Developing a ‘healing building envelope’ in healthcare design

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(Image: https://www.advancedglazings.com/case-studies/healing_power_of_daylight)

Background and motivation

This research is an attempt to converge my personal experience of studying & working in **two distinct labs at the Georgia Institute of Technology** over the course of my master’s degree, the **High-Performance building lab** and **SimTigrate design lab**. In my opinion, the Healthcare sector is one of the most energy-intensive ones, considering the nature of its operation and use. Combining high-performance building strategies in the healthcare sector can result in creating more **sustainable, energy-efficient, and healing healthcare environments.**

logo courtesy: https://arch.gatech.edu/high-performance-building-lab, https://simtigrate.gatech.edu/

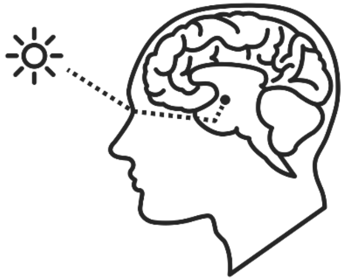
Research Objectives

- This research will focus on the **importance of daylighting** and its impact on **circadian rhythms** within a **patient room** setting of a **healthcare facility**.
- This objective will be achieved through an experiment that will **simulate design parameters** like the **window-to-wall ratio** and **shading mechanisms like louvers/fins** to evaluate the performance of the **building envelope.**
- Daylighting within the patient rooms will be evaluated using metrics such as **spatial daylight autonomy(sDA) and annual sunlight exposure (ASE)**
- The **equivalent melanopic lux (EML) levels** will be evaluated using the **circadian lighting software ALFA**.

Healthcare facility

Patient room

Building envelope



Circadian rhythm

Icons courtesy: https://thenounproject.com/

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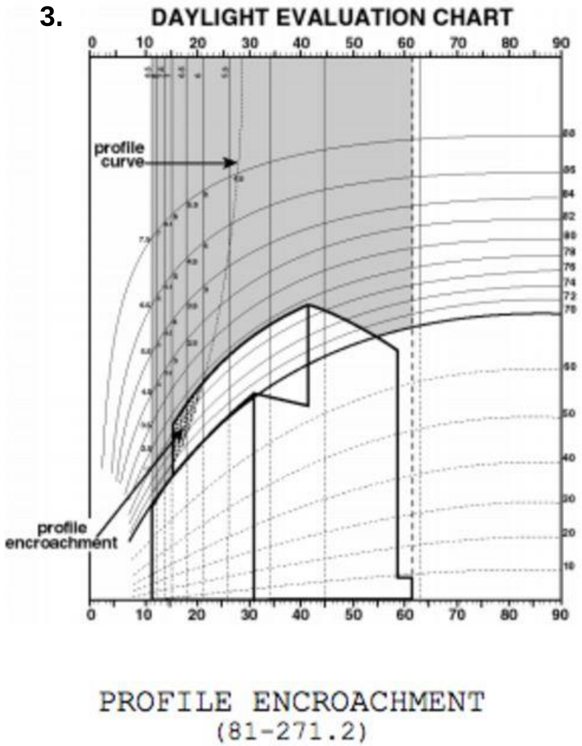
Icons courtesy: https://thenounproject.com/

Introduction

History of daylighting



An **oculus** that **symbolized** the ruler as God.

A city aiming for sky, whereas the **streets scramble for daylight.**

A **zoning resolution** that shaped the city and its neighborhoods.

Image 1: https://www.transformit.com/Daylighting-Past-Present-Future,
Image 2&3. https://www.bloomberg.com/news/articles/2016-12-18/new-york-city-zoning-and-the-fight-for-sunlight

Daylighting in healthcare design

a) Patient room setting with **controlled lighting** and no exposure to **daylighting & exterior views.**

b) Patient room setting with a balance of **daylighting** and **views of nature.**

Research Question:

Which patient room setting provides a more **comforting experience** for its occupants?

Image 4: Comparison of healthcare with architectural environment design (Kellert and Callebrese(2015))
Image 5: Capturing daylight – Healthcare market trends (https://huntonbrady.com/capturing-daylight/)

Therapeutic environment in healthcare design

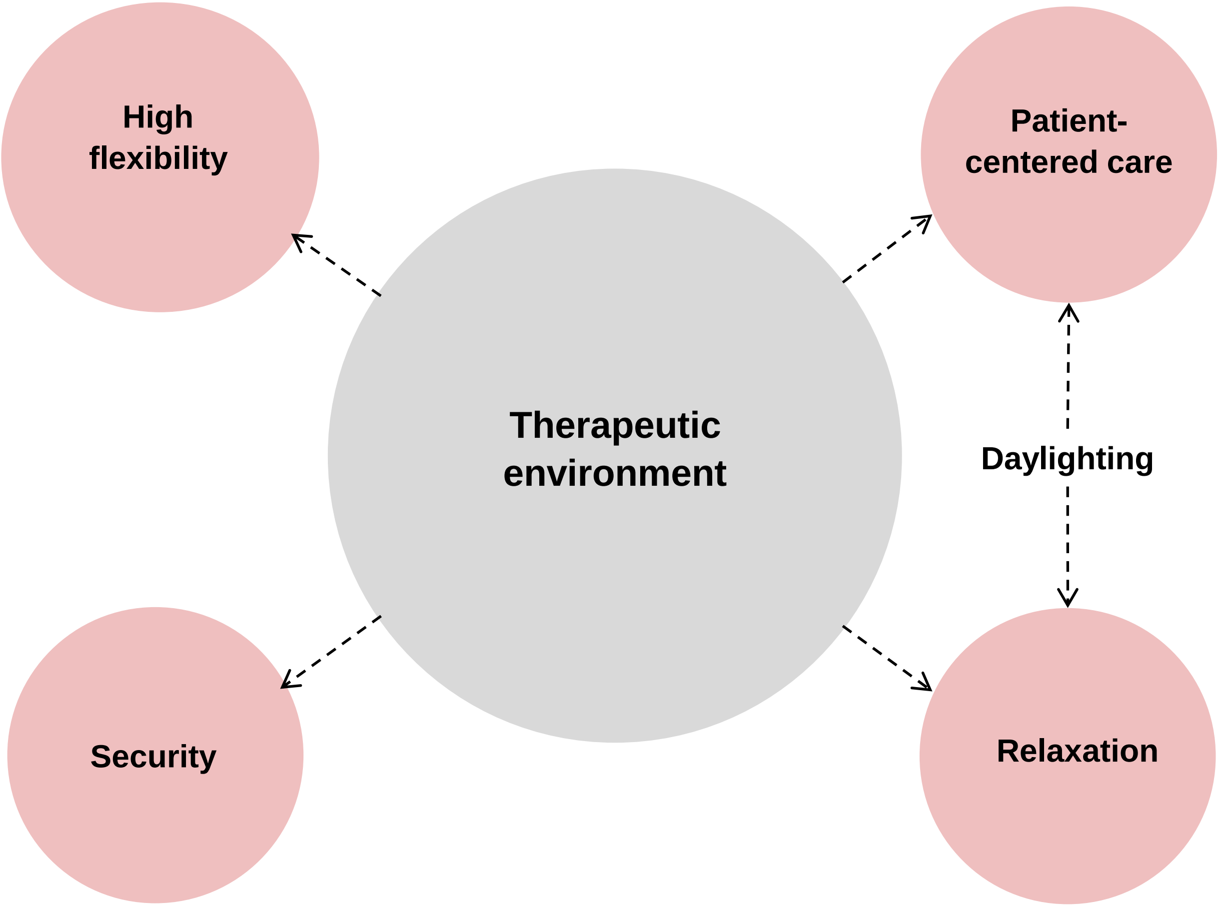


Figure 1: Therapeutic environment framework

Lighting design especially **daylighting** plays a major role in accentuating such **therapeutic environment** settings.

Literature review

Daylighting in healthcare setting

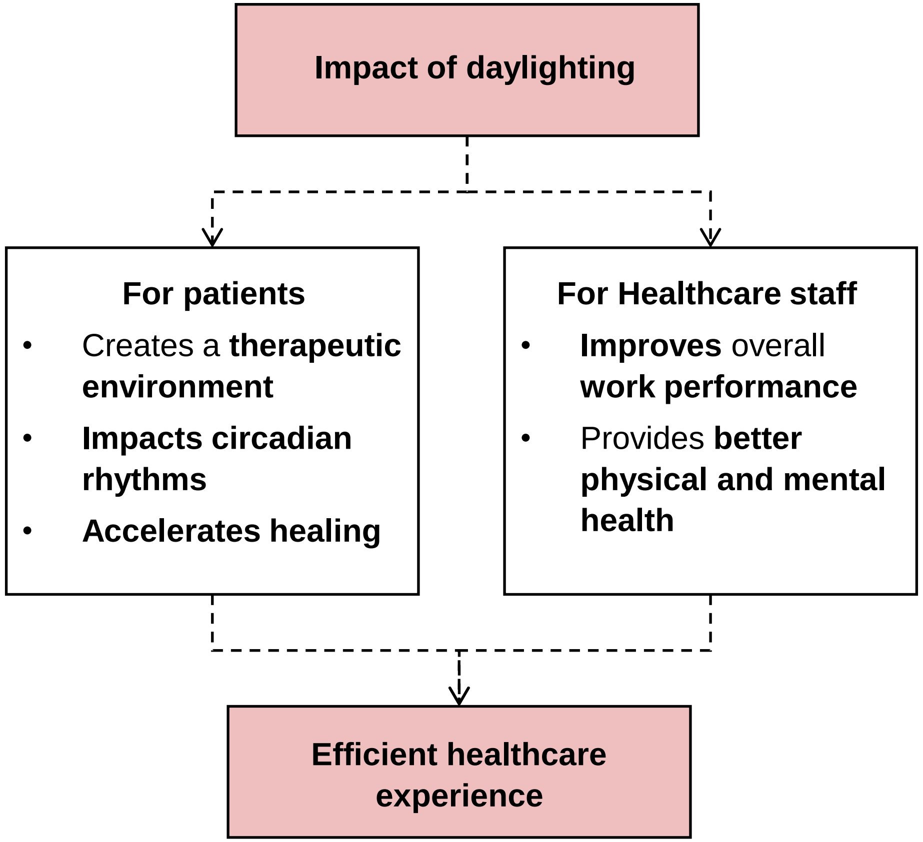
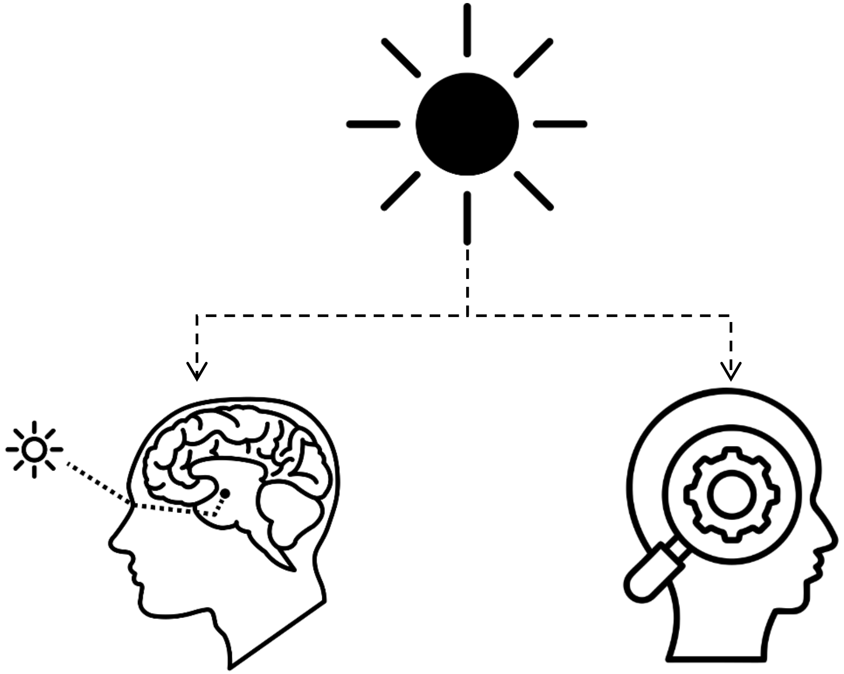


Figure 2: daylighting and its impacts on patients & health care staff



Research[1] indicates that **daylighting** affects the **human circadian system** and **cognitive performance.**

Icons courtesy: https://thenounproject.com/

1. Maria Englezou, A. M. (2020). Assessment of daylight performance and the impact of shading devices for typical in-patient rooms in healthcare facilities in Cyprus.Optimization-Driven Architectural Design (OPTARCH 2019), (pp. 277-285).

Lighting and circadian rhythm

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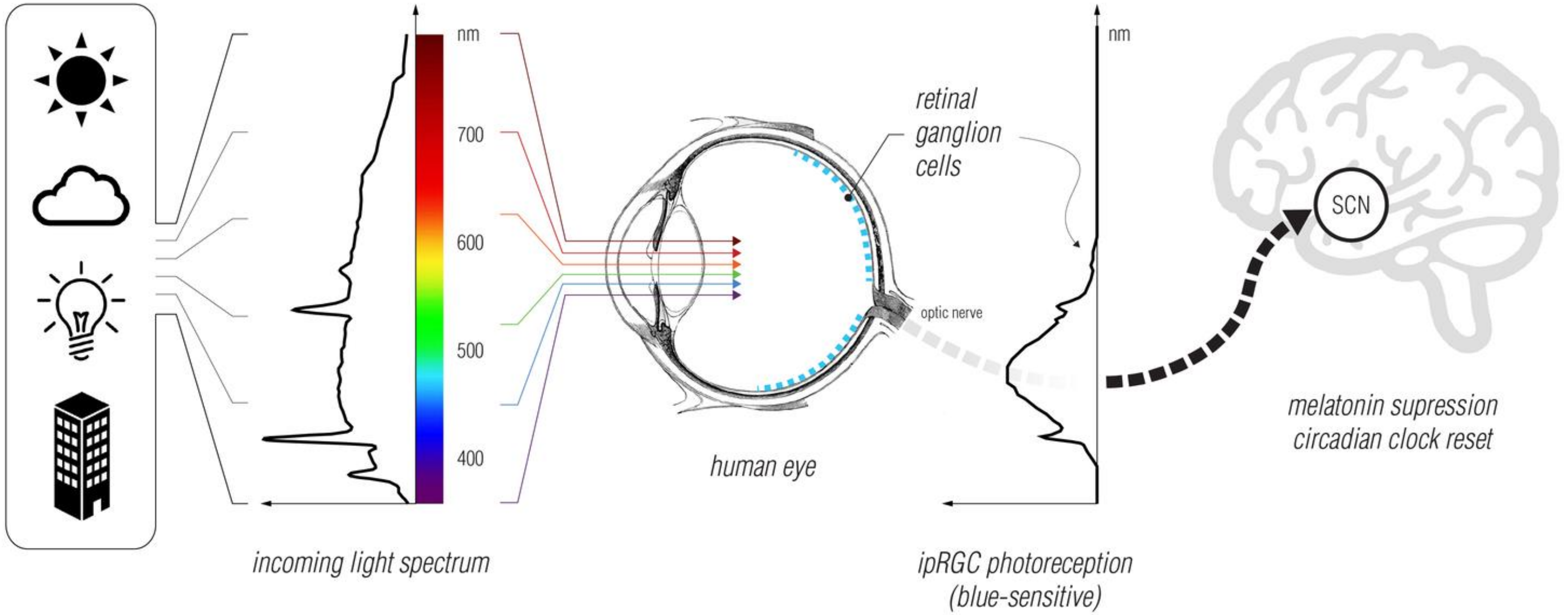

Circadian biology framework

- The circadian rhythm is controlled by the brain's **hypothalamus.**
- It operates via a small bundle of cells called the **suprachiasmatic nucleus(SCN)**
- The **SCN is connected to the optic nerve** behind the eye and receives information about the **varying levels of light and darkness** from our environment throughout the day and night.

Image 6: https://leddynamics.com/understanding-circadian-rhythm-and-how-tuning-leds-can-increase-health-wellness

Daylighting and building envelope: window to wall ratio

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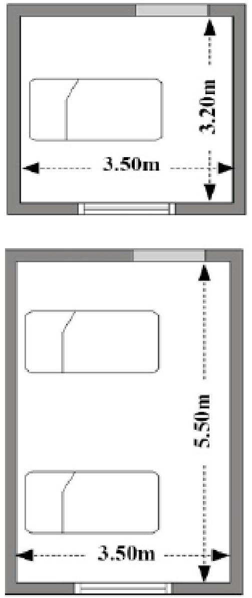

Patient room typology

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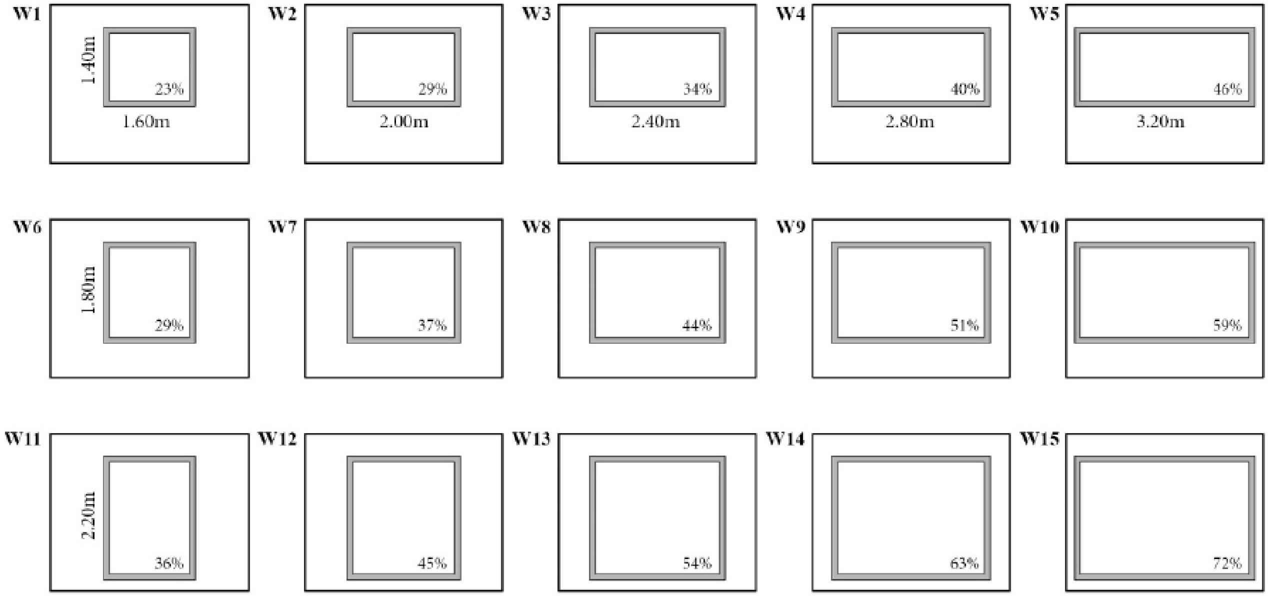

Window to wall ratio considerations

- **Window-to-wall ratio** is one of the primary factors affecting daylighting performance.
- Previous research focused on considering varying **window-to-wall ratios** to analyze their impact on **daylighting performance** through a simulation framework.

Images 7,8: Maria Englezou, A. M. (2020). Assessment of daylight performance and the impact of shading devices for typical in-patient rooms in healthcare facilities in Cyprus.Optimization-Driven Architectural Design (OPTARCH 2019), (pp. 277-285).

Daylighting and building envelope: shading devices

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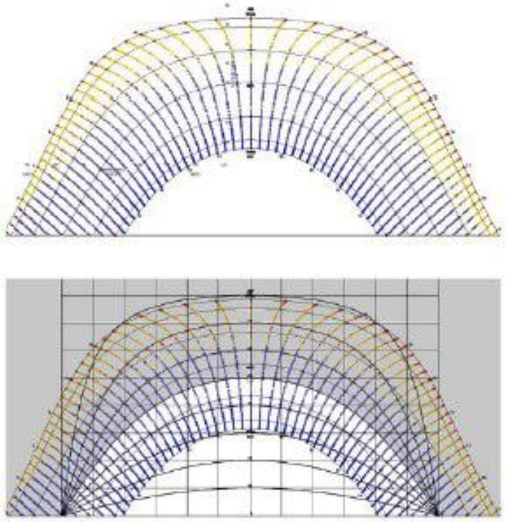

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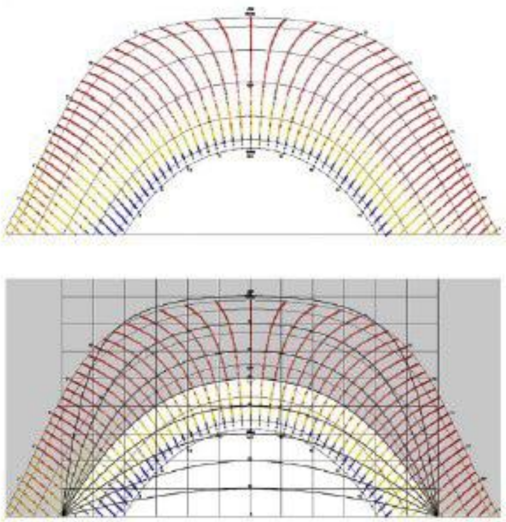
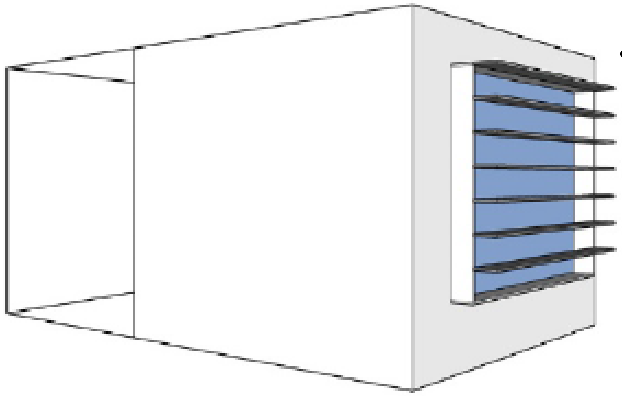


Sun shading charts for calculation of shading devices.
9a. winter and spring, 9b. summer and fall

10.



Perspective view of patient room integrated with shading devices

- Another important design parameter **impacting daylighting performance** is the **shading device.**
- Shading devices primarily aid **in reducing the glare potential** and help in reducing the heat gain which results in the **reduction of HVAC cooling loads** to some extent.

Image 9a,9b,10: Maria Englezou, A. M. (2020). Assessment of daylight performance and the impact of shading devices for typical in-patient rooms in healthcare facilities in Cyprus.Optimization-Driven Architectural Design (OPTARCH 2019), (pp. 277-285)

Identifying gaps in existing literature

The existing literature indicates that **daylighting has a significant impact** on the circadian rhythms of patients within a patient room setting. However, **specific gaps in the literature review** which have been identified are as follows:

- Analyzing **spatial daylight autonomy and annual sunlight exposure** to assess daylighting and glare effects during occupied hours.

sDA + ASE

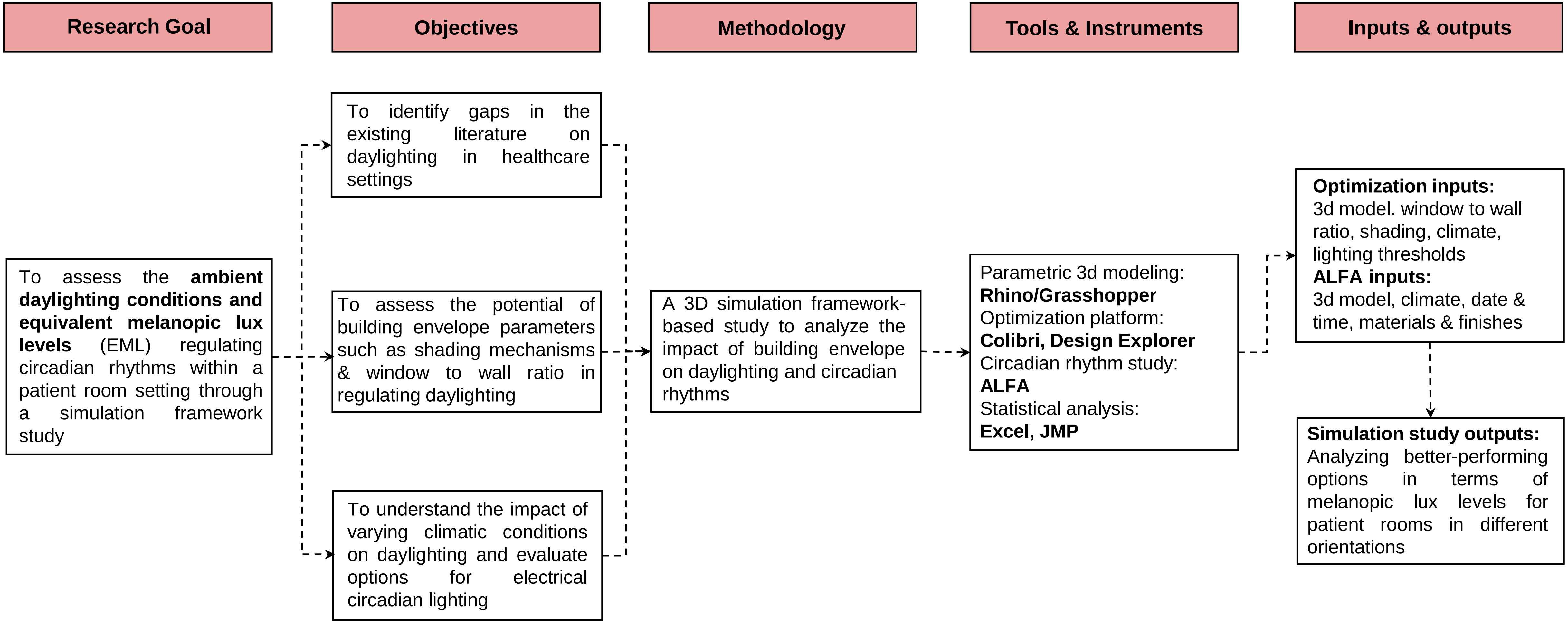
- The impact of **different orientations on patient room building envelope design**, with an emphasis on automated **interior and exterior shading devices** impacting daylighting performance.

- Assessing the combination of daylighting & circadian electrical lighting in impacting the patient healing experience during **variations in climatic conditions.**

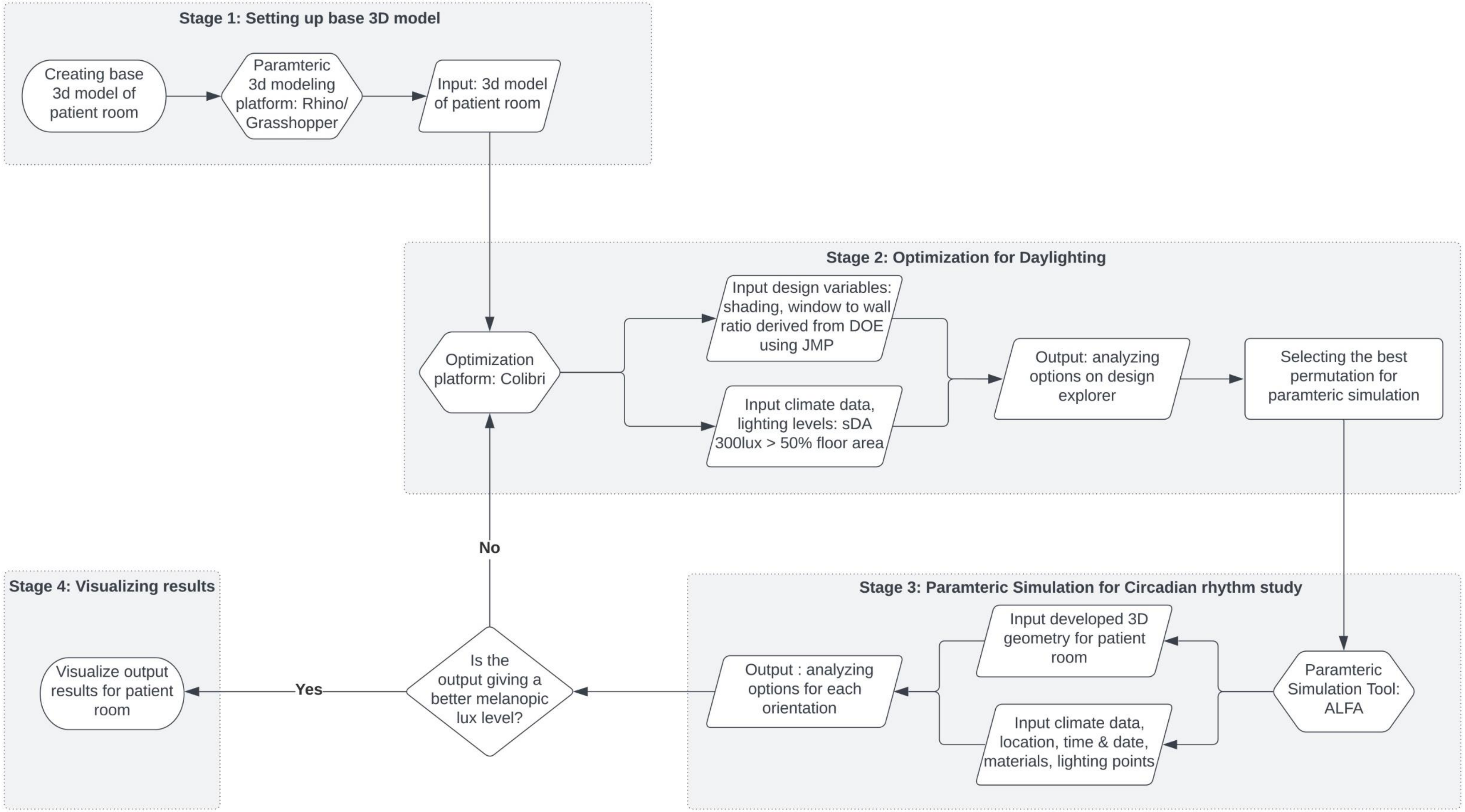
Icons courtesy: https://thenounproject.com/

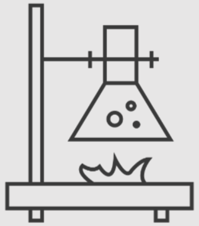
Research methodology

Research methodology framework



Experiment design framework





Experimental design

Experimental design backdrop

- For the purpose of the experiment study, **patient rooms on the acute stabilization unit level of the Huntsman Medical Health Institute (HMHI) Receiving center** in Salt Lake City, Utah will be used as the contextual backdrop.
- Building envelope parameters such as **window-to-wall ratio and shading** will be considered to understand their impact on daylighting in **patient rooms in all orientations in the Acute Stabilization unit level** of the HMHI receiving center.
- The simulation study will also consider **varying climatic conditions** to **assess daylighting and electrical circadian lighting** in order to maintain ambient melanopic lux levels in the patient room setting.

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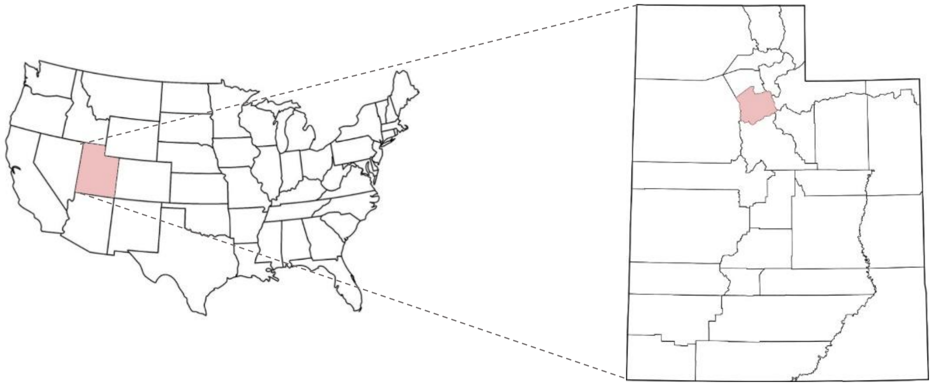

Context map: Salt Lake City, Utah, USA.

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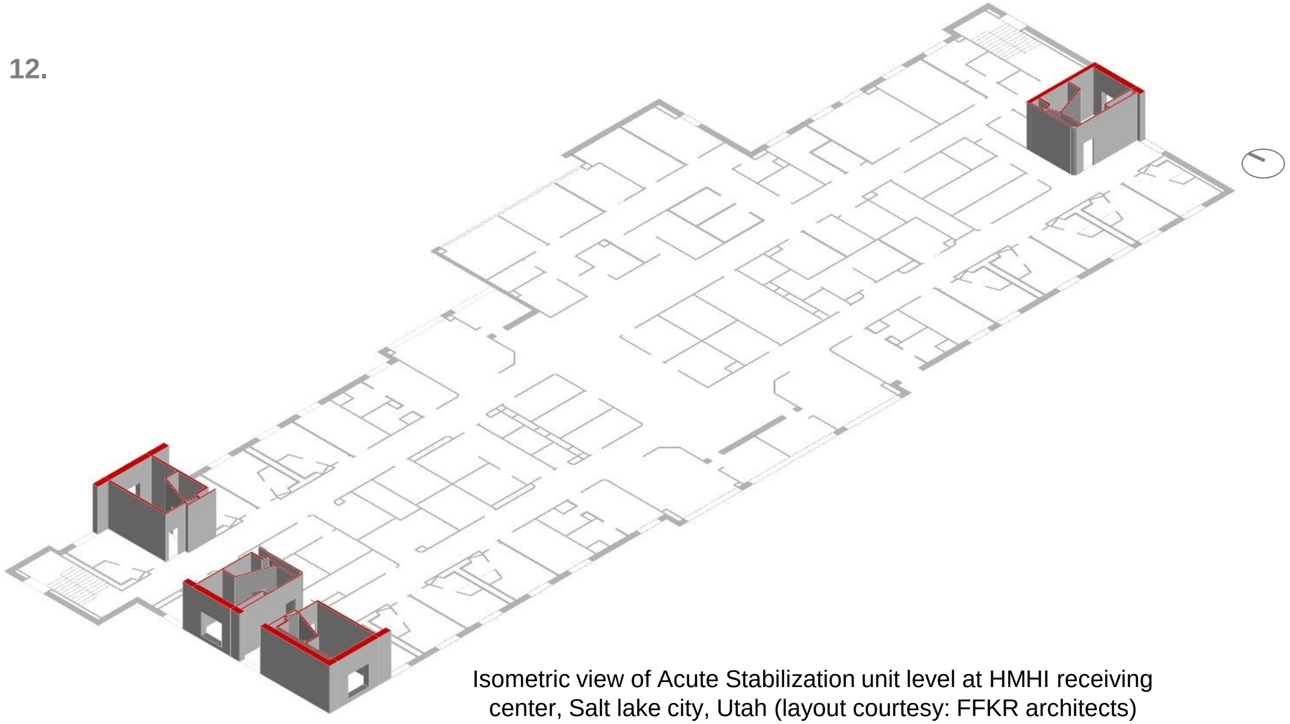


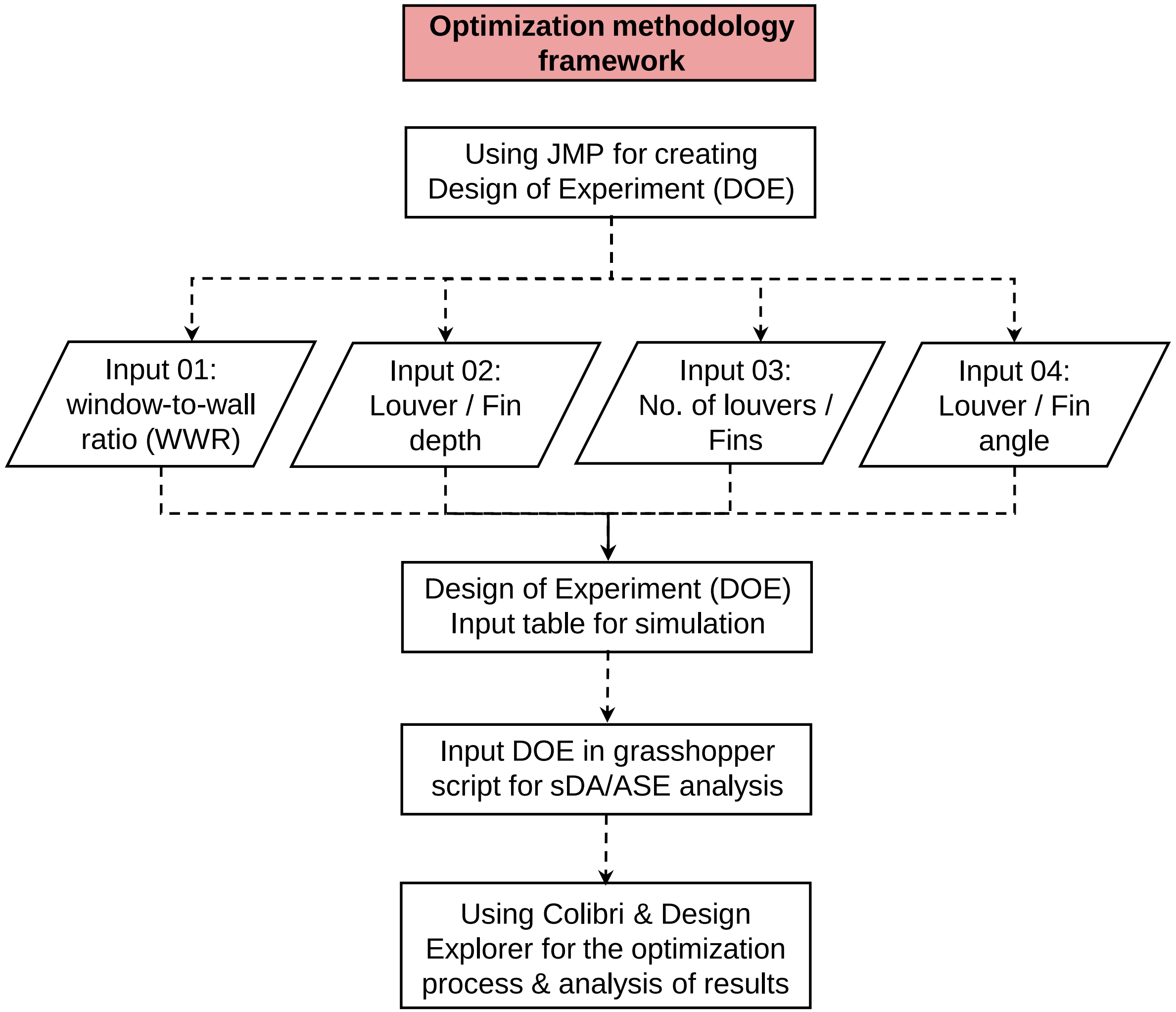
Isometric view of Acute Stabilization unit level at HMHI receiving center, Salt lake city, Utah (layout courtesy: FFKR architects)

Image 11: https://commons.wikimedia.org/wiki/File:Blank_US_map_borders
Image 12: Level 3 layout of HMHI Receiving Center – FFKR Architects.

Patient room North Orientation: Optimization for daylighting analysis

Optimization methodology framework

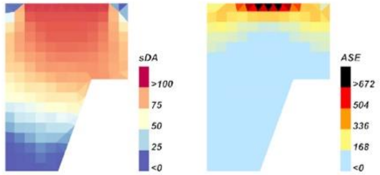
- For the Optimization process, a Design of Experiment (DOE) table is created using JMP by adding different parameters like window-to-wall ratio, louver/fin depth, no. of louvers/fins, and louver/fin angle. **Based on the number of input parameters a total of 25 iterations would be simulated for each of the shading mechanisms (louvers/fins) resulting in a total no. of 50 iterations for each patient room orientation.**



Iteration no.	WWR	Louver / Fin depth	No. of Louvers / Fins	Louver / Fin angle
1	0.5	0.6	2	15
2	0.4	0.6	3	0
3	0.6	0.4	3	15
4	0.5	0.4	4	0
5	0.6	0.6	2	45
6	0.7	0.5	2	0
7	0.4	0.3	2	15
8	0.6	0.6	5	15
9	0.5	0.3	5	0
10	0.6	0.5	5	30
11	0.5	0.6	2	30
12	0.7	0.4	2	30
13	0.7	0.6	3	0
14	0.6	0.3	4	45
15	0.4	0.5	2	45
16	0.7	0.3	3	45
17	0.7	0.5	4	15
18	0.4	0.6	4	30
19	0.4	0.4	5	45
20	0.4	0.5	5	0
21	0.7	0.3	5	30
22	0.5	0.5	3	45
23	0.6	0.3	2	0
24	0.4	0.3	3	30
25	0.7	0.6	5	45

Design of Experiment (DOE) table

Patient room North Orientation: **Daylighting Optimization iterations using louvers as shading mechanism**



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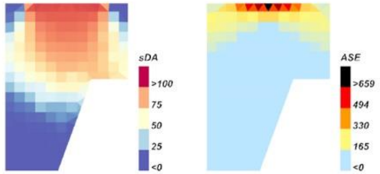

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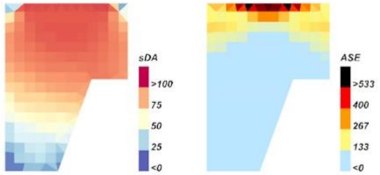

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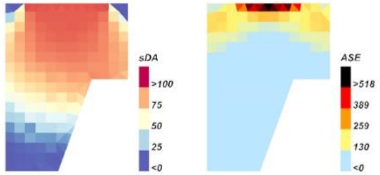

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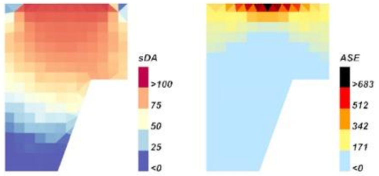

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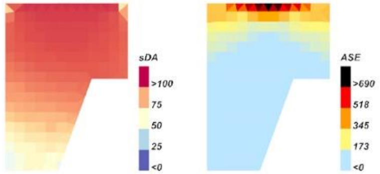

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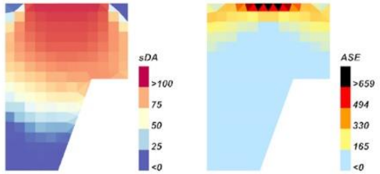

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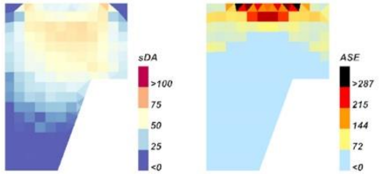

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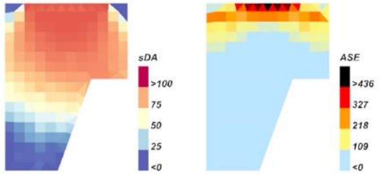

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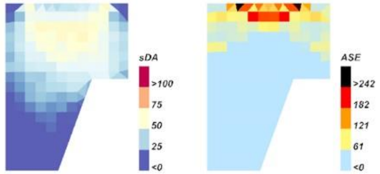

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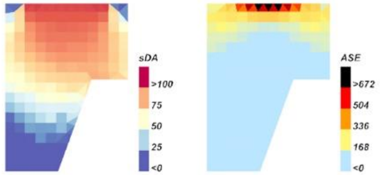

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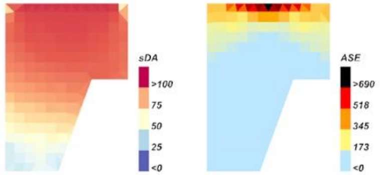

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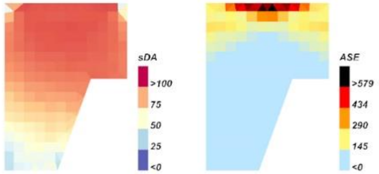

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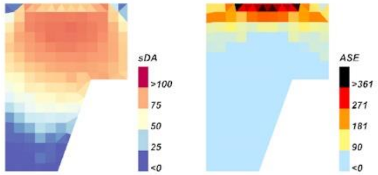

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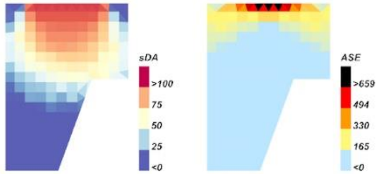

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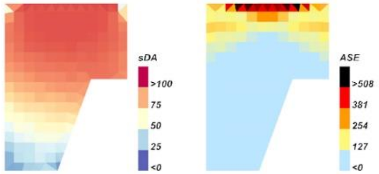

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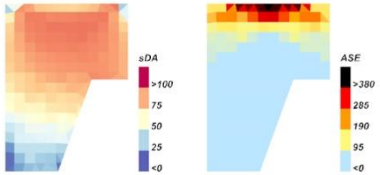

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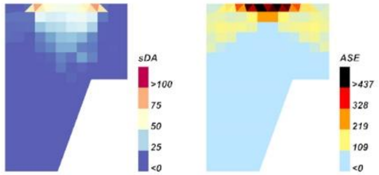

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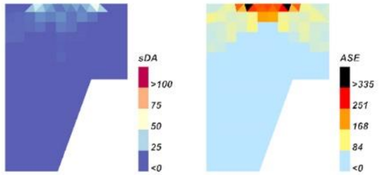

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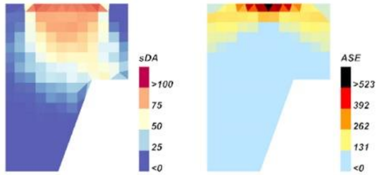

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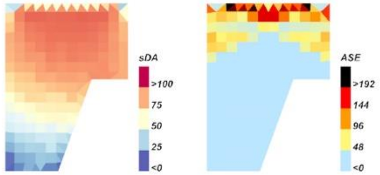

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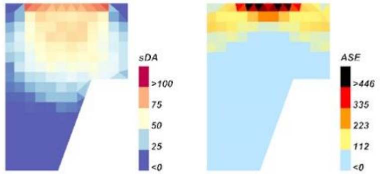

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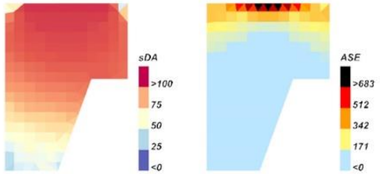

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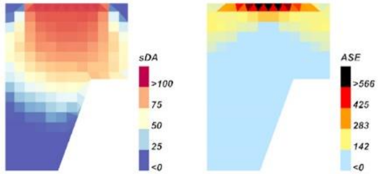

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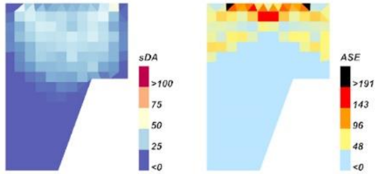
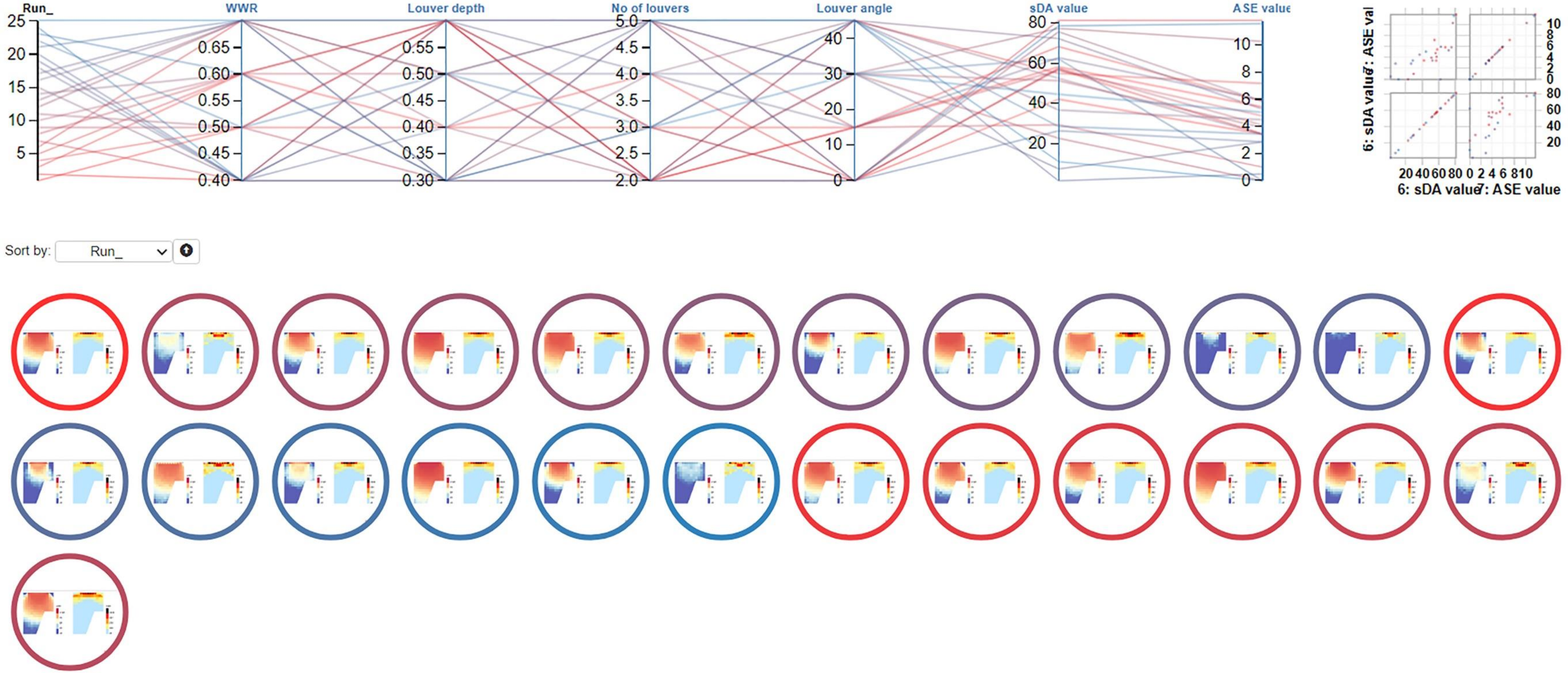
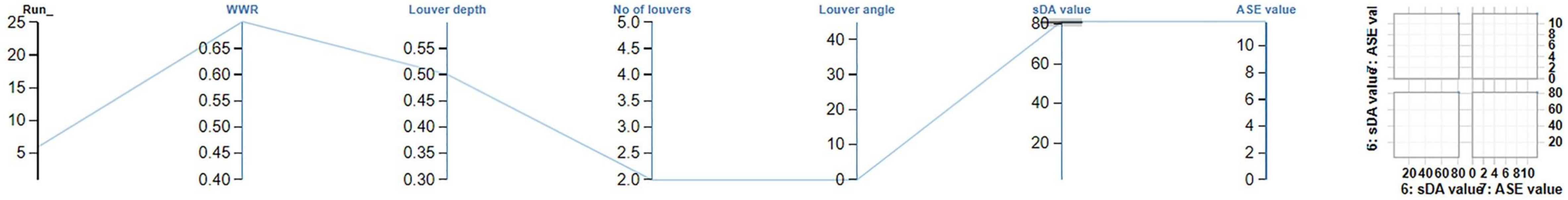


25.

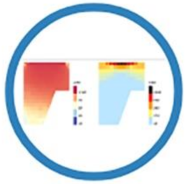
Patient room North Orientation: **Comparative analysis of iterations using Design Explorer**



Patient room North Orientation: **Selection of optimum iteration**



Sort by: Run_



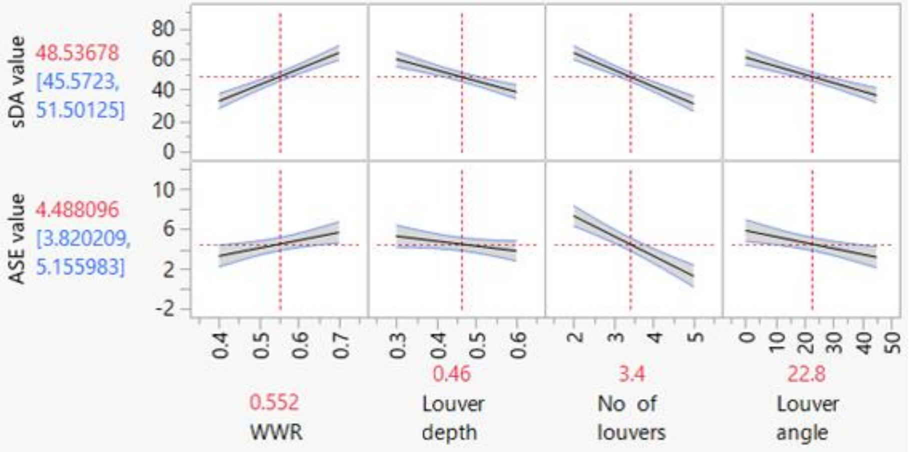
Run_	WWR	Louver depth	No of louvers	Louver angle	sDA value	ASE value	img	Rating	scid
6	0.7	0.5	2	0	81.027027	11.777506	Run_6.png	0	5

- Based on the comparative analysis **iteration no. 06** provides the right balance of sDA and ASE values as compared to other iterations.

Sensitivity Analysis:

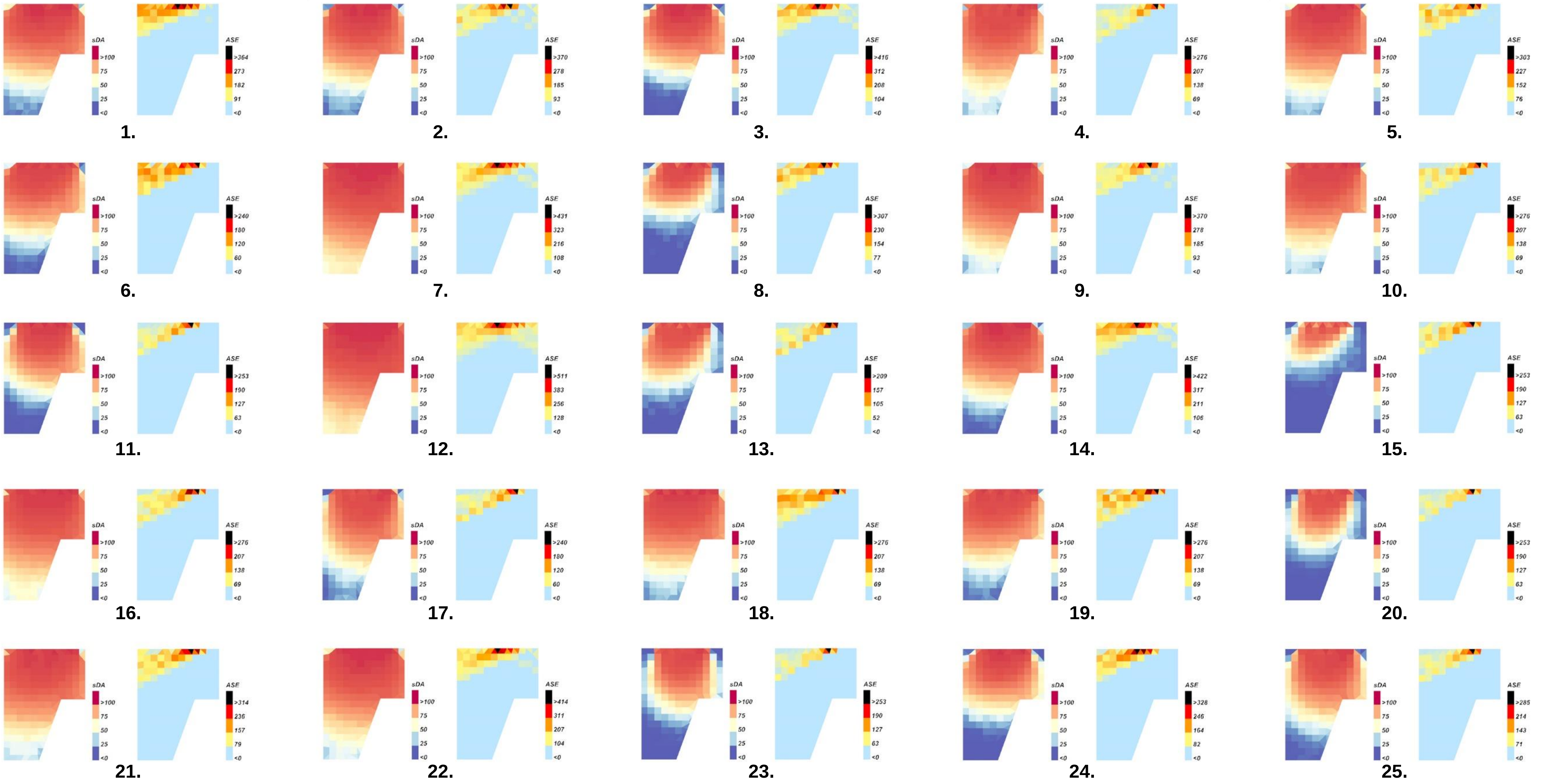
- From the sensitivity analysis, it can be observed that no. of louvers as a parameter has a considerable impact on the sDA and ASE values followed by the window-to-wall ratio (WWR).

Source	LogWorth	PValue
No of louvers	7.916	0.00000
WWR	7.362	0.00000
Louver angle	5.793	0.00000
Louver depth	5.081	0.00001

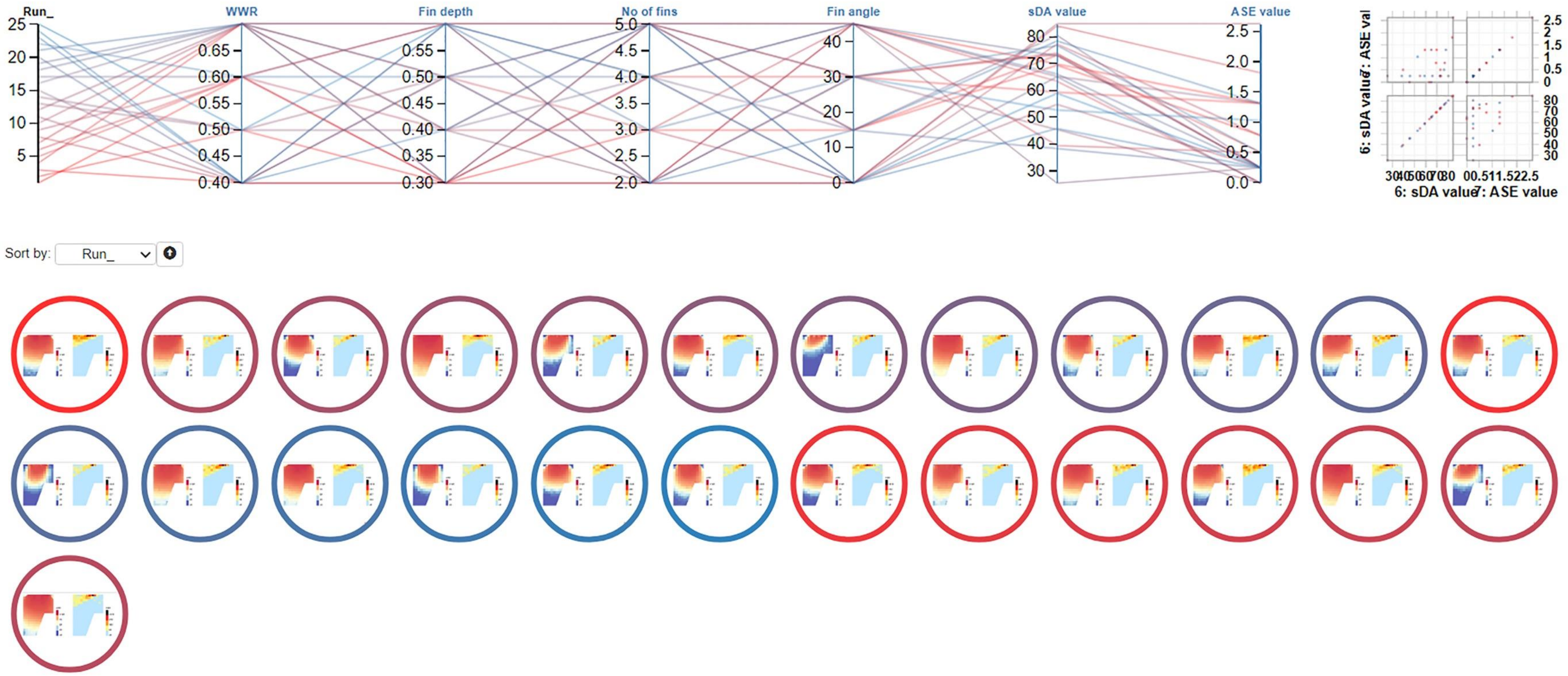


Patient room North Orientation: **Shortlisted louvers iteration**

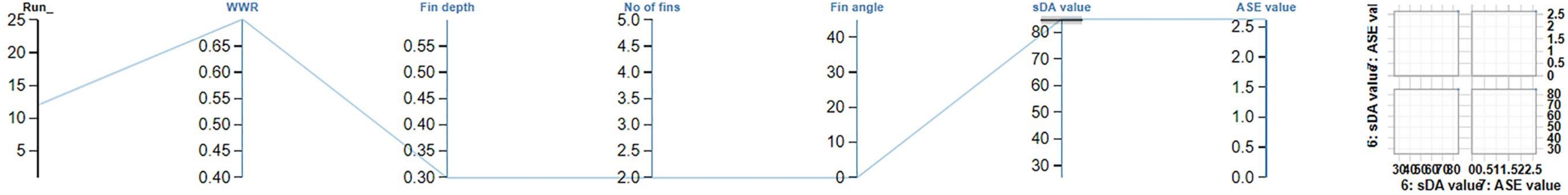
Patient room North Orientation: **Daylighting Optimization iterations using fins as shading mechanism**



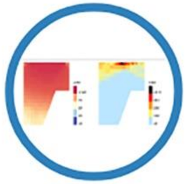
Patient room North Orientation: **Comparative analysis of iterations using Design Explorer**



Patient room North Orientation: **Selection of optimum iteration**



Sort by: Run_



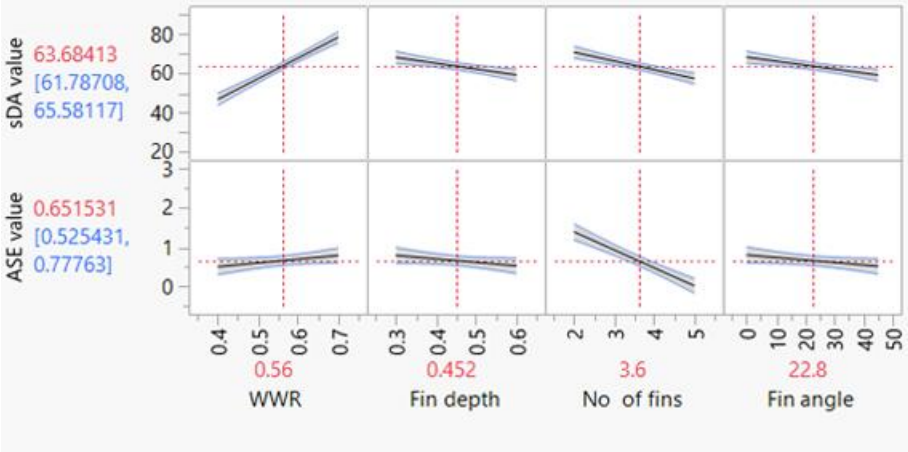
Run_	WWR	Fin depth	No of fins	Fin angle	sDA value	ASE value	img	Rating	scid
12	0.7	0.3	2	0	84.633135	2.619425	Run_12.png	0	11

- Based on the comparative analysis **iteration no. 12** provides the right balance of sDA and ASE values as compared to other iterations.

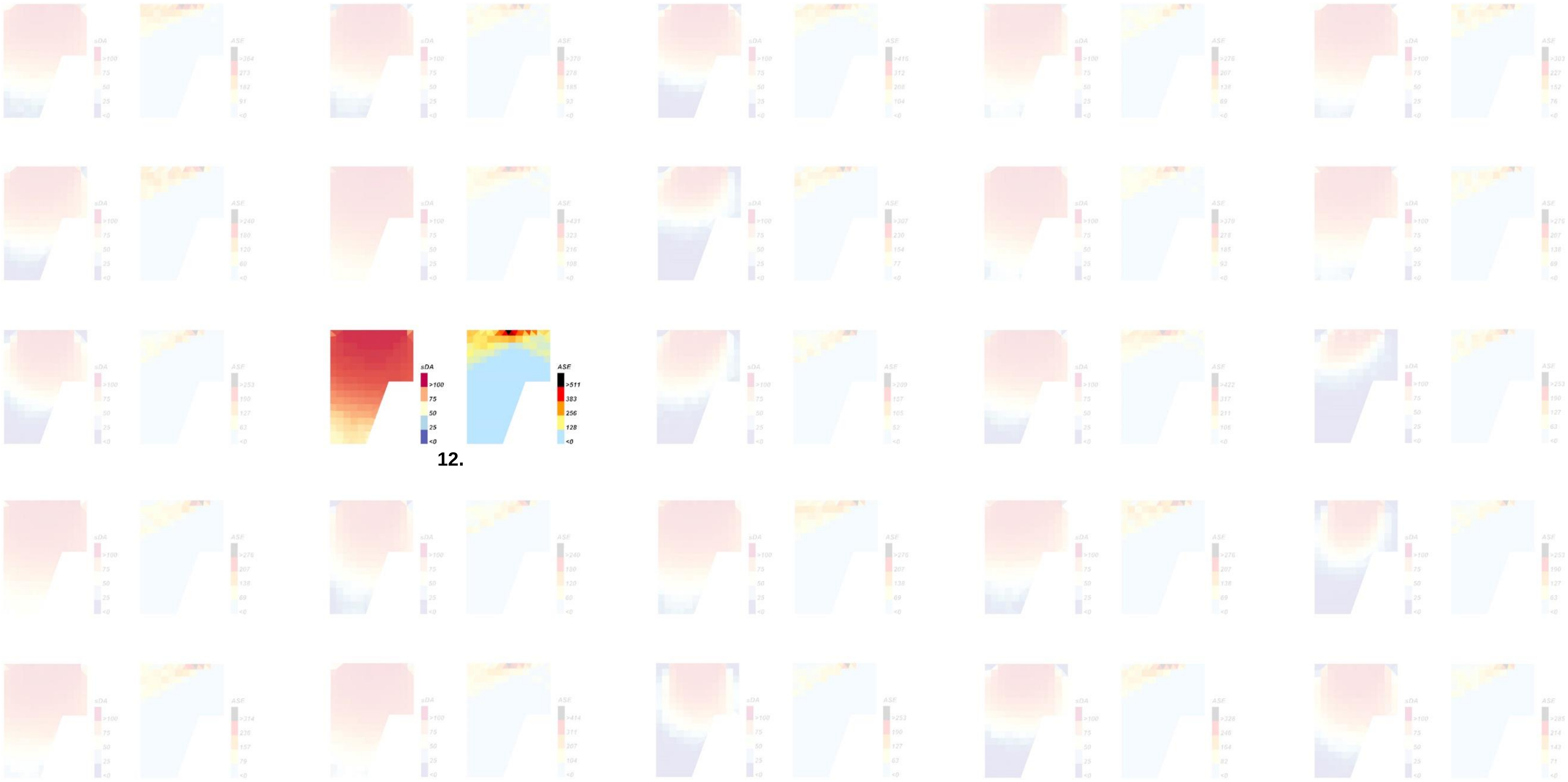
Sensitivity Analysis:

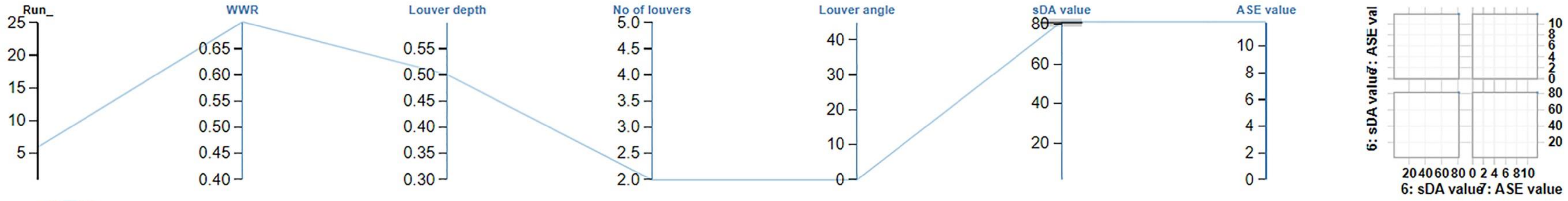
- From the sensitivity analysis, it can be observed that the window-to-wall ratio (WWR) parameter has a significant impact on the sDA and ASE values.

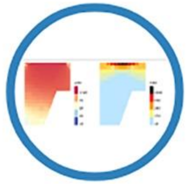
Source	LogWorth		PValue
WWR	11.026		0.00000
No of fins	7.821		0.00000
Fin angle	3.070		0.00085
Fin depth	2.994		0.00101



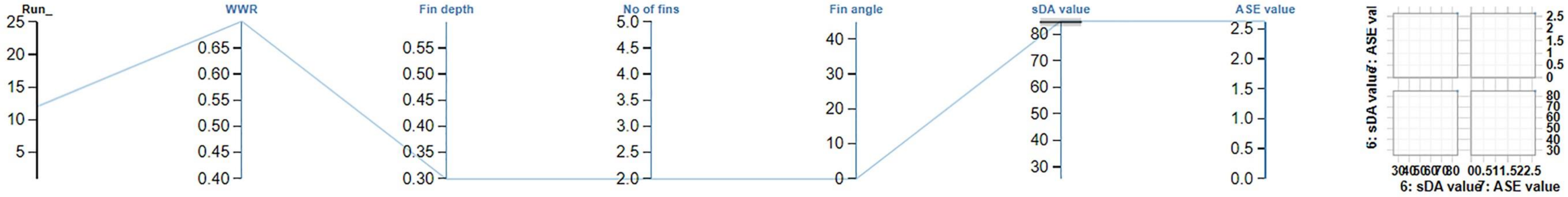
Patient room North Orientation: **Shortlisted fins iteration**

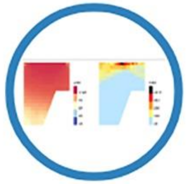






Run_	WWR	Louver depth	No of louvers	Louver angle	sDA value	ASE value	img	Rating	scid
6	0.7	0.5	2	0	81.027027	11.777506	Run_6.png	0	5





Run_	WWR	Fin depth	No of fins	Fin angle	sDA value	ASE value	img	Rating	scid
12	0.7	0.3	2	0	84.633135	2.619425	Run_12.png	0	11

Optimization Analysis summary:

- After a careful study of the results derived from the optimization process studying different window-to-wall ratios and shading mechanisms like louvers and fins, it can be inferred that the **fins iteration provides a better balance between the sDA and ASE values compared to the louvers iteration.**

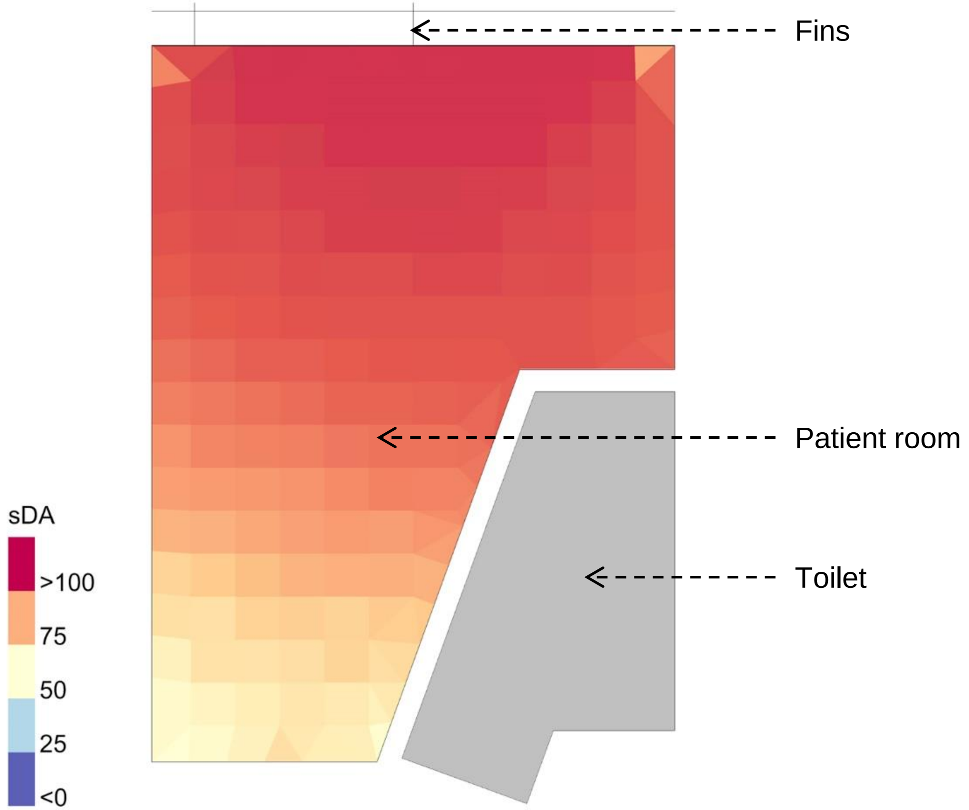
Patient room North Orientation: **Shortlisted iteration sDA analysis**

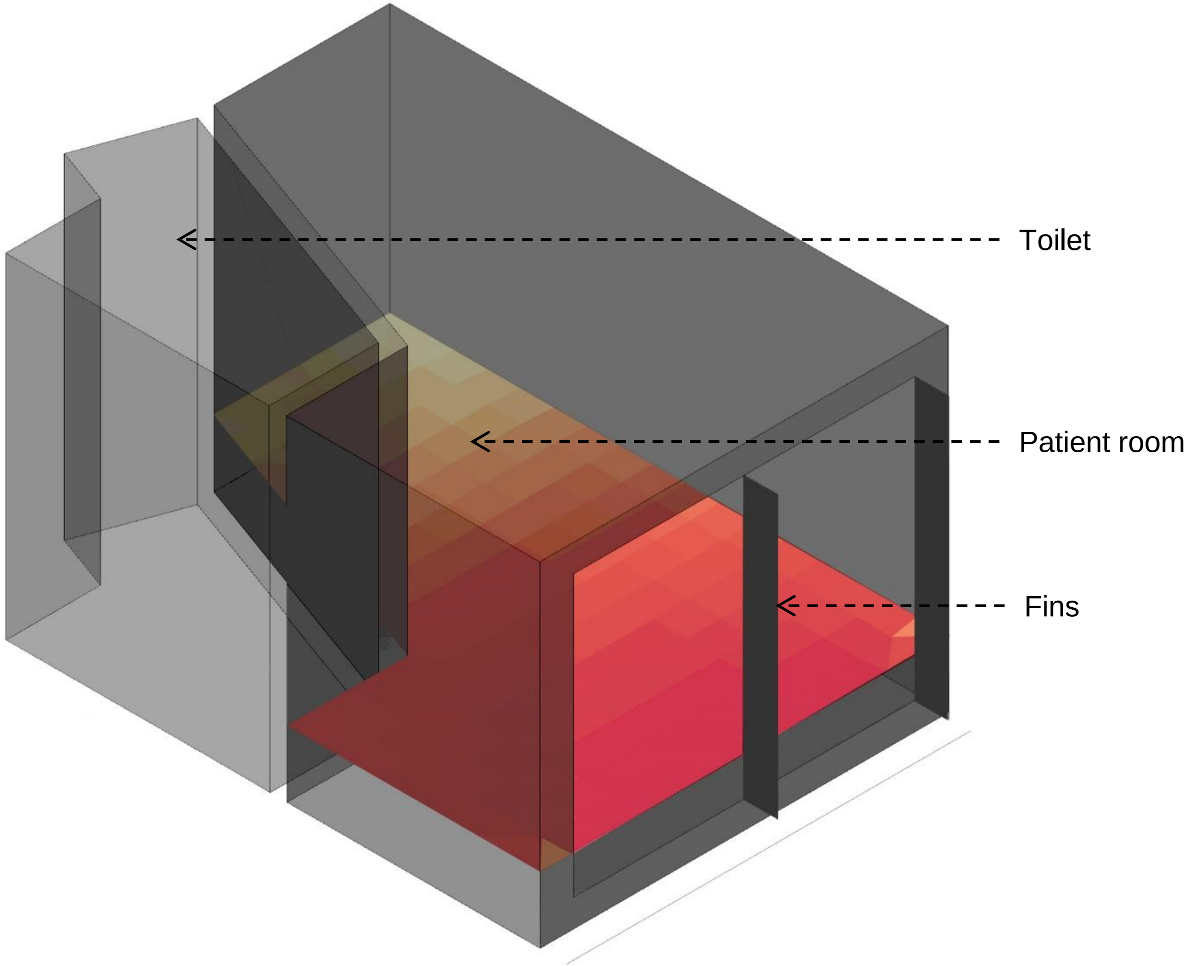
Input parameters:

- Window-to-wall ratio (WWR) – 70%
- Fin depth – 0.30m
- No. of fins – 2
- Fin angle – 0^o

Spatial daylight autonomy (sDA) output:

- sDA value – 84.63%





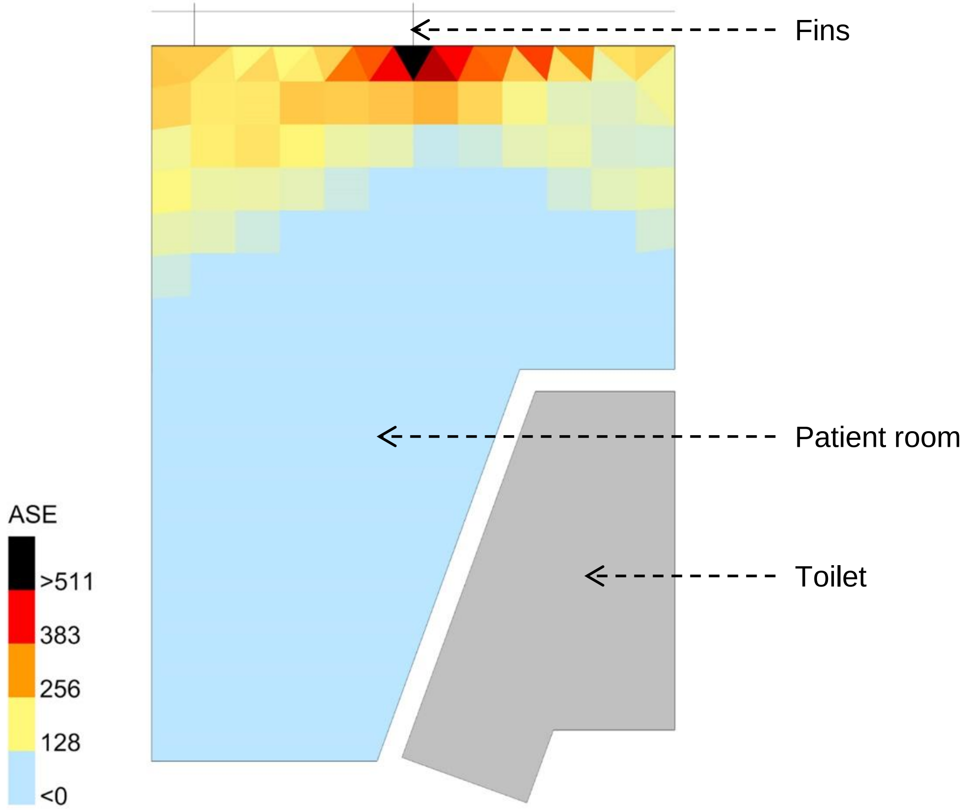
Patient room North Orientation: **Shortlisted iteration ASE analysis**

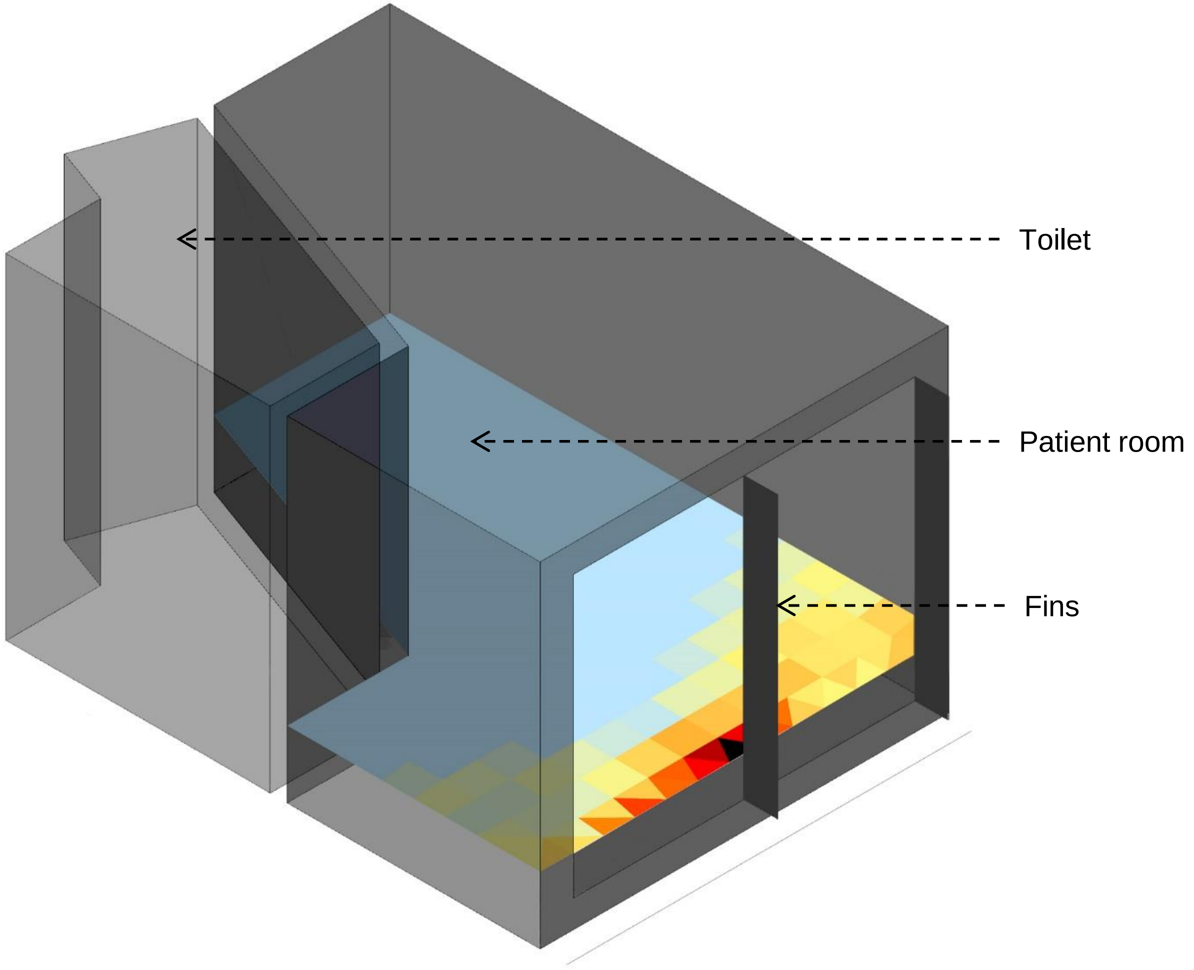
Input parameters:

- Window-to-wall ratio (WWR) – 70%
- Fin depth – 0.30m
- No. of fins – 2
- Fin angle – 0^{o}

Annual Sunlight Exposure (ASE) output:

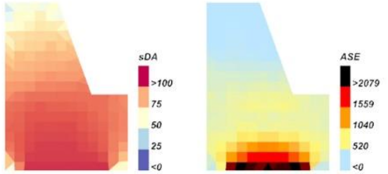
- ASE value – 2.61%





Patient room South Orientation: **Optimization for daylighting analysis**

Patient room South Orientation: Daylighting Optimization iterations using louvers as shading mechanism



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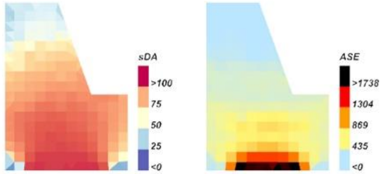

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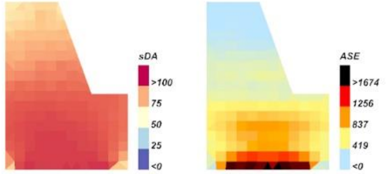

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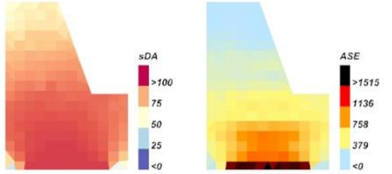

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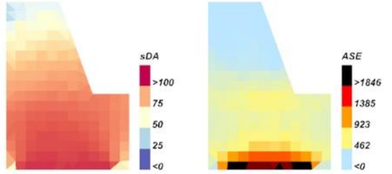

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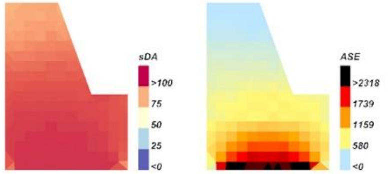

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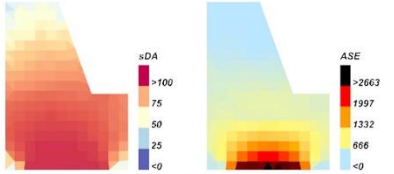

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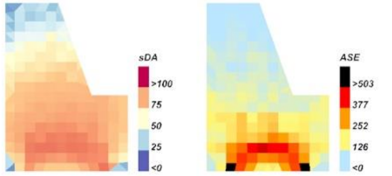

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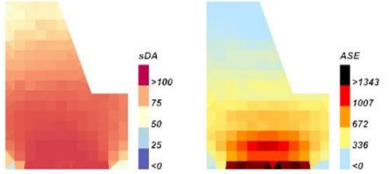

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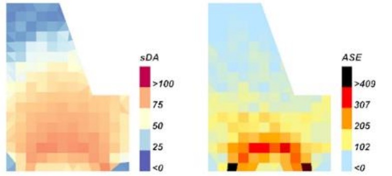

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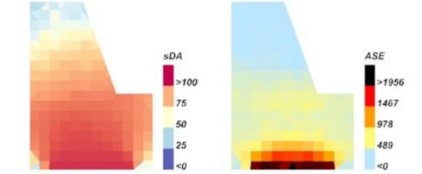

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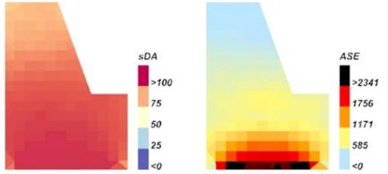

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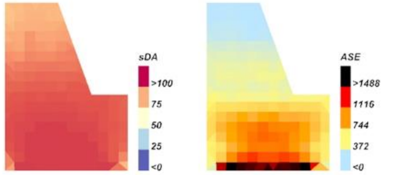

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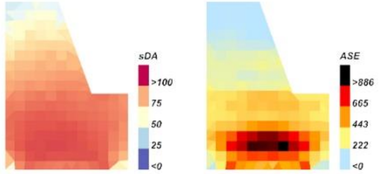

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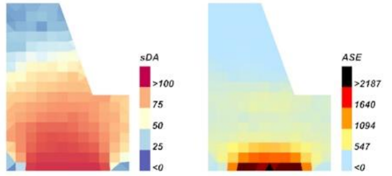

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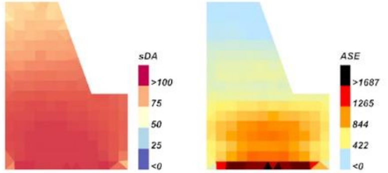

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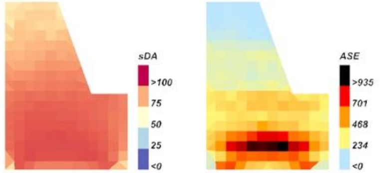

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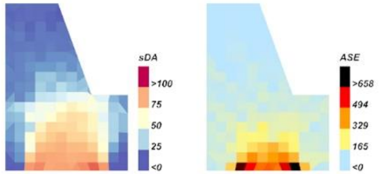

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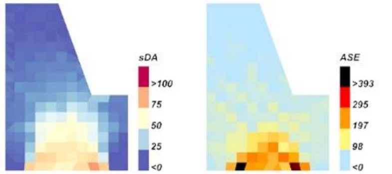

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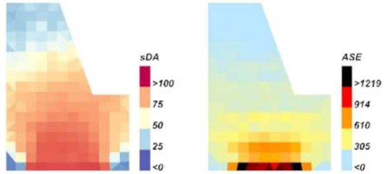

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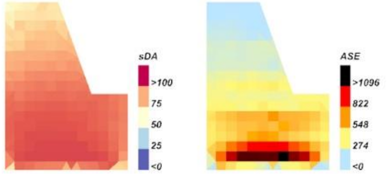

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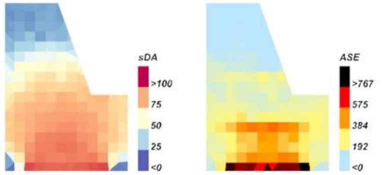

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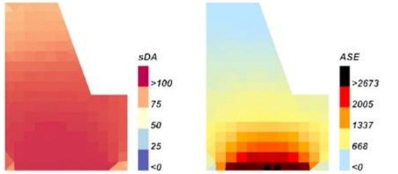

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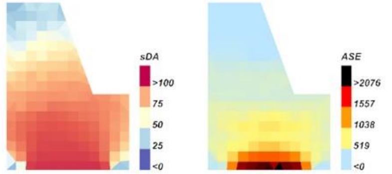

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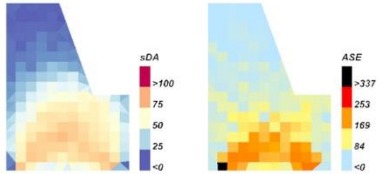
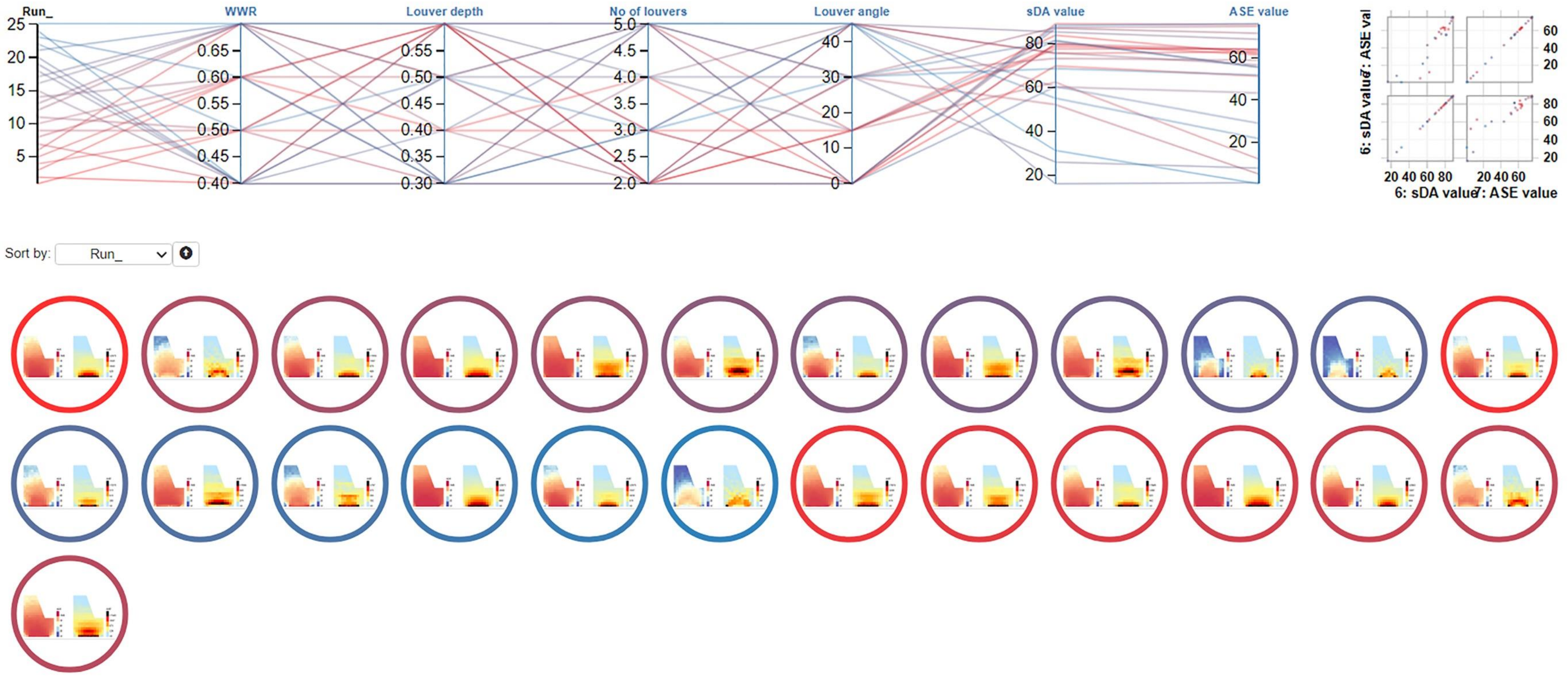
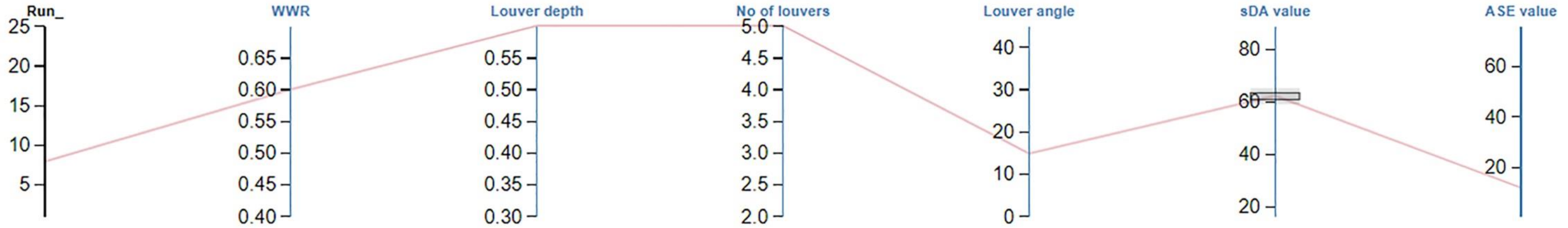


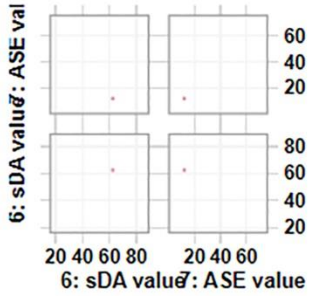
25.

Patient room South Orientation: **Comparative analysis of iterations using Design Explorer**

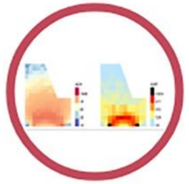


Patient room South Orientation: **Selection of optimum iteration**





Sort by: Run_



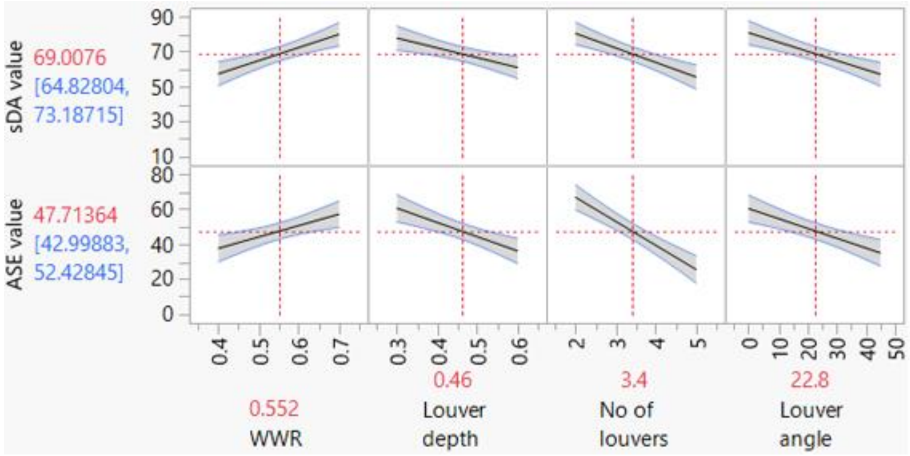
Run_	WWR	Louver depth	No of louvers	Louver angle	sDA value	ASE value	img	Rating	scid
8	0.6	0.6	5	15	62.438377	12.14655	Run_8.png	0	7

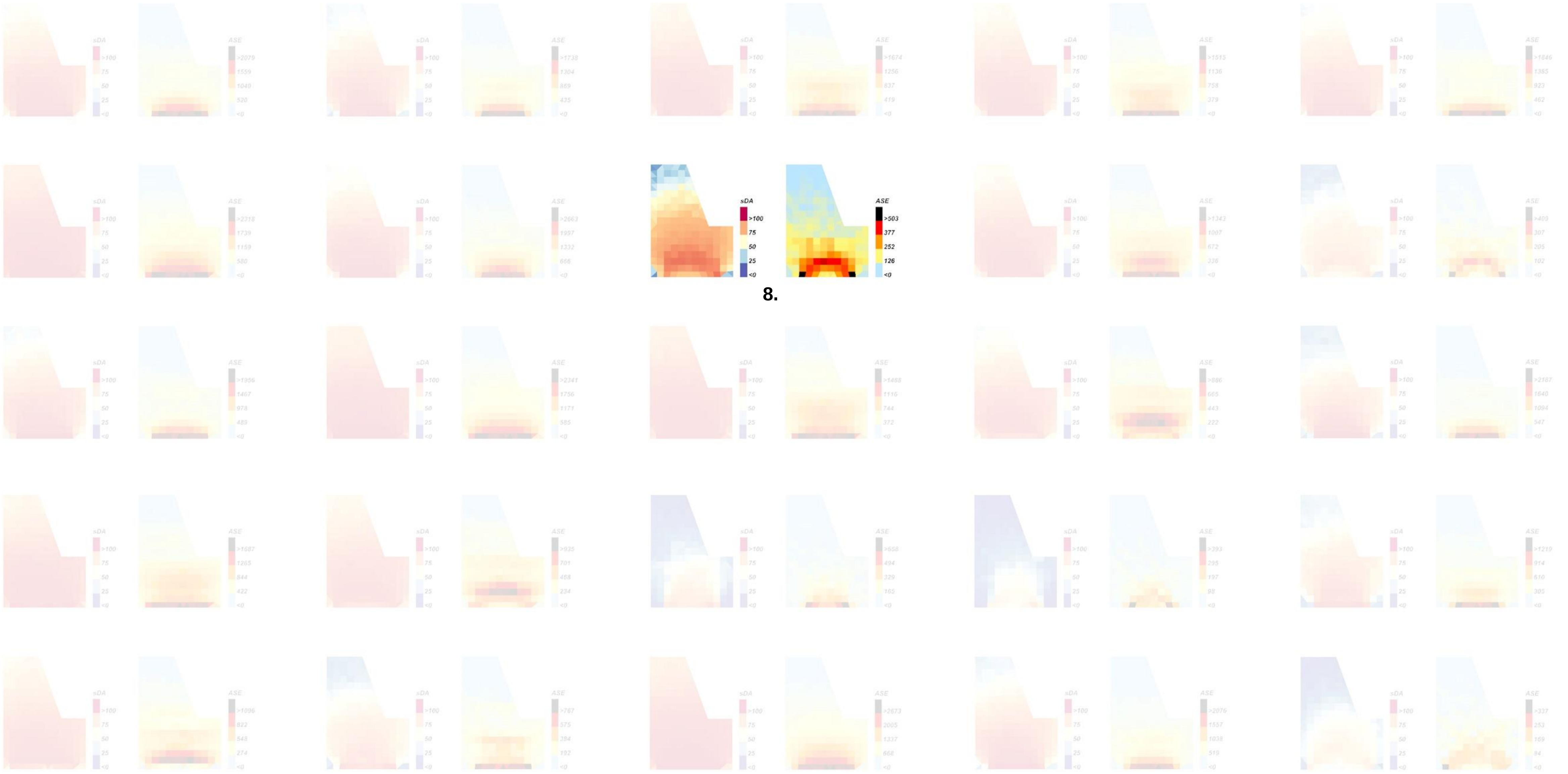
- Based on the comparative analysis **iteration no. 08** provides the right balance of sDA and ASE values as compared to other iterations.

Sensitivity Analysis:

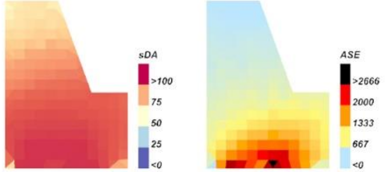
- From the sensitivity analysis, it can be observed that no. of louvers as a parameter has a considerable impact on the sDA and ASE values followed by the window-to-wall ratio (WWR).

Source	LogWorth	PValue
No of louvers	6.328	0.00000
Louver angle	3.773	0.00017
WWR	3.547	0.00028
Louver depth	3.480	0.00033




sDA
>100
75
50
25
<0
ASE
>503
377
252
126
<0
8.

Patient room South Orientation: **Daylighting Optimization iterations using fins as shading mechanism**



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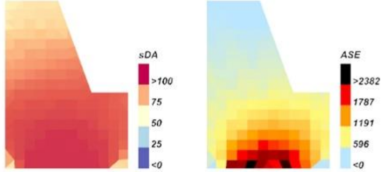

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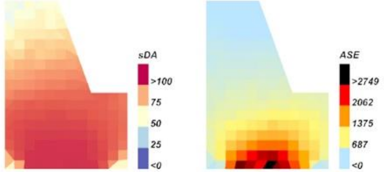

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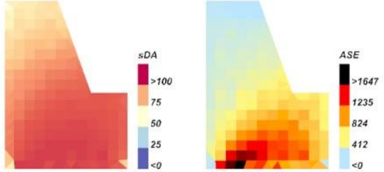

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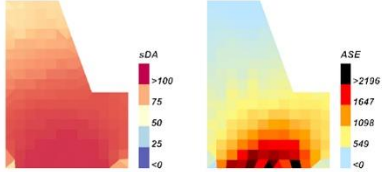

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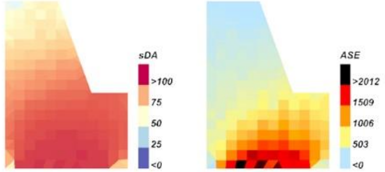

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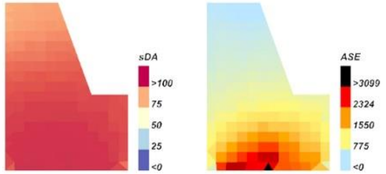

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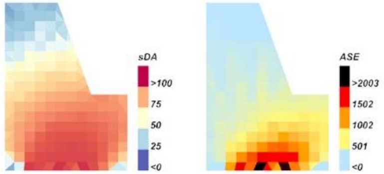

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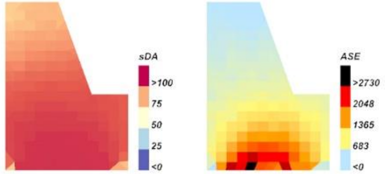

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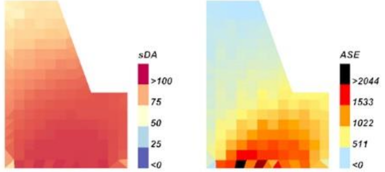

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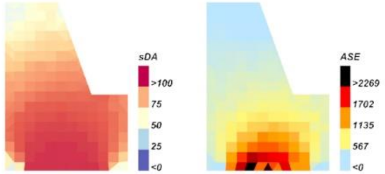

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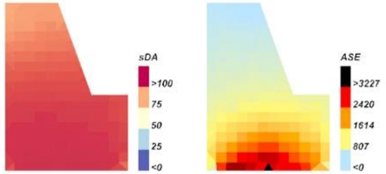

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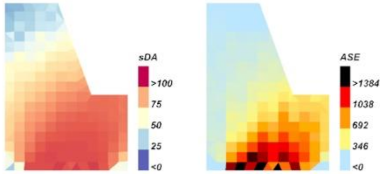

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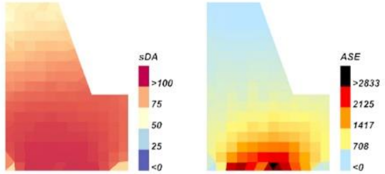

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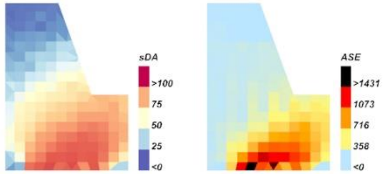

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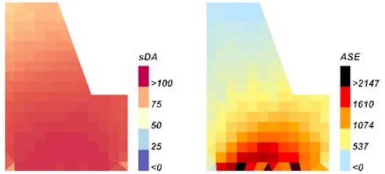

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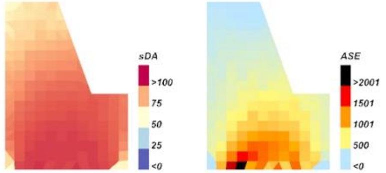

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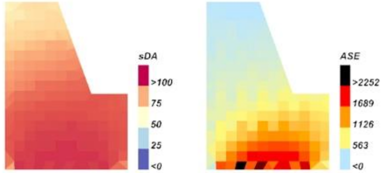

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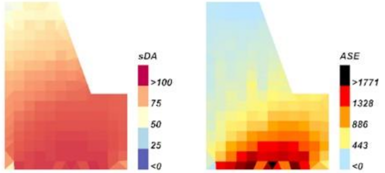

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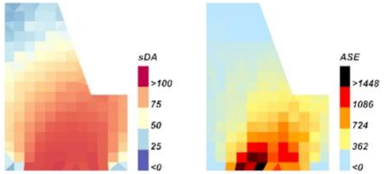

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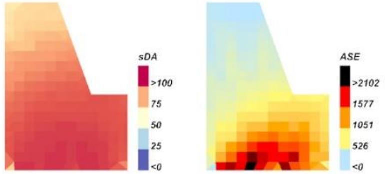

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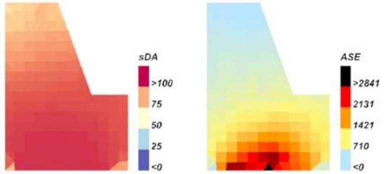

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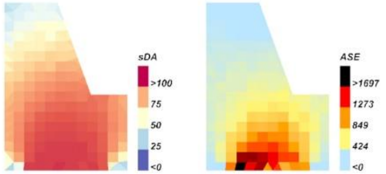

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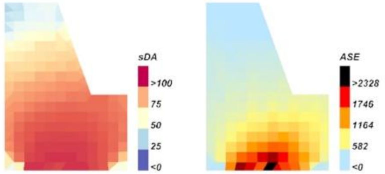

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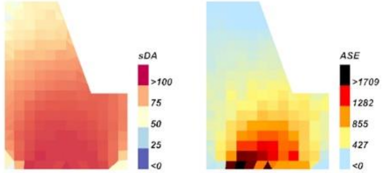
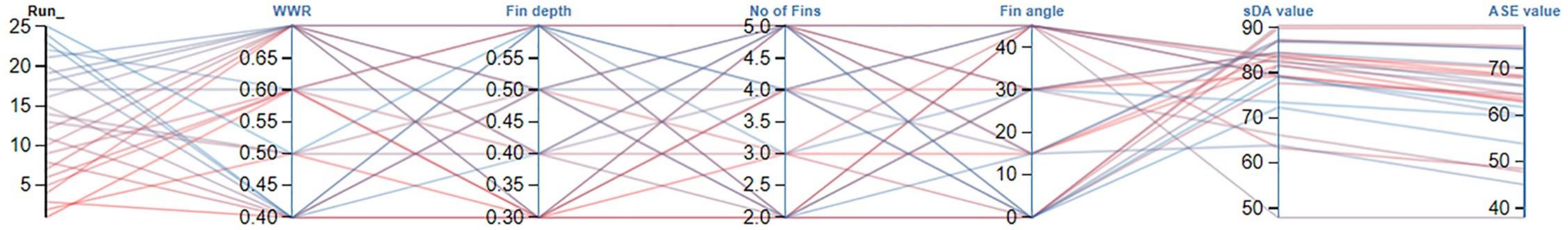
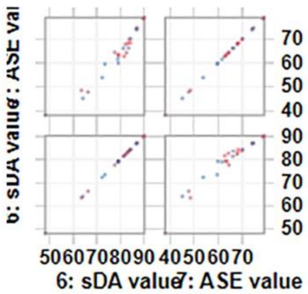


25.

Patient room South Orientation: Comparative analysis of iterations using Design Explorer





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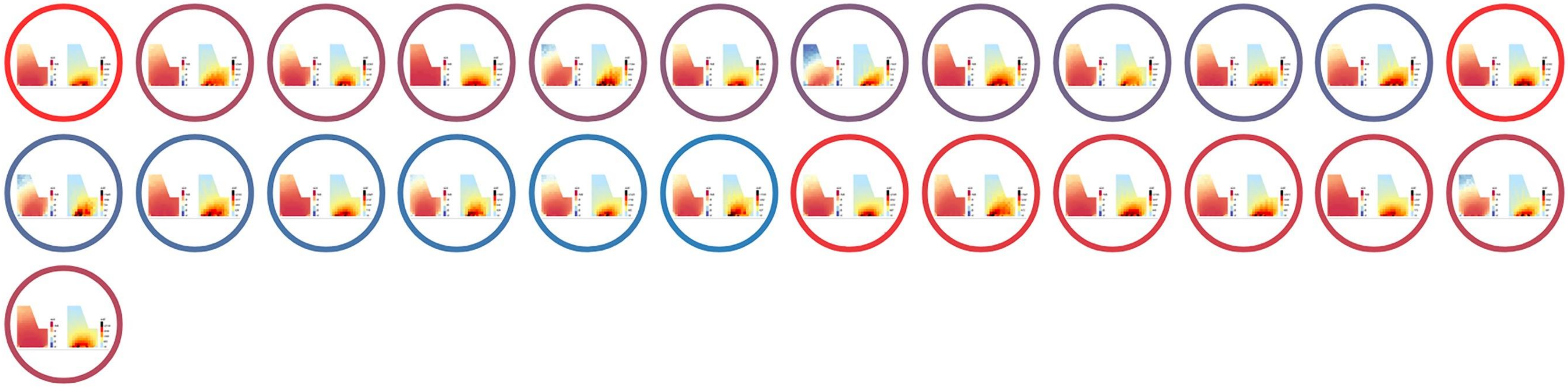
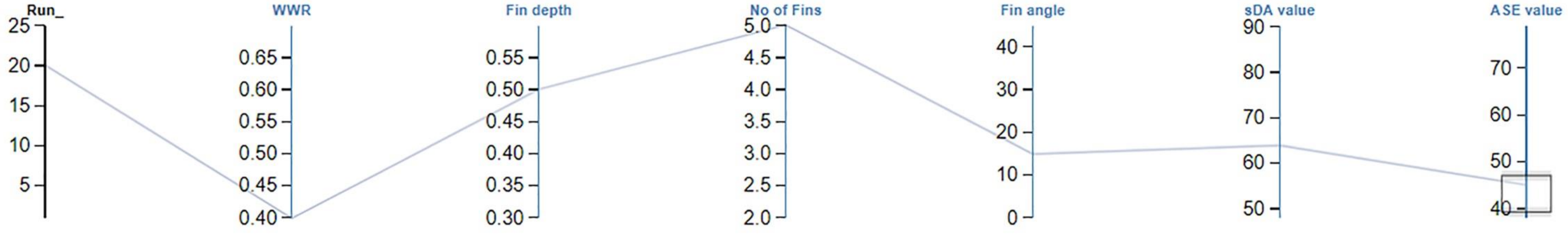
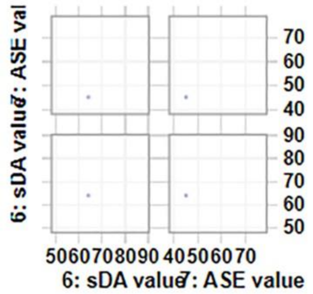
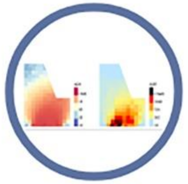


 Selection of optimum iteration





Sort by: Run_



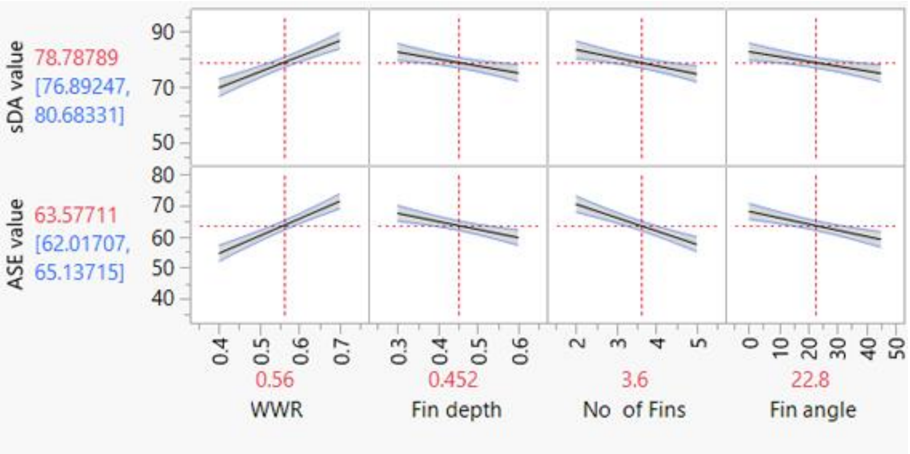
Run_	WWR	Fin depth	No of Fins	Fin angle	sDA value	ASE value	img	Rating	scid
20	0.4	0.5	5	15	64.020785	45.185548	Run_20.png	0	19

- Based on the comparative analysis **iteration no. 20** provides the right balance of sDA and ASE values as compared to other iterations.

Sensitivity Analysis:

- From the sensitivity analysis, it can be observed that the window-to-wall ratio (WWR) parameter has a significant impact on the sDA and ASE values.

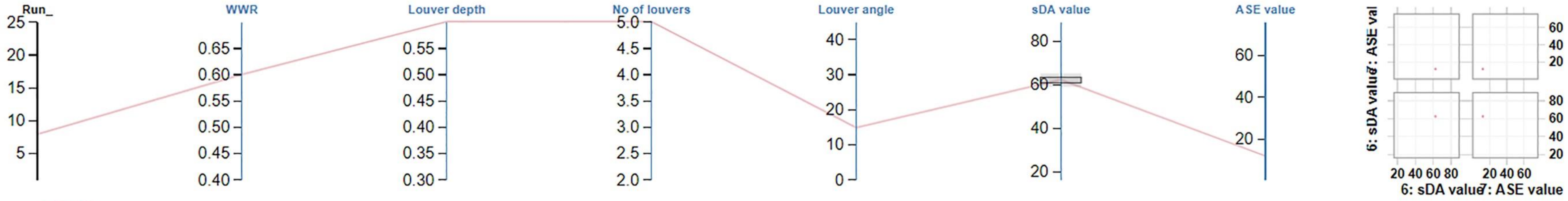
Source	LogWorth	PValue
WWR	7.699	0.00000
No of Fins	5.979	0.00000
Fin angle	3.869	0.00014
Fin depth	3.232	0.00059

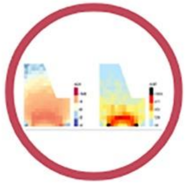


Patient room South Orientation: **Shortlisted fins iteration**

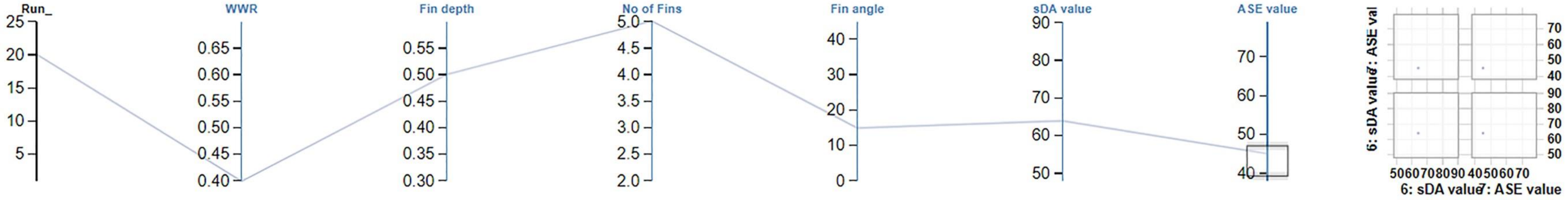
20.

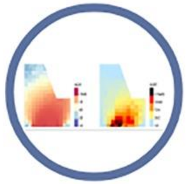
Patient room South Orientation: Comparative analysis of shortlisted louvers and fins iterations





Run_	WWR	Louver depth	No of louvers	Louver angle	sDA value	ASE value	img	Rating	scid
8	0.6	0.6	5	15	62.438377	12.14655	Run_8.png	0	7





Run_	WWR	Fin depth	No of Fins	Fin angle	sDA value	ASE value	img	Rating	scid
20	0.4	0.5	5	15	64.020785	45.185548	Run_20.png	0	19

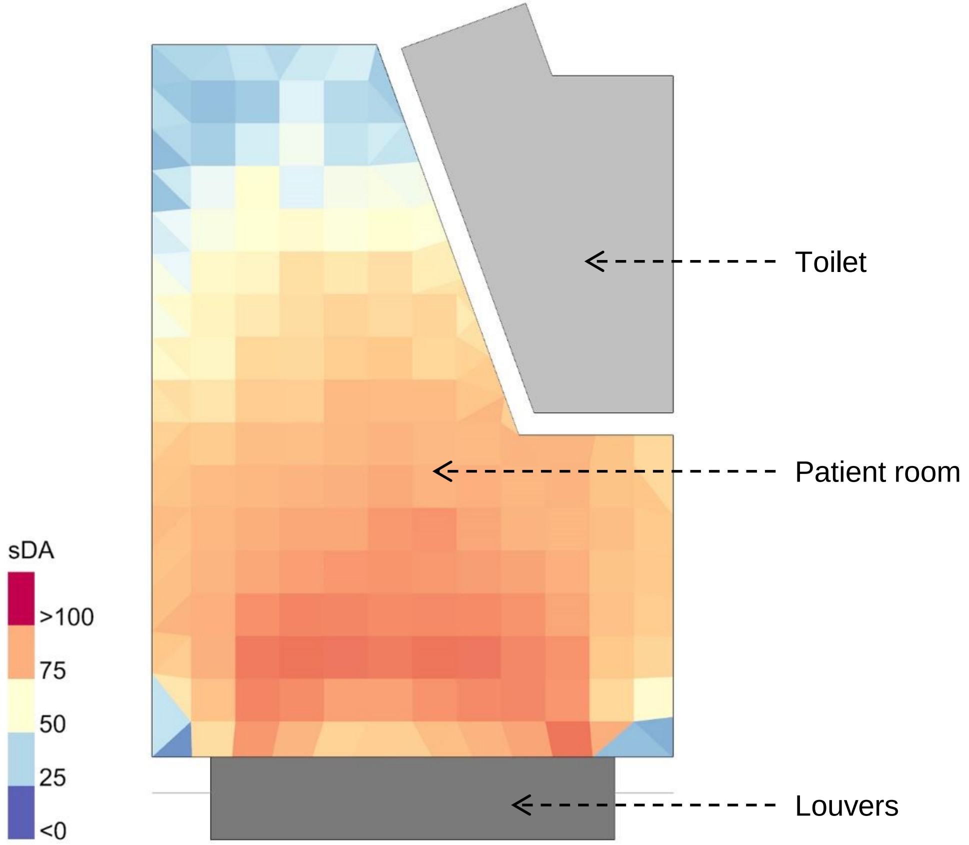
Optimization Analysis summary:

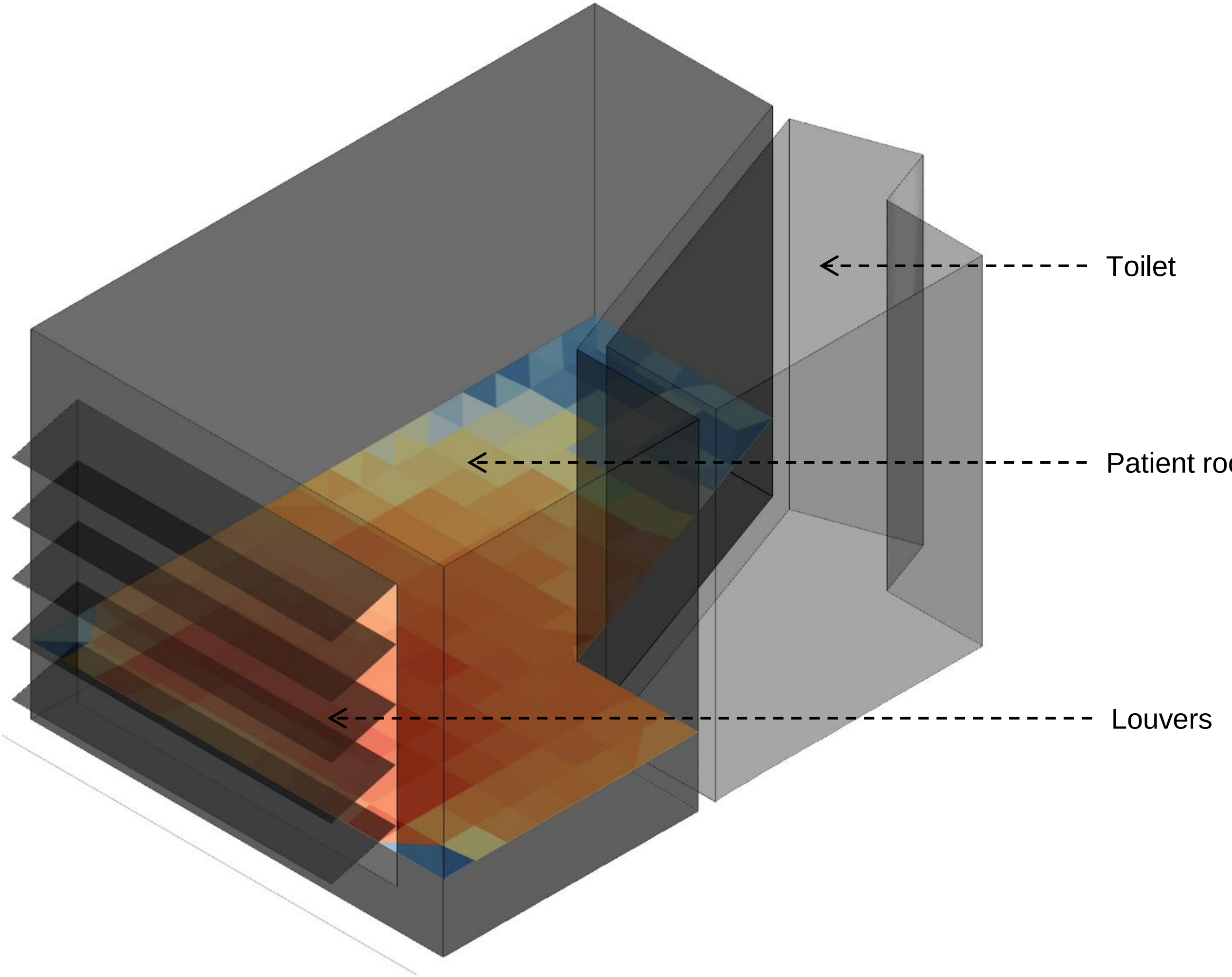
- After a careful study of the results derived from the optimization process studying different window-to-wall ratios and shading mechanisms like louvers and fins, it can be inferred that the **louvers iteration provides a better balance between the sDA and ASE values compared to the fins iteration.**

Patient room South Orientation: **Shortlisted iteration sDA analysis**

Input parameters:
- Window-to-wall ratio (WWR) – 60%
- Louver depth – 0.60m
- No. of louvers – 5
- Louver angle – 15º

Spatial daylight autonomy (sDA) output:
- sDA value – 62.43%





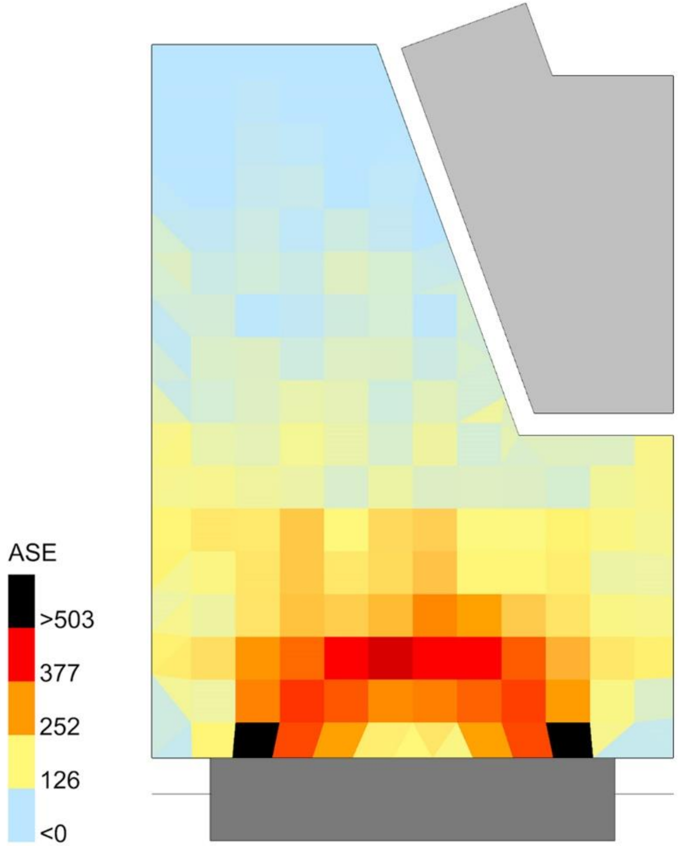
Patient room South Orientation: **Shortlisted iteration sDA analysis**

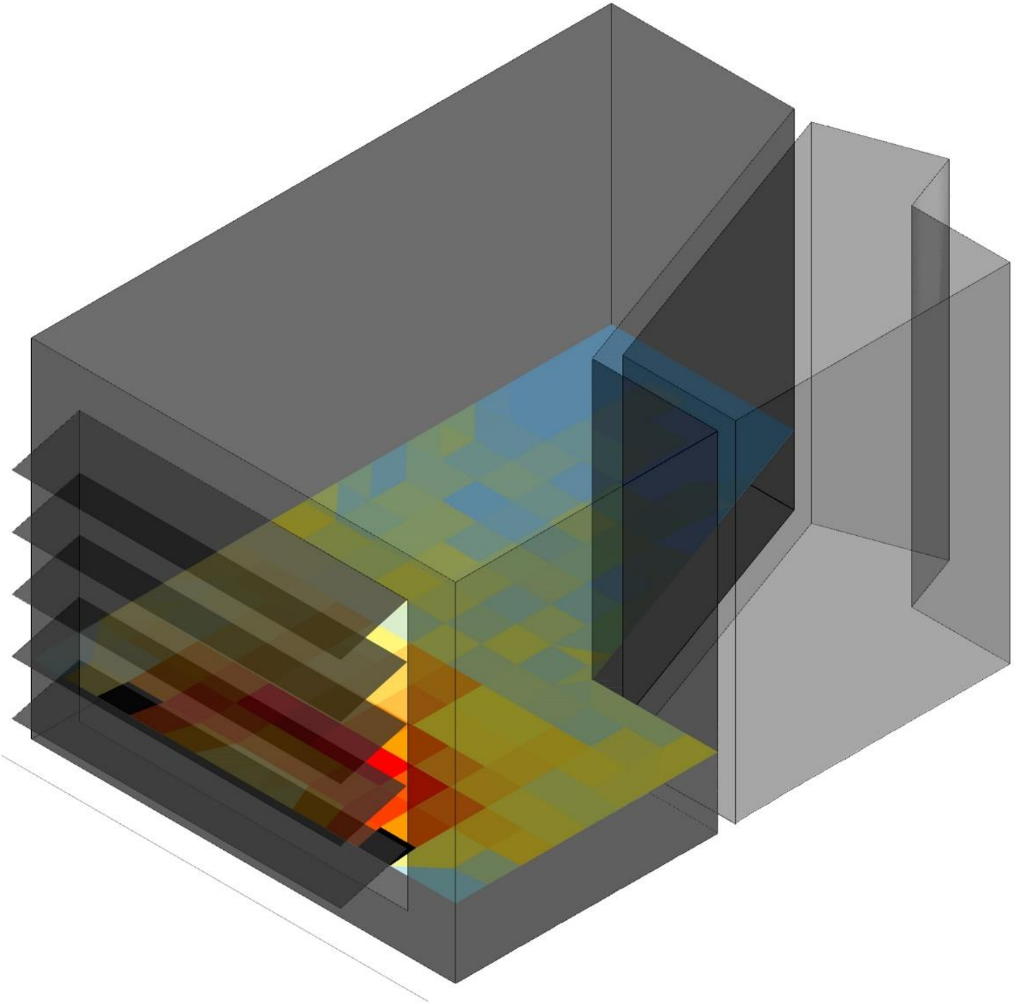
Input parameters:

- Window-to-wall ratio (WWR) – 60%
- Louver depth – 0.60m
- No. of louvers – 5
- Louver angle – 15º

Annual Sunlight Exposure (ASE) output:

- ASE value – 12.14%





Patient room East Orientation: Optimization results of daylighting analysis

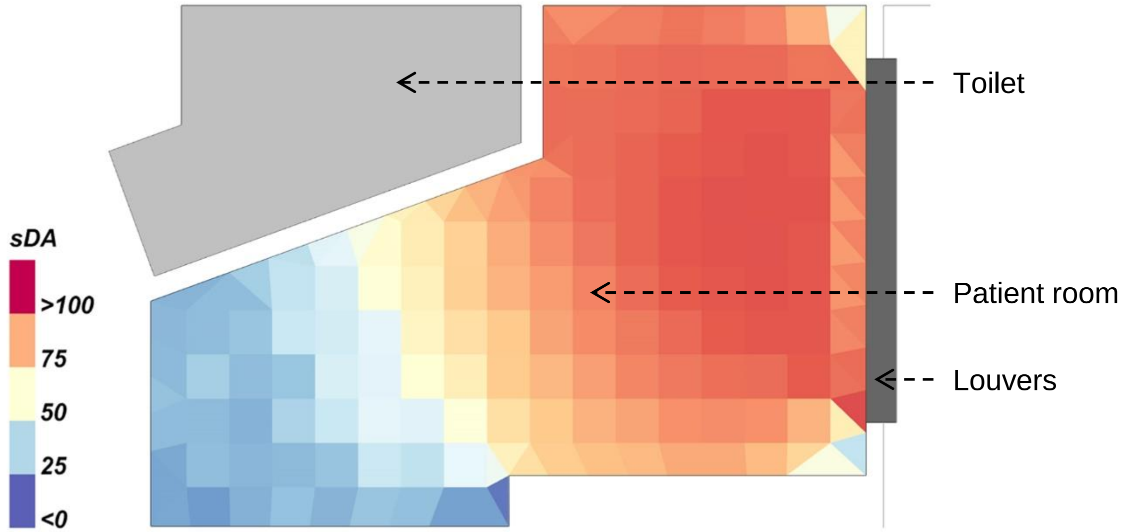
Patient room East Orientation: Shortlisted iteration sDA analysis

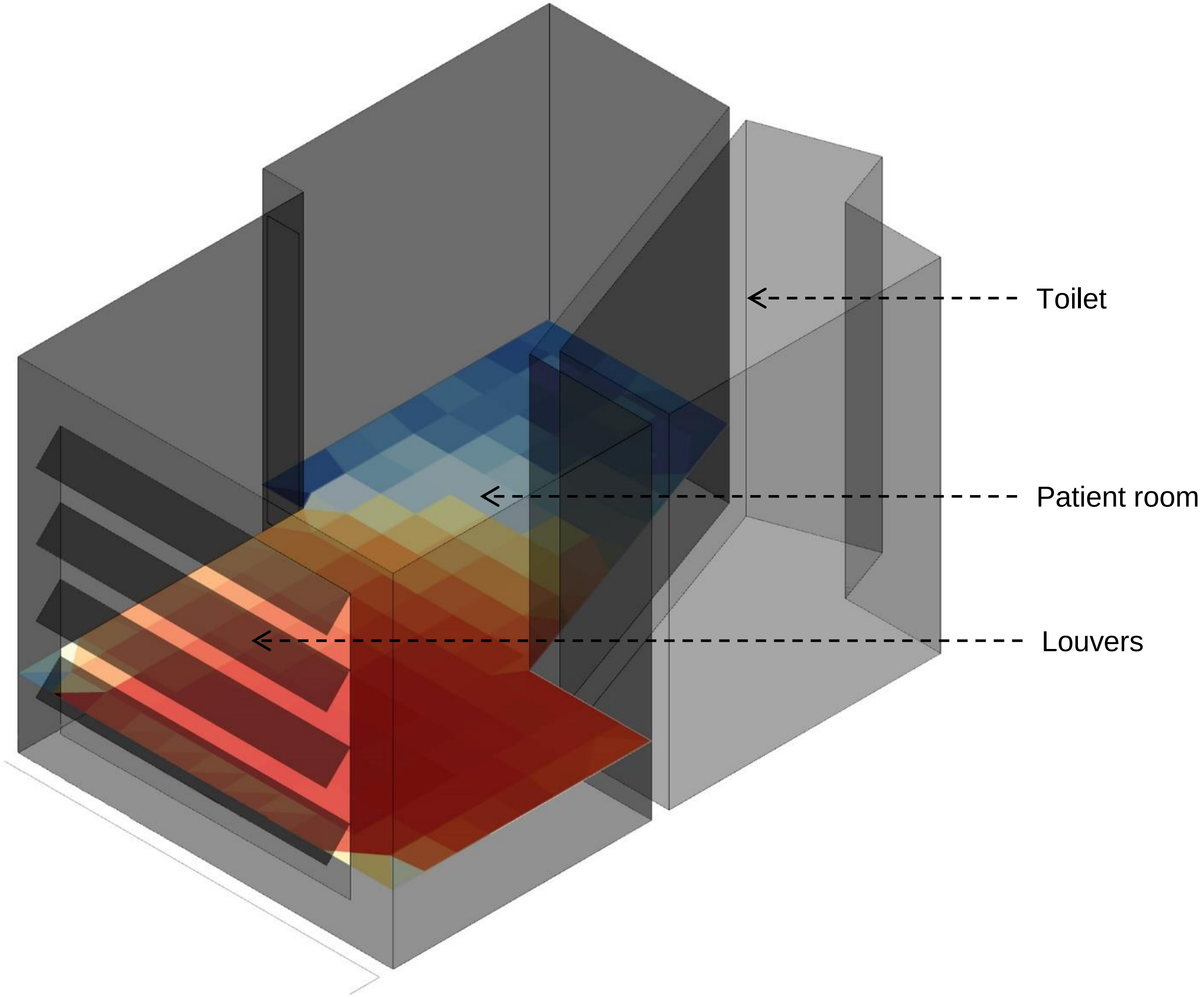
Input parameters:

- Window-to-wall ratio (WWR) – 60%
- Louver depth – 0.30m
- No. of louvers – 4
- Louver angle – 45°

Spatial daylight autonomy (sDA) output:

- sDA value – 62.97%





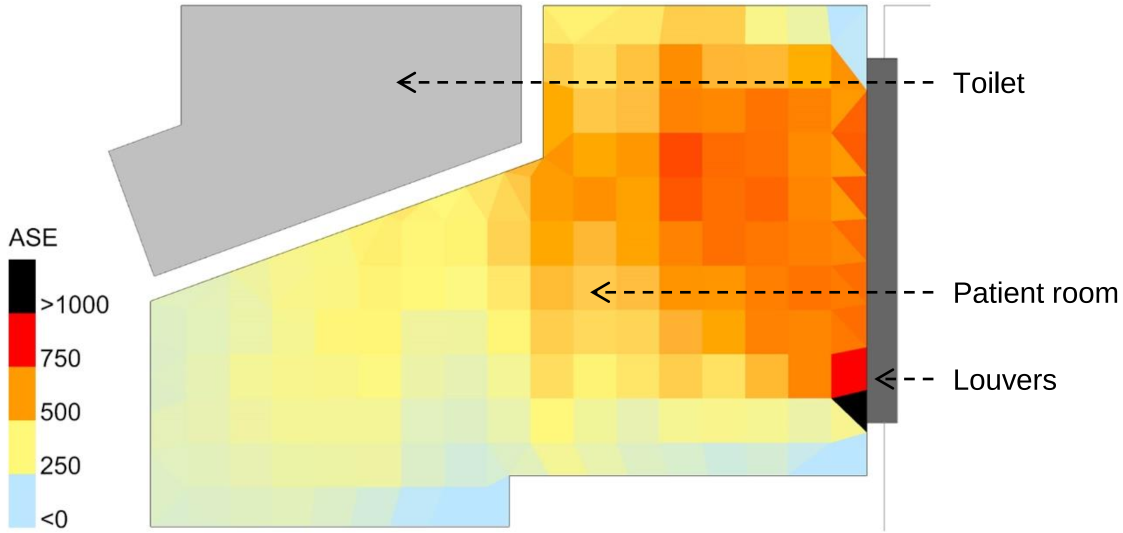
Patient room East Orientation: **Shortlisted iteration ASE analysis**

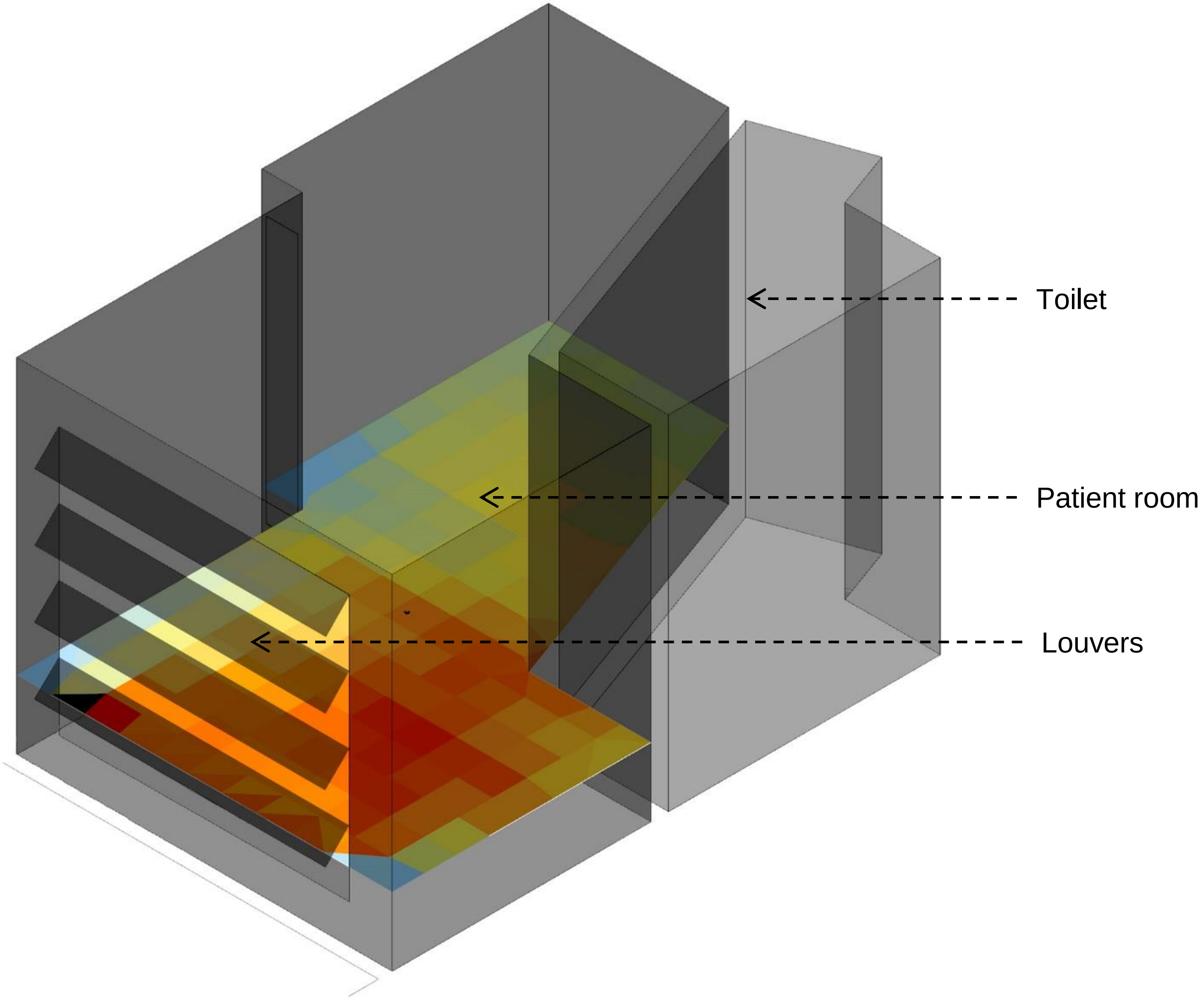
Input parameters:

- Window-to-wall ratio (WWR) – 60%
- Louver depth – 0.30m
- No. of louvers – 4
- Louver angle – 45º

Annual Sunlight Exposure (ASE) output:

- ASE value – 55.04%



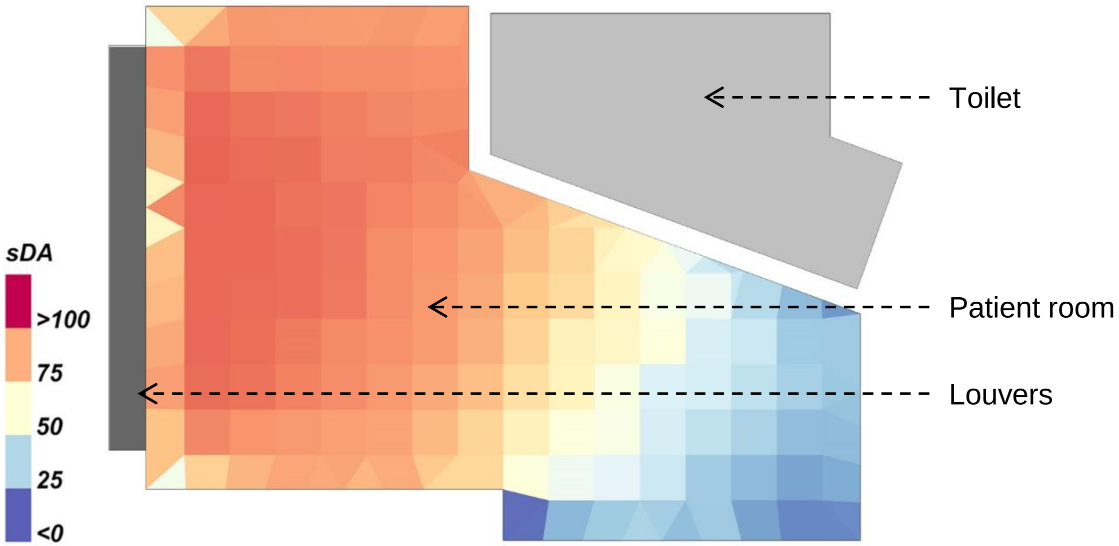


Patient room West Orientation: Optimization results of daylighting analysis

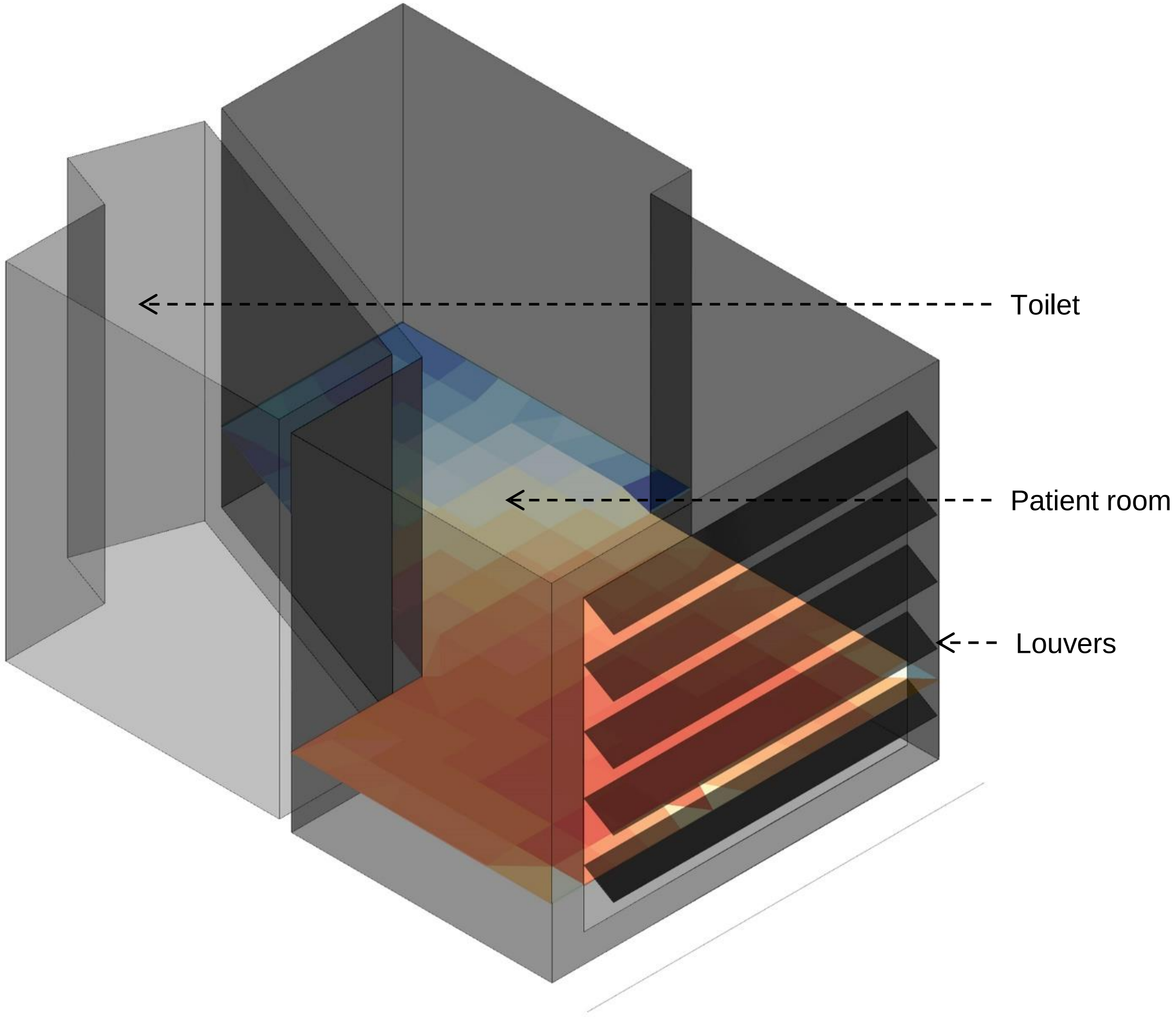
Patient room West Orientation: Shortlisted iteration sDA analysis

Input parameters:
- Window-to-wall ratio (WWR) – 70%
- Louver depth – 0.30m
- No. of louvers – 5
- Louver angle – 30^o

Spatial daylight autonomy (sDA) output:
- sDA value – 60.90%



Patient room layout

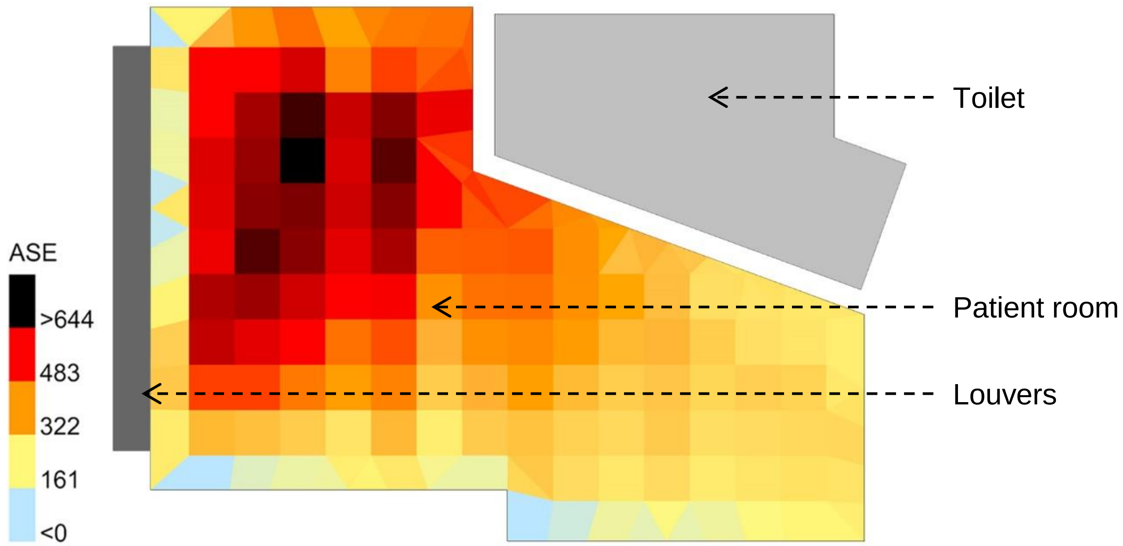


Patient room isometric view

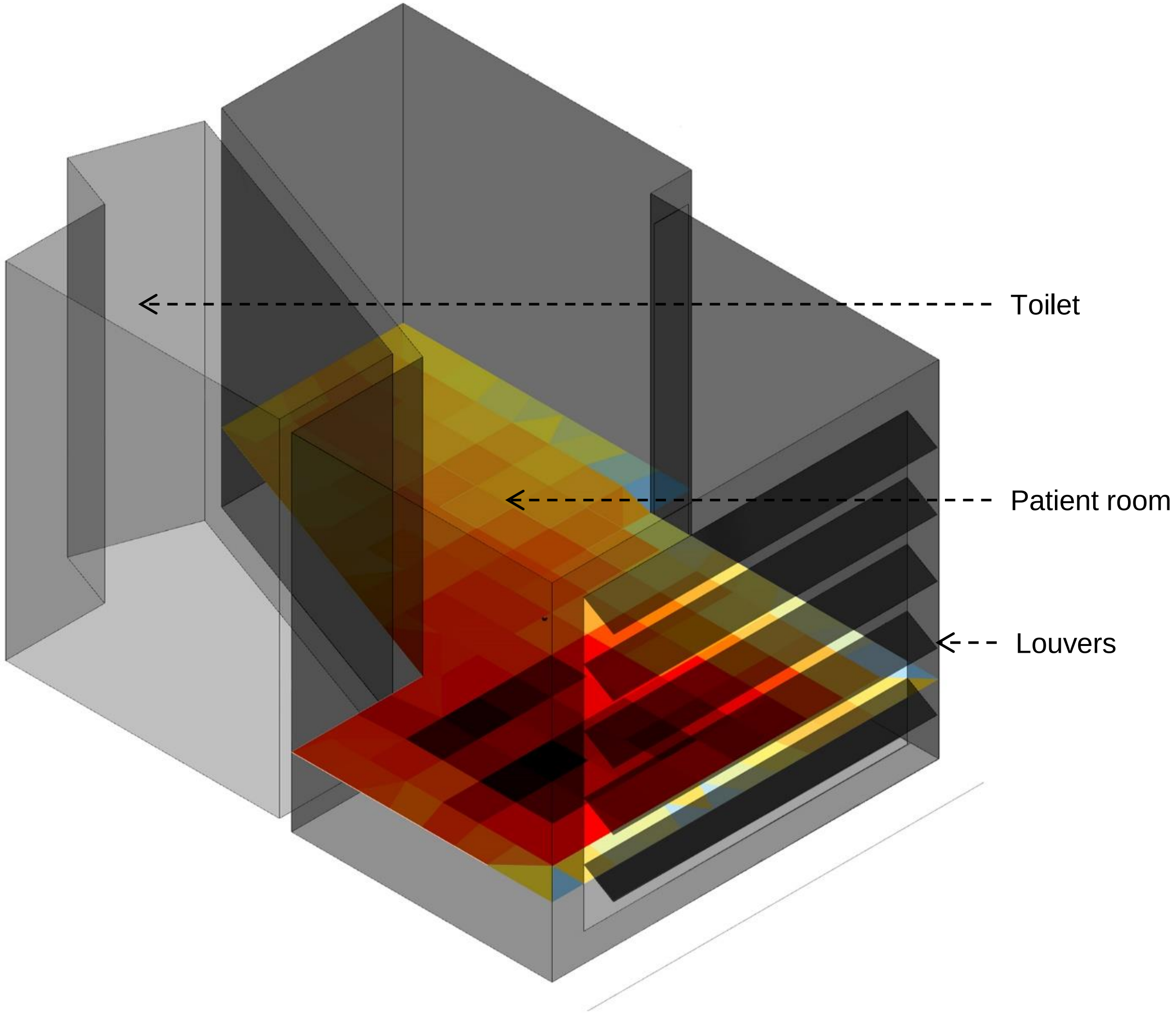
Patient room West Orientation: **Shortlisted iteration ASE analysis**

Input parameters:
- Window-to-wall ratio (WWR) – 70%
- Louver depth – 0.30m
- No. of louvers – 5
- Louver angle – 30°

Annual Sunlight Exposure (ASE) output:
- ASE value – 59.55%



Patient room layout



Patient room isometric view

Conclusion

Moving Forward

- The next stage of this research will focus on **evaluating the equivalent melanopic lux (EML) levels for each of the shortlisted iterations of patient rooms** and assessing the **impact of daylighting and electrical lighting on the circadian rhythms of the patients.**
- A 3d model developed on Rhino of the shortlisted iterations for each orientation would be used to evaluate the EML to assess the impact of daylighting and electrical lighting on the circadian rhythms of patients.
- The resultant simulation analysis would **provide a framework for designing patient rooms in healthcare settings by balancing daylighting and electrical circadian lighting.**

ALFA

Adaptive Lighting for Alertness

A new circadian lighting design software.

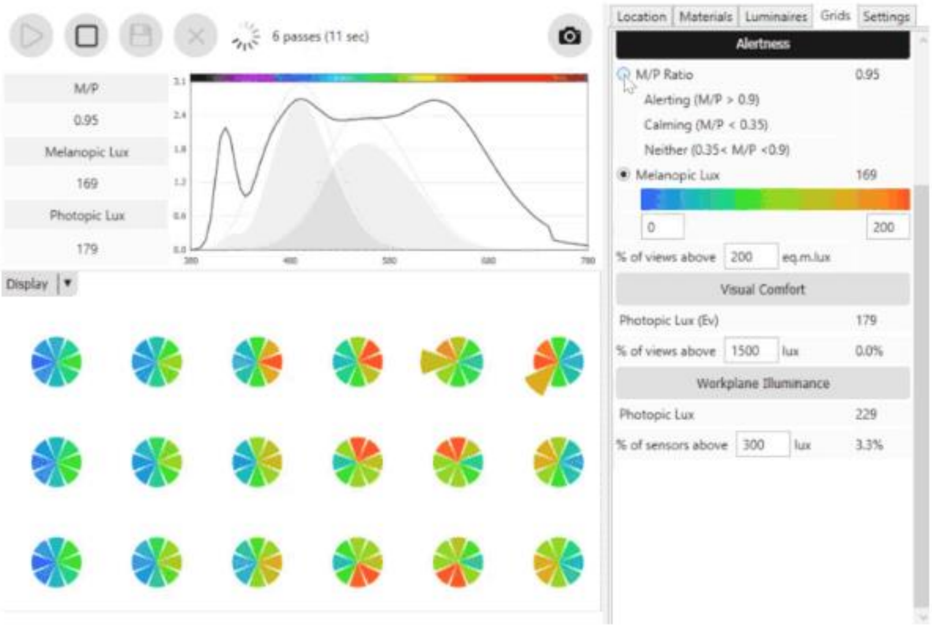


Image 13&14: https://www.solemma.com/alfa

Developing a ‘healing building envelope’ in healthcare design

Thank you! Q&A

(Image: https://www.advancedglazings.com/case-studies/healing_power_of_daylight)