℃)	14	16	May 6th
Radiant Temperature (℃)	23	23	
Relative Humidity (%)	70	70	Source by Korea Meteorological Administration, the average humidity from 1961 to 1990.
Activity Rate (met)	1.5	1.5	Standing
Clothing (clo)	1	1	Light Business Suit
Air Velocity (m/s)	1	1	
Predicted Mean Vote	-1.48	-0.83	-3 too cold, +3hot
Percentage Dissatisfied	33.00%	19.20%	

Table 5-3 May 6th Predicted Mean Vote (PMV)

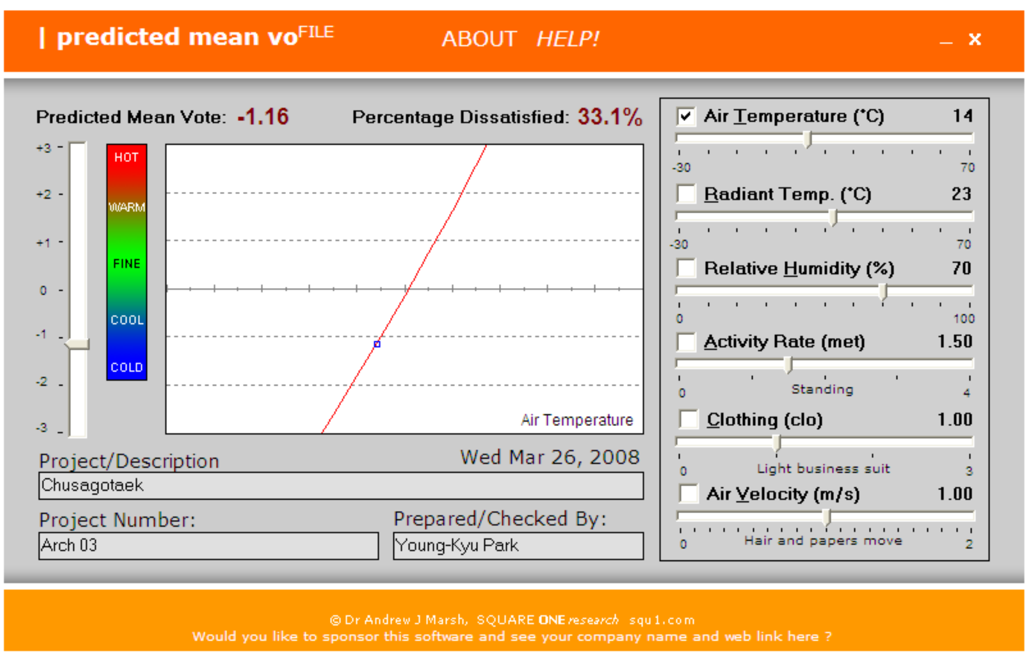


Figure 5-36 Predicted Mean Vote, in May 6th, when the lowest temperature is 14℃, the percentage dissatisfied 33% (the percentage satisfied 67%). Over the percentage, satisfied 50% means that the buildings have good condition without the electrical appliance.

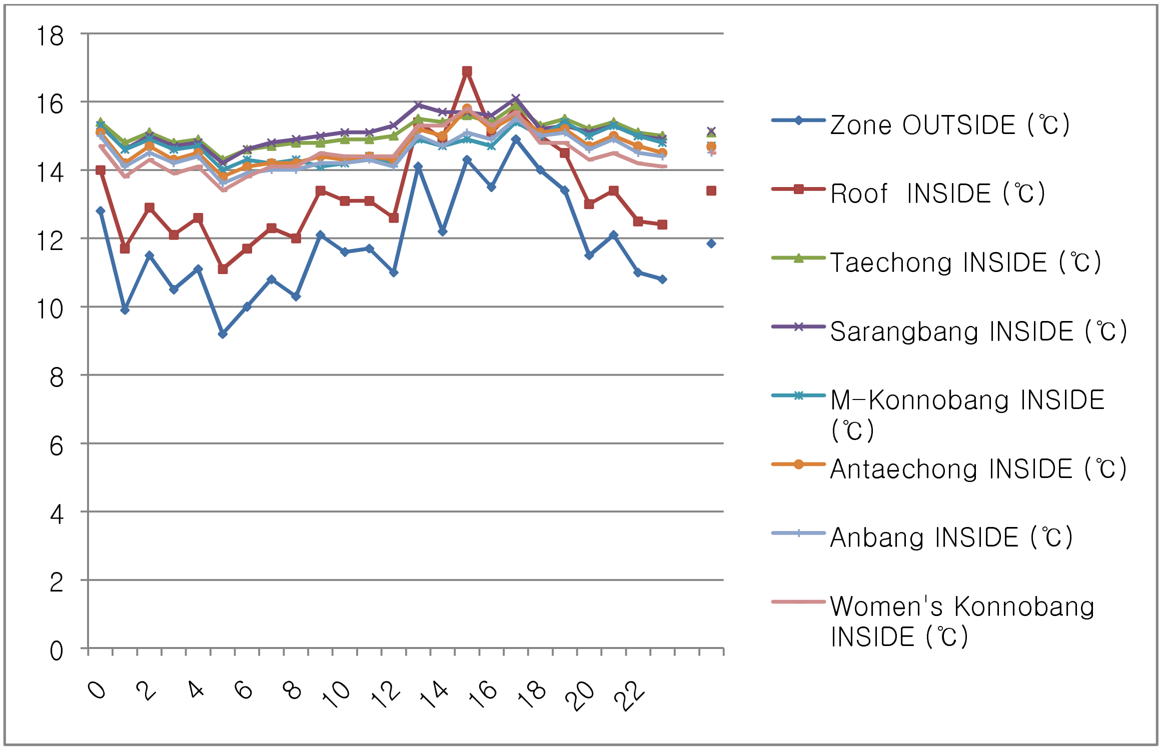


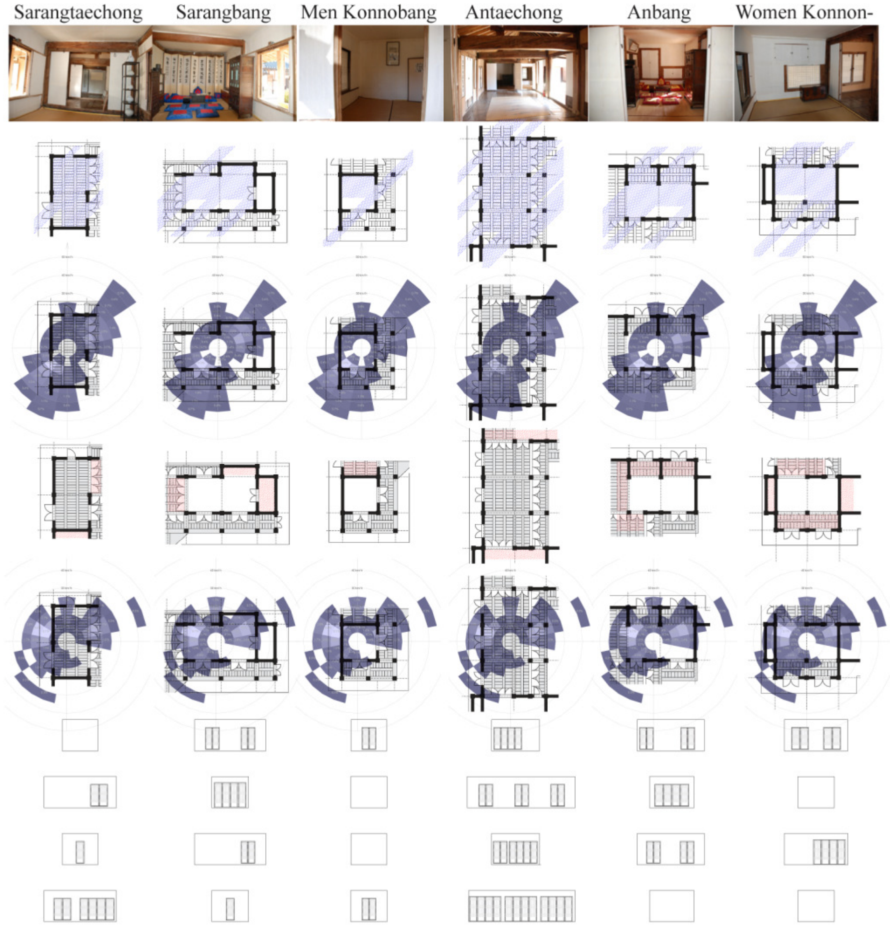
Figure 5-37 Hourly Temperature, May 6th

5.5. Summary

The *Chusagotaek* research trough Ecotect software manly divide three big analyses to control sunlight and daylight, shading, wind flow, and the thermal performance. Those factors are related and linked together. In this chapter analyzing the *Chusagotaek*, the main idea of sunlight protects the strong sunlight in the summer until august 23rd same as *Yeongyeongdang* and *Unjoru*. Otherwise, the *sarangbang* eaves are designed shorter than any other eaves, but the eaves length affects the solar heat gain imperceptibly. Especially, the short eaves makes lighter inside, and there can be a small garden, instead of the reflected white madang unlike *Yeongyeongdang* and *Unjoru*. The prevailing wind also assists to look at Chusagotaek plan well.

In the thermal performance, the priority rooms define different order using by the different seasons, then in the winter season, the order are these following rooms: *sarangbang* > men *konnobang* > *sarangtaechong* > *anbang* > women *konnobang* > men *konnobang* > *antaechong*. In the summer, the priority rooms, which are cooler rooms, are these following rooms: *anbang* > women *konnobang* > men *konnobang* > *antaechong* > *taechong* > *sarangbang*. These orders are satisfied with the rooms function in the summer. In the winter the inside temperature in the all of rooms are independent on the outside temperature, even though there is no ondol system, thermal heating system.

	Sarangtaechong	Sarangbang	Men Konnobang	Antaechong	Anbang	Women Konnon-



Area		Sarangtaechong	Sarangbang	Men Konnobang	Antaechong	Anbang	Women Konnon-
Total Floor Area(m²):		12.60	14.77	6.22	25.31	11.39	11.34
Total Surface Area(m²):		58.51	66.03	34.38	98.60	54.06	53.46
		464%	447%	553%	390%	475%	471%
Total Exposed Area(m²):		34.83	39.93	22.73	67.68	36.33	30.90
		276%	270%	366%	267%	319%	272%
Total South Window(m²):		0.00	2.88	1.44	0.00	2.16	6.48
		0%	20%	23%	0%	19%	57%
Total Window Area(m²):		4.32	4.32	2.88	17.04	11.88	11.16
		34%	29%	46%	67%	104%	98%
Priority Room In Summer		5	6	3	4	1	2
Building Fabric	6-May	-5,484	-6,136	-3,862	-14,283	-7,721	-8,154
	21-Jun	354	203	254	294	43	-9
	23-Jul	2,042	2,229	1,481	4,810	2,543	2,591
	23-Aug	520	586	396	1,181	629	624
Solar Heat Gain	6-May	109	77	50	764	208	366
	21-Jun	248	144	95	2,376	372	655
	23-Jul	141	119	84	1,242	327	576
	23-Aug	64	64	43	409	176	309
Ventilation Gain	6-May	-2,022	-2,362	-998	-4,053	-1,828	-1,819
	21-Jun	-16	-18	-8	-31	-14	-14
	23-Jul	673	786	332	1,349	608	605
	23-Aug	130	152	64	260	117	117
Internal Loads		1,512	1,772	746	3,037	1,366	1,361
Inter-zonal Loads	6-May	-308	-406	39	122	-55	90
	21-Jun	-59	-49	143	496	169	386
	23-Jul	-128	-197	78	252	50	106
	23-Aug	-303	-449	29	113	-57	59
Priority Room in Winter		3	1	2	6	4	5
Building Fabric	23-Dec	-16,468	-18,292	-11,561	-41,277	-22,176	-23,105
	13-Jan	-26,062	-28,933	-18,358	-66,016	-354,783	-37,139
Solar Heat Gain	23-Dec	93	180	108	732	263	519
	13-Jan	77	177	109	524	265	506
Ventilation Gain	23-Dec	-5,313	-6,207	-2,622	-10,649	-4,803	-4,778
	13-Jan	-7,641	-8,926	-3,771	-15,315	-6,907	-6,872
Internal Loads		1,512	1,772	746	3,037	1,366	1,361
Inter-zonal Loads	23-Dec	-9	-119	42	142	42	-33
	13-Jan	-319	-513	16	146	-76	154

Table 5-4 *Chusagotaek* Summary of the Environmental Analysis

5.6. Drawings

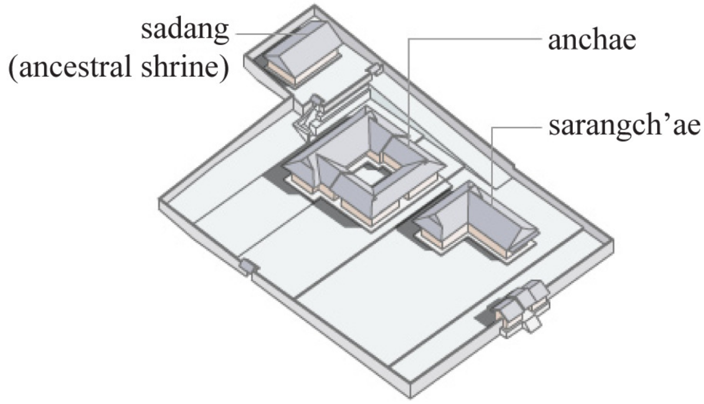


Figure 5-38 Isometric View (Korea Culture & Content Agency 2003)

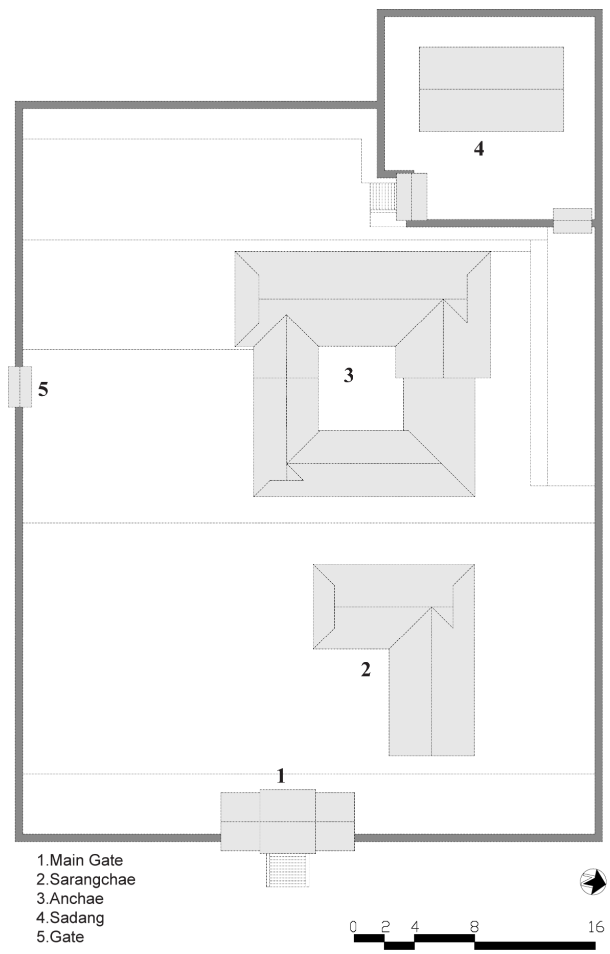
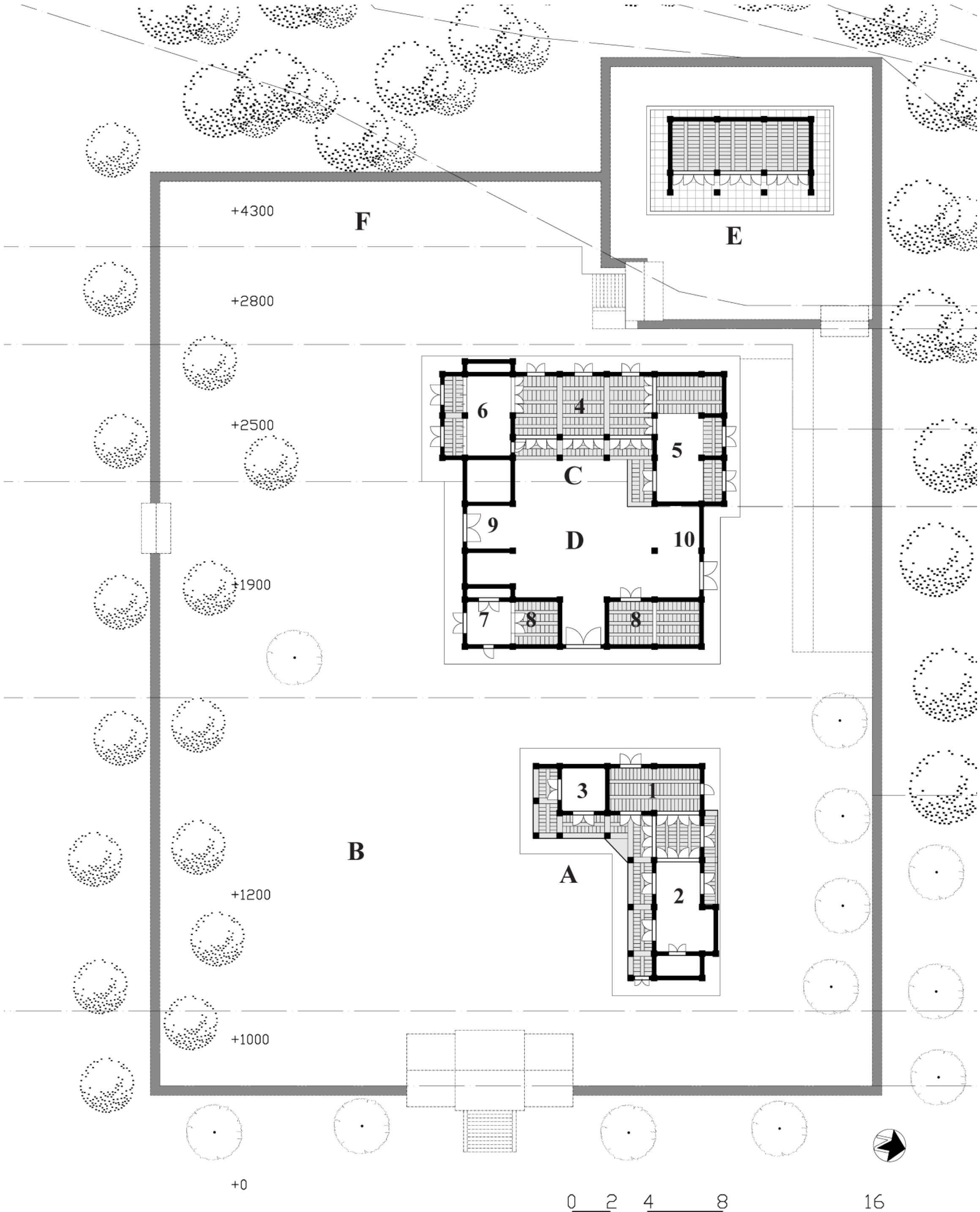


Figure 5-39 Roof Plan



A.Sarangchae B.Sarangmaddang C.Anchae D.Anmadang E.Sadang(ancestral shrine) F. Twit-madang

1.SarangTaechong 2.Sarangbang 3. Men Konnobang 4..Antaechong 5. Anbang 6. Women Konnobang 7.Haengnangbang 8.Haengnangtaechong 9.Inner Gate 10. Puok

Figure 5-40 Site Layout

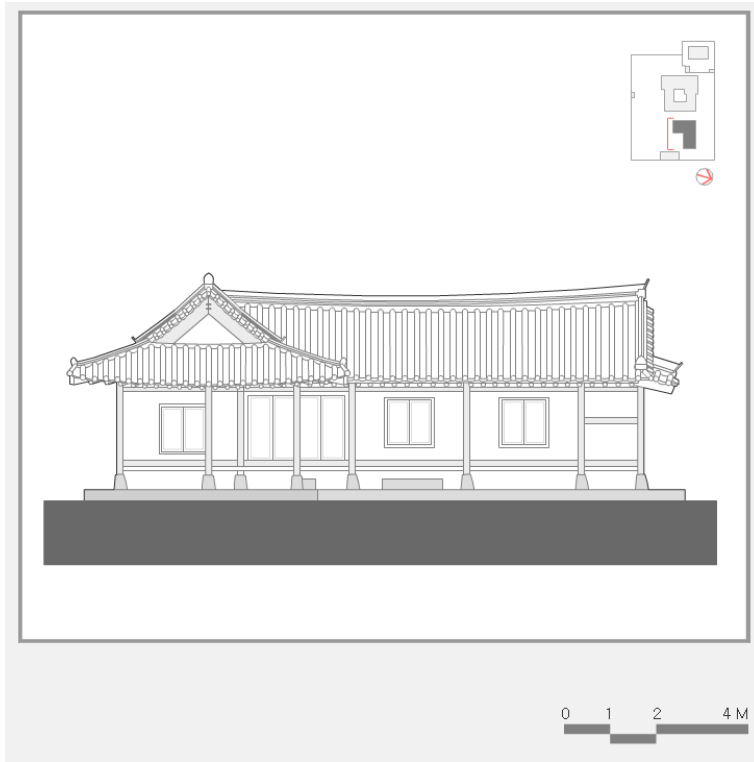


Figure 5-41 South Elevation of *Sarangchae* (Korea Culture & Content Agency 2003)

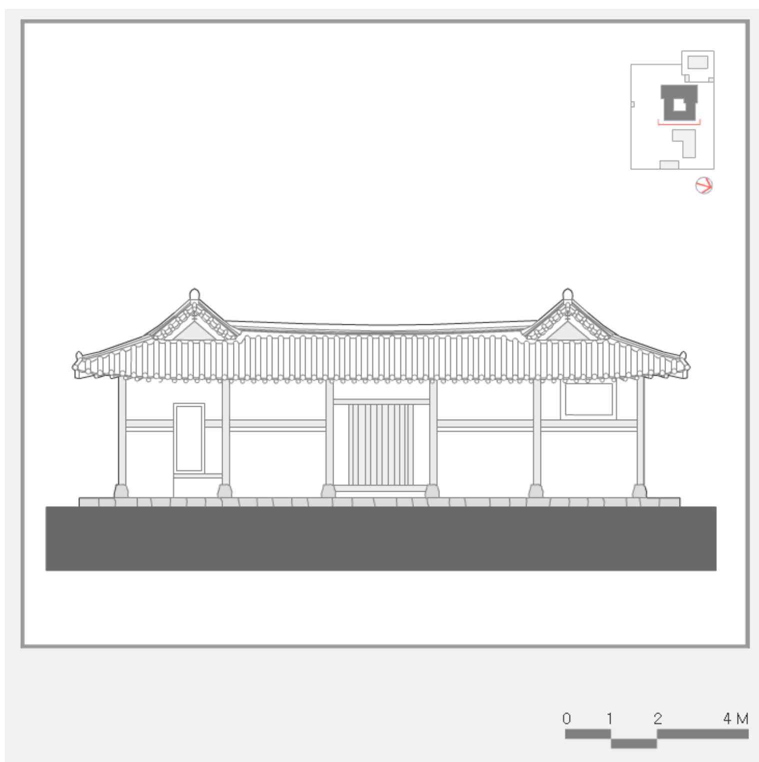


Figure 5-42 East Elevation of *Anchae* (Korea Culture & Content Agency 2003)

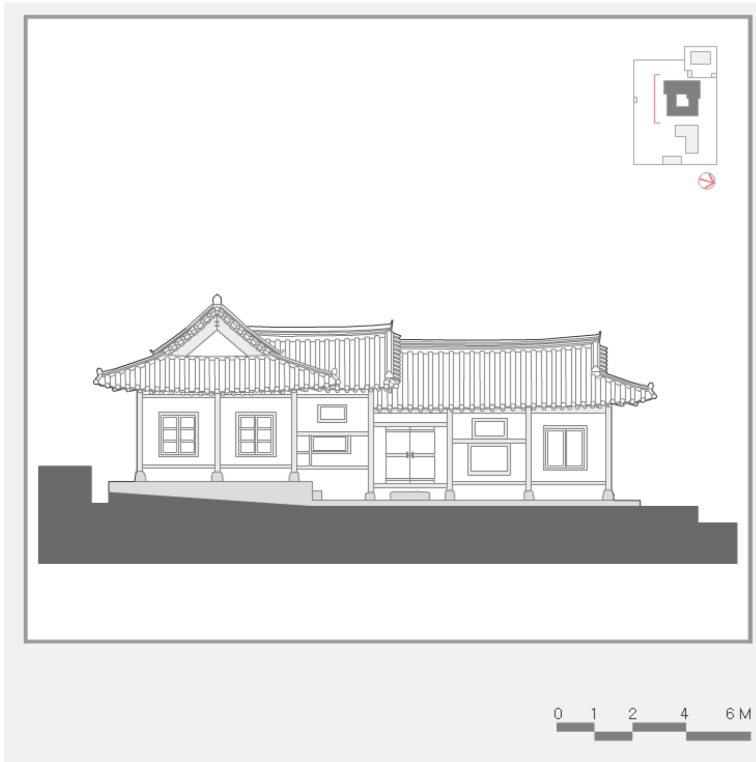


Figure 5-43 South Elevation of *Anchae* (Korea Culture & Content Agency 2003)

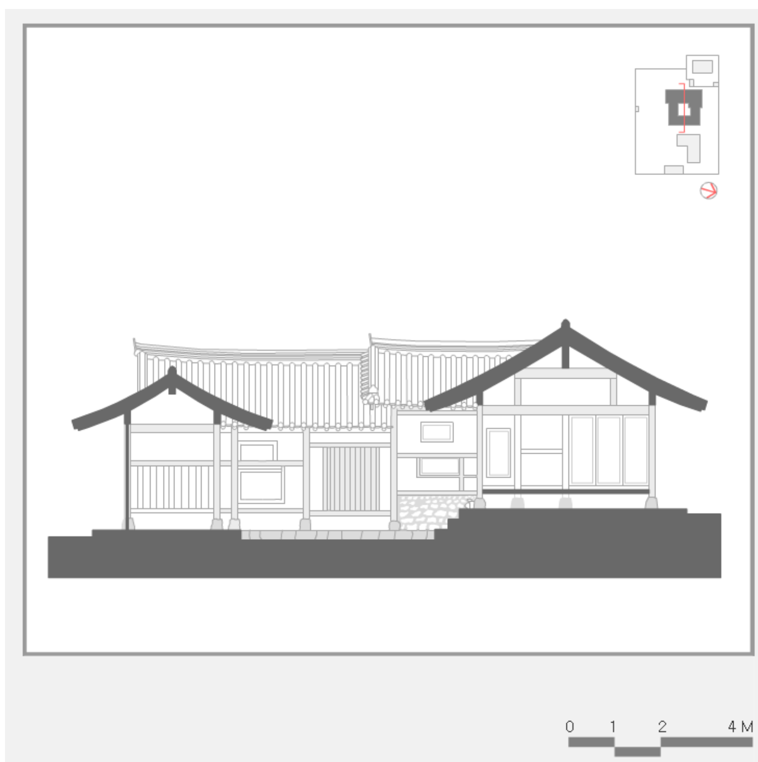


Figure 5-44 *Anchae* Section (Korea Culture & Content Agency 2003)

6. COMPARISON

6.1. Introduction

This chapter coordinates three-selected projects, *Yeongyeongdang*, *Unjoru* and *Chusagotaek*, which are analyzed in previous chapters. Analyzing and interpreting software, Ecotect is used to compare those buildings and collect data. The compared residences were built in the same age of *Joseon* (1392~1910) period, which emphasize the centralism under the Neo Confucianism that provide to conduct weddings, funerals, family ceremonies, and the veneration of ancestors and kings. The Neo Confucianism architecture separates men and women's quarter, and master and savants quarter in all of analytic buildings - *Yeongyeongdang*, *Unjoru,* and *Chusagotaek.* Those selective buildings maintain unremitted concepts of the philosophy and life style in the same period, but each building characterizes their adoptions with geographical circumstances and particulars. These spatial features of each building had been compromised by not only each room function and the basic philosophy, Neo Confucianism. Local characteristics and micro natural features heavily influence the component of building as well. This chapter classifies various environmental design characteristics in three buildings, and what kinds of factors compose the buildings to outcome design responses.

6.2. History

Unjoru was built earliest in 1776 than 10years ago built *Chusagotaek* in 1786 and 53years ago built *Yeongyeongdang* in 1828 during the *Joseon* (1392~1910). Unlike *Unjoru* and *Chusagotaek*, *Yeongyeongdang* was built inside the palace to show the king's family how typical master's resident looked like (N. Zu 2003). Through the literature review, it is undefined that someone had lived in *Yeongyeongdang*, but under kings' indication, it was used to have some celebration for Chinese ambassador and to take pleasure in looking at the building. Additionally, it is possible to hypothesize that the best carpenters built *Yeongyeongdang*, because Ikjong, son of King Sunjo of *Joseon* indicated to build *Yeongyeongdang* and control the building. *Unjoru* also could hypothesize to provide the good ecological characteristics, because the designer, Yu Eui-ju, who was as the town country headman, and a national architect in charge, had enough architectural practice and experience through his charge. On the other hands, the *Chusagotaek* was leaded to build by the Kim Han-shin, who was the scholar and politics. Unlike *Yeongyeongdang* and *Unjoru*, the *Chusagotaek* provides the geographical style more than two buildings, because it was built by the local carpenters.

Unjoru and *Chusagotaek* are located on the slope site, valley, like most of the upper residence during *Joseon* period. Although *Yeongyeongdang* is also located in middle of valley, the site is not on the slope site. *Yeongyeongdang* and *Chusagotaek* are located in the rural site, which is surrounding the forest. Otherwise, *Unjoru* is also located in the country site, but it is surrounded by houses instead of the forest. All of those buildings layouts emphasize the Neo Confucian principles, which were established as the dominant philosophy where ancestor worshipping became the core practice of people's spiritual. In terms of the Neo Confucianism, *Unjoru* and *Chusagotaek* have the ancestral shrines, which became fundamental elements in the composition of the traditional Korean residence. Otherwise, *Yeongyeongdang* has the pavilion, *nongsujung*, because the ancestor-worshipping place is located in the other site of the palace for kings. It also provides that the philosophy emphasize the separation of men from women and superior from inferior under the Neo Confucianism. *Yeongyeongdang* and *Unjoru* was preserved most of quarters; men, women, servants and worship place, but *Chusagotaek* does not remain the servant's place, which was located outside of the existing *Chusagotaek* structures (S.-H. Park 2007).

		Yeongyeongdang	*Unjoru*	*Chusagotaek*
Built in		1828	1776	1786
Size	Original	99 kan[15]	99 kan	53 kan
	Existing	99 kan (2445 x 2445 mm)	55 kan (2400~2600 x 3150~4300 mm)	20 kan (2500~2560 x 2200~2500 mm)
Location		In Seoul	Rural area, southern part	Rural area, in middle of south Korea
Built by		Joseon 28th king Sunjo	Eui-Ju Yu	Han-Shin Kim, grandfather of Jung-he Kim

Table 6-1 Comparing three residences

15 Kan measurement is equal to the width of the span between columns.

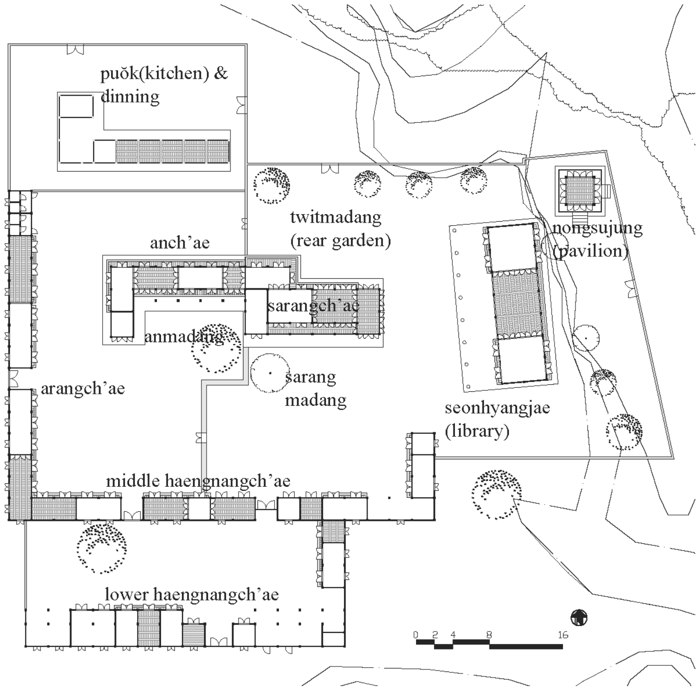


Figure 6-1 ***Yeongyeongdang***

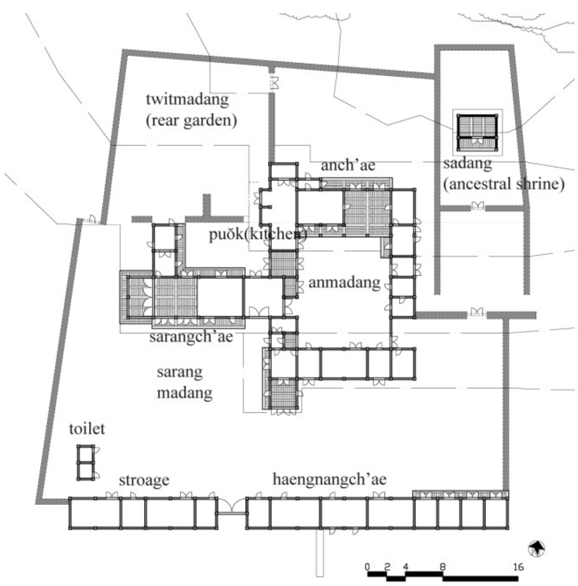


Figure 6-2 ***Unjoru***

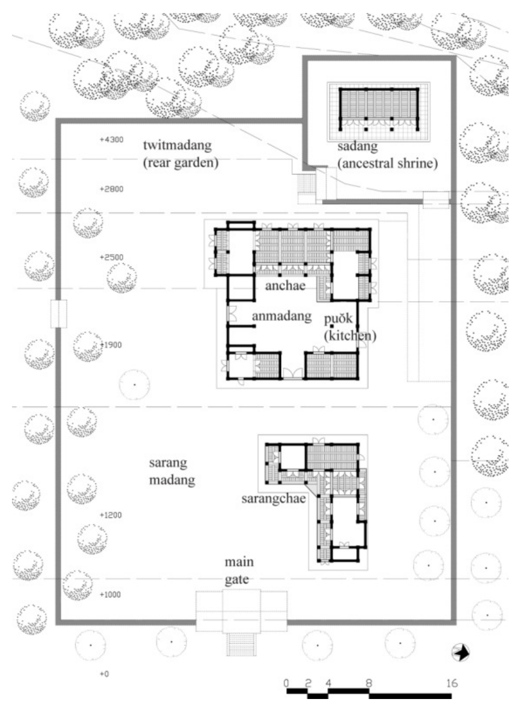
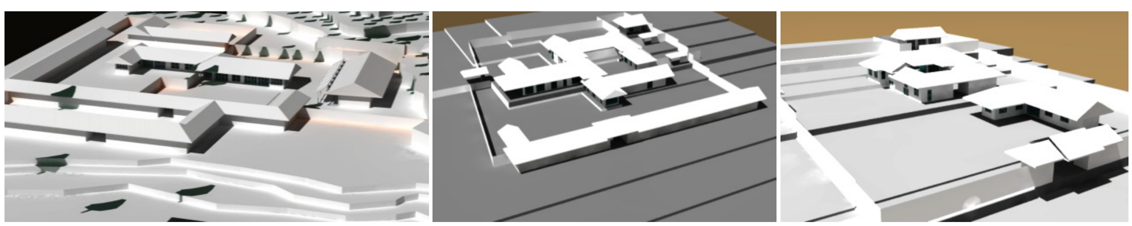


Figure 6-3 ***Chusagotaek***

6.3. Methodology

The analysis of *Yeongyeongdang*, *Unjoru* and *Chusagotaek* in this chapter starts from gathering data of the previous working. The data includes the building layout, windows position and size, landscape, overhang, building distance, orientation, material selection, human comfort, and thermal performance, which are from literature review, AutoCAD and Ecotect. First, the analysis defines the rooms of which rooms should be compared in the same function. All of buildings remain the master men and women rooms, and *taechong*, but the *antaechong* in *Chusagotaek* is excepted to analysis because there is opening without walls or windows in the antaechong that is same as outside temperature. Therefore, *Chusagotaek* women *konnobang* is added for analysis.

This conclusive chapter analyzes first the shadows, shading & solar analysis, second cooling strategies included the prevailing winds, and thermal performance, which includes the heat gain & loss, spatial comfort, ventilation and sunlight.



Yeongyeongdang ***Unjoru*** ***Chusagotaek***

Figure 6-4 Ecotect Modeling (left), and Rendering by Radiance (Right)

Experiments are focused on summer and winter of Korea, which require secondary needs to maintain environmental comfort in a building:

- ✓ January 13 - the coldest date
- ✓ May 6 - the start of summer
- ✓ June 21-the summer solstice: Sun at its highest noon altitude
- ✓ July 23-the hottest date
- ✓ August 23 -the end of summer
- ✓ December 23 - the winter solstice: Sun at its lowest noon altitude. (Korea National Heritage Online 2000, squ1.com 2007)

6.4. Investigation

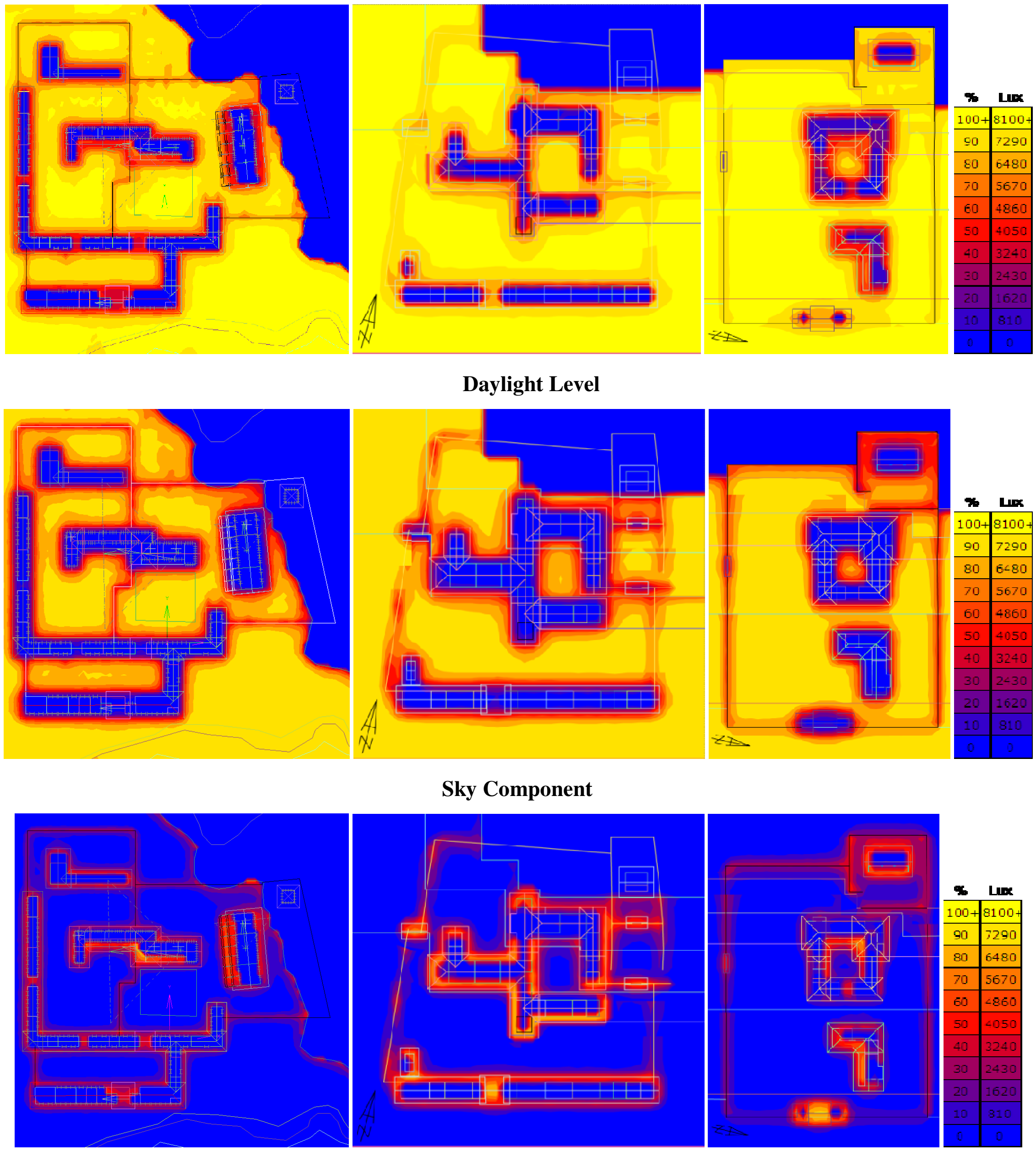
Like most of the traditional Korean residence, *Yeongyeongdang*, *Unjoru* and *Chusagotaek* building orientations face on the south. *Yeongyeongdang* orientation has changed in the layout many times during Japanese occupation (1910~1945), and the unreliability layout induces that the previous Chapter 3 employ the exactly south face of building. Orientation of *Unjoru* is faced the south and tiled the east about 8 degree, and *Chusagotaek* building orientation is faced the south and tiled the east about 12 degree. This tiled east of south orientation offers the best results of both winter heating and summer shading for activity in that period, because during the day with sunlight from 5~7 o'clock AM to 5~7 o'clock PM they have to have activity with the sunlight.

All of buildings follow the principles of *pungsu* similar to the other traditional architectures, "mountain behind and river or water in front" and the architectural structure face south. However, there is no river or any bigger water place in front of *Chusagotaek*, therefore it does not seem to follow the theory but in front of *Chusagotaek*, there is a small pond. The pond is very small, which does not seem to support the *pungsu* theory, but the pond could be a small gesture of symbolizing the *pungsu* theory. However in front of *Chusagotaek* structure are almost empty, the sunlight spread out to the building very well without interruption. *Yeongyeongdang* and *Unjoru* have the main gate on the southern part of buildings, and those buildings are faced toward south. *Unjoru* has the main gate on the eastern part of buildings, and the building are faced toward south for considering the daylight.

The Daylight Analysis in the Ecotect provides the decision of the layout, which one should be used for analyzing the environmental factor. The daylight levels are not time dependant and it represent a worst-case design condition base on a sunless cloudy or uniform sky distribution. Daylight Factor (DF) is related with three principle components, which are Sky component (SC), Externally Reflected Component (ERC), and Internally Reflected Component (IRC). Ecotect assumes the Design Sky Illumination maximized 8500 lux. Daylight usually enters a building by means of oilpaper windows or doors, but these windows or doors also transmit heat, which is related with the thermal performance. The amount of daylight provides the decision of lighting as well as the cooling energy. The provision of natural lighting in a residence needs to be considered together with factors of artificial lighting, heating, ventilation and sound control.

In the previous Chapters, the result from Daylight Analysis shows the Daylight Factors (DF) including the Externally Reflect light (ER), and the Internally Reflect light (IR). Otherwise, in this chapter, the Internally Reflected Lights (IR) are small portion of comparing, and then it is exception. In *Yeongyeongdang*, the Externally Reflected Light (ER) spreads out evenly in most of rooms (Figure 6-5). In *Unjoru*, the Externally Reflected Light (ER) is stronger and wider than *Yeongyeongdang* and Unjoru (Figure 6-5). The higher ground level in *Unjoru* provides more the Externally Reflected Light (ER) and more open view space in front of rooms. In *Chusagotaek*, the anbang and women's *konnobang* are located in the west of north, the corner of buildings, but the Externally Reflect light (ER) spreads out evenly to the corner (Figure 6-5). The higher level of the *anchae* site leads to the sunlight to spread out to the corner. The *anbang*, *antaechong*, and a *konnobang* are placed on the higher site level than the other servant's rooms and kitchen.

1. *Yeongyeongdang* 2. *Unjoru* 3. *Chusagotaek*



Daylight Level

Sky Component

Externanlly Reflected Light

Figure 6-5 Daylight Analysis, Reflected Light

6.4.1. Shadows, Shading and Solar Analysis

Shadows, Shading and Solar Analysis offer the greatest tool in Ecotect for embodying features. This analysis could monitor use of natural energy flows as the primary means of harvesting solar energy. It also provides the space heating, cooling load avoidance, natural ventilation and natural light. Ecotect provides three big functions in analysis: Shadows & Reflections Analysis, Shading Design, and Incident Solar Radiation in Solar Analysis. First, Shadows & Reflections Analysis is an important aspect of analysis. Through the Ecotect analysis, the display of Daily Sun Path, Annual Sun Path tool, and Sun Path Diagrams provides to observe quickly the layout and structure as soon as to accomplish an Ecotect model of buildings (Figure 6-6). Second, Shading Design Analysis that generates the Optimized Shading Device to shade the currently selected window object, the Project Solar Shading Potential to visualize clearly, which part of an obstruction or shading device is the most important. Sun path diagram also provide outside shading design. The shading design wizard in Ecotect provides buildings through the process of shading requirements (Ecotect 2007). One very useful function of this Wizard is to generate automatically the exact shading shape perfectly to shade a window and specified period. Lastly, Incident Solar Radiation, one of the main functions in the Solar Analysis refers to the wide spectrum radiant energy from the Sun, which strikes an object or surface. Excessive solar exposure is one of the main causes of summer overheating in buildings. However, it is also one of the most effective sources of natural energy available in winter. Thus, Shading systems and the analysis of solar gains are linked with the solar access and incident solar radiation (squ1.com 2007).

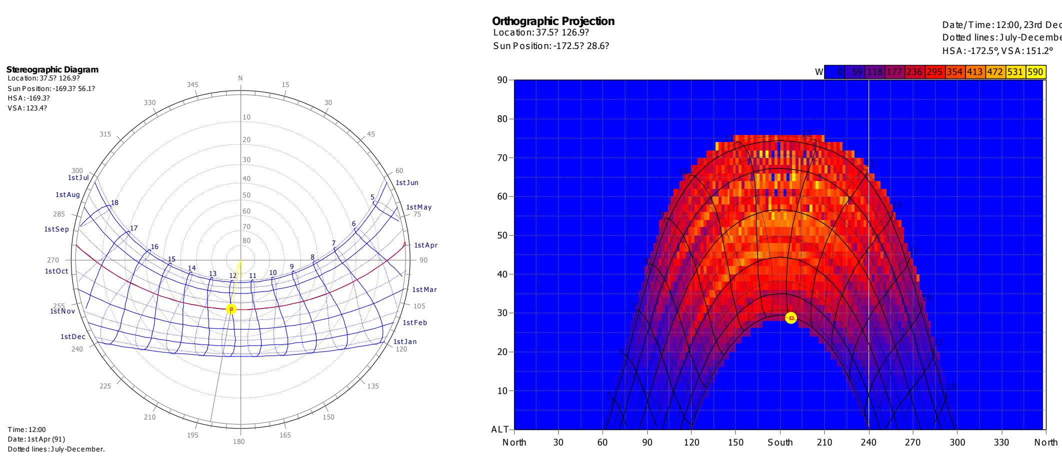


Figure 6-6 Stereographic Diagram (left), Waldram Diagram (right), April 1st 12:00 Sun Position, Location 37.5°, 126.9°, South Korea

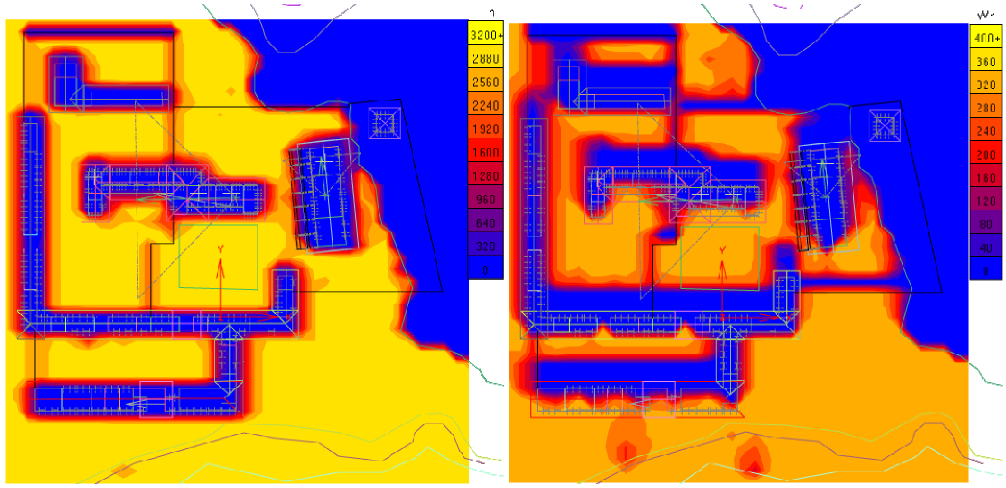


Figure 6-7. ***Yeongyeongdang*** **Total Direct Radiation of solar analysis, summer solstice, June 21st (left) and winter solstice, Dec 23(right)**

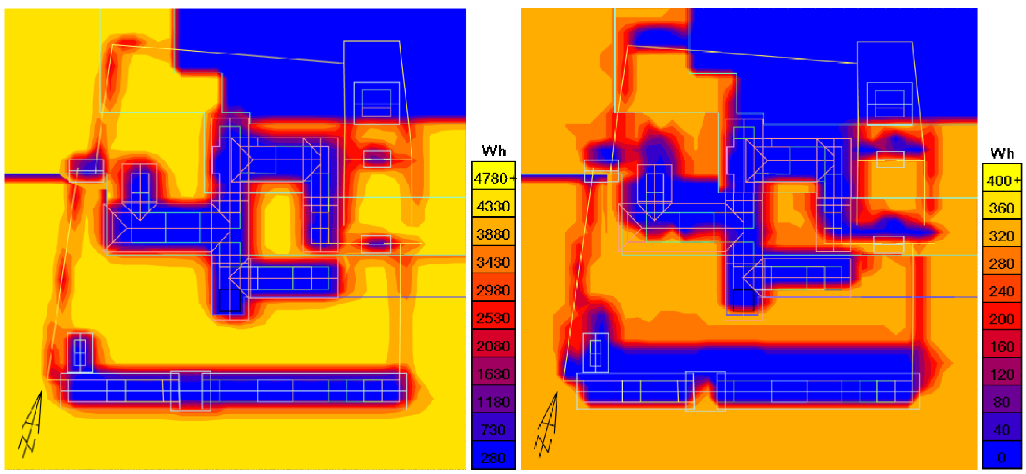


Figure 6-8. ***Unjoru*** **Total Direct Radiation of solar analysis, summer solstice, June 21st (left) and winter solstice, Dec 23(right)**

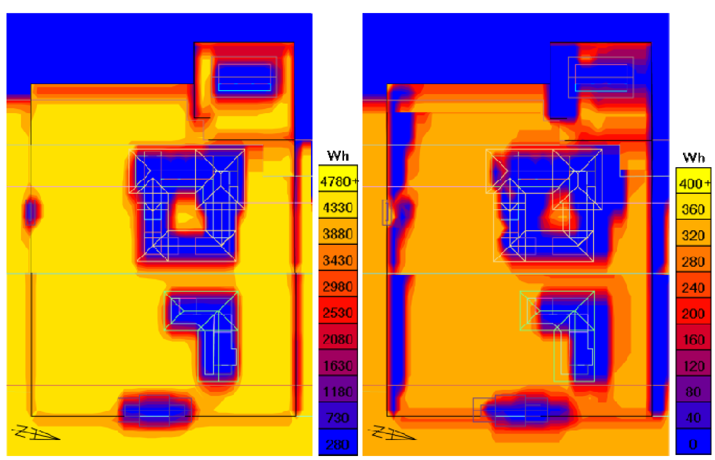


Figure 6-9 ***Chusagotaek*** **Total Direct Radiation of solar analysis, summer solstice, June 21st (left) and winter solstice, Dec 23(right)**

In summer, the sun path rotates on the higher altitude and the sun light affects the roof side more than the wall side. The summer sky component shows stronger than the winter sky component, which leads more heat gain in the summer (Figure 6-7, Figure 6-8 and Figure 6-9). The roof in the traditional Korean residence expresses noteworthy consideration to decide the building environmental consideration, which is related with heat gain and loose for inside temperature. The thick roof of the traditional Korean residence provides to protect the strong sunlight during summer. The thick roof preserves the heat gain from the sunlight, the heat energy from the ondol system, and it releases the heat in night during the winter. In the summer, all of tested buildings protect the strong sunlight during the summer, and then the heat gain minimizes into all of rooms.

On the other hands, the sun light is very significant factor to supply the heat inside room during the winter. The roof can reflect, transmit and absorb the solar radiation into the room through conduction. Additionally, the wall including the windows can transmit and absorb the heat energy. Excessive solar exposure is one of the main causes of summer overheating, but it is also one of the most important sources of natural energy in winter. In the summer, the all roof of *Yeongyeongdang*, *Unjoru* and *Chusagotaek* perfectly protect the strong sunlight. *Yeongyeongdang* receives the sunlight in all of rooms equally during the winter and summer (Figure 6-7). *Unjoru* and *Chusagotaek* receive the sunlight unevenly in the winter, some structure interrupts to penetrate into each rooms (Figure 6-8 and Figure 6-9). In the winter, the sunlight penetrates the roof, the wall, which absorbs the solar radiation, and the windows transmit the solar radiation into the room. This following section clarifies the sunlight efficiency for each room.

6.4.1.1. Protecting the Strong Sunlight in the Summer

In the summer, solar analysis tests how the roof eaves protect, and provides sunlight during the winter. Daily Sun Path and Annual Sun Path Display in the Shadow Settings panel of Ecotect are set to shadow on the special day and time. The Shading Design Wizard extrudes objects for solar envelope that crates reference lines and planes to test or interrupt buildings heights (Figure 6-10, Figure 6-12, Figure 6-13, Figure 6-15, and Figure 6-16). In three buildings analyses, the measured value takes off the ambiguous when and how the eaves' length was decided. The summer starts from May 6th to August 23rd. The sun's altitude is at its highest at noon, July 21, and at it's lowest on August 23rd during the summer. On the last day of summer and the lowest altitude[16] sun during the summer, which is august 23rd, at 10 AM, this sun will hit the tip of the roof on the side, and it creates angel that is always at 56.6 degree every year. At this angle 56.6 degree, it creates shading towards the house that encloses the whole house creating friendly or cooler atmosphere inside. The eaves angle of the main building is at same angel 56.6 degree at 10 AM or 1:30 PM, azimuth 45.7° and at 2 PM, azimuth 134.3°. *Yeongyeongdang* and Unjoru roof were designed the altitude, angle 56.6 degree, but *Yeongyeongdang* shows more strictly to be followed the angle (Figure 6-11 and Figure 6-14). In the *Chusagotaek*, the *sarangbang* eaves are shorter than any other rooms in *Yeongyeongdang* and *Unjoru*. Usually the sarangbang eaves in *Yeongyeongdang* and *Unjoru* perfectly protect sunlight as far as the maru in front of *sarangbang* in August 23rd, and the *sarangbang* eaves in *Chusagotaek* protects the sunlight to *sarangbang* but not to the *maru* in front of *sarangbang*. It means that *sarangbang* has more sunlight, and has more heat gain from outside. Unlike, *Yeongyeongdang* and *Unjoru*, *Chusagotaek* has small garden in front of the *sarangbang*. Most of the traditional Korean residences did not put tree or plans in front of building structures, but the *Chusagotaek* has one small garden in front of *sarangbang*. The garden could gradually reduce the heat energy. Otherwise, there are a stone, inscribed '*seoknyeo'*, meaning the year stone in a literal translation, in front of the small garden[17]. The stone had used for measuring time, and then there should not be tree behind the stone (N.-C. Zu 2003). I think the garden was different shape, for example, there maybe were only lawn, small sculpture, or small pond instead of the trees.

[16] Altitude represents the vertical angle the sun makes with the horizontal ground plane. It is given as an angle in the range 0° < alt < 90°. In the winter, the sunlight can penetrate to inside room about half of room's floor on December 23rd, the winter solstice. Azimuth represents the horizontal angle of the sun relative to true north. This angle is always positive in a clockwise direction from north, and is usually given in the range 0° < azimuth < 180° (squ1.org 2007).

[17] See also Chapter 5. *Chusagotaek*, Model III in more detail

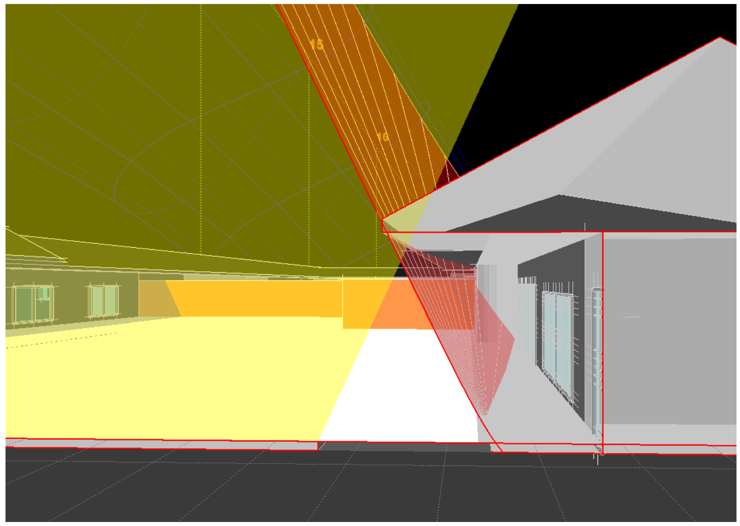


Figure 6-10 Yeongyeongdang Sarangbang Section of Daily and Annual Sun Path Analysis with Extrude Sunlight for Solar Envelope on August 23rd, Summer Solstice

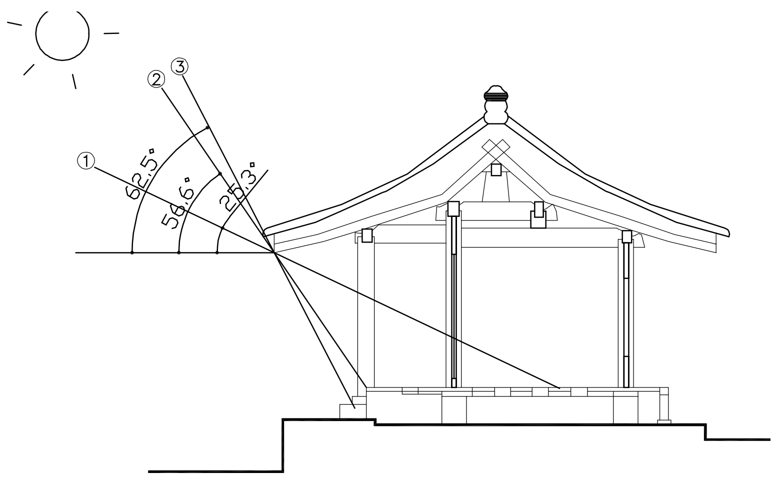


Figure 6-11 *Yeongyeongdang Sarangchae* sunlight angle section, 1. Winter solstice, 23rd December, 10 o'clock 2.August 23rd Sunlight Angle, 10 o'clock 3.Summer Solstice, 23rd July, Noon

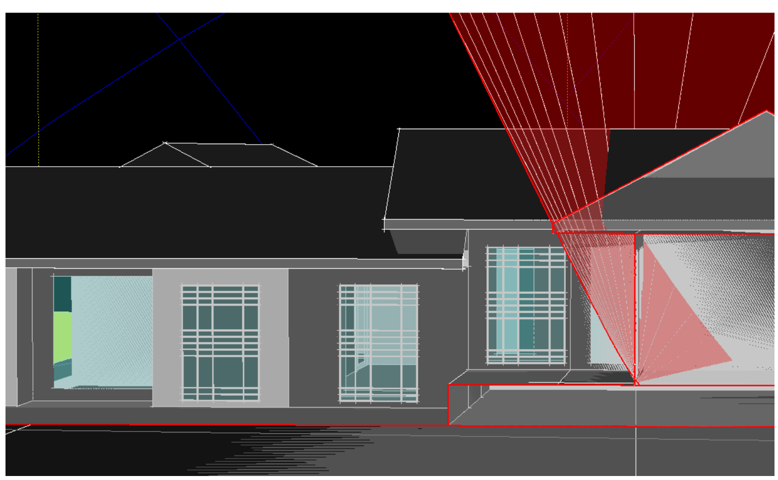


Figure 6-12 *Unjoru* Extrude Sunlight for Analyzing shading and shadow, *antaechong* on August 23rd, the end of Summer

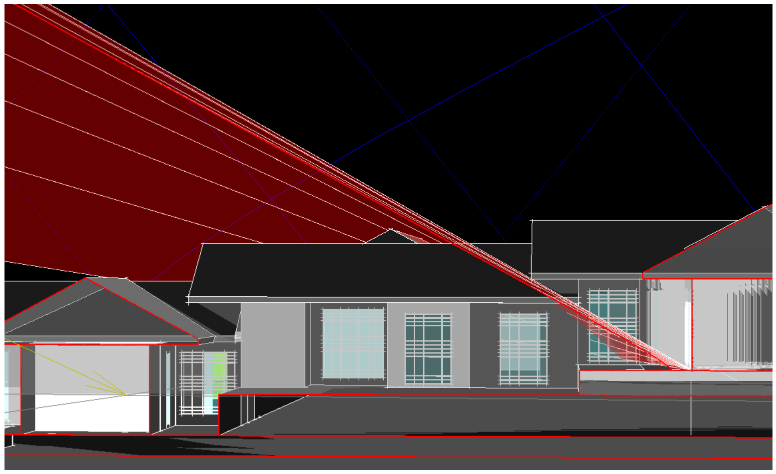


Figure 6-13 ***Unjoru*** **Sunlight for Analyzing shading and shadow,** ***antaechong*** **on December 23rd, the winter solstice**

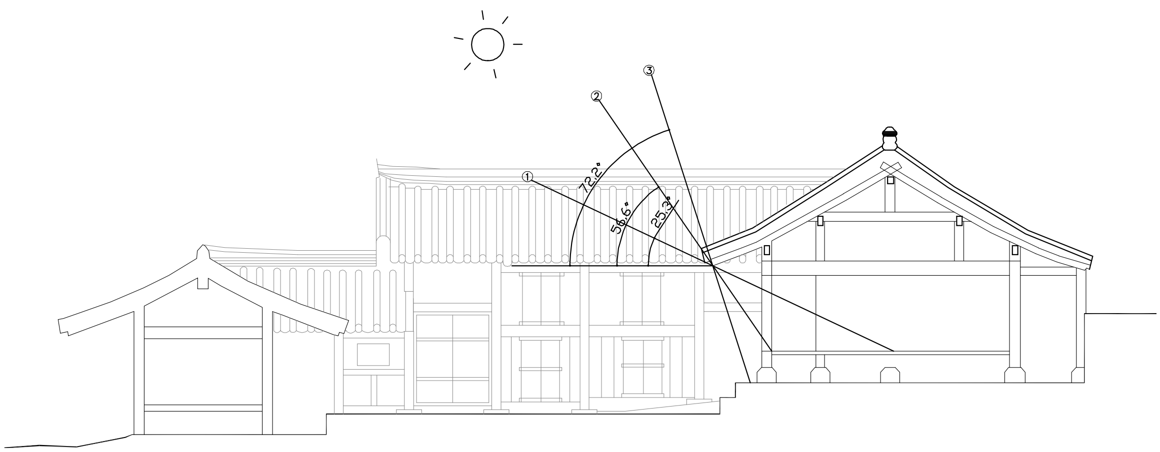


Figure 6-14 ***Unjoru Anbang*** **sunlight angle section, 1. Winter solstice, 23rd December, 10 o'clock 2.August 23rd Sunlight Angle, 10 o'clock 3.Summer Solstice, 23rd July, Noon**

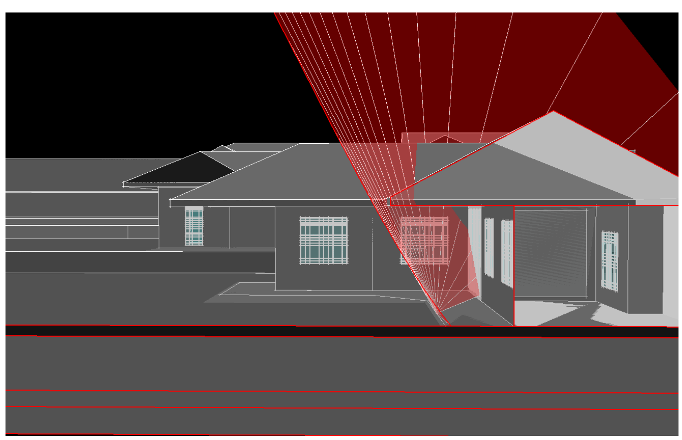


Figure 6-15 ***Chusagotaek*** **Extrude Sunlight for Analyzing shading and shadow,** ***Sarangbang*** **on August 23rd, the end of Summer**

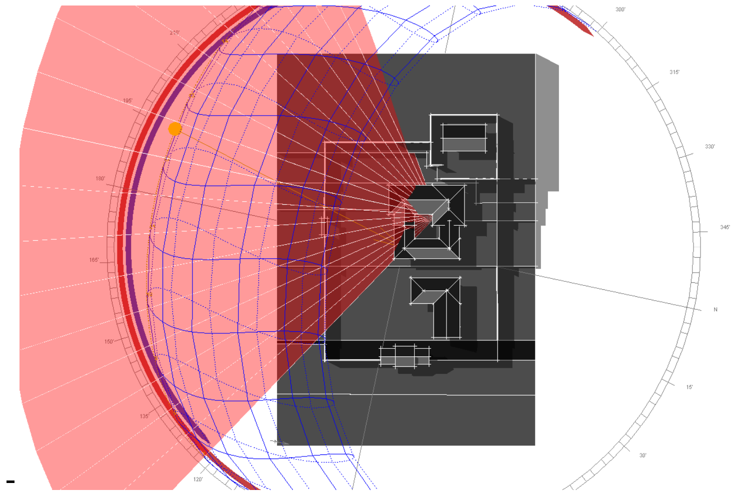


Figure 6-16 ***Chusagotaek*** **Sunlight Floor Plan for Analyzing shading and shadow,** ***anbang taechong*** **on December 23rd, the winter solstice**

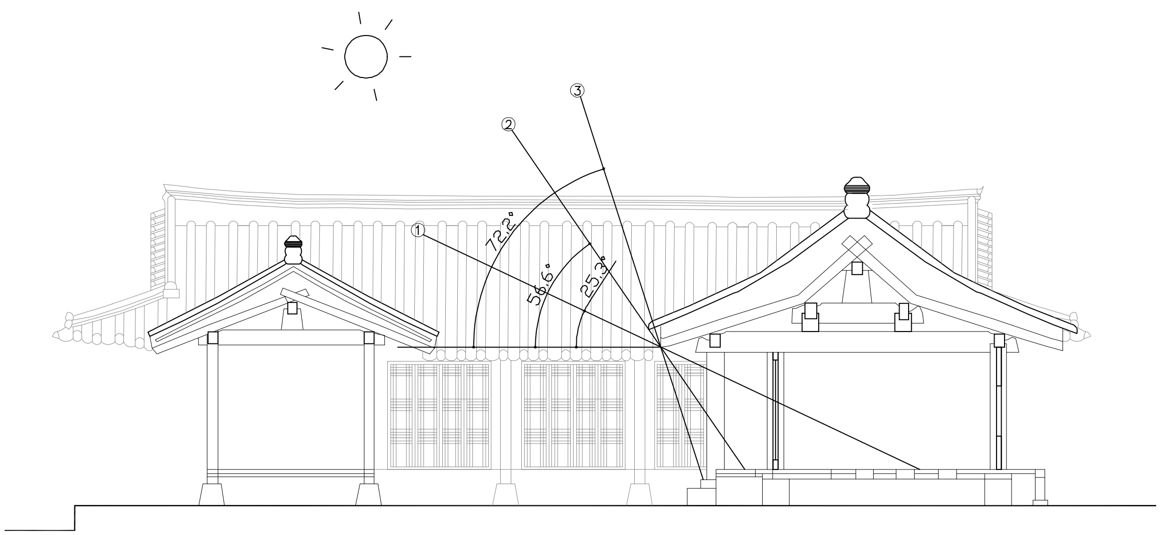


Figure 6-17 ***Chusagotaek Anbang*** **sunlight angle section, 1. Winter solstice, 23rd December, 10 o'clock 2.August 23rd Sunlight Angle, 10 o'clock 3.Summer Solstice, 23rd July, Noon**

In the Hourly Heat Gains of the Ecotect Thermal Calculation, the more hourly heat gaining rooms, which unnecessarily can get heat a room in the summer, are ordered these following rooms; *C-antaechong* 〉 *Y-anbang* 〉 *Y-sarangtaechong* > *Y-antaechong* 〉 *U-sarangtaechong* 〉 *C-anbang* 〉 *U-sarangbang* 〉 *U-anbang* 〉 *Y-sarangbang* 〉 *C-sarangtaechong* 〉 *U*-women *konnobang* 〉 *C-sarangbang* (Figure 6-21, Figure 6-22 and Figure 6-23).

The analysis defines the rooms of which rooms should be compared in the same function. All of buildings remain the master men and women rooms and *taechong*

(Figure 6-18, Figure 6-19 and Figure 6-20), but the *antaechong* in *Chusagotaek* is excepted to analysis because there is opening without walls or windows in the *antaechong* that is same as outside temperature. Therefore, the women *konnobang* is added for analysis (Figure 6-19). The drawings (Figure 6-18, Figure 6-19 and Figure 6-20) provides the analytic rooms; the pink color rooms represents the women rooms such as *anbang* and *antaechong*, women living room, and the pale blue represents the men rooms such as *sarangbang* and *sarangtaechong*.

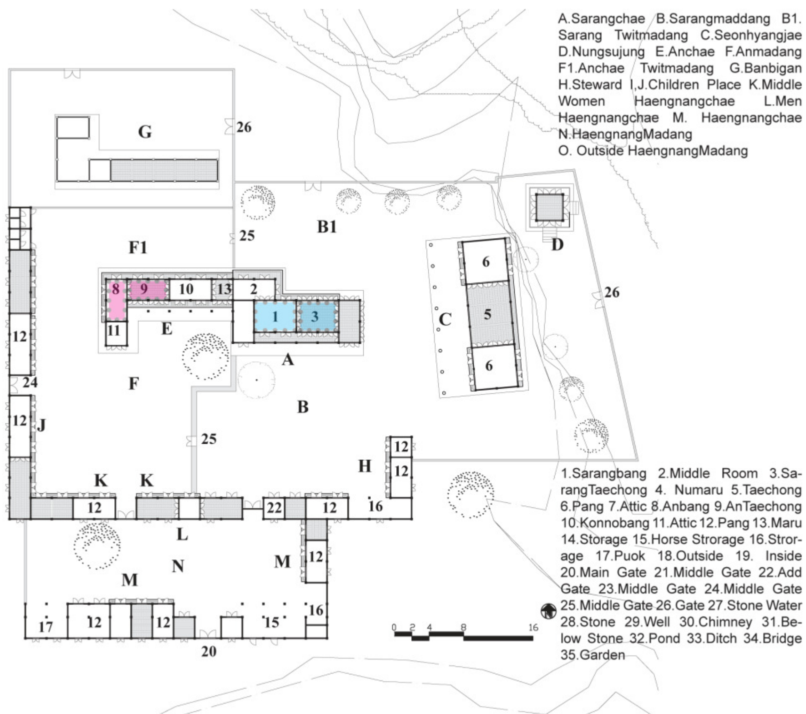


Figure 6-18 *Yeongyeongdang*, Selected Analytic Rooms

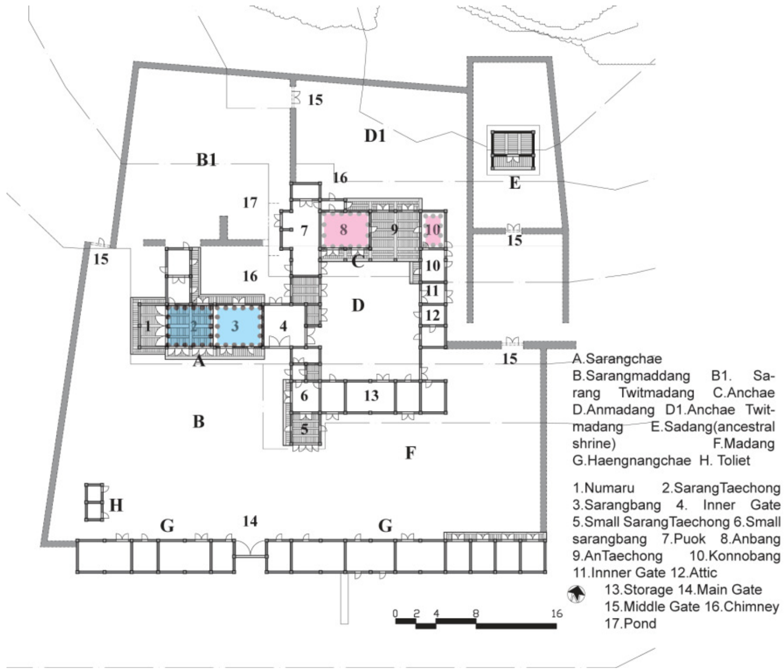


Figure 6-19 ***Unjoru*****, Selected Analytic Rooms**

Figure 6-20 ***Chusagotaek*****, Selected Analytic Rooms**

In the summer, based on the hottest date, July 23rd , and the last summer date, August 23rd , the most solar heat gain room is the *Chusagotaek antaechong*, the women living room. The room has numerous heat gains that can increase the Percentage Dissatisfied, because there are many big windows about 67% of the floor area without the total south window (Table 6-2). Otherwise, many windows in *antaechong* sustain to increase the ventilation heat loose. If the rooms avoid the strong sunlight, the heat gain does not affect the comfort zone. On June 21st and July 23rd, between 3 o'clock and 5o'clock afternoon the heat gain is very higher than any other times, because there are three bigger windows on the west of *antaechong* (Figure 6-21 and Figure 6-22). The west windows in *antaechong* makes to heat the room, but also it increase daylight to the *anbang* and *antaechong*, which is located in the corner of *anchae*. The women's *konnobang* and *anbang*, in which are women's quarter, are the next heat gain rooms, and even though the anchae is shaped exclusive form, 'ㅁ", one of Korean alphabet (Figure 6-20). The solar heat gain spreads out properly to each room in *anchae*. The outcome of the exclusive form, which could be interrupting the sunlight and closing the outside view, could be selected by the different levels of rooms in the *anchae*. The *antaechong*, *anbang* and women *konnobang* raise up more than kitchen and servant's area about one meter higher, which could also explain hierarchy distinction between master and servant.

Most of the *Yeongyeongdang* rooms reports the next highest heat gain rooms after the *Chusagotaek antaechong*, the windows size mainly contributes the heat gains. The windows percentage of the floor area in *Yeongyeongdang anbang* reports 52 %, it in *sarangtaechong* is 82%, and it in *antaechong* is 123%. Otherwise, the windows percentages of the floor area in *Unjoru* are the following percentage: *anbang* is 23%, women *konnobang* is 21%, *sarangbang* is 24.8%, and *sarangtaechong* is 33.3%. Additionally, *Chusagotaek anbang* has more window area about 104 % windows area of the total floor are, but it has only 19% south windows area, and then *anbang* states 6th ranked heat gain room after *Unjoru sarangtaechong*. The windows percentage in *Chusagotaek sarangbang* and *sarangtaechong* reports each 29% and 34%. The result of summer heat gain provides how windows size and area affects the amount of the solar heat gain.

Zone	Yeongyeongdang				Unjoru				Chusagotaek			
	Y-Sarangbang	Y-Sarangtaechong	Y-Anbang	Y-Antaechong	U-Sarangbang	U-Sarangtaechong	U-Anbang	U-Women Konnobang	C-Sarangbang	C-Sarangtaechong	C-Anbang	C-Antaechong
	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)
Total Floor Area(㎡):	18.13	18.13	18.13	12.25	11.52	20.49	20.41	19.38	9.31	14.77	12.60	11.39
Total Surface Area(㎡):	81.43	81.43	64.34	61.14	80.87	80.63	78.49	46.08	66.03	58.51	54.06	98.60
	449%	449%	525%	531%	395%	395%	405%	495%	447%	464%	475%	390%
Total Exposed Area(㎡):	21.63	27.414	25.08	27.291	41.58	36.24	51.37	31.35	39.93	34.83	36.33	67.68
	119%	151%	205%	237%	203%	178%	228%	337%	270%	276%	319%	267%
Total South Window(㎡):	6.09	7.79	0.00	7.08	2.93	6.80	4.32	0.00	2.88	0.00	2.16	0.00
	34%	43%	0%	62%	14.3%	33.3%	23%	0%	20%	0%	19%	0%
Total Window Area(㎡):	8.09	14.87	6.32	14.16	5.09	8.96	5.40	1.98	4.32	4.32	11.88	17.04
	45%	82%	52%	123%	24.8%	43.9%	29%	21%	29%	34%	104%	67%

Table 6-2 Area and Environmental Factors Calculation

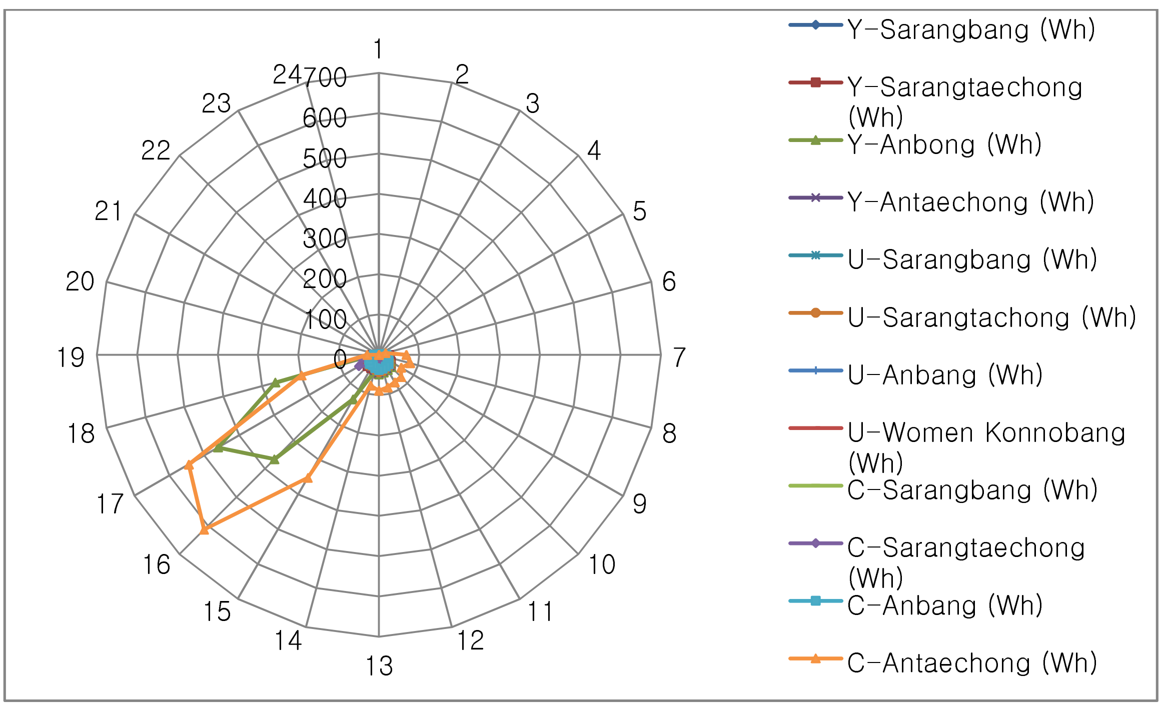


Figure 6-21 Solar Hourly Gains, June 21, the summer solstice

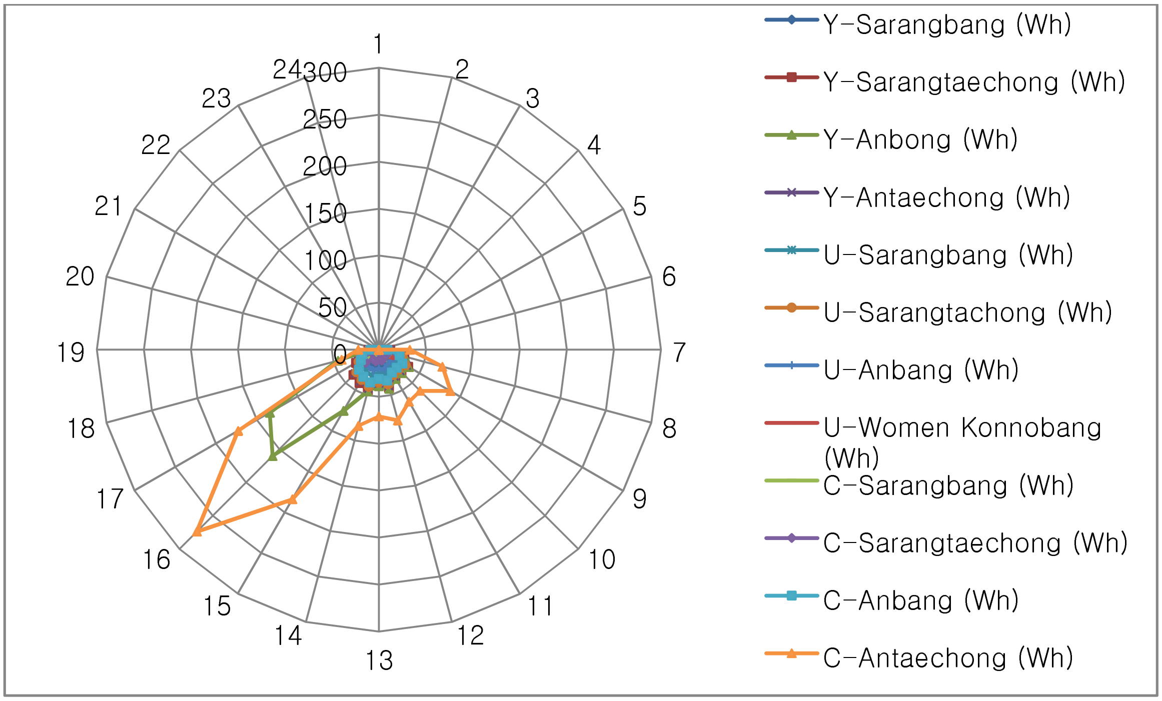


Figure 6-22 Solar Hourly Gains, July 23rd, the hottest date

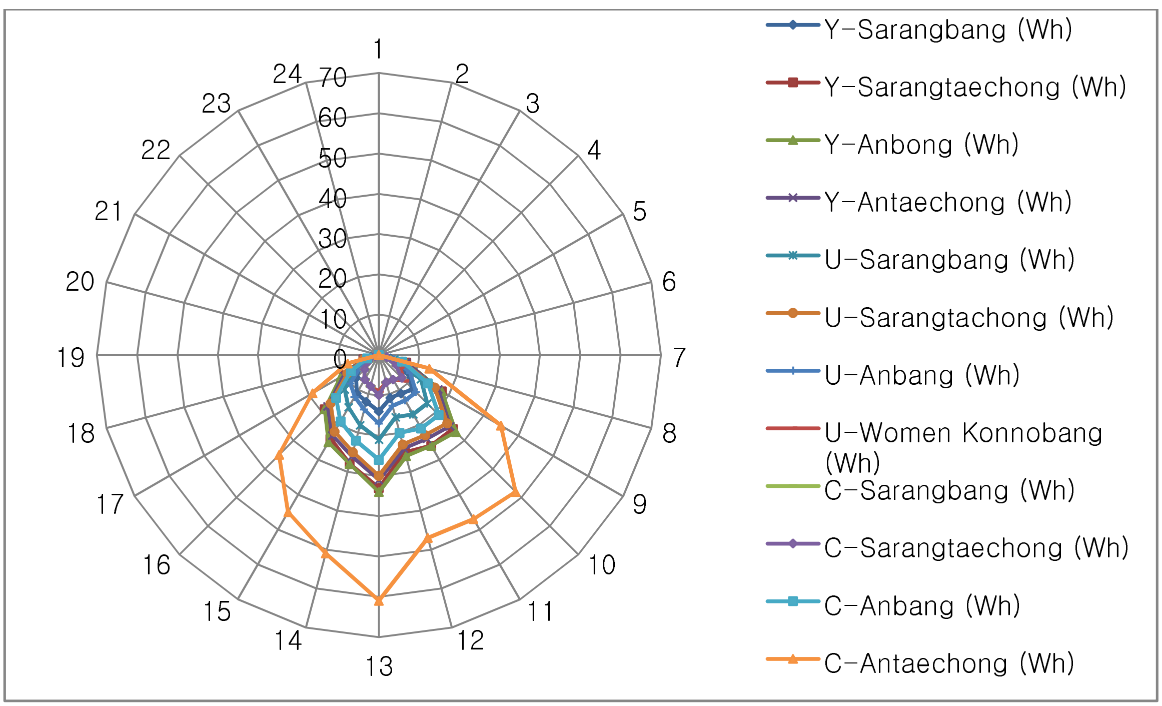


Figure 6-23 Solar Hourly Gains, August 23rd, the end of summer

In the August 23rd, the end of summer, the Solar Hourly Gains affect equally from 9 AM to 4 PM, because the sunlight altitude is getting lower and the sunlight closes to the rooms more and more after the day. In the August 23rd, *Chusagotaek antaechong*, has still higher solar heat gains. *Chusagotaek* also almost perfectly enclose the strong sunlight. There are several sustainability strategies, which can be remarkable mention to outcome the hierarchy impact of the design limitation. First, the axis to 12 degree west of south with the reasonable west windows provides enough light and ventilation heat loose. Second, the different ground level assists the open view, and approximately receives the sunlight.

6.4.1.2. Penetrating the Sunlight into each Rooms evenly in the Winter

In the winter, the solar energy flows associated with radiation, conduction, and convention to the roofs, windows, and walls. Through windows, Sunlight directly penetrates to the room and increase temperature. The roof and wall absorb the solar energy and provide heating effects in night.

In the winter, solar analysis provides how long sunlight penetrates inside of *anchae* in *Unjoru* and *Chusagotaek*, which is 'ㅁ' shaped, one of Korean alphabet, and enclosed by other rooms, which seems some part not to have enough sunlight. In the Hourly Heat Gains of the Ecotect Thermal Calculation, the more hourly heat gaining rooms, which necessarily can get heat a room in the winter, are ordered these following rooms; *Y-sarangtaechong* 〉 *C-antaechong* 〉 *Y-antaechong* 〉 *Y-sarangbang* 〉 *Y-anbang* 〉 *C*-anbang 〉 *U-sarangtaechong* 〉 *C-sarangbang* 〉 *U-sarangbang* 〉 *U-anbang* 〉 *C-sarangtaechong* 〉 *U*-women *konnobang*.

Yeongyeongdang anchae rooms (women rooms) have wide-open view more than *Unjoru* and *Chusagotaek* rooms. Otherwise, *Unjoru* and *Chusagotaek anchae* encompass by the wall, and each room is composed toward inside *madang*. Through the sunlight analysis in *Yeongyeongdang*, in case of the south face, the sunlight penetrates to the rooms more than half of floor in the winter, which is so much bigger than nothing is penetration during the summer because the roof eave protects the strong sunlight. *Anbang*, which is place on the west of the building, has the third heat gain room among the analyzing rooms mostly afternoon during the winter. Through the result of heat gain , the women master room (*anbang*) provides solar energy in the night.

In *Unjoru*, *Sarangtaechong* and saranbang have the solar heat gain continually during the light. Anbang also has the slar heat gain allmost amount of *sarangbang*, even though the *anbang* is the corner of left behide inside *anchae* (women quarter). While, the amount of heat gain increases between 10 to 11 o'clock in ther morning, and during that time, anbang have the solar heat gain directly from the sun (Figure 6-24 and Figure 6-25). After 11:30 AM, the sun passes over the kicthen roof , in middle of the buidling, and then the anbang has the indirect solar heat gain. Women's *konnobang* also have the solar gain evnenly, it is in the corner of building, anchae. Women *konnobang's* windows open to maily west and east, and the west windows are twice bigger than the east windows, therfore afternon *konnobang* has more solar heat gain, which provides to remain the heat in the night.

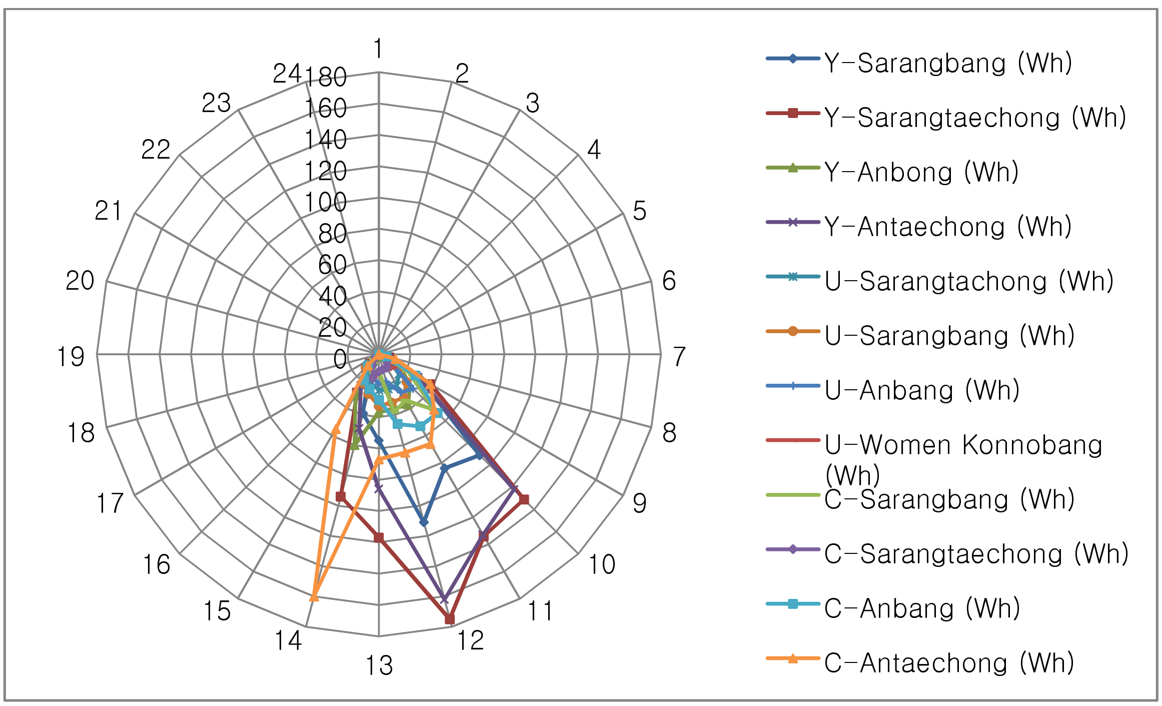


Figure 6-24 Solar Hourly Gains, January 13th, the coldest date

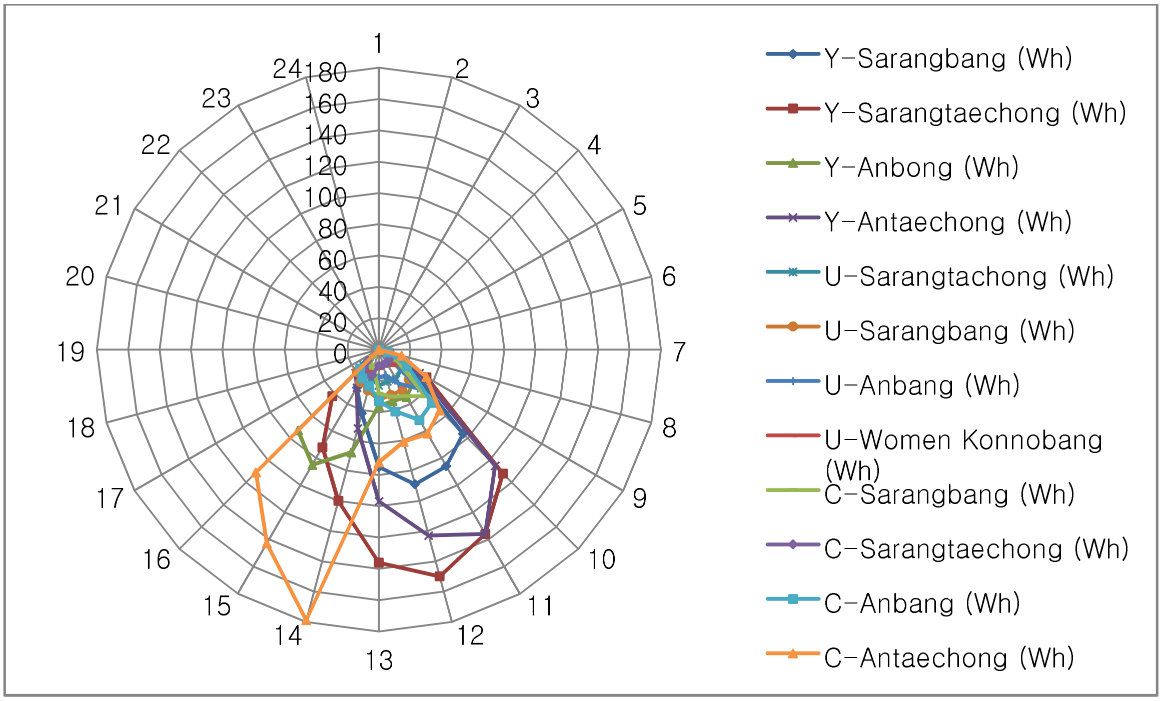


Figure 6-25 Solar Hourly Gains, December 23rd, the winter solstice

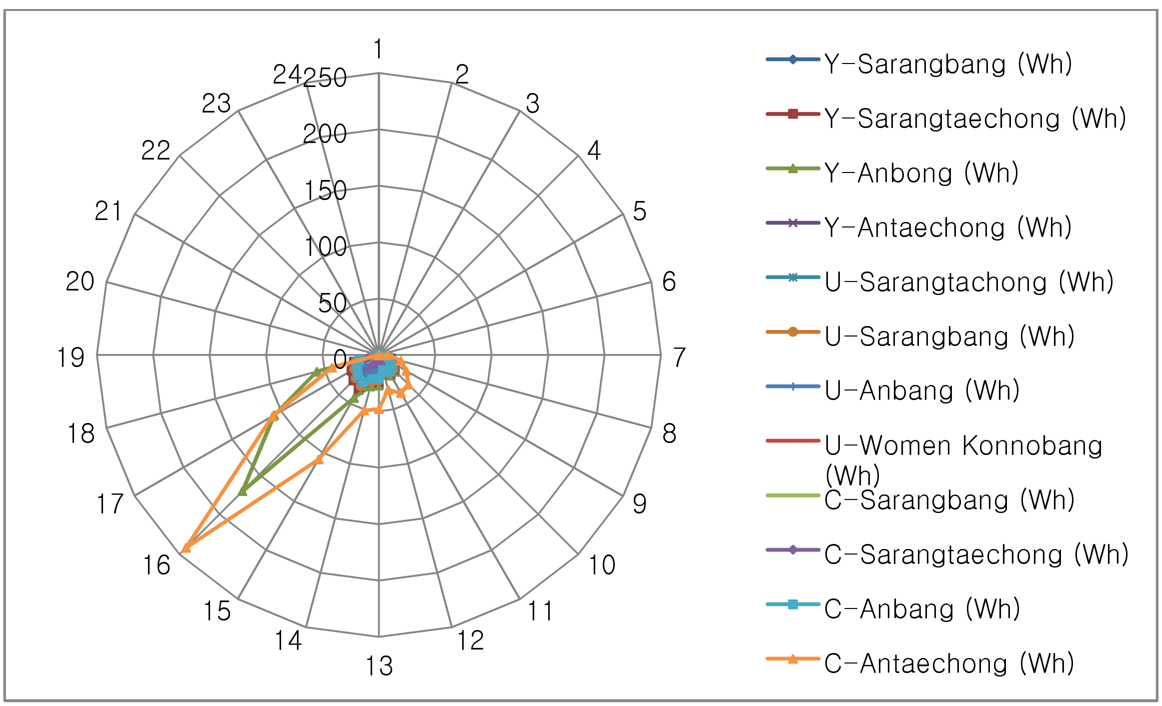


Figure 6-26 Solar Hourly Gains, May 6th

In *Chusagotaek*, from January 13th to December 23rd, the solar heat gains shows

(Figure 6-24 and Figure 6-25) that *anbang* and *antaechong* are higher position, even though the rooms are in corner of anchae. In the winter, the solar altitude is lower than any other seasons. Therefore, the sunlight can penetrate to rooms more than any other seasons, if there are enough windows, but it also can affect ventilation loose. The *antaechong* has the peak of the sun heat gain at 2 o'clock, which is the sunlight to penetrate to the west window of *antaechong*. Women's *konnobang* is located on the southern part of the anchae. the outside windows of *konnobang* has two window places installed, of which one is the regular oiled-paper windows, and the other outside windows are made by only wood without the oiled-paper. The outside windows made by wood are faced by the outside madang. Therefore, the outside windows' function emphasizes the privacy as well the wind protection in the winter. *Anbang* and *sarangbang* have the heat gains more morning time, because the sunlight is blocked by the west part of buildings, *antaechong* and *sarangtaechong*.

In this result of the analysis, *Yeongyeodang*, *Unjoru* and *Chusagotaek*, all of rooms equally receive the solar heat gain, even though the *anchae* (women quarters) empasize the social status based on the Neo Confuciam. The social status sperate women quarter from men quarter, and emphasizes to protect the view from outside for privacy.

Zone	Solar Hourly Heat Gains											
	Yeongyeongdang				Unjoru				Chusagotaek			
	Y-Sarangbang (m^2)	Y-Sarangtaech (m^2)	Y-Anbong (m^2)	Y-Antaechong (m^2)	U-Sarangbang (m^2)	U-Sarangtacho (m^2)	U-Anbang (m^2)	U-Women Konnobang (m^2)	C-Sarangbang (m^2)	C-Sarangtaech (m^2)	C-Anbang (m^2)	C-Antaechong (m^2)
Total Surface Area:	81.434	81.434	64.34	61.14	80.87	80.63	78.49	46.08	66.03	58.51	54.06	98.60
	449%	449%	525%	531%	394.7%	395.1%	405%	495%	447%	464%	475%	390%
Total Exposed Area:	21.63	27.414	25.08	27.291	41.58	36.24	51.37	31.35	39.93	34.83	36.33	67.68
	119%	151%	205%	237%	202.9%	177.6%	228%	337%	270%	276%	319%	267%
Total South Window:	6.092	7.788	0	7.08	2.93	6.80	4.32	0.00	2.88	0.00	2.16	0.00
	34%	43%	0%	62%	14.3%	33.3%	23%	0%	20%	0%	19%	0%
Total Window Area:	8.092	14.868	6.32	14.16	5.09	8.96	5.40	1.98	4.32	4.32	11.88	17.04
	45%	82%	52%	123%	24.8%	43.9%	29%	21%	29%	34%	104%	67%
Total Conductance (AU)(W/m^2K):	47	64	61	62	66.00	60.00	82.00	52.00	62	55.00	66	126
Total Admittance (AY)(W/m^2K):	229	233	187	172	231.00	242.00	225.00	128.00	186	163.00	155	301
Response Factor:	4.4	3.39	2.91	2.65	3.62	3.69	2.61	2.39	2.84	2.82	2.25	2.29

HOUR	Y-Sarangbang (Wh)	Y-Sarangtaech (Wh)	Y-Anbong (Wh)	Y-Antaechong (Wh)	U-Sarangbang (Wh)	U-Sarangtacho (Wh)	U-Anbang (Wh)	U-Women Konnobang (Wh)	C-Sarangbang (Wh)	C-Sarangtaech (Wh)	C-Anbang (Wh)	C-Antaechong (Wh)
13th January												
7	6	7	6	7	4	5	3	2	2	3	5	11
8	30	38	16	29	10	14	8	6	21	8	27	38
9	91	131	28	122	18	25	31	12	50	8	53	50
10	84	134	37	133	23	32	28	11	34	10	53	66
11	111	175	36	162	23	32	18	10	38	10	46	65
12	55	117	37	86	23	33	19	10	11	11	29	67
13	39	94	60	49	19	26	15	15	12	16	23	160
14	12	28	30	23	15	21	12	7	7	8	19	55
15	4	8	2	12	8	12	7	2	4	3	10	10
TOTAL	**432**	**732**	**252**	**623**	**143**	**200**	**141**	**75**	**179**	**77**	**265**	**522**
6th May												
6	2	5	5	4	3	4	2	1	1	1	4	8
7	5	11	11	10	7	10	5	3	3	3	9	20
8	7	15	16	15	10	14	8	4	4	4	12	28
9	9	20	21	19	13	18	10	6	6	6	16	37
10	9	21	21	20	13	19	11	6	6	6	17	39
11	8	17	18	16	11	15	9	5	5	5	14	32
12	11	26	27	25	17	23	13	7	8	8	21	48
13	12	28	29	26	18	25	14	8	8	8	22	51
14	16	36	44	34	23	32	18	10	10	10	28	107
15	14	32	171	31	21	29	16	9	9	27	26	242
16	12	28	107	26	18	25	14	8	8	21	22	109
17	10	23	57	22	15	21	12	7	8	10	18	43
TOTAL	**115**	**262**	**527**	**248**	**169**	**235**	**132**	**74**	**76**	**109**	**209**	**764**
21st June												
5	4	9	10	9	6	8	5	3	3	3	7	17
6	10	26	24	25	15	21	12	7	7	7	19	68
7	12	28	29	27	18	25	14	17	8	8	22	80
8	15	34	35	33	22	31	18	26	10	10	28	64
9	19	42	43	40	27	38	22	15	12	12	34	78
10	19	42	44	40	27	38	22	12	12	12	34	79
11	20	45	46	43	29	41	23	13	13	13	36	84
12	21	48	49	46	31	43	25	14	14	14	38	89
13	19	43	44	41	28	39	22	12	12	12	34	79
14	17	38	128	36	24	34	19	11	11	11	30	353
15	18	40	367	38	26	37	21	11	12	36	32	614
16	15	35	461	33	22	31	18	10	10	57	28	545
17	10	23	266	22	15	21	12	6	13	43	18	199
18	7	18	17	15	10	14	8	6	7	10	12	29
TOTAL	**206**	**471**	**1563**	**448**	**300**	**421**	**241**	**163**	**144**	**248**	**372**	**2378**
23rd July												
6	5	12	11	12	7	10	6	3	3	3	9	33
7	12	28	29	27	18	26	15	10	8	8	23	70
8	16	36	37	34	23	33	19	18	10	10	29	88
9	15	34	35	32	22	30	17	10	10	10	27	62
10	15	35	36	33	22	31	18	10	10	10	28	64
11	19	42	43	40	27	38	22	12	12	12	34	78
12	17	38	39	36	25	35	20	11	11	11	31	71
13	20	45	46	43	29	41	23	13	13	13	36	84
14	18	41	75	39	27	37	21	12	12	12	33	184
15	17	38	160	36	24	34	19	11	11	20	30	274
16	12	28	134	26	18	25	14	8	8	20	22	173
17	10	22	45	22	14	20	11	6	7	9	18	41
18	5	11	11	11	8	11	6	3	3	2	9	22
TOTAL	**181**	**410**	**701**	**391**	**264**	**371**	**211**	**127**	**118**	**140**	**329**	**1244**
23rd August												
7	3	7	7	7	4	6	4	2	2	2	6	13
8	8	18	18	17	12	16	9	6	5	5	14	35
9	12	26	27	25	17	24	13	9	8	8	21	48
10	11	26	26	24	17	23	13	7	7	7	21	47
11	11	25	26	24	16	23	13	7	7	7	20	47
12	14	33	34	31	21	30	17	9	10	10	26	61
13	12	28	28	26	18	25	14	8	8	8	22	51
14	11	24	25	23	15	22	12	7	7	7	19	45
15	8	19	19	18	12	17	10	5	5	5	15	35
16	5	10	11	10	7	9	5	3	3	3	8	19
17	2	4	4	4	3	4	2	1	1	1	3	8
TOTAL	**97**	**220**	**225**	**209**	**142**	**199**	**112**	**64**	**63**	**63**	**175**	**409**
23rd December												
7	3	6	8	7	5	7	4	2	2	2	6	15
8	23	35	17	30	11	15	9	5	13	6	21	35
9	76	112	31	105	19	27	35	14	42	9	48	55
10	86	136	35	136	22	30	25	11	34	10	52	62
11	89	150	34	123	21	30	17	9	31	10	41	61
12	75	136	36	97	23	32	18	12	28	10	33	72
13	42	100	68	52	19	27	15	12	12	17	24	179
14	28	72	85	28	17	24	14	16	11	19	21	143
15	15	42	73	21	14	20	11	12	6	10	17	111
TOTAL	**572**	**1094**	**699**	**889**	**348**	**488**	**303**	**181**	**179**	**93**	**263**	**733**
	Y-Sarangbang	Y-Sarangtaech	Y-Anbong	Y-Antaechong	U-Sarangbang	U-Sarangtacho	U-Anbang	U-Women Konnobang	C-Sarangbang	C-Sarangtaech	C-Anbang	C-Antaechong

Table 6-3 Solar Hourly Heat Gain

6.4.2. Cooling Strategies: Wind Flow and Air Flow

Human comfort within residence is depends on the air temperature, mean radiant temperature, humidity, and airflow. In addition, clothing and activity affect the human comfort. The Psychometric chart show that the comfort temperature is between 20℃ and 27℃. Additionally, there is natural ventilation, and then the comfort temperature extends by 32℃ and the relative humidity can extend from 80% to 98%. The natural ventilation means the air speed to be about 1.53 m/s, which can make by home ceiling fan.

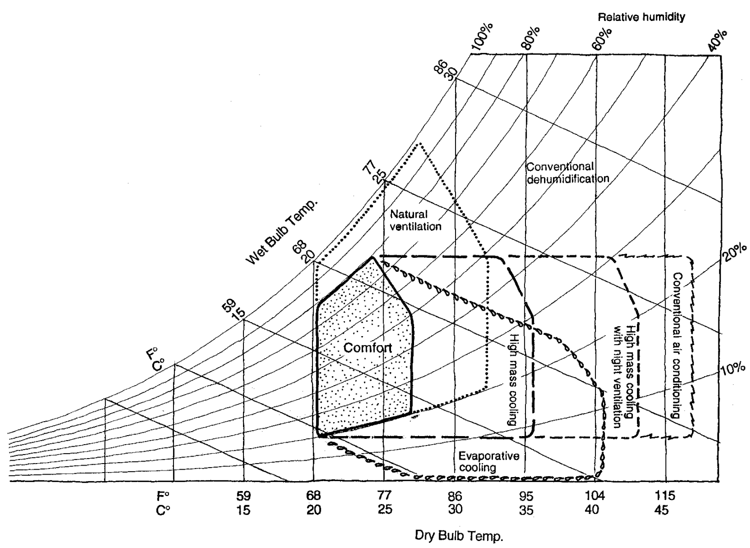
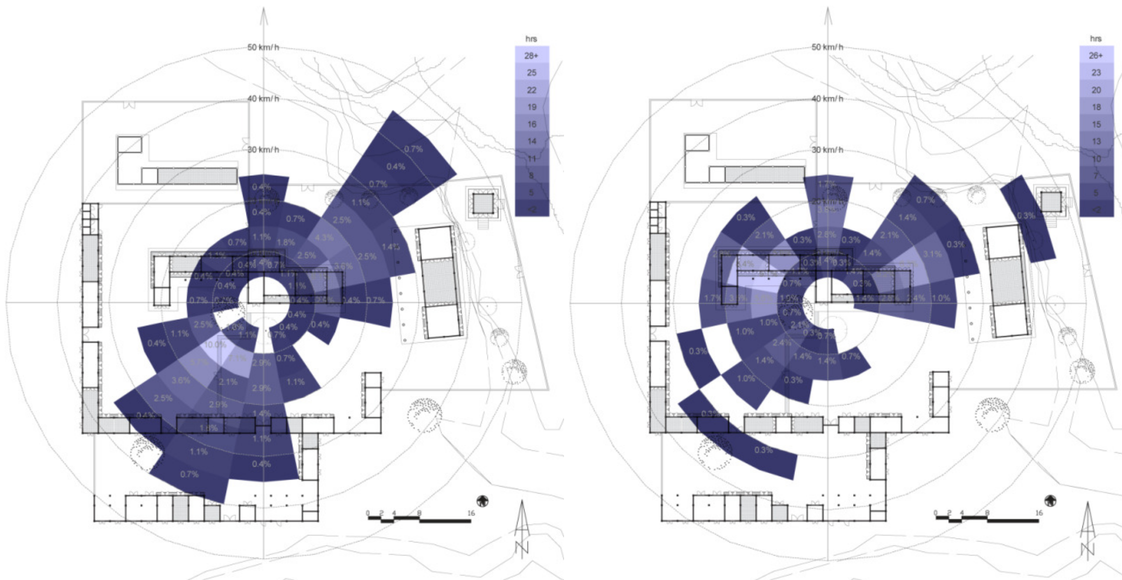


Figure 6-27 Psychometric Chart shows that the Natural Ventilation increases the comfort zone, Passive Cooling design strategies (Stein and Reynoldsd 2000)

Two cooling strategies dominate Yeongyeongdang, Unjoru, and Chusagotaek. First strategy is Natural Ventilation, which is cross ventilations driven by wind and accomplished with windows. It relies on narrow plans with large ventilation openings on either side. Second strategy is High-mass Cooling, which is for warm, dry summers, when the extremes of hot days are tempered by the still cool thermal mass, thicker roof. Cool nights then slowly drain away the heat that such mass accumulates during the day. The roof has the advantage of radiating to the cold night sky.

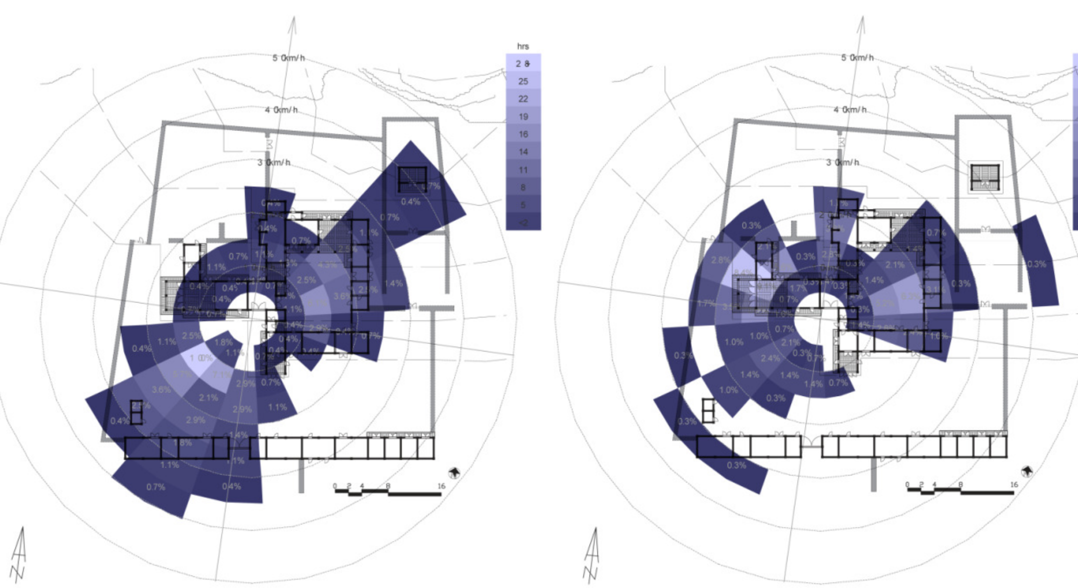
If the 2.4m/s airflow constantly affects *Yeongyeongdang, Unjoru and Chusagotaek*, during summer, there is enough cooling for human comfort. The traditional sliding door of *Yeongyeongdang*, *Unjoru* and Chusagotaek, especially taechong sliding door, can be opened 100% of the window-installed space (D.-K. Kim 2000). During the summer, the open door offers enough air inside. Additionally, for the wind flow from the southwest in the summer, the building layout was so well suited to the each room. Ecotect shows the prevailing winds, which is able to display in the 3D model. Ecotect prevailing winds displays the wind speed, frequency and the direction. In the prevailing winds, the wind flows 35% of the total wind from east of north to the building in the morning (6:00~10:00), and 40% of the total wind from west of south trough the building during the day (10:00~6:00PM) (Figure 6-28, Figure 6-29 and Figure 6-30). Diurnal airflow in the valley cools also down the temperature during the summer. Mountain breezes and valley breezes are due to a combination of differential heating and geometry (Wikipedia Foundation 2000). During day, the sun heats first the tops of the mountain, and the heats make high pressure. The temperature inequity make that the warm air raises off the slopes, and cool air moves up the valleys, which is called the valley breeze. The mountain breeze is the opposite effect that takes place in the afternoon. The mountain wind flows from the peaks gravitationally and convectively.

Due to the southwest wind and the valley breezes, the traditional Korean residence including *Yeongyeongdang*, *Unjoru* and *Chusagotaek* are faced the south, and built on the slope site. Microclimate such as mountain breezes and valley breezes affects each room, and even the different pressure wind impinge on the anchae place enclosed from outside. The white madang in *Unjoru* and *Chusagotaek anchae* is higher temperature, and the rear garden provides greenery. The more heat temperature in madang causes the air to move to higher, and the lower pressure from the garden flows to inside madang through each room.



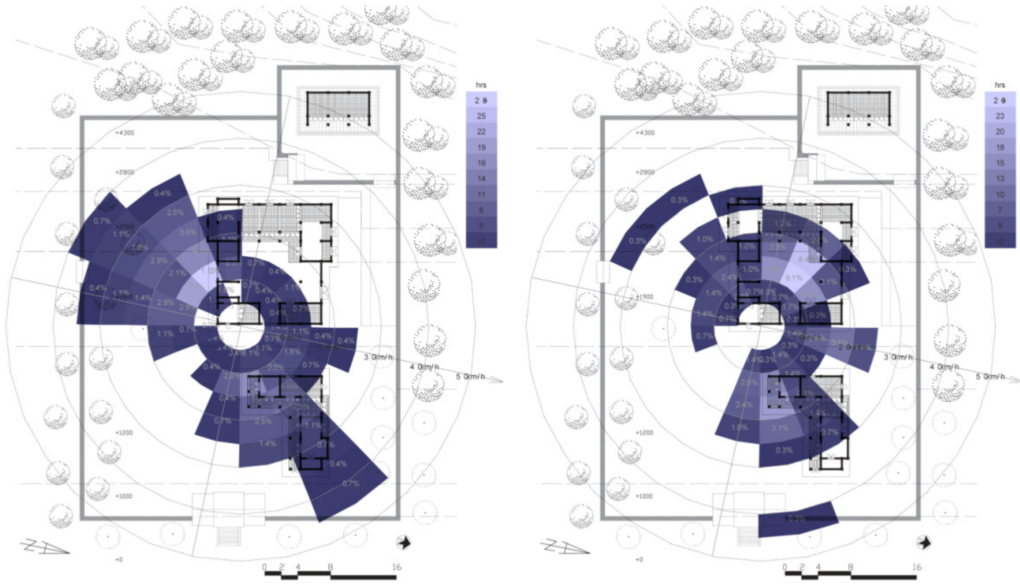
Summer, 1st June ~ 31st August **Winter, 1st December ~ 28th February**

Figure 6-28 *Yeongyeongdang* Prevailing Winds, Wind Frequency (Hrs). Seoul, Korea. Time: 10:00 ~14:00



Summer, 1st June ~ 31st August **Winter, 1st December ~ 28th February**

Figure 6-29 *Unjoru* Prevailing Winds, Wind Frequency (Hrs). Seoul, Korea. August. Time: 10:00 ~14:00



Summer, 1st June ~ 31st August **Winter, 1st December ~ 28th February**

Figure 6-30.*Chusagotaek* Prevailing Winds, Wind Frequency (Hrs). Seoul, Korea. Time: 10:00 ~14:00

In the winter, the north mountain protects against the strong wind during the winter. All of tested buildings are enclosed by mountain. The Ecotect prevailing winds provide that the winter winds flow from the west or east of north to the building. In addition, the windows on the north pace or the windward windows in the winter are smaller than the south pace.

6.4.3. Thermal Performance

Thermal performance is related to materials, windows and doors sizes, height, length, temperature, orientation, and many other factors. In Ecotect, the Chartered Institute of Building Services Engineers (CIBSE) Admittance Method determines internal temperatures and heat loads. The internal temperature of any building will always tend towards the local mean outdoor temperature. Any fluctuations in outside temperature or solar load will cause the internal air temperature to fluctuate in a similar way, though delayed and dampened somewhat by thermal capacitance and resistance within the building fabric. When the total of all heat losses become equal to the total of all gains, then internal temperatures stabilize (Ecotect 2007).

The thermal performance is related with the effects of conductive heat flow through building fabric, infiltration and ventilation through openings, direct solar gains through transparent materials, indirect solar gains through opaque elements, internal heat gains from equipment, lights and people and the effects of inter-zonal heat flow (Ecotect 2007). Thermal performance of Ecotect evaluates the thermal comfort of human beings that is governed by many physiological mechanisms of the body and varies from person to person. In any particular thermal environment, it is difficult to get more than 50 per cent of the people affected to agree that the conditions are comfortable (McMullan and Seeley 2007). The principal factors affecting thermal comfort can be conveniently considered in the following sections: Personal variables included activity, age, clothing, and gender; and Physical Variables included air temperature, air movement, surface temperatures, and humidity.

The analysis defines the rooms of which rooms should be compared in the same function. All of buildings remain the men and women rooms and *taechong*, but the *antaechong* in *Chusagotaek* is excepted to analysis because there is opening without wall in the *antaechong* that is same as outside temperature. Therefore, the women *konnobang* is added for analysis. The drawings (Figure 6-31, Figure 6-32 and Figure 6-32) provides the analytic rooms; the pink color rooms represents the women rooms such as *anbang* and *antaechong*, women living room, and the pale blue represents the men rooms such as *sarangbang* and *sarangtaechong*.

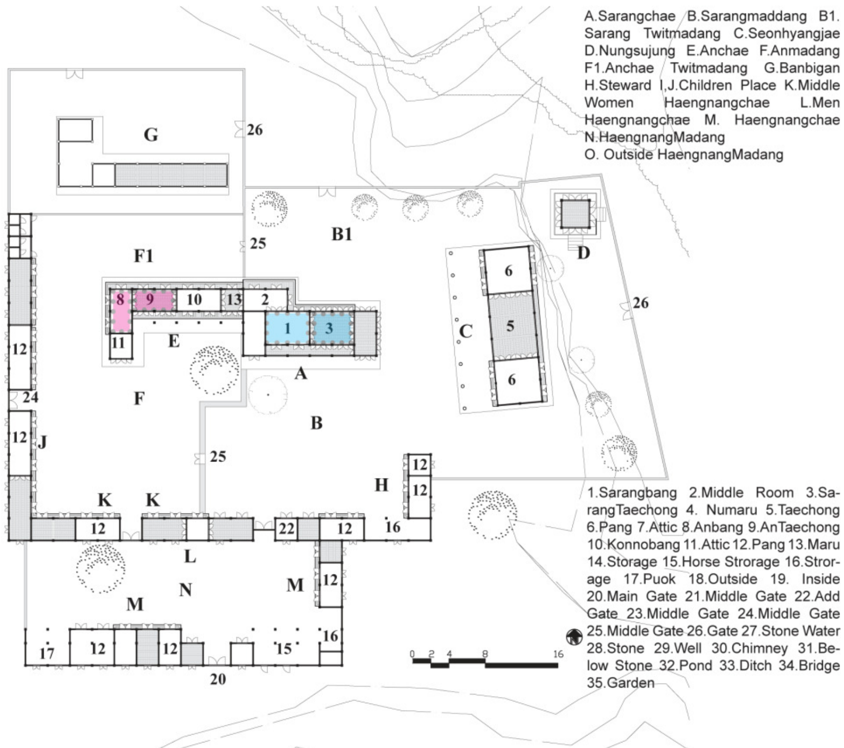


Figure 6-31 Yeongyeongdang, Selected Analytic Rooms

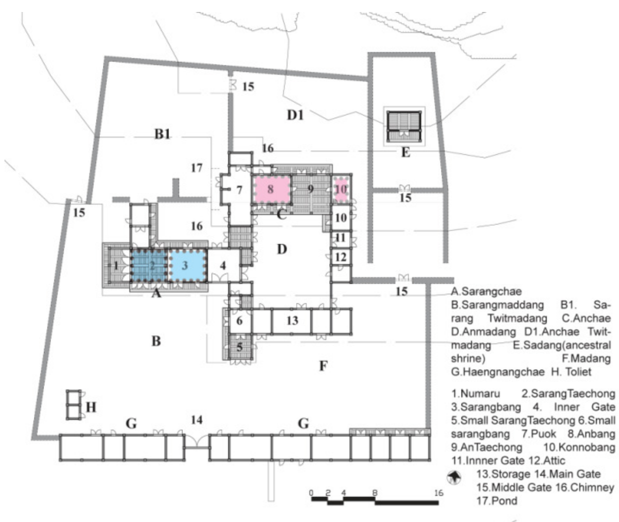


Figure 6-32 Unjoru, Selected Analytic Rooms

Figure 6-33 Chusagotaek, Selected Analytic Rooms

Zone	*Yeongyeongdang*				*Unjoru*				*Chusagotaek*			
	Y-Sarangbang	*Y-Sarangtaechong*	*Y-Anbang*	*Y-Antaechong*	*U-Sarangbang*	*U-Sarangtaechong*	*U-Anbang*	U-Women Konnobang	*C-Sarangbang*	*C-Sarangtaechong*	*C-Anbang*	*C-Antaechong*
	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)	(㎡)
Total Floor Area(㎡):	18.13	18.13	18.13	12.25	11.52	20.49	20.41	19.38	9.31	14.77	12.60	11.39
Total Surface Area(㎡):	81.43	81.43	64.34	61.14	80.87	80.63	78.49	46.08	66.03	58.51	54.06	98.60
	449%	449%	525%	531%	395%	395%	405%	495%	447%	464%	475%	390%
Total Exposed Area(㎡):	21.63	27.414	25.08	27.291	41.58	36.24	51.37	31.35	39.93	34.83	36.33	67.68
	119%	151%	205%	237%	203%	178%	228%	337%	270%	276%	319%	267%
Total South Window(㎡):	6.09	7.79	0.00	7.08	2.93	6.80	4.32	0.00	2.88	0.00	2.16	0.00
	34%	43%	0%	62%	14.3%	33.3%	23%	0%	20%	0%	19%	0%
Total Window Area(㎡):	8.09	14.87	6.32	14.16	5.09	8.96	5.40	1.98	4.32	4.32	11.88	17.04
	45%	82%	52%	123%	24.8%	43.9%	29%	21%	29%	34%	104%	67%
Total Conductance (AU)(W/㎡ K):	47	64	61	62	66	60	82	52	62	55	66	126
Total Admittance (AY)(W/㎡ K):	229	233	187	172	231	242	225	128	186	163	155	301
Response Factor:	4.40	3.39	2.91	2.65	3.62	3.69	2.61	2.39	2.84	2.82	2.25	2.29

Table 6-4 Area and Environmental Factors Calculation

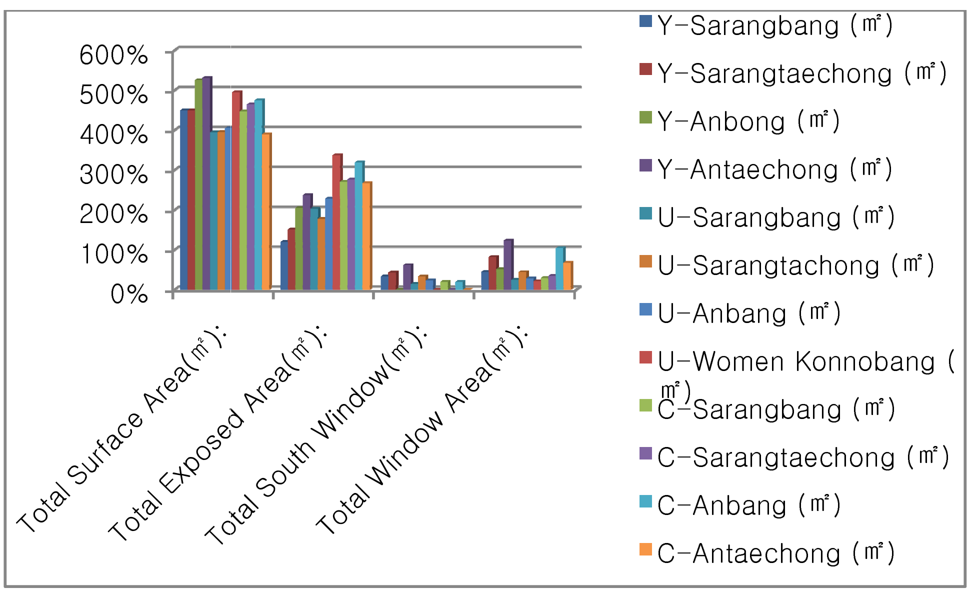


Figure 6-34 Percentage of Total area

6.4.3.1. Summer

In the summer, the hottest date is the July 23rd, the hottest date, at which the sun position is highest. The outside average temperature is the 27.5℃, and the range is from 23.5℃ at 24 o'clock to 31.8℃ at 1o'clock. The priority comfortable rooms, the cooling rooms, in the summer are ordered these following rooms; *C-anbang* ＞ *Y-antaechong* ＞ *Y-anbang* ＞ *Y-sarangtaechong* ＞ *C-antaechong* ＞ *C-sarangtaechong* ＞ *U*-women *konnobang* ＞ *Y-sarangbang* ＞ *U-sarangtaechong* ＞ *C-sarangbang* ＞ *U-anbang* ＞ *U-sarangbang.*

Chusagotaek Anbang reported most comfortable rooms, which are cooler than any other rooms. These rooms have the windows on the each side, south and north that can produce the enough ventilation. The wind flows from the east of south to west of north in the winter. Therefore, the opening of *Chusagotaek anbang* does not interrupt to flow the wind, which makes more comfortable in those rooms. On the other hands, the *Chusagotaek sarangbang* zone and *sarangtaechong* are reported worse than anbang. Total part of *sarangbang* is little lower satisfied, but some part of *sarangbang* can have the wind very well like upper *sarangbang* part near *sarangtaechong*, because there are many openings in the *sarangtaechong*. Once there are more windows on the west part of *sarangtaechong*, the air winds flow very well. The element of reducing windows on the west part of *sarangtaechong* emphasizes the women privacy and it represents the social status, which must distinguish between men and women.

Next priority rooms are *antaechong*, *anbang* and *sarangtaechong* in *Yeongyeongdang,* which is not only satisfied within the thermal comfort in the summer. It also shows that the air velocity is important factor. The *Yeongyeongdang* total window area of the total floor area excesses open over 50%, the *antaechong* case is 123%, and the s*arangtaechong* are 92% windows area of the total floor area. The window is also very flexibly moveable, and can open 100% of windows installation (Table 6-4).

Unjoru rooms are relative worse than *Yeongyeongdang* and *Chusagotaek* rooms. The total windows area percentage of the total floor area reports smaller than other residences' rooms, the percentage starts from 21% of women *konnobang* to 33.3% *sarangtaechong*, which excludes the partitioning windows between *sarangbang* and *sarangtaechong*. Otherwise, the other room in *Yeongyeongdang* and *Unjoru* exceeds 30 % and usually from 60% to 100%. This data shows that the traditional Korean residence have lots of windows area comparing the contemporary residence.

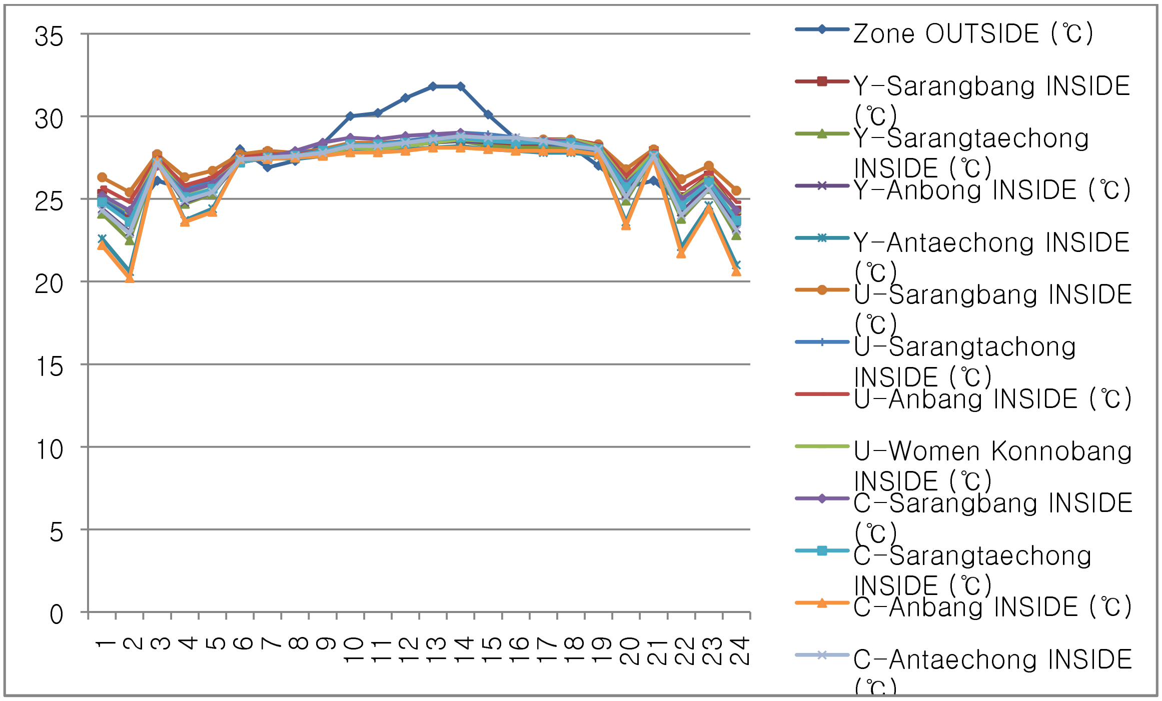


Figure 6-35 Hourly Temperature, July 23rd

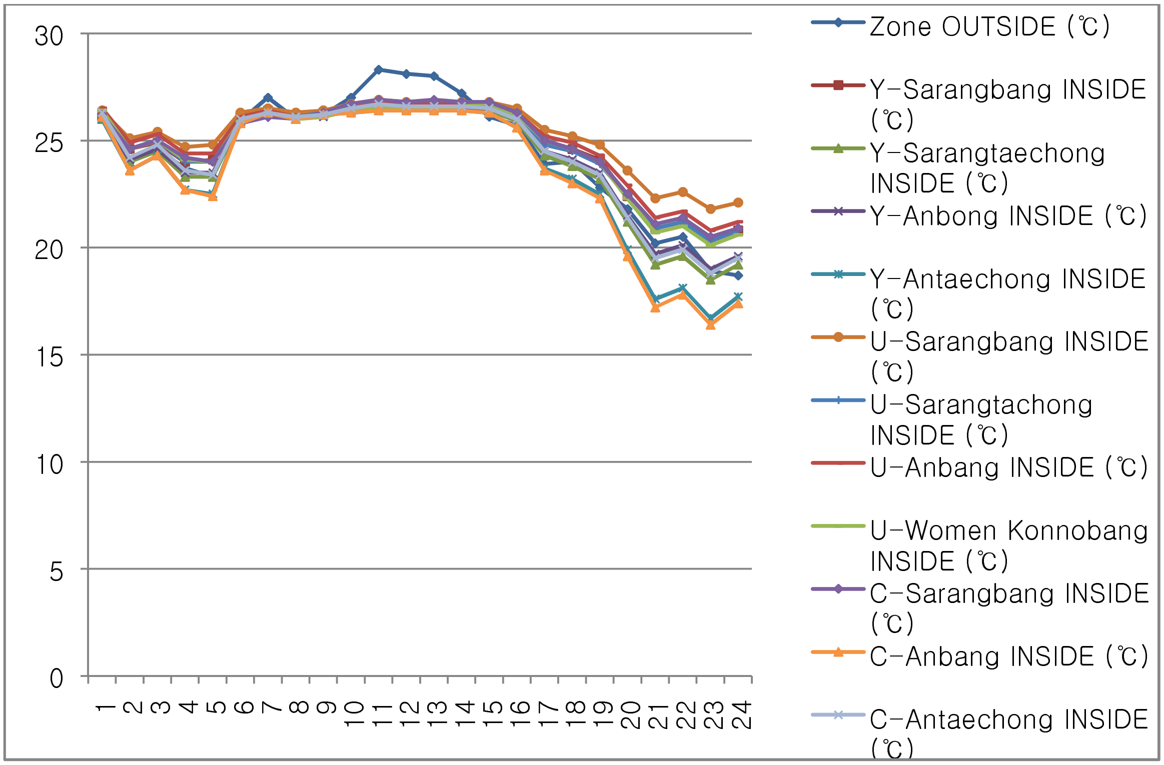


Figure 6-36 Hourly Temperature, August 23rd

6.4.3.2. Winter

In the winter, the better inside thermal comfort in Seoul, Korea definably should be warm temperature inside and keep the lasting warm energy. On January 13, the coldest date, the priority comfortable rooms are ordered these following rooms; *U-anbang* 〉 *U-sarangbang* 〉 *U-sarangtaechong* 〉 *U*-women *konnobang* 〉 *Y-sarangbang* 〉 *C-sarangbang* 〉 *C-sarangtaechong* 〉 *Y-sarangtaechong* 〉 *Y-anbang* 〉 *C-antaechong* 〉 *Y-antaechong* 〉 *C-anbang* (Figure 6-37).

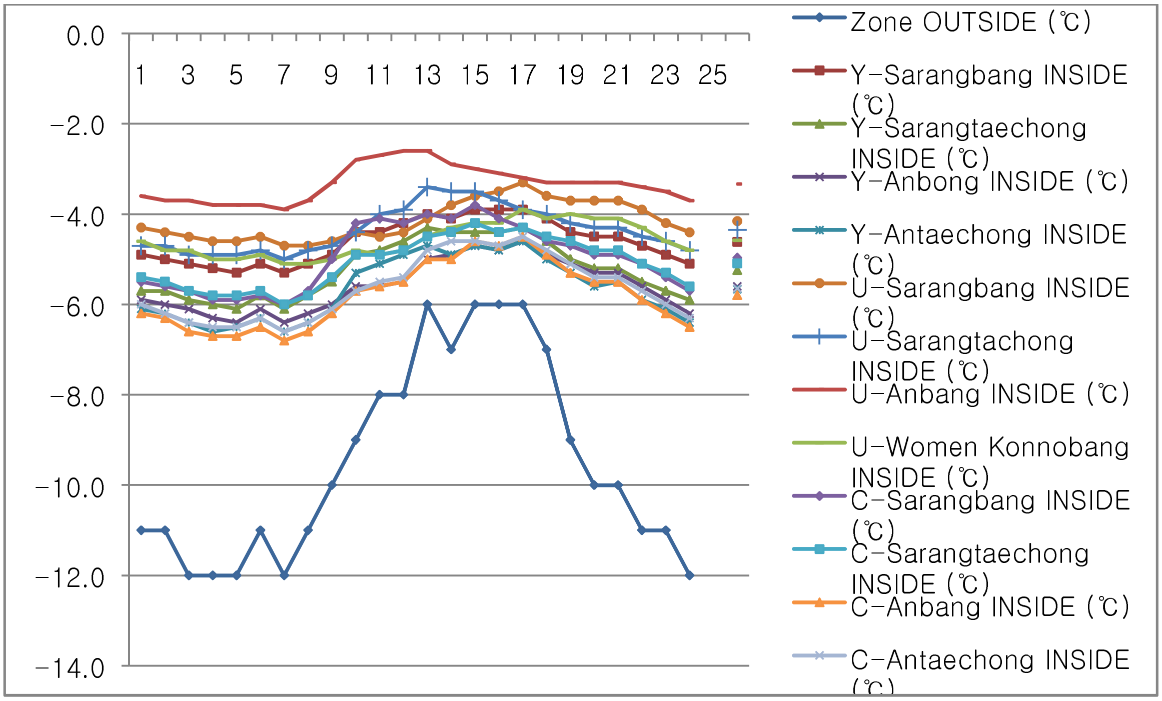


Figure 6-37. Hourly Temperatures, 13th January

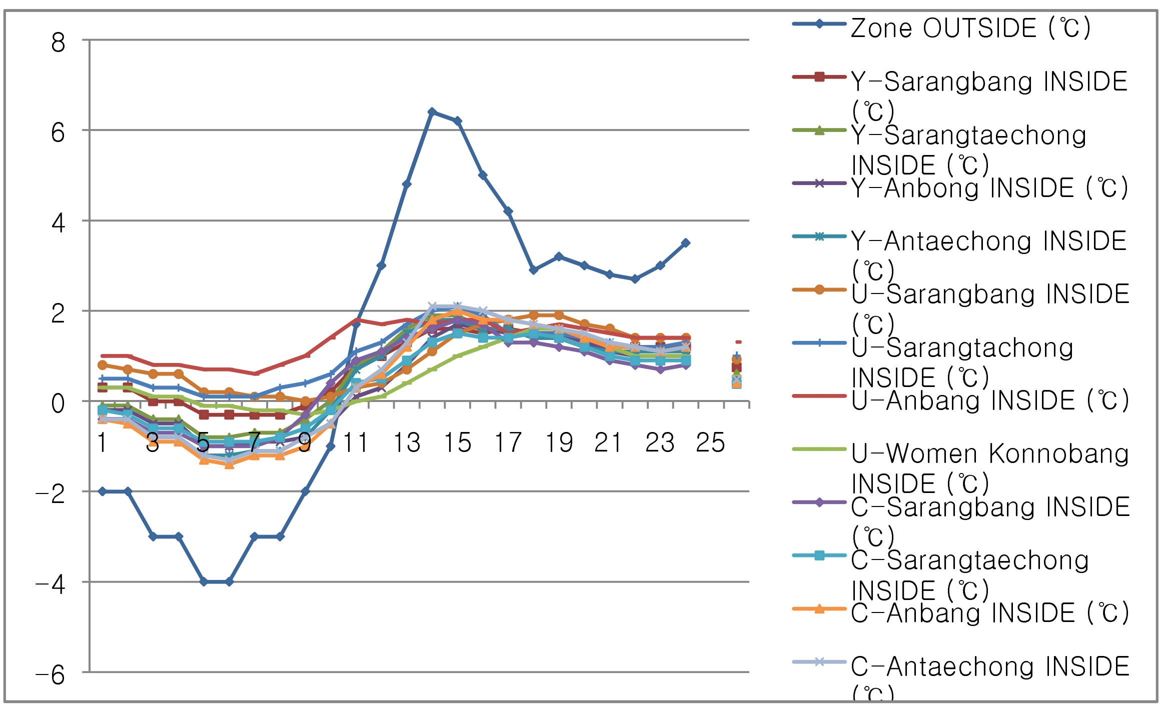


Figure 6-38 Hourly Temperatures, 23rd December

All of tested *Unjoru* rooms are ranked the highest comfortable rooms in the winter. The thermal performance employs each zone condition, fabric, ventilation and infiltration. All of materials of the tested buildings are same materials, and therefore, the fabric is unrelated with these comparable factors in this analysis. *Unjoru* room is superior to *Yeongyeongdang* and *Unjoru* due to the ventilation and zone condition. The *Unjoru* tested rooms, anbang and *sarangbang* are enclosed next by the other rooms. The warmest room reports *Unjoru anbang*, which is master women room. Even though *Unjoru anbang* is placed on the corner of the west of *anchae*, the *anbang* condition is better condition for living. In this analysis, there is no considering installing the ondol system, of which the furnace is placed in the kitchen next by anbang that can have more benefit the heating system. The reason of the better condition in anbang is to be in middle of the other zones such as kitchen, *antaechong* and *maru*. The other zones transmit the heat to *anbang* and preserve the heat in *anbang* (Figure 6-32). The backside hill also provides to keep the *anbang* heat in the winter, and there are no north side windows directly from outside. There are small maru between *anbang* and north hill. Additionally the analysis reports *sarangbang* to be next good condition in winter, because sarangbang also is surrounded by other rooms such *sarangtaechong* and middle gate. Otherwise, *sarangbang* condition is worse than small *sarangbang* and *anbang*, because *sarangbang* has more total exposed area and total surface area (Table 6-4).

The next comfortable room is the *Yeongyeongdang* and *Chusagotaek sarangbang*. These rooms have less windows area percentage of the total floor area and more south window percentage than any other rooms (Table 6-4). The south windows generate more heat gain, and make more satisfied room in the winter. There are a buffer zone like the closet and maru next by *sarangbang* (Figure 6-31 and Figure 6-32). The other rooms including *Chusagotaek anbang* and *Yeongyeongdang anbang* reports lower temperature than any other rooms. The *Yeongyeongdang anbang* window area is only 52%, which is good to save energy, but there is no the total south window (Table 6-4). The less south window size in the *Yeongyeongdang anbang* causes the worse condition, and the bigger north side windows can have the northwest cold winter wind. Additionally, in the *Chusagotaek*, the *Chusagotaek anbang* window area is bigger about 104% on the south and north. Those windows supplies enough wind in the summer, but in the winter it makes down inside temperature.

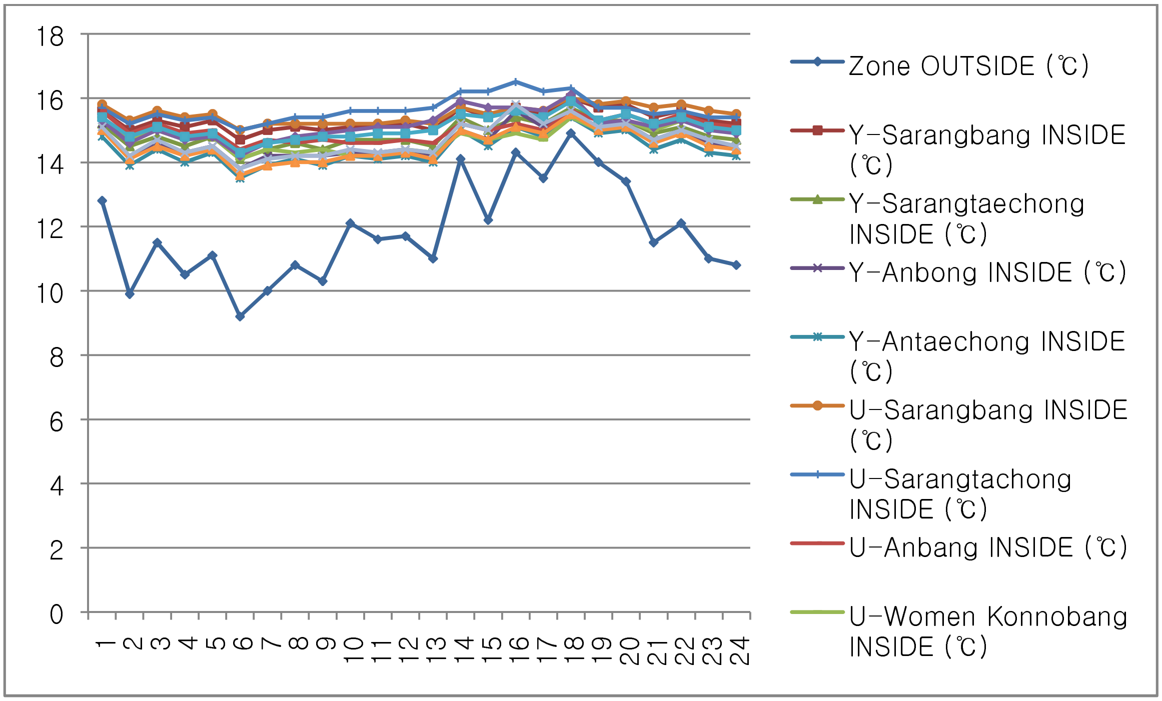


Figure 6-39 Hourly Temperature, May 6th

6.4.3.3. Spring and Autumn

In the May 6th, which starts to change the weather point to the summer, the average temperature is 14.6 ℃, and the range is from the 14℃ to the 16℃ in all of rooms in the tested buildings. The dissatisfied percentage at the 14℃ air temperature point to 33% in Predicted Mean Vote (PMV) software (Figure 6-40) offered by SQUARE One research, and the dissatisfied percentage at16℃ is 19.2%[18] (Table 6-4). In any particular thermal environment, it is difficult to get more than 50 per cent of the people affected to agree that the conditions are comfortable (McMullan, 2007). In the date, the thermal comfort is mostly satisfied, but one could feel little cold for sleeping. If the clothing level is changed, the percentage dissatisfied should be changed.

[18] See also Chapter 2 Methodology Predicted Mean Vote Section

	The lowest temperature	The highest temperature	
Air Temperature (℃)	14	16	May 6th
Radiant Temperature (℃)	23	23	
Relative Humidity (%)	70	70	Source by Korea Meteorological Administration, the average humidity from 1961 to 1990.
Activity Rate (met)	1.5	1.5	Standing
Clothing (clo)	1	1	Light Business Suit
Air Velocity (m/s)	1	1	
Predicted Mean Vote	-1.48	-0.83	-3 too cold, +3hot
Percentage Dissatisfied	33.00%	19.20%	

Table 6-5 May 6th Predicted Mean Vote (PMV)

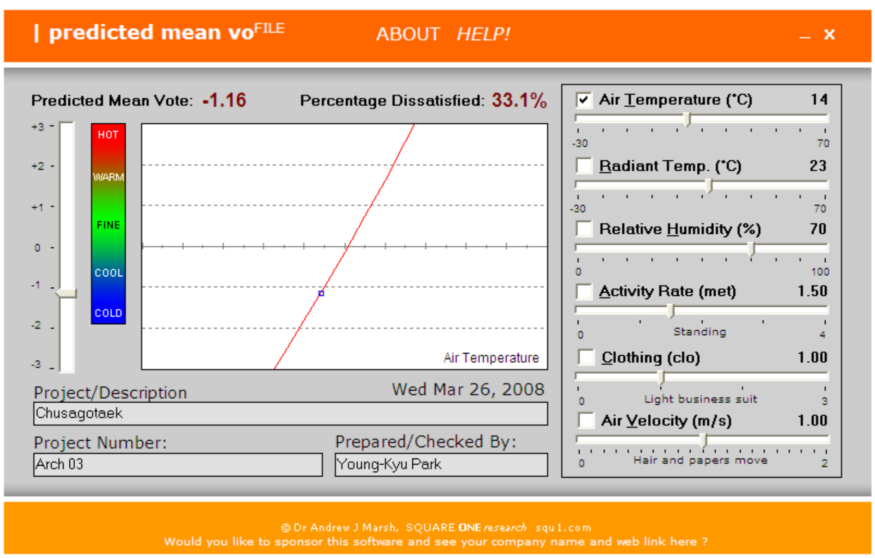


Figure 6-40 Predicted Mean Vote, in May 6th, when the lowest temperature is 14℃, the percentage dissatisfied 33% (the percentage satisfied 67%). Over the percentage satisfied 50% means that the buildings have good condition without the electrical appliance.

6.4.3.4. Modular system: Kan Measurement

Most materials are environmentally friendly and flexible. The *Chusagotaek* employed the *kan* measurement, which is equal to the width of the span between columns. In the traditional Korean residences, the width of the span varies in length from 1.8 meters to 2.8 meters. It is the basic unit of measurement used in traditional Korean residence. The modular measure depends on the local environment. They used not only the fine and straight trees, but they also used bent tree for building. This saved labor fee and preserved trees. Different *kan* measurements are used by various conditions of buildings. The length used in *Yeongyeongdang* is strictly followed on the 2445mm XY-grid. *Unjoru* used 2400mm to 2600mm in horizontal X-axis, and 3150mm to 4300mm in vertical Y-axis. *Chusagotaek* used 2500mm to 2560mm in horizontal X-axis, and 2200mm to 2500mm in vertical Y-axis.

		Yeongyeongdang	*Unjoru*	*Chusagotaek*
Grid	Horizontal X-axis	2445 mm	2400 ~ 2600 mm	2500 ~ 2560 mm
	Vertical Y-axis	2445 mm	3150 ~ 4300 mm	2200 ~ 2500 mm

Table 6-6 *Yeongyeongdang*, *Unjoru*, and *Chusagotaek* Grid

6.5. Summary

In the analytic models-*Yeongyeongdang*, *Unjoru* and *Chusagotaek,* this research through Ecotect software manly divide three big analyses to control sunlight and daylight, shading, wind flow, and the thermal performance. Those factors are interactions together.

In this shading, shadows and solar analysis, the main idea of sunlight protects the strong sunlight in the summer until august 23rd same as *Yeongyeongdang* and *Unjoru*. Otherwise, the *Chusagotaek sarangbang* eaves are designed shorter than any other eaves, but the eaves length affects the solar heat gain imperceptibly. Especially, the short eaves makes lighter inside, and there can be existed small garden, instead of the reflected light by white *madang*.

The prevailing wind also assists to look at *Yeongyeongdang*, *Unjoru*, and *Chusagotaek* plan well. In summer, there are two cooling strategies, which dominate the evaluation models. First, one of strategies is Natural Ventilation, which is cross ventilations driven by wind and accomplished with windows. It relies on narrow plans with large ventilation openings on either side. Second, the other strategy is High-mass Cooling, which is for warm, dry summers, when the extremes of hot days are tempered by the still cool thermal mass, thicker roof. All of tested models oriented toward south, which can adopt the west of south wind during summer. In the winter, other function rooms such as taechong, closet, maru and others enclose the sleeping rooms such as anbang and sarangbang. Therefore, the zonal rooms protect the strong wind from north and reduce the heat energy loads.

In the thermal performance, the priority rooms define different order using by the different seasons, then in the winter season, the order are these following rooms: *U-anbang* ＞ *U-sarangbang* ＞ *U-sarangtaechong* ＞ *U*-women *konnobang* ＞ *Y-sarangbang* ＞ *C-sarangbang* ＞ *C-sarangtaechong* ＞ *Y-sarangtaechong* ＞ *Y-anbang* ＞ *C-antaechong* ＞ *Y-antaechong* ＞ *C-anbang.*

In the summer, the priority rooms, which are cooler rooms, are these following rooms: C-*anbang* ＞ Y-*antaechong* ＞ Y-*anbang* ＞ Y-*sarangtaechong* ＞ C-*antaechong* ＞ C-*sarangtaechong* ＞ U-women *konnobang* ＞ Y-*sarangbang* ＞ U-*sarangtaechong* ＞

C-*sarangbang* 〉 U-*anbang* 〉 U-*sarangbang*. These orders are satisfied with the rooms function in the summer. In the winter the inside temperature in the all of rooms are independent on the outside temperature, even though there is no ondol system, thermal heating system. This research provide that the inside temperature interacted with windows size, orientation, heat gain and inter-zonal load, which is related with the layout.

7. DISCUSSION

This research introduced a methodology to analyze three traditional Korean residences - *Yeongyeongdang*, *Unjoru*, and *Chusagotaek* through Ecotect. This new analytic method provided a holistic view of the traditional residences. These residences were retrieved, tested and simulated using Ecotect, and the methods derived the environmental design responses. The analysis were organized by three big factors- Shadows, Shading and Solar analysis, Wind flow, and Thermal Performance.

7.1. Findings

In the summer, through the Shadows, Shading and Solar analysis of Ecotect, the roof eaves perfectly protected the direct sunlight during summer. The solar altitude, at 56.6°, determined to be the best roof length in the summer between May 6th and August 23rd. The solar altitude, at 56.6°, showed at 10 o'clock AM and about 2 o'clock PM in August 23rd, when is the summer end date and the lowest sun altitude date in the summer (Figure 7-1). Figure 7-1 shows that roof angle 56.6° from the *maru* edge shaded the residences that enclose the whole house creating good environmental response.

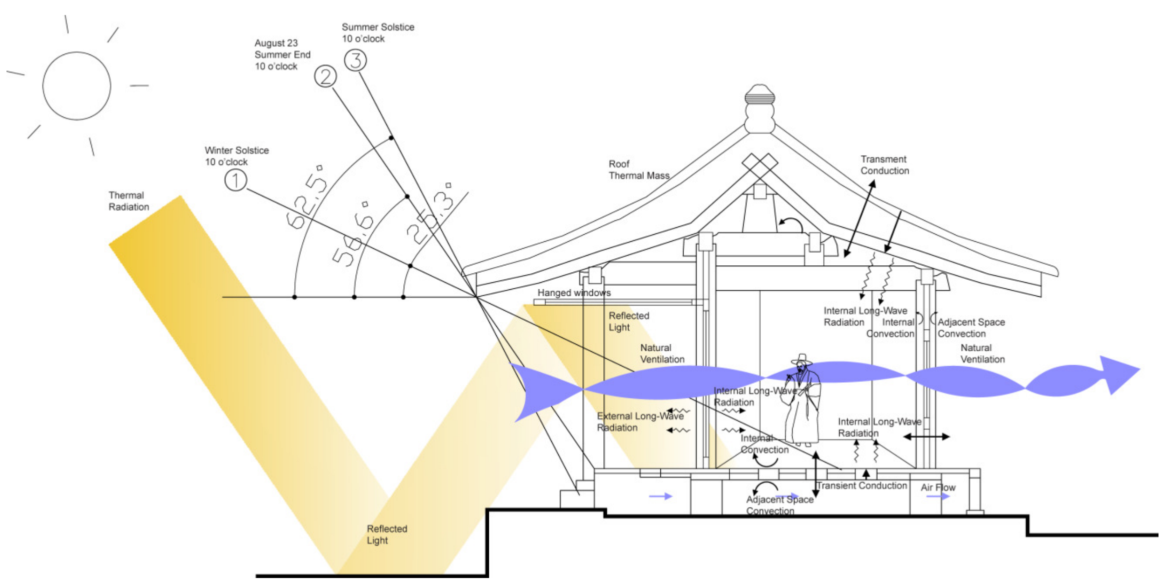


Figure 7-1 Summary of Findings for Summer in *Yeongyeongdang sarangbang*

While, *Chusagotaek sarangbang* (man's master room) roof length was shorter than any other room in there tested residences. The remarkable observation of the *Chusagotaek sarangbang* in this analysis defined the function of the inner garden in front of its *sarangbang*. The inner garden in *Chusagotaek* provided to reduce the reflected solar energy during the summer. The shorter roof overhang had leaded to making the inner garden that cooled down the reflect sunlight. The inner garden style could not be existed in the formal traditional Korean residence.

Through the prevailing wind analysis, this research showed that the prevailing wind data overlaid with the floor layout, and then this analysis provided how three tested residences could response to the wind flow. The summer wind flowed from the east to south mostly, and the windows placed on the south were bigger to offer enough air circulation and daylight. The winter wind flowed from the east or west to the north, which makes cold effect in the room. The 'mountain behind' characteristic followed the *Pungsu* theory protecting the cold wind from the north during the winter.

During the winter, the most important factors in the environmental design responses emphasized maximizing the amount of solar heat gain and keeping the solar heat energy or the heated energy from *ondol* system. Maximizing the amount of the solar heat gain leads to the roof overhang, which determined the length of the roof overhang (not too long for the cold season and not too short for the hot season). Figure 7-2 showed that the sun light penetrated the two third of the room.

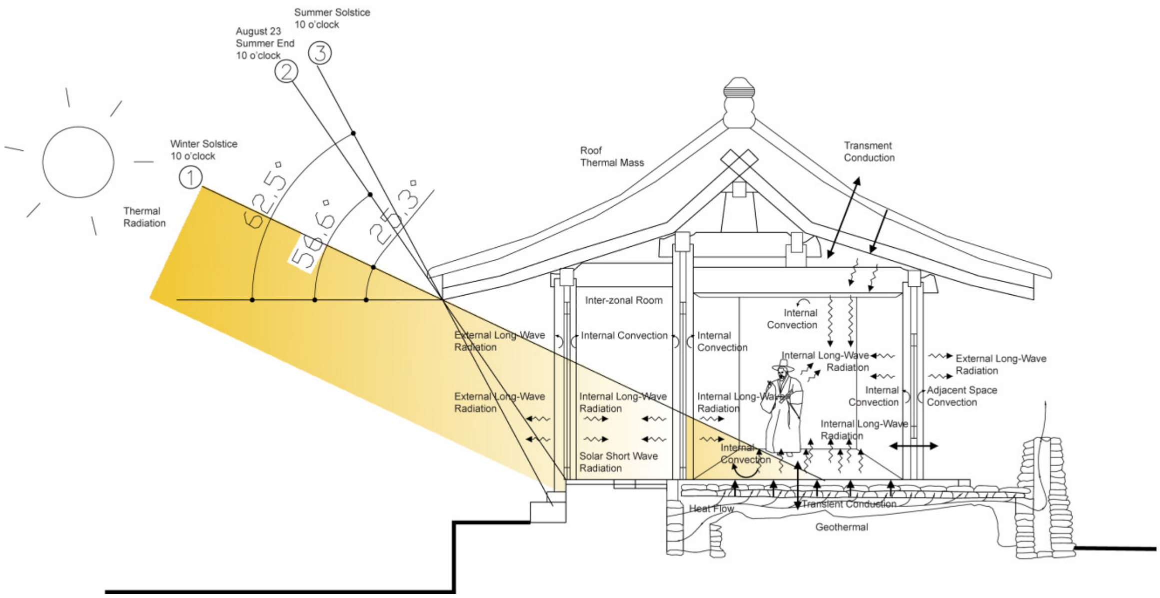


Figure 7-2 Summary of Findings for Winter in *Yeongyeongdang sarangtaechong*

In order to keep the solar heat energy, three traditional Korea residences used Inter-zonal Loads, which allowed the residences to keep the heat energy by closet, taechong, maru, and storage. The rooms reduced the cold wind temperature and preserved the heat from bang. The residences also maintained the heat energy by thermal masses such as the thicker room and the *ondol* floors.

7.2. Discussion

The Current Ecotect application, however did not show any support for material properties available for the traditional architecture such as the Korean oil-paper and the red soiled wall. This research had referred to similar materials. In the future, research should include the corrected properties of the materials. Also, Ecotect did not have support for *ondol* system, and the *ondol* system had its various layouts and styles. The *ondol* system should be investigated further in future studies.

Through Ecotect, recorded climate resources can refer back as far as to 1961. This makes it impossible to recreate the exact same climate conditions when *Yeongyeongdang* was actually built in the 19th century. However, the climate data obtained from Korea Meteorological Administration showed that the climate have rapid changes after 1980, and the summer had been getting longer approximately half a day for a year. For test purposes, rather than using the current climate data, Ecotect allowed climate data to be assessed as far back as 1961. This allowed to view the climate data of *Yeongyeongdang* before the drastic changes. This has been one of technical hindrances for the analysis of *Yeongyeongdang*.

This research provided the modeling and visualization results of *Yeongyeongdang*, *Unjoru*, and *Chusagotaek* through Ecotect. It allowed to define the environmental design responses, and how the traditional Korean residences had considered deliberately the sunlight, daylight, shading, wind flow, and thermal performance. The environmental analysis tool, Ecotect, covered three traditional Korean residences on the broad range of simulation and analysis its functions required to truly understand how they operated and performed.

GLOSSARY

Anbang: The inner pang located closer to the furnace, when tow adjacent pang are served by one furnace in a traditional Korean dwelling, as opposed to *utpang*, or outer pang.

Anchae: The wing or building of a traditional Korean residence used as the family's living quarters.

Anmadang: A "white" garden (area of bare earth) on the south side of the anchae family's living quarters in a traditional Korean residence.

Bueok: Food preparation area or kitchen in a traditional Korean dwelling.

Chagyeong: Borrowed scenery, which by Korean garden-making standards relates to selecting a site and positioning and constructing the buildings on that site so as to enjoy the prospect. See also Jeomang.

Chungin: The second of five classes of *Joseon* Korean society, which included

Haengang madang: A "white" garden, with no vegetation, located in front of the haengnangchae servant's quarters in a traditional Korean residence. Used as a work space.

Haengnangchae: A long, narrow building of a traditional Korean residence used to accommodate lesser family members and servants.

Jeomang: Prospect, or panoramic view; one of the criteria that defines a choice residential building site by traditional Korean standards, and for positioning and constructing the buildings and gardens on that site. The principal garden-making approach applied to inner and rear gardens.

Joseon: Korea as the kingdom was known for the six hundred year period from A.D 1392 to 1910.

Kan: A square measure each side of which is equal to the width of the span between columns, which varies in length from 1.8 meters to 2.8 meters.

Konnobang: An ondol-heated room located just beyond the taechong, on the side furthest form the bueok (kitchen), which has its own furnace and is used as part of the women and children's quarters, or as a study.

Madang: Generic term for inner gardens, usually bare of vegetation, in a traditional Korean residence.

Maru: Rooms in a traditional Korean dwelling which have wooden floors and are completely open to the elements on at least one side.

Numaru: A special reception room in the sarangchae master's quarters in a traditional Korean residence, the floor level of which is raised approximately 40 centimeters (15.75 inches) above that of the other rooms in the dwelling, to enjoy the benefit of the view.

Ondol: the traditional Korean system of floor heating, which utilizes the heat of smoke form an enclosed furnace forced through flues located beneath the floor to a chimney at the other end of the room or rooms.

Pang: Enclosed rooms with floor heating in a traditional Korean dwelling.

Pungsu: Korean geomancy; a system of principles which defines favourable and unfavourable land characteristics, based on ancient Chinese theories of yin and yang and the five basic elements.

Sadang: An ancestral shrine located in an elevated area at the northern end of the compound of a traditional Korean residence, facing south and overlooking the other buildings. It is dedicated to the four previous generations of ancestors.

Sarang madang: A "white" garden, with little or no vegetation, located in front of the sarangchae master's quarters in a traditional Korean residence. sarangchae

Sarangbang: An ondol-heated, enclosed room within the sarangchae.

Taechong: The central living room in a traditional Korean dwelling. The northern side is enclosed by tow sliding wooden doors, but the southern side is completely open to the elements.

Twitmadang: The rear garden, which lies to the north of the anchae in a traditional Korean residence on a southern slope, or as the uppermost of a series of terraces. This was a private space used mainly by women and children. If features grass and shrubs as well as fruit trees and is surrounded by a wall that traces the natural contours of the land (Inaji, 1998).

BIBLIOGRAPHY

Abaza, Hussein Fued. *An Integrated Design and Control Strategy for Energy Efficient Buildings.* PhD Thesis, Blacksburg, Virginia: Virginia Polytechnic Institute and State University, 2002.

An, Hee-June, and Byoung-Young Yu. *동궐도 읽기 (Read the Korea Palace Drawing).* Seoul: 한국문화재보호재단 (Korea Cultural Heritage Foundation), 2005.

Andrew, Marsh J. "natural frequency." *natural frequency.* 2008. http://naturalfrequency.com/node (accessed January 2008).

Cho, Sung-Heui, and Soo-Been Park. "Housing Culture for the Design of Water Using Areas in regard to Cooking." *Interior Institute of Korea*, September 2004.

Choi, Jong-Duk. *The Palace Drawing in Korea.* Seoul, Korea: Cultural Heritage Administration, 2005.

Choi, Sang-Hun. "A Study on the Relationships between Human Dimensions and Interior Space of the Residence yeongyeongdang." Thesis.

Chun, Byung-Ok. *Decorative Designs in the Houses of Chosun Dynasty Period.* Seoul, Korea: Chin Chai, 1988.

Chun, Jae-Hung. *한국전통조경 (Traditional Landscape Architecture of Korea).* Korea: Jo-Kyung, 2005.

Crawley, Drury B, Jon W Hand, Michael Kummert, and Brent T Griffith. *Contrasting the Capabilities of Building Energy Performance Simulation Programs.* USA: United States Department of Energy, University of Stratchclyde, and University of Wisconsin. , 2005.

Crouch, Dora P, and June G Johnson. *Traditions in Architecture: Africa, America, Asia,* *and Oceania.* Oxford, 1993.

Cultural Heritage Administration. *Royal Palaces: Changdeokgung.* 1996. http://www.cha.go.kr (accessed July 2007).

Daniels, Klaus. *The Technology of Ecological Building: Basic Principles and Measures, Examples and Ideas.* Translated by Elizabeth Schwaiger. Germany: Birkhäuser Verlag fűr Architektur, 1997.

Development and Land Use. *Energy Efficient Building Design: Developmet and Land Use Policy Manual.* Perth Wa, Australia: Western Australia, 2000.

Do, Yun-Su. *A Study on Architectural Characteristics Related with Specialization of Chosŏn Confucianism in the 16th~17th Century.* Thesis, Seoul: Han-Yang University, 2006.

Ecotect. 2007.

Fairey, P. W. "Passive Cooling and Human Comfort." (Florida Solar Energy Center) 1994.

Fanger, P O. *Thermal Comfort-analysis and Applications in Envrionmental Engineering.* New York: McGraw-Hill, 1970.

Hur, Nahmkeon, Myungsung Lee, and Sungjin Yang. "Numerical Simulation of Ventilation in the Storage Hall of Tripitaka Koreana at Haein Temple in Case of Builing Rearangement." *Journal of the Society of Air-Conditioning And Refrigerating Engineers Of Korea*, 2007: 379-385.

Inaji, T, and P.(ed) Virgilio. *The garden as architecture: Form and spirit in the gardens of Japan, China, and Korea.* Japan: Kodansha International, 1998.

Kang, Yun-Sik, and Dong-Eon Lee. "The Comples Relationships on the Late Kim Swoo-Geun's Architecture in terms of the Harold Bloom's "The Theory of Influence."."

Korea Architecture Insitution, Vol 189 (Architectural Institute of Korea), 2004.

Kim, Do Kyung. *한옥살림집을 짓다 (Building Haok).* Seoul: Hyeonamsa, 2004.

Kim, Do-Kyung. *A Study on the Evolution of Wooden Architecture in Ancient Korea.* Seoul, Korea: Goryeo University, 2000.

Kim, Dong-Hyeo. *한국 목조 건축의 기법 (Traditional Korean Capenter Technique).* Seoul: 발언 (Balun), 1995.

Kim, J.J. *Green Principles in Architecture.* Proceedings of Symposium, USA: Green and Global Architecture, 2000.

Kim, Yeon-Jeong, and Yeun-Sook Lee. "Comparative Analysis on Interior Spaces of the Selected Historical Residences in teh Western and Eastern Countries." *Interior Institute of Korea, Vol 27*, June 2001.

Korea Culture & Content Agency. *Korean Traditional Architecture.* 2003. http://korealike.culturecontent.com/index.htm (accessed November 2007).

Korea Meteorological Adiministration. *Korea Meteorological Adiministration.* 2006. http://www.kma.go.kr/intro.html (accessed June 2007).

Korea National Heritage Online. 2000. http://www.heritage.go.kr (accessed November 2007).

Lawrence Berkeley National Laboratory. *Desktop Radiance.* 2002. http://floyd.lbl.gov/deskrad/index.html (accessed July 2007).

Lee, Byong-Ju, interview by Young-Kyu Park. *Unjoru* (November 1, 2007).

Lee, Jin-Gil, Hae-Kyeong Nam, and Han-Kyu Park. "A Study on the Characteristics of the Inter-Space in Tradtioanal Korean Archtiecture."

Marsh, A J, and C Raines. *Ecotect: The Complete Environmental Design Tool.* United

Kingdom: Square One research, Isle of Man, 2007.

McMullan, R, and I H.(ed) Seeley. *Environmental Science in Building: Building & Surveying*. Parlgrave Macmillan, 2007.

Park, Kyung-Ae, and Bum-Pal Hur. "A Study on the Triadic analysis of Korean Traditional Space Design by Peirces's Semiotics." *Interior Institute of Korea*, June 2005.

Park, Sam Y. *Korean Architecture: A Cultural Treasure to Cherish Volume one and two.* Seoul, Korea: Jungwoo Sa Publishing Co., 1992.

Park, Sewng-Hae, interview by Young-Kyu Park. *Chusagoteak* (November 4, 2007).

Roodman, D M, and N Lenssen. *Building Revolution: How Ecology and Health Concerns are Transforming Construction.* Washington, DC: Worldwatch Institute, 1995.

Shin, Young-Hoon. *우리가 정말 알아야 할 우리 한옥 (Korean should know their Hanok).* Seoul: 현암사 (Haeamsa), 2000.

Sin, Young-Hoon. *한국의 고궁 (The Korean Palace).* Seoul, Korea: Hanokmoonhwa, 2005.

squ1.com. 2007. http://www.squ1.com (accessed Jaunary 2008).

squ1.org. SQUARE ONE research. 2007. http://squ1.org/wiki (accessed January 2008).

Stein, Benjamin, and John S Reynoldsd. *Mechanical and Electrical Equipment for Buildings.* United States of America: John Wiley & Sons, Inc, 2000.

U.S. Department of Energy. *Energy Efficiency and Renewable Energy.* March 24, 2008. http://www.eere.energy.gov/ (accessed July 2007).

University of Connecticut. *Psychrometric Chart Use.*

http://www.sp.uconn.edu/~mdarre/NE-127/NewFiles/psychrometric_inset.html (accessed July 2007).

Whitehead, Alfred North. *The Philosophy of Alfred North Whitedhead.* New York: Tudor Publishing Company, 1951.

Wikipedia Foundation. *Wikipedia.* 2000. http://en.wikipedia.org (accessed January 2008).

Yeo, Myoung-Souk, and Dae-Sik Jung. *Architectural Environmental Planning Research Laboratory, Seoul National Unviersity.* http://home.snu.ac.kr/index_eng.htm (accessed October 2007).

Yesan County. *Yesan.* 2007. http://www.yesan.go.kr/index.jsp (accessed July 2007).

Yim, Eun-Young. "The Approach of Environmental Design on the system of Pattern Language." *Interior Institute of Korea*, September 2001.

Yoon, Chang Sup. *History of Korean Architecture.* Seoul: Dong Myung SA, 1974.

Yu, Byung-Youn. *세밀화로 그린 건축 일러스트 백과 (Illusted Encylopedia in miniatures for architecture).* Seoul: 국일 미디어 (Kuk-il Media), 2002.

Zo, Jae-Young. *The Rituals and Architectural Norms in the Royal Palaces of Chosŏn Dynasty.* Thesis, Seoul: Seoul University, 2003.

Zu, Nam-Chul. *궁집 (The Court Style House).* Seoul: 일진사 (Iljinsa), 2003.

Zu, Namchul. *연경당 (Yeongeyongdang).* Seoul: 일진사 (Iljinsa), 2003.

REFERENCES (NOT REFERRED TO IN RESEARCH)

Bay, Joo-Hwa, and Boon Lay Ong. *Tropical Sustainable Architecture: Social and Environmental Dimensions.* Oxford: Elsevier Ltd, 2006.

Bea, Ji-Min. *전통목조건축의 지붕곡 결정과정에 관한 연구 경복궁, 창덕궁 보수, 복원 현장을 중심으로 (A Study on the Process and Practice of Making the Roof Curve of Traditional Korean Architecture).* Thesis, Seoul: Seoul University, 2003.

Brown, G Z, and Mark Dekay. *Sun, Wind & Light: Architectural Design Strategies.* 2nd Edition. New York: John Wiley & Sons, INC., 2001.

Kim, Kyung-Hee. *안동하회마을, 반가와 민가 (Andong Village, Banga and Minga.* Pusan: Bionhoo, 2001.

Krasner, Leonard, ed. *Environmental Design and Human Behavior: A Psychology of the Individual in Society.* New York: Pergamon Press Inc, 1980.

Kwok, Alison G, and Walter T Grondzik. *The Green Studio Handbook: Environmental Strategies for Schematic Design.* Oxford: Elsevier Ltd, 2007.

Lee, Do-Won, ed. *한국의 전통생태학 (Traditional Korean Ecology).* Seoul: Sciencebooks, 2004.

Lee, Yeon-Ja. *천년의 전통과 맥을 이어가는 명문 종가 이야기 (The famous main family story through one thousand).* Seoul: Colar of Dream, 2004.

Lim, Suk-Jae. *한국 전통건축과 동양사상.* Pazu City: Bookhouse, 2005.

Olgyay, Victor. *Design With Climate: Bioclimatic Approach To Architectural Regionalism.* New Jersey: Princeton University Press, 1963.

Park, Si-Ick. *한국의 풍수지리와 건축 (Traditional Korean Pungsu and Architecture).* Seoul: Ilbick, 1999.

Pitts, Adrian. *Planning and Design Strategies for Sustainability and Profit: Pragmatic sustainable design on building and urban scales.* Oxford: An imprint of Elsevier, 2004.

Sarvimäki, Marja. *Structures, Symbols and Meanings; Chinese and Korean Influence on Japanese Architecture.* PhD Thesis, Helsinki: Department of Architecture, Helsinki University of Technology, 2000.

Shin, Yong-Hoon. *한옥의 향기: 아름다운 종가집 구경 (flavor of Hanok; looking at the main family).* Seoul: 대원사 (Daewonsa), 2000.

Son, Young-Sik. *전통 과학 건축 (Scientic traditional Korean Architecture).* Seoul: 대원사 (Daewonsa), 1995.

Stang, Alanna, and Christopher Hawthorne. *The Green House: New Directions in Sustainable Architecture.* New York: Princeton Architectural Press, 2005.

Zu, Nam-Chul. *한국건축의장 (Design of Traditional Korean Architecture).* Seoul: Iljisa, 2005.

APPENDIX

A. Tabulated Daily Solar Data

Latitude: 37.5
Longitude: 126.9
TimeZone: 120.0?[+8.0hrs]
Orientation: 0.0

Date: 13th January
Julian Date: 13
Sunrise: 06:52
Sunset: 16:29

Local Correction: 19.1 mins
Equation of Time: -8.5 mins
Declination: -21.8

Local	(Solar)	Azimuth	Altitude	HSA	VSA	Stress
07:00	(07:19)	119.0	1.4	119.0	177.2	--
07:30	(07:49)	123.8	6.4	123.8	168.6	--
08:00	(08:19)	128.9	11.2	128.9	162.5	--
08:30	(08:49)	134.5	15.7	134.5	158.2	--
09:00	(09:19)	140.4	19.7	140.4	155.1	--
09:30	(09:49)	146.9	23.2	146.9	152.9	--
10:00	(10:19)	153.8	26.2	153.8	151.3	--
10:30	(10:49)	161.2	28.4	161.2	150.2	--
11:00	(11:19)	169.0	30.0	169.0	149.6	--
11:30	(11:49)	177.0	30.7	177.0	149.3	--
12:00	(12:19)	-174.9	30.6	-174.9	149.3	--
12:30	(12:49)	-166.9	29.6	-166.9	149.7	--
13:00	(13:19)	-159.2	27.9	-159.2	150.5	--
13:30	(13:49)	-151.9	25.4	-151.9	151.7	--
14:00	(14:19)	-145.1	22.3	-145.1	153.4	--
14:30	(14:49)	-138.8	18.6	-138.8	155.8	--
15:00	(15:19)	-132.9	14.5	-132.9	159.2	--
15:30	(15:49)	-127.5	10.0	-127.5	163.9	--
16:00	(16:19)	-122.5	5.1	-122.5	170.6	--

Table 0-1 Tabulated Daily Solar Data: 13th January

Latitude: 37.5
Longitude: 126.9
TimeZone: 120.0?[+8.0hrs]
Orientation: 0.0

Date: 6th May
Julian Date: 126
Sunrise: 04:37
Sunset: 18:20

Local Correction: 31.0 mins
Equation of Time: 3.4 mins
Declination: 16.2

Local	(Solar)	Azimuth	Altitude	HSA	VSA	Stress
05:00	(05:31)	72.8	4.2	72.8	14.1	--
05:30	(06:01)	77.2	10.0	77.2	38.4	--
06:00	(06:31)	81.5	15.8	81.5	62.4	--
06:30	(07:01)	85.8	21.8	85.8	79.6	--
07:00	(07:31)	90.3	27.7	90.3	90.6	--
07:30	(08:01)	95.0	33.6	95.0	97.5	--
08:00	(08:31)	100.2	39.5	100.2	102.1	--
08:30	(09:01)	106.0	45.3	106.0	105.2	--
09:00	(09:31)	112.8	50.9	112.8	107.4	--
09:30	(10:01)	121.0	56.3	121.0	109.0	--
10:00	(10:31)	131.3	61.1	131.3	110.1	--
10:30	(11:01)	144.6	65.1	144.6	110.8	--
11:00	(11:31)	161.3	67.8	161.3	111.2	--
11:30	(12:01)	-179.3	68.7	-179.3	111.3	--
12:00	(12:31)	-160.1	67.6	-160.1	111.1	--
12:30	(13:01)	-143.6	64.8	-143.6	110.7	--
13:00	(13:31)	-130.5	60.8	-130.5	110.0	--
13:30	(14:01)	-120.3	55.9	-120.3	108.9	--
14:00	(14:31)	-112.2	50.6	-112.2	107.3	--
14:30	(15:01)	-105.6	44.9	-105.6	105.0	--
15:00	(15:31)	-99.8	39.1	-99.8	101.8	--
15:30	(16:01)	-94.7	33.2	-94.7	97.1	--
16:00	(16:31)	-90.0	27.3	-90.0	89.9	--
16:30	(17:01)	-85.5	21.3	-85.5	78.7	--
17:00	(17:31)	-81.2	15.4	-81.2	60.9	--
17:30	(18:01)	-76.9	9.6	-76.9	36.6	--
18:00	(18:31)	-72.5	3.9	-72.5	12.6	--

Table 0-2 Tabulated Daily Solar Data: 6th May

Latitude: 37.5
Longitude: 126.9
TimeZone: 120.0?[+8.0hrs]
Orientation: 0.0

Date: 21st June
Julian Date: 172
Sunrise: 04:16
Sunset: 18:51

Local Correction: 26.0 mins
Equation of Time: -1.6 mins
Declination: 23.4

Local	(Solar)	Azimuth	Altitude	HSA	VSA	Shading
04:30	(04:56)	62.0	2.4	62.0	5.1	--
05:00	(05:26)	66.3	7.7	66.3	18.7	--
05:30	(05:56)	70.5	13.3	70.5	35.2	--
06:00	(06:26)	74.5	18.9	74.5	52.1	--
06:30	(06:56)	78.5	24.7	78.5	66.7	--
07:00	(07:26)	82.6	30.6	82.6	77.7	--
07:30	(07:56)	86.8	36.5	86.8	85.7	--
08:00	(08:26)	91.3	42.5	91.3	91.4	--
08:30	(08:56)	96.3	48.4	96.3	95.5	--
09:00	(09:26)	102.0	54.3	102.0	98.5	--
09:30	(09:56)	109.1	60.0	109.1	100.7	--
10:00	(10:26)	118.3	65.5	118.3	102.2	--
10:30	(10:56)	131.2	70.4	131.2	103.2	--
11:00	(11:26)	150.2	74.2	150.2	103.8	--
11:30	(11:56)	176.3	75.9	176.3	104.1	--
12:00	(12:26)	-156.5	74.9	-156.5	103.9	--
12:30	(12:56)	-135.6	71.5	-135.6	103.4	--
13:00	(13:26)	-121.3	66.8	-121.3	102.5	--
13:30	(13:56)	-111.2	61.5	-111.2	101.1	--
14:00	(14:26)	-103.7	55.8	-103.7	99.2	--
14:30	(14:56)	-97.7	50.0	-97.7	96.4	--
15:00	(15:26)	-92.6	44.0	-92.6	92.6	--
15:30	(15:56)	-88.0	38.1	-88.0	87.4	--
16:00	(16:26)	-83.7	32.2	-83.7	80.1	--
16:30	(16:56)	-79.6	26.3	-79.6	69.9	--
17:00	(17:26)	-75.6	20.5	-75.6	56.3	--
17:30	(17:56)	-71.6	14.8	-71.6	39.8	--
18:00	(18:26)	-67.4	9.2	-67.4	22.9	--
18:30	(18:56)	-63.1	3.8	-63.1	8.3	--

Table 0-3 Tabulated Daily Solar Data: 21st June

Latitude: 37.5
Longitude: 126.9
TimeZone: 120.0?[+8.0hrs]
Orientation: 0.0

Date: 23rd July
Julian Date: 204
Sunrise: 04:32
Sunset: 18:44

Local Correction: 21.2 mins
Equation of Time: -6.4 mins
Declination: 20.3

Local	(Solar)	Azimuth	Altitude	HSA	VSA	Stress
05:00	(05:21)	68.1	4.9	68.1	13.0	--
05:30	(05:51)	72.4	10.5	72.4	31.6	--
06:00	(06:21)	76.6	16.2	76.6	51.6	--
06:30	(06:51)	80.8	22.1	80.8	68.5	--
07:00	(07:21)	85.0	28.0	85.0	80.7	--
07:30	(07:51)	89.4	33.9	89.4	89.1	--
08:00	(08:21)	94.1	39.9	94.1	94.9	--
08:30	(08:51)	99.3	45.8	99.3	99.0	--
09:00	(09:21)	105.4	51.6	105.4	101.9	--
09:30	(09:51)	112.6	57.2	112.6	103.9	--
10:00	(10:21)	121.9	62.5	121.9	105.4	--
10:30	(10:51)	134.3	67.2	134.3	106.4	--
11:00	(11:21)	151.3	70.8	151.3	107.0	--
11:30	(11:51)	173.1	72.7	173.1	107.2	--
12:00	(12:21)	-163.5	72.2	-163.5	107.1	--
12:30	(12:51)	-143.6	69.5	-143.6	106.8	--
13:00	(13:21)	-128.7	65.3	-128.7	106.0	--
13:30	(13:51)	-117.7	60.4	-117.7	104.8	--
14:00	(14:21)	-109.4	54.9	-109.4	103.1	--
14:30	(14:51)	-102.7	49.2	-102.7	100.8	--
15:00	(15:21)	-97.1	43.3	-97.1	97.5	--
15:30	(15:51)	-92.1	37.4	-92.1	92.8	--
16:00	(16:21)	-87.6	31.5	-87.6	86.0	--
16:30	(16:51)	-83.2	25.5	-83.2	76.2	--
17:00	(17:21)	-79.1	19.6	-79.1	62.0	--
17:30	(17:51)	-74.9	13.8	-74.9	43.4	--
18:00	(18:21)	-70.7	8.2	-70.7	23.4	--
18:30	(18:51)	-66.3	2.6	-66.3	6.5	--

Table 0-4 Tabulated Daily Solar Data: 23rd July

Latitude: 37.5	Date: 23rd August	Local Correction: 25.0 mins
Longitude: 126.9	Julian Date: 235	Equation of Time: -2.6 mins
TimeZone: 120.0?[+8.0hrs]	Sunrise: 04:58	Declination: 11.7
Orientation: 0.0	Sunset: 18:11	

Local	(Solar)	Azimuth	Altitude	HSA	VSA	Stress
05:00	(05:25)	75.4	0.3	75.4	1.3	--
05:30	(05:55)	79.9	6.1	79.9	31.5	--
06:00	(06:25)	84.4	12.0	84.4	65.2	--
06:30	(06:55)	88.8	18.0	88.8	86.4	--
07:00	(07:25)	93.4	23.9	93.4	97.7	--
07:30	(07:55)	98.3	29.8	98.3	104.2	--
08:00	(08:25)	103.6	35.7	103.6	108.2	--
08:30	(08:55)	109.5	41.4	109.5	110.8	--
09:00	(09:25)	116.4	46.8	116.4	112.6	--
09:30	(09:55)	124.5	52.0	124.5	113.9	--
10:00	(10:25)	134.3	56.6	134.3	114.7	--
10:30	(10:55)	146.3	60.4	146.3	115.3	--
11:00	(11:25)	160.8	63.1	160.8	115.6	--
11:30	(11:55)	177.2	64.2	177.2	115.8	--
12:00	(12:25)	-166.1	63.6	-166.1	115.7	--
12:30	(12:55)	-150.9	61.4	-150.9	115.4	--
13:00	(13:25)	-138.0	58.0	-138.0	115.0	--
13:30	(13:55)	-127.5	53.6	-127.5	114.2	--
14:00	(14:25)	-118.9	48.6	-118.9	113.1	--
14:30	(14:55)	-111.7	43.2	-111.7	111.5	--
15:00	(15:25)	-105.5	37.6	-105.5	109.2	--
15:30	(15:55)	-100.0	31.8	-100.0	105.7	--
16:00	(16:25)	-95.0	25.9	-95.0	100.2	--
16:30	(16:55)	-90.3	19.9	-90.3	90.9	--
17:00	(17:25)	-85.8	14.0	-85.8	73.7	--
17:30	(17:55)	-81.4	8.1	-81.4	43.5	--
18:00	(18:25)	-76.9	2.2	-76.9	9.8	--

Table 0-5 Tabulated Daily Solar Data: 23rd August

Latitude: 37.5	Date: 23rd December	Local Correction: 28.7 mins
Longitude: 126.9	Julian Date: 357	Equation of Time: 1.1 mins
TimeZone: 120.0?[+8.0hrs]	Sunrise: 06:49	Declination: -23.5
Orientation: 0.0	Sunset: 16:13	

Local	(Solar)	Azimuth	Altitude	HSA	VSA	Stress
07:00	(07:28)	121.8	1.8	121.8	176.5	--
07:30	(07:58)	126.6	6.8	126.6	168.8	--
08:00	(08:28)	131.8	11.4	131.8	163.2	--
08:30	(08:58)	137.4	15.6	137.4	159.2	--
09:00	(09:28)	143.4	19.4	143.4	156.3	--
09:30	(09:58)	149.9	22.7	149.9	154.2	--
10:00	(10:28)	156.8	25.3	156.8	152.7	--
10:30	(10:58)	164.2	27.3	164.2	151.8	--
11:00	(11:28)	171.8	28.6	171.8	151.2	--
11:30	(11:58)	179.7	29.0	179.7	151.0	--
12:00	(12:28)	-172.5	28.6	-172.5	151.2	--
12:30	(12:58)	-164.8	27.5	-164.8	151.7	--
13:00	(13:28)	-157.4	25.5	-157.4	152.6	--
13:30	(13:58)	-150.5	22.9	-150.5	154.1	--
14:00	(14:28)	-143.9	19.7	-143.9	156.1	--
14:30	(14:58)	-137.9	16.0	-137.9	158.9	--
15:00	(15:28)	-132.3	11.7	-132.3	162.8	--
15:30	(15:58)	-127.1	7.2	-127.1	168.2	--
16:00	(16:28)	-122.2	2.3	-122.2	175.7	--

Table 0-6 Tabulated Daily Solar Data: 23rd December