GREENRE - UTM RESEARCH FINAL REPORT

ASSESSMENT OF OVERALL THERMAL TRANSFER VALUE (OTTV) UNDER THE EFFECT OF ADJACENT SHADING AND NATURAL VENTILATION

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PROJECT DETAIL

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EXECUTIVE SUMMARY

With the arising concern about climate change and energy crisis, various building performance assessment methods have been established to evaluate building energy efficiency. The Overall Thermal Transfer Value (OTTV) and Residential Envelope Transmittance Value (RETV) are the metrics developed to measure the average heat gain transmitted through envelope of non-residential and residential buildings respectively. The OTTV has been included in Malaysian Standard (MS) 1525 and made mandatory in Malaysia Uniform Building By-law (UBBL) Amendment 2012. However, the assumptions surrounding the assessment have raised questions to its reliability and actual efficiency in determining building energy use in the contemporary scenarios. The OTTV/RETV quantifies solar heat gain through a building's external envelope. The standard calculation method takes into account shading contributions of conventional shading devices but does not account for shading contributions from adjacent buildings. Likewise, the relative contribution of naturally ventilated spaces to the OTTV/RETV performance has not been empirically substantiated to justify the exclusion in the by-law. Thereby, this research presents empirical studies and methods towards the improvement of OTTV/RETV assessment in Malaysia. Inventory of existing multi-block developments and buildings with air conditioning and natural ventilation spaces were conducted to develop cases for building information modelling (BIM). Then, dynamic computer simulation of annual heat gain through building envelope and OTTV/RETV calculation of the selected cases were performed for comparison. Finally, the impacts and correlations of adjacent shading and natural ventilation with OTTV/RETV performance were established. The findings from the study puts forward supplementary data to the standard OTTV/RETV calculation in a bid to address the effect of adjacent shading in multi-block development and naturally ventilated spaces in a building.

Keywords: Building envelope; Overall Thermal Transfer Value (OTTV); Residential Envelope Transmittance Value (RETV); inter-blocking shading; natural ventilation; tropical climate

1.0 INTRODUCTION

1.1 Background of Study

The energy consumption of the building sector accounts for nearly 40% of the total global energy consumption, a significant proportion of the total energy demand for buildings corresponds to the electricity required to maintain occupants' thermal comfort level. 37% of the total energy accounted for in the United States' building industry is channelled to heating, ventilation, and air-conditioning (HVAC) systems (US-DOE, 2012). Furthermore, 25%−30% of the same energy consumption was recorded in Japan and Hong Kong commercial buildings (ECCJ, 2010; EMSD, 2016). In Malaysia, cooling systems alone contributes a substantial 60% of energy consumption in office buildings (BSEEP, 2013). Thus, it can be implied that achieving the goals of using the energy-efficiency design strategies is greatly reliant on how the occupants behave and interact with the building. However, building characteristics and components still directly impact significantly the energy use in a building up to about 42% (Santin et al., 2009; de Meester et al., 2013).

The building envelope is adjudged to be the most essential element affecting energy efficiency in the built environment (Egwunatum et al., 2016). Studies have demonstrated the role thermal properties of building enclosure materials play on the operational energy use, especially for cooling and heating systems (Yuan et al., 2016; Jalei & Jrade, 2014). This establishes its significance in achieving green building certifications. Hence, to maintain comfortable indoor conditions, the entire building envelope must provide a good thermal barrier and regulate heat losses and gains. Overall Thermal Transfer Value (OTTV) is a popular index for quantifying the rate of heat transfer through building envelopes in the southeast Asian continent. Many countries in this sub-tropical region have legally mandated OTTV compliance for building development as a measure to effectively regulate energy use and improve efficiency through the building components.

The OTTV compliance has been made mandatory for buildings as supported in UBBL 38A clause. The implementation of this regulation has presented certain misconceptions in the assessment procedures as different local authorities have different perspectives and interpretations of the code in a bid to satisfy current situations in the building sector. Although, the concept in practice is quite clear but one of the common misconceptions is the inclusion or exclusion of naturally ventilated spaces from the assessment regardless of its function and ventilation rate or profile. In the current OTTV regulation (MS1525:2019), a building (which is surrounded by adjacent buildings) is assumed as a self-standing building, i.e., any shading effect cast by adjacent buildings against solar radiation is excluded from the OTTV calculation. However, in a highly urbanised and dense environment, it is common to have neighbouring buildings overshadowing another. This will inadvertently affect the heat gains through the facade. Malaysia's OTTV methodology does not consider the shading from neighbouring buildings. This assumption becomes invalid in cases of multi-block developments because buildings within the same project or development are expected to have the same lifespan. In such instances, inter-block shading then becomes a valuable design tool in reducing solar heat gains and should be adequately considered in OTTV assessment.

It is apparent that the lack of scientific justification is responsible for the inadequate assumptions in the concept leading to non-uniform standards of implementation of OTTV in Malaysia and neighbouring countries. Based on the prevalent issues raised above, this study has presented strategies aimed at improving OTTV assessment method in Malaysia for accurate and effective evaluation even in unconventional instances.

1.2 Research Questions

1. What are the types of multi-block development in the local context?
2. What is the impact of adjacent shading on OTTV performance?
3. What is the effect of naturally ventilated spaces on OTTV performance?

1.3 Research Objectives

1. To characterise the existing multi-block developments in Malaysia.
2. To evaluate the impact of adjacent shading on the OTTV performance.
3. To study the effect of natural ventilation on the OTTV performance of a building with air conditioned and naturally ventilated spaces.

1.4 Methodology

This research was carried out in 3 phases as presented in Table 1. Phase 1 included the inventory and modelling stage; Phase 2 involved the simulation and assessment; and Phase 3 comprised of the comparison and correlation analysis. This research studied the building envelope OTTV assessment methods based on MS1525:2019. The project inventory was focused on the selected non-residential buildings (with air conditioned and naturally ventilated spaces) and multi-block developments in Malaysia. Due to the limited time and resources, the research method was mainly based on computer simulation. Field measurement or other means of validation were not included in the research project. The details of each phase are outlined as follows:

1.4.1 Phase 1: Inventory and Modelling

The aim of this project phase was to create an inventory of the local context. The data acquired served as the starting point for the study and furthermore, the development of the best possible solutions to integrate the effect of adjacent shading on the envelope towards the improvement of thermal performance, since it provided insight into the boundary conditions necessary to be considered. A survey of the existing multi-block development stock in Malaysia depicted a more detailed overview of the building conditions and characteristics. Through this, various scenarios of building with air conditioned and natural ventilated spaces were determined. The data from the inventory was employed to select the cases for building information modelling (BIM).

1.4.2 Phase 2: Simulation and Assessment

In this phase, empirical evaluations were carried out by using dynamic energy simulations. In addition, parametric simulations were executed to identify the dominant factors influencing the effect of adjacent shading and natural ventilation on the OTTV performance. At the same time, the OTTV performance of the selected cases was calculated based on MS1525:2019. Finally, the simulation results were compared with the OTTV performance to evaluate the impacts of the adjacent shading and natural ventilation.

1.4.3 Phase 3: Comparison and Correlation Analysis

Based on comprehensive analyses in the second project phase, correlation analyses were conducted to identify the relationship between different design variables and OTTV performance. Then, the correlation factors for adjacent shading and naturally ventilated spaces for the OTTV performance was established. The final results were compiled and presented as recommendations for improving the current OTTV assessment method.

Table 1.1. Summary of objectives, methods, and deliverables

	Objectives	Method/ Activities	Deliverables
1.	To characterise the existing multi-block developments in Malaysia	Inventory of existing development; BIM modelling	Inventory report, model
2.	To evaluate the impact of adjacent shading on the OTTV performance	Computer simulation; OTTV assessment; correlation analysis	Simulation report, correlation
3.	To study the effect of natural ventilation on the OTTV performance of a building with air conditioned and naturally ventilated spaces	Computer simulation; OTTV assessment; correlation analysis	Simulation report, correlation

2.0 LITERATURE REVIEW

2.1 Introduction

This section provides an overview of previous studies and contributions to OTTV and building thermal performance research. This includes the review of the chronological development of OTTV assessment methods in selected Asian countries and their peculiar differences relative to prevalent climate. The impacts of interblock shading and natural ventilation on building thermal performance are also discussed accordingly to understand their significance in OTTV assessment. The reviews presented in this section forms the basis of the research project.

2.2 OTTV Equation Development

The OTTV equation established many years back has been adopted by many countries and scientifically adapted to reflect variance in climatic conditions. Over time, these equations have been modified and some are still being amended to accommodate certain criteria and innovations that were erstwhile not considered. The first revision of the equation in the Asian region was formulated by modelling a generic commercial building and using results from DOE-2 computer simulations as a database of heat gains in Singapore (Chou & Lee 1988). The new equation notably increased the weight of the solar heat gain as compared to the currently used OTTV equation at that time and results proved that the revised equation gave the best correlation between the OTTV and the total heat gain through the building envelope. Later on, the new equation was modified to include coefficients for heat conduction through fenestrations and opaque walls in addition to solar correction factors for wall facades of different orientations are computed from local weather data using same simulation method as the first revision (Chou & Chang, 1996).

In the wake of advanced building science research and resources, the Singaporean OTTV underwent a major revision to introduce what is known as Envelope Thermal Transfer Value (ETTV) nowadays (Chua & Chou, 2010). The ETTV approach was aimed solely at improving energy performance in conditioned commercial buildings. On the other hand, Residential Envelope Transfer Value (RETV) was developed for residential buildings based on the ETTV by modifying the coefficients (Chua & Chou, 2010). In India, energy simulations were done with various combinations (floor plan, climate and building envelope) of inputs to calculate the Roof Envelope Thermal Value (RETV). RETV formula included key envelope parameters and multiple linear regression analysis was done to minimize the error between the simulated RETV and calculated RETV. Notably, coefficients added in the equation to consider different climates prevalent in the region (Bhanware et al., 2019). An overview of the equation development in a chronological order is presented in Table 2.1.

Table 2.1. Summary of OTTV equation development

Reference	Country	Method	Equation	Notes
(Chou & Lee 1988)	Singapore	DOE-2 computer simulations	OTTV = 11(1-WWR) U_w + 4.8(WWR)U_f + 230(WWR)(SC)	Increases the weight of the solar heat gain
(Chou & Chang 1996)	Singapore	DOE-2 computer simulations	OTTV = 11(1-WWR) U_w + 4.8(WWR)U_f + 230(WWR)(CF)(SC)	Solar correction factors (CF) for different orientations are computed from local weather data
(Chua & Chou 2010)	Singapore	DOE-2 computer simulations	EETV = 12(1-WWR) U_w + 3.4(WWR)U_f + 211(WWR)(CF)(SC)	ETTV-based approach to improving energy performance of commercial buildings
(Chua & Chou 2010)	Singapore	eQuest Energy Simulation tool	RETV = 3.4(1-WWR) U_w + 1.3(WWR)U_f + 58.6(WWR)(CF)(SC)	Coefficients modified for residential buildings
(Bhanware et al., 2019)	India	Energy simulation		Coefficients added for different climates
Malaysia Standard (MS1525 2019)	Malaysia	----	OTTVi=15α (1 - WWR) U_w + 6 (WWR) U_f + (194 x OF x WWR x SC)	

2.3 OTTV and RETV Concept

The concept of OTTV originates from the energy conservation standards of ASHRAE Standard 90-75, which was later adopted in many countries and subsequently revised based on respective weather conditions and energy requirements (Bhanware et al., 2019). OTTV is a measure of heat transfer into mechanically cooled buildings through its envelope. Hence it acts as an index for assessing the thermal performance of commercial buildings. The concept of OTTV generally assumes that the envelope of a building is completely enclosed and based on three major components including:

a) Conduction through opaque walls

b) Conduction through window or transparent elements

c) Solar radiation through transparent elements

According to MS1525:2019, the adopted OTTV equation in Malaysia is given in the equation below:

$$OTTV=15\alpha\ (1 - WWR)\ U_w + 6\ (WWR)\ U_f + (194 \times OF \times WWR \times SC)$$

RETV is also an assessment index for energy consumption of buildings developed to accommodate the limitation of OTTV which is restricted to commercial and mechanically cooled spaces. It was introduced as an indicator for the envelope thermal performance of residential buildings (Wienerberger, 2019). RETV takes into consideration the same components of building envelope heat gain as OTTV — the heat conduction through walls, heat conduction through windows, and solar radiation through windows. The major difference is the adjustment of components' coefficients with respect to the thermal efficiency of residential envelope (Chua & Chou, 2010). The RETV equation as adopted by BCA is given below:

$$RETV = 3.4(1\text{-}WWR)\ U_w + 1.3(WWR)U_f + 58.6(WWR)(CF)(SC)$$

2.4 Effect of Interblock Shading

Since 2001, the OTTV assessment has been adopted in the Malaysian Standard, especially for mechanically cooled commercial buildings (Djamila et al., 2018). The OTTV concept focused on four parameters which are the U-value of structural elements, solar absorption, window-to-wall ratio, and shading coefficient. (Djamila et al., 2018). According to MS1525:2019, these parameters were estimated based on several studies and simulations to adapt the equation with the climatic characteristic of Malaysia. Based on this, the OTTV of the building envelope for a building with a total air-conditioned area exceeding 4000 m^2 shall not exceed 50 W/m^2.

The effect of adjacent solar shading on other building related fields have been studied to some extent in various parts of the world. In Singapore, Chong et al. (2013) investigated how the outdoor environment and its neighbouring morphology affected the indoor built environment. Two pointers of envelope performance named as "increase in conduction heat gain" and "solar heat gain through glazing" were used, considering the shading by surrounding buildings. The findings show that conduction and solar radiation gains were dependent on both the urban morphology and building construction. Research in the similar direction were conducted by Van Esch et al. (2012), David et al. (2011) and Carvalho et al. (2010). Likewise, Fong et al. (2009) derived four correction factors and proposed their incorporation into the current ETTV formula. To extract these four factors, a simulation methodology was proposed to the ETTV of the building under non-conventional shading.

Figure 2.1. Examples of multi-block development (Chan, L.S., 2021)

Case study of 14 multi-block building developments were conducted in Hong Kong (Figure 2.1). A correlation between annual heat gain through building envelope and the corresponding OTTV was developed through computer modelling and simulation using EnergyPlus (Chan, L.S. 2021). In Jamaica, buildings with partition walls with other buildings are not included in the OTTV calculation because they are assumed to be insulated from thermal effect and solar radiation (JNBC, 1994). Moreover, adjustments can be applied in buildings with partial shading on the walls. If the total shaded area of a building's partition wall exceeds 50% or 75% of the total wall area, the OTTV calculated can be multiplied by a factor of 0.7 or 0.5 to meet the OTTV requirement.

Díaz-Vilarino et al. (2013) developed a methodology for automatic generation of an as-built Building Information Model (BIM) including shaded surfaces for solar analysis. The generated model can be directly transferred to an energy analysis program for further analysis. The thermal performance of cool wall under shading and reflection effects by adjoining buildings was studied by Levinson (2019). A solar availability factor (SAF), defined as "the ratio of sunlight incident on a central wall with shading effect from neighbouring wall to that in the absence of the neighbouring wall'', was derived. With these SAFs, energy saving derived from the utilisation of cool wall with neighbouring shading effect can be evaluated. The previous studies support that the effect of adjacent shading is significant on the building envelope and should be considered in the study of building thermal and energy performance.

2.5 Effect of Air Infiltration on OTTV

Li and Rezgui (2017) presented novel method to determine building envelope thermal transmittance (U-values) and air infiltration rate by a combination of Energy modelling (DesignBuilder), regression models, and genetic algorithm at quasi-steady state conditions. Genetic algorithm was then applied to obtain a set of U-values and air infiltration rate with the minimum difference between the field measurement and model prediction. The calibrated U-values and air infiltration rate were employed as inputs in EnergyPlus to model one workday heat consumption. The accuracy of the calibrated model improved significantly when compared with thermal demand from measured data. In India, Mathur and Damle (2021) conducted a measurement of ACH in apartments and a simulation to find the impact of infiltration on RETV with a calibrated model because OTTV/RETV assessments do not consider the heat gains due to infiltration. Heat gain from infiltration accounted for 10%–33% of the overall envelope heat gains. Furthermore, the existing RETV equation was revised with the addition of a linear infiltration factor for each climate. Subsequently, 1 ACH of infiltration was found to contribute 5.46 W/m2 to RETV in hot-dry climate, 4.22 W/m2 in composite climate, and 3.53 W/m2 in warm-humid climate.

Hwang et al. (2021) proposed envelope design criteria for hybrid ventilation thermal management of school buildings in hot–humid climates. School buildings were selected to simulate cooling load, thermal comfort, and the natural ventilation potential to discuss the parameters related to building envelope design. In the study correction factors for OTTV were established. The coefficient of azimuth correction factor and area ratio correction factor are clarified for equivalent ventilation area. Design criteria for balancing seasonal energy conservation and thermal comfort were likewise proposed. Adopting the proposed criteria based on the OTTV and equivalent ventilation area enables rapid analysis of building envelope performance. Pramesti et al. (2021) provided a calculation of OTTV to a multi-story building in Semarang. The method used in this study was field measurements and simulation using Autodesk Ecotect Software. Valuable recommendations were provided as well in this study in an effort to reach the ideal OTTV value for its façade. Thus, to minimize external thermal loads, the design criteria for building envelope with the OTTV must be ≤35 W/m². The study denoted that air infiltration significantly affects the thermal load and energy use. Furthermore, it was suggested that the addition of sun shading device designs, material engineering can considerably reduce air infiltration by making the building envelope tighter.

2.6 Summary

In summary, inter-block shading plays a crucial role in influencing the thermal performance of a building's envelope. Numerous studies have contributed to the development of factors and coefficients incorporated into the OTTV/ETTV equation to account for this effect. Several studies have also highlighted the significant impact of natural ventilation and air infiltration on the thermal performance of a building's envelope. These factors play a vital role in regulating heat transfer and overall energy efficiency. Over time, the OTTV formula has undergone continuous revisions, particularly in tropical countries, to align with the specific weather conditions prevalent in these regions. These revisions aim to ensure that the OTTV calculation accurately reflects the thermal performance of buildings in such climates. To enhance the accuracy of the OTTV calculation, additional revisions have been made, including the incorporation of a linear infiltration factor that varies based on different climate conditions. Overall, these ongoing revisions and the consideration of factors such as inter-block shading, natural ventilation, and air infiltration aim to improve the reliability and applicability of the OTTV standard, particularly in relation to the thermal performance of building envelopes.

3.0 INVENTORY AND MODEL DEVELOPMENT

3.1 Introduction

In this section, the process of developing the building inventory and test models according to the objectives are outlined. A selection of buildings with interblock development are presented followed by the three simulation scenarios developed from the inventory. At the end of this section, the preliminary simulation tests and comparisons to determine a suitable dynamic simulation tool for the project are also presented.

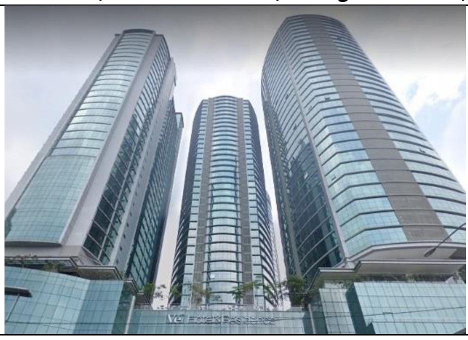
3.2 Building Inventory

The first objective of the project is to develop the building inventory of actual instances of the research problem within the study area. The inventory includes a survey of the existing multi-block development and characteristics that will be used to create the simulation models and scenarios to be examined subsequently in the project.

Table 3.1 Building inventory of existing interblock shading developments

<table>
<tr><td colspan="2">IOI City Tower</td></tr>
<tr><td colspan="2">31 storey office towers</td></tr>
<tr><td colspan="2">Location: Persiaran IRC 2, IOI Resort City, Lebuhraya Lembah Klang Selatan, 62502 Putrajaya,</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">KL Gateway</td></tr>
<tr><td colspan="2">42 & 38 storey office towers</td></tr>
<tr><td colspan="2">Location: 2, Jalan Kerinchi, Gerbang Kerinchi Lestari, 59200 Kuala Lumpur</td></tr>
<tr><td></td><td></td></tr>
</table>

Table 3.1 Building inventory of existing interblock shading developments (cont'd)

Naza Tower	
50 storey office building	
Location: *10, Persiaran KLCC, Kuala Lumpur, 50088 Kuala Lumpur, Wilayah Persekutuan*	
	
Centrepoint North & South	
19 storey office building	
Location: *Lingkaran Syed Putra, Mid Valley City, 58000, Wilayah Persekutuan Kuala Lumpur*	
	
The Vertical Business Suites	
35 & 32 storey office towers	
Location: *8, Jalan Kerinchi, Bangsar South, Pantai Dalam, 59200 Kuala Lumpur*	
	

3.3 Model Development

From the building inventory, the following building information models were developed to represent the scenarios to be tested under the adjacent shading and natural ventilation effects on OTTV performance.

Simulation Model 1

- High-rise, open-plan office building with a central core;
- Double-tower development, sub-divided into 4 respective AC zones on the north, east, south and west orientations (Fig 3.1).

Objective 1

- To evaluate the impact of adjacent shading on the OTTV performance.

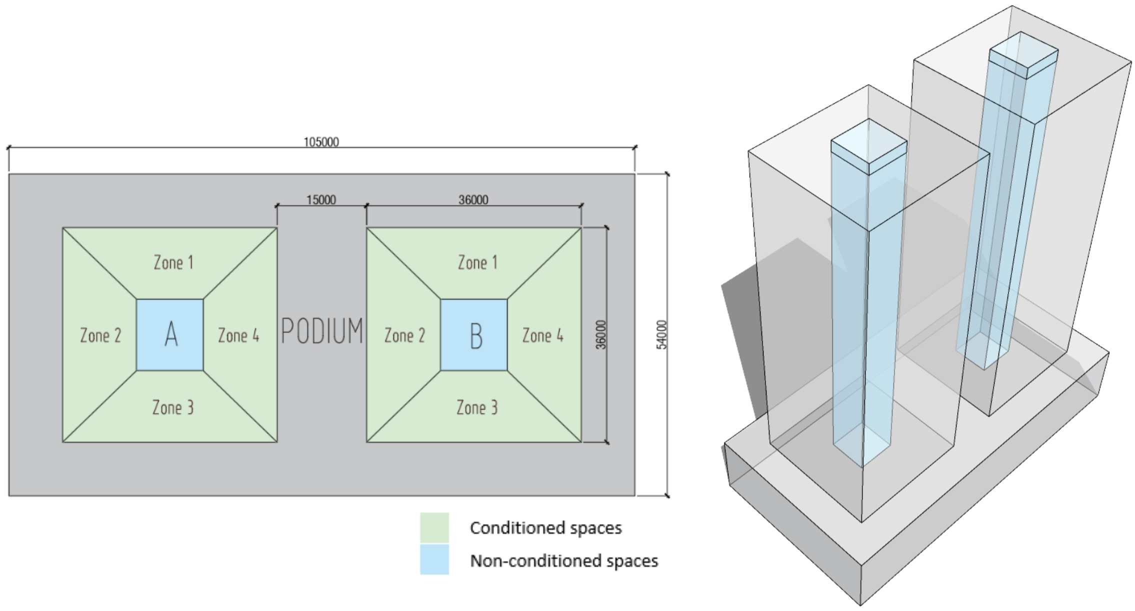


Figure 3.1 Plan and view of simulation model 1

Simulation Model 2

- Conditioned open-plan office building with a central core and an east-facing naturally ventilated corridor (Fig 3.2).

Objective 2

- To study the effect of natural ventilation on the OTTV performance of a building with air conditioned and naturally ventilated spaces.

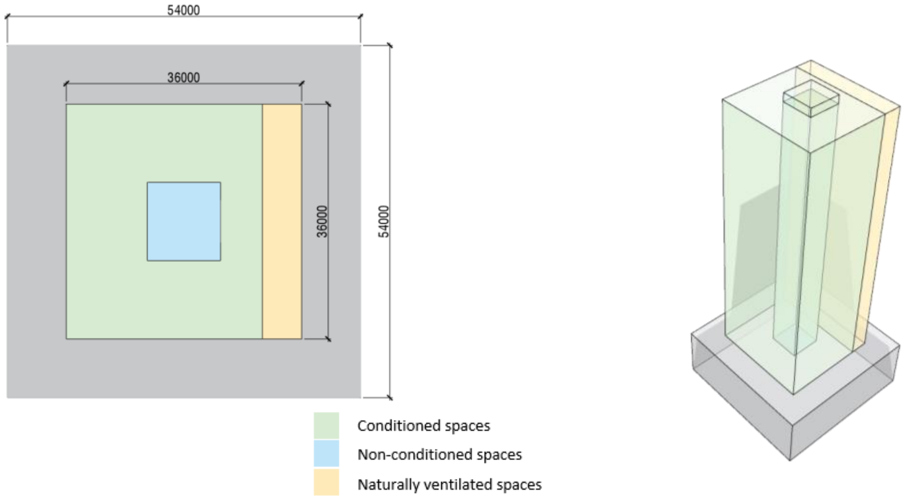


Figure 3.2 Plan and view of simulation model 2

Simulation Model 3

- Square high-rise residential building with a central core and naturally ventilated corridor and circulation.
- Apartment units sub-divided into 12 zones on north, east, south and west orientations (Fig 3.3).

Objective 2

- To compare the overall energy consumption through residential building envelope air conditioned and naturally ventilated spaces.

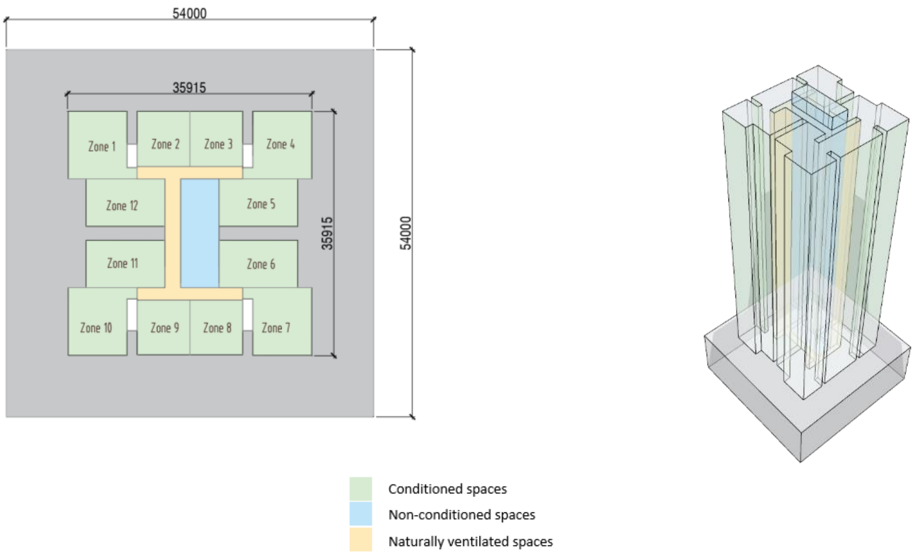


Figure 3.3 Plan and view of simulation model 3

3.4 Computer Simulation and Pilot Study

There are several building performance simulation software programs commercially available in the design industry in current times for users to choose from in solving their tasks. These choices arise as a result of a wide range of factors such as user expertise, user interface, simulation periods and presentation, affordability, availability of technical data and accessible support (Iverson et al., 2013). In addition, to create an accurate simulation study with reliable robust results, a significant amount of time has to be invested to model the building's geometry and mechanical systems, internal loads, construction materials and other building properties (Yezioro, Dong, and Leite 2008).

Capability of the tools in simulating detailed and complex building components and assimilating these components into a design framework is paramount. Therefore, IES-VE and eQuest simulation programs were initially selected based on their sufficient capabilities in handling energy modelling and proven result reliability in the industry (Hoesseini et al., 2021; Elnabawi, 2020, Adrian et al., 2013). The following were the performance criteria for the selection of the appropriate computer simulation tool:

- Building geometry
- Construction parameters
- Weather data
- Simulation schedules
- Hourly performance results

Furthermore, to test the efficiency and results validity of the selected programs, a hypothetical rectangular built form measuring 84m^2 was modelled as a representation of an open office space in the respective sinulation environment of IES-VE and eQuest. Construction and schedule parameters typified the Malaysian practice for a one-year heat gain simulation run. Heat gain performance parameters extracted from the simulation tools include: heat conduction through wall & glazing, solar radiation through glazing. These parameters form the components of the OTTV Malasyia equation (MS1525:2019) which was used to validate the simulation outputs. The heat gain parameters from the simulation were computed and assessed for OTTV (Table 3.2) using the equation below as derived from (Chou and Chang, 1996).

$$\text{OTTV} = \frac{\text{Total heat gain through the building envelope}}{(\text{Total Operation Hrs}) \text{ x } (\text{Total Envelope Area})}$$

$$\text{TD}_{\text{eq}}(1 - \text{WWR})(U_{\text{w}}) = \frac{\sum_{1\text{ year}} Q_{\text{wall,cond}}}{\text{annual operating hours} \times A}$$

$$\Delta T(\text{WWR})\left(U_{\text{f}}\right) = \frac{\sum_{1\text{ year}} Q_{\text{win,cond}}}{\text{annual operating hours} \times A}$$

$$\text{SF}(\text{WWR})(\text{SC}) = \frac{\sum_{1\text{ year}} Q_{\text{win,rad}}}{\text{annual operating hours} \times A}$$

Table 3.2 Simulation results and validation

Simulation Tool	IES-VE	eQuest	Equation (MS1525)
OTTV	34.28	89.81	84.83

Results analysis and previous research show that eQuest is likely a more robust tool for accurately predicting building heat transfer compared to IES-VE (Mostafavi et al., 2013). For energy modelling purposes, the level of control over input parameters that eQUEST allows is significantly better. Contrary to IES-VE, desired level of details and format of the expected results is quite accessible for annual analysis and further evaluation in eQuest.

3.5 Summary

This section has outlined the methodology of the simulation study, starting from the inventory development which led to the generation of the three simulation scenarios in line with the stated research objectives. Furthermore, the criteria for selecting the appropriate dynamic simulation tool for the research was justified after executing a preliminary heat gain simulation comparison between three software tools and subsequent validation with the OTTV equation.

4.0 SIMULATION RESULTS AND FINDINGS

4.1 Introduction

The simulation scenarios and the results generated from the dynamic simulations are presented in this section. The heat gain reduction for conduction and radiation through walls and windows are illustrated and the derived correlation factors are analysed for simulation model 1 while the effect of including NV spaces in the evaluation of OTTV is compared in simulation model 2. In the third model, a comparison between RETV, OTTV and heat gain simulation is presented. The final subsection introduces the overall findings from the study.

4.2 Simulation Model 1

The objective of this simulation is to evaluate the effect of adjacent shading on OTTV performance. A 25-storey commercial building model was developed incorporating building envelope properties assumed to represent conventional design and construction characteristics in Malaysia as referenced in the building inventory. To simplify the simulation model, building A (100m high) was adopted as the test building while B was modelled as the adjacent shade to the right of the test building (Figure 4.1).

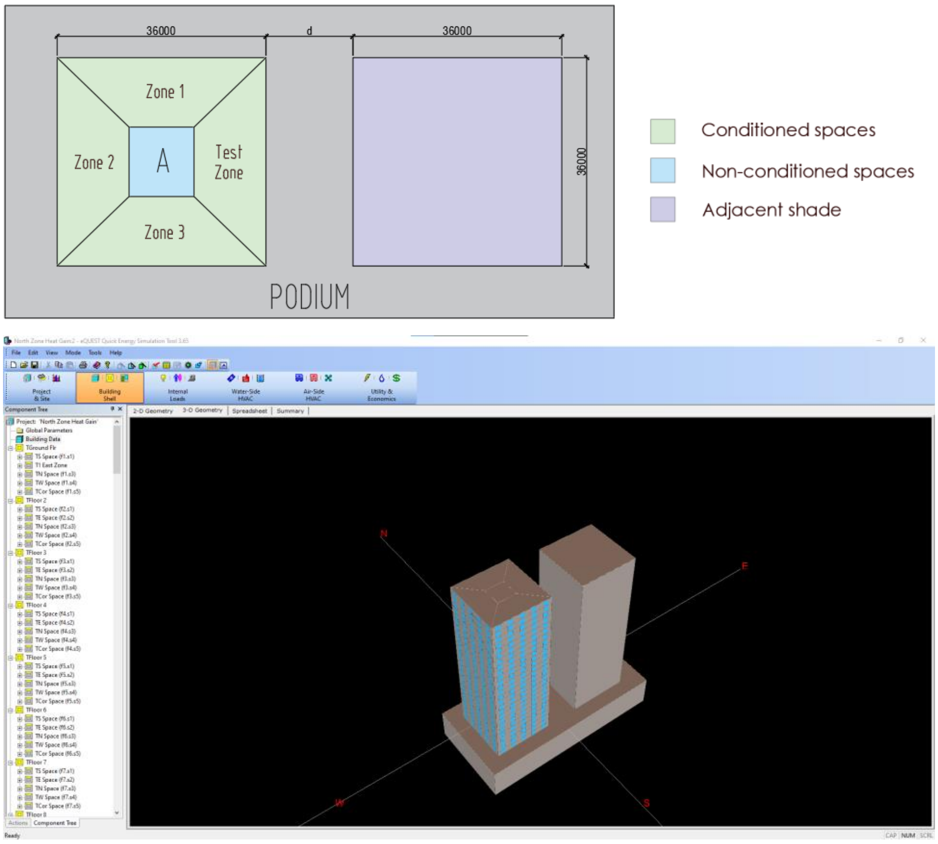


Figure 4.1 Plan and simulation view of simplified model 1

On eight orientations, the simplified model was evaluated for OTTV performance on the test zone façade for a detailed assessment of the three heat gain components over the envelope area using the variables listed in Table 4.1. The results of the models with adjacent shade were compared with a building model without adjacent shading. The heat gain reduction percentage on each floor level were computed for heat gain component. Correlation factors were derived for these components using obstruction angles and shaded area on the façade. Graphical images showing the percentage reduction and correlation factors (CF) based on obstruction angles are outlined in the next section. For a clearer view of the exterior thermal flow in the simulation model, heat flux simulations were carried out for graphical delineations as shown in Figure 4.2.

Table 4.1. Simulation variables

Ratio	Distance (m)	Height(m)
1:1	20	20
1:2		40
1:3		60
1:4		80
1:5		100
1:10	10	100
1:3	30	90
2:5	40	100

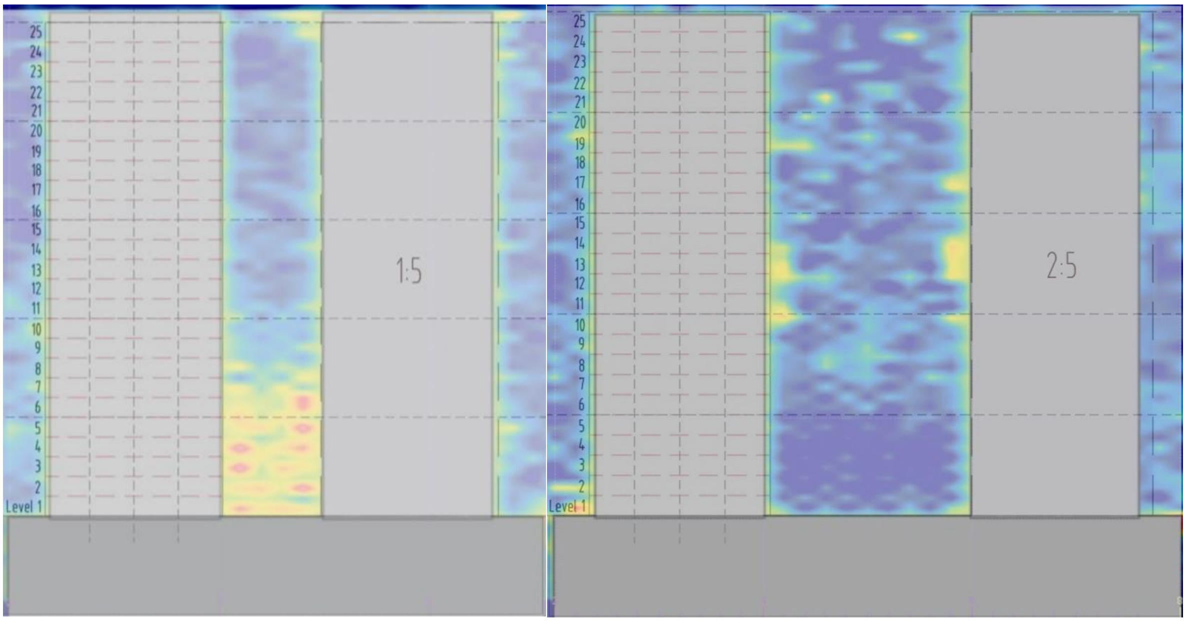
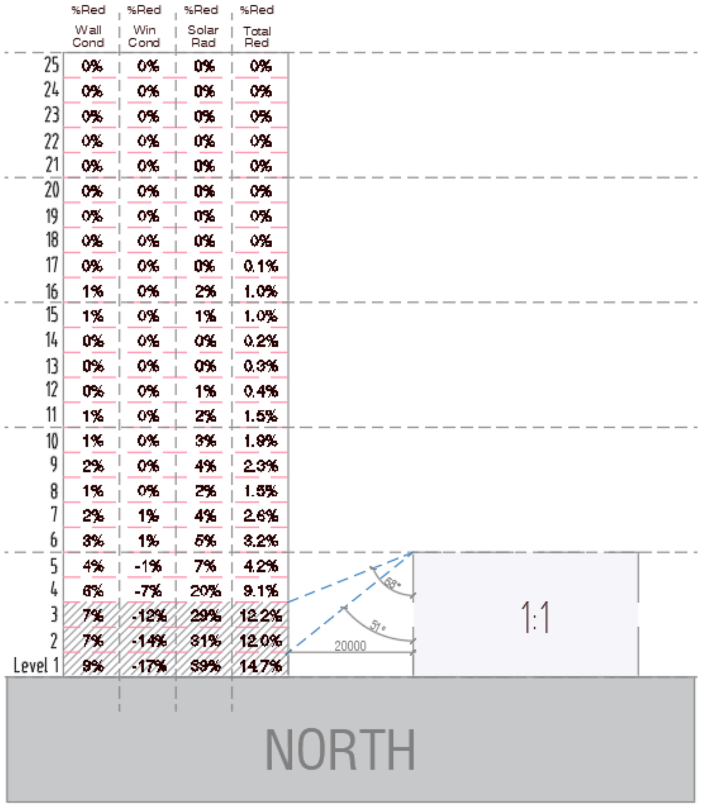
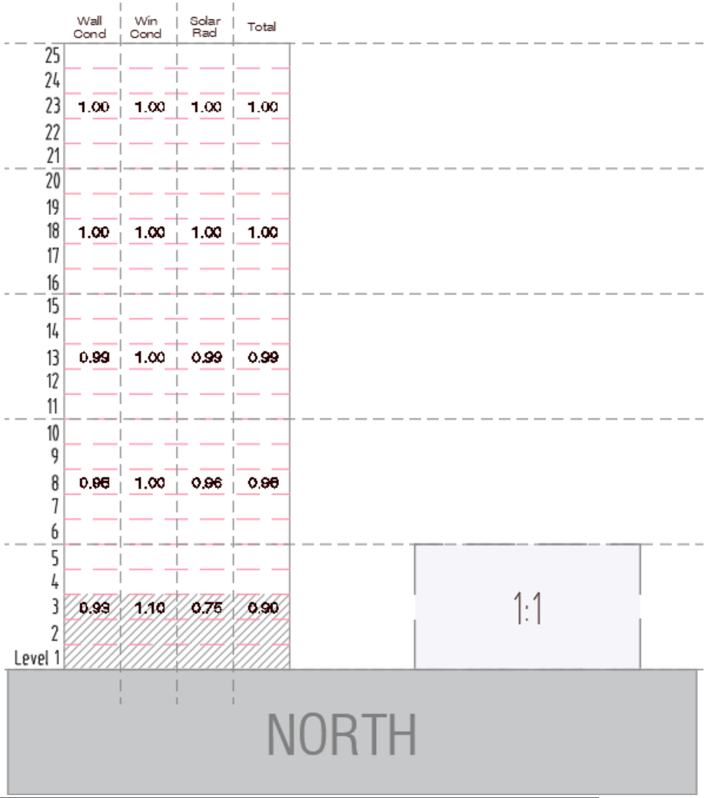


Figure 4.2 Heat flux images of simulation model

4.2.1 Ratio 1:1 (d=20m)

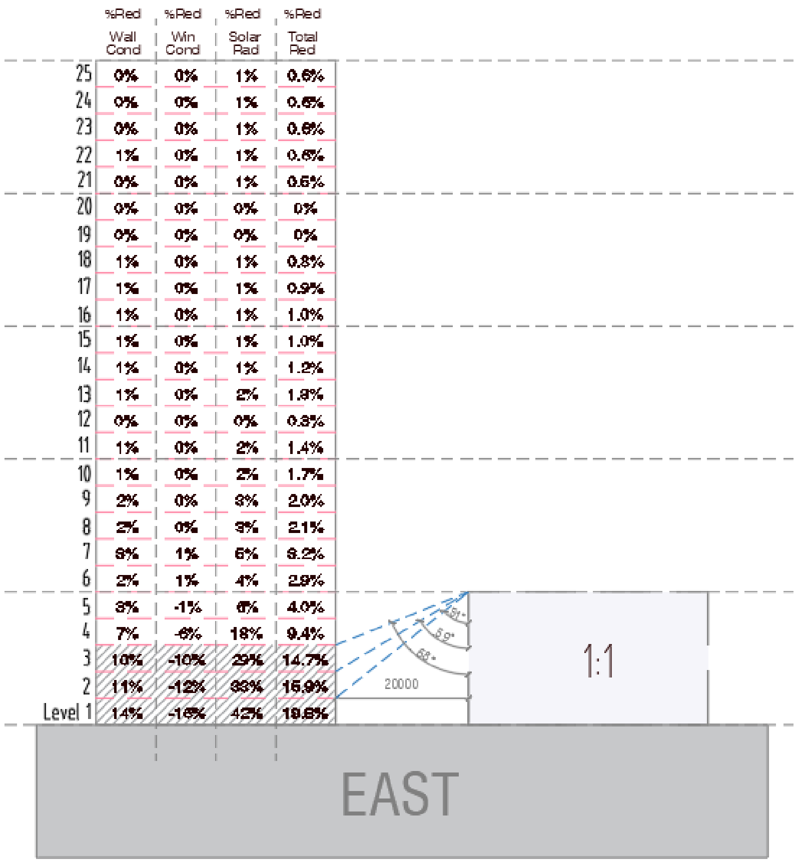
A: NORTH ORIENTATION

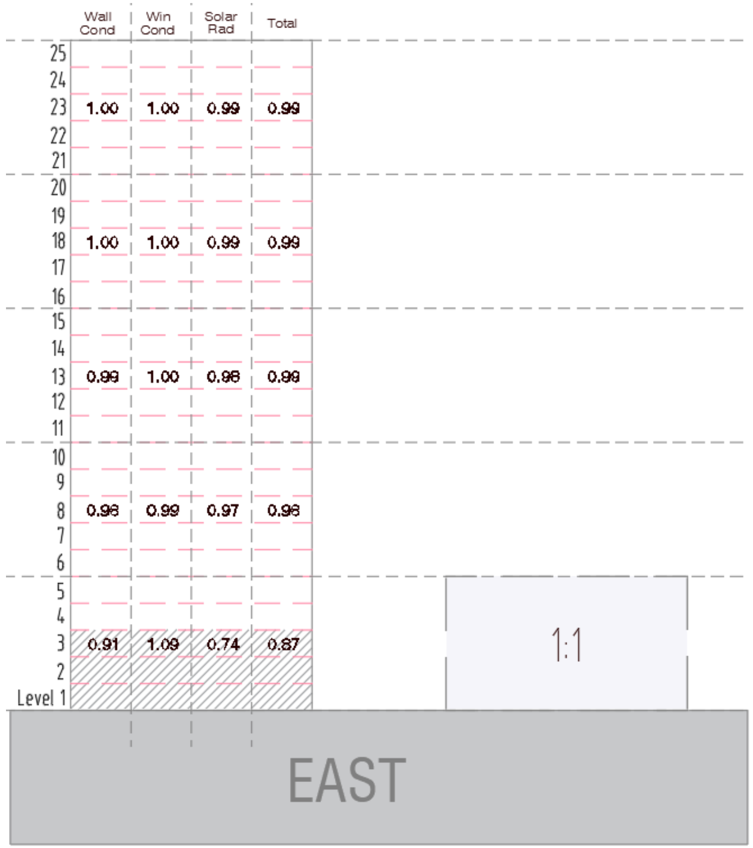




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
North	70	1:1	0.93	1.07	0.70	0.88
	50		0.91	1.17	0.61	0.85

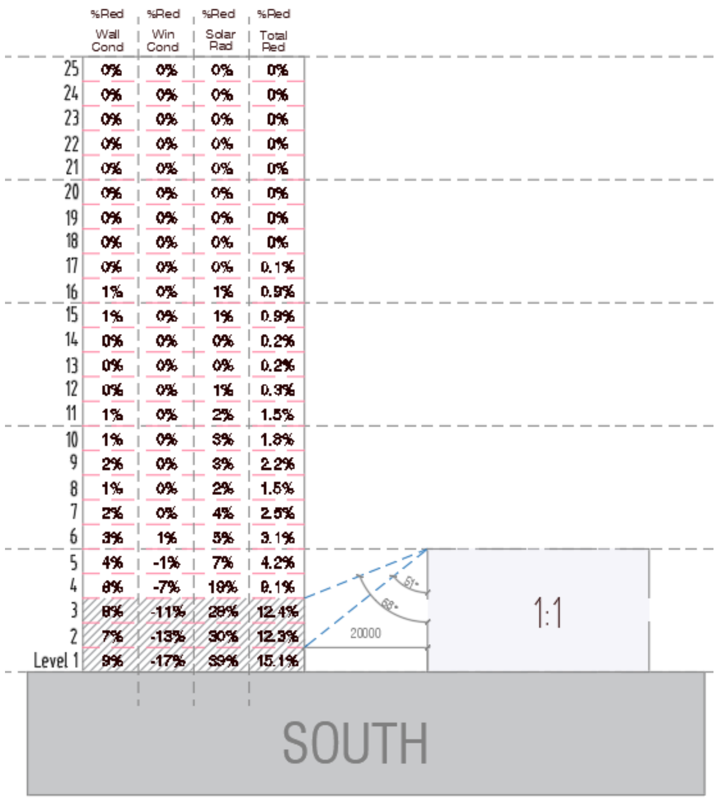
B. EAST ORIENTATION

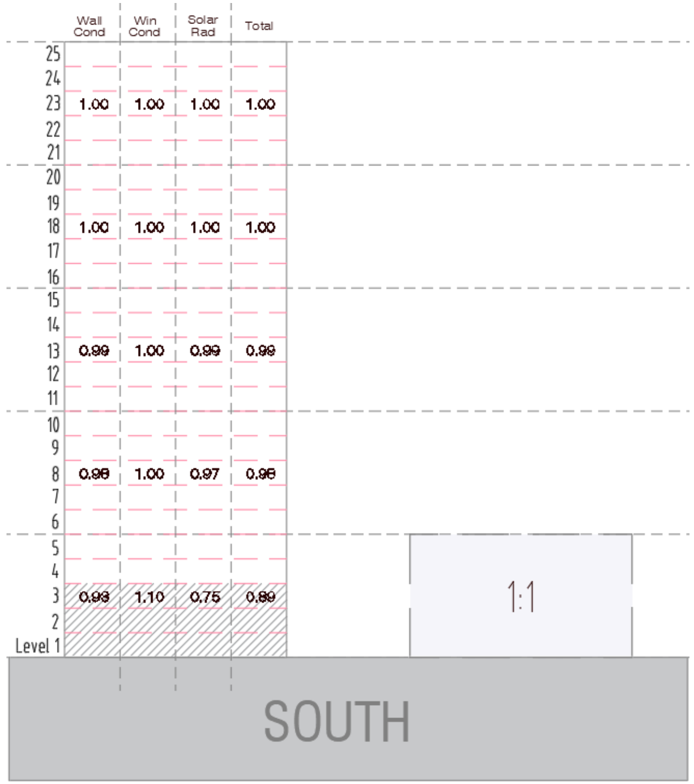




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
East	70	1:1	0.90	1.10	0.71	0.85
	60		0.89	1.12	0.67	0.84
	50		0.86	1.16	0.58	0.80

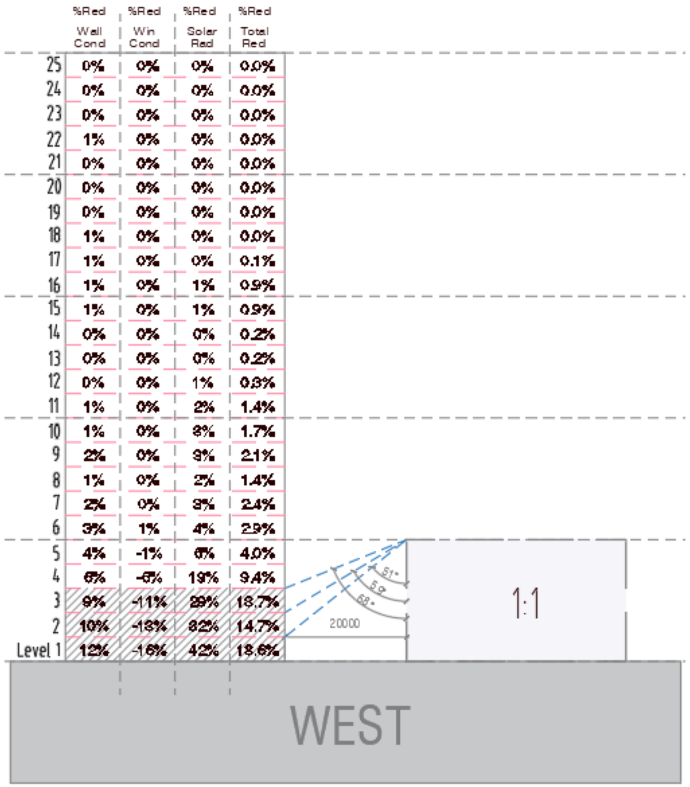
C. SOUTH ORIENTATION

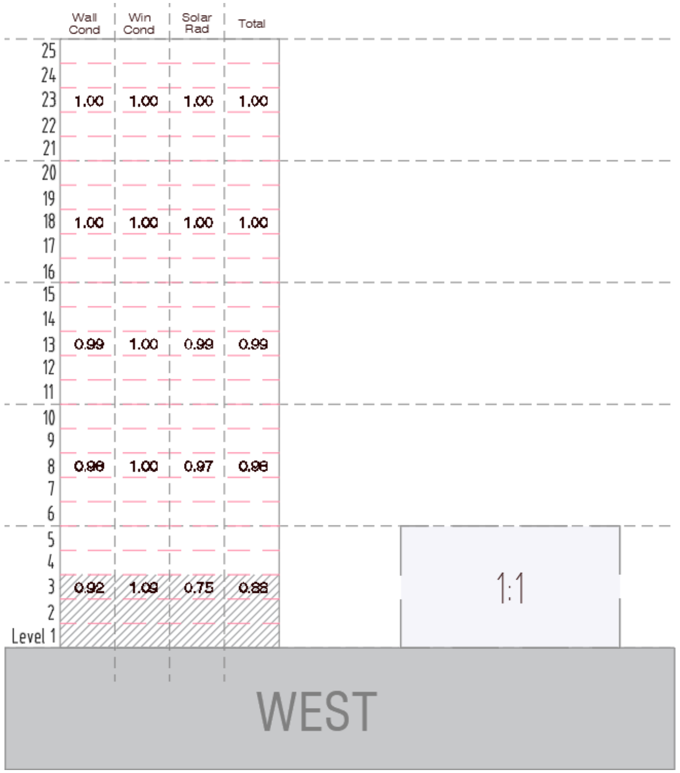




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
South	70	1:1	0.93	1.12	0.71	0.88
	50		0.91	1.17	0.61	0.85

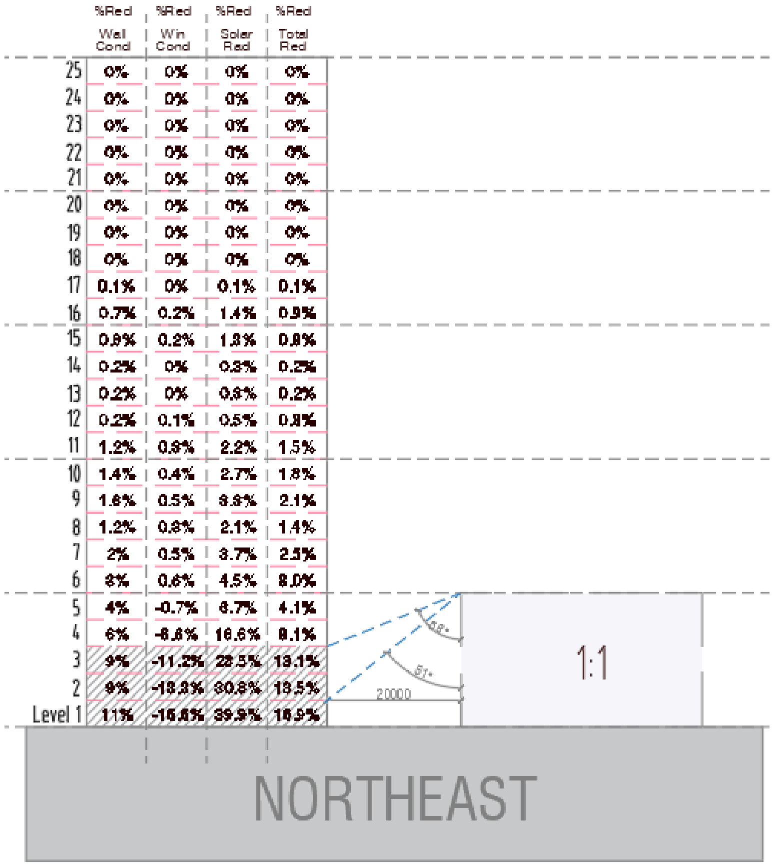
D. WEST ORIENTATION

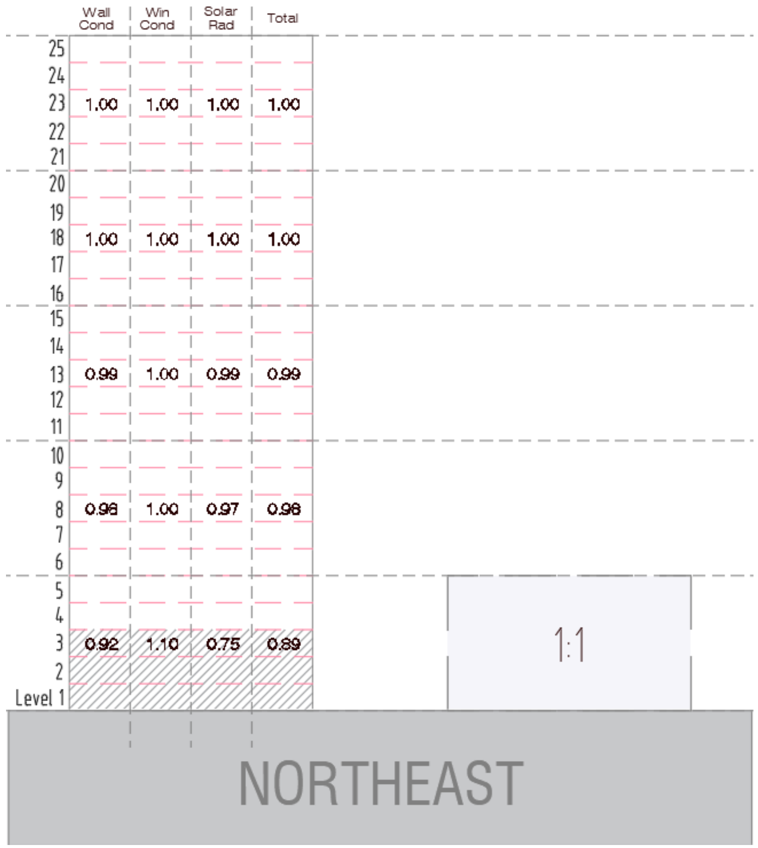




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
West	70	1:1	0.90	1.10	0.71	0.85
	60		0.89	1.12	0.67	0.84
	50		0.86	1.16	0.58	0.80

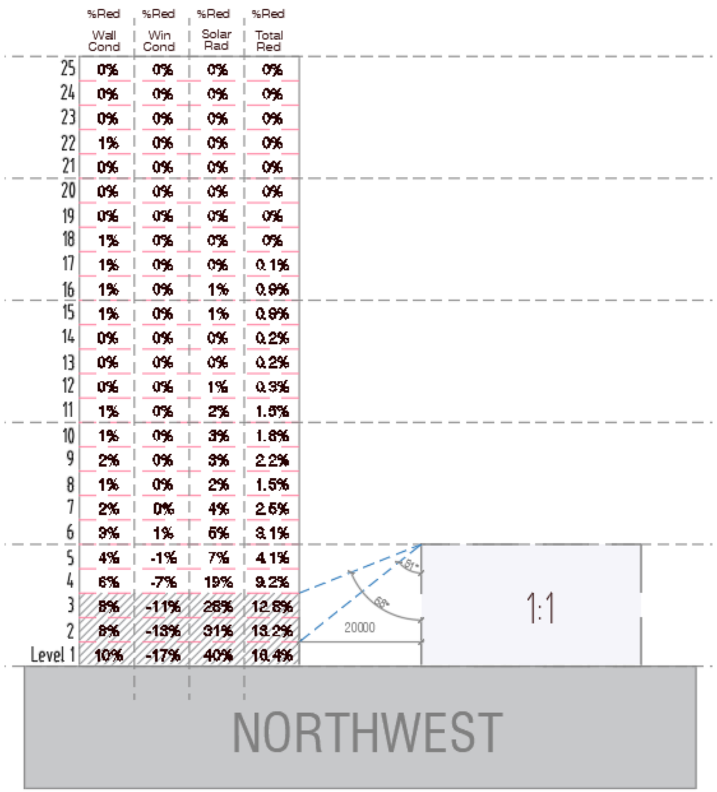
E. NORTHEAST ORIENTATION

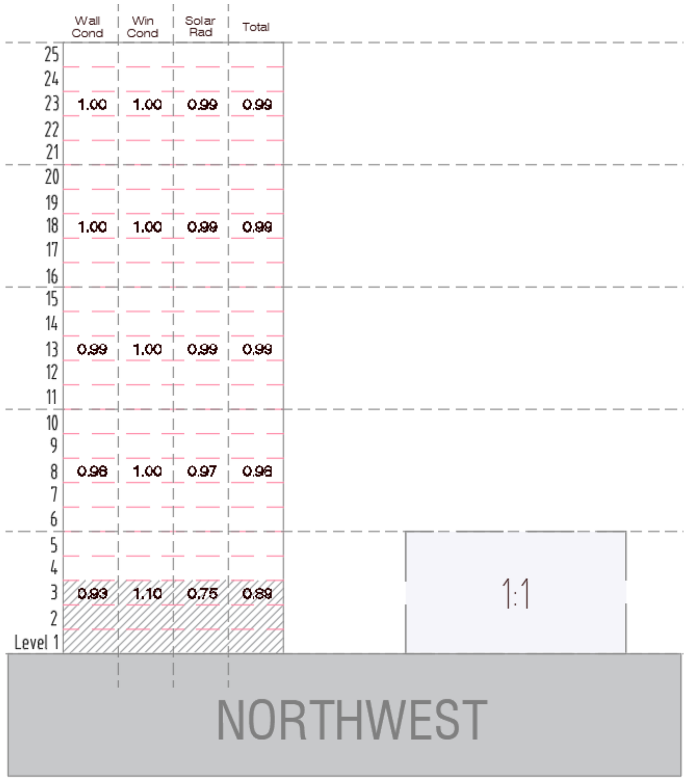




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
NE	70	1:1	0.91	1.12	0.70	0.87
	50		0.89	1.17	0.60	0.83

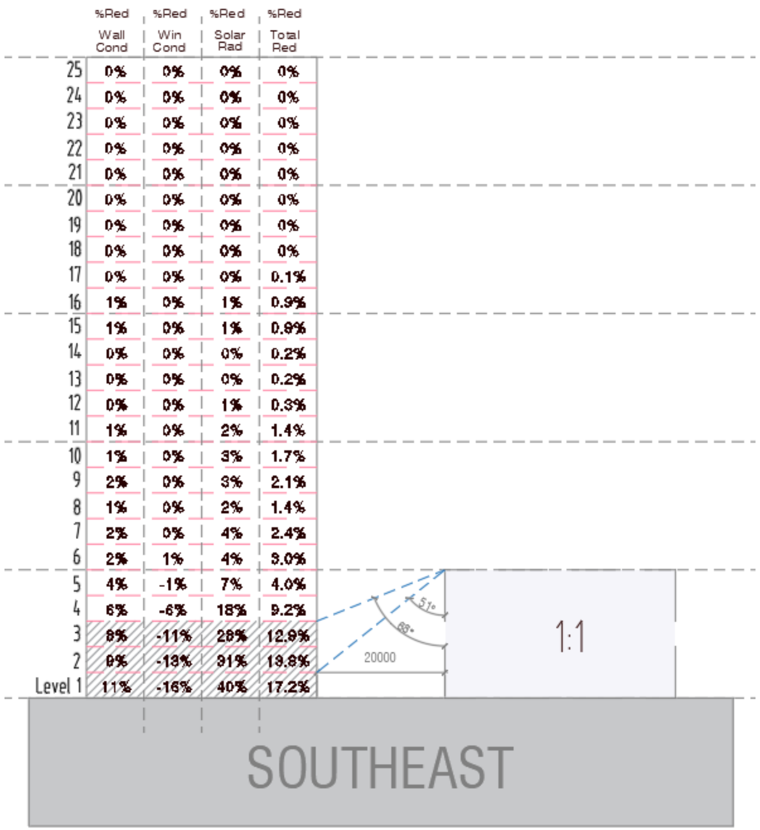
F. NORTHWEST ORIENTATION

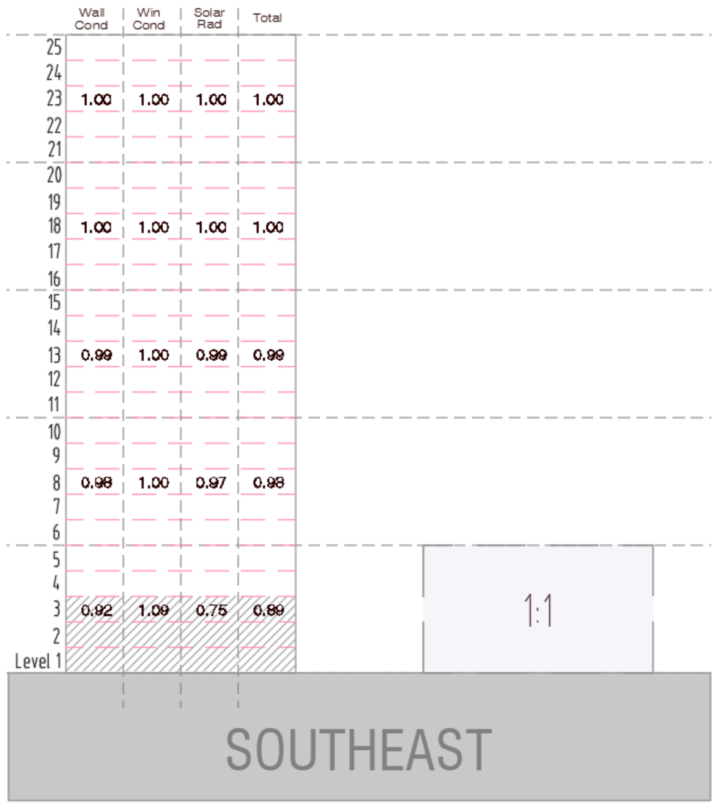




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
NW	70	1:1	0.92	1.12	0.70	0.87
	50		0.90	1.17	0.60	0.86

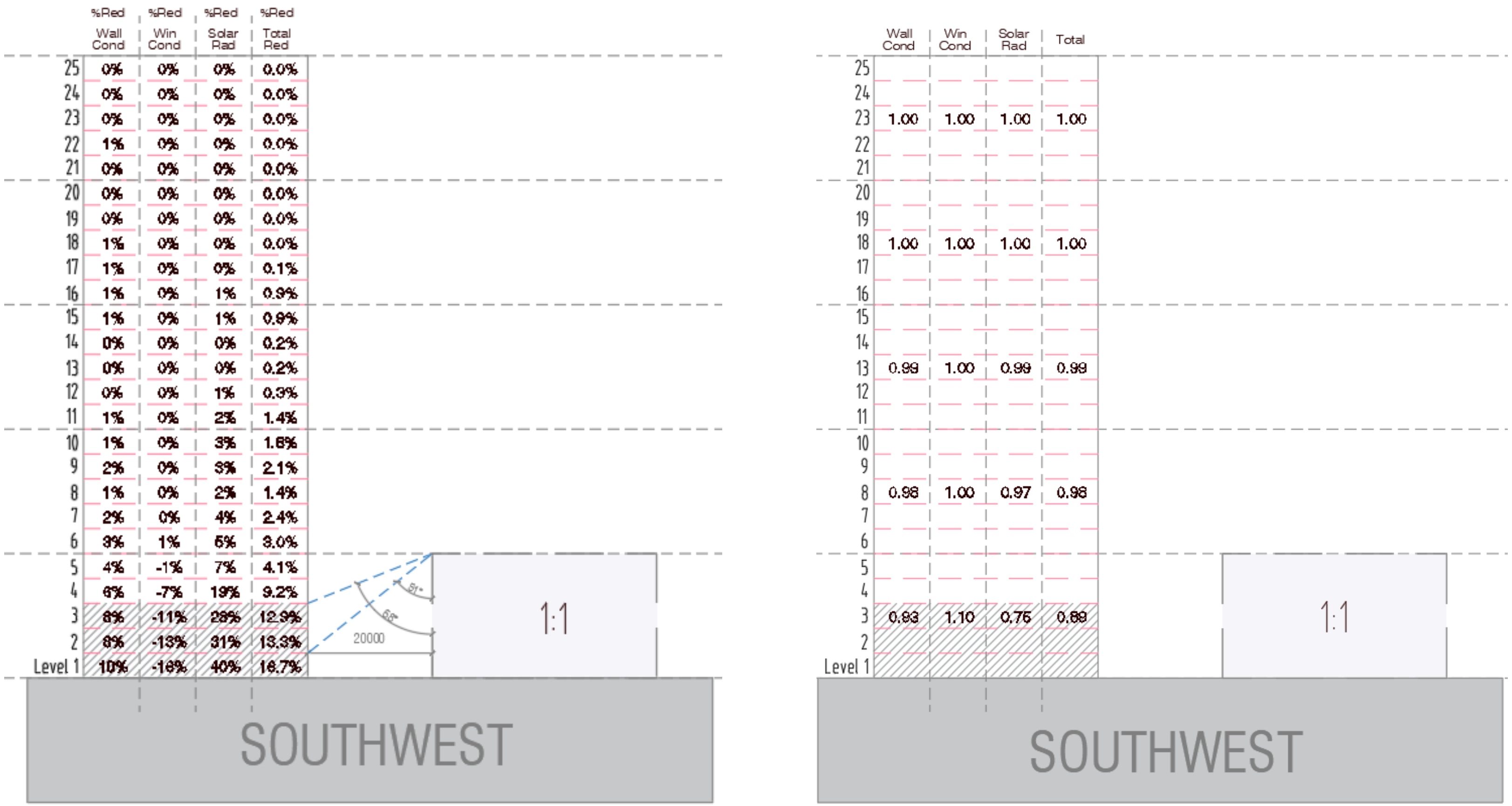
G. SOUTHEAST ORIENTATION





Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
SE	70	1:1	0.91	1.12	0.71	0.87
	50		0.89	1.16	0.60	0.83

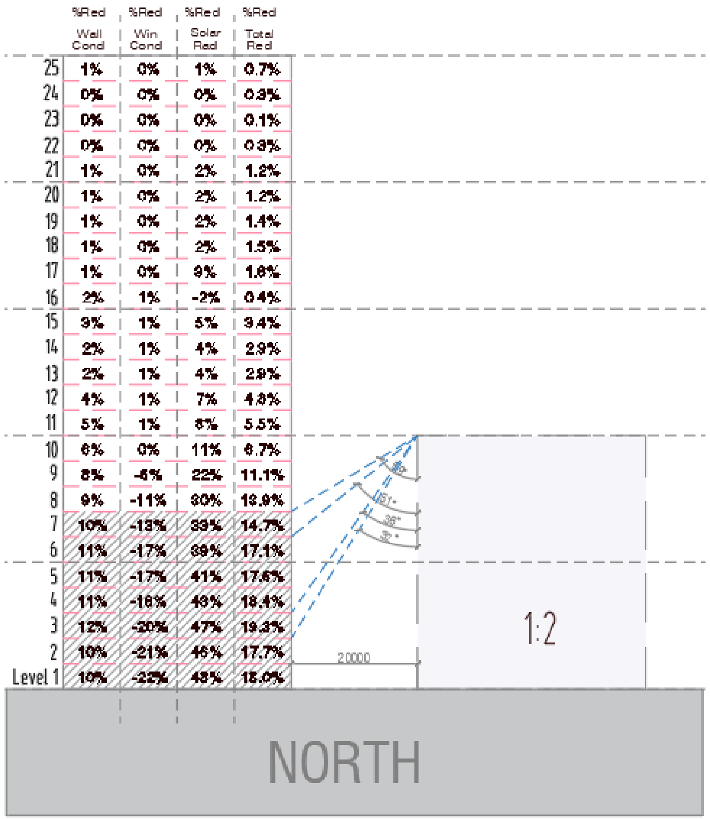
H. SOUTHWEST ORIENTATION

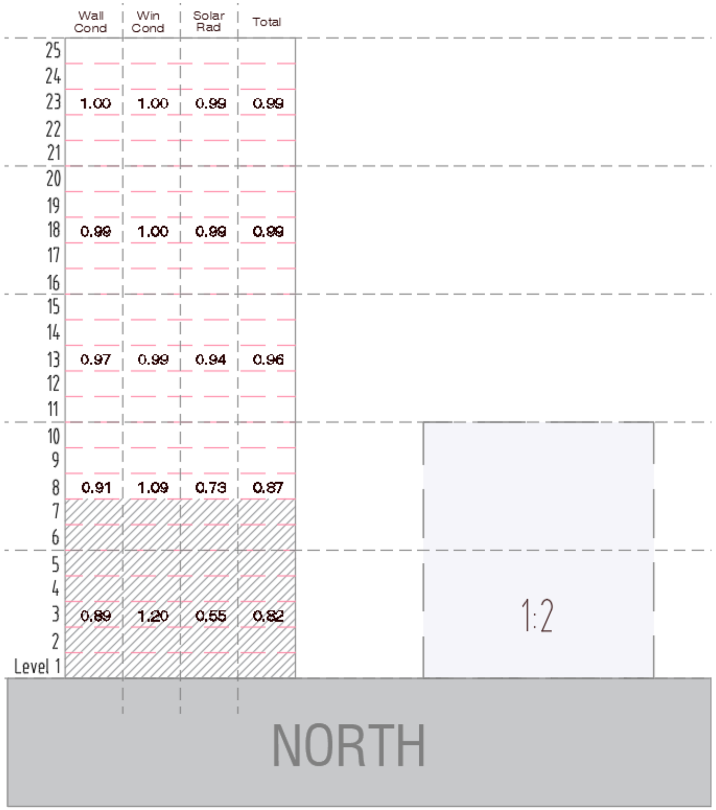


Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
SW	70	1:1	0.92	1.12	0.71	0.87
	50		0.90	1.16	0.60	0.83

4.2.2 Ratio 1:2 (d=20m)

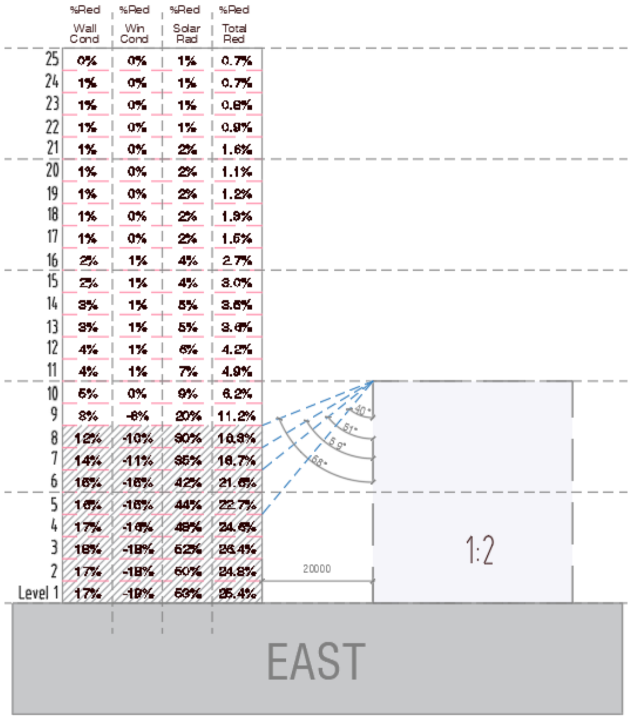
A. NORTH ORIENTATION

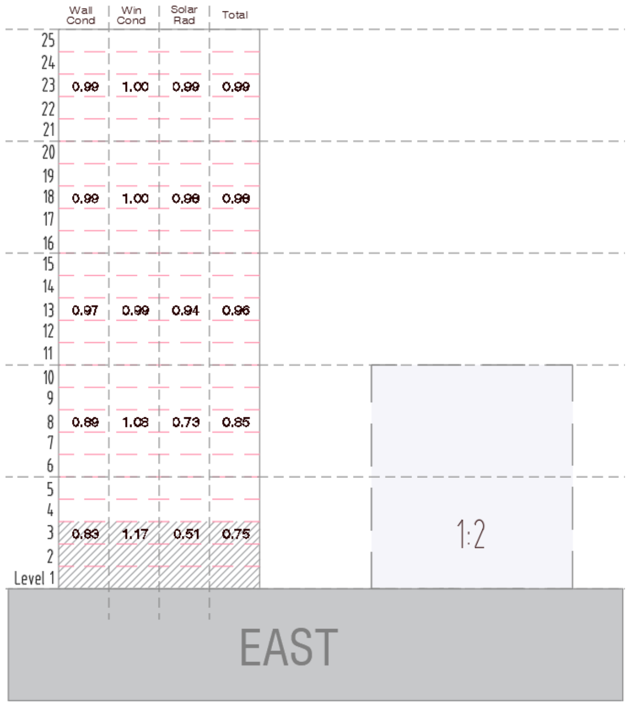




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
North	60	1:2	0.90	1.13	0.67	0.85
	50		0.89	1.17	0.59	0.82
	30		0.90	1.21	0.53	0.82

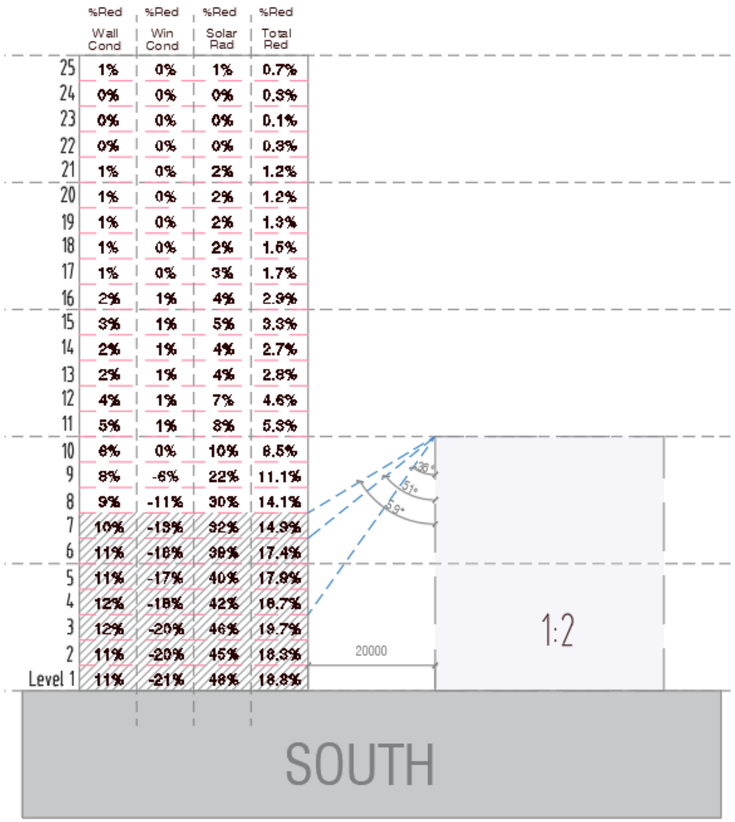
B. EAST ORIENTATION

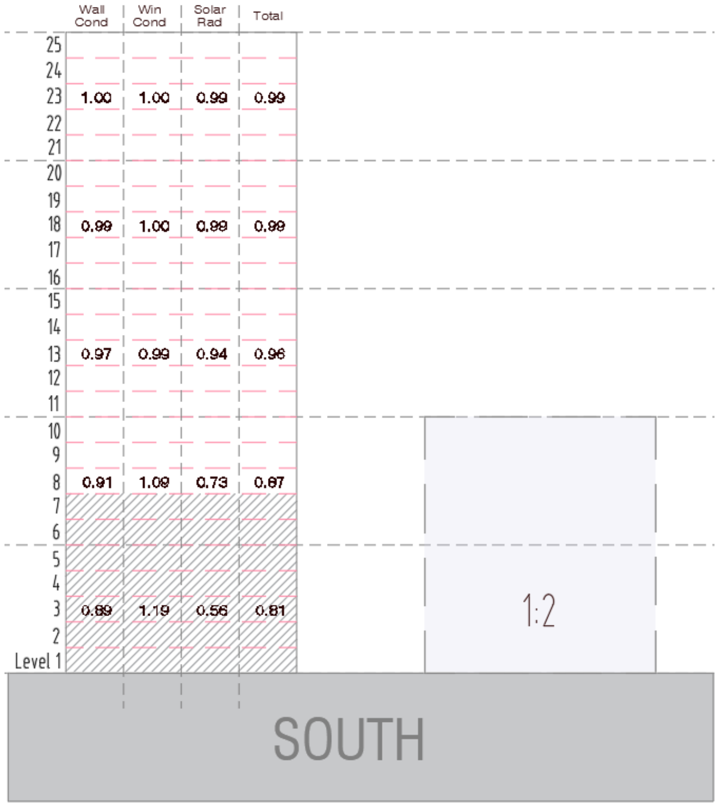




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
East	70	1:2	0.88	1.10	0.70	0.84
	60		0.86	1.11	0.65	0.81
	50		0.84	1.15	0.57	0.78
	40		0.82	1.18	0.49	0.75

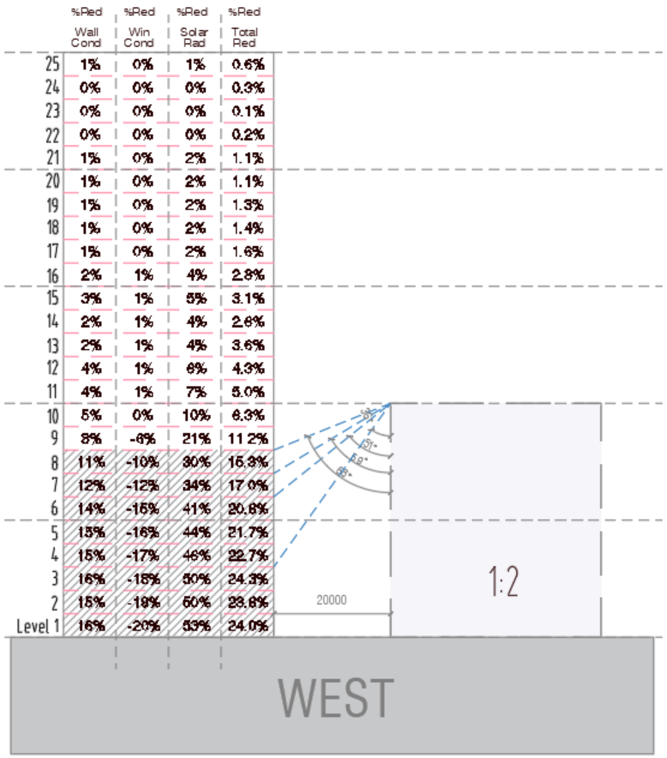
C. SOUTH ORIENTATION

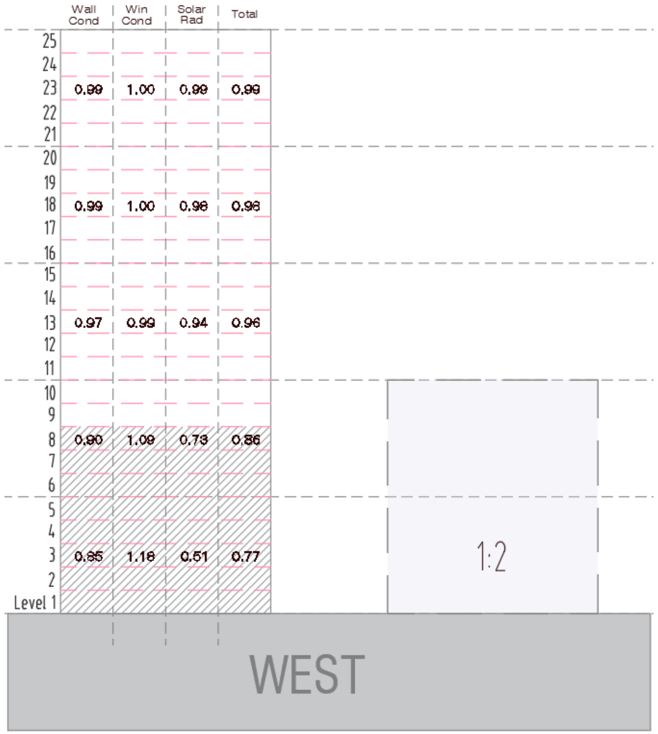




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
South	60	1:2	0.90	1.13	0.68	0.85
	50		0.89	1.17	0.59	0.87
	30		0.89	1.20	0.54	0.81

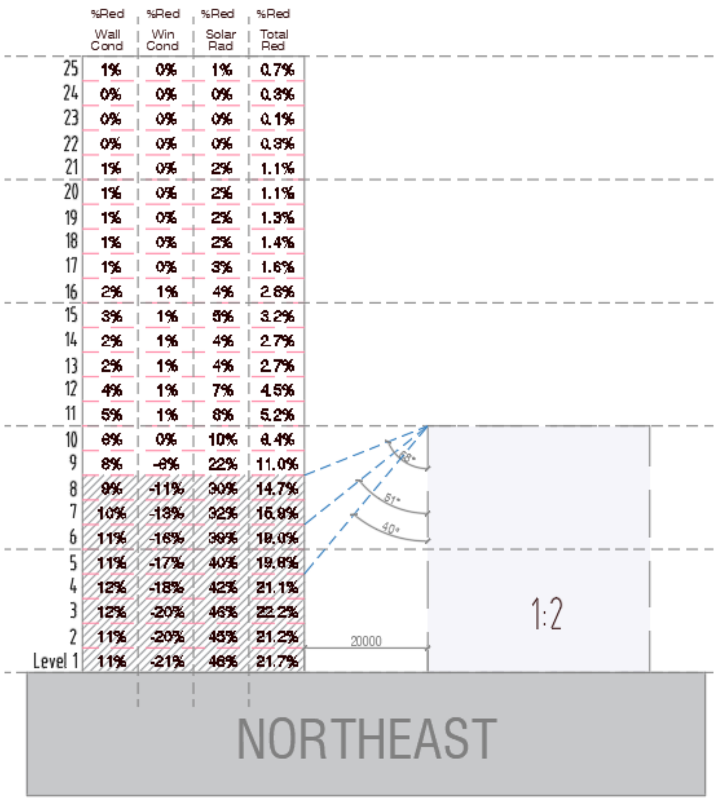
D. WEST ORIENTATION

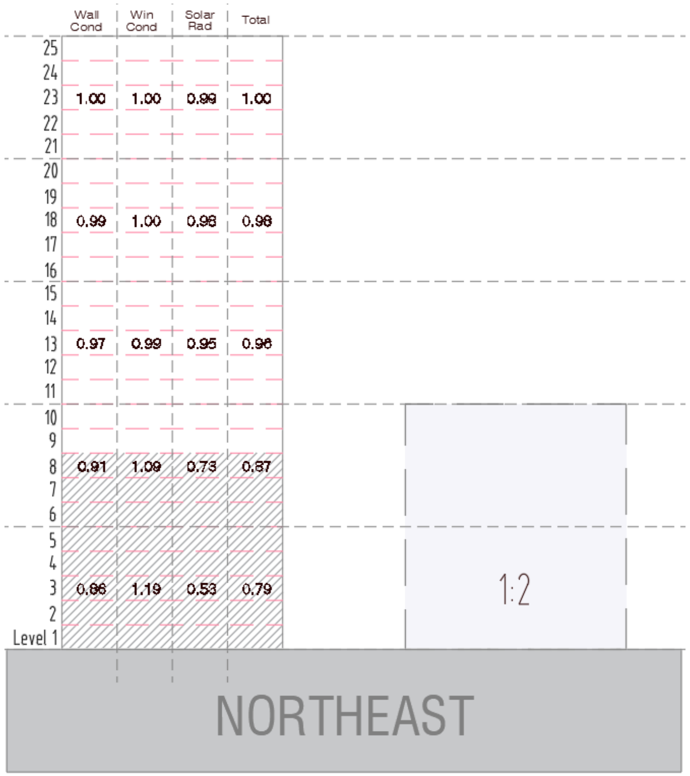




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
West	70	1:2	0.89	1.10	0.70	0.85
	60		0.88	1.12	0.66	0.83
	50		0.85	1.16	0.56	0.78
	40		0.84	1.19	0.49	0.76

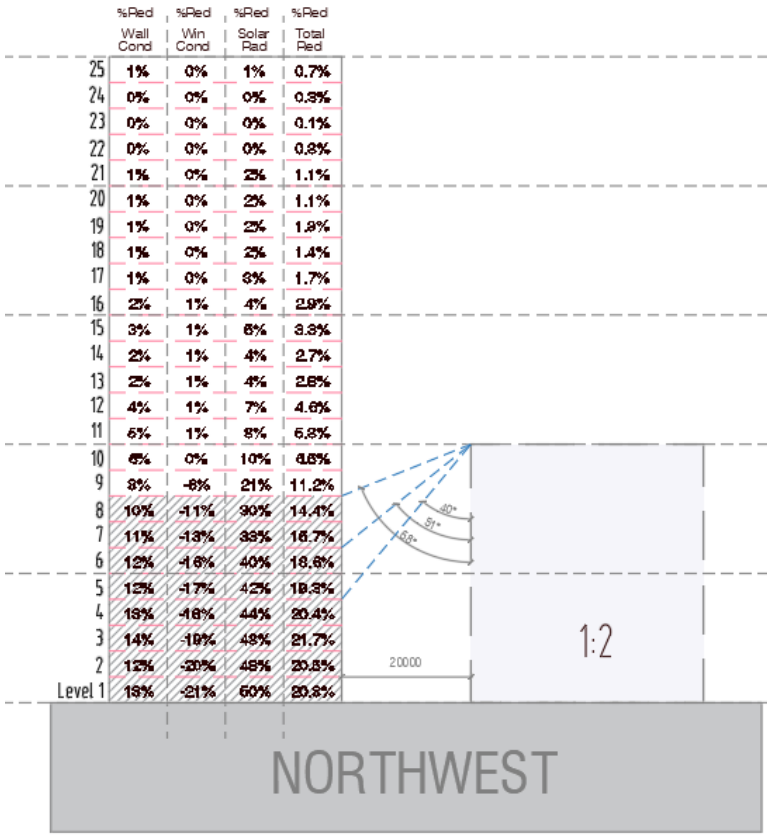
E. NORTHEAST ORIENTATION

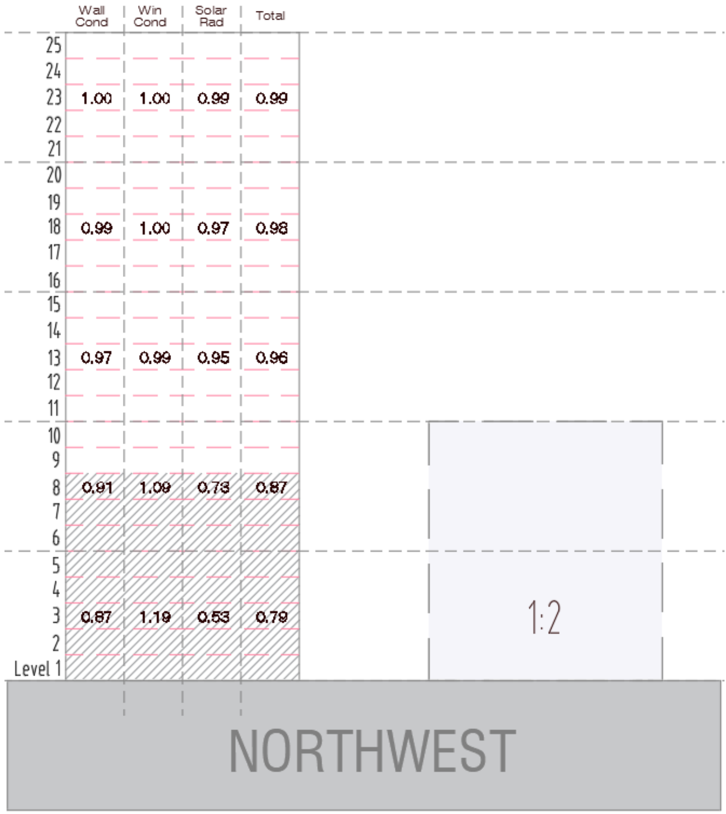




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northeast	70	1:2	0.89	1.12	0.69	0.85
	50		0.87	1.16	0.59	0.81
	40		0.86	1.19	0.52	0.78

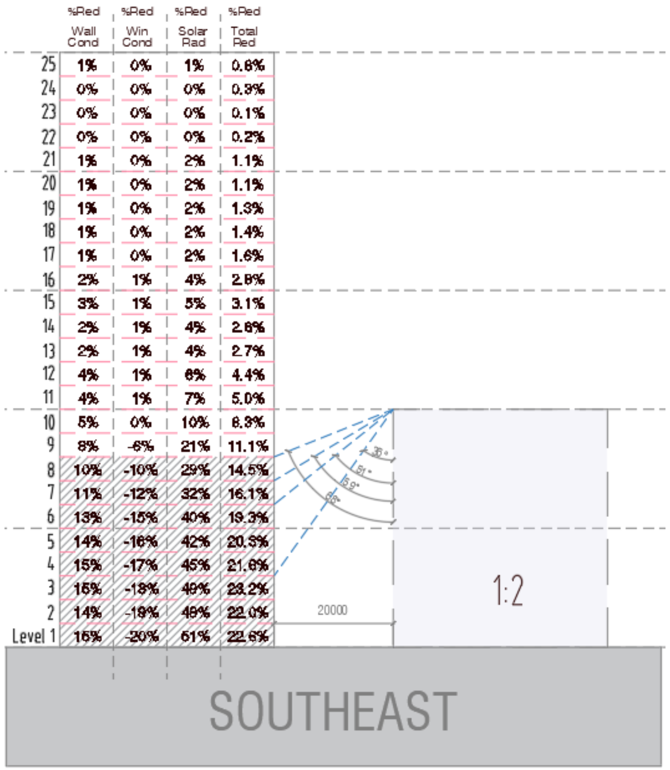
F. NORTHWEST ORIENTATION

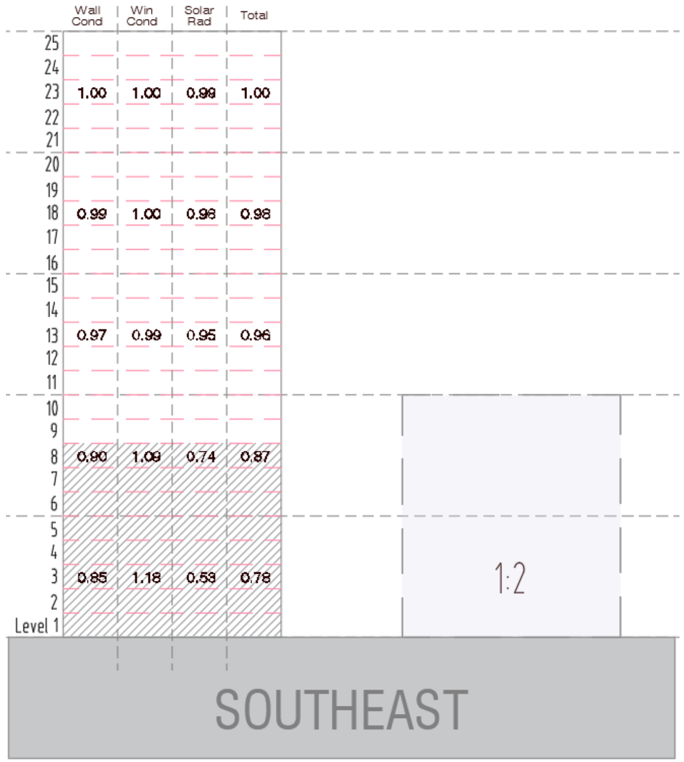




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northwest	70	1:2	0.90	1.12	0.69	0.85
	50		0.88	1.16	0.59	0.81
	40		0.87	1.19	0.52	0.79

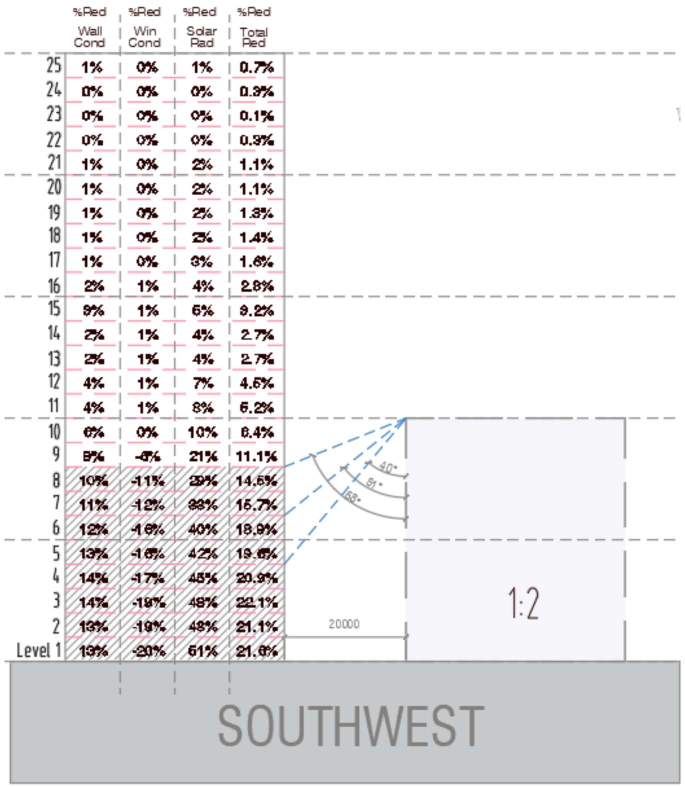
G. SOUTHEAST ORIENTATION





Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southeast	70	1:2	0.90	1.10	0.71	0.85
	60		0.89	1.12	0.68	0.84
	50		0.86	1.16	0.58	0.80
	40		0.85	1.19	0.51	0.77

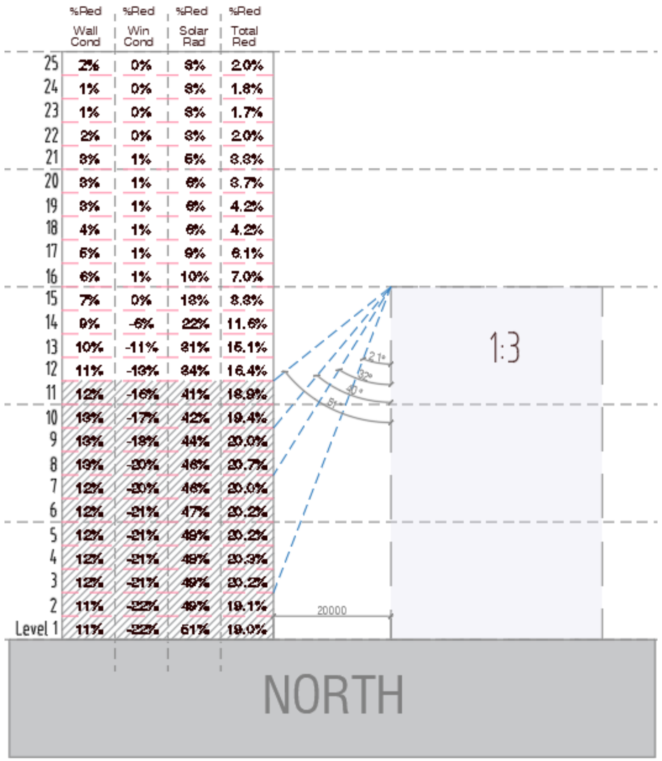
H. SOUTHWEST ORIENTATION

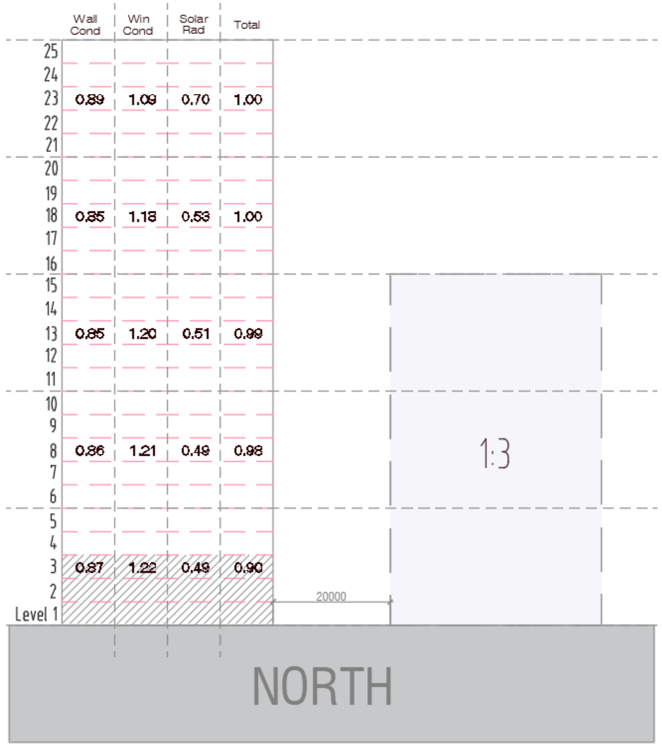


Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southwest	70	1:2	0.90	1.11	0.69	0.85
	50		0.87	1.16	0.59	0.81
	40		0.86	1.19	0.52	0.79

4.2.3 Ratio 1:3 (d=20m)

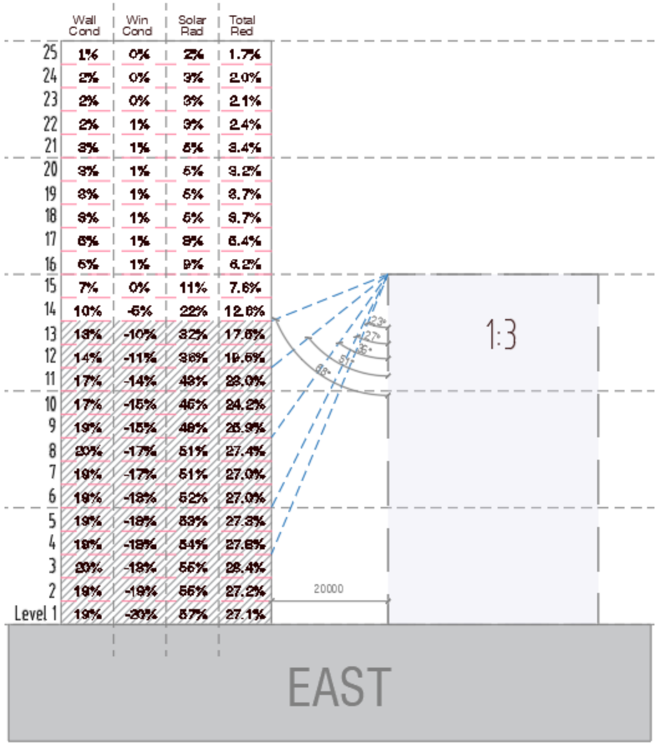
A. NORTH ORIENTATION

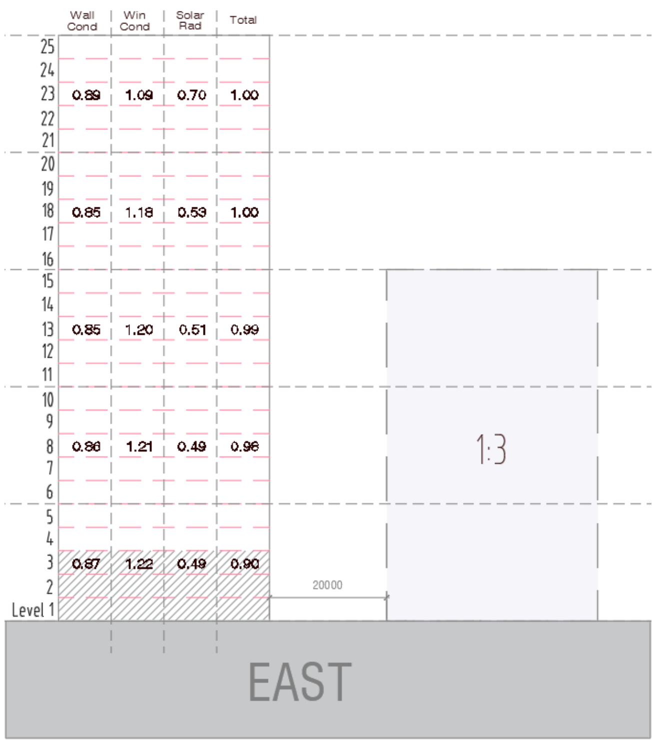




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
North	50	1:3	0.87	1.16	0.58	0.81
	40		0.87	1.19	0.55	0.80
	30		0.88	1.21	0.52	0.80
	20		0.89	1.22	0.50	0.80

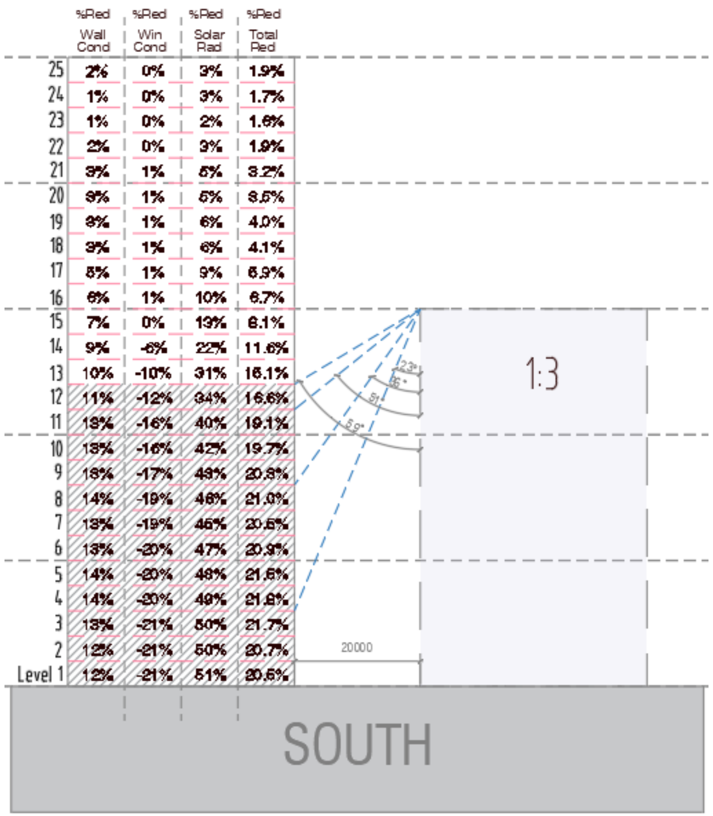
B. EAST ORIENTATION

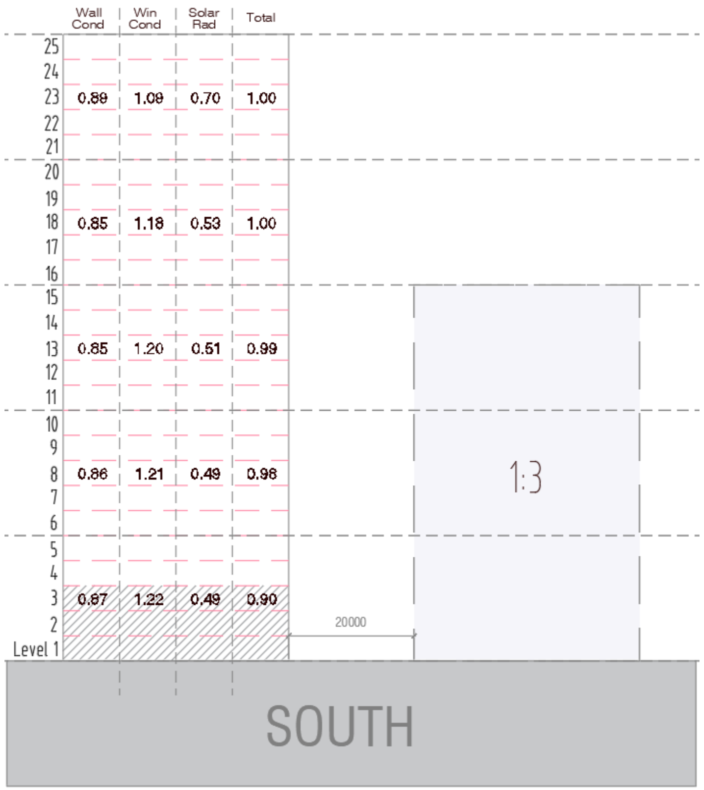




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
East	70	1:3	0.86	1.10	0.66	0.81
	60		0.82	1.15	0.55	0.76
	50		0.81	1.17	0.48	0.73
	40		0.81	1.18	0.47	0.72
	20		0.81	1.20	0.43	0.72

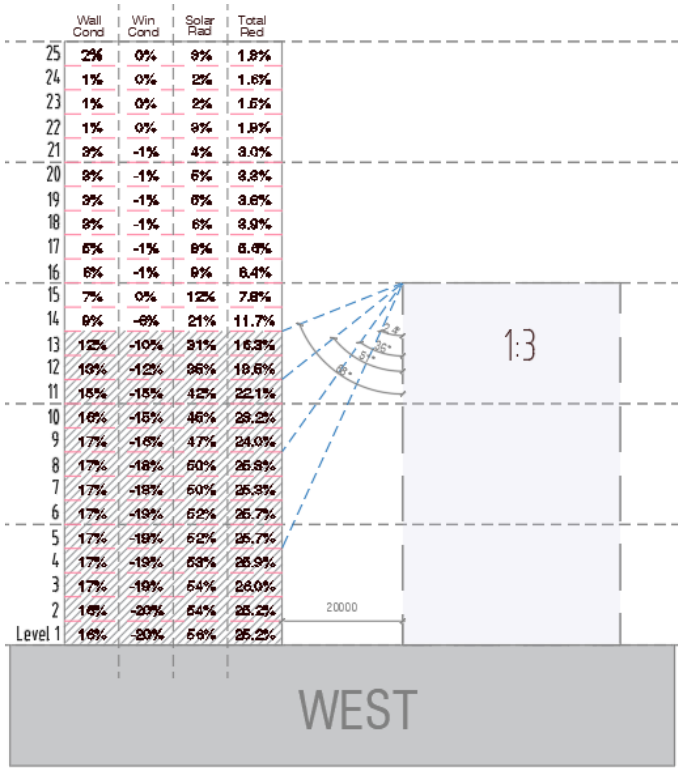
C. SOUTH ORIENTATION

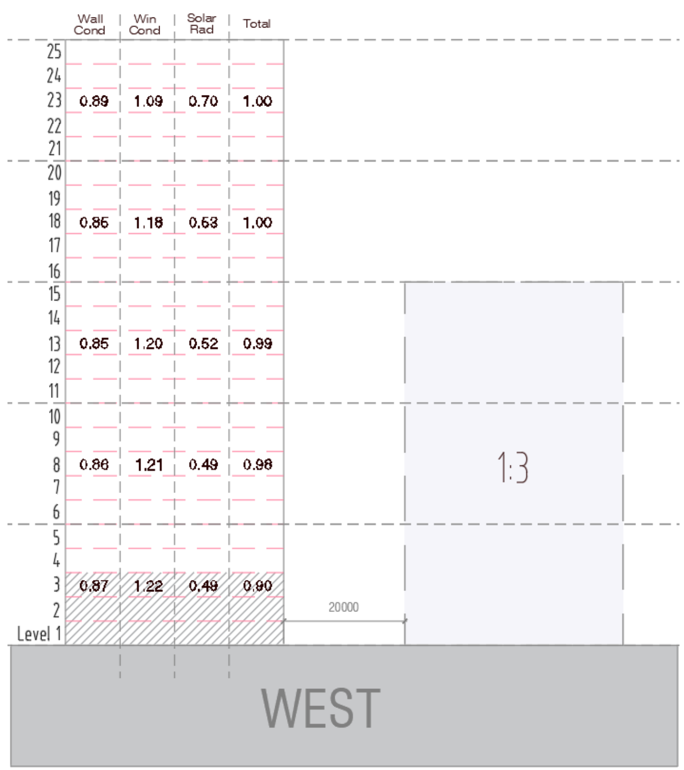




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
South	60	1:3	0.89	1.12	0.66	0.83
	50		0.13	1.16	0.42	0.80
	30		0.13	1.20	0.47	0.79
	20		0.13	1.21	0.50	0.78

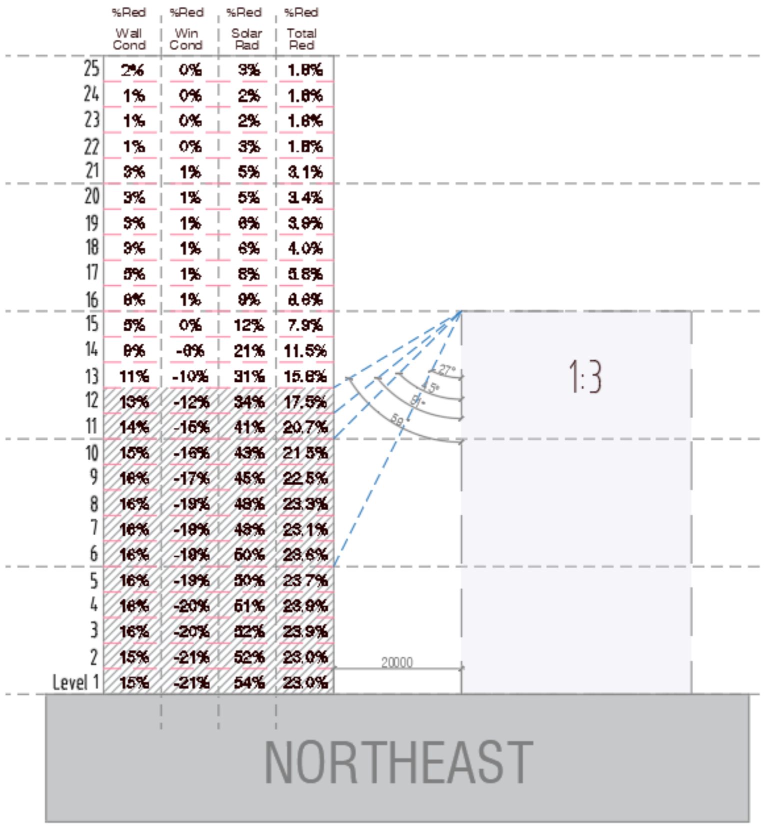
D. WEST ORIENTATION

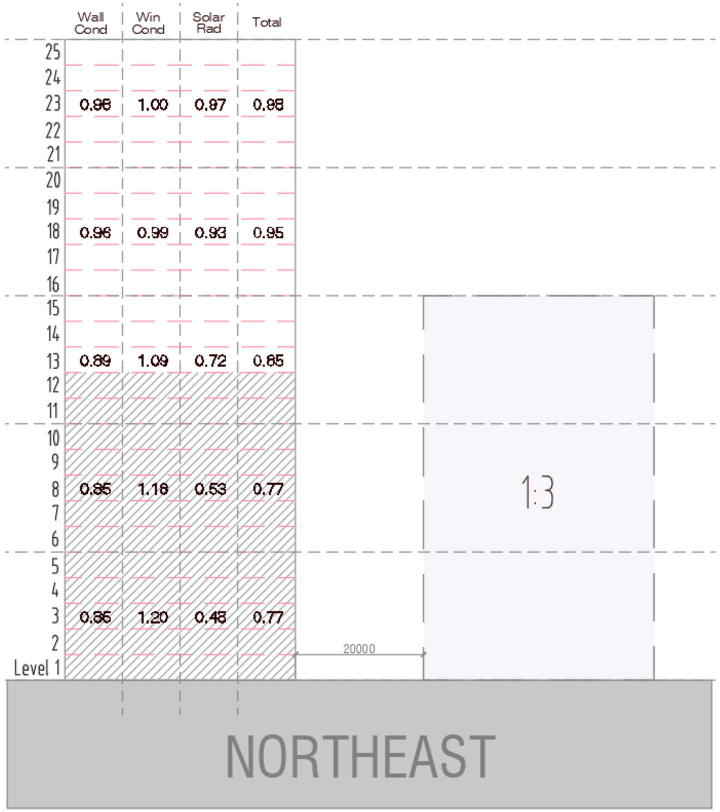




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
West	70	1:3	0.87	1.11	0.67	0.83
	50		0.84	1.15	0.55	0.77
	40		0.83	1.19	0.48	0.74
	30		0.84	1.20	0.44	0.74

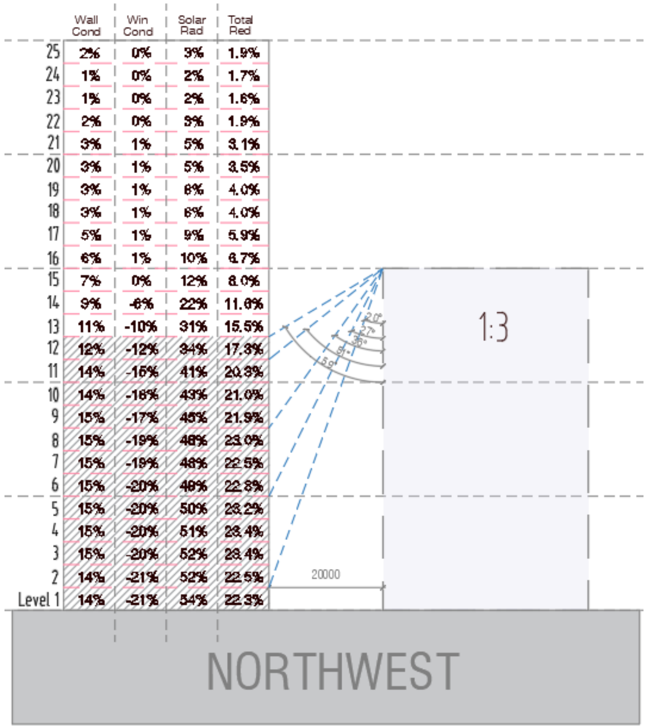
E. NORTHEAST ORIENTATION

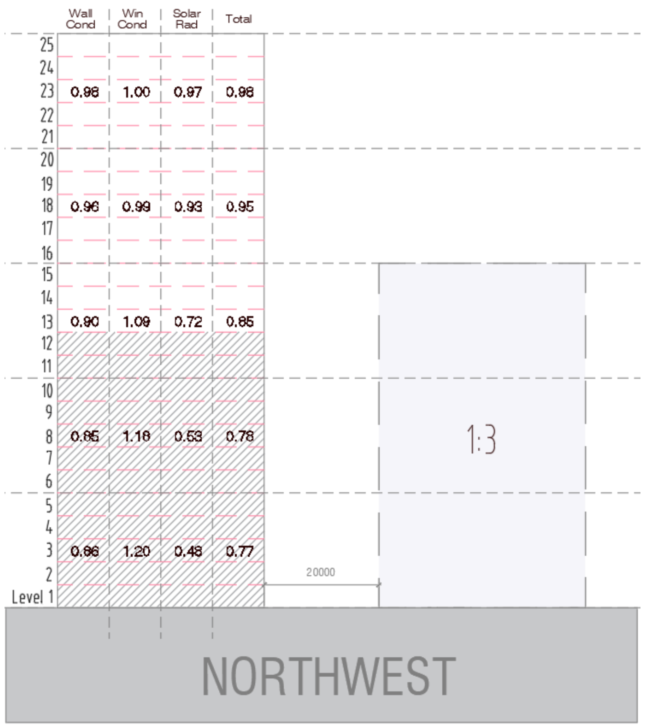




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northeast	60	1:3	0.87	1.12	0.66	0.82
	50		0.86	1.15	0.59	0.79
	40		0.85	1.18	0.53	0.77
	30		0.85	1.20	0.48	0.77

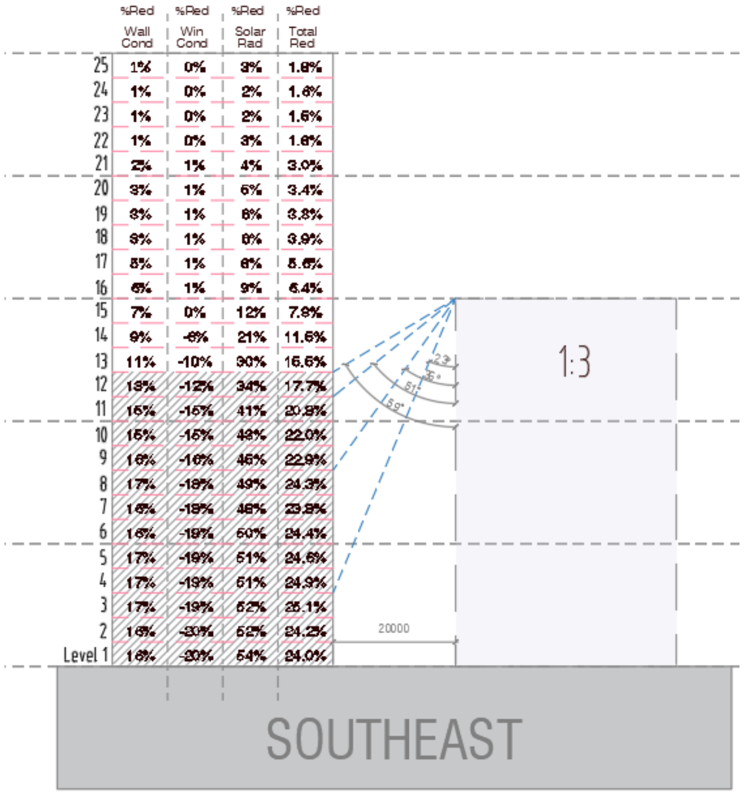
F. NORTHWEST ORIENTATION

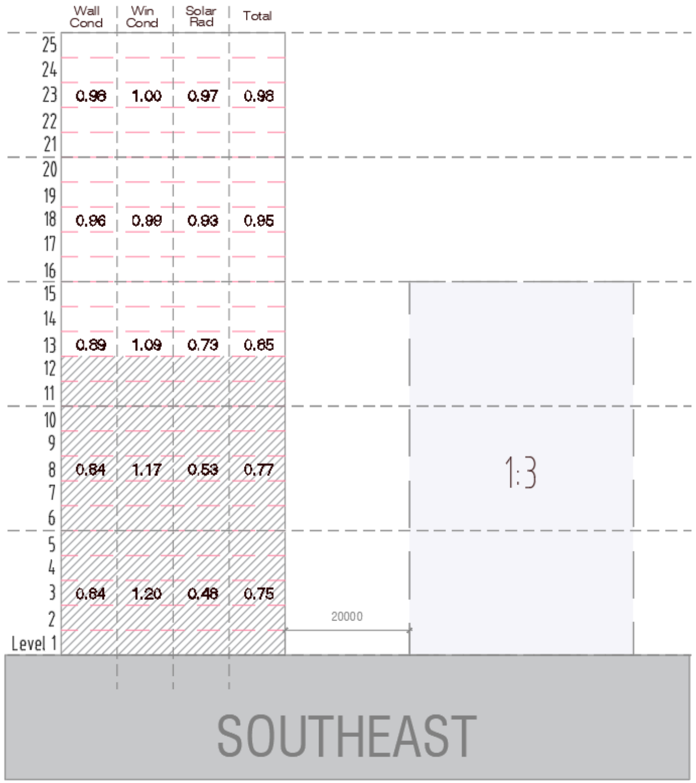




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northwest	60	1:3	0.88	1.12	0.66	0.83
	50		0.86	1.16	0.57	0.79
	40		0.85	1.19	0.52	0.77
	30		0.85	1.20	0.49	0.77
	20		0.86	1.21	0.46	0.77

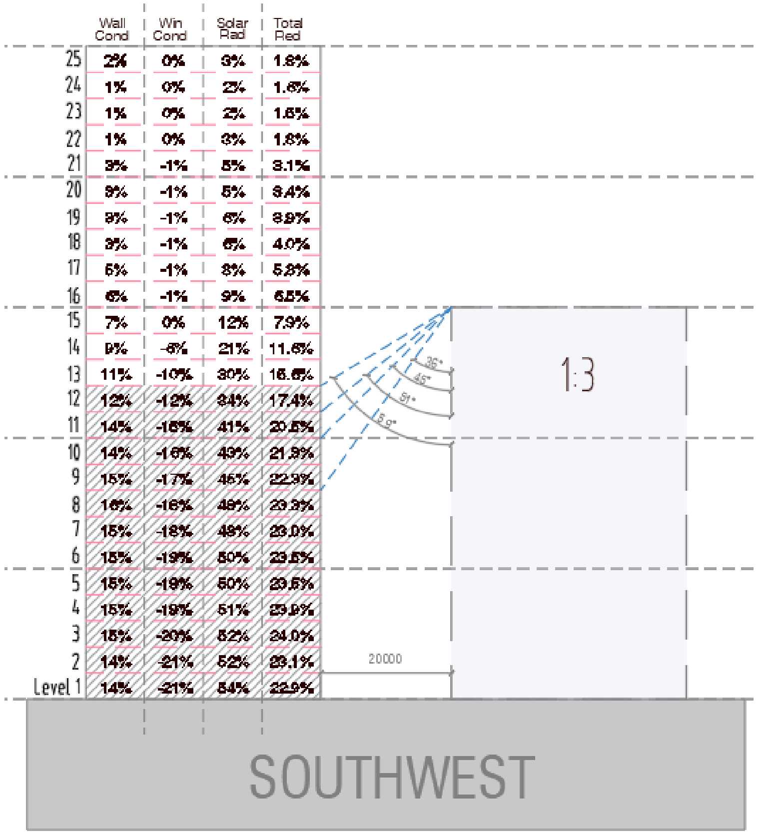
G. SOUTHEAST ORIENTATION

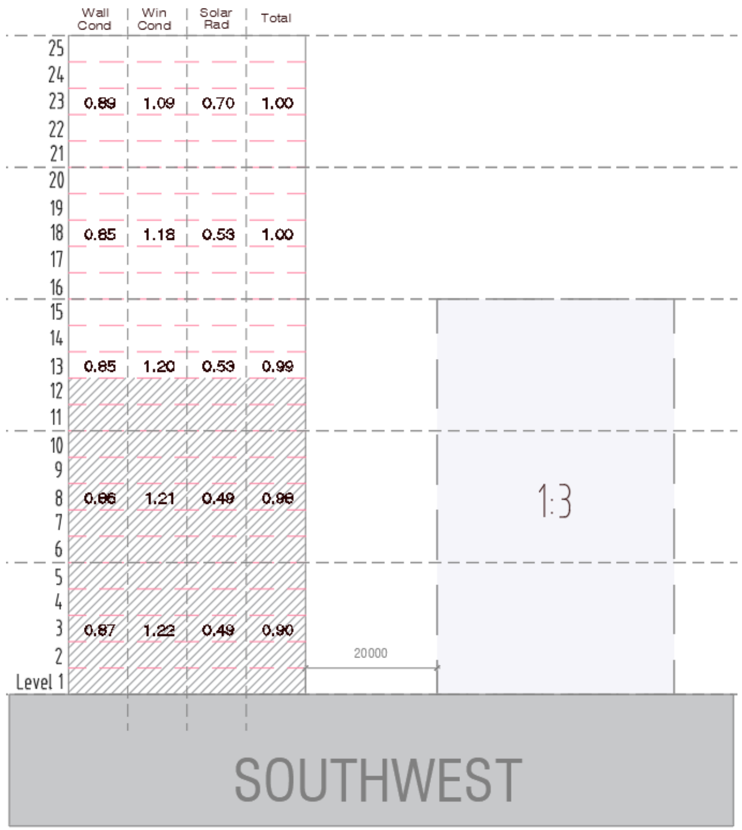




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southeast	60	1:3	0.87	1.12	0.66	0.82
	50		0.85	1.16	0.57	0.78
	40		0.83	1.19	0.50	0.76
	20		0.84	1.20	0.47	0.76

H. SOUTHWEST ORIENTATION

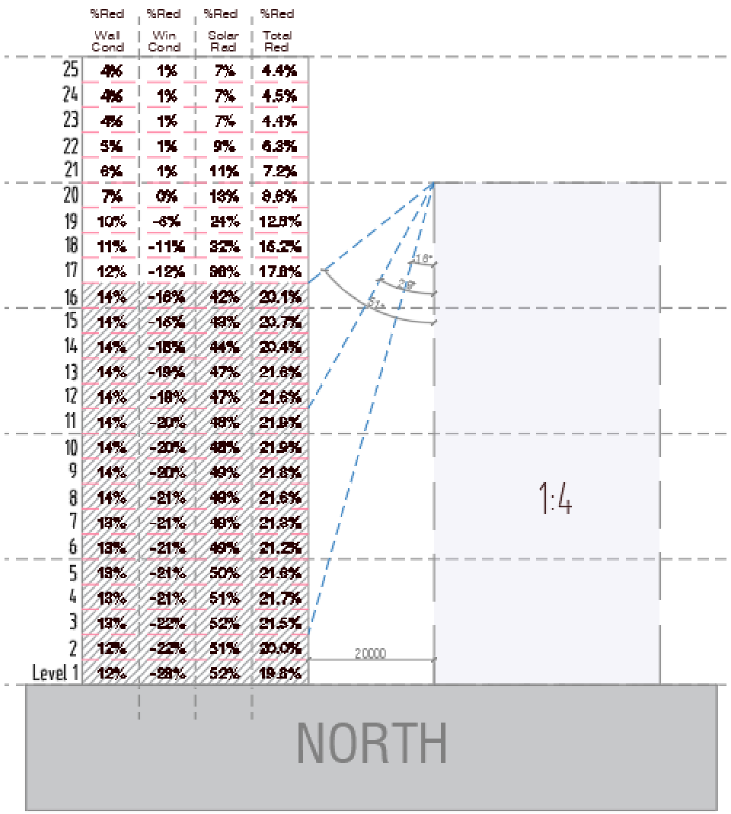


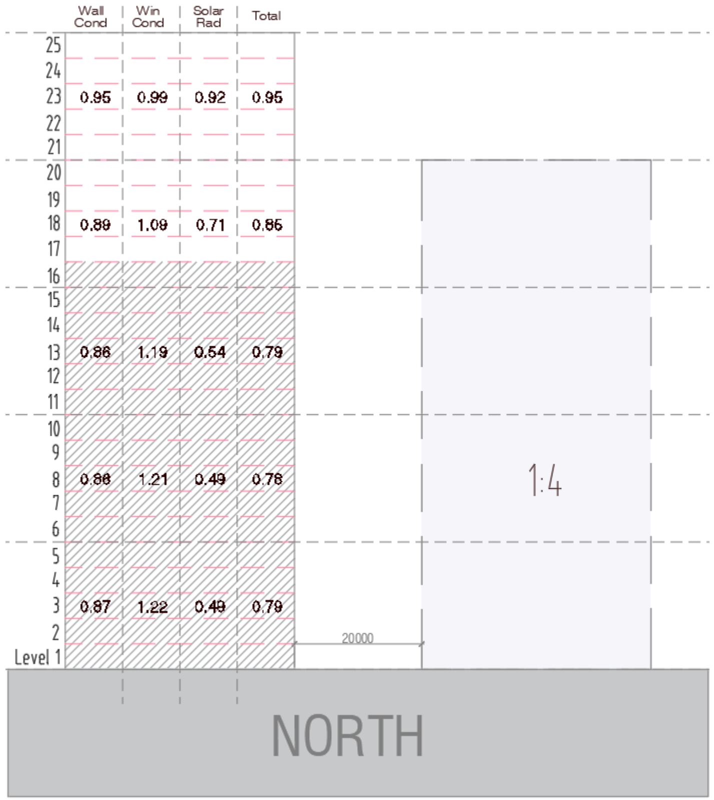


Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southwest	60	1:3	0.88	1.12	0.66	0.83
	50		0.86	1.15	0.59	0.80
	40		0.85	1.16	0.56	0.78
	30		0.85	1.19	0.49	0.77

4.2.4 Ratio 1:4 (d=20m)

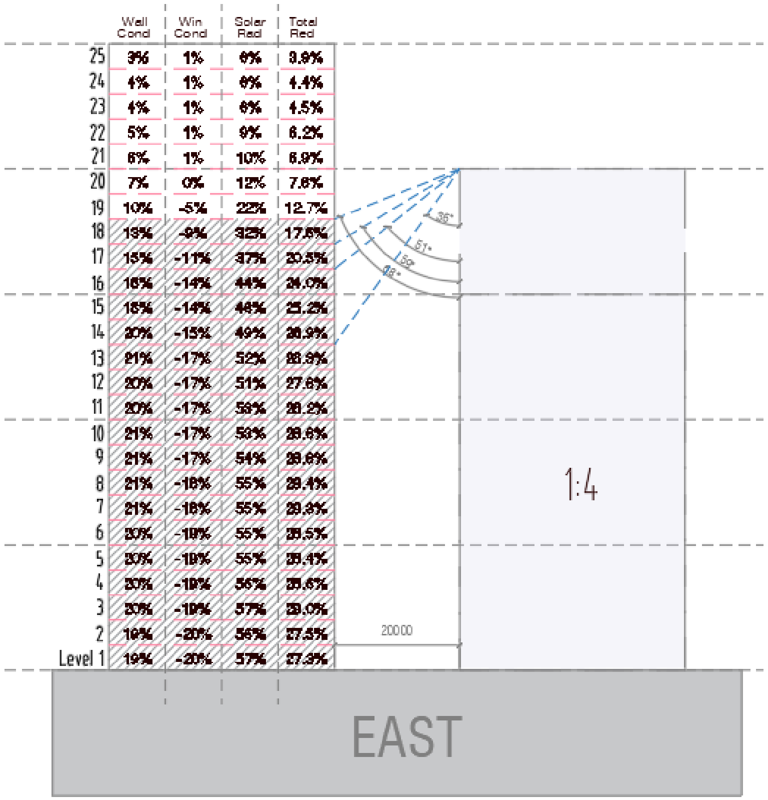
A. NORTH ORIENTATION

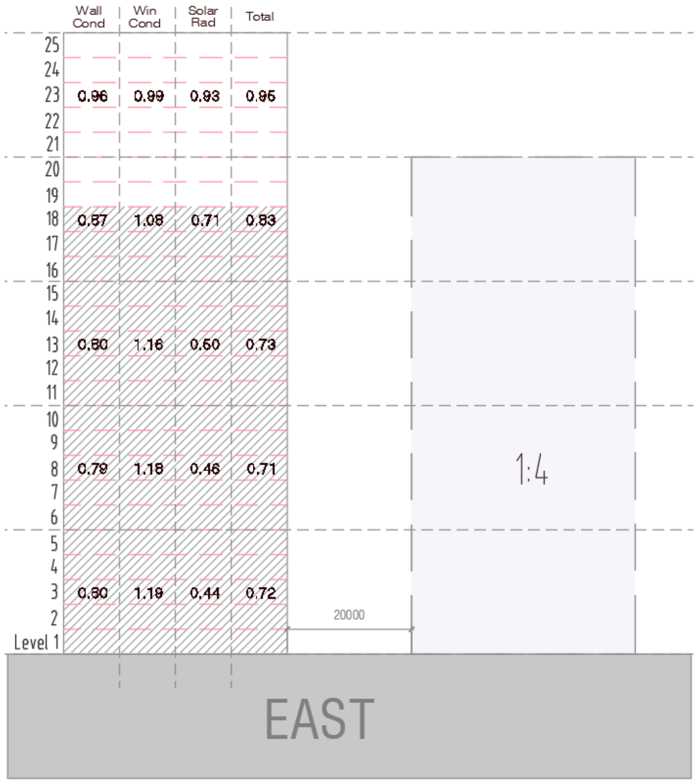




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
North	50	1:4	0.86	1.18	0.55	0.79
	30		0.87	1.16	0.59	0.81
	20		0.88	1.22	0.49	0.80

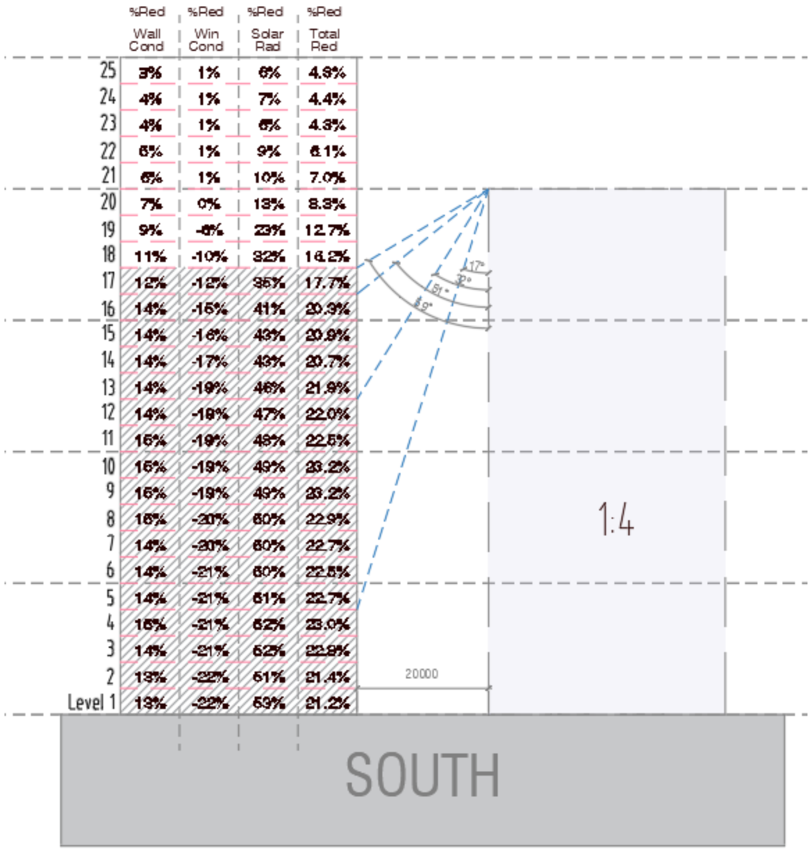
B. EAST ORIENTATION

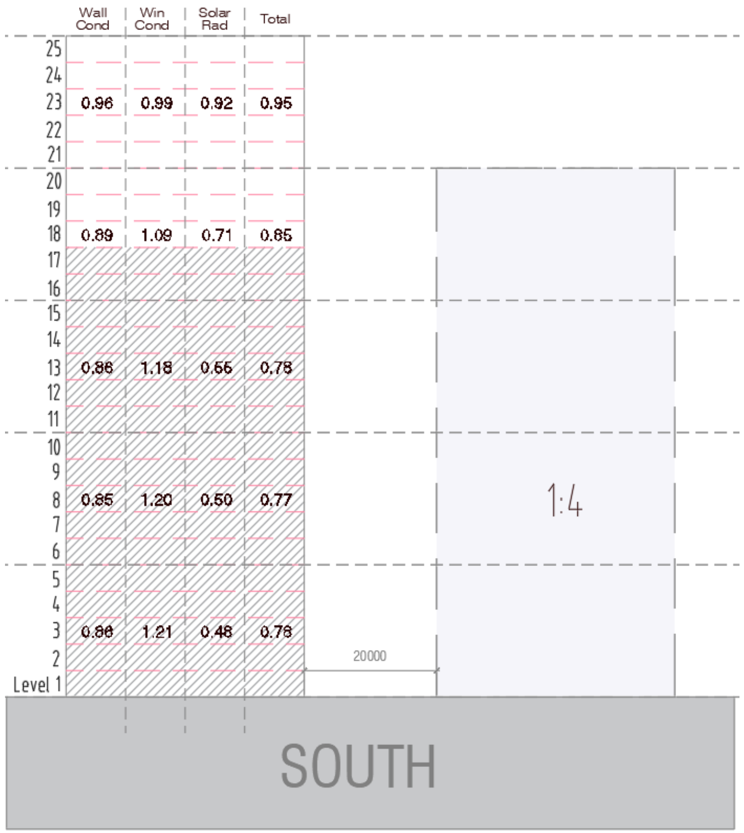




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
East	70	1:4	0.87	1.09	0.68	0.82
	60		0.85	1.11	0.63	0.80
	50		0.81	1.14	0.54	0.75
	40		0.80	1.18	0.45	0.72

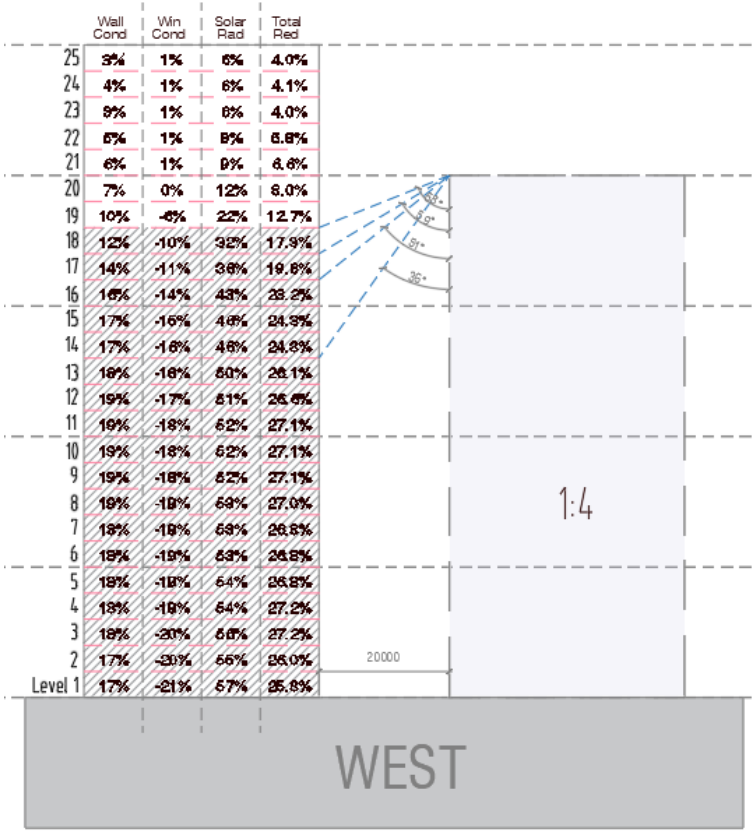
C. SOUTH ORIENTATION

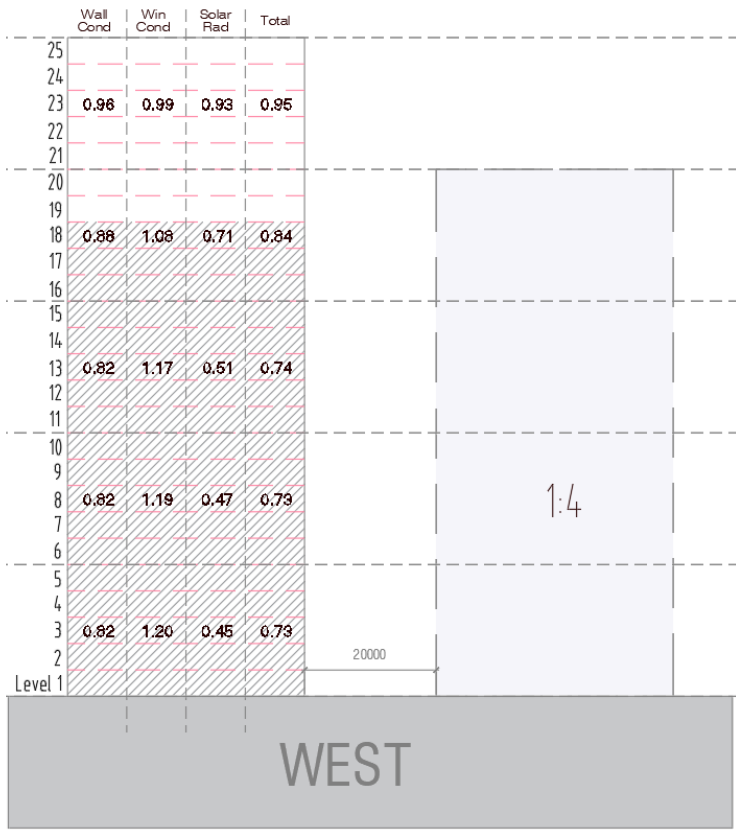




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
South	60	1:4	0.88	1.12	0.65	0.82
	50		0.86	1.17	0.57	0.79
	30		0.85	1.20	0.51	0.77
	20		0.86	1.21	0.48	0.77

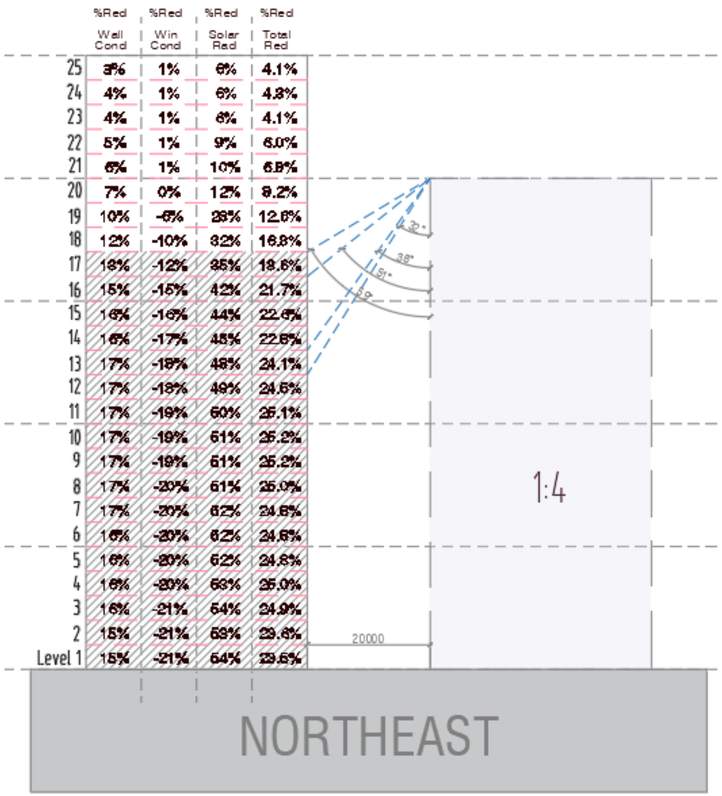
D. WEST ORIENTATION

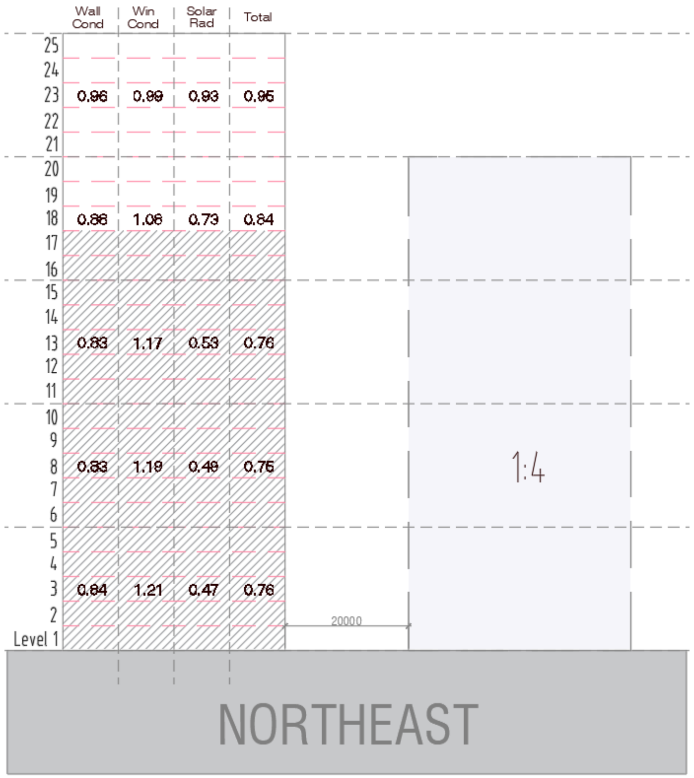




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
West	70	1:4	0.88	1.10	0.68	0.83
	60		0.86	1.11	0.64	0.80
	50		0.83	1.15	0.55	0.76
	40		0.82	1.19	0.46	0.73

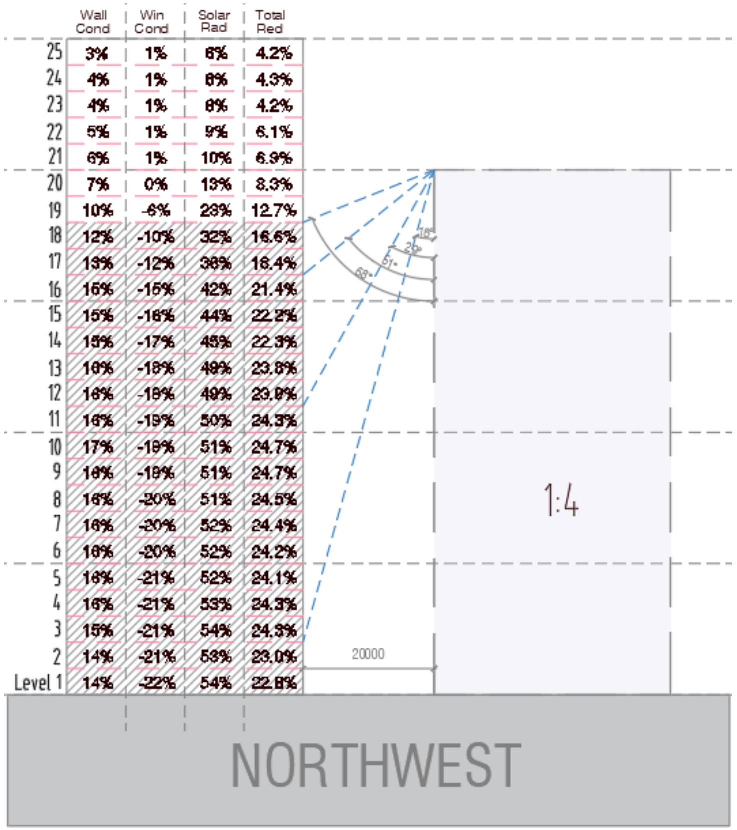
E. NORTHEAST ORIENTATION

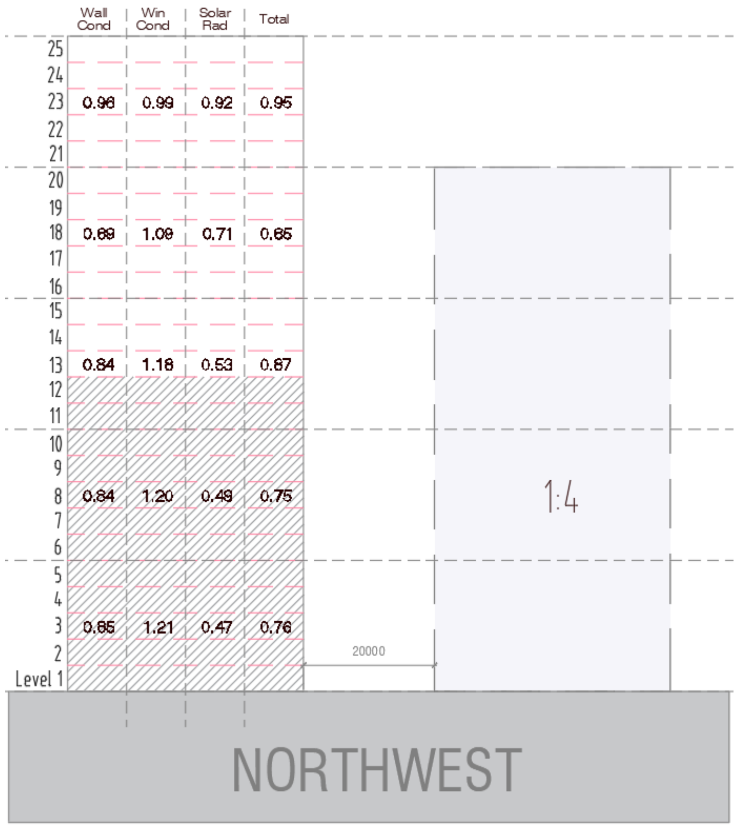




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northeast	60	1:4	0.87	1.12	0.65	0.81
	50		0.84	1.16	0.56	0.78
	40		0.83	1.18	0.52	0.76
	30		0.84	1.20	0.48	0.75

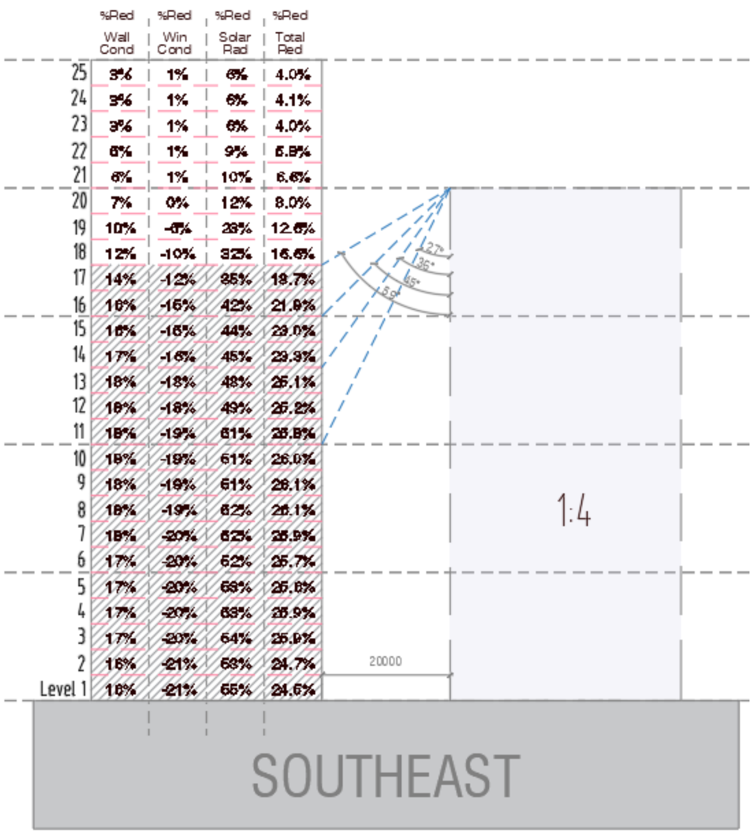
F. NORTHWEST ORIENTATION

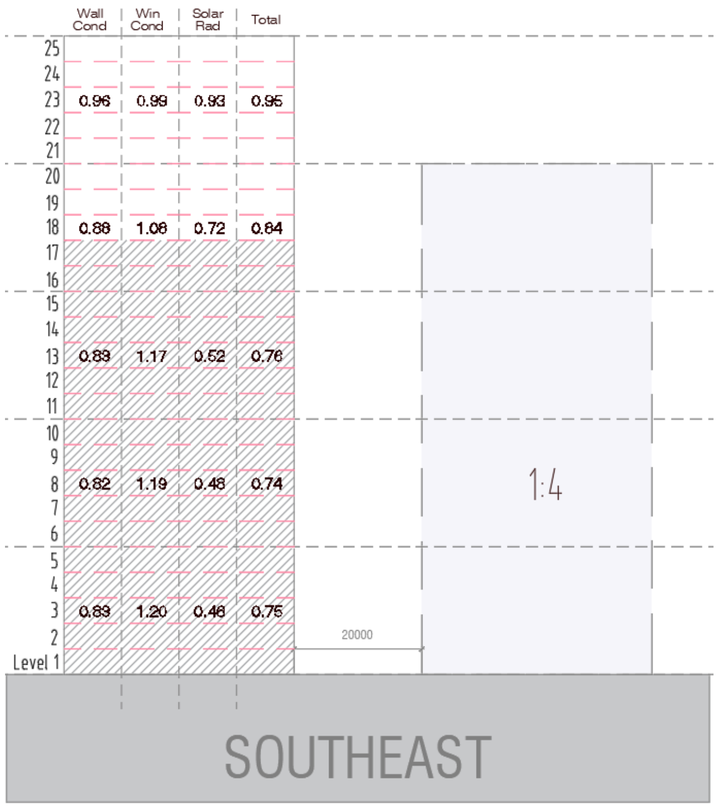




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northwest	70	1:4	0.88	1.11	0.66	0.83
	50		0.84	1.17	0.54	0.77
	30		0.84	1.20	0.48	0.76
	20		0.86	1.21	0.46	0.76

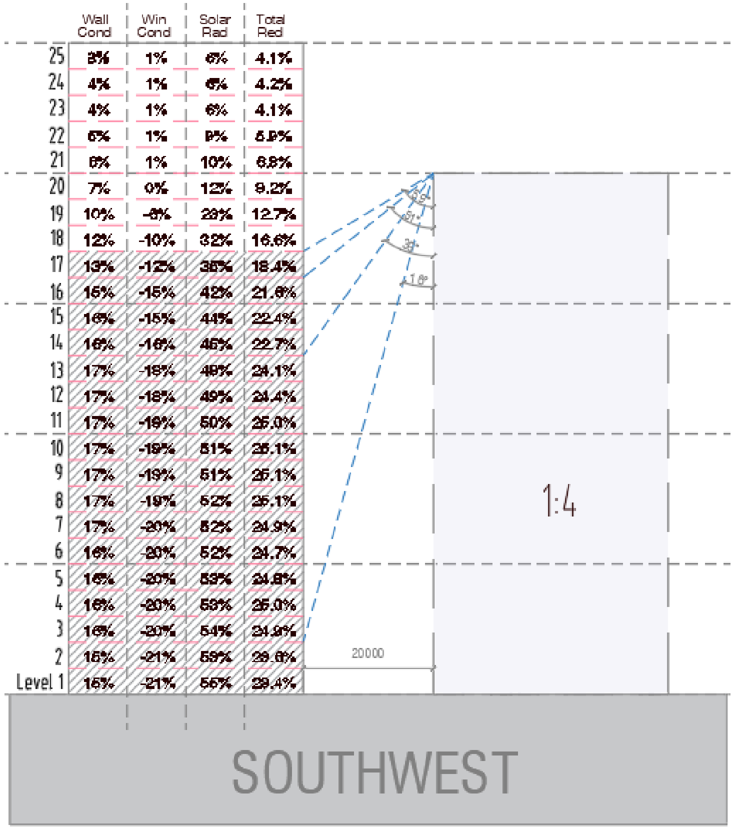
G. SOUTHEAST ORIENTATION

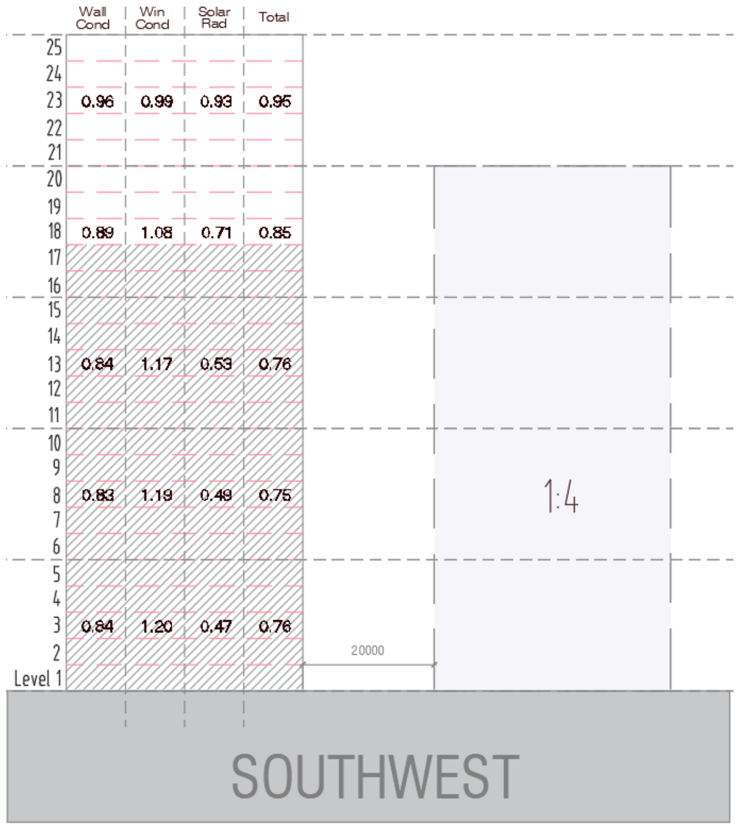




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southeast	60	1:4	0.85	1.13	0.62	0.80
	50		0.84	1.16	0.55	0.77
	40		0.82	1.18	0.50	0.75
	30		0.83	1.19	0.47	0.74

H. SOUTHWEST ORIENTATION

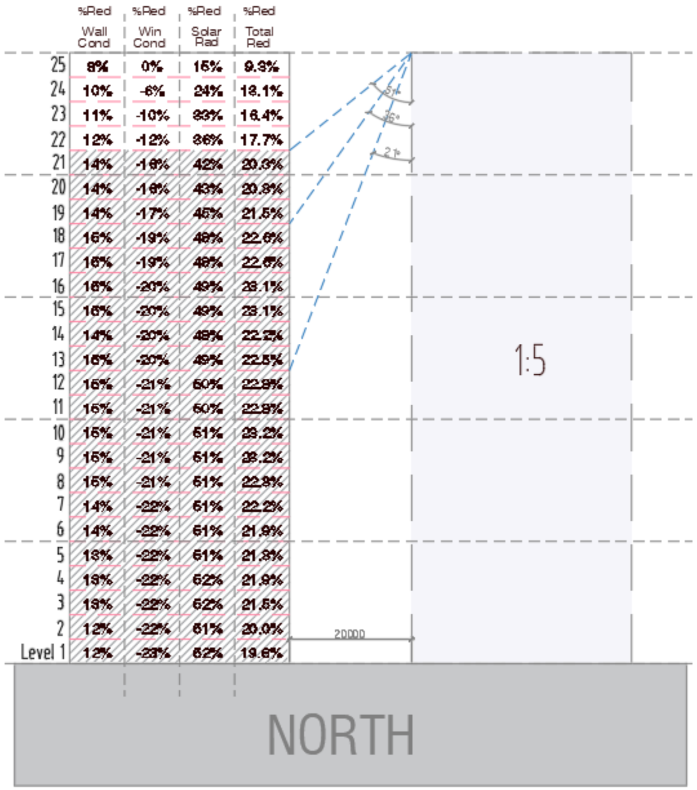


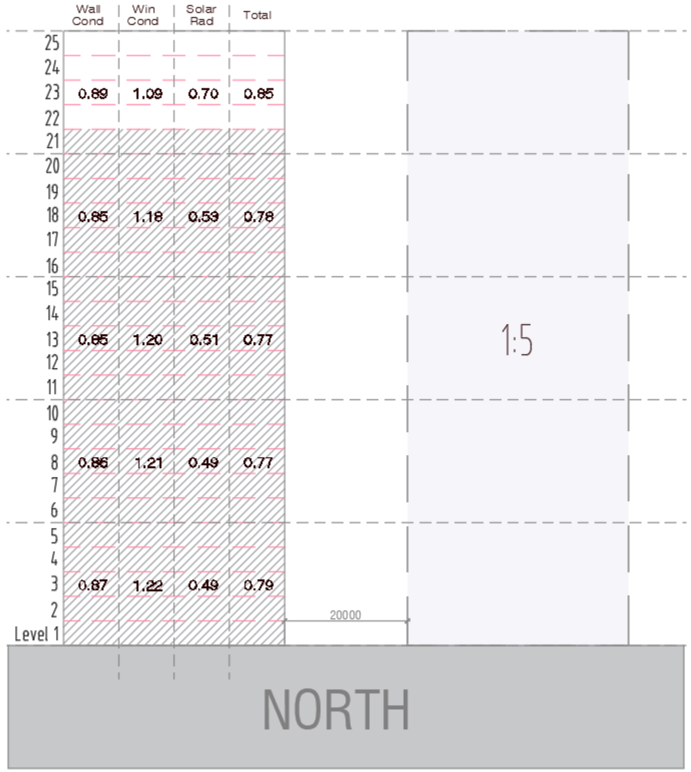


Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southwest	60	1:4	0.87	1.12	0.65	0.82
	50		0.85	1.16	0.56	0.78
	40		0.84	1.19	0.49	0.75
	20		0.85	1.21	0.46	0.77

4.2.5 Ratio 1:5 (d=20m)

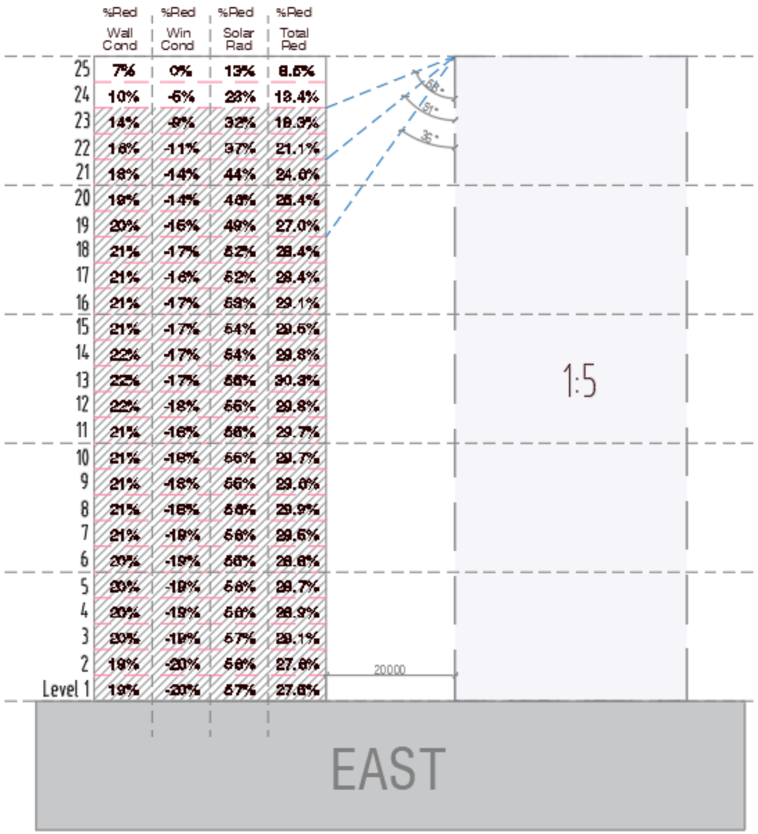
A. NORTH ORIENTATION

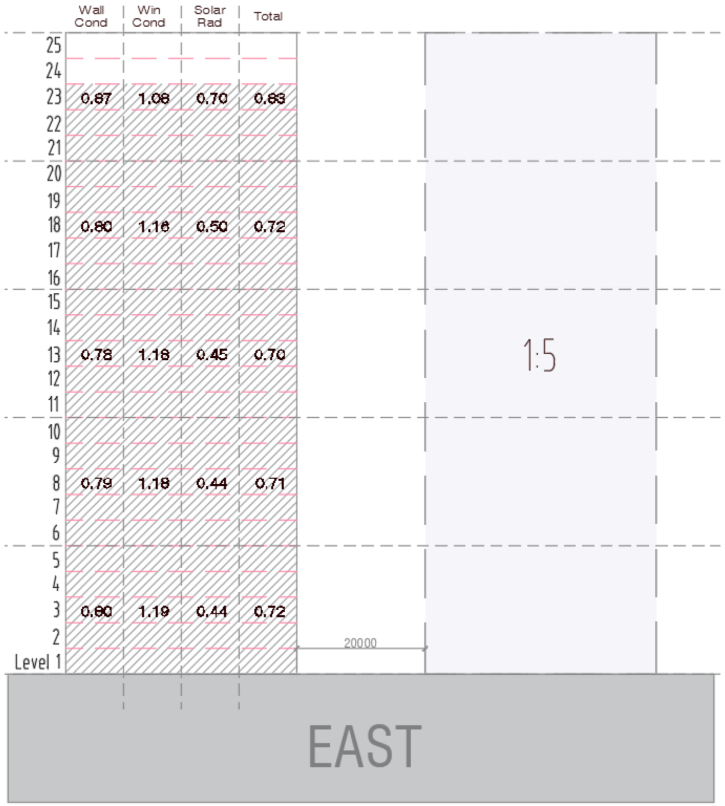




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
North	50	1:5	0.86	1.16	0.57	0.79
	40		0.85	1.20	0.51	0.77
	20		0.86	1.21	0.49	0.78

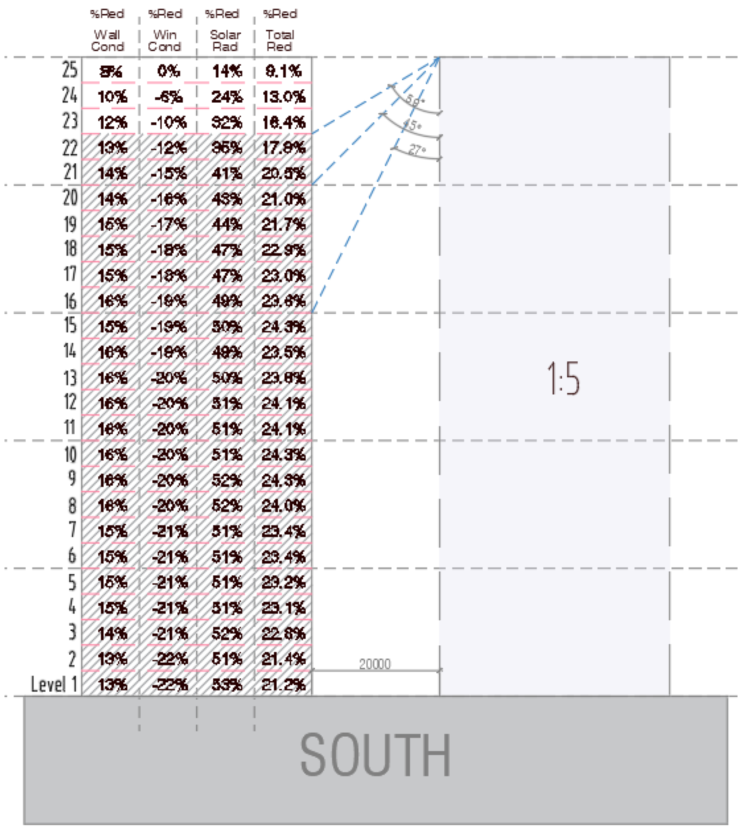
B. EAST ORIENTATION

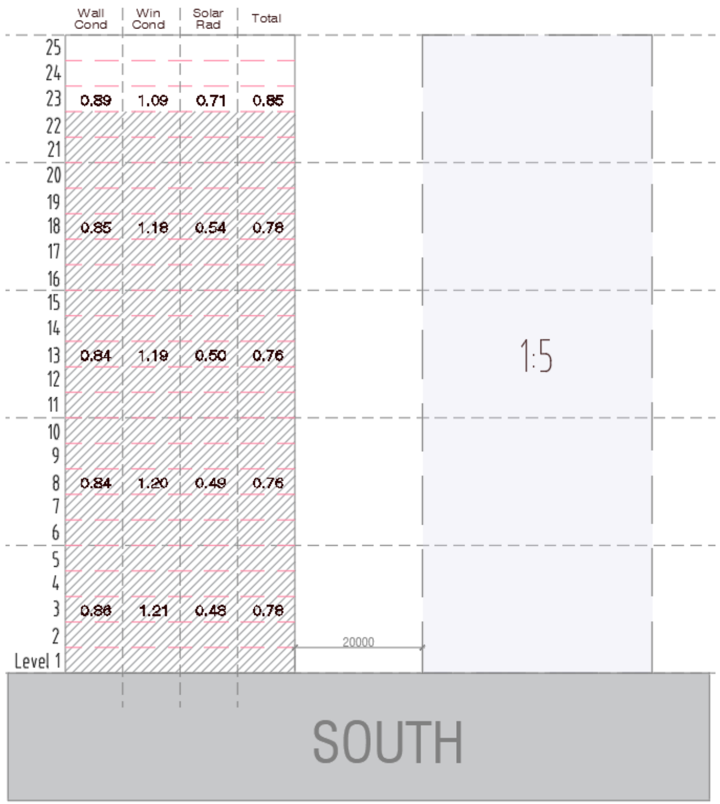




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
East	70	1:5	0.85	1.10	0.65	0.80
	50		0.81	1.14	0.54	0.74
	40		0.79	1.18	0.45	0.71

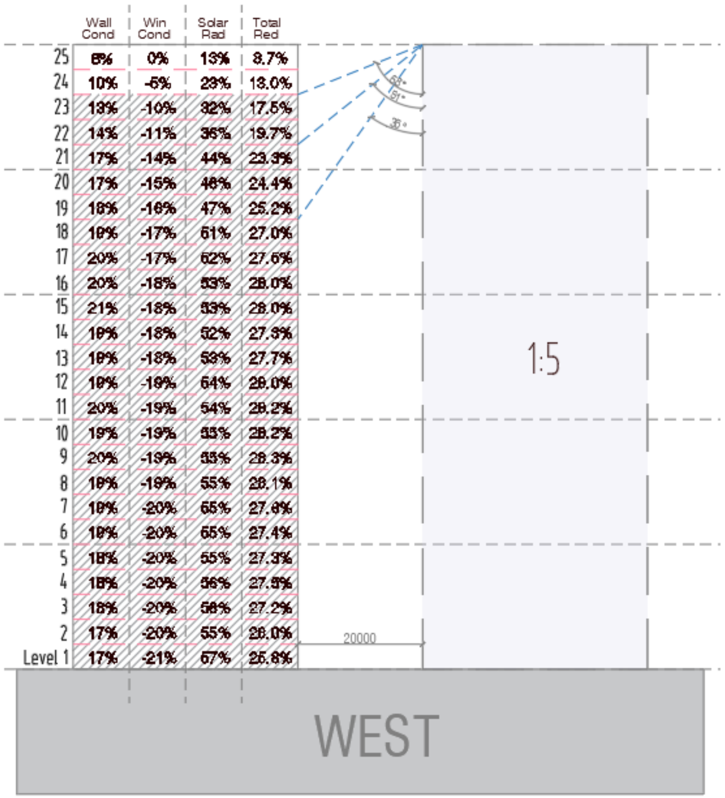
C. SOUTH ORIENTATION

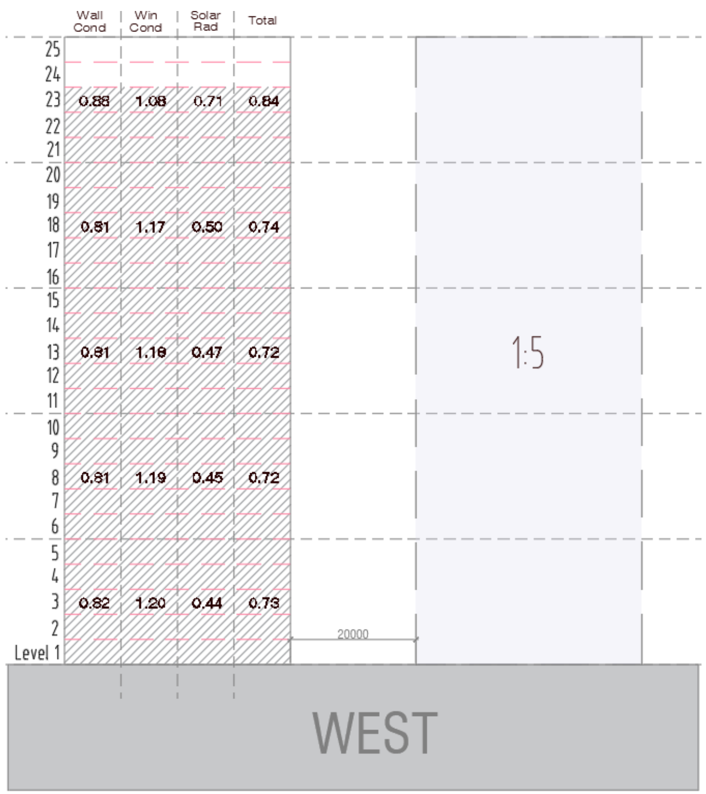




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
South	60	1:5	0.87	1.13	0.62	0.81
	50		0.85	1.18	0.54	0.78
	30		0.85	1.20	0.49	0.77

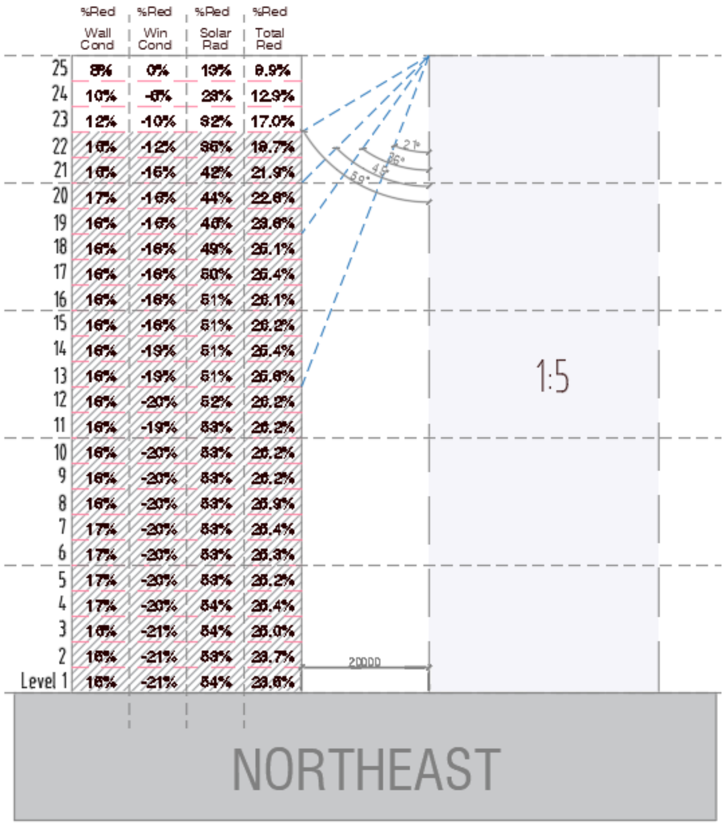
D. WEST ORIENTATION

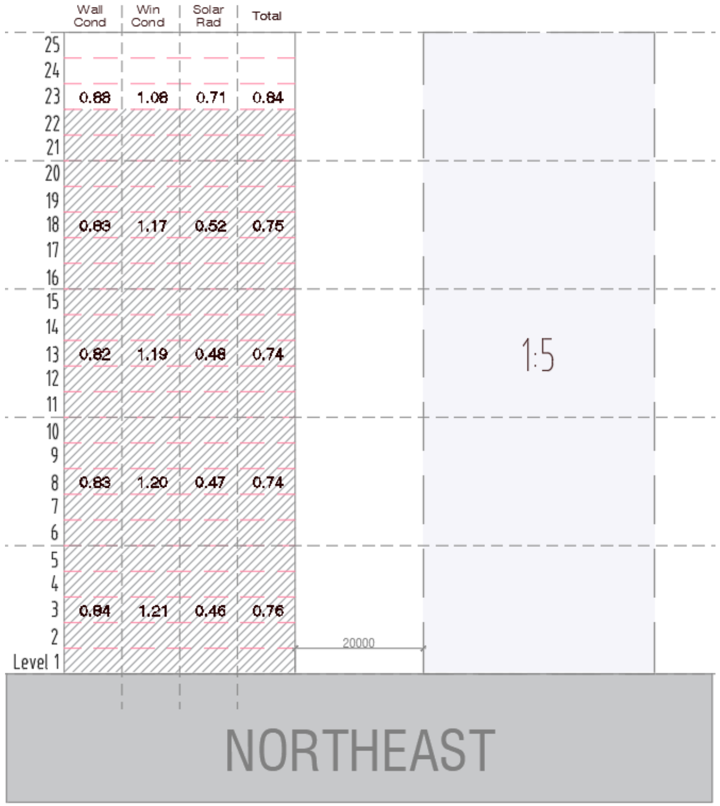




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
West	70	1:5	0.86	1.10	0.66	0.81
	50		0.83	1.15	0.54	0.76
	40		0.81	1.19	0.46	0.72

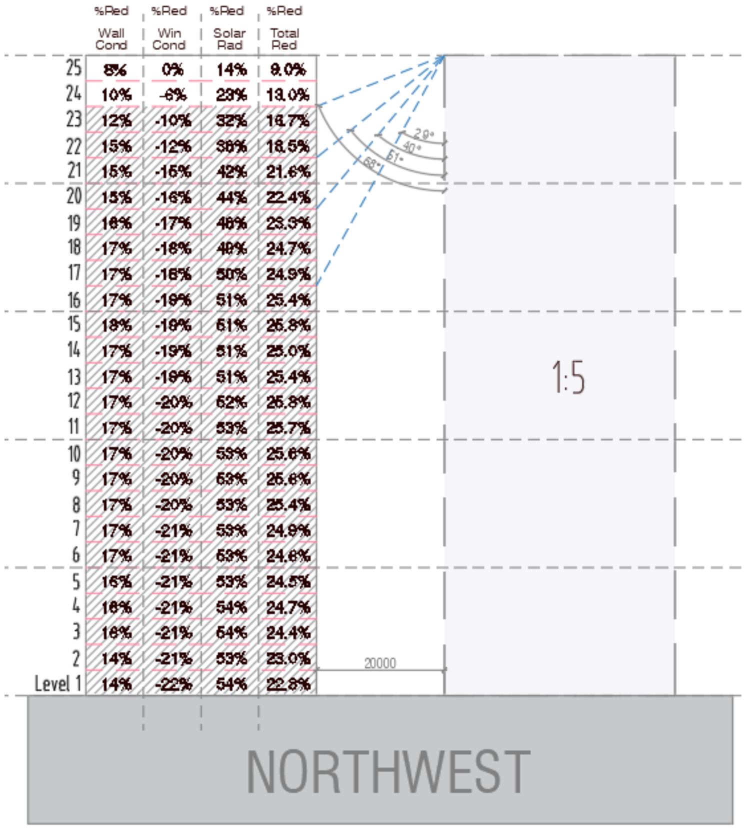
E. NORTHEAST ORIENTATION

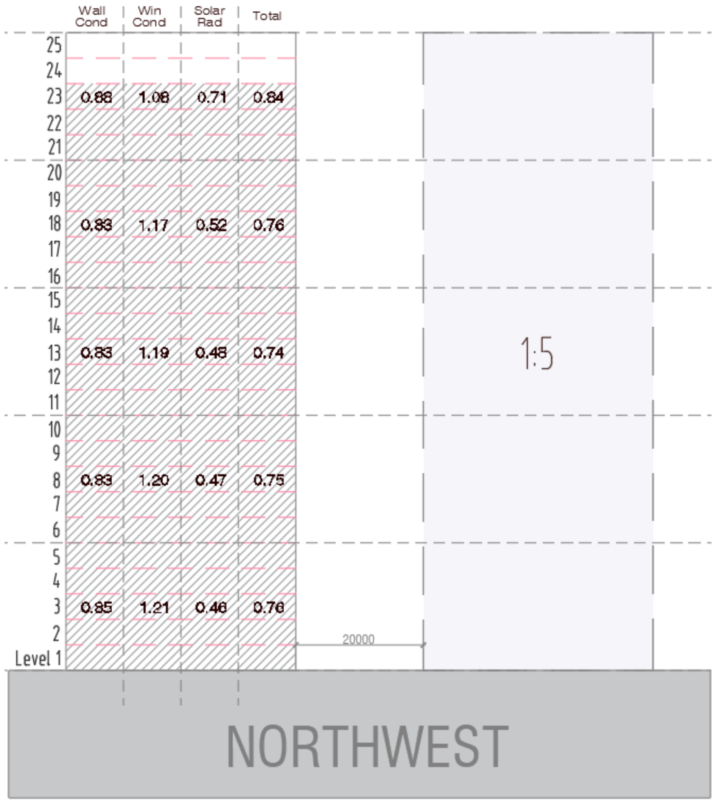




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northeast	60	1:5	0.85	1.13	0.61	0.80
	50		0.84	1.16	0.55	0.77
	40		0.82	1.18	0.49	0.74
	20		0.83	1.20	0.47	0.75

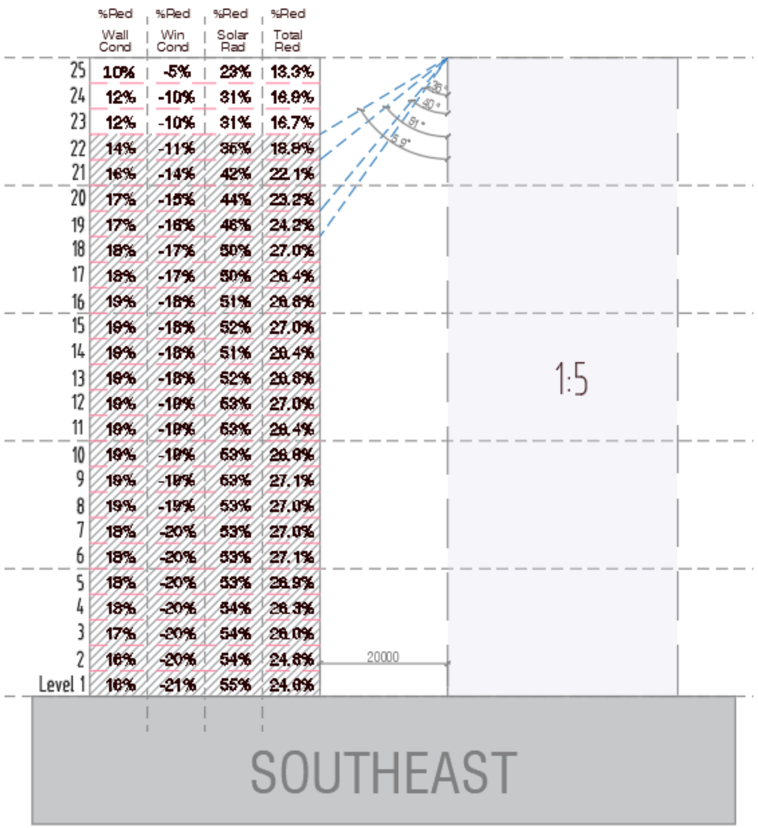
F. NORTHWEST ORIENTATION

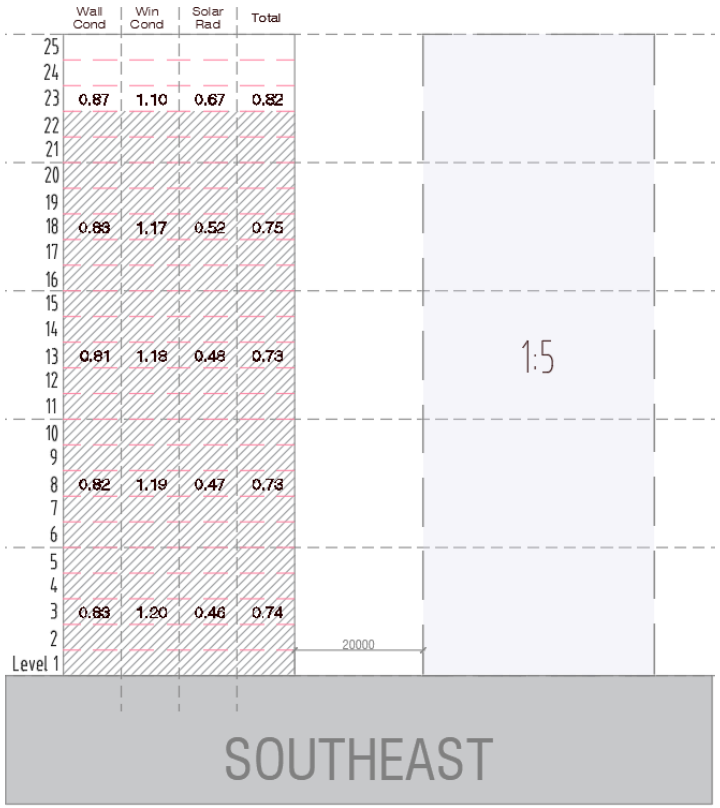




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northwest	70	1:5	0.87	1.11	0.76	0.82
	50		0.85	1.15	0.57	0.78
	40		0.83	1.18	0.52	0.76
	30		0.84	1.20	0.47	0.75

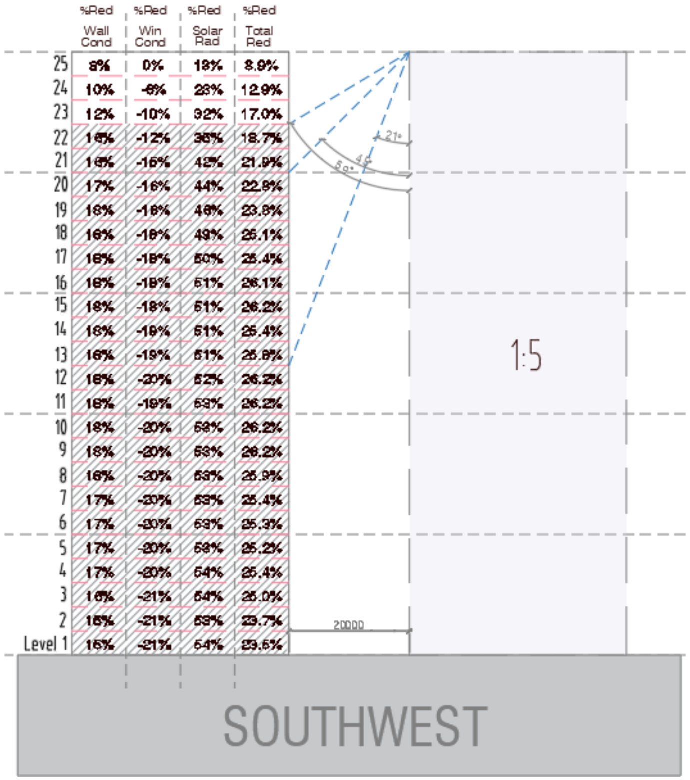
G. SOUTHEAST ORIENTATION

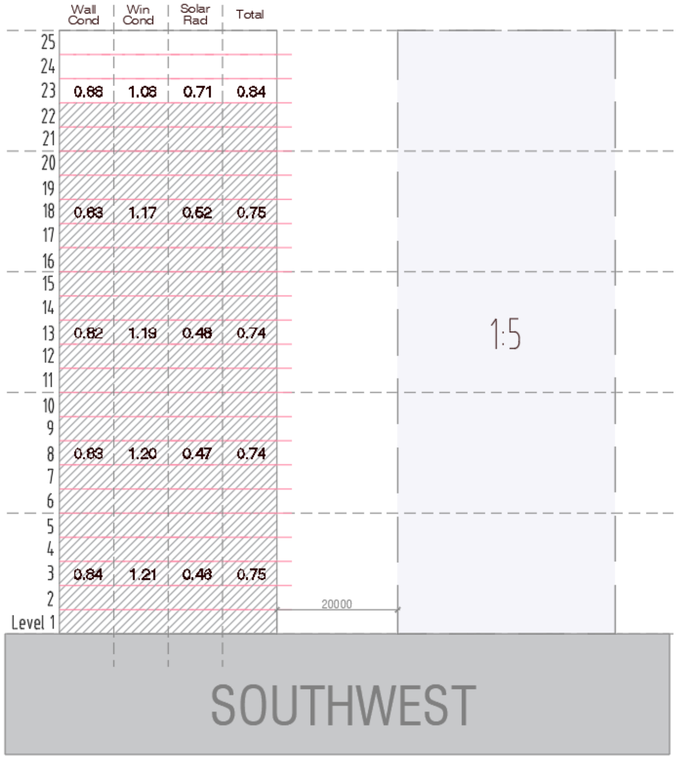




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southeast	60	1:5	0.86	1.11	0.65	0.81
	50		0.84	1.15	0.57	0.77
	40		0.83	1.16	0.54	0.76
	30		0.82	1.19	0.47	0.74

H. SOUTHWEST ORIENTATION

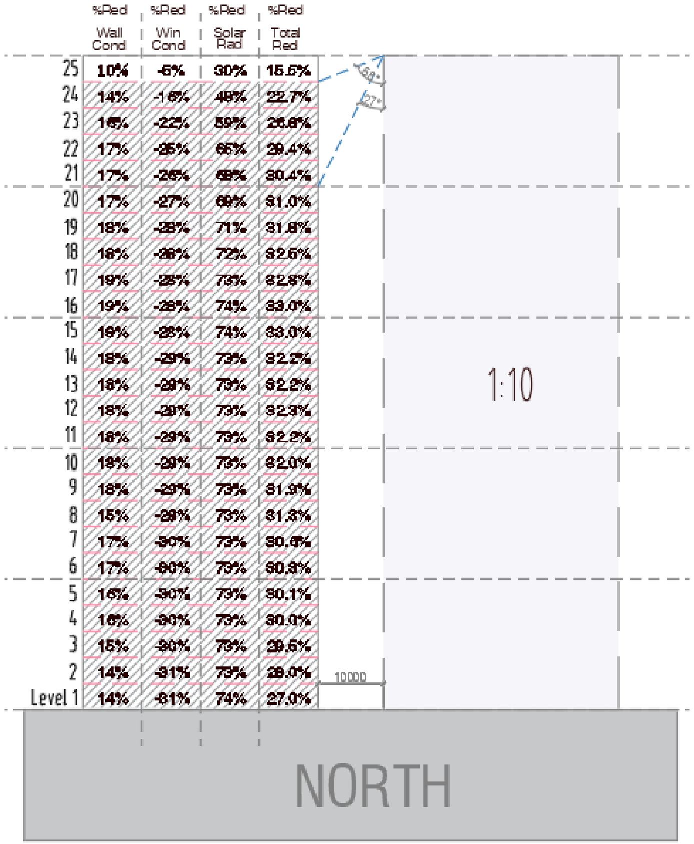


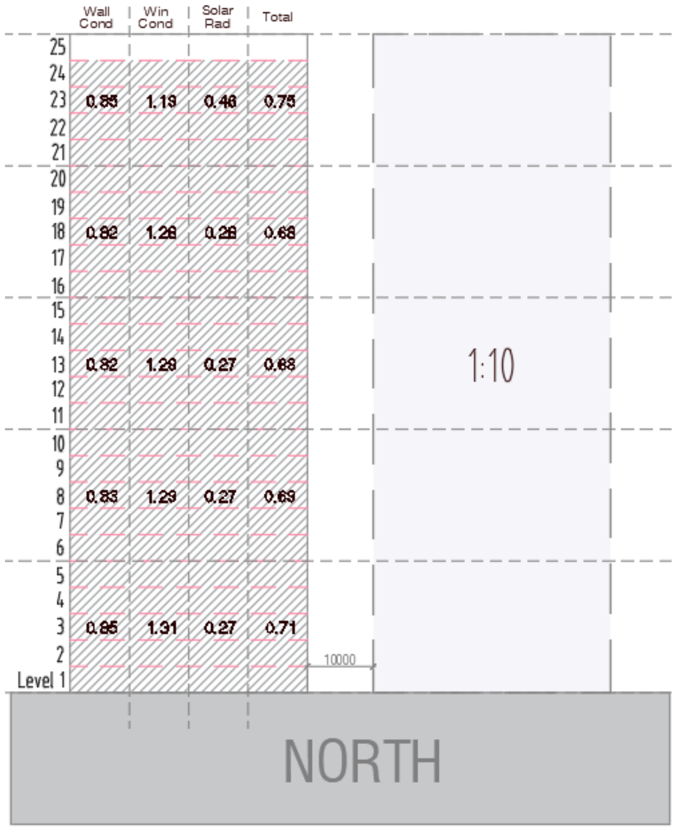


Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southwest	60	1:5	0.86	1.13	0.61	0.80
	50		0.83	1.18	0.51	0.75
	40		0.83	1.20	0.47	0.75

4.2.6 Ratio 1:10 (d=10m)

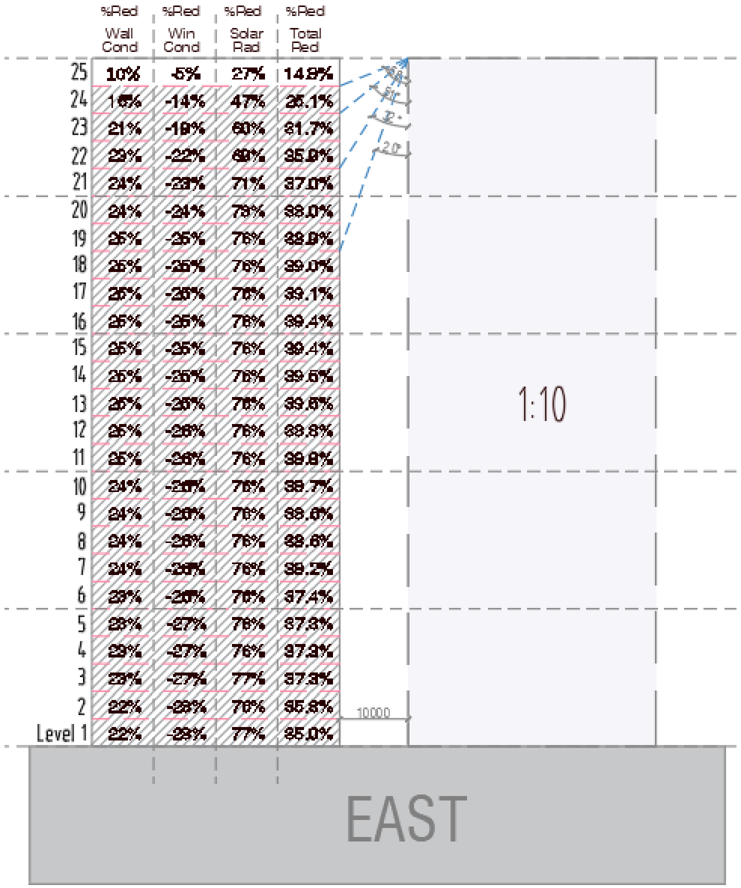
A. NORTH ORIENTATION

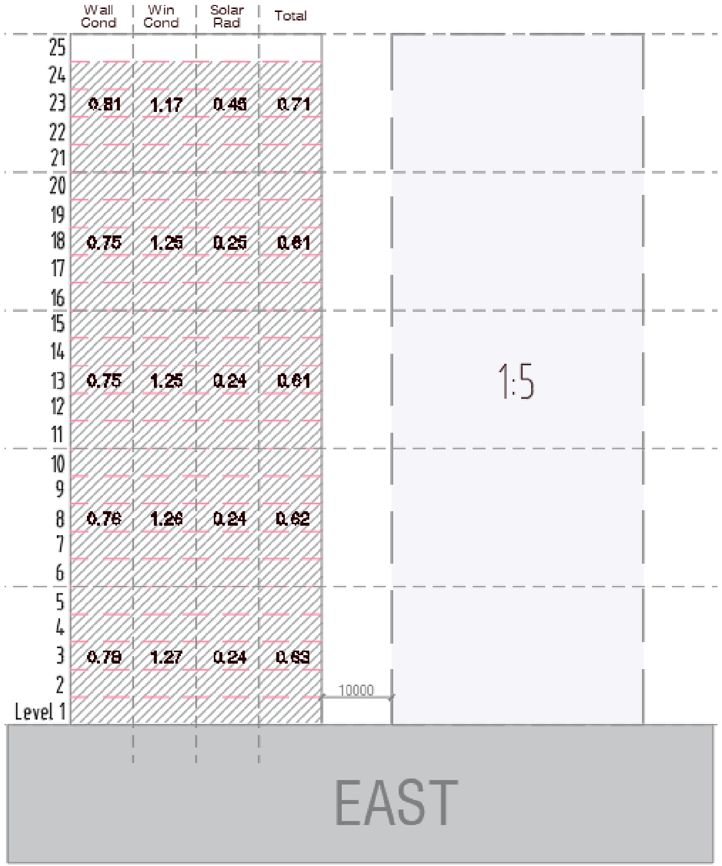




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
North	70	1:10	0.84	1.22	0.40	0.73
	30		0.83	1.29	0.27	0.69

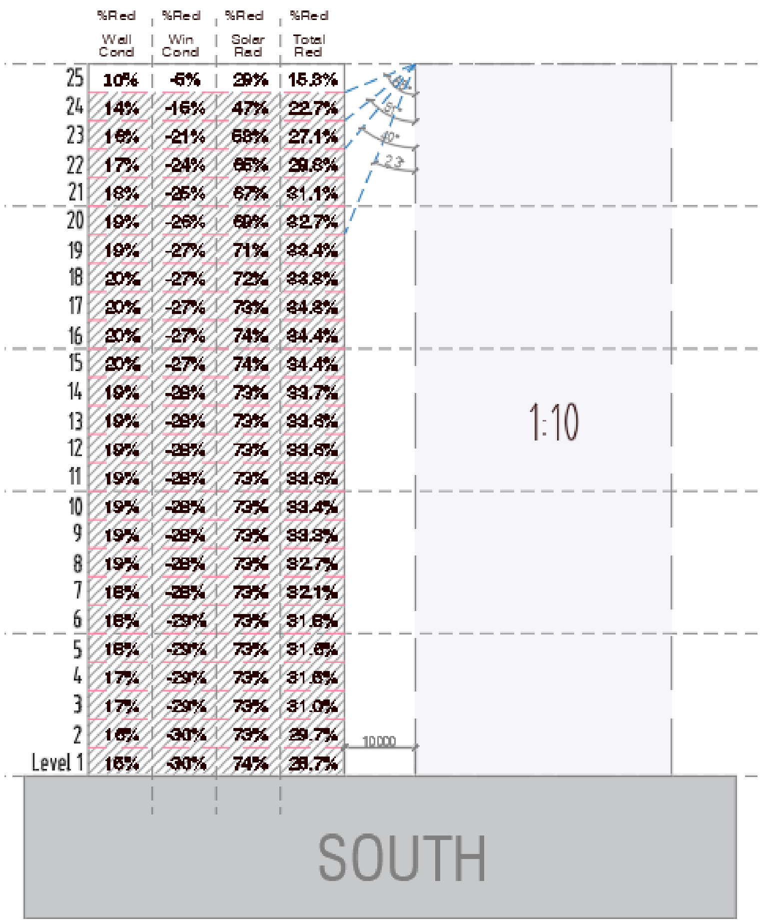
B. EAST ORIENTATION

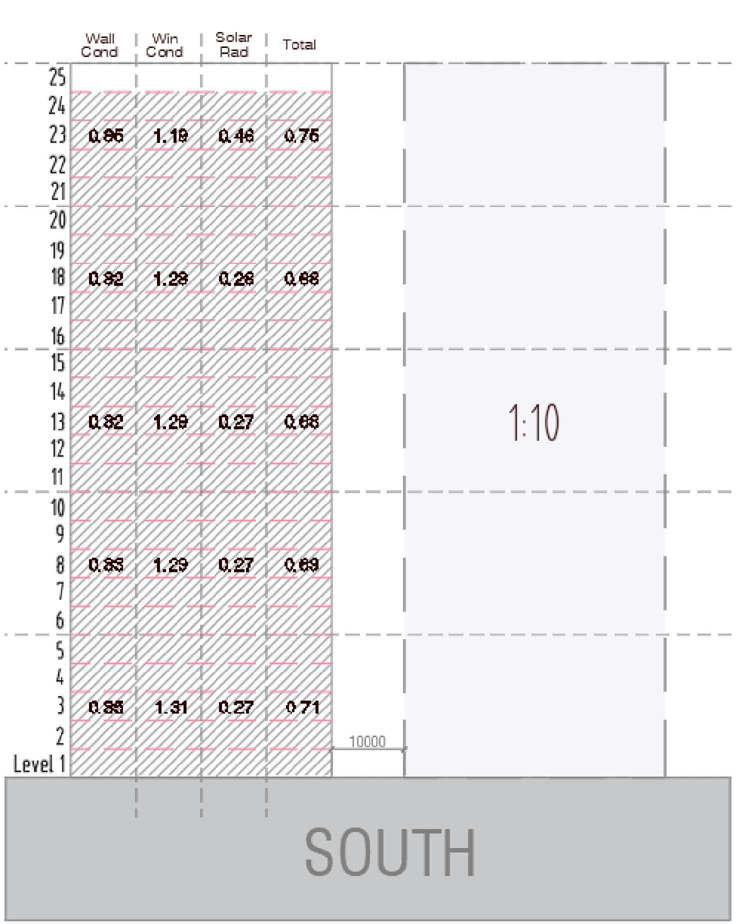




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
East	40	1:10	0.88	1.10	0.68	0.83
	30		0.88	1.11	0.65	0.82

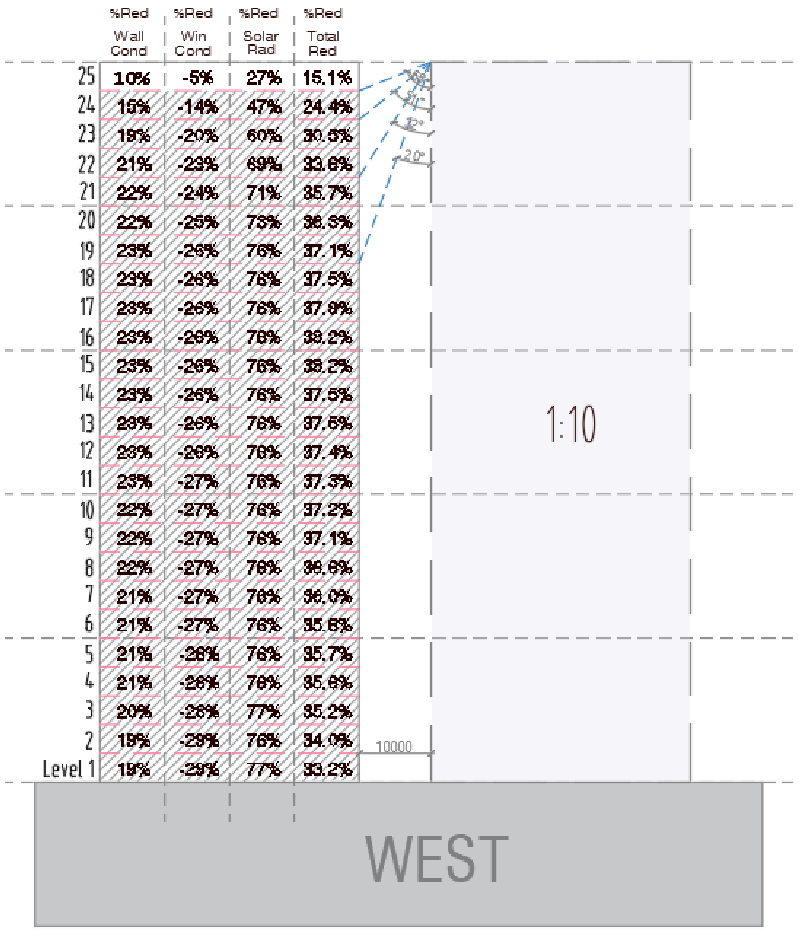
C. SOUTH ORIENTATION

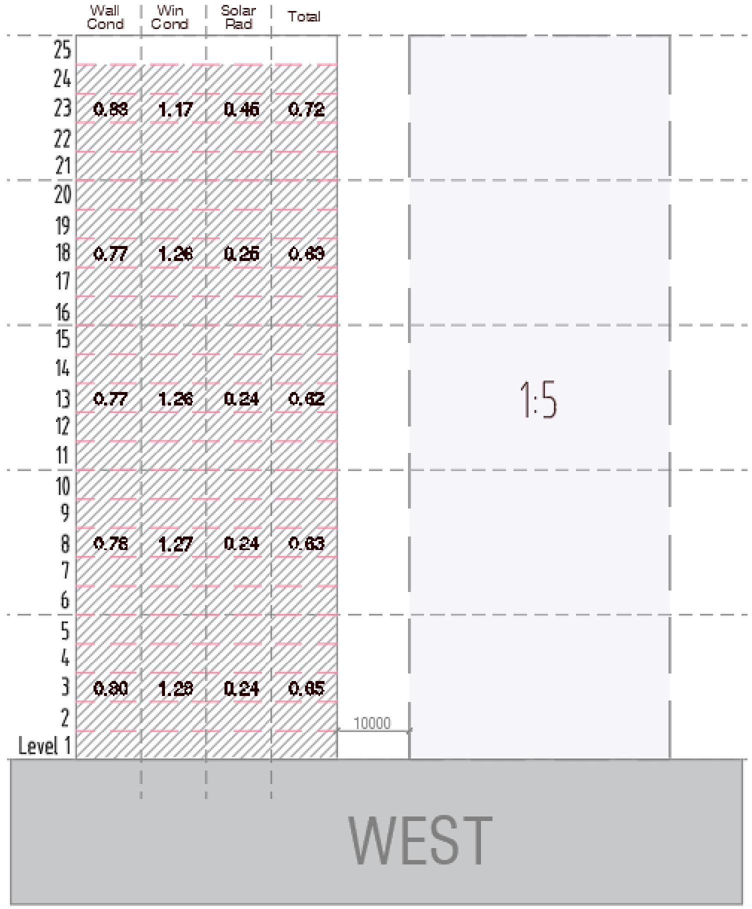




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
South	30	1:10	0.93	1.13	0.70	0.87
	20		0.93	1.13	0.69	0.88

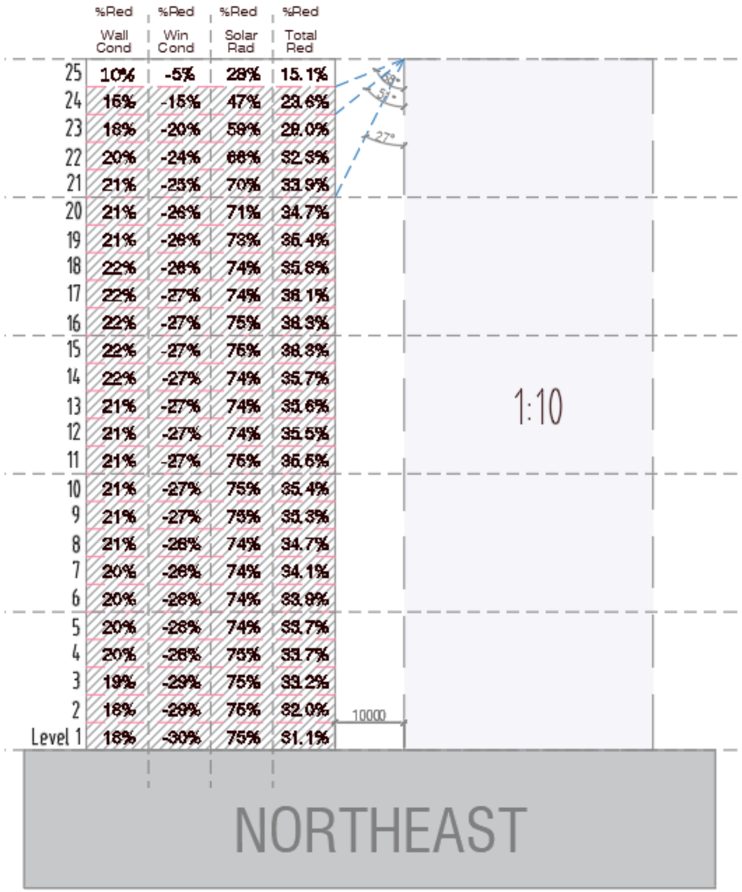
D. WEST ORIENTATION

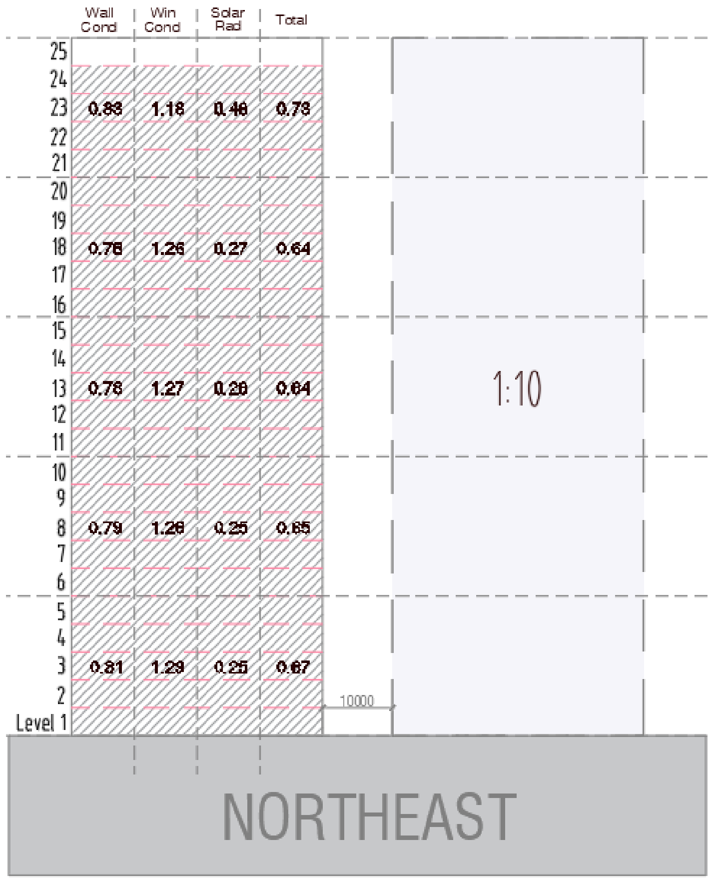




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
West	40	1:10	0.90	1.11	0.68	0.84
	30		0.90	1.12	0.66	0.84

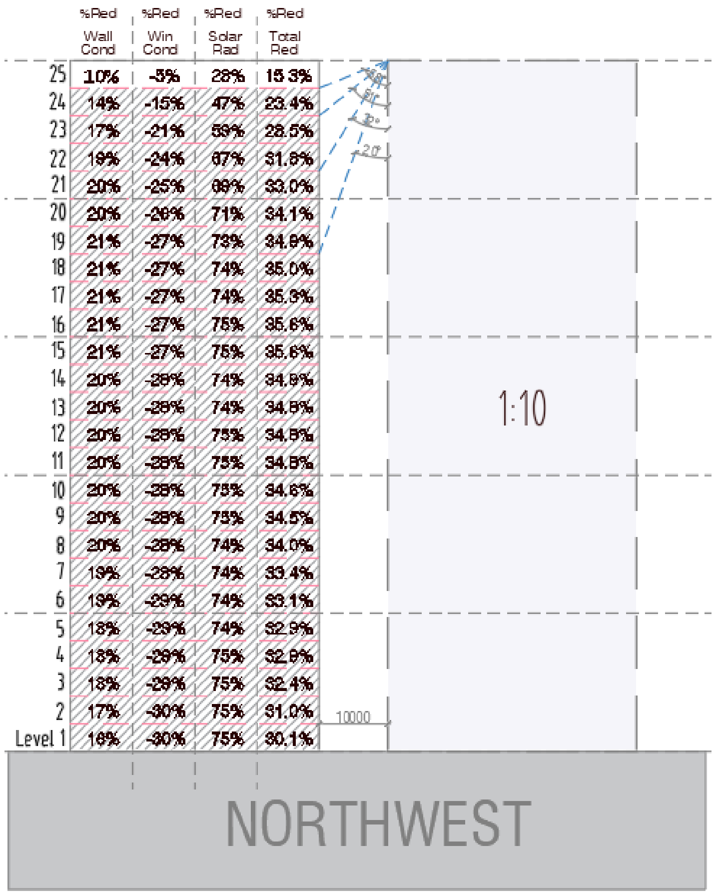
E. NORTHEAST ORIENTATION

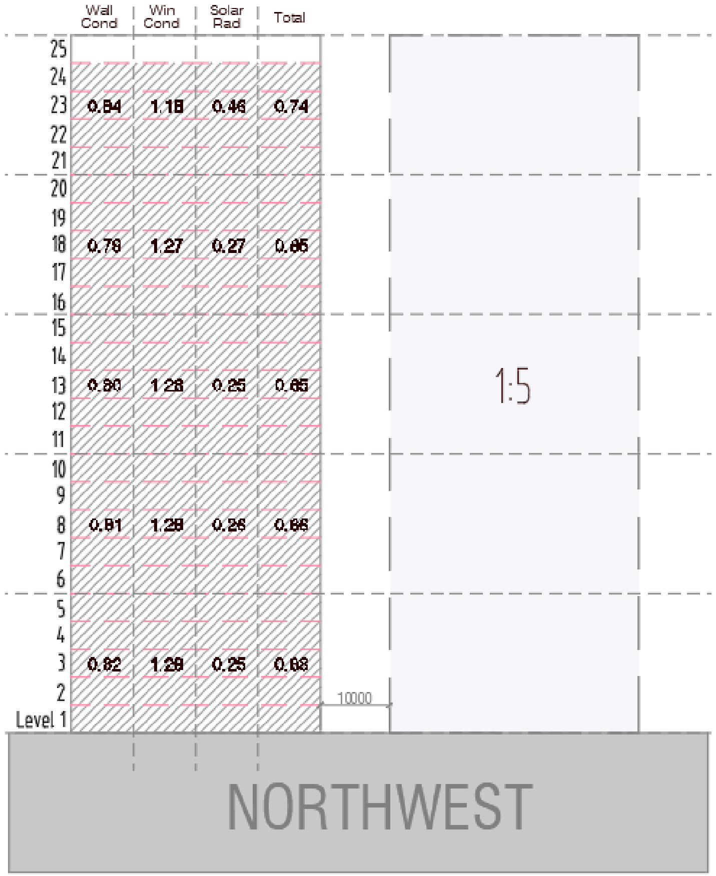




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northeast	30	1:10	0.91	1.12	0.68	0.85
	20		0.92	1.13	0.68	0.86

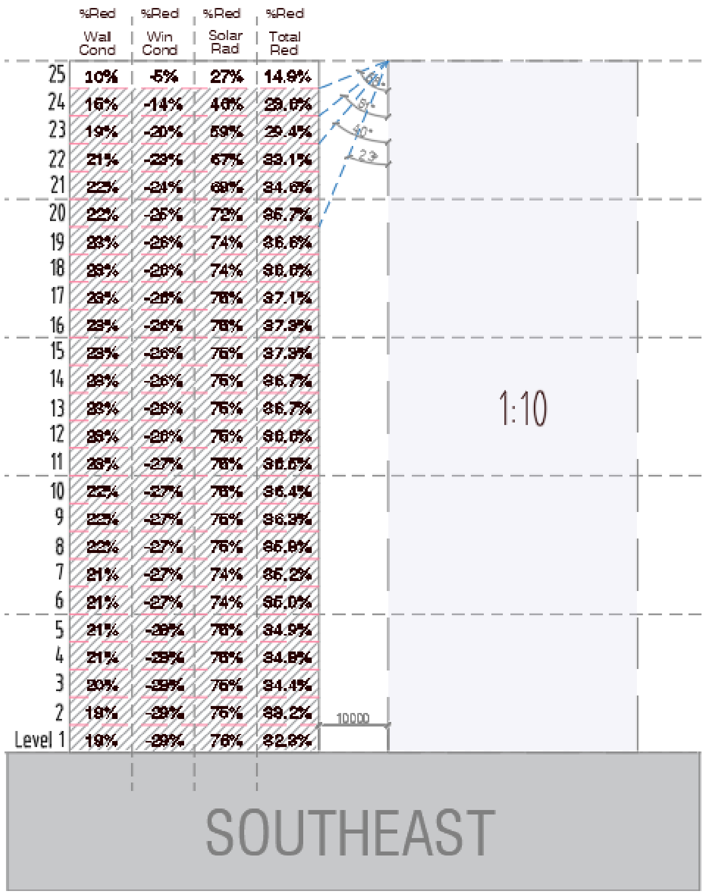
F. NORTHWEST ORIENTATION

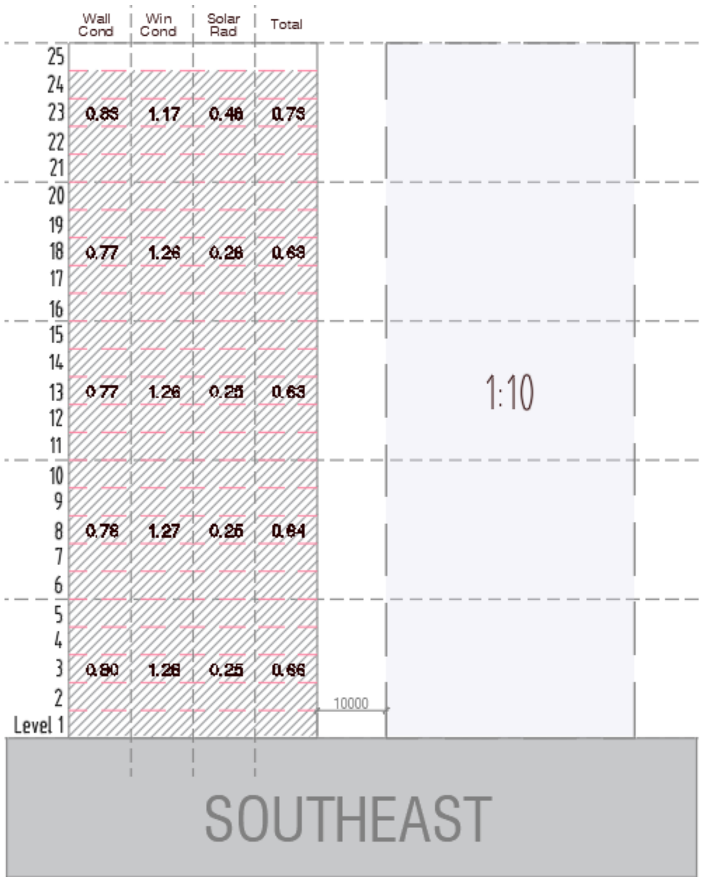




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northwest	30	1:10	0.92	1.13	0.68	0.86
	20		0.92	1.13	0.68	0.87

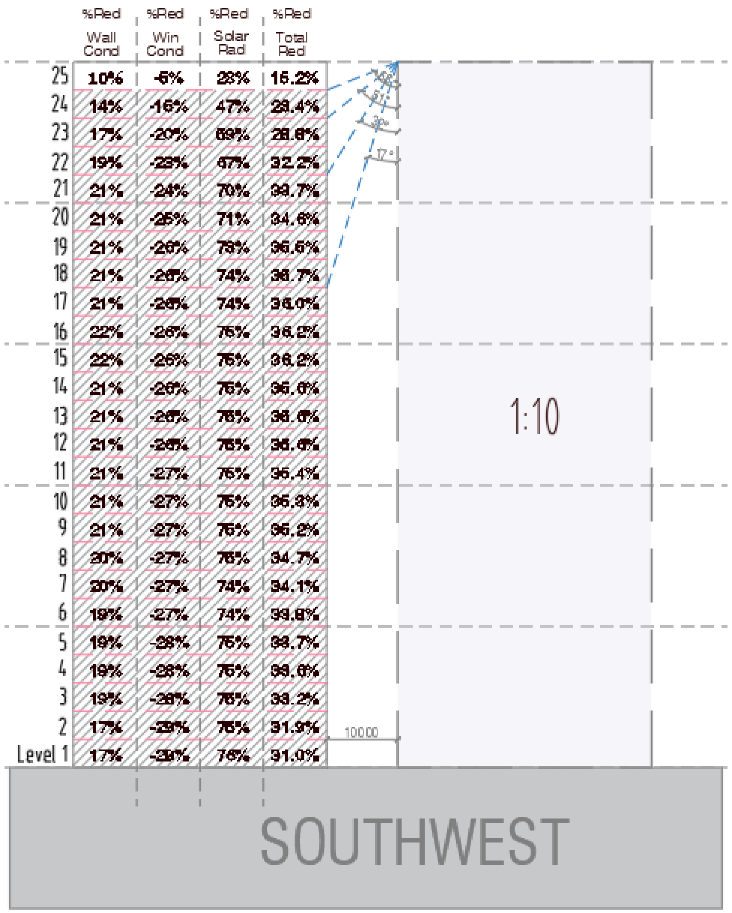
G. SOUTHEAST ORIENTATION

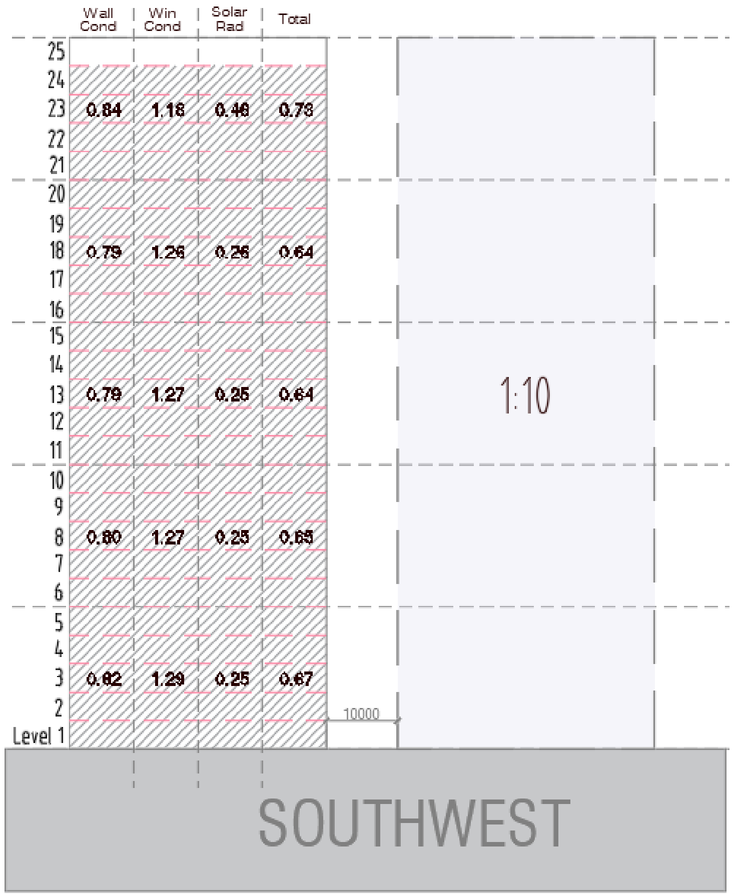




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
South East	40	1:10	0.90	1.12	0.68	0.84
	30		0.90	1.12	0.68	0.85
	20		0.91	1.13	0.67	0.85

H. SOUTHWEST ORIENTATION

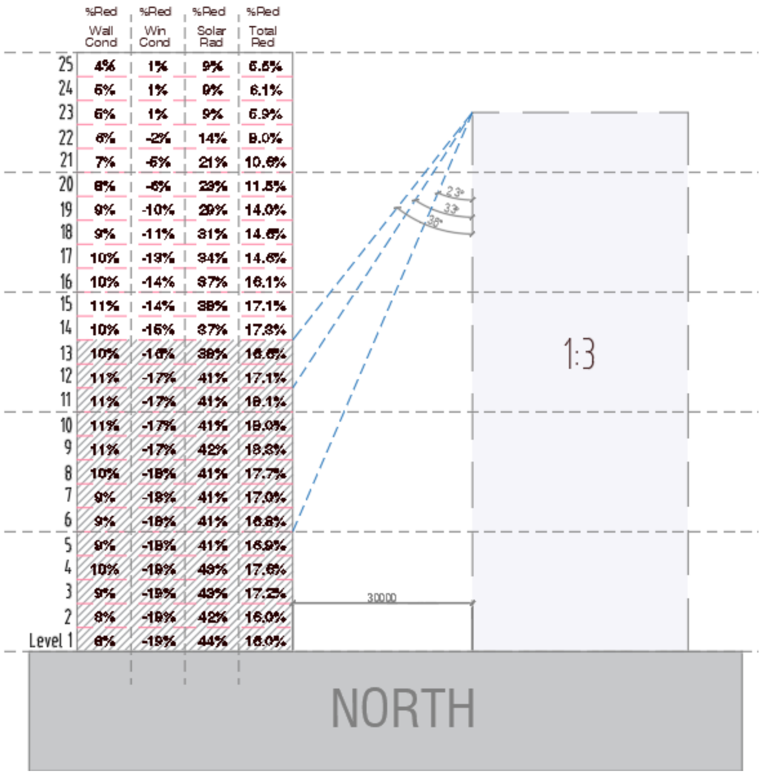


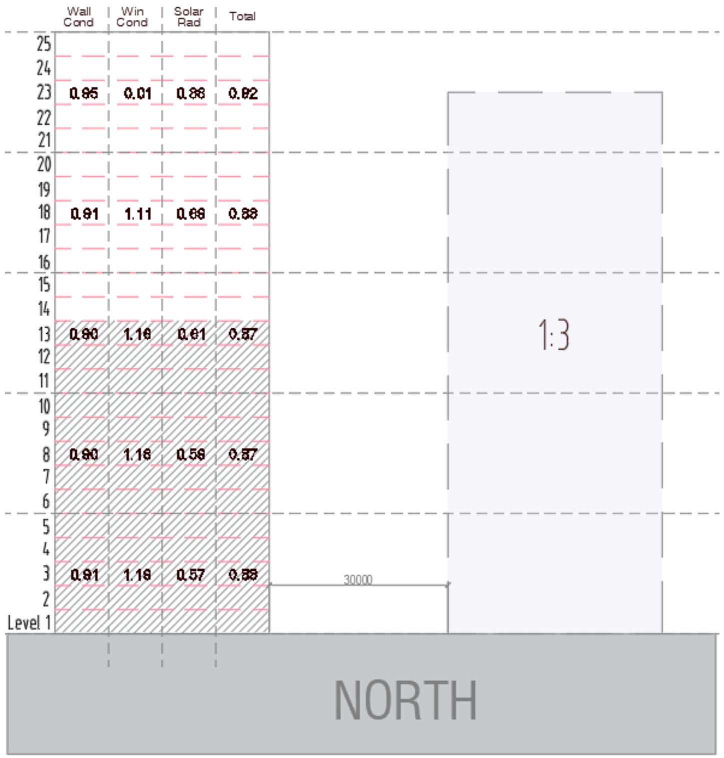


Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southwest	40	1:10	0.91	1.12	0.68	0.85
	30		0.92	1.13	0.67	0.86

4.2.7 Ratio 1:3 (d=30m)

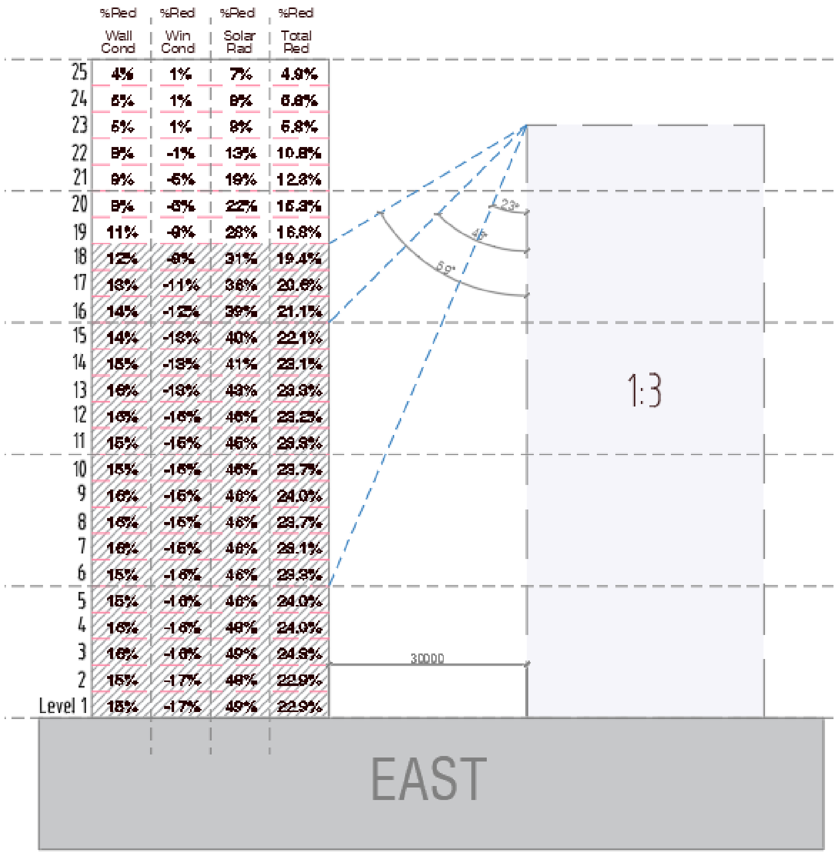
A. NORTH ORIENTATION

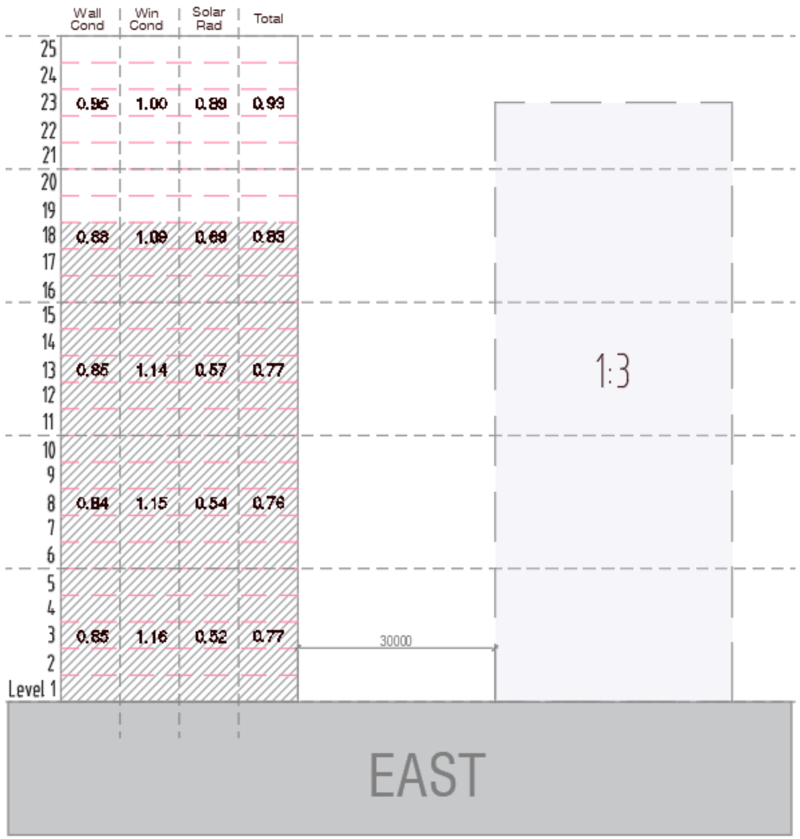




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
North	40	1:3	0.90	1.16	0.60	0.82
	30		0.90	1.17	0.59	0.82
	20		0.91	1.19	0.57	0.83

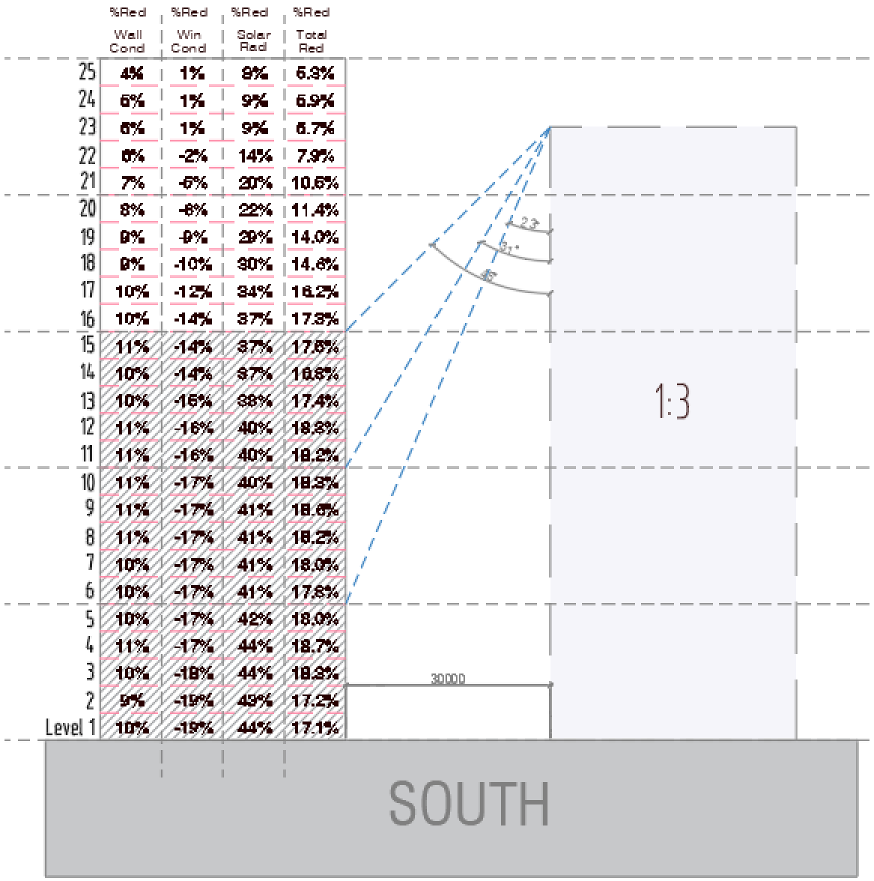
B. EAST ORIENTATION

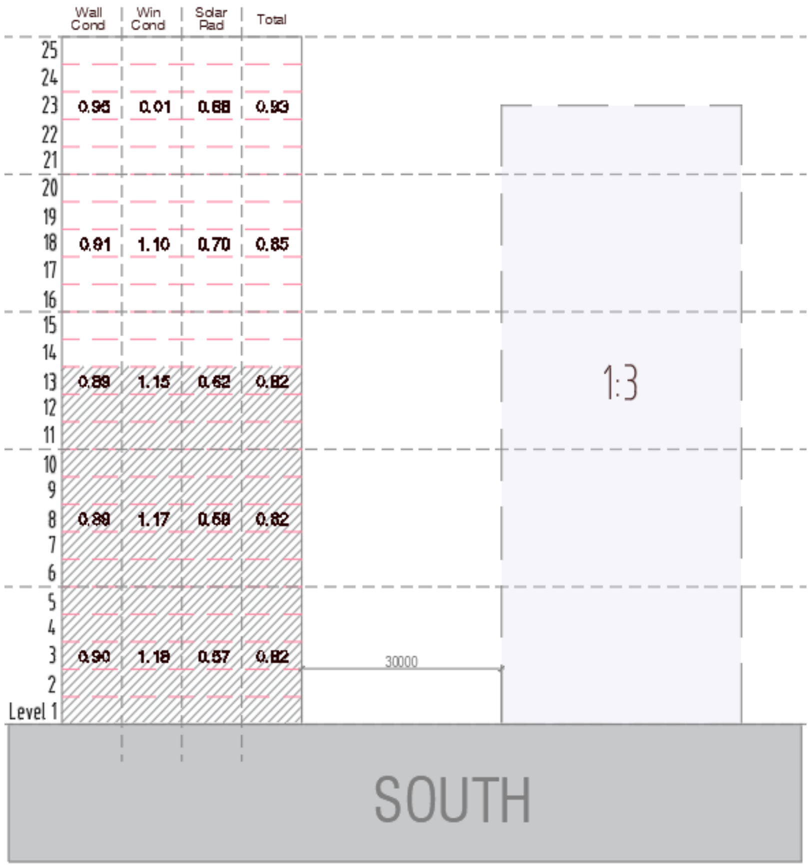




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
East	60	1:3	0.87	1.11	0.65	0.81
	40		0.85	1.14	0.56	0.77
	20		0.85	1.16	0.52	0.77

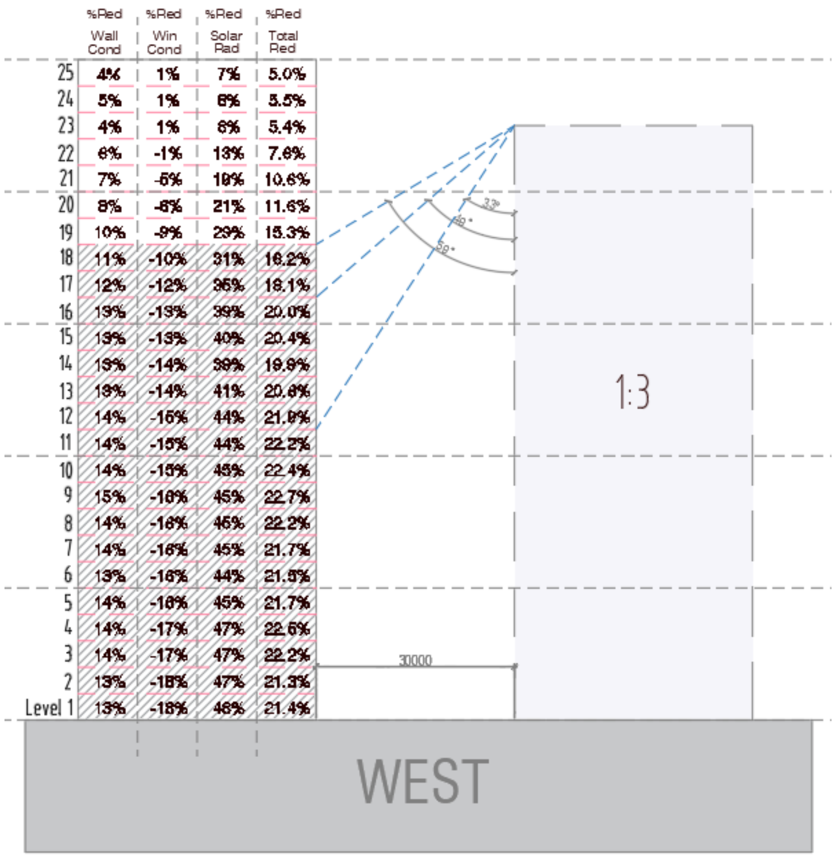
C. SOUTH ORIENTATION

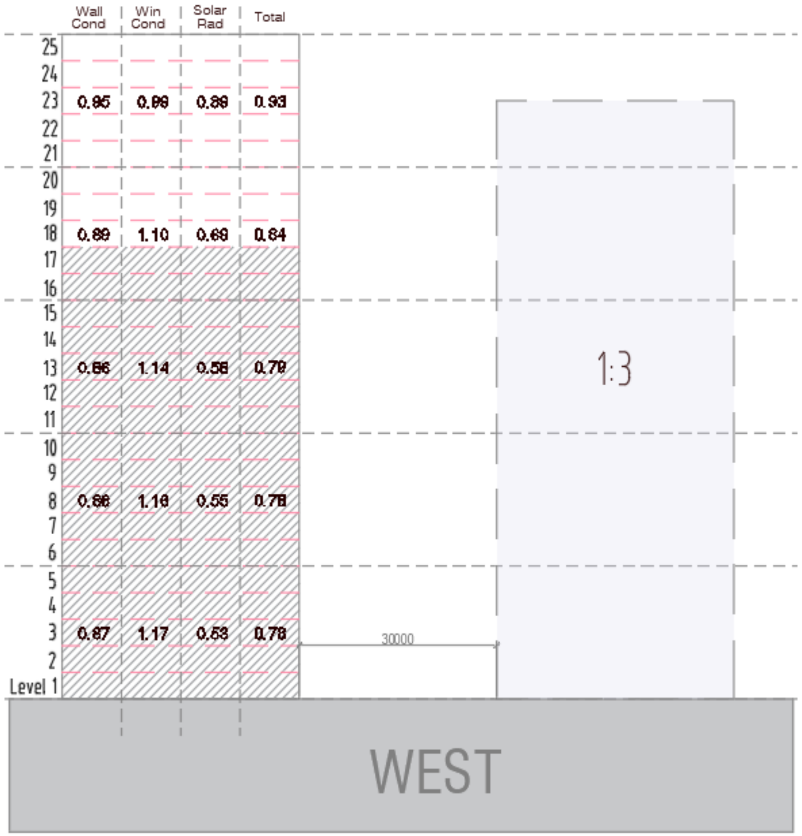




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
South	40	1:3	0.89	1.19	0.62	0.77
	30		0.89	1.15	0.59	0.77
	20		0.90	1.17	0.57	0.82

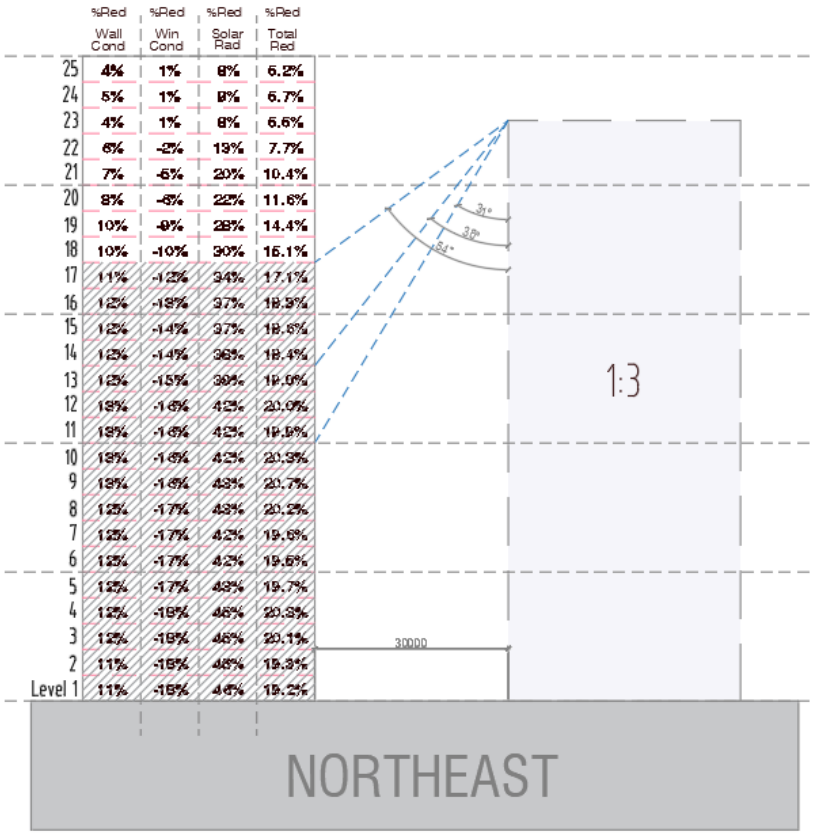
D. WEST ORIENTATION

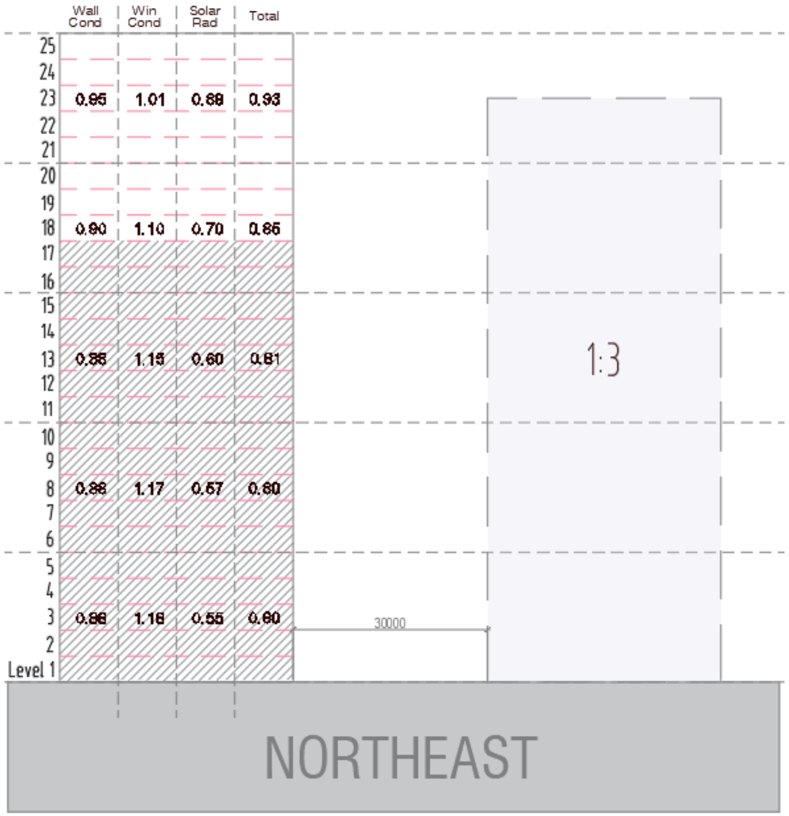




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
West	60	1:3	0.89	1.11	0.67	0.83
	50		0.87	1.14	0.60	0.79
	30		0.86	1.16	0.54	0.78

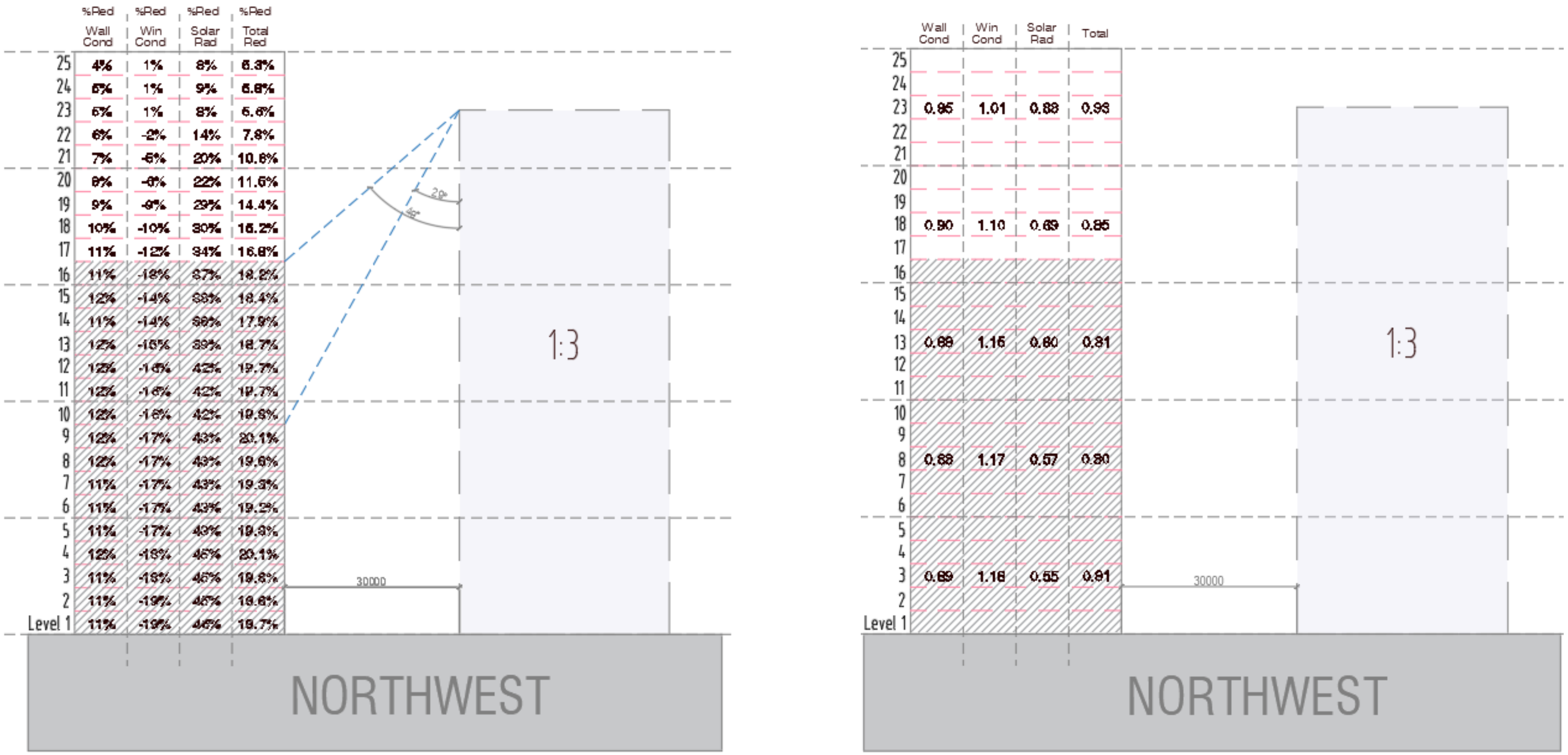
E. NORTHEAST ORIENTATION





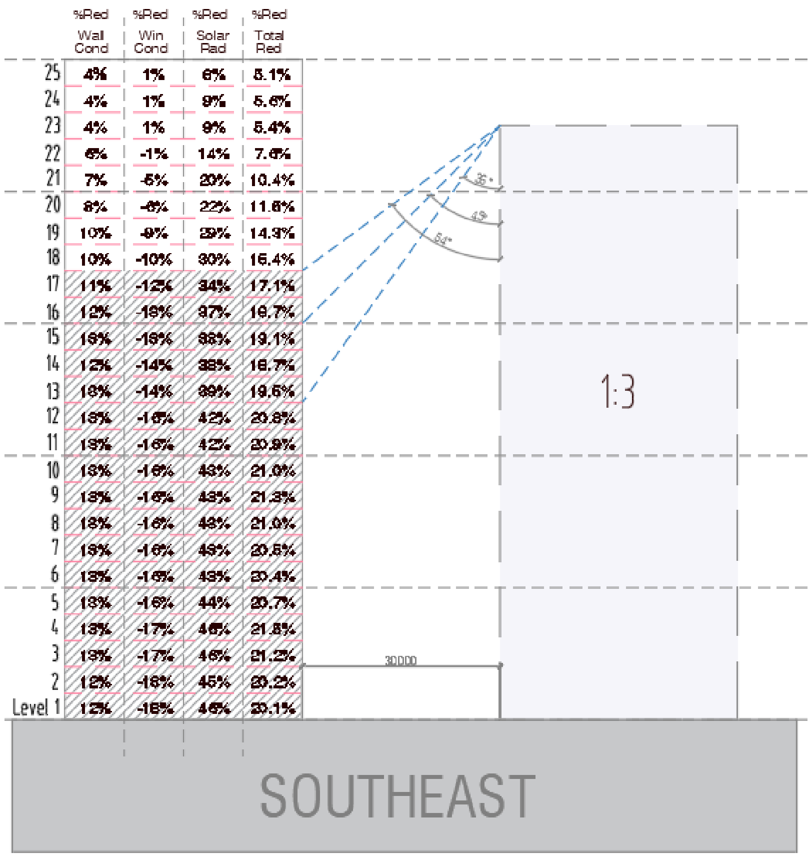
Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northeast	60	1:3	0.88	1.13	0.63	0.82
	40		0.88	1.16	0.59	0.80
	30		0.88	1.17	0.56	0.80

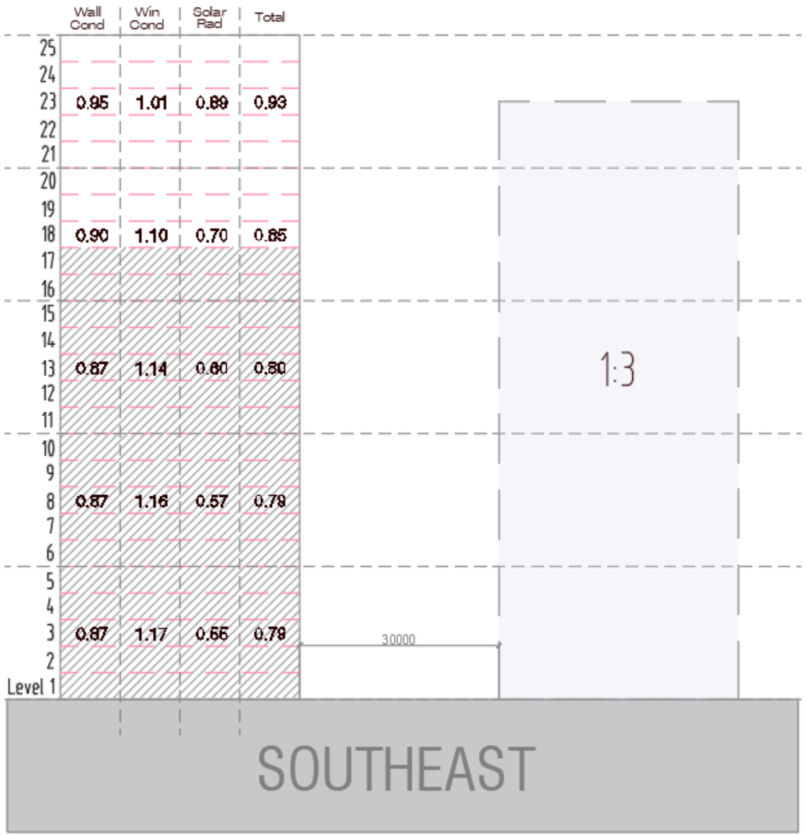
F. NORTHWEST ORIENTATION



Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northwest	50	2:5	0.88	1.15	0.60	0.81
	30		0.89	1.18	0.56	0.81

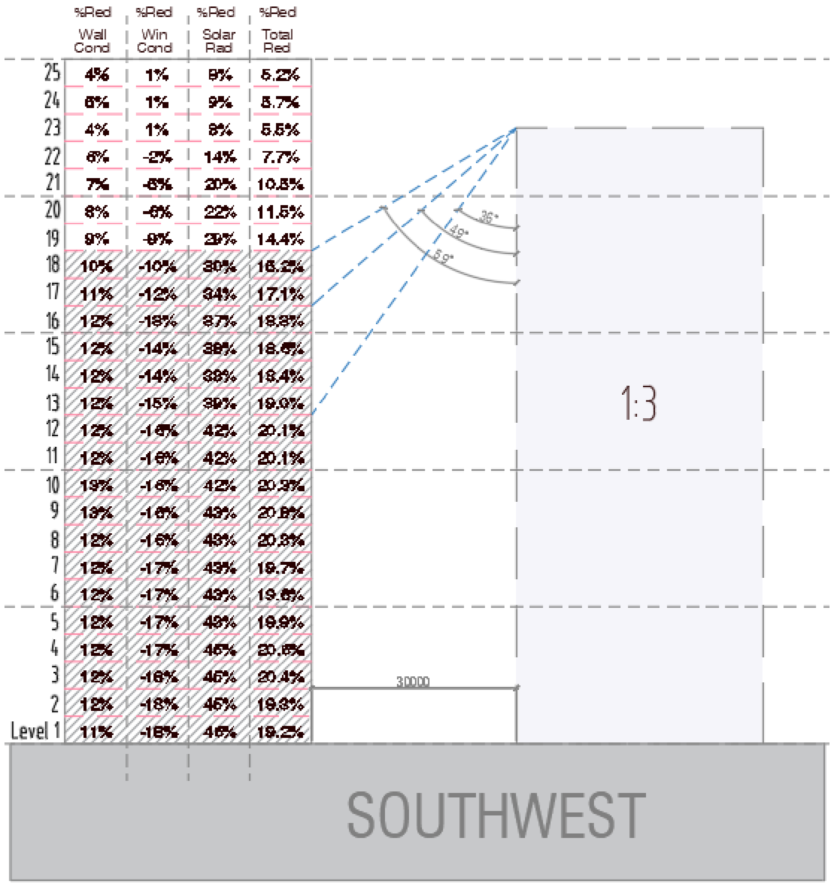
G. SOUTHEAST ORIENTATION

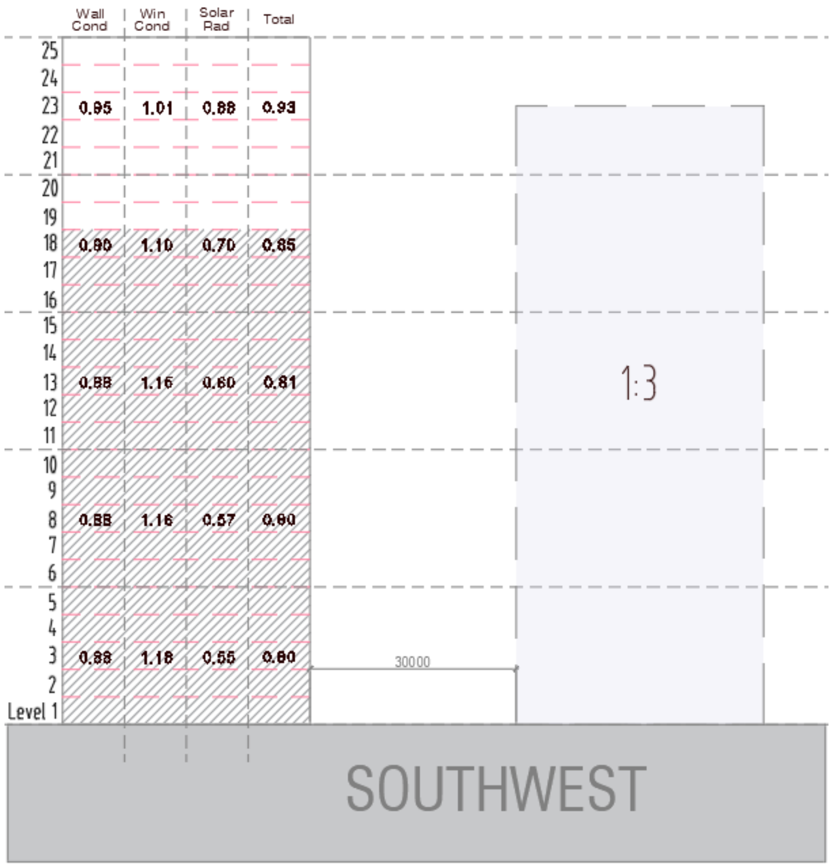




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southeast	60	1:3	0.88	1.12	0.65	0.82
	40		0.88	1.14	0.62	0.81
	30		0.87	1.16	0.56	0.79

H. SOUTHWEST ORIENTATION

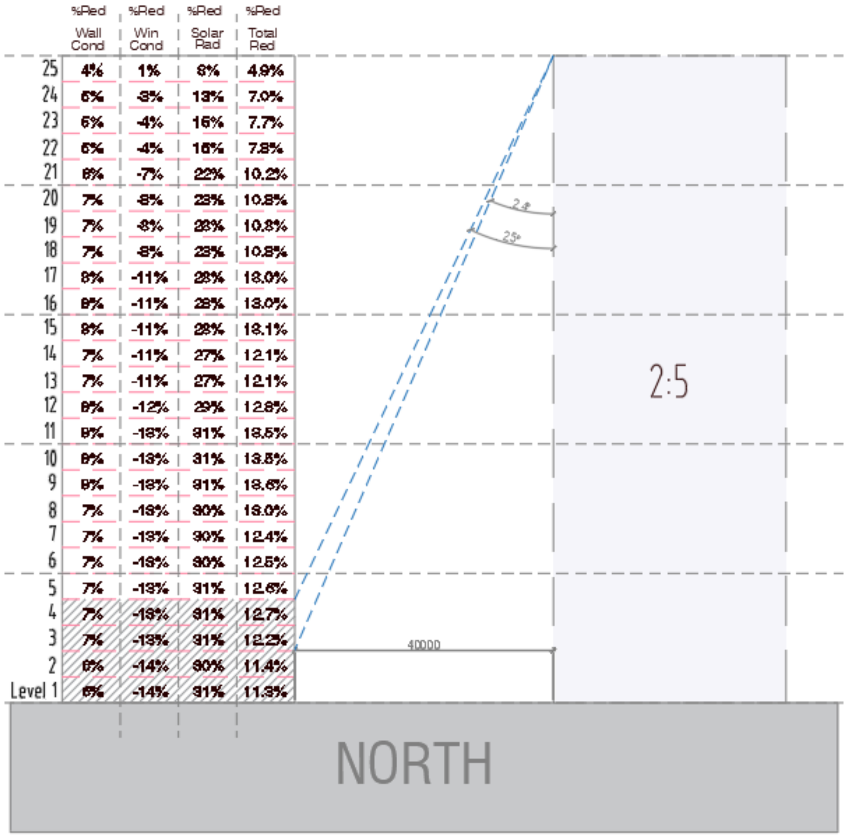


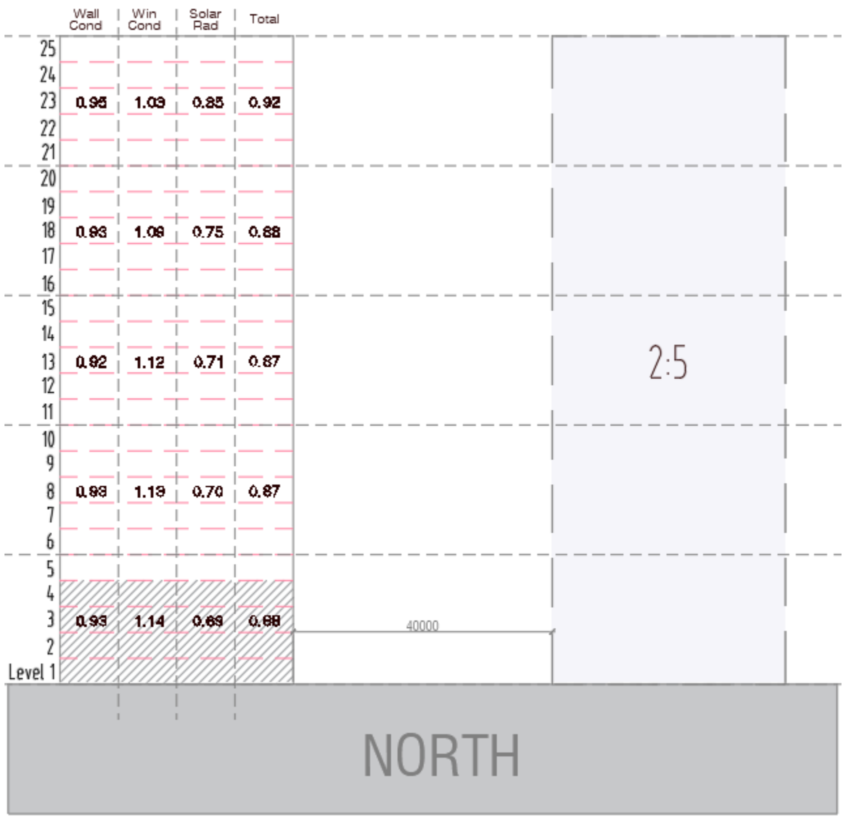


Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southeast	60	1:3	0.90	1.11	0.68	0.84
	50		0.88	1.14	0.62	0.81
	40		0.88	1.17	0.56	0.80

4.2.8 Ratio 2:5 (d=40m)

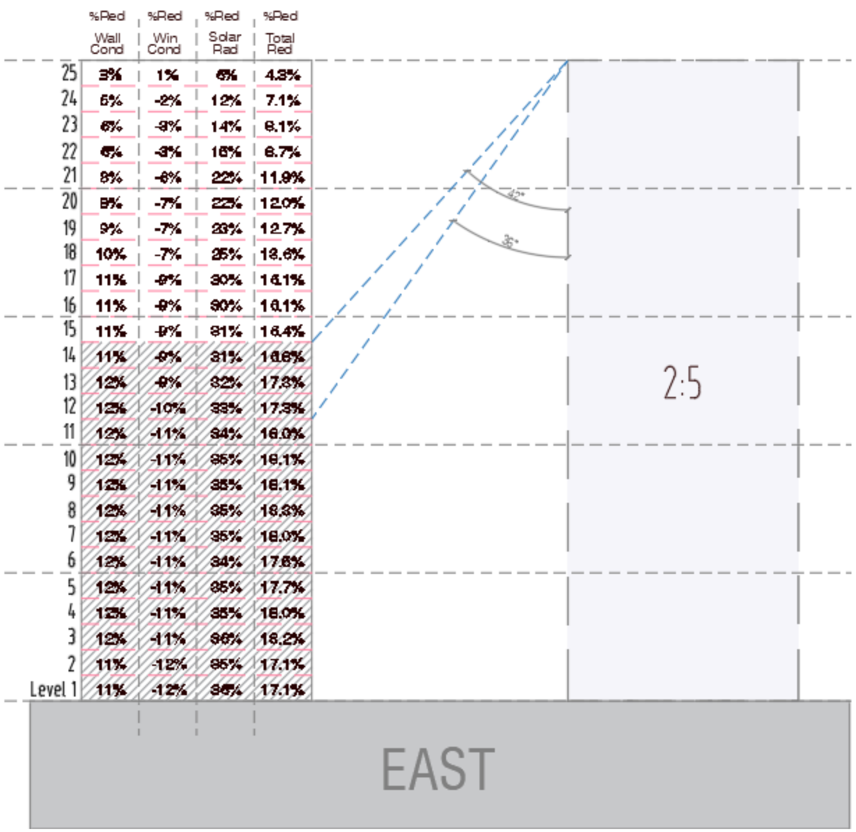
A. NORTH ORIENTATION

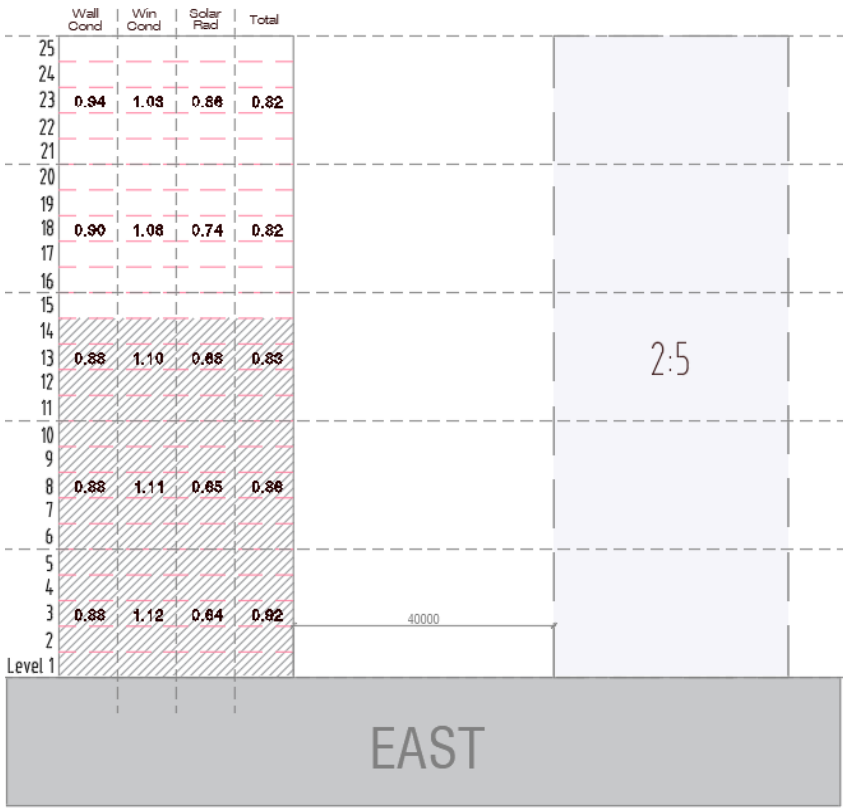




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
North	30	2:5	0.93	1.13	0.69	0.88
	20		0.94	1.14	0.69	0.89

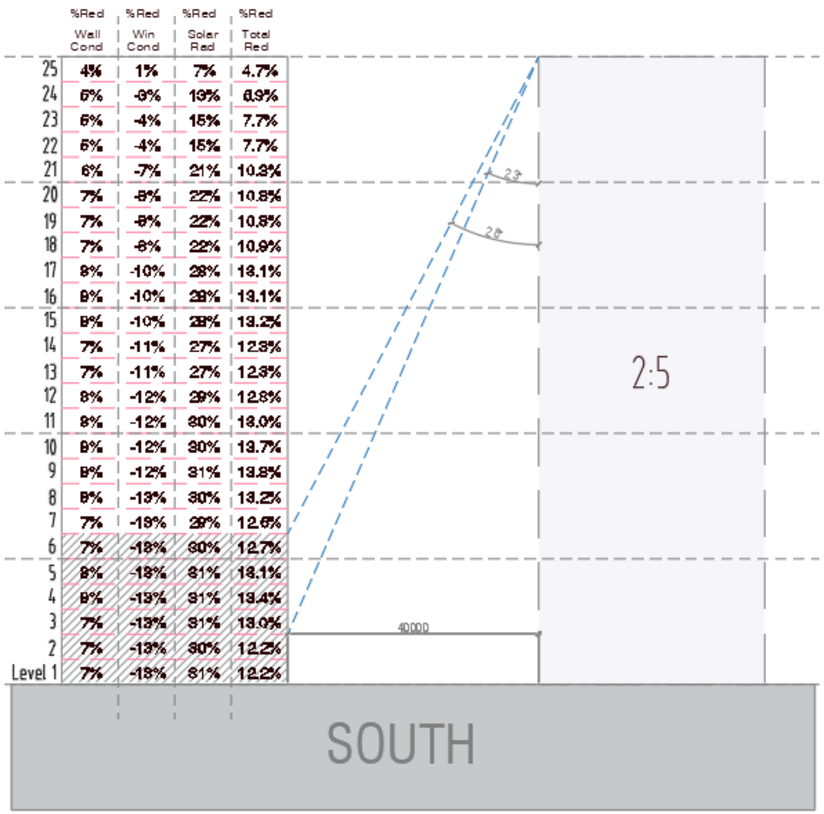
B. EAST ORIENTATION

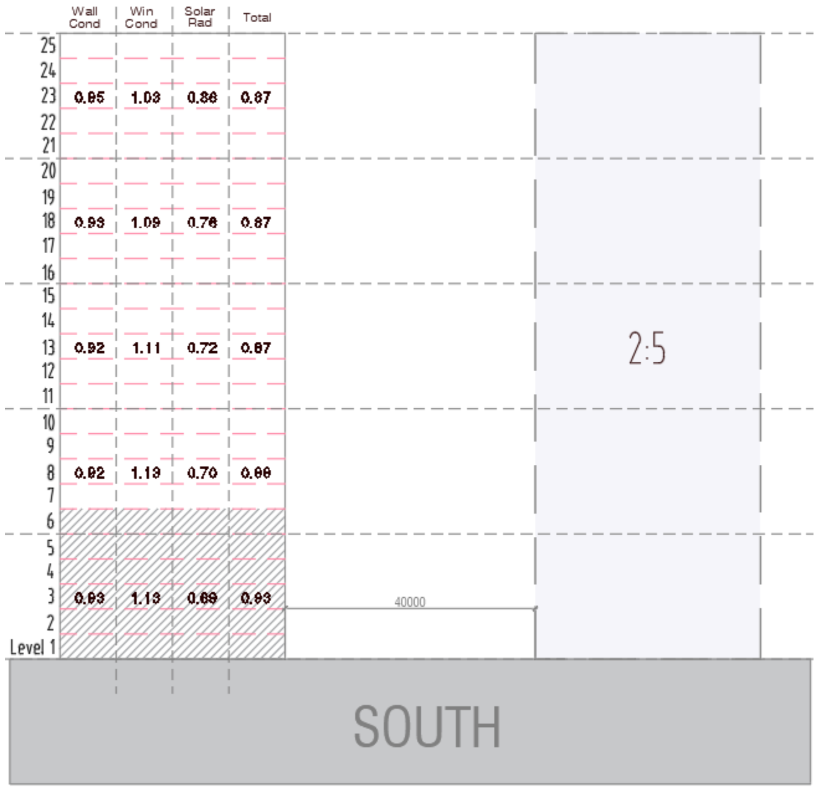




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
East	40	2:5	0.88	1.10	0.68	0.83
	30		0.88	1.11	0.65	0.82

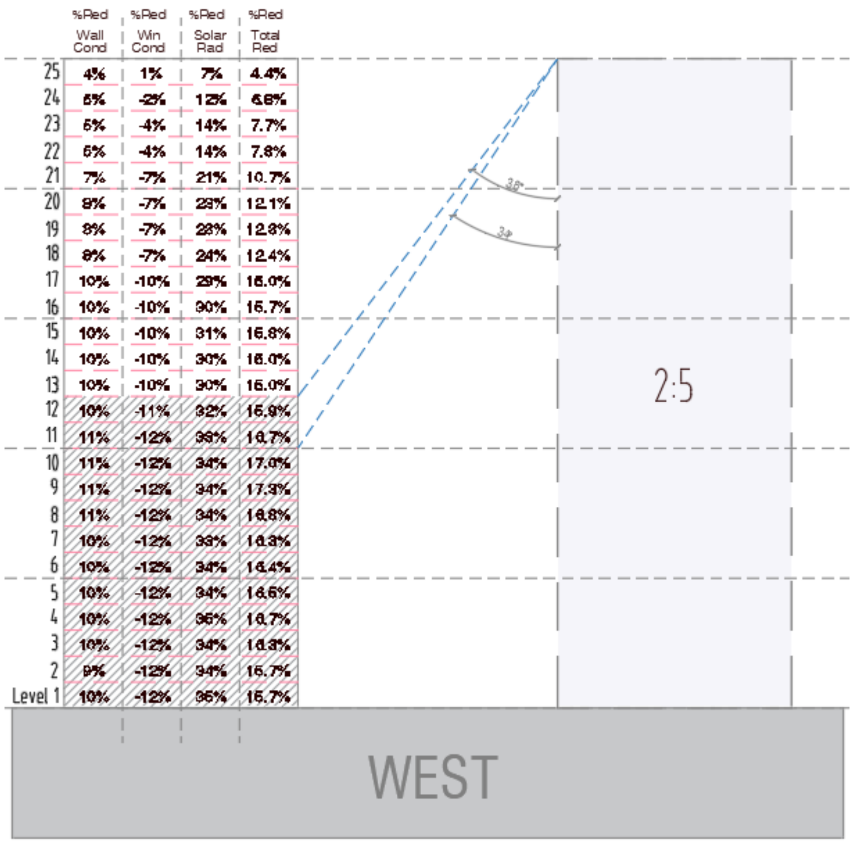
C. SOUTH ORIENTATION

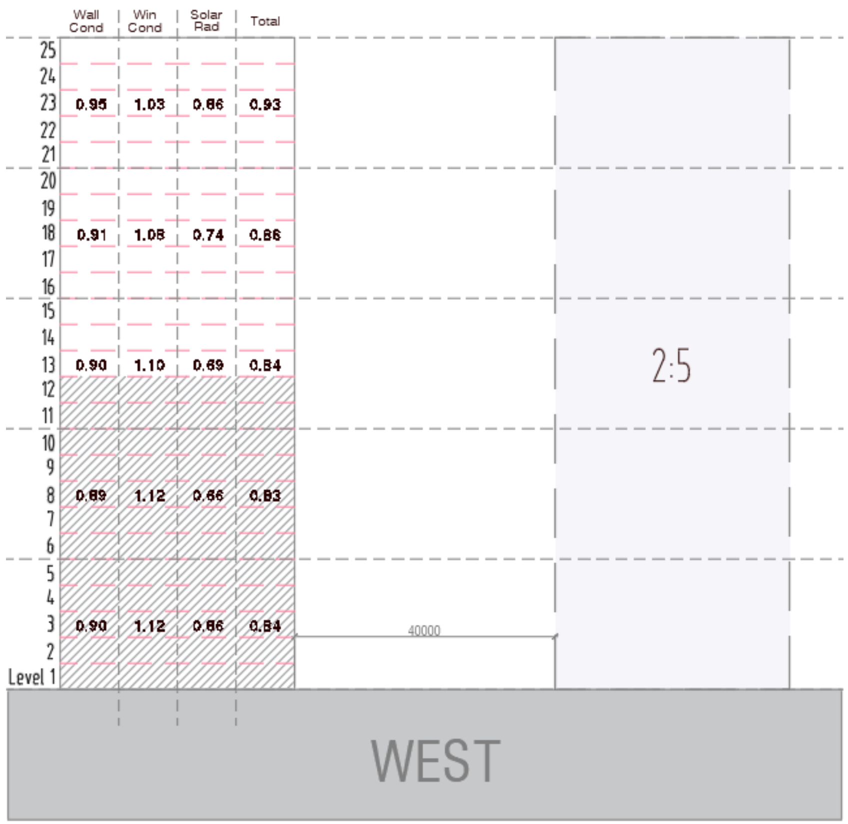




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
South	30	2:5	0.93	1.13	0.70	0.87
	20		0.93	1.13	0.69	0.88

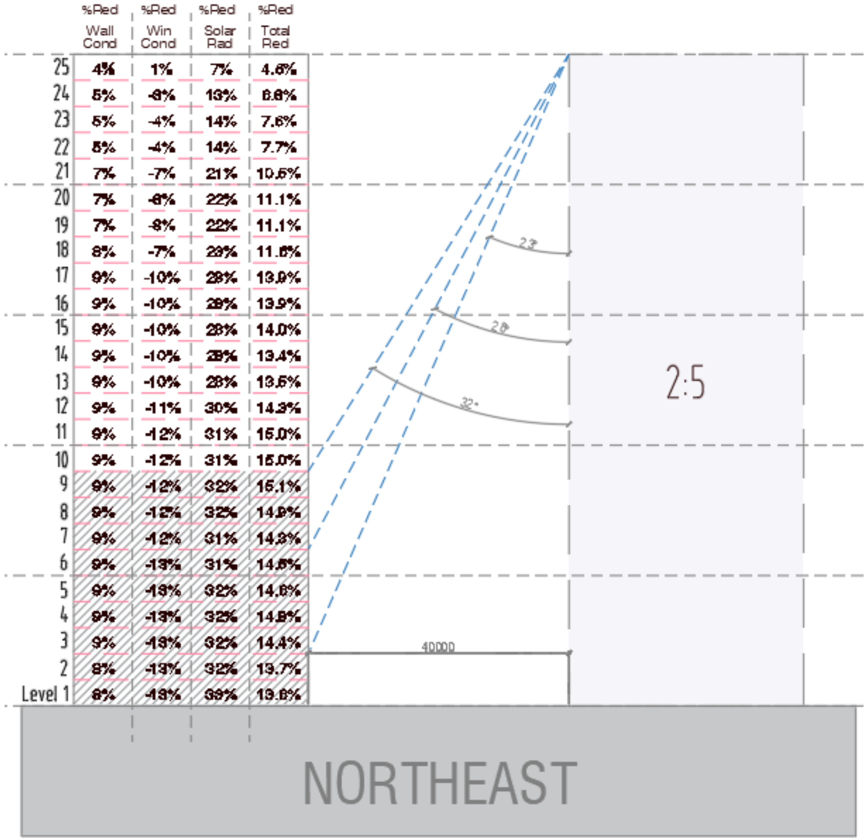
D. WEST ORIENTATION

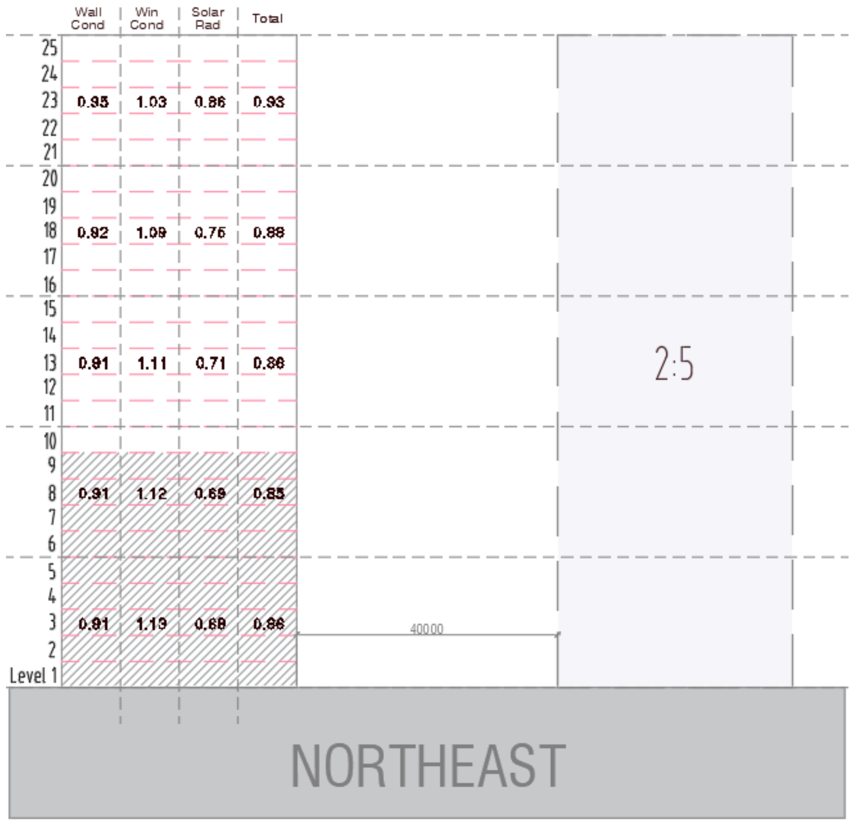




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
West	40	2:5	0.90	1.11	0.68	0.84
	30		0.90	1.12	0.66	0.84

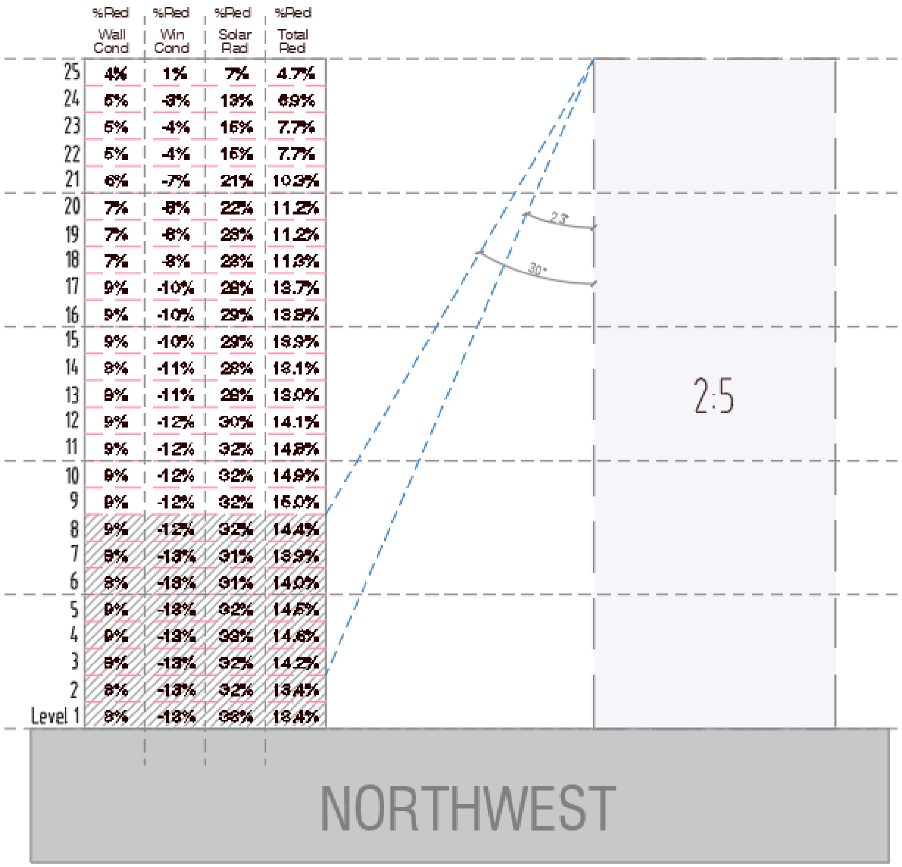
E. NORTHEAST ORIENTATION

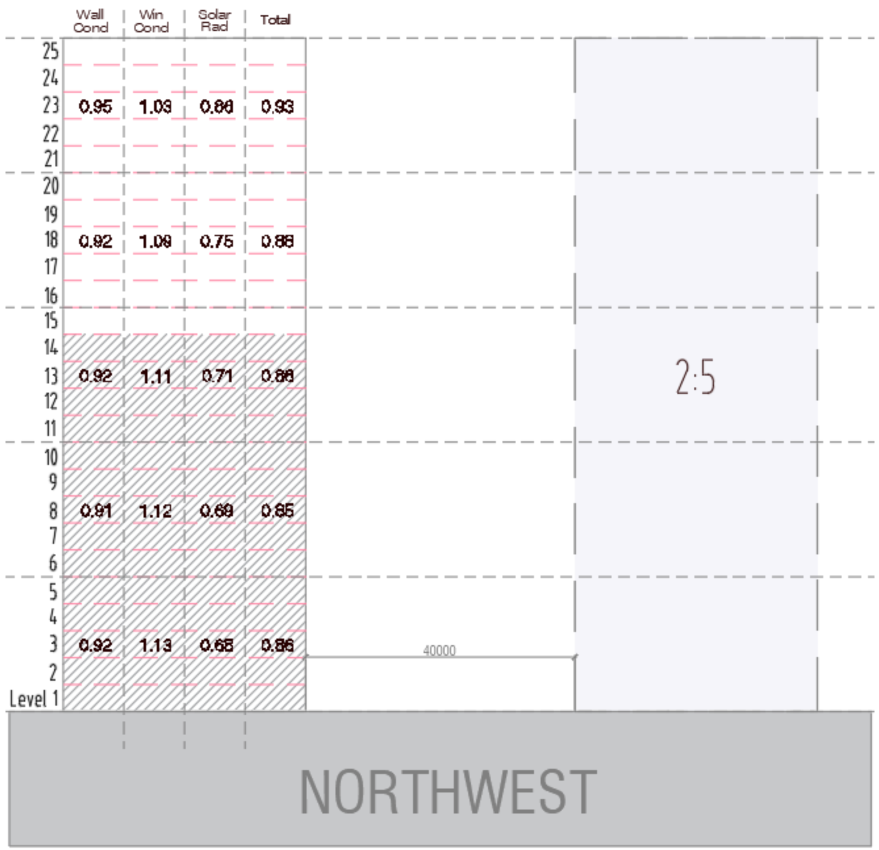




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northeast	30	2:5	0.91	1.12	0.68	0.85
	20		0.92	1.13	0.68	0.86

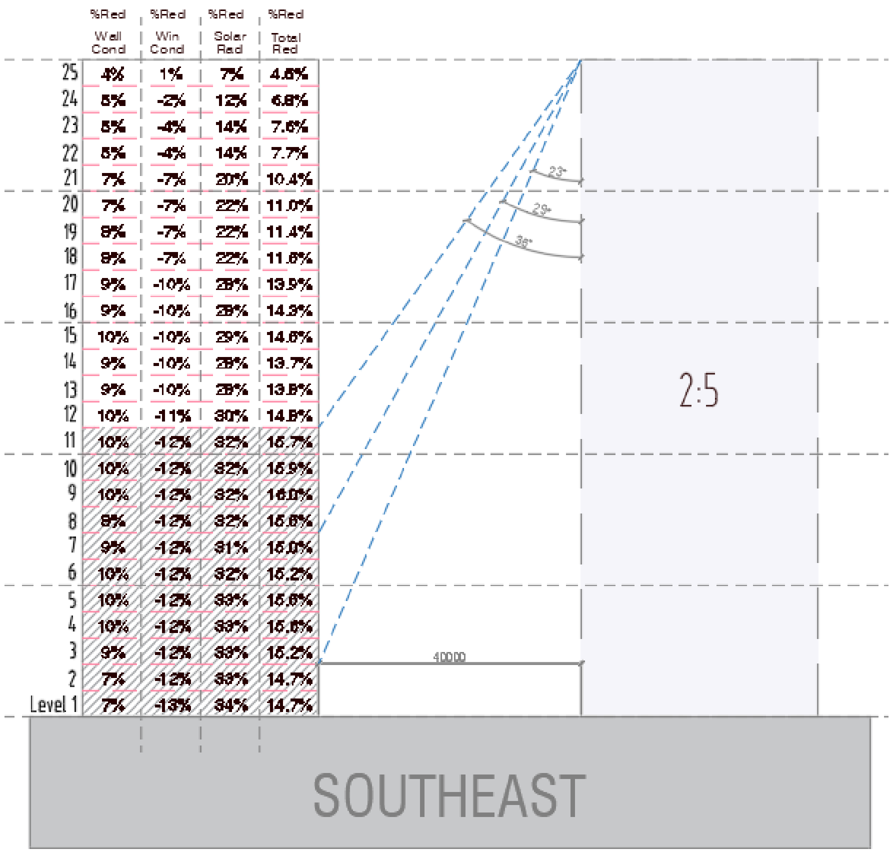
F. NORTHWEST ORIENTATION

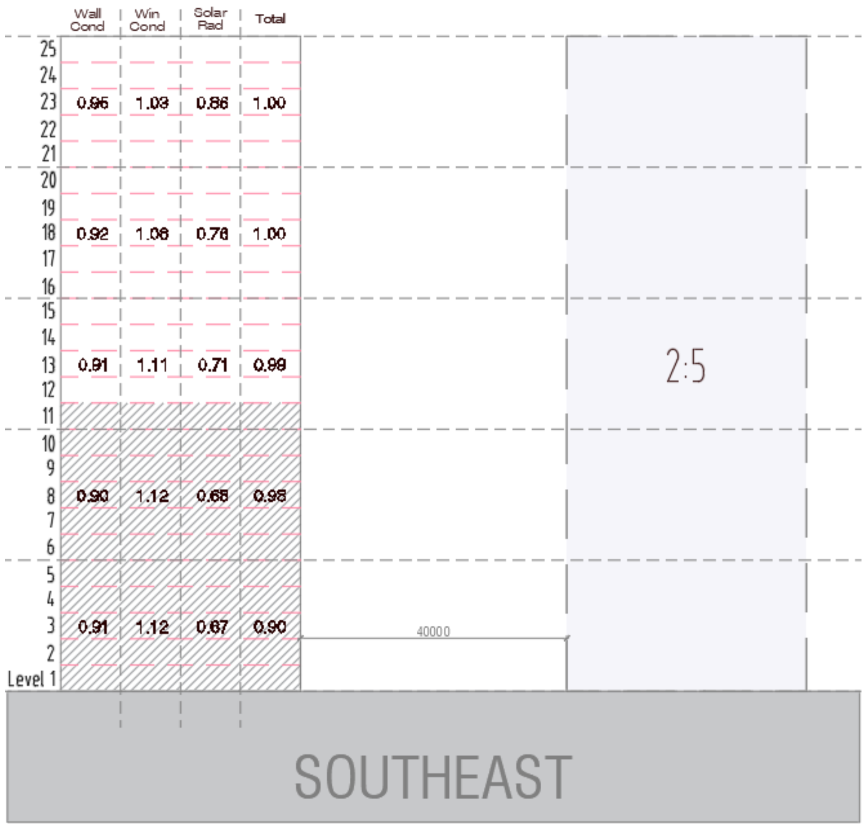




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Northwest	30	2:5	0.92	1.13	0.68	0.86
	20		0.92	1.13	0.68	0.87

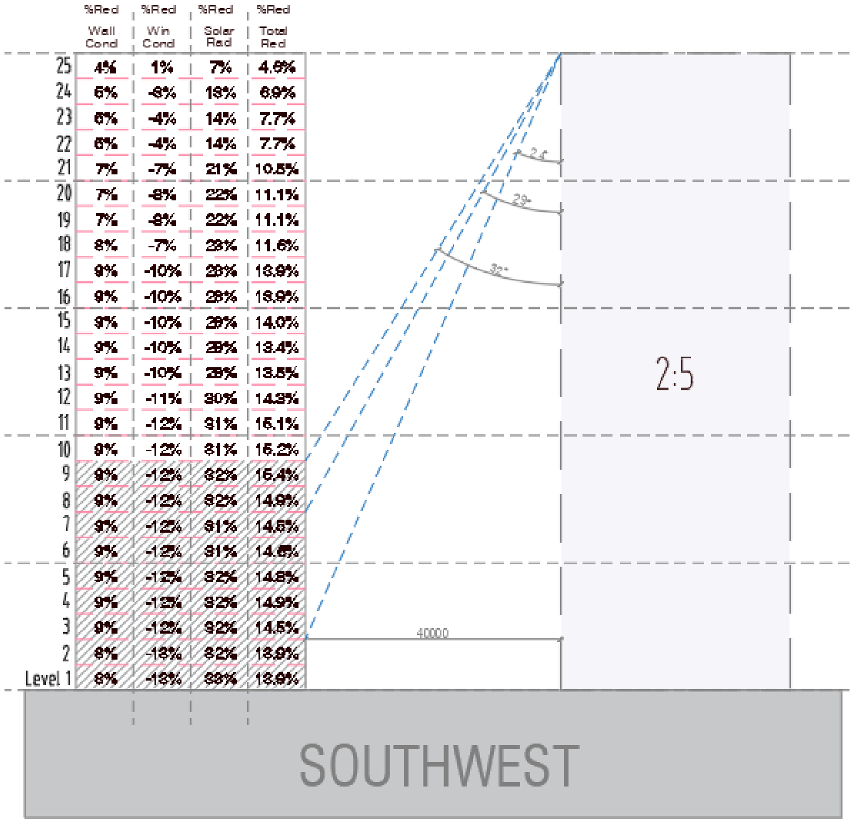
G. SOUTHEAST ORIENTATION

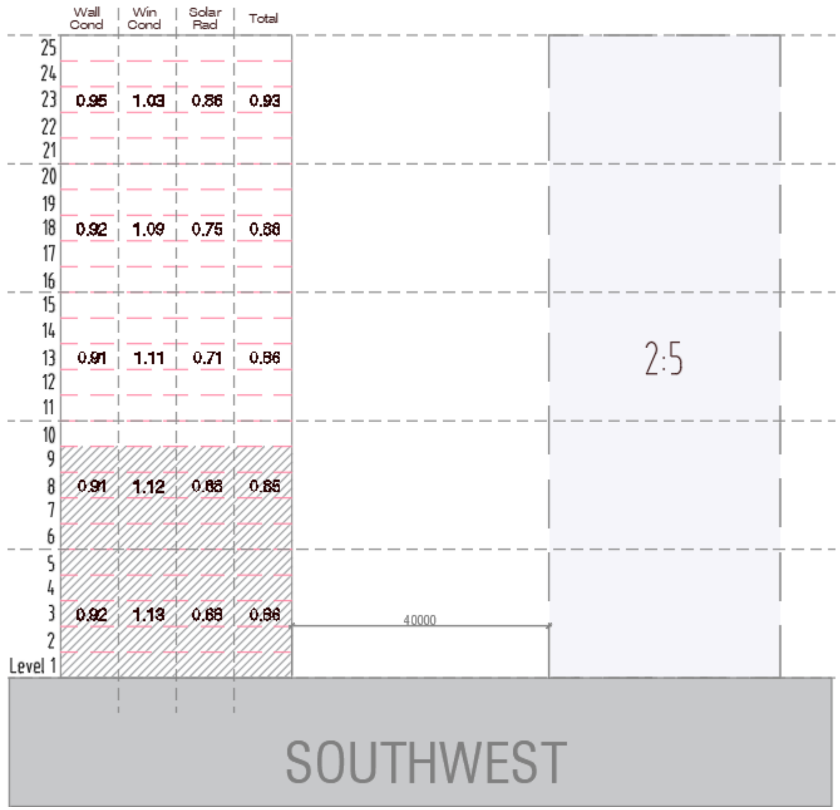




Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southwest	40	2:5	0.90	1.12	0.68	0.84
	30		0.90	1.12	0.68	0.85
	20		0.91	1.13	0.67	0.85

H. SOUTHWEST ORIENTATION





Orientation	Obstruction Angle	Ratio (d:h)	CF			
			Wall Conduction	Window Conduction	Window Radiation	Total
Southwest	40	2:5	0.91	1.12	0.68	0.85
	30		0.92	1.13	0.67	0.86

4.3 Simulation Model 2

The objective of the second scenario is to study the effect of natural ventilation on the OTTV performance of a building with air conditioned and naturally ventilated spaces in a bid to ascertain the suitable approach to evaluating thermal performance of commercial building envelopes. For this objective, computer simulations and heat gain calculations combined with OTTV equations were used to study the overall thermal performance of the envelope. This scenario was executed to include and also exclude naturally ventilated (NV) spaces (corridor) respectively in the assessment of OTTV performance simulations and equation computations (Figure 4.3). Three iterations of the model were developed to include different corridor WWR of 30%, 50% and 70% as well as corridor depths of 3m, 6m, 9m and 12m through four orientations in order to test the effect of opening sizes in the overall thermal performance.

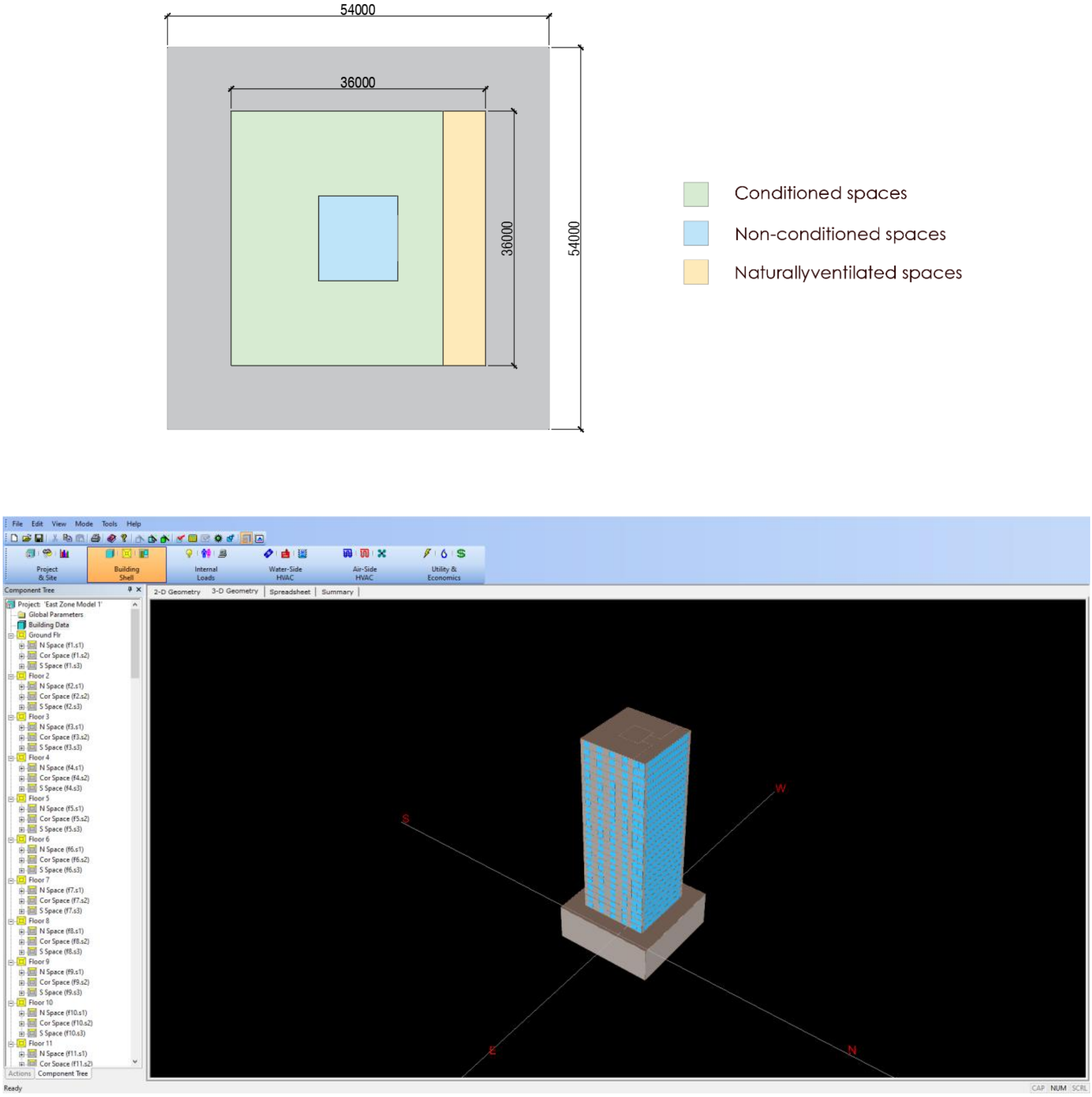


Figure 4.3 Plan and simulation view of model 2

Heat gain performance parameters extracted from the simulation tools include: heat conduction through wall & glazing, solar radiation through glazing. These parameters form the components of the OTTV Malaysia equation (MS1525:2019) which was used to validate the simulation outputs. The heat gain parameters from the simulation were computed and assessed for OTTV (Table 4.2) using the equation below as derived from (Chou and Chang, 1996).

$$\text{OTTV} = \frac{\text{Total heat gain through the building envelope}}{(\text{Total Operation Hrs}) \times (\text{Total Envelope Area})}$$

$$TD_{eq}(1 - WWR)(U_w) = \frac{\sum_{1\text{ year}} Q_{\text{wall,cond}}}{\text{annual operating hours} \times A}$$

$$\Delta T(WWR)\left(U_f\right) = \frac{\sum_{1\text{ year}} Q_{\text{win,cond}}}{\text{annual operating hours} \times A}$$

$$SF(WWR)(SC) = \frac{\sum_{1\text{ year}} Q_{\text{win,rad}}}{\text{annual operating hours} \times A}$$

Table 4.2. Comparison results on the effect of NV spaces on OTTV performance

	NV Depth	NV Space WWR- 30%					NV Space WWR- 50%					NV Space WWR- 70%				
		Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.	Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.	Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
NORTH	3m	115.41	77.00	33.3%	77.66	32.7%	121.04	83.77	30.8%	77.66	35.8%	126.07	91.05	27.8%	77.66	38.4%
	6m	117.90	77.00	34.7%	77.52	34.2%	125.11	83.77	33.0%	77.52	38.0%	131.72	91.05	30.9%	77.52	41.1%
	9m	120.04	77.00	35.9%	77.36	35.6%	128.69	83.77	34.9%	77.36	39.9%	136.71	91.05	33.4%	77.36	43.4%
	12m	117.65	77.00	34.6%	77.17	34.4%	127.68	83.77	34.4%	77.17	39.6%	137.07	91.05	33.6%	77.17	43.7%

	NV Depth	NV Space WWR- 30%					NV Space WWR- 50%					NV Space WWR- 70%				
		Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.	Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.	Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
EAST	3m	115.39	77.00	33.3%	72.91	36.8%	121.70	83.77	31.2%	72.91	40.1%	127.33	91.05	28.5%	72.91	42.7%
	6m	117.81	77.00	34.6%	72.69	38.3%	125.67	83.77	33.3%	72.69	42.2%	132.86	91.05	31.5%	72.69	45.3%
	9m	119.81	77.00	35.7%	73.02	39.1%	129.03	83.77	35.1%	73.02	43.4%	137.57	91.05	33.8%	73.02	46.9%
	12m	117.80	77.00	34.6%	73.08	38.0%	128.29	83.77	34.7%	73.08	43.0%	138.07	91.05	34.1%	73.08	47.1%

	NV Depth	NV Space WWR- 30%					NV Space WWR- 50%					NV Space WWR- 70%				
		Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.	Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.	Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
SOUTH	3m	115.32	77.00	33.2%	77.34	32.9%	121.16	83.77	30.9%	77.34	36.2%	126.37	91.05	27.9%	77.34	38.8%
	6m	117.84	77.00	34.7%	77.17	34.5%	125.29	83.77	33.1%	77.17	38.4%	132.10	91.05	31.1%	77.17	41.6%
	9m	120.00	77.00	35.8%	76.99	35.8%	128.90	83.77	35.0%	76.99	40.3%	137.16	91.05	33.6%	76.99	43.9%
	12m	117.63	77.00	34.5%	76.78	34.7%	127.93	83.77	34.5%	76.78	40.0%	137.53	91.05	33.8%	76.78	44.2%

	NV Depth	NV Space WWR- 30%					NV Space WWR- 50%					NV Space WWR- 70%				
		Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.	Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.	Simulatio	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
WEST	3m	115.45	77.00	33.3%	77.59	32.8%	121.65	83.77	31.1%	77.59	36.2%	127.17	91.05	28.4%	77.59	39.0%
	6m	117.84	77.00	34.7%	77.93	33.9%	125.57	83.77	33.3%	77.93	37.9%	132.62	91.05	31.3%	77.93	41.2%
	9m	119.82	77.00	35.7%	78.32	34.6%	128.91	83.77	35.0%	78.32	39.2%	137.30	91.05	33.7%	78.32	43.0%
	12m	117.80	77.00	34.6%	78.77	33.1%	128.12	83.77	34.6%	78.77	38.5%	137.76	91.05	33.9%	78.77	42.8%

4.4 Simulation Model 3

The third objective is to compare the overall energy consumption through residential building envelope using air conditioned and naturally ventilated scenarios. To this effect, OTTV and RETV equations were used respectively to evaluate and compare thermal performance in addition to heat gain calculations from computer simulations (Figure 4.4). The heat gain through the residential building envelope is calculated through the cooling period of 12 months (Jan-Dec) totalling 8760 hours. The results of this assessment are presented in Figure 4.5 with detailed analysis in the Appendix.

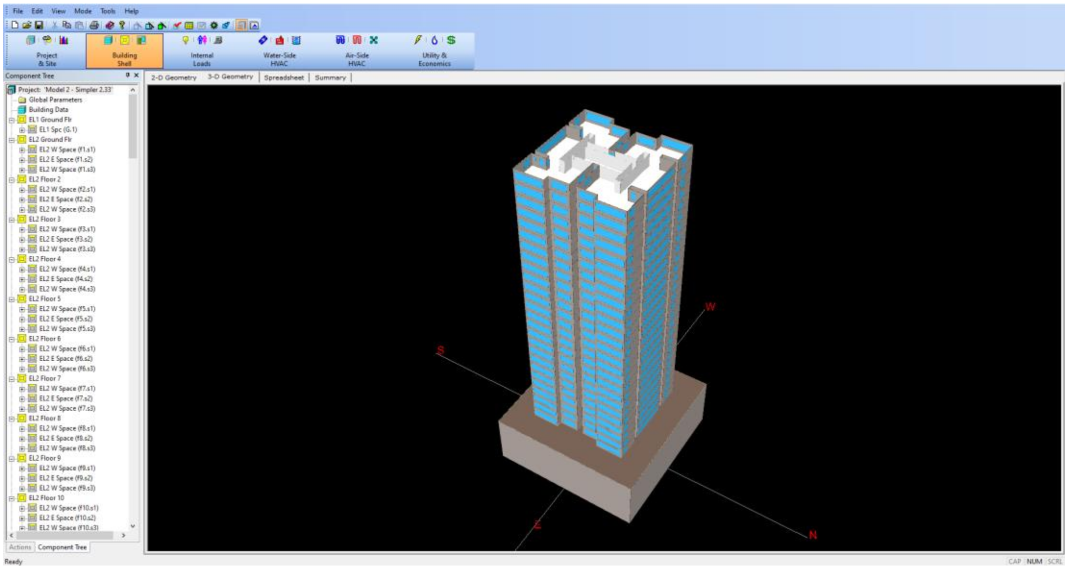


Figure 4.4 Simulation view of model 3

	GWA	RETV
NORTH	3160.00	63740.6820
EAST	3360.00	104344.2526
SOUTH	3160.00	65021.2751
WEST	3360.00	109438.9366
Total	**13040.00**	**342545.1463**
Building RETV		**26.27**

(a)

	GWA	OTTV
NORTH	3750.00	244232.6288
EAST	3360.00	367503.8940
SOUTH	3750.00	247058.9663
WEST	3360.00	306363.3390
Total	**14220.00**	**1165158.8280**
Building OTTV		**81.94**

(b)

	Wall Conduction (kW)	**Window Conduction (kW)**	**Window Radiation (kW)**
Annual Loads	1383177.275	599138.827	1858904.325
Cooling Hours	8760		
Envelope Area	14220.00		
OTTV (simulation)	**30.84**		

(c)

Figure 4.5 Model 3 results: (a) RETV; (b) OTTV and (c) heat gain simulation results

4.5 Key Findings

4.5.1 Simulation Model 1

- The objective of this simulation is to evaluate the effect of adjacent shading on OTTV performance.
- Findings from the results demonstrate a gradual change in shading performance on facades on all orientations.
- Adopting absolute values for adjacent shading coefficients in the assessment of OTTV could result in overestimation or underestimation of building thermal performance.
- Thus, floor-to-floor correction factors were derived from thermal performance simulations conducted using conventional models in the local context as developed through the building inventory.
- Obstruction angles between adjacent development are significant in selecting the appropriate correction factor depending on the building orientation as the ratio of distance to height of adjacent buildings is not always proportional to the effect of shading performance.

4.5.2 Simulation Model 2

- The objective of the second simulation is to study the effect of natural ventilation on the OTTV performance of a building with air conditioned and naturally ventilated spaces in a bid to ascertain the suitable approach to evaluating thermal performance of commercial building envelopes.
- Assessment of OTTV with the inclusion of naturally ventilated spaces presented results with closer margin to the validated heat gain simulation and calculation methods adopted for the study compared to the results of excluding naturally ventilated spaces from the evaluation.
- WWR of naturally ventilated spaces significantly impact whole building thermal performance.
- This comparison suggests that the incorporation of the overall building envelope area ("closed-loop) could be a suitable approach to evaluating building OTTV considering the heat transfer phenomenon between connected building spaces.

4.5.3 Simulation Model 3

- The third simulation attempts to compare the overall energy consumption through residential building envelope using air conditioned and naturally ventilated scenarios. A comparison of RETV, OTTV and heat gain simulations are carried out on a test residential building.

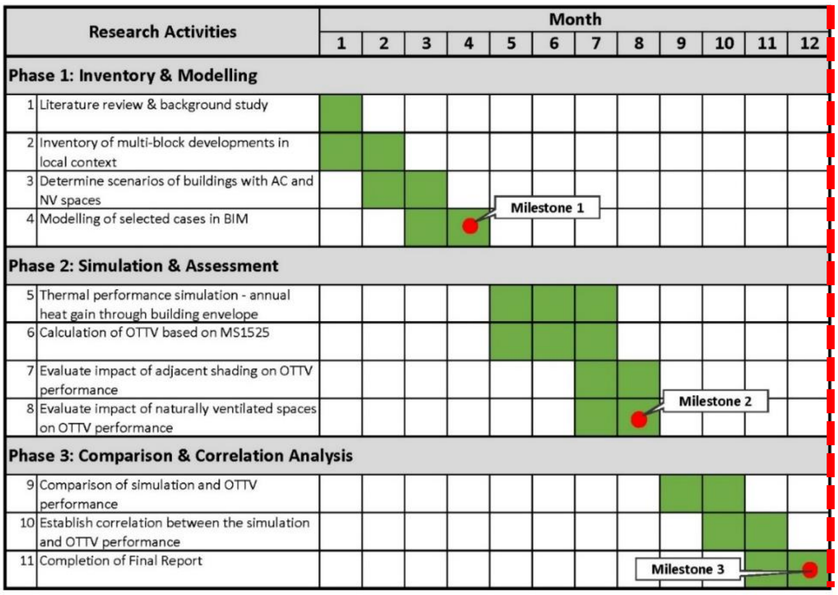
- Heat gain simulation result show proximate value with RETV assessment compared to OTTV calculations.
- The disparity in the RETV and OTTV results can be traced to the difference in the equation components (coefficients, constants and orientation factors) in respective equations. This led to higher result margin in the OTTV assessment in comparison to the other sets of results in this study.
- This also suggests the suitability of RETV against OTTV for residential developments fundamentally because of the dissimilarity in their evaluation methods.

5.0 CONCLUSION

This study highlights the limitation of OTTV in the assessment of adjacent shading and natural ventilation effect on the building envelope. This report covers first, second and third phases of the project which includes modelling, dynamic simulation and and heat gain calculations as well as the comparison and correlation analysis as outlined in the research schedule. Thus, all project milestones have been achieved.

This phase of the project marks the completion of the research project upon the evaluation of the impact of adjacent shading, natural ventilation on thermal performance on the three simulation models as proposed. Correlation factors have been developed to incorporate adjacent shading effect in the evaluation of building energy performance under prescriptive building energy codes for Malaysian buildings. Furthermore, a simple web tool has been developed to guide and support professionals in the evaluation of OTTV. The tool- currently at its preliminary version can be used to determine correlation factors for interblock shading in the calculation of OTTV (refer Appendix D).

The outcomes of this study are not yet conclusive for practical adoption by industry professionals. Further work on this project includes validation studies and extensive testing for adaptability to the current standards. In conclusion, this study contributes to active emerging strategies for reduction in energy use in a bid to promote sustainable built environment. Likewise, the proposed method outlined for evaluating adjacent shading effect will support green building design professionals in evaluating the OTTV criteria adequately for certification requirements.



	Milestone	Month
1	Completion of Inventory and Modelling	4
2	Completion of Simulation and Assessment	8
3	Completion of Research and Final Report	12

Figure 5.1 Research Gantt chart

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APPENDIX

APPENDIX A: OBSTRUCTION ANGLES AND CORRELATION FACTORS FOR ADJACENT SHADING

A1: d=20m

D:H Ratio (D=20m)	Orientation	Obstr. Angle	CF			
			Wall Cond.	Win. Cond.	Win. Rad.	Total
1:1	North	70	0.93	1.13	0.70	0.88
		50	0.91	1.17	0.61	0.85
	East	70	0.9	1.10	0.71	0.85
		60	0.89	1.12	0.67	0.84
		50	0.86	1.16	0.58	0.80
	South	70	0.93	1.12	0.71	0.88
		50	0.91	1.17	0.61	0.85
	West	70	0.91	1.11	0.71	0.86
		60	0.9	1.13	0.68	0.85
		50	0.88	1.16	0.58	0.81
1:2	North	60	0.90	1.13	0.67	0.85
		50	0.89	1.17	0.59	0.82
		30	0.90	1.21	0.53	0.82
	East	70	0.88	1.10	0.70	0.84
		60	0.86	1.11	0.65	0.81
		50	0.84	1.15	0.57	0.78
		40	0.82	1.18	0.49	0.75
	South	60	0.90	1.13	0.68	0.85
		50	0.89	1.17	0.59	0.87
		30	0.89	1.20	0.54	0.81
	West	70	0.89	1.10	0.70	0.85
		60	0.88	1.12	0.66	0.83

D:H Ratio (D=20m)	Orientation	Obstr. Angle	CF			
			Wall Cond.	Win. Cond.	Win. Rad.	Total
1:1	Northeast	70	0.91	1.12	0.70	0.87
		50	0.89	1.17	0.60	0.83
	Northwest	70	0.92	1.12	0.70	0.87
		50	0.90	1.17	0.60	0.84
	Southeast	70	0.91	1.12	0.71	0.87
		50	0.89	1.16	0.60	0.83
	Southwest	70	0.92	1.12	0.71	0.87
		50	0.90	1.16	0.60	0.83
1:2	Northeast	70	0.89	1.12	0.69	0.85
		50	0.87	1.16	0.59	0.81
		40	0.86	1.19	0.52	0.78
	Northwest	70	0.90	1.12	0.69	0.85
		50	0.88	1.16	0.59	0.81
		40	0.87	1.19	0.52	0.79
	Southeast	70	0.90	1.10	0.71	0.85
		60	0.89	1.12	0.68	0.84
		50	0.86	1.16	0.58	0.80
		40	0.85	1.19	0.51	0.77
	Southwest	70	0.90	1.11	0.69	0.85
		50	0.87	1.16	0.59	0.81

D:H Ratio (D=20m)	Orientation	Obstr. Angle	CF				D:H Ratio (D=20m)	Orientation	Obstr. Angle	CF			
			Wall Cond.	Win. Cond.	Win. Rad.	Total				Wall Cond.	Win. Cond.	Win. Rad.	Total
		50	0.85	1.16	0.56	0.78			40	0.86	1.19	0.52	0.79
		40	0.84	1.19	0.49	0.76							
1:3	**North**	50	0.87	1.16	0.58	0.81	1:3	**Northeast**	60	0.87	1.12	0.66	0.82
		40	0.87	1.19	0.55	0.80			50	0.86	1.15	0.59	0.79
		30	0.88	1.21	0.52	0.80			40	0.85	1.18	0.53	0.77
		20	0.89	1.22	0.50	0.80			30	0.85	1.20	0.48	0.77
	East	70	0.86	1.10	0.66	0.81		**Northwest**	60	0.88	1.12	0.66	0.83
		50	0.82	1.15	0.55	0.76			50	0.86	1.16	0.57	0.79
		40	0.81	1.17	0.48	0.73			40	0.85	1.19	0.52	0.77
		30	0.81	1.18	0.47	0.72			30	0.85	1.20	0.49	0.77
		20	0.81	1.20	0.43	0.72			20	0.86	1.21	0.46	0.77
	South	60	0.89	1.12	0.66	0.83		**Southeast**	60	0.87	1.12	0.66	0.82
		50	0.87	1.16	0.58	0.80			50	0.85	1.16	0.57	0.78
		30	0.87	1.20	0.53	0.79			40	0.83	1.19	0.50	0.76
		20	0.87	1.21	0.50	0.78			20	0.84	1.20	0.47	0.76
	West	70	0.87	1.11	0.67	0.83		**Southwest**	60	0.88	1.12	0.66	0.83
		50	0.84	1.15	0.55	0.77			50	0.86	1.15	0.59	0.80
		40	0.83	1.19	0.48	0.74			40	0.85	1.16	0.56	0.78
		30	0.84	1.20	0.44	0.74			30	0.85	1.19	0.49	0.77
1:4	**North**	50	0.86	1.18	0.55	0.79	1:4	**Northeast**	60	0.87	1.12	0.65	0.81
									50	0.84	1.16	0.56	0.78
		30	0.87	1.21	0.51	0.78			40	0.83	1.18	0.52	0.76
		20	0.88	1.22	0.49	0.80			30	0.84	1.20	0.48	0.75
	East	70	0.87	1.09	0.68	0.82		**Northwest**	70	0.88	1.11	0.66	0.83
		60	0.85	1.11	0.63	0.80			50	0.84	1.17	0.54	0.77
		50	0.81	1.14	0.54	0.75			30	0.84	1.20	0.48	0.76
		40	0.80	1.18	0.46	0.72			20	0.86	1.21	0.46	0.76
	South	60	0.88	1.12	0.65	0.82		**Southeast**	60	0.85	1.13	0.62	0.80

D:H Ratio (D=20m)	Orientation	Obstr. Angle	CF				D:H Ratio (D=20m)	Orientation	Obstr. Angle	CF			
			Wall Cond.	Win. Cond.	Win. Rad.	Total				Wall Cond.	Win. Cond.	Win. Rad.	Total
		50	0.86	1.17	0.57	0.79			50	0.84	1.16	0.55	0.77
		30	0.85	1.20	0.51	0.77			40	0.82	1.18	0.50	0.75
		20	0.86	1.21	0.48	0.77			30	0.83	1.19	0.47	0.74
	West	70	0.88	1.10	0.68	0.83		Southwest	60	0.87	1.12	0.65	0.82
		60	0.86	1.11	0.64	0.80			50	0.85	1.16	0.56	0.78
		50	0.83	1.15	0.55	0.76			40	0.84	1.19	0.49	0.75
		40	0.82	1.19	0.46	0.73			20	0.85	1.21	0.46	0.77
1:5	North	50	0.86	1.16	0.57	0.21	1:5	Northeast	60	0.85	1.13	0.61	0.80
									50	0.84	1.16	0.55	0.77
		40	0.85	1.20	0.51	0.23			40	0.82	1.18	0.49	0.74
		20	0.86	1.21	0.49	0.22			20	0.83	1.20	0.47	0.75
	East	70	0.85	1.10	0.65	0.20		Northwest	70	0.87	1.11	0.66	0.82
									50	0.85	1.15	0.57	0.78
		50	0.81	1.14	0.54	0.26			40	0.83	1.18	0.52	0.76
		40	0.79	1.18	0.45	0.29			30	0.84	1.20	0.47	0.75
	South	60	0.87	1.13	0.62	0.19		Southeast	60	0.86	1.11	0.65	0.81
									50	0.84	1.15	0.57	0.77
		50	0.85	1.18	0.54	0.22			40	0.83	1.16	0.54	0.76
		30	0.85	1.20	0.49	0.23			30	0.82	1.19	0.47	0.74
	West	70	0.86	1.10	0.66	0.19		Southwest	60	0.86	1.13	0.61	0.80
		50	0.83	1.15	0.54	0.24			50	0.83	1.18	0.51	0.75
		40	0.81	1.19	0.46	0.28			20	0.83	1.20	0.47	0.75

A2: d=10m

D:H Ratio (D=10m)	Orientation	Obstr. Angle	CF		
			Win. Cond.	Win. Rad.	Total
1:10	North	70	1.22	0.40	0.73
		30	1.29	0.27	0.69
	East	40	1.10	0.68	0.83
		30	1.11	0.65	0.82
	South	30	1.13	0.70	0.87
		20	1.13	0.69	0.88
	West	40	1.11	0.68	0.84
		30	1.12	0.66	0.84
1:10	Northeast	30	1.12	0.68	0.85
		20	1.13	0.68	0.86
	Northwest	30	1.13	0.68	0.86
		20	1.13	0.68	0.87
	Southeast	40	1.12	0.68	0.84
		30	1.12	0.68	0.85
		20	1.13	0.67	0.85
	Southwest	40	1.12	0.68	0.85
		30	1.13	0.67	0.86

A3: d=40m

D:H Ratio (D=40m)	Orientation	Obstr. Angle	CF			
			Wall Cond.	Win. Cond.	Win. Rad.	Total
2:5	North	30	0.93	1.13	0.69	0.88
		20	0.94	1.14	0.69	0.89
	East	40	0.88	1.10	0.68	0.83
		30	0.88	1.11	0.65	0.82
	South	30	0.93	1.13	0.70	0.87
		20	0.93	1.13	0.69	0.88
	West	40	0.90	1.11	0.68	0.84
		30	0.90	1.12	0.66	0.84
2:5	Northeast	30	0.91	1.12	0.68	0.85
		20	0.92	1.13	0.68	0.86
	Northwest	30	0.92	1.13	0.68	0.86
		20	0.92	1.13	0.68	0.87
	Southeast	40	0.90	1.12	0.68	0.84
		30	0.90	1.12	0.68	0.85
		20	0.91	1.13	0.67	0.85
	Southwest	40	0.91	1.12	0.68	0.85
		30	0.92	1.13	0.67	0.86

A4: d=30m

D:H Ratio (D=30m)	Orientation	Obstr. Angle	CF			
			Wall Cond.	Win. Cond.	Win. Rad.	Total
1:3	North	40	0.90	1.16	0.60	0.82
		30	0.90	1.17	0.59	0.82
		20	0.91	1.19	0.57	0.83
	East	60	0.87	1.11	0.65	0.81
		40	0.85	1.14	0.56	0.77
		20	0.85	1.16	0.52	0.77
	South	40	0.89	1.15	0.62	0.82
		30	0.89	1.17	0.59	0.82
		20	0.90	1.18	0.57	0.82
	West	60	0.89	1.11	0.67	0.83
		50	0.87	1.14	0.60	0.79
		30	0.86	1.16	0.54	0.78
1:3	Northeast	50	0.88	1.13	0.63	0.82
		40	0.88	1.16	0.59	0.80
		30	0.88	1.17	0.56	0.80
	Northwest	50	0.88	1.15	0.60	0.81
		30	0.89	1.18	0.56	0.81
	Southeast	60	0.88	1.12	0.65	0.82
		40	0.88	1.14	0.62	0.81
		30	0.87	1.16	0.56	0.79
	Southwest	60	0.90	1.11	0.68	0.84
		50	0.88	1.14	0.62	0.81
		40	0.88	1.17	0.56	0.80

APPENDIX B: OTTV COMPARISON BETWEEN AIR-CONDITIONED AND NATURALLY VENTILATED SPACES

	NV Depth	NV Space WWR- 30%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
NORTH	**3m**	115.41	77.00	**33.3%**	77.66	**32.7%**
	6m	117.90	77.00	**34.7%**	77.52	**34.2%**
	9m	120.04	77.00	**35.9%**	77.36	**35.6%**
	12m	117.65	77.00	**34.6%**	77.17	**34.4%**

	NV Depth	NV Space WWR- 30%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
EAST	**3m**	115.39	77.00	**33.3%**	72.91	**36.8%**
	6m	117.81	77.00	**34.6%**	72.69	**38.3%**
	9m	119.81	77.00	**35.7%**	73.02	**39.1%**
	12m	117.80	77.00	**34.6%**	73.08	**38.0%**

	NV Depth	NV Space WWR- 30%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
SOUTH	**3m**	115.32	77.00	**33.2%**	77.34	**32.9%**
	6m	117.84	77.00	**34.7%**	77.17	**34.5%**
	9m	120.00	77.00	**35.8%**	76.99	**35.8%**
	12m	117.63	77.00	**34.5%**	76.78	**34.7%**

	NV Depth	NV Space WWR- 30%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
WEST	**3m**	115.45	77.00	**33.3%**	77.59	**32.8%**
	6m	117.84	77.00	**34.7%**	77.93	**33.9%**
	9m	119.82	77.00	**35.7%**	78.32	**34.6%**
	12m	117.80	77.00	**34.6%**	78.77	**33.1%**

	NV Depth	NV Space WWR- 50%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
NORTH	**3m**	121.04	83.77	**30.8%**	77.66	**35.8%**
	6m	125.11	83.77	**33.0%**	77.52	**38.0%**
	9m	128.69	83.77	**34.9%**	77.36	**39.9%**
	12m	127.68	83.77	**34.4%**	77.17	**39.6%**

	NV Depth	NV Space WWR- 50%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
EAST	**3m**	121.70	83.77	**31.2%**	72.91	**40.1%**
	6m	125.67	83.77	**33.3%**	72.69	**42.2%**
	9m	129.03	83.77	**35.1%**	73.02	**43.4%**
	12m	128.29	83.77	**34.7%**	73.08	**43.0%**

	NV Depth	NV Space WWR- 50%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
SOUTH	**3m**	121.16	83.77	**30.9%**	77.34	**36.2%**
	6m	125.29	83.77	**33.1%**	77.17	**38.4%**
	9m	128.90	83.77	**35.0%**	76.99	**40.3%**
	12m	127.93	83.77	**34.5%**	76.78	**40.0%**

	NV Depth	NV Space WWR- 50%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
WEST	**3m**	121.65	83.77	**31.1%**	77.59	**36.2%**
	6m	125.57	83.77	**33.3%**	77.93	**37.9%**
	9m	128.91	83.77	**35.0%**	78.32	**39.2%**
	12m	128.12	83.77	**34.6%**	78.77	**38.5%**

NORTH	NV Depth	NV Space WWR- 70%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
	3m	126.07	91.05	**27.8%**	77.66	**38.4%**
	6m	131.72	91.05	**30.9%**	77.52	**41.1%**
	9m	136.71	91.05	**33.4%**	77.36	**43.4%**
	12m	137.07	91.05	**33.6%**	77.17	**43.7%**

EAST	NV Depth	NV Space WWR- 70%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
	3m	127.33	91.05	**28.5%**	72.91	**42.7%**
	6m	132.86	91.05	**31.5%**	72.69	**45.3%**
	9m	137.57	91.05	**33.8%**	73.02	**46.9%**
	12m	138.07	91.05	**34.1%**	73.08	**47.1%**

SOUTH	NV Depth	NV Space WWR- 70%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
	3m	126.37	91.05	**27.9%**	77.34	**38.8%**
	6m	132.10	91.05	**31.1%**	77.17	**41.6%**
	9m	137.16	91.05	**33.6%**	76.99	**43.9%**
	12m	137.53	91.05	**33.8%**	76.78	**44.2%**

WEST	NV Depth	NV Space WWR- 70%				
		Simulation	Equation (+NV)	% Diff.	Equation (-NV)	% Diff.
	3m	127.17	91.05	**28.4%**	77.59	**39.0%**
	6m	132.62	91.05	**31.3%**	77.93	**41.2%**
	9m	137.30	91.05	**33.7%**	78.32	**43.0%**
	12m	137.76	91.05	**33.9%**	78.77	**42.8%**

APPENDIX C: OTTV & RETV COMPARISON WITH HEAT GAIN SIMULATION

APPENDIX C1: COMPUTER SIMULATION RESULTS

	Wall Conduction (kW)	**Window Conduction (kW)**	**Window Radiation (kW)**
Annual Loads	1383177.275	599138.827	1858904.325
Cooling Hours	8760		
Envelope Area	14220.00		
OTTV	**30.84**		

Wall Cond (mbtu)	**Window Cond (mbtu)**	**Window Radiation (mbtu)**
4719.614	2044.354	6342.868

Orientation	**Area (m^2)**
N	3750
E	3360
S	3750
W	3360
Total	**14220**

APPENDIX C2: OTTV CALCULATION RESULT

	ORIENTATION	TOTAL SURFACE AREA	TOTAL GLAZING AREA	CONSTANT	SOLAR ABSORPTION FACTOR	WWR	1-WWR	U-VALUE	ORIENTATION FACTOR	SC1	SC2	SHADING COEFFICIENT (SC)	OTTV	OTTV x A
HEAT CONDUCTION THROUGH	*15α(1-WWR)Uw*													
	NORTH Wall	3750.00	1040.63	**15**	**0.70**	0.2775	**0.7225**	**2.8316**					21.4812	80554.5956
	EAST Wall	3360.00	1552.50	**15**	**0.70**	0.4621	**0.5379**	**2.8316**					15.9941	53740.2285
	SOUTH Wall	3750.00	1040.63	**15**	**0.70**	0.2775	**0.7225**	**2.8316**					21.4812	80554.5956
	WEST Wall	3360.00	1552.50	**15**	**0.70**	0.4621	**0.5379**	**2.8316**					15.9941	53740.2285
HEAT CONDUCTION THROUGH GLAZING	*6(WWR)Uf*													
	NORTH Window	3750.00	1040.63	**6**		**0.2775**		**5.8447**					9.7314	36492.8456
	EAST Window	3360.00	1552.50	**6**		**0.4621**		**5.8447**					16.2034	54443.3805
	SOUTH Window	3750.00	1040.63	**6**		**0.2775**		**5.8447**					9.7314	36492.8456
	WEST Window	3360.00	1552.50	**6**		**0.4621**		**5.8447**					16.2034	54443.3805
SOLAR RADIATION THROUGH GLAZING	*194(OF x WWR x SC)*													
	NORTH Window	3750.00	1040.63	**194**		**0.2775**			**0.90**	0.7	1.00	**0.70**	33.9161	127185.1875
	EAST Window	3360.00	1552.50	**194**		**0.4621**			**1.23**	0.7	1.00	**0.70**	77.1787	259320.2850
	SOUTH Window	3750.00	1040.63	**194**		**0.2775**			**0.92**	0.7	1.00	**0.70**	34.6697	130011.5250
	WEST Window	3360.00	1552.50	**194**		**0.4621**			**0.94**	0.7	1.00	**0.70**	58.9821	198179.7300

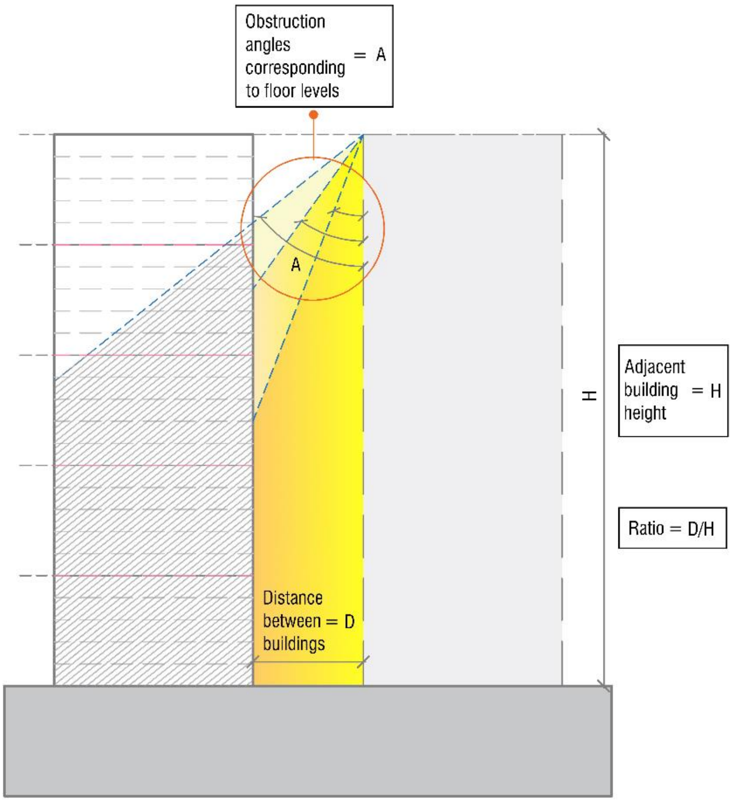
	GWA	OTTV
NORTH	3750.00	244232.6288
EAST	3360.00	367503.8940
SOUTH	3750.00	247058.9663
WEST	3360.00	306363.3390
Total	**14220.00**	**1165158.8280**
Building OTTV	**81.94**	

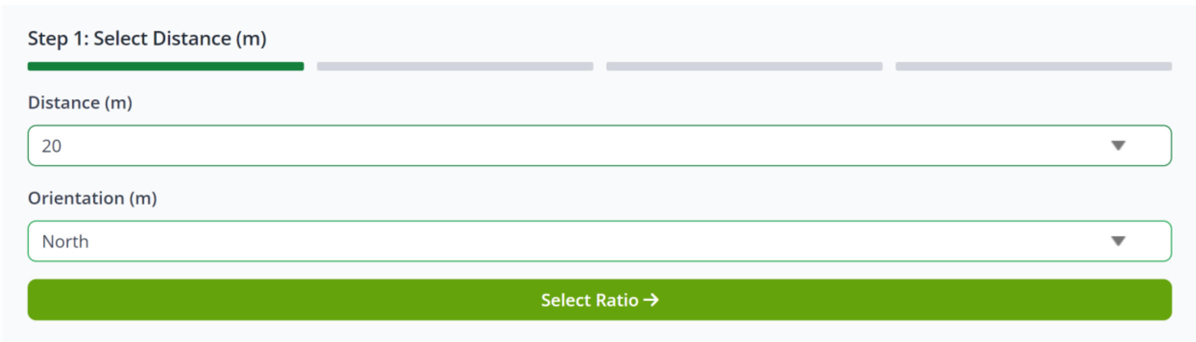
APPENDIX C3: RETV CALCULATION RESULT

	ORIENTATION	TOTAL SURFACE AREA	TOTAL GLAZING AREA	CONSTANT	WWR	1-WWR	U-VALUE	OF	SC1	SC2	SHADING COEFFICIENT (SC)	OTTV	OTTV x A
HEAT CONDUCTION THROUGH OPAQUE ELEMENTS	*3.4(1-WWR)Uw*												
	NORTH Wall	3160.00	1040.63	**3.4**	0.3293	**0.6707**	**2.8316**					6.4570	20404.1557
	EAST Wall	3360.00	1552.50	**3.4**	0.4621	**0.5379**	**2.8316**					5.1790	17401.5978
	SOUTH Wall	3160.00	1040.63	**3.4**	0.3293	**0.6707**	**2.8316**					6.4570	20404.1557
	WEST Wall	3360.00	1552.50	**3.4**	0.4621	**0.5379**	**2.8316**					5.1790	17401.5978
HEAT CONDUCTION THROUGH GLAZING	*1.3(WWR)Uf*												
	NORTH Window	3160.00	1040.63	**1.3**	**0.3293**		**5.8447**					2.5021	7906.7832
	EAST Window	3360.00	1552.50	**1.3**	**0.4621**		**5.8447**					3.5107	11796.0658
	SOUTH Window	3160.00	1040.63	**1.3**	**0.3293**		**5.8447**					2.5021	7906.7832
	WEST Window	3360.00	1552.50	**1.3**	**0.4621**		**5.8447**					3.5107	11796.0658
SOLAR RADIATION THROUGH GLAZING	*58.6(WWR x CF x SC)*												
	NORTH Window	3160.00	1040.63	**58.6**	**0.3293**			**0.83**	0.7	1.00	**0.70**	11.2119	35429.7431
	EAST Window	3360.00	1552.50	**58.6**	**0.4621**			**1.18**	0.7	1.00	**0.70**	22.3651	75146.5890
	SOUTH Window	3160.00	1040.63	**58.6**	**0.3293**			**0.86**	0.7	1.00	**0.70**	11.6172	36710.3363
	WEST Window	3360.00	1552.50	**58.6**	**0.4621**			**1.26**	0.7	1.00	**0.70**	23.8813	80241.2730

	GWA	RETV
NORTH	3160.00	63740.6820
EAST	3360.00	104344.2526
SOUTH	3160.00	65021.2751
WEST	3360.00	109438.9366
Total	**13040.00**	**342545.1463**
Building RETV	**26.27**	

APPENDIX D: OTTV INTER-BLOCK SHADING (SC3) CORRECTION FACTOR TOOL





Step 2: Select D:H Ratio

Distance (m)
20

Orientation
North

D:H Ratio

1:2

Reset

Select Obstruction Angle →

Step 3: Select Obstruction Angle

Distance (m)
20

Orientation
North

D:H Ratio
1:2

Obstruction Angle

60

Reset

Get Correction Factor →

Correction Factor

Distance (m)
20

Orientation
North

D:H Ratio
1:2

Obstruction Angle
60

Correction Factor

0.67

Calculate Again