

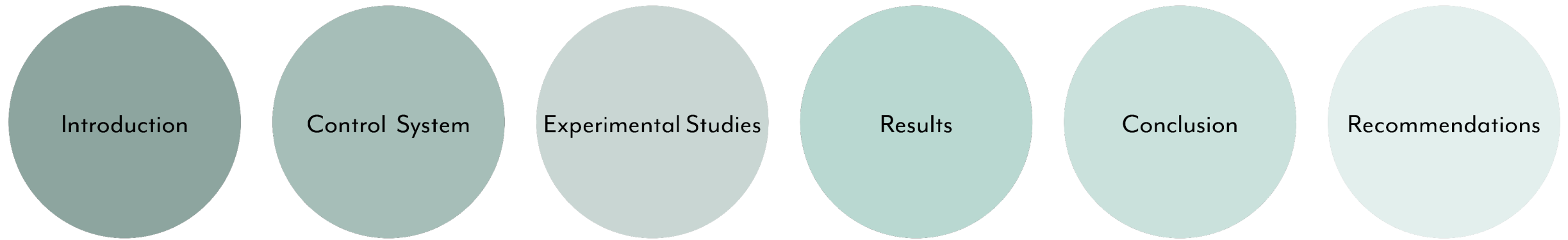
Affective window: a seamless interaction between switchable glazing and the occupant

Sustainable Design Graduation studio
Christianne Neeltje Luijten, TU Delft
4474732

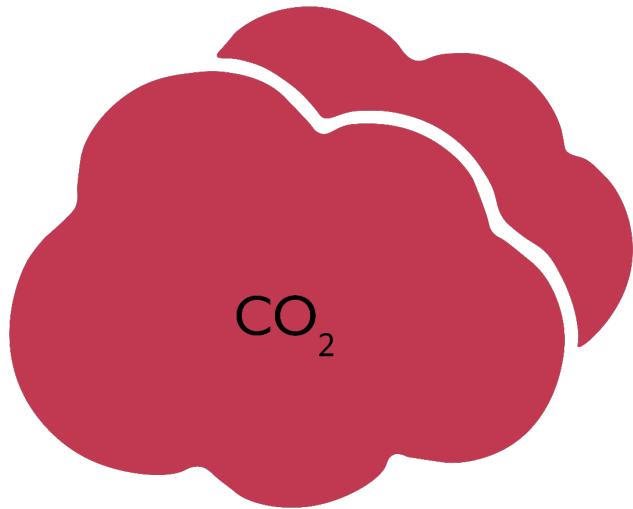
Supervisors:
Mauro Overend, TU Delft
Regina Bokel, TU Delft

External advisors:
Mark Allen, University of Cambridge
Alessandra Luna-Navarro, University of Cambridge

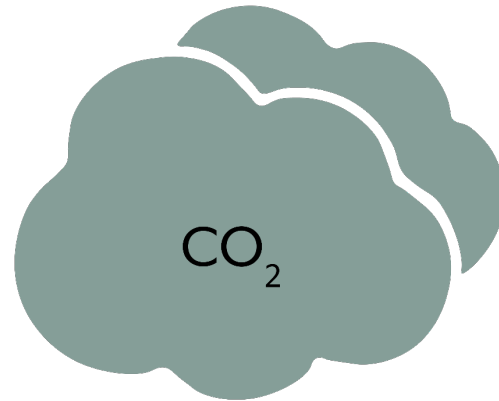




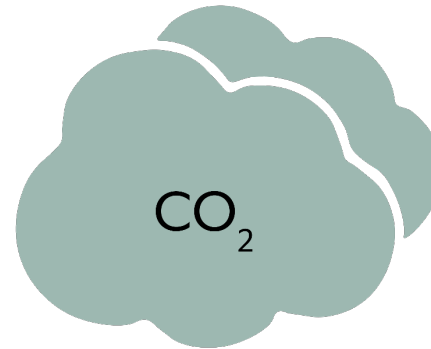
EU's total CO₂ emissions



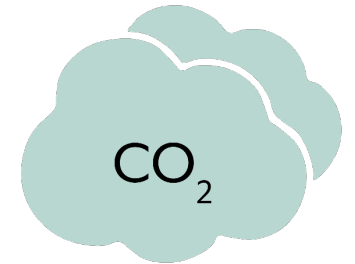
Construction and buildings (36%)



Transport (28%)

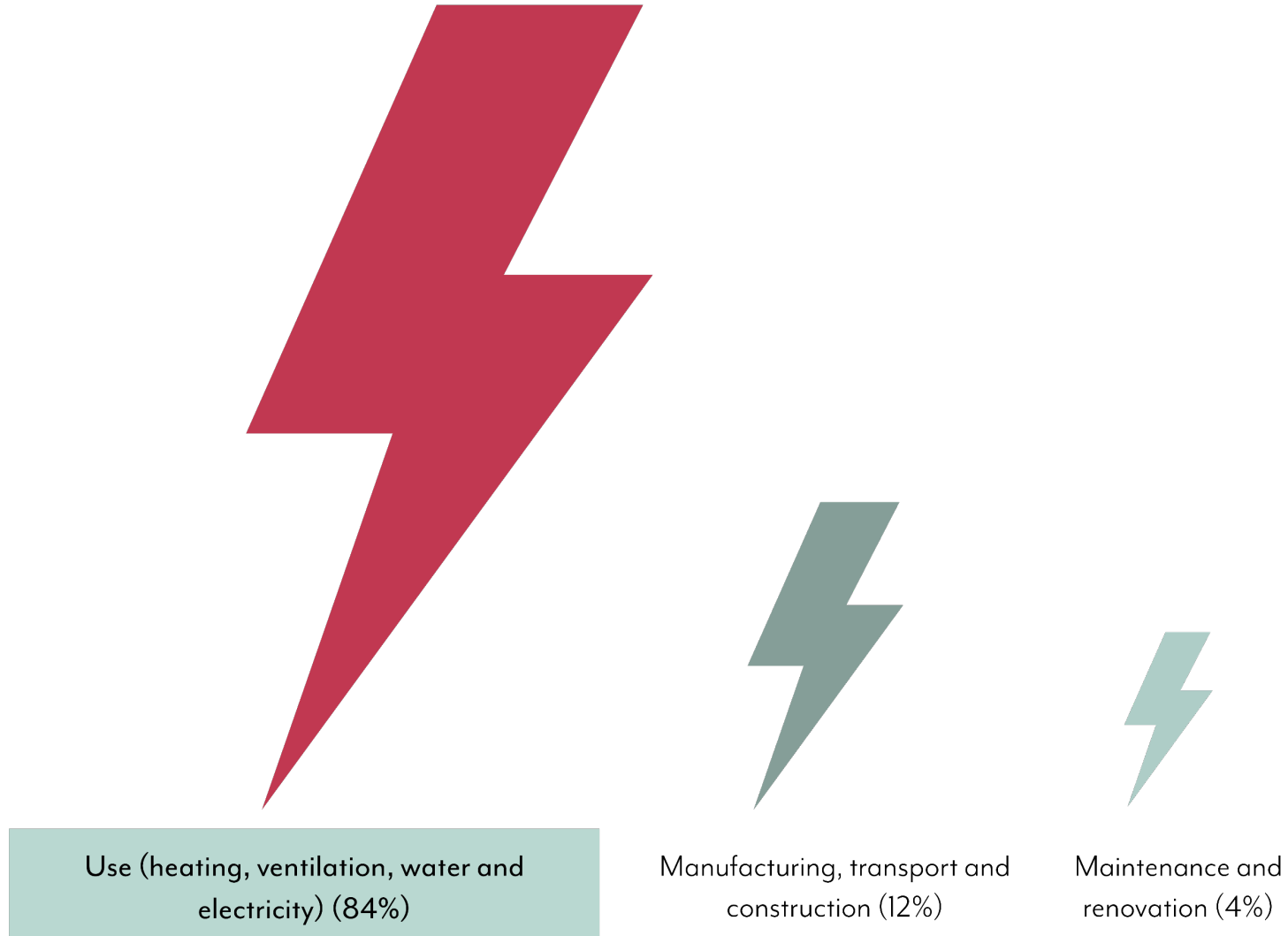


Other (20%)

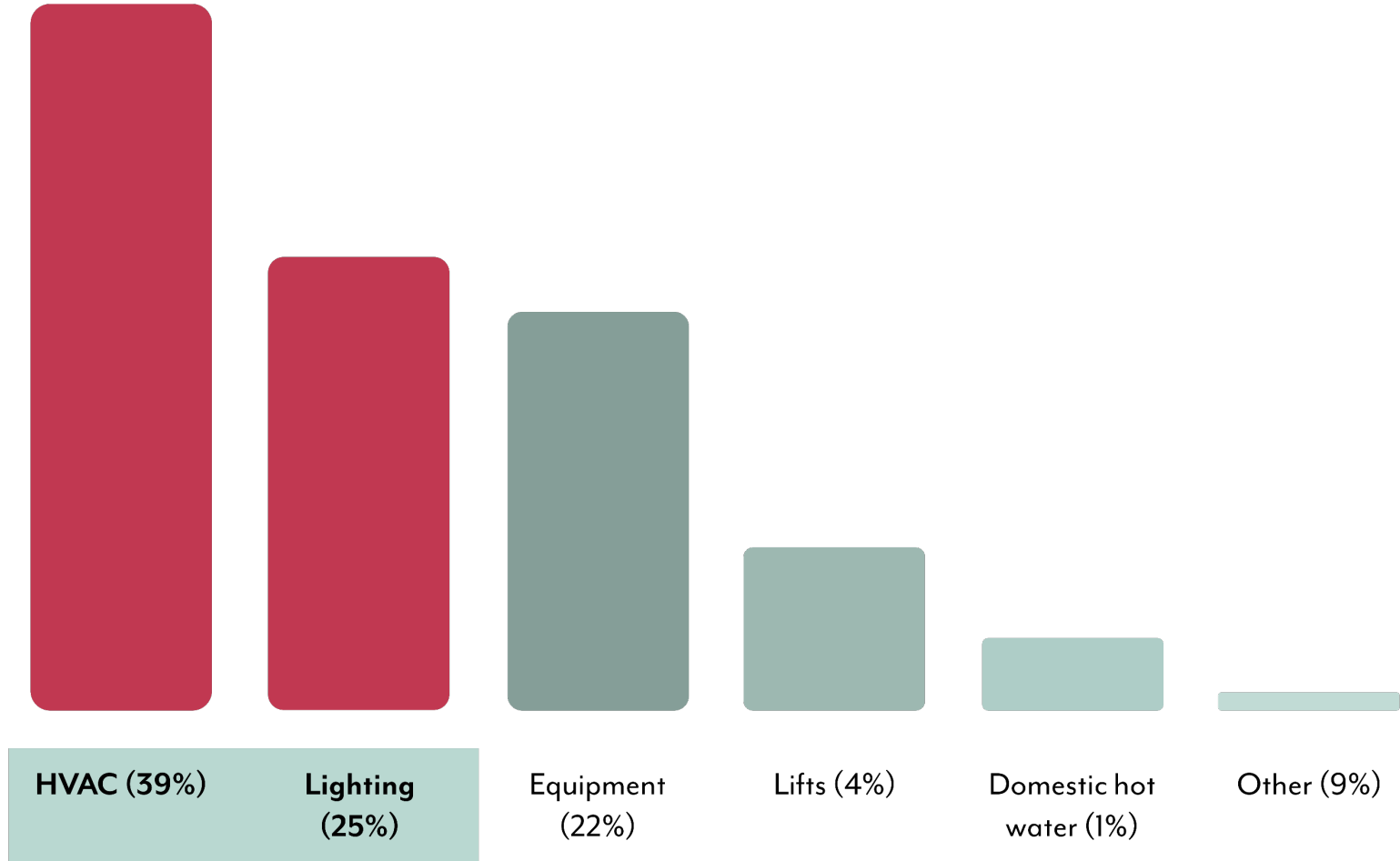


Manufacturing (16%)

A building's energy use



Energy consumption breakdown



Typical energy distribution

Glazed façades unnecessary blinds closed

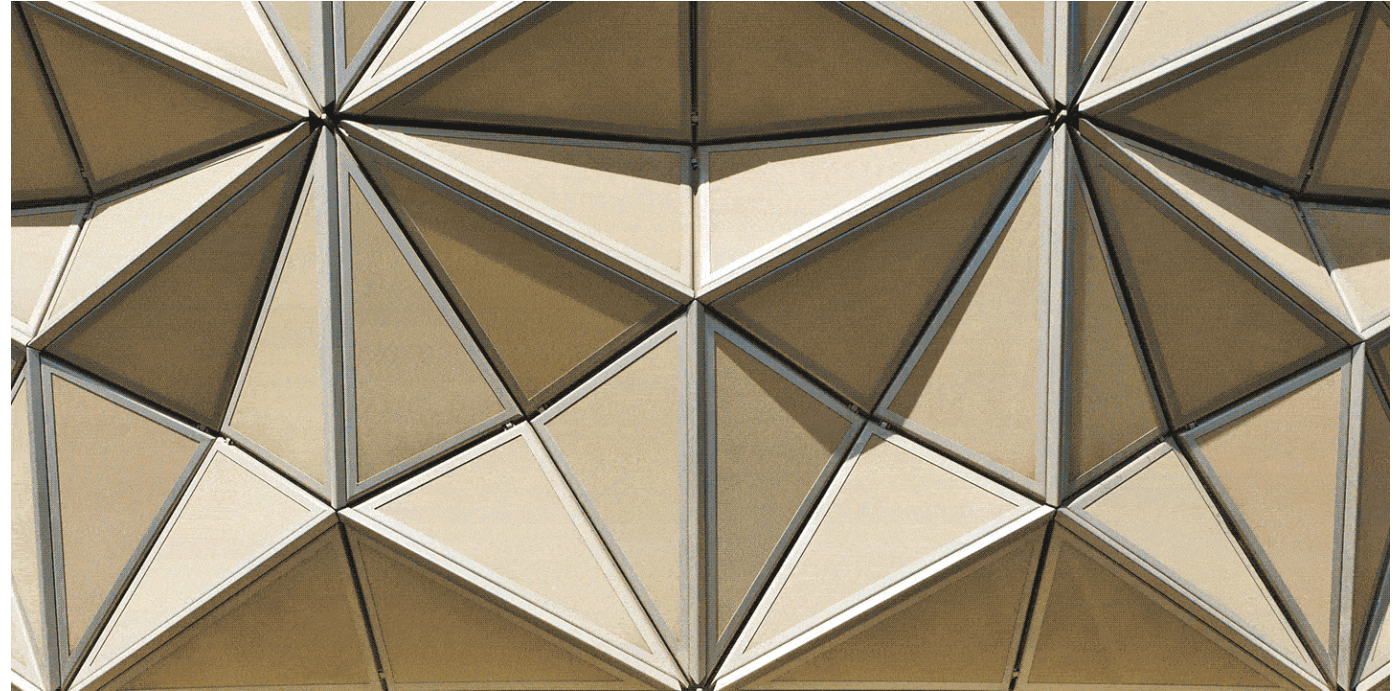
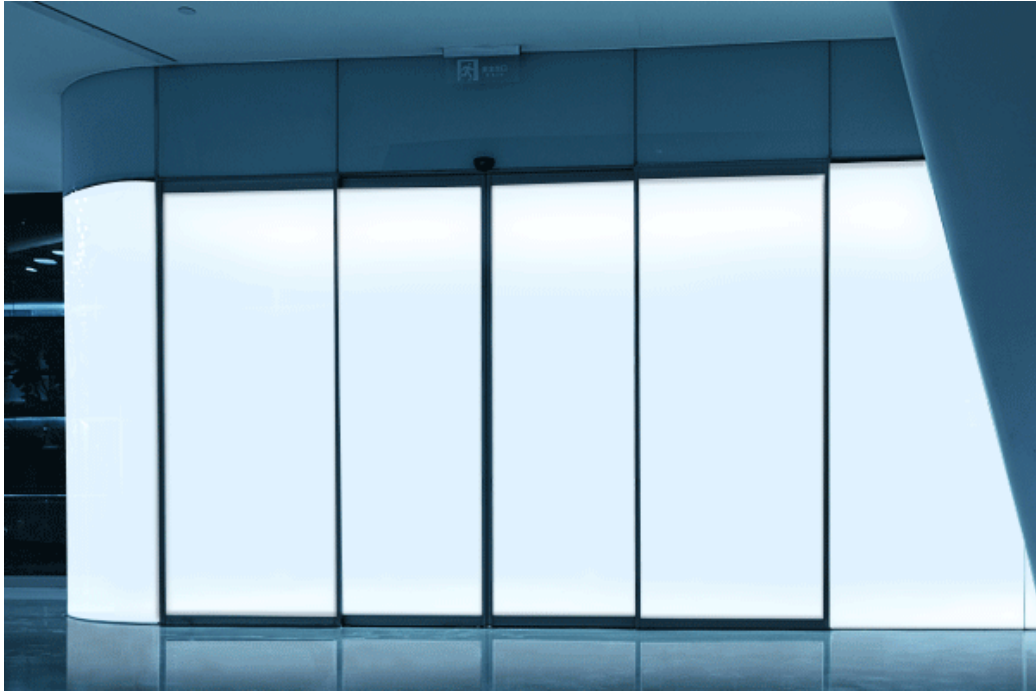


30% of the time the blinds are closed

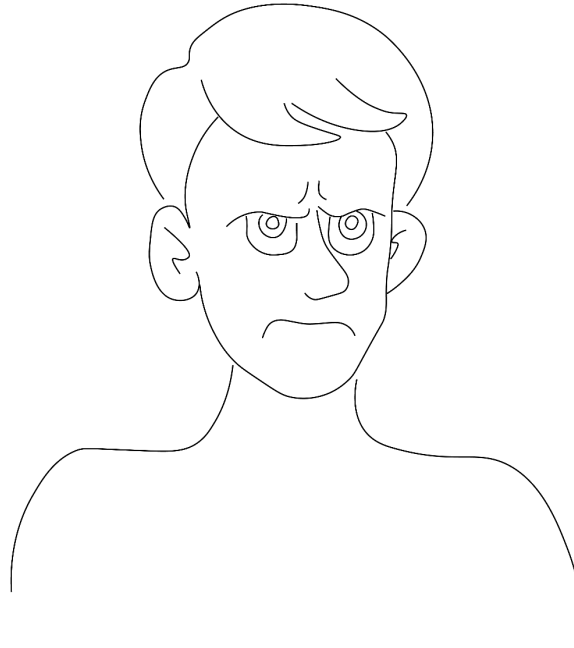


75% of the time the blinds are closed **unnecessary**

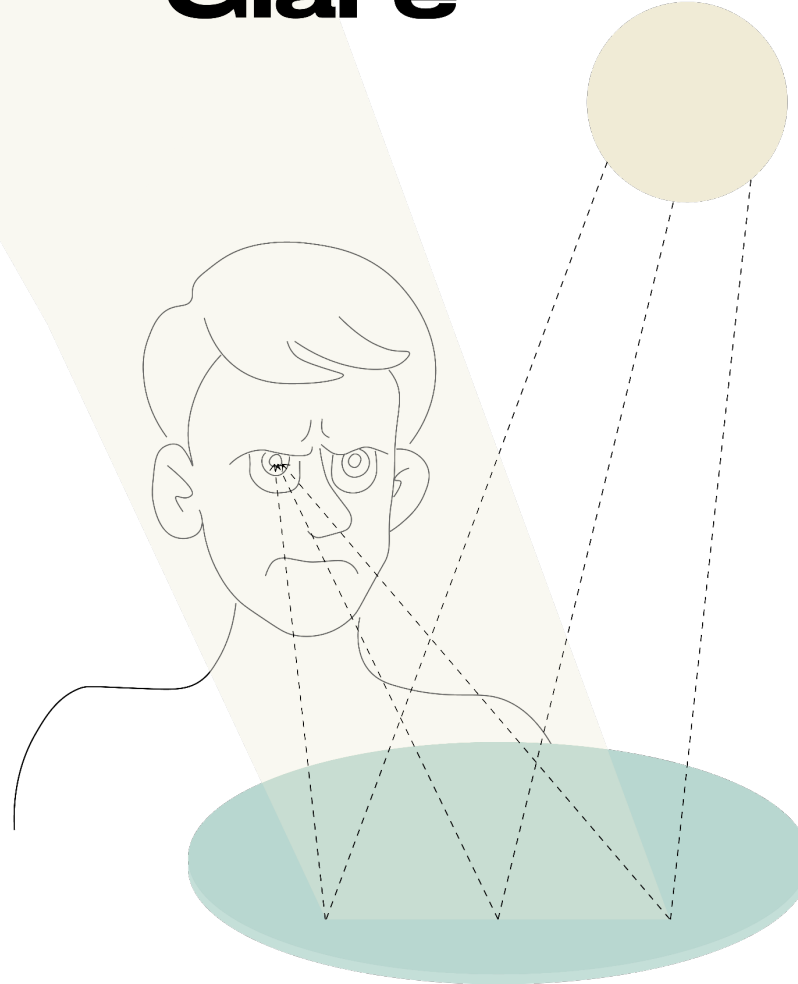
New dynamic façade technologies



Visual discomfort

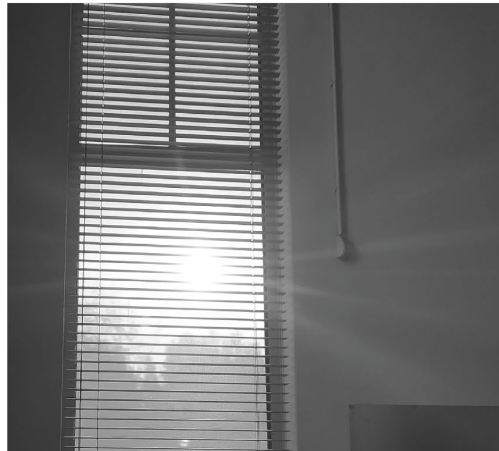


Glare

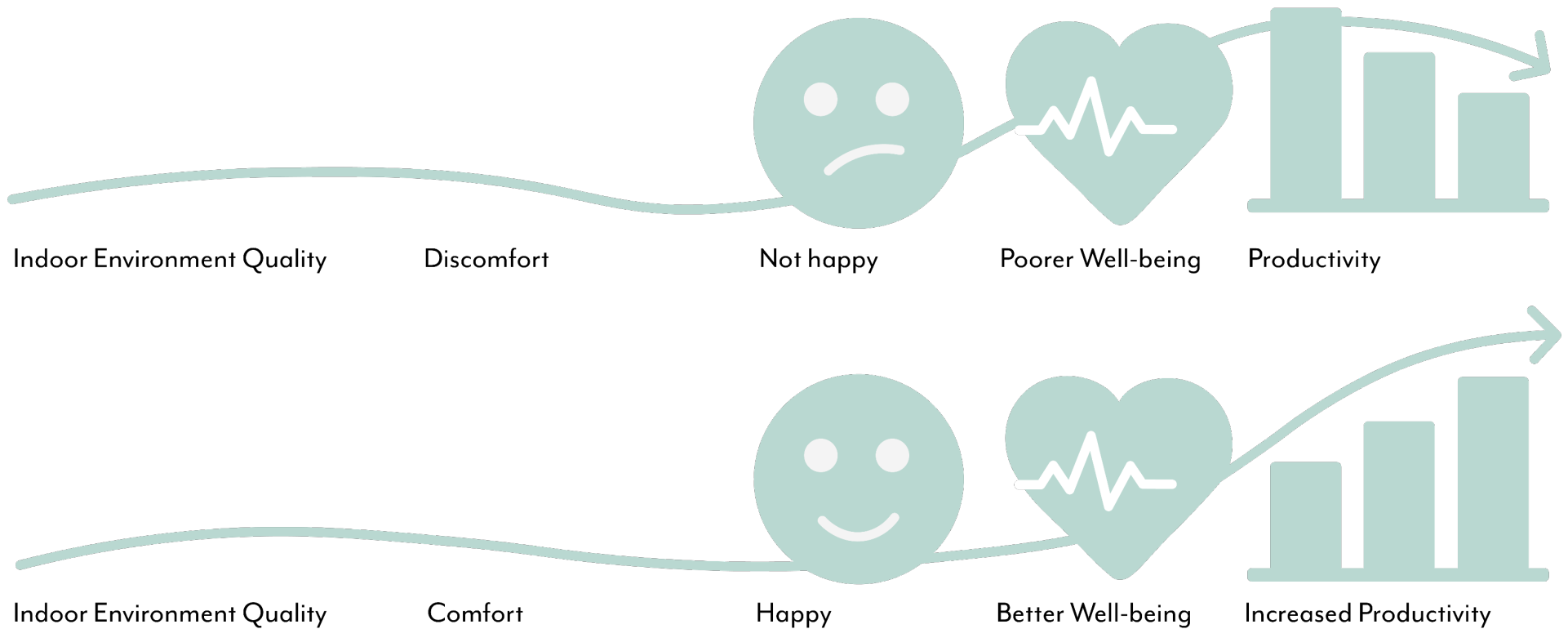


Disability glare
Discomfort glare

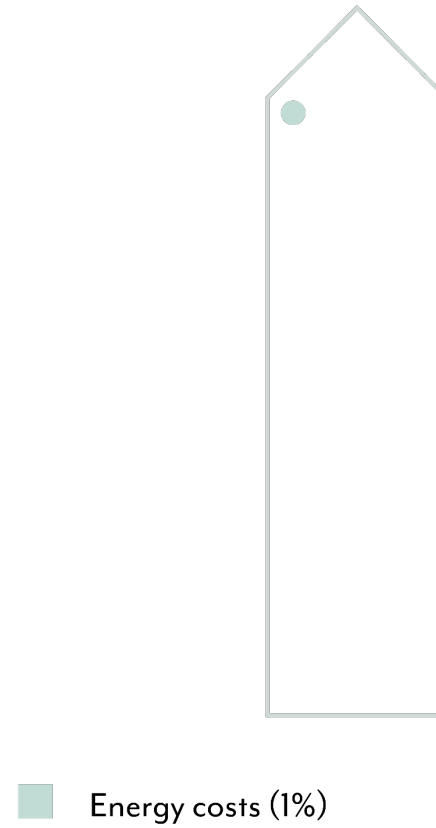
Glare



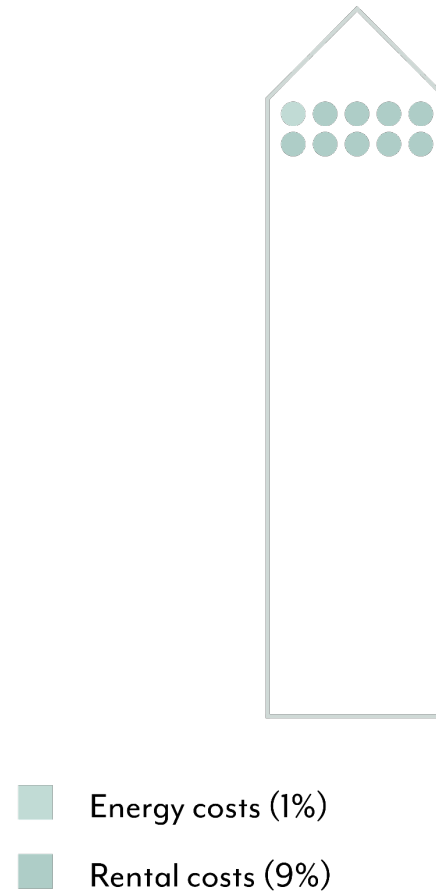
Occupants' comfort



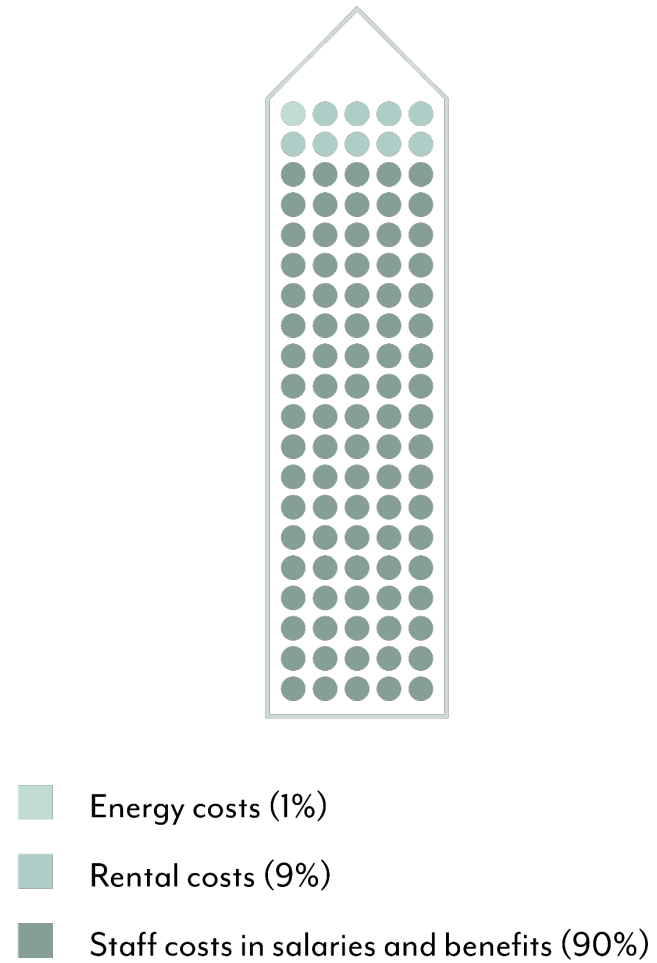
Economic impact



Economic impact



Economic impact



Posed problem



“The existing building technologies of automated systems controlling the amount of daylight through glass often fail to correlate with the occupant’s (visual) comfort.”

Project aim

Effectively controlling switchable glazing:

Improving visual comfort for the occupant

By minimising glare, and optimising the use of daylight and availability of view

Research Question

Main question:

“How can an automated system, consisting of switchable glazing and a system that can sense the needs of the occupant, be used to control glare in an effective manner?”

Key performance indicators of “effective”

non-disruptive

optimize the use of daylight

enhance the energy performance of the building

increase the visual comfort

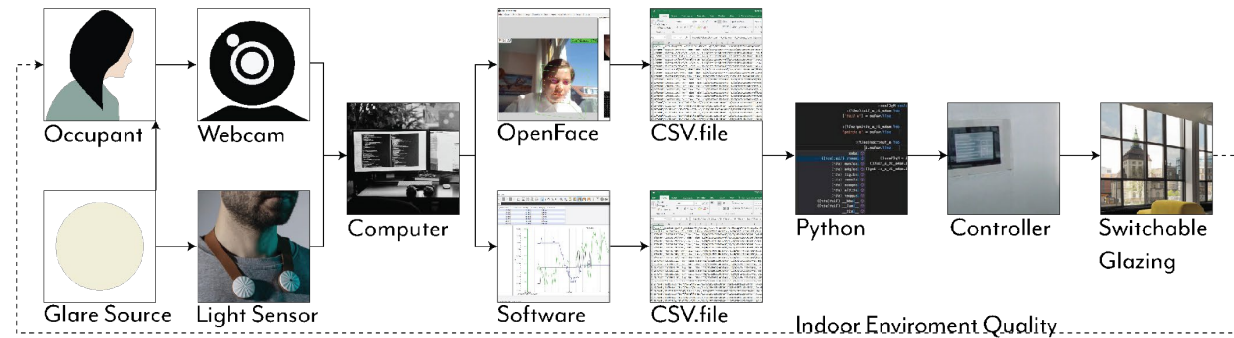
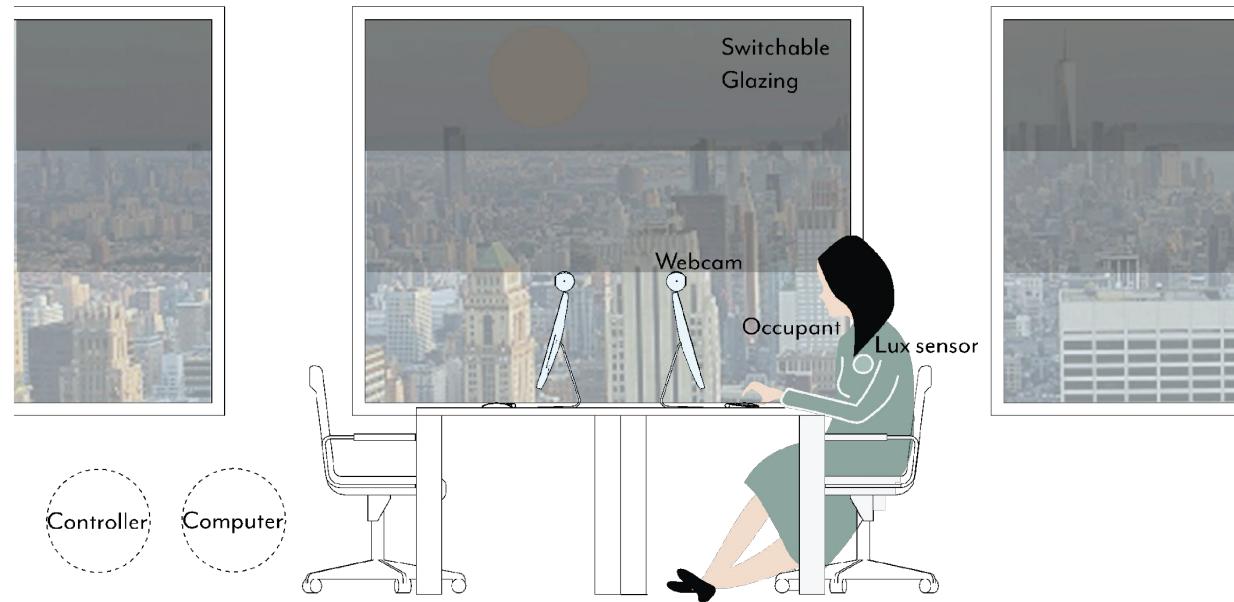
increase availability of view

benefit health and well-being of the occupant

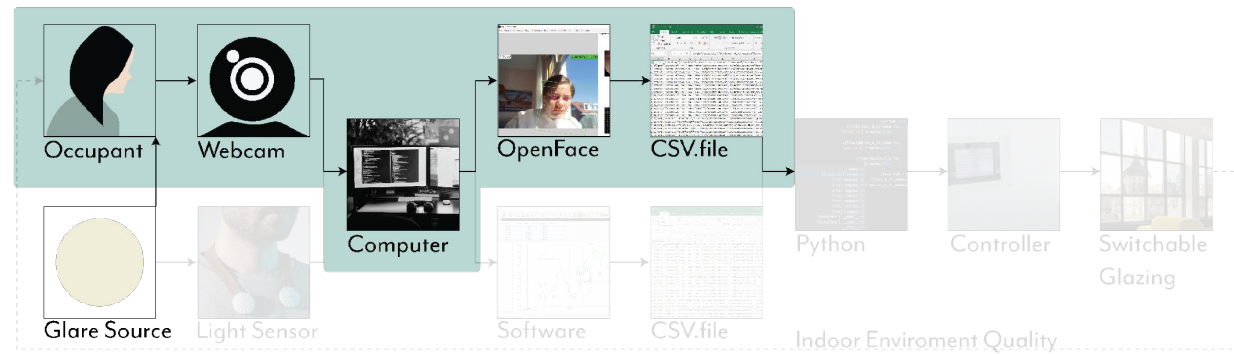
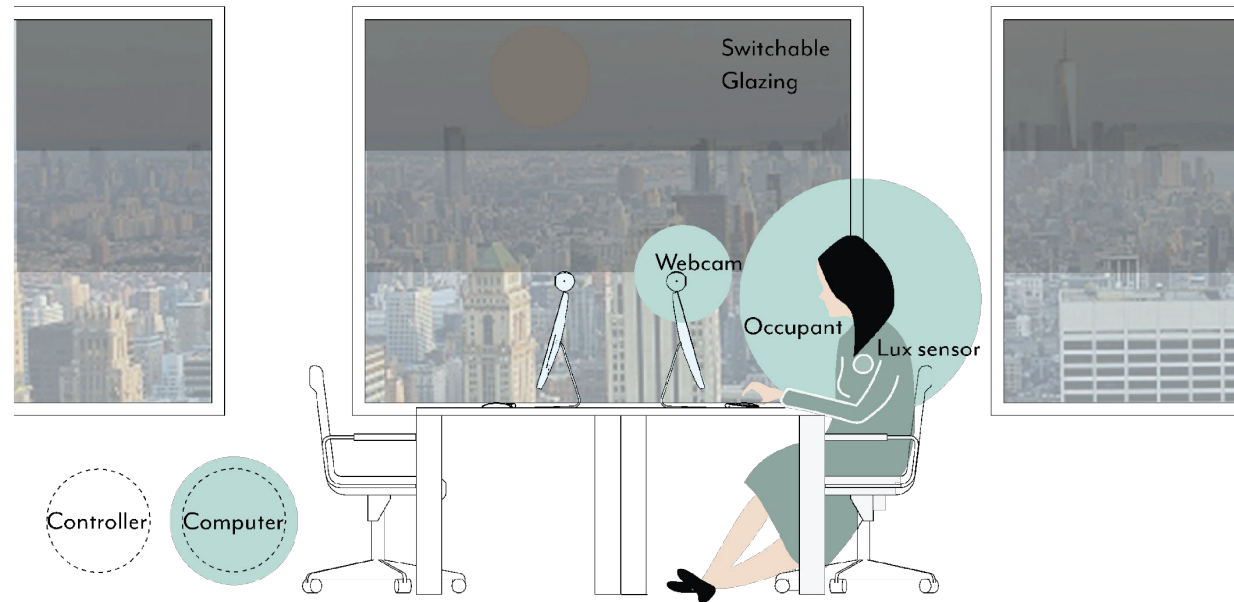
increase the productivity

reduce visual discomfort, glare

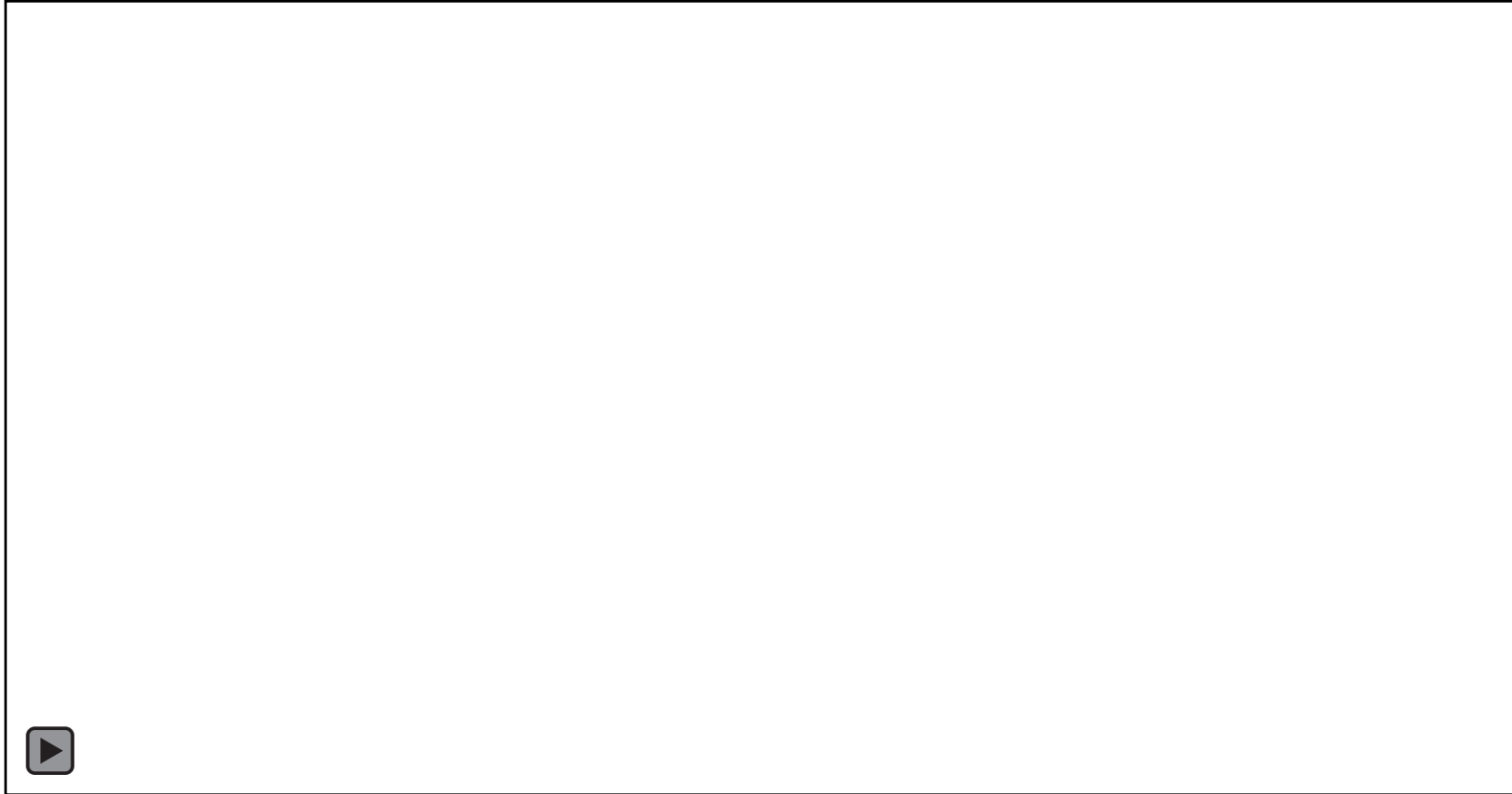
Control system



The Face



OpenFace



Facial Action Coding System



AU01
Inner Brow Raiser



AU02
Outer Brow Raiser



AU04
Brow Lowerer



AU05
Upper Lid Raiser



AU06
Cheek Raiser



AU07
Lid Tightener



AU09
Nose Wrinkler



AU10
Upper Lip Raiser



AU12
Lip Corner Puller



AU12
Dimpler



AU15
Lip Corner Depressor



AU17
Chin Raiser



AU20
Lip stretcher



AU23
Lip Tightener



AU23
Lips part



AU26
Jaw drop



AU28
Lip Suck



AU45
Blink

Facial Action Coding System



AU01
Inner Brow Raiser



AU02
Outer Brow Raiser



AU04
Brow Lowerer



AU05
Upper Lid Raiser



AU06
Cheek Raiser



AU07
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AU26
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AU28
Lip Suck



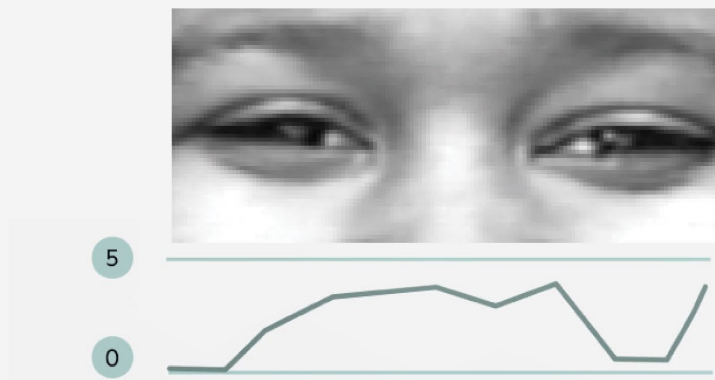
AU45
Blink

Action Units

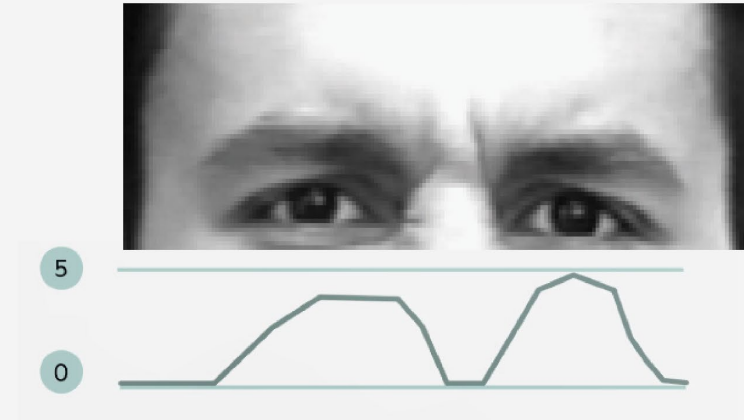
AU02
Outer Brow Raiser



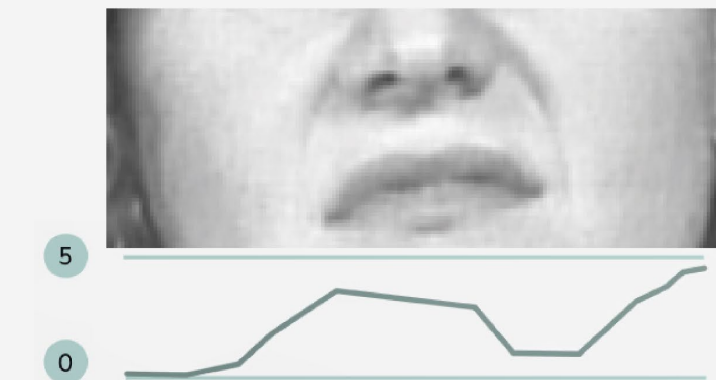
AU06
Cheek Raiser



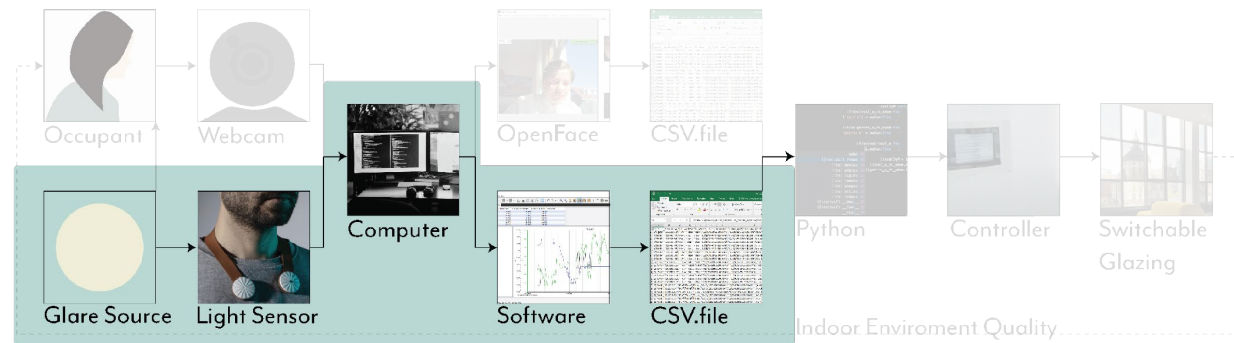
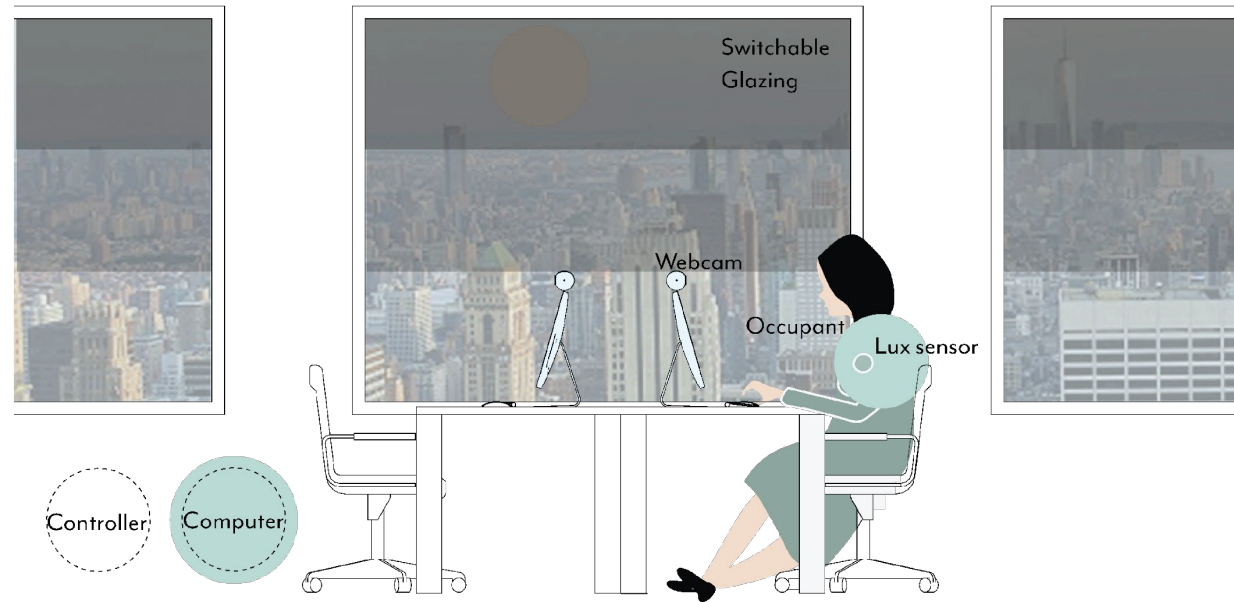
AU04
Brow Lowerer



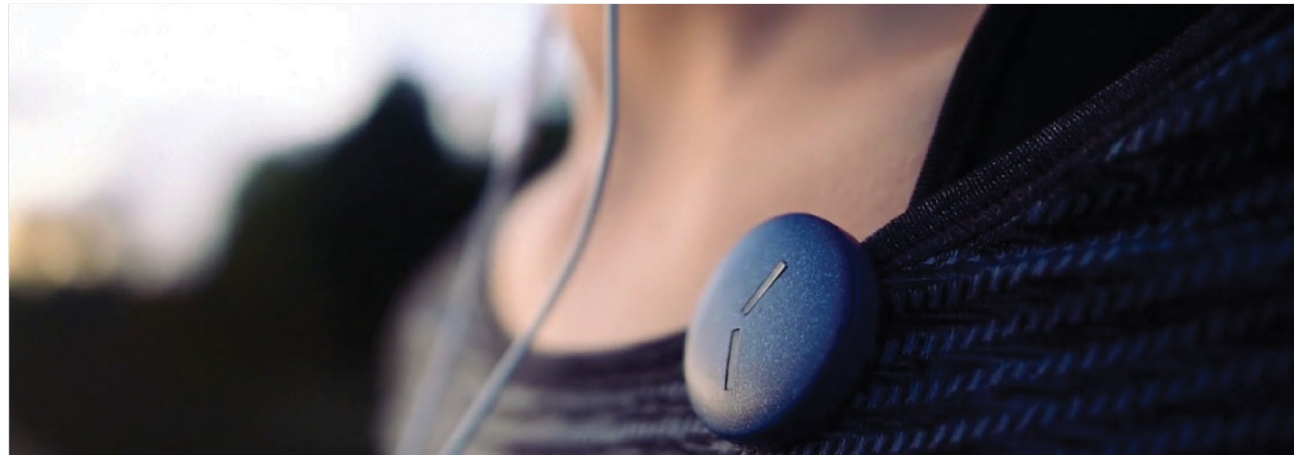
AU10
Upper Lip Raiser



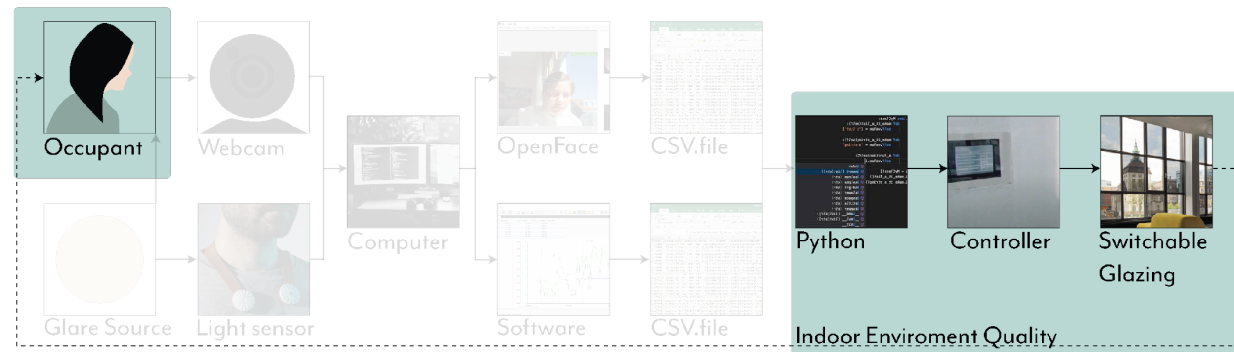
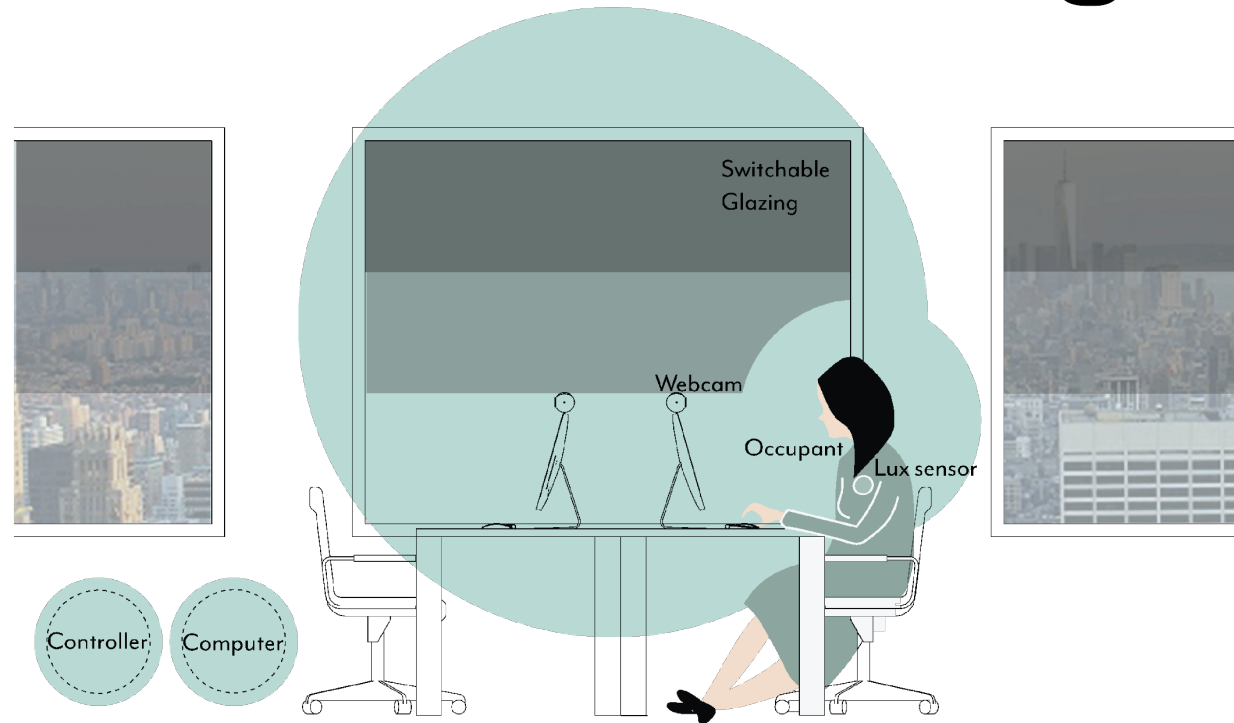
Light



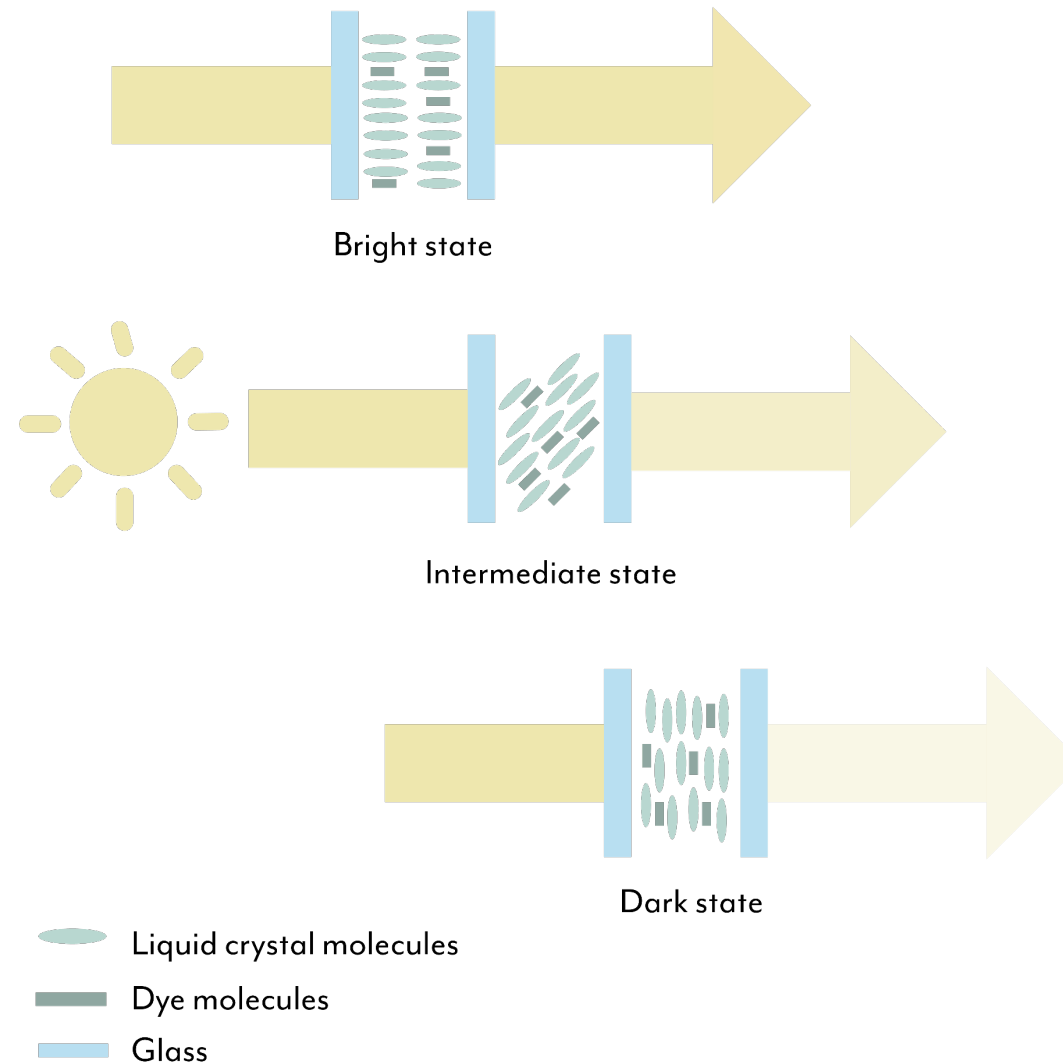
Wearable Light Sensors



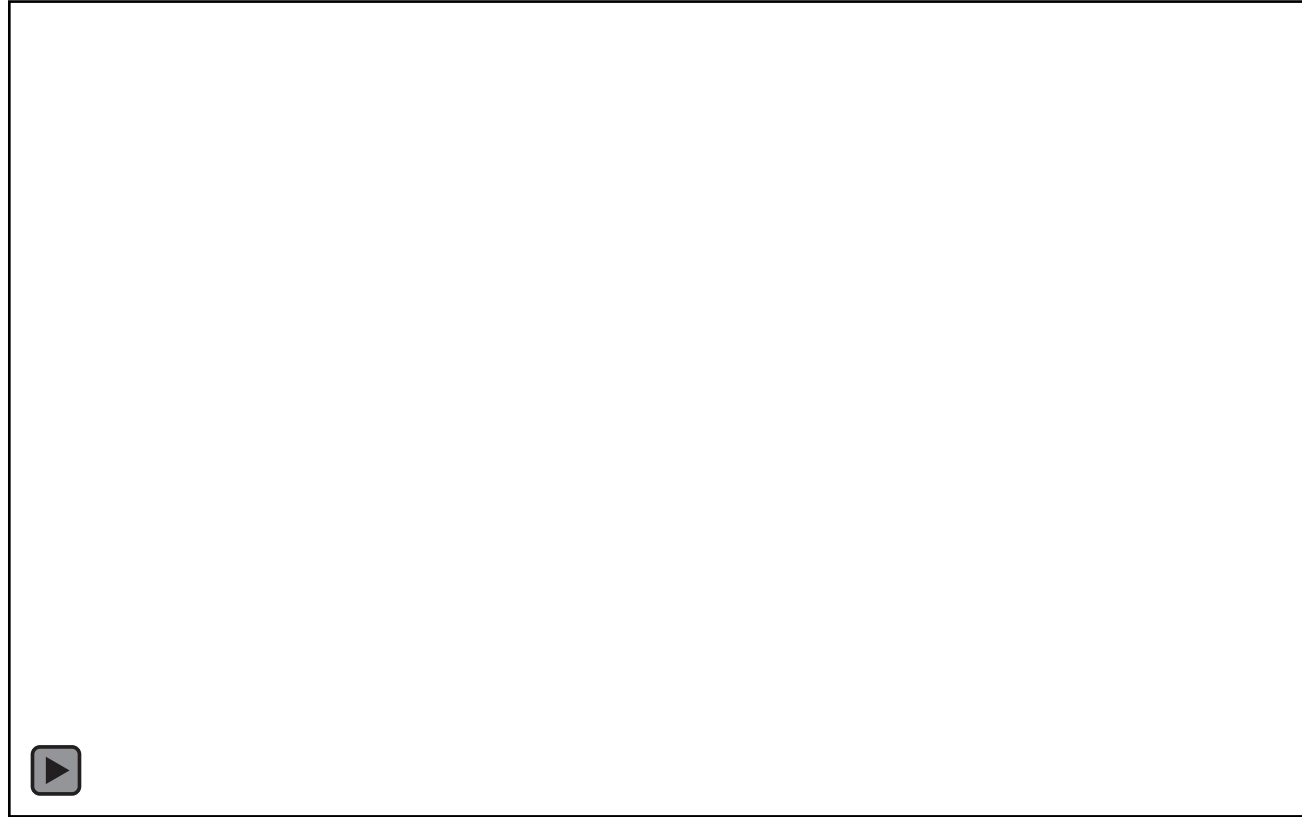
Switchable Glazing



Switchable Glazing: Merck Eyrise



Switchable Glazing: Merck Eyrise



The Novel System



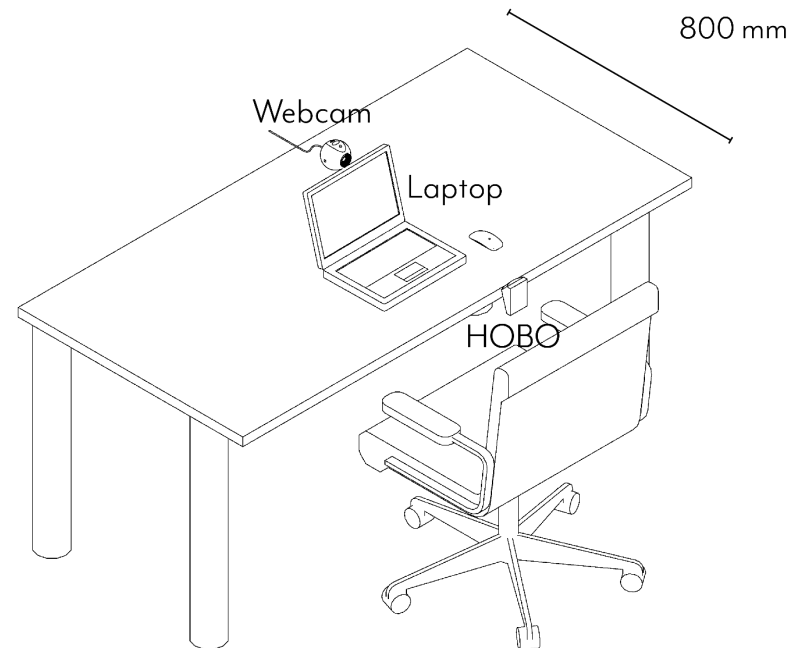
The Novel System



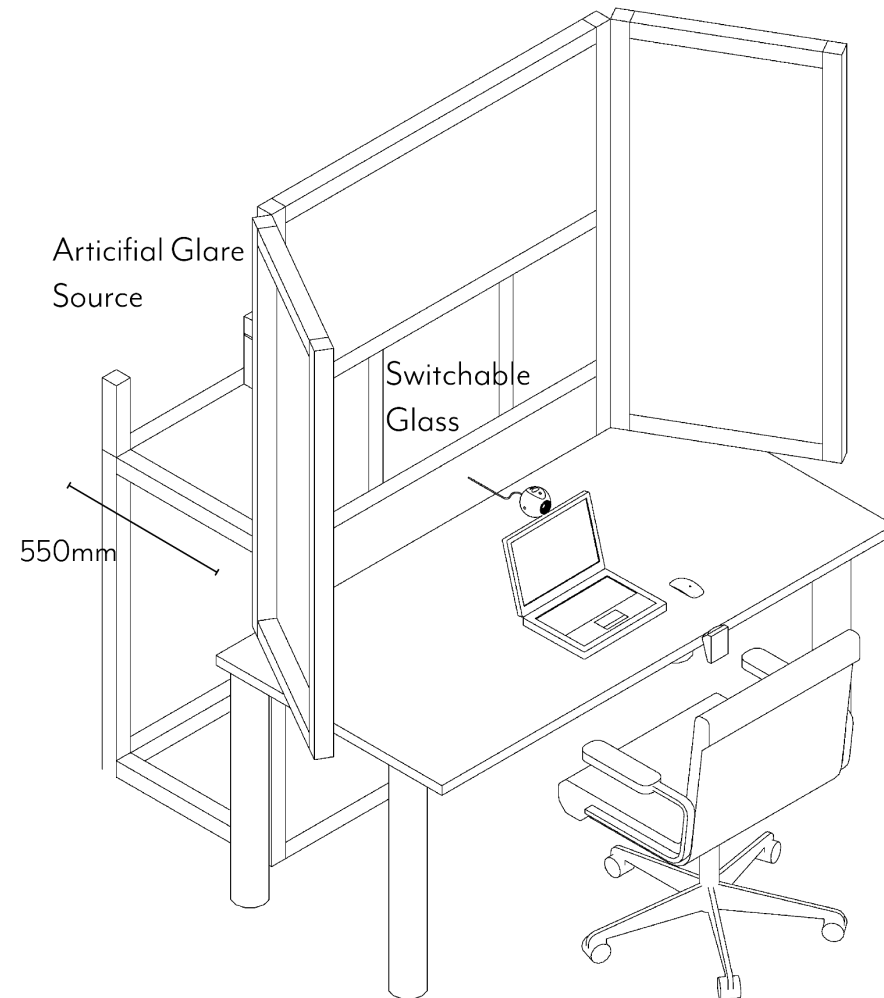
The Novel System



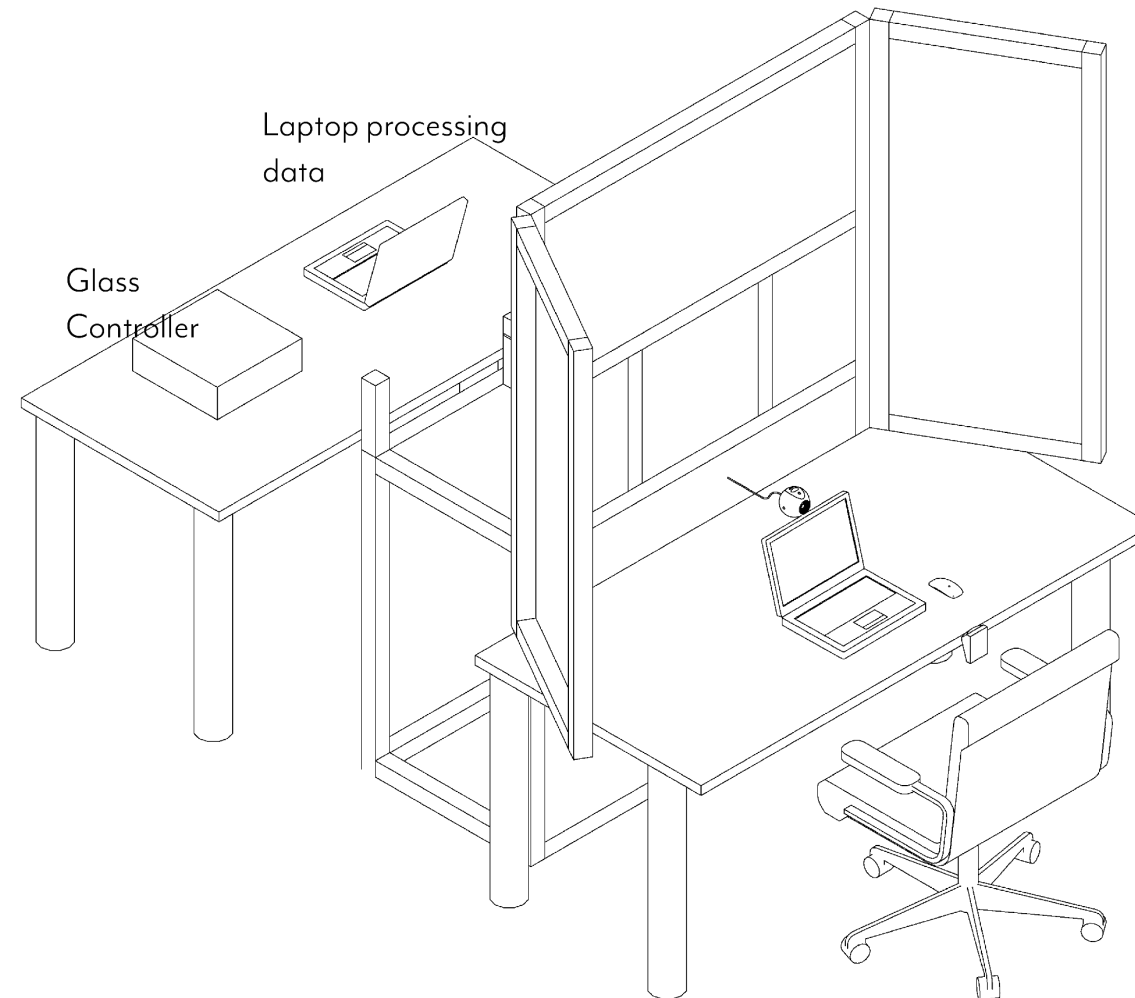
Experimental set up



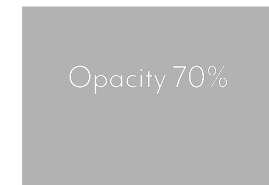
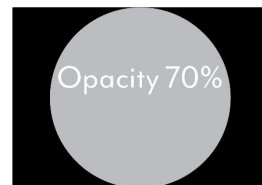
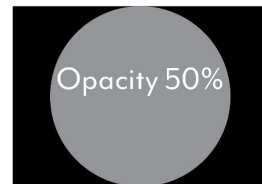
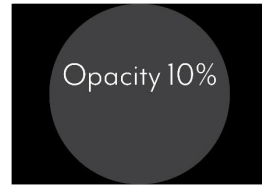
Experimental set up



Experimental set up



Artificial Glare source: Projection



Experiment I: Objectives

Objectives:

Developing the physical characteristics for Experiment II

Indicating what setting the participants may find comfortable and what not

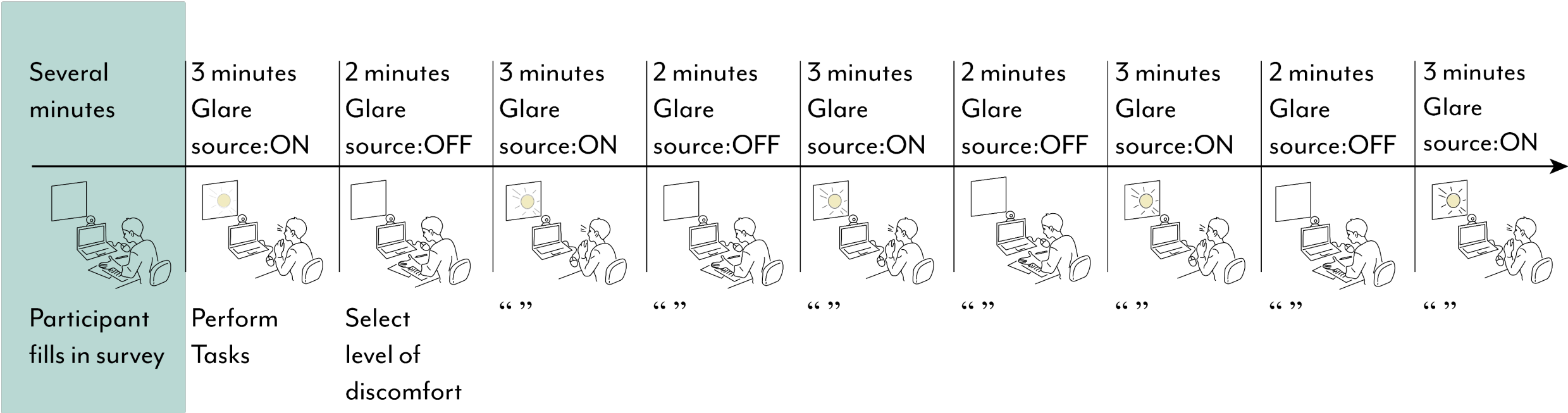
Evaluating if the source can create glare

Indicating and verifying threshold values

Experiment I: Participants

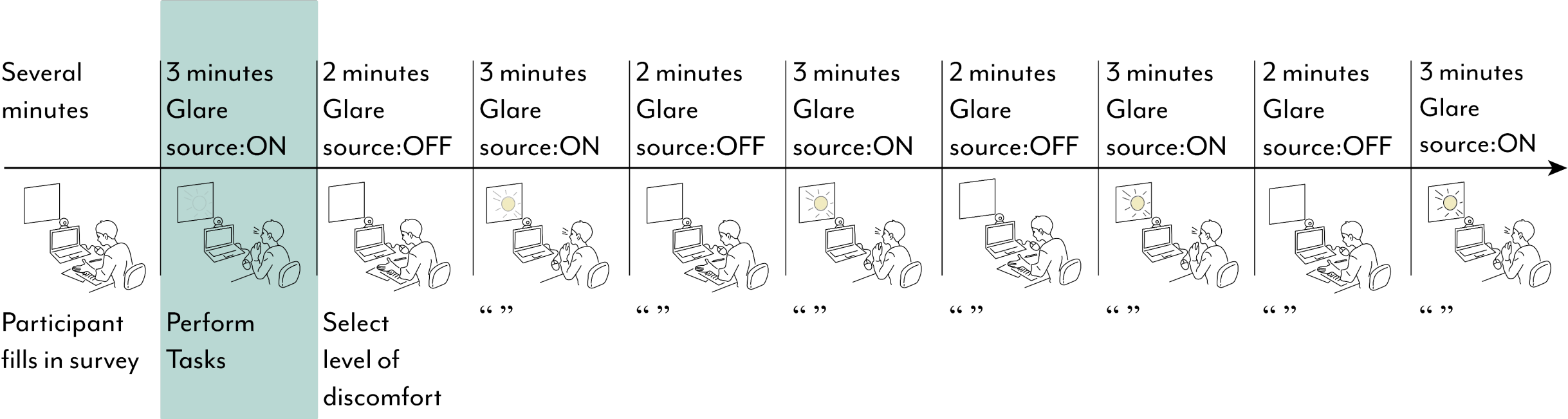
A number of **14 participants**, of which 11 females and 3 males took part in this study

Experiment I: Procedure



Initial survey

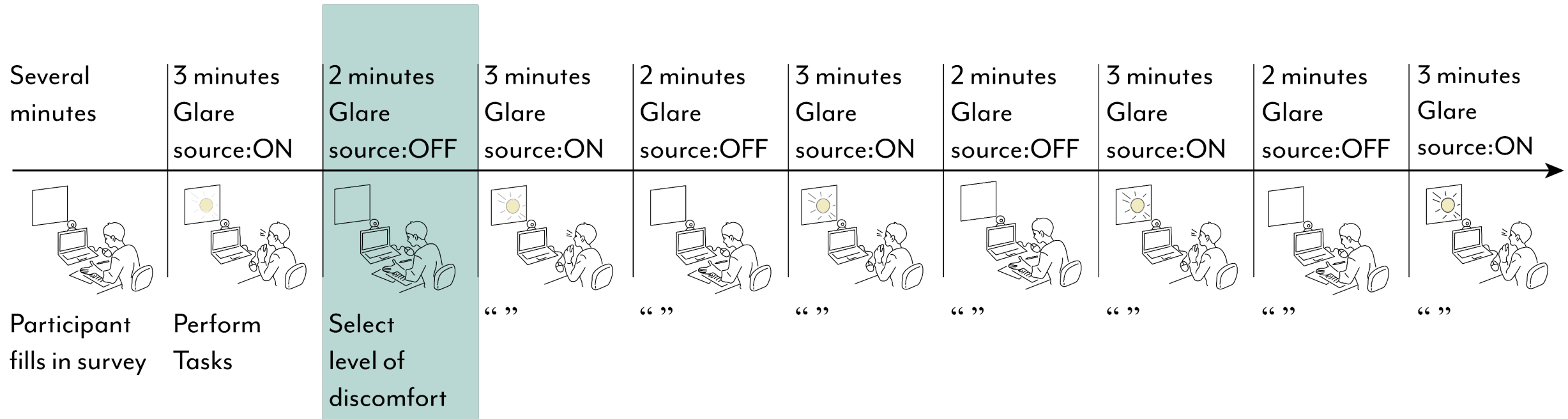
Experiment I: Procedure



Perform tasks

Exposed to glare source

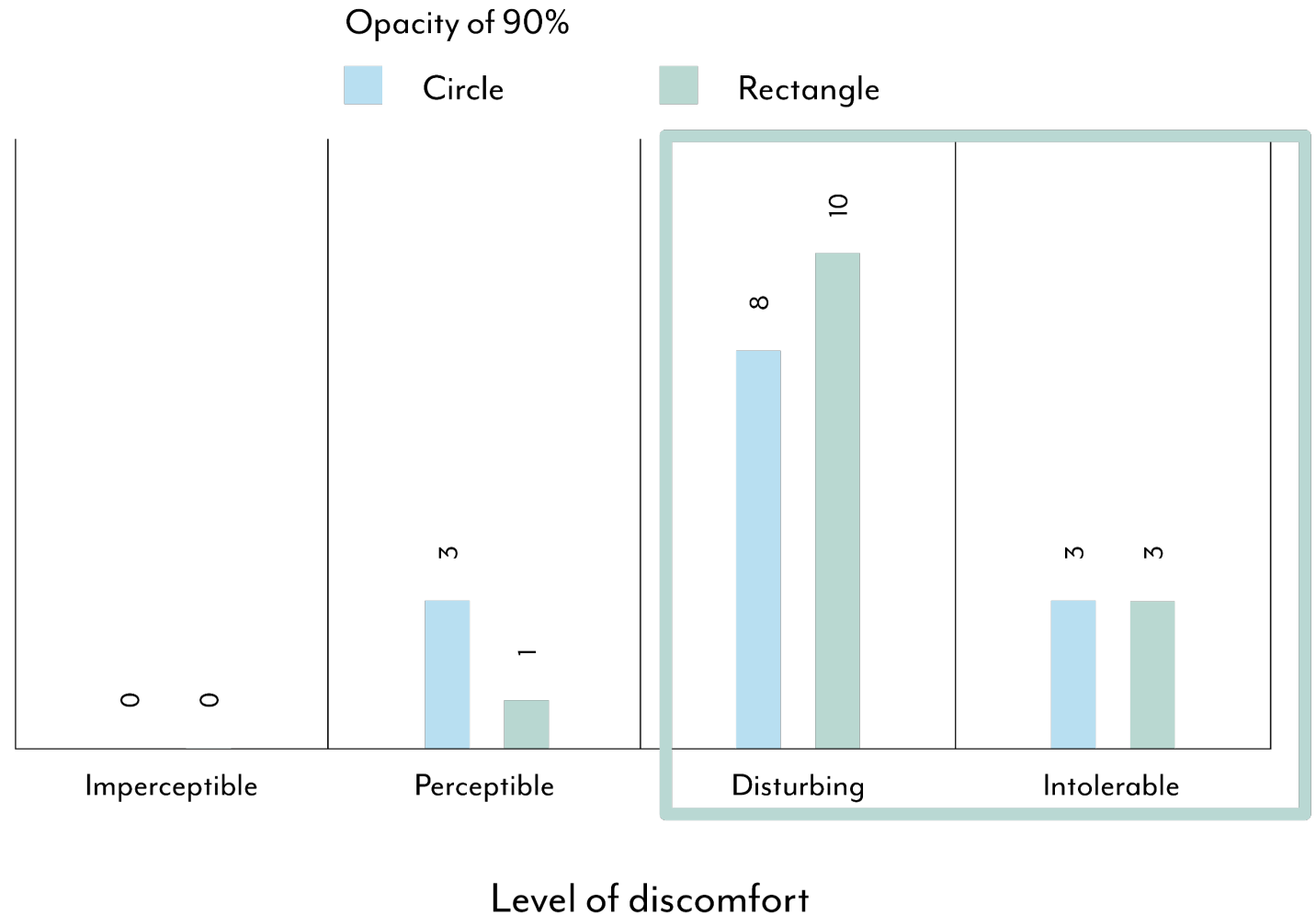
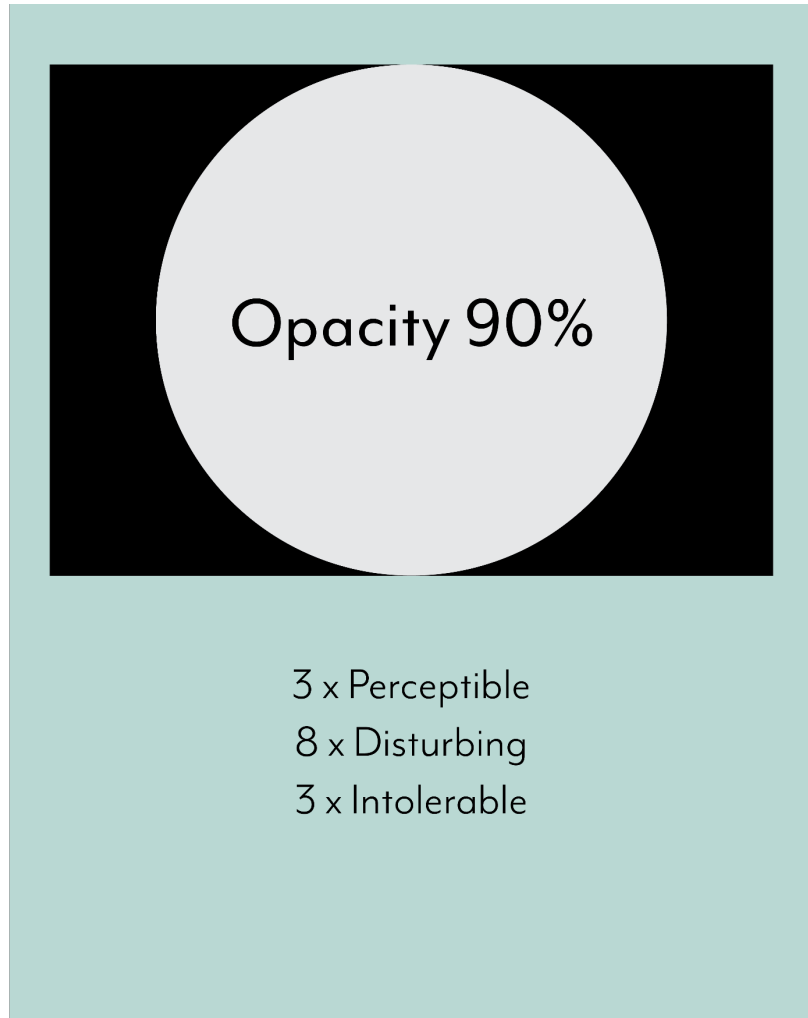
Experiment I: Procedure



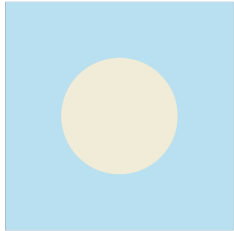
Interval: glare source off for 2 minutes
Choose level of discomfort

Imperceptible, Perceptible, Disturbing, Intolerable

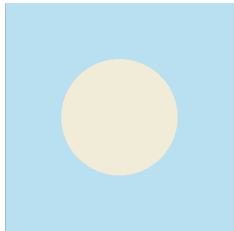
Experiment I: Results



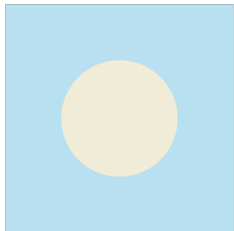
Threshold Values



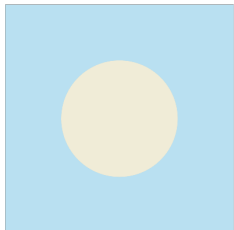
> 200 Lux + Action Unit ---> Glass state intermediate



> 250 Lux + Action Unit ---> Glass state dark



> 270 Lux ---> Glass state intermediate



> 300 Lux > ---> Glass state dark



Experiment I: Discussion

Different tasks at different moments

The order

The anchor point

Experiment I: Conclusion

White circle projected by the artificial glare with an opacity of 90% can be sufficient to provide a level of discomfort glare

Threshold values are set

Method to link the time of the data

Eye level of participants should be the same height

Same visual tasks

Experiment II : Objectives

Compare the Novel system with the Benchmark system

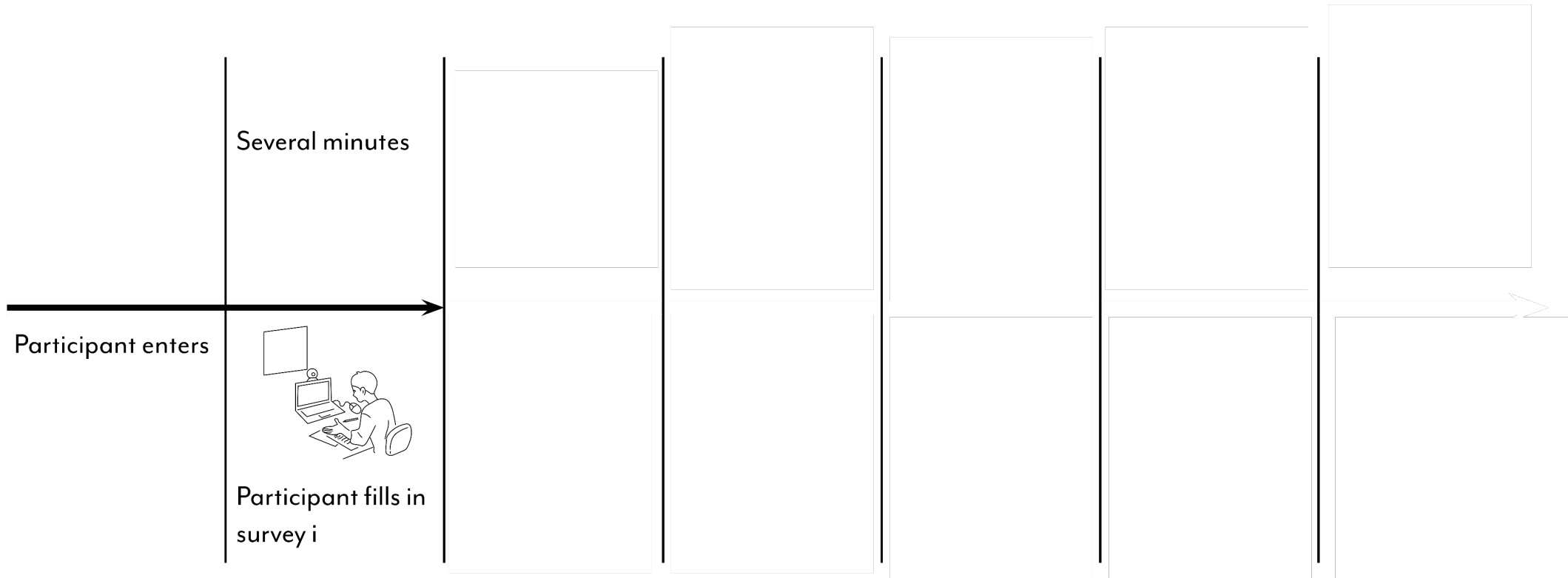
Test the effectiveness of the Novel system

Identify extra Action Units that show a response to light

Experiment II: Participants

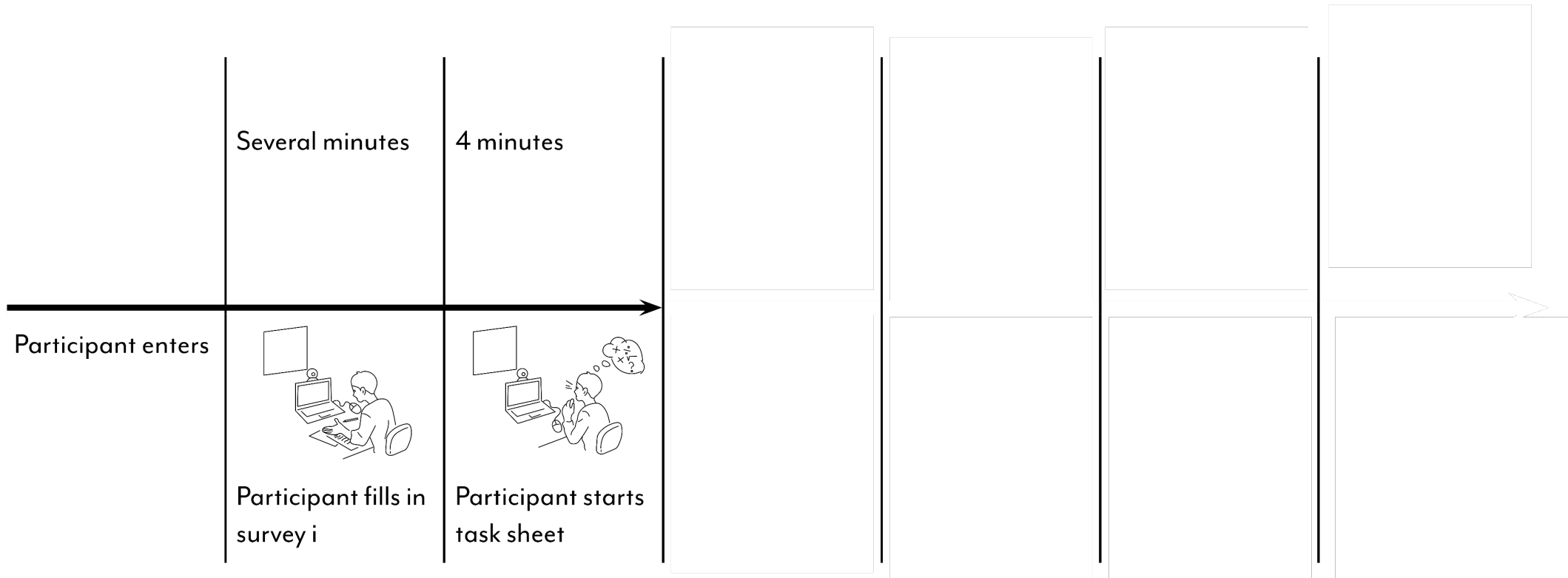
A number of **16 participants**, of which 11 females - and 5 males took part in this study.

Experiment II: Procedure



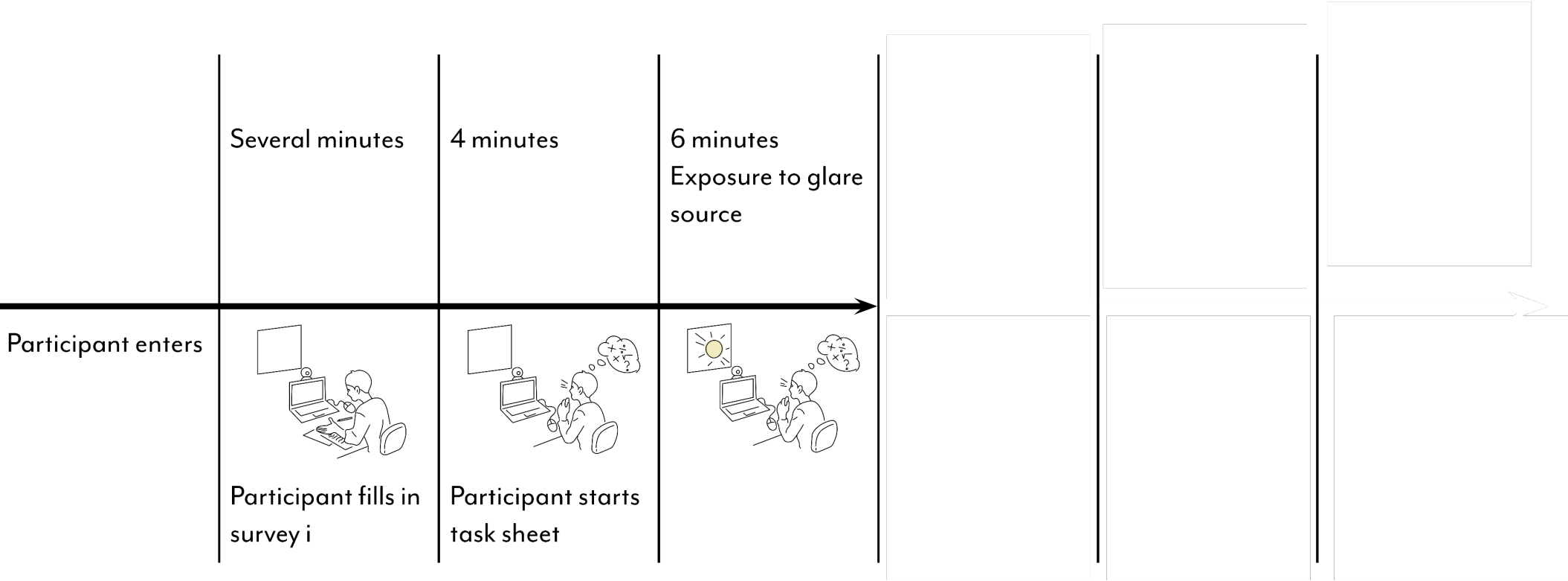
Experimental procedure, one half (26 minutes)

Experiment II: Procedure



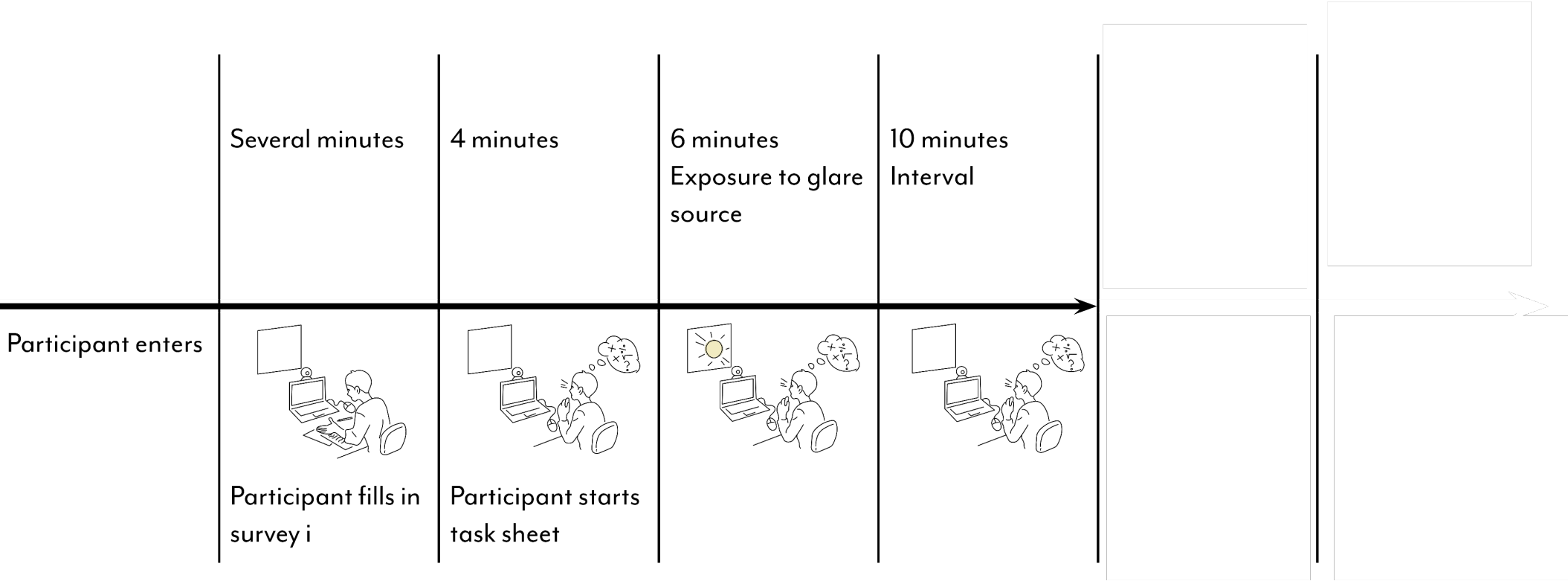
Experimental procedure, one half (26 minutes)

Experiment II: Procedure



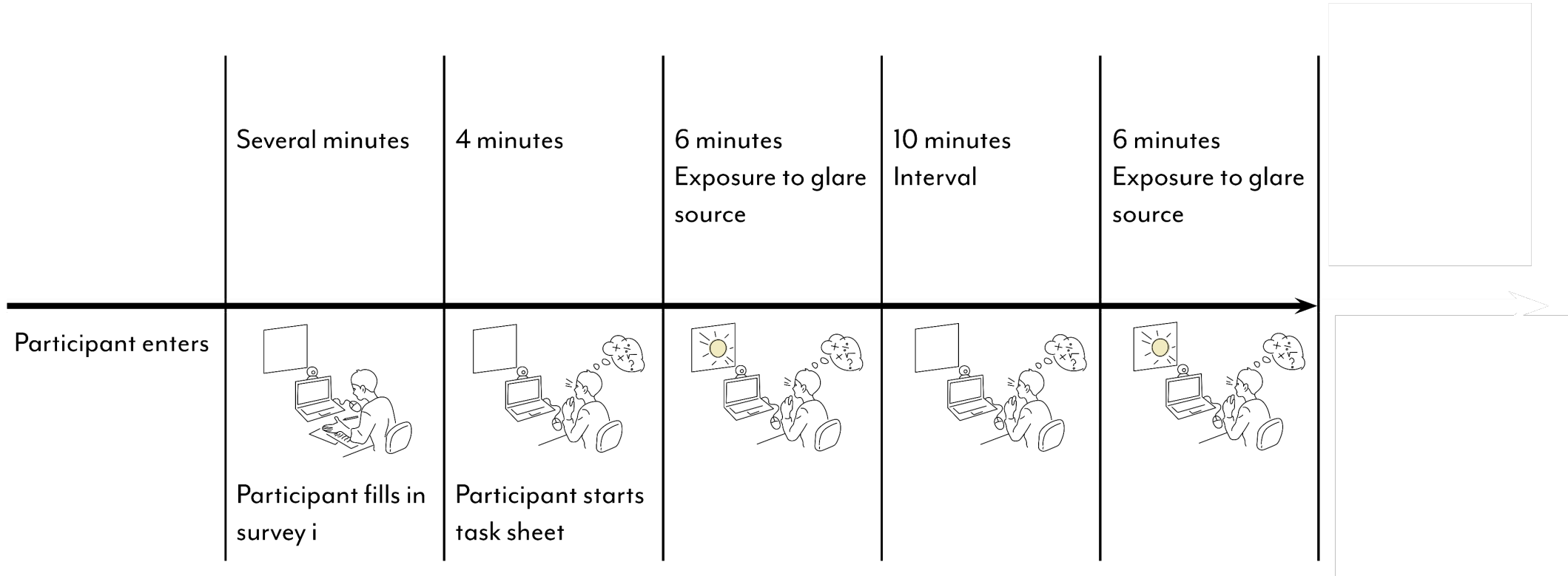
Experimental procedure, one half (26 minutes)

Experiment II: Procedure



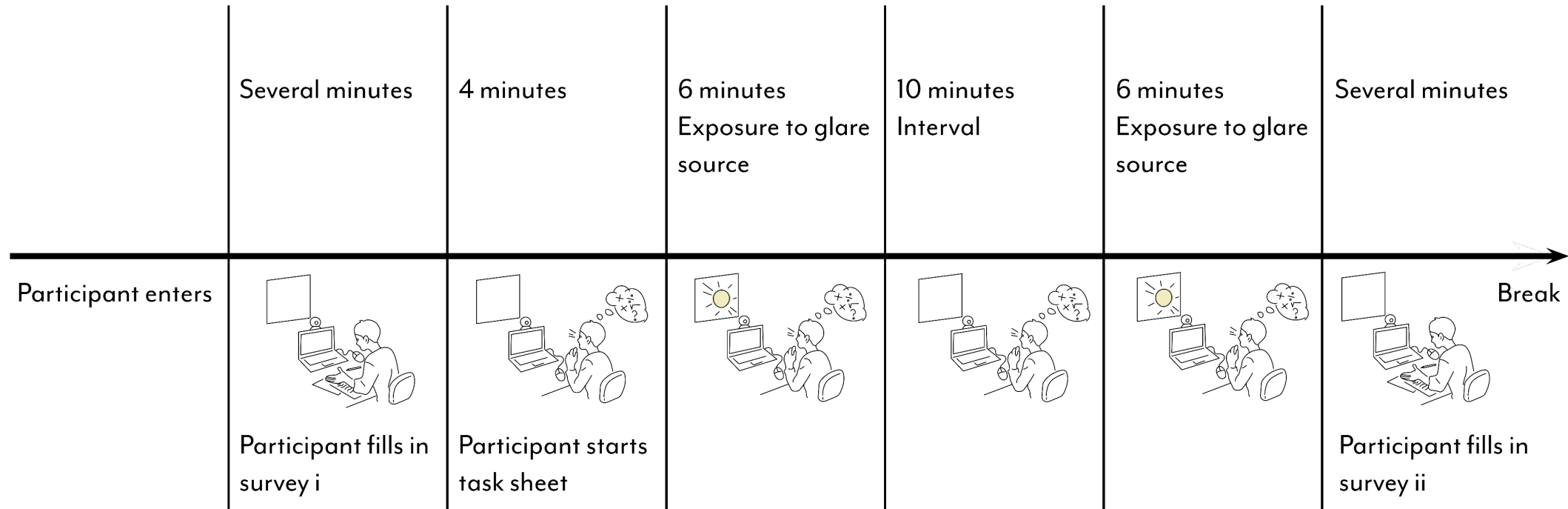
Experimental procedure, one half (26 minutes)

Experiment II: Procedure



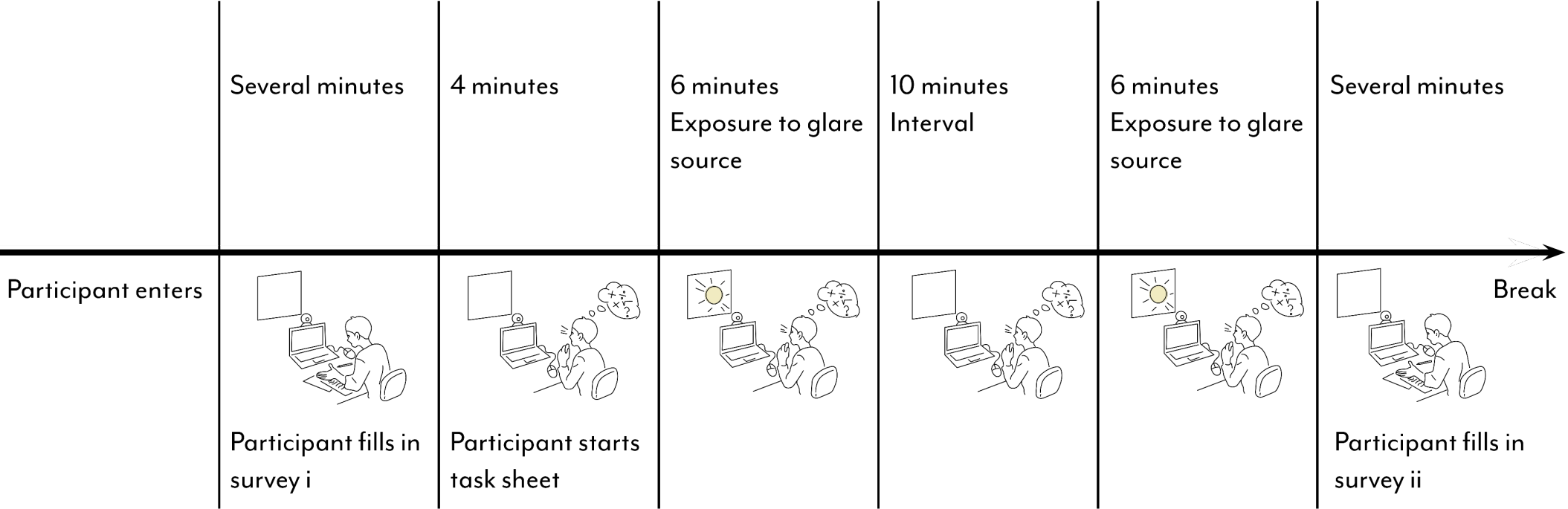
Experimental procedure, one half (26 minutes)

Experiment II: Procedure



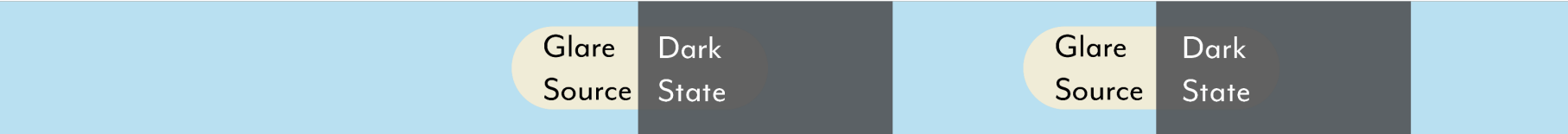
Experimental procedure, one half (26 minutes)

Experiment II: Procedure



Experimental procedure, one half (26 minutes)

Glass state
Benchmark



Experiment II: Results

Data retrieved from:

Tasks

OpenFace

Lux Sensor

Surveys

Glass state: view and daylight

Experiment II: Results

Task sheets:

124 mathematical questions

Same difficulty

Randomized order

Scores compared:

made

correctness

mistakes

More questions made and correct during Benchmark condition

Less mistakes during Novel condition

Experiment II: Results

Openface

AU02_r - Outer Brow Raiser



AU02

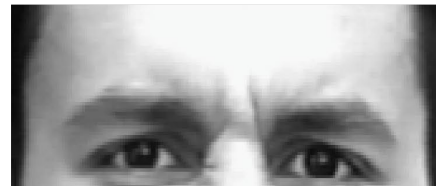
Outer Brow Raiser

Extra AU's:



AU01

Inner Brow Raiser



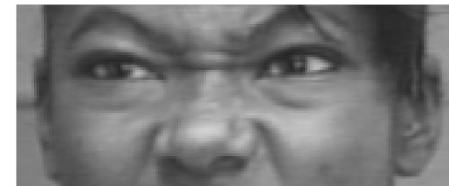
AU04

Brow Lowerer



AU07

Lid Tightener



AU09

Nose Wrinkler

Experiment II: Results

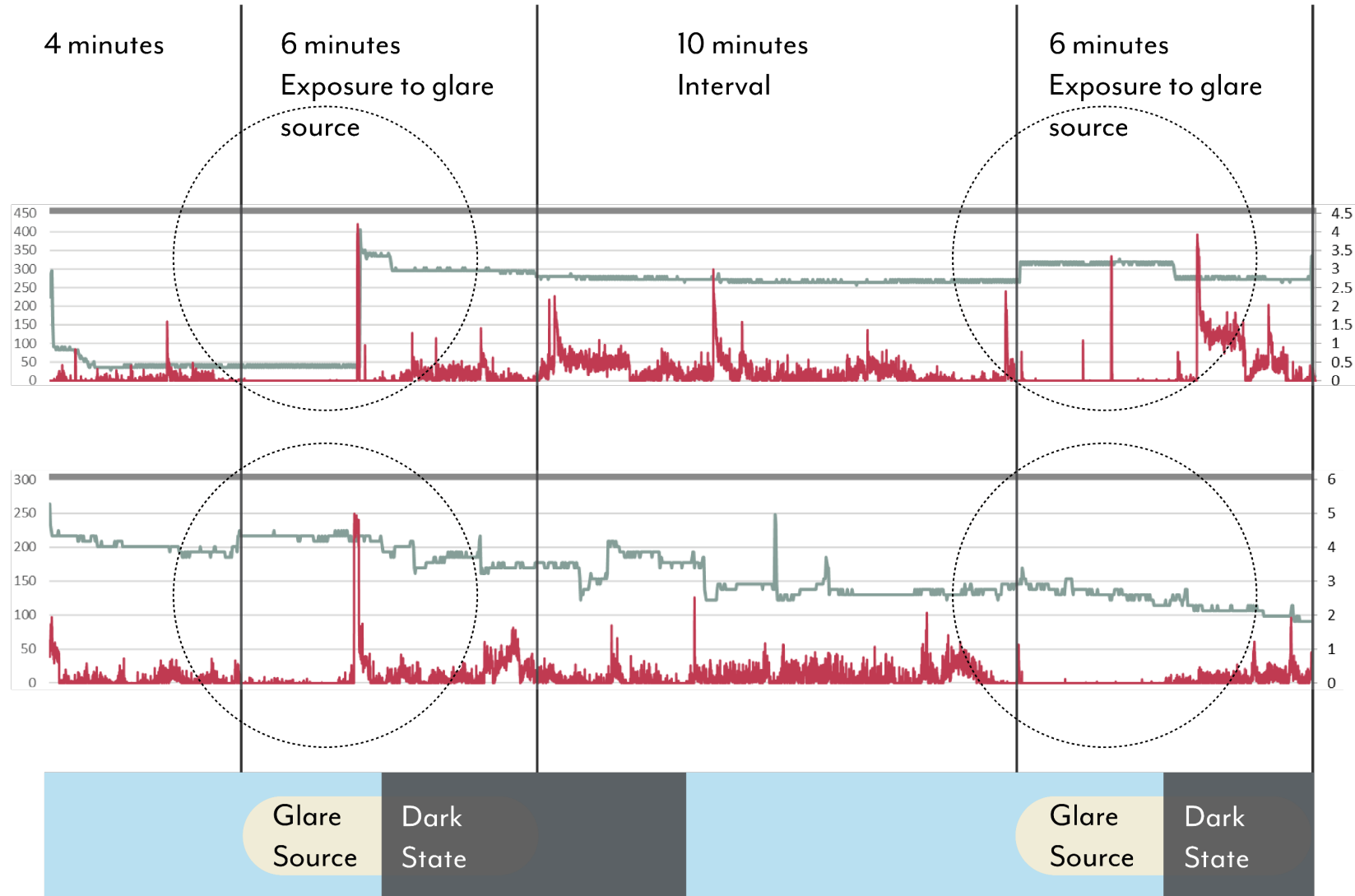


AU02

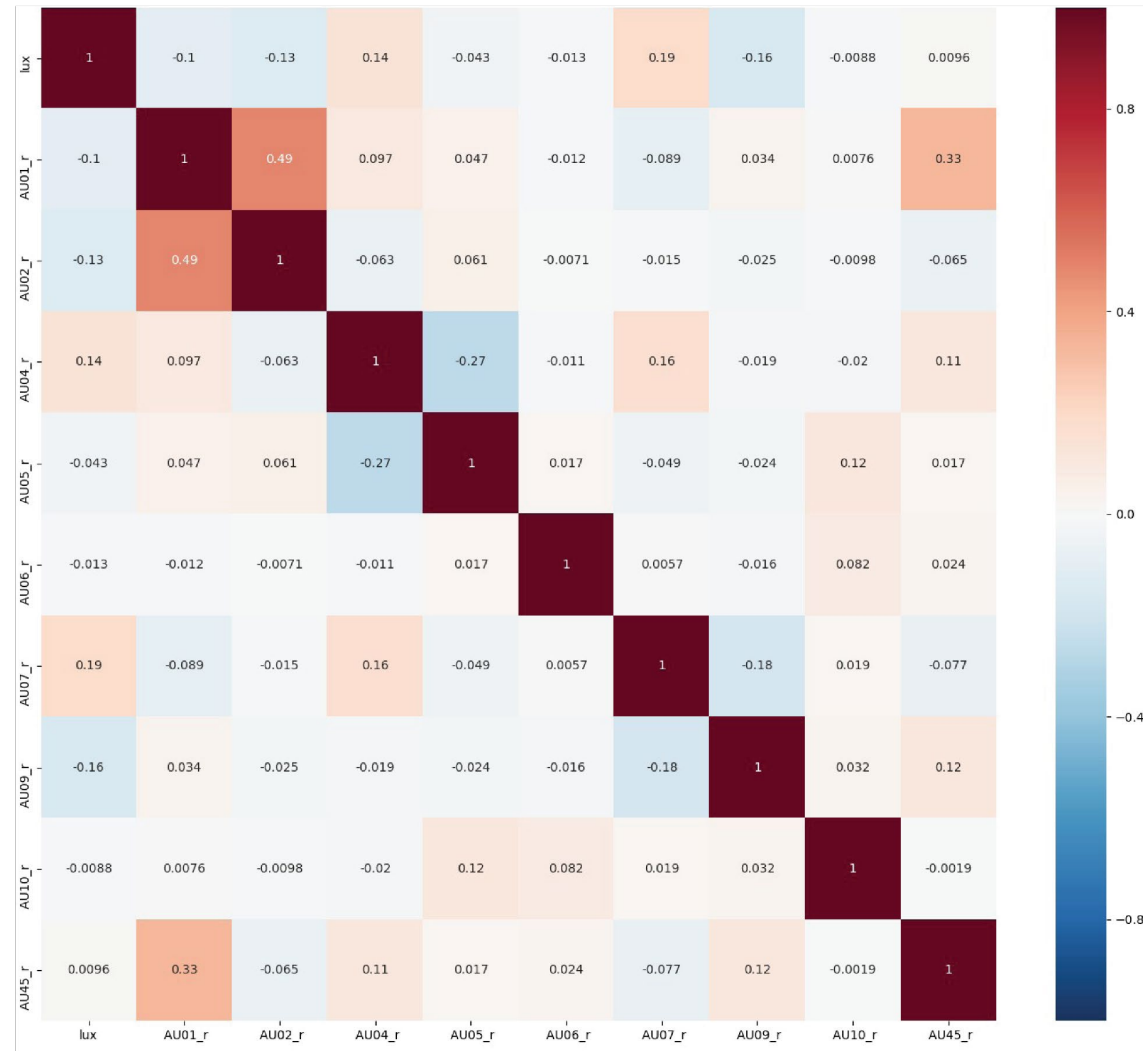
Outer Brow Raiser



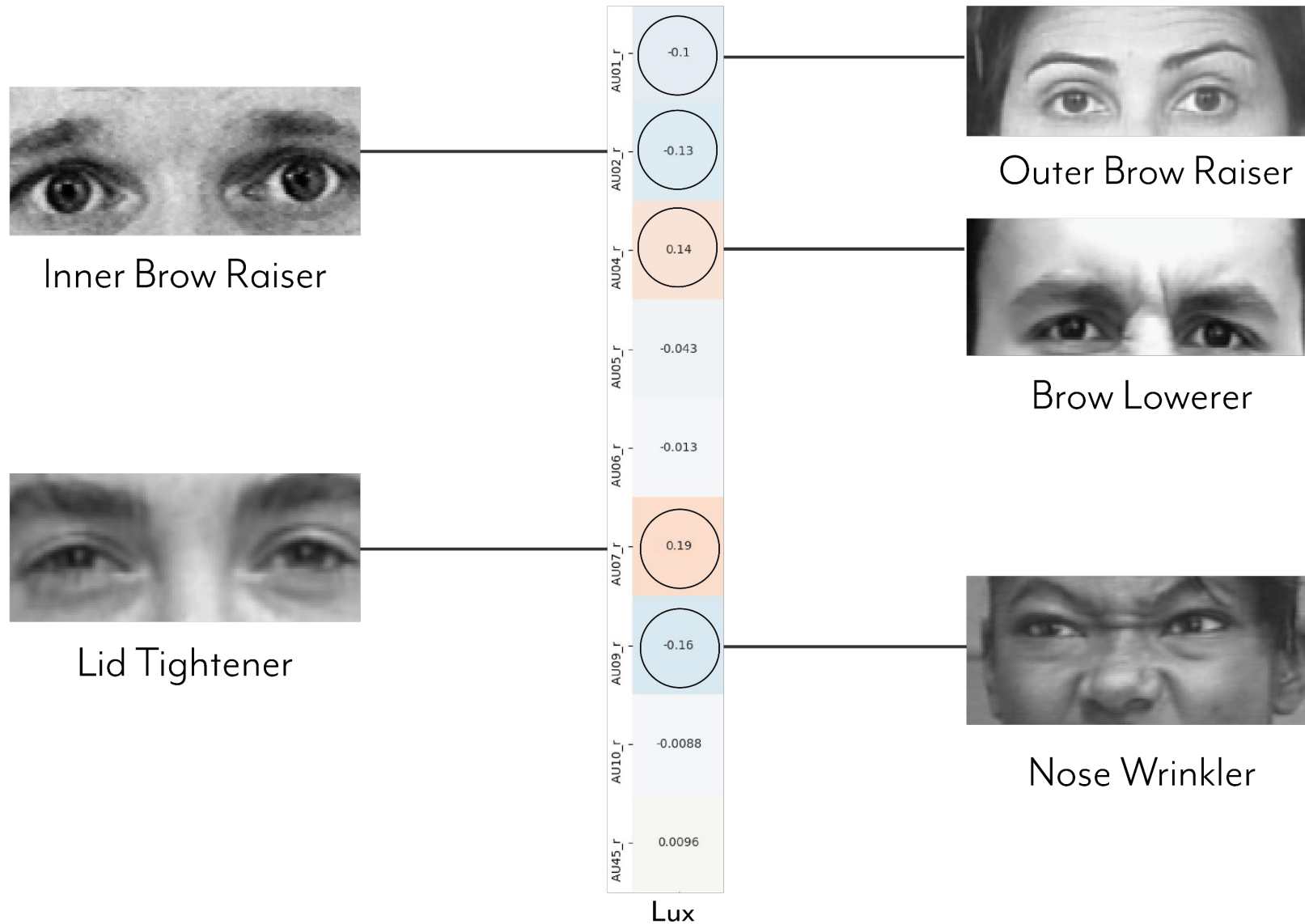
Experiment II: Results



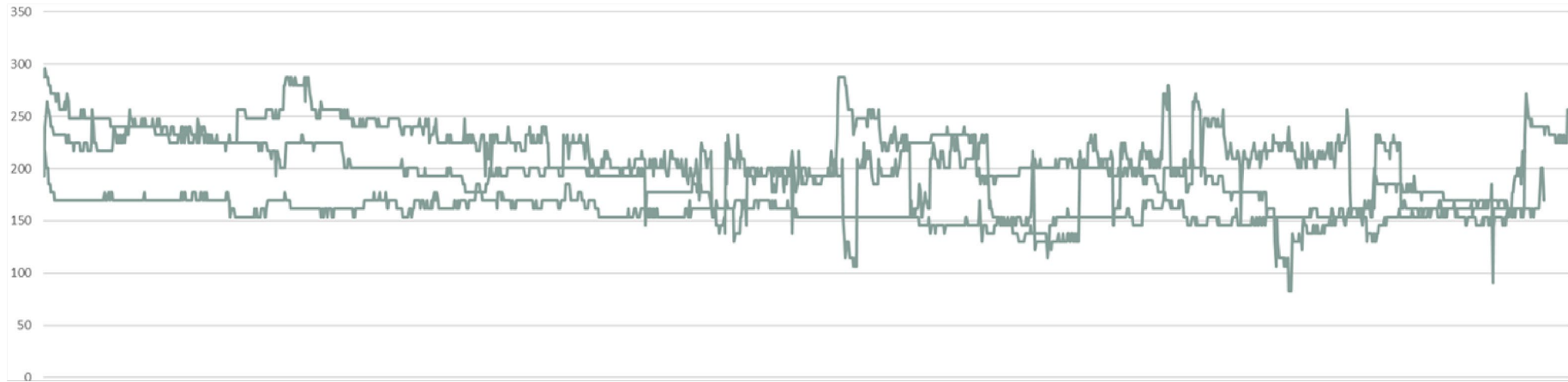
Experiment II: Results



Experiment II: Results



Experiment II: Results

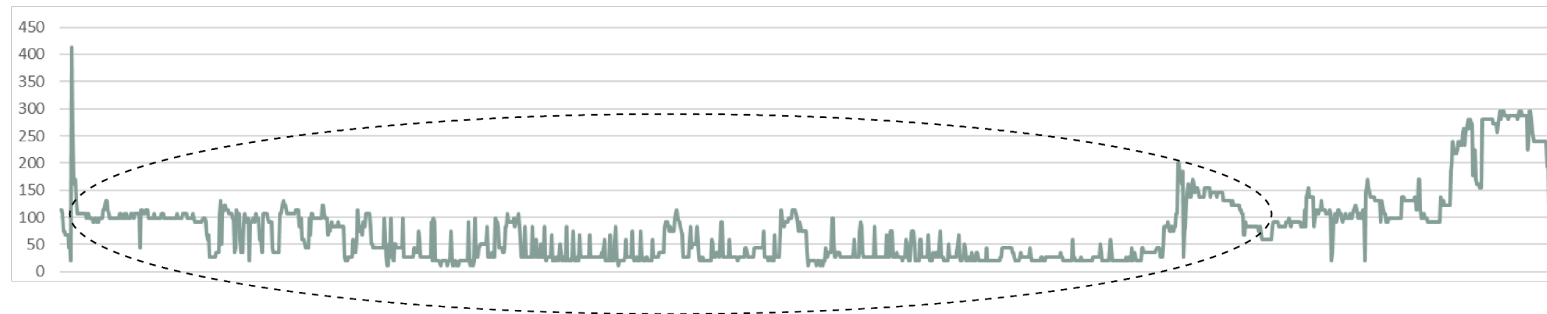
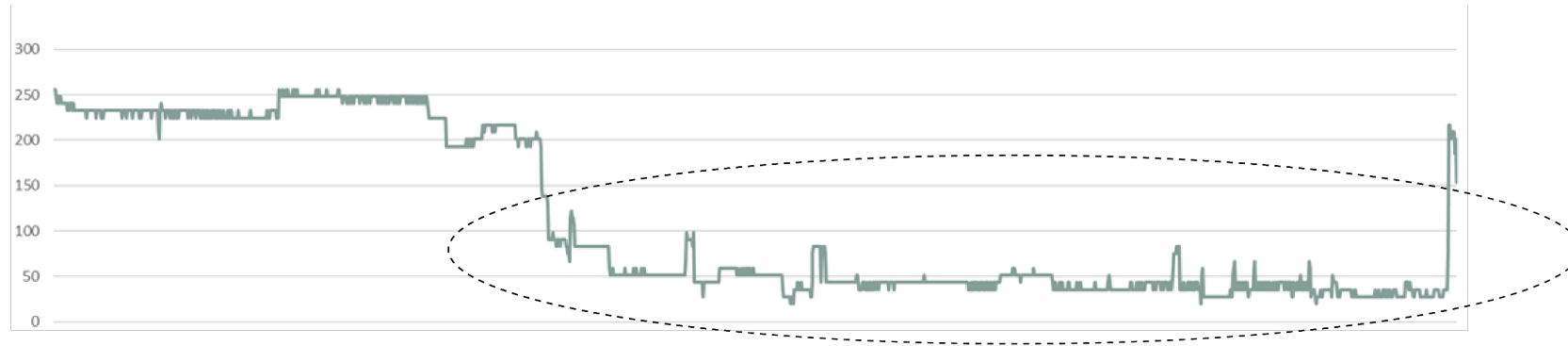


Lux readings 3 participants during Benchmark conditions

one half (26 minutes)

Fluctuating

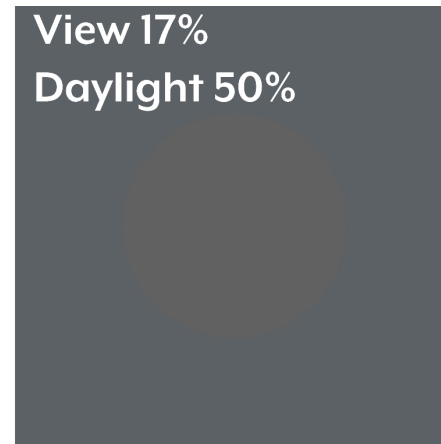
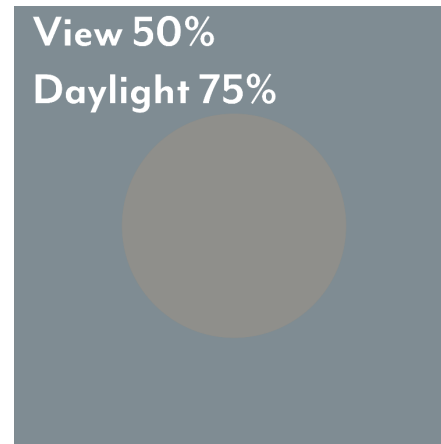
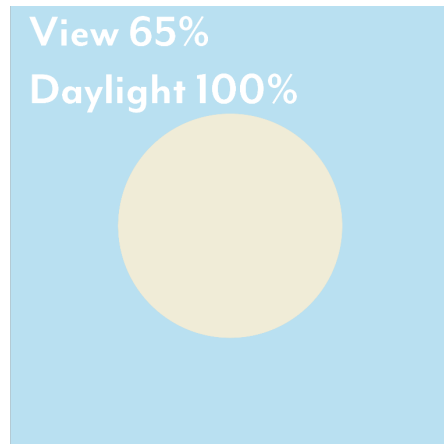
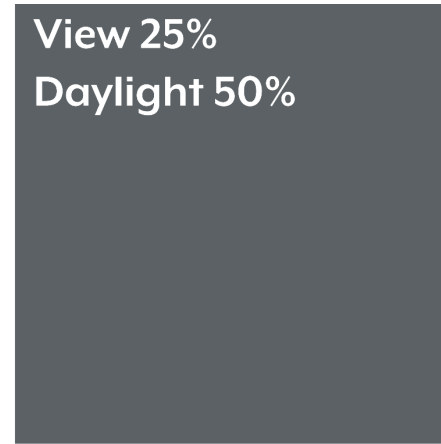
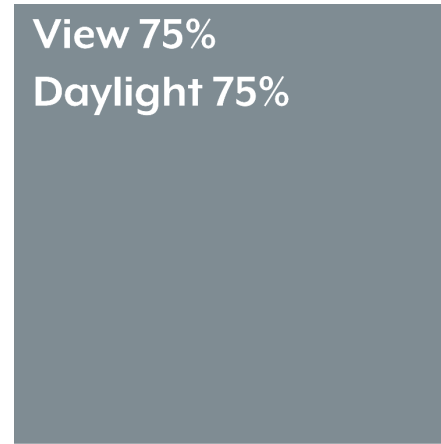
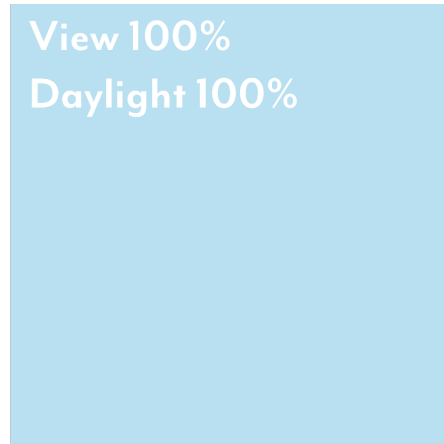
Experiment II: Results



Lux readings too low

most likely covered by **obstacle**

Experiment II: Results



Scoring system

Experiment II: Results

Glass State: Benchmark condition



Glass State: Novel condition Participant 1



Experiment II: Results

	Benchmark Daylight	Novel Daylight	Benchmark View	Novel View	Novel View (-5, 7, 15)
Mean	83%	79%	64%	62%	71%

Experiment II: Results

Survey ii

Preference:

9 participants responded: No Difference

4 participants responded: The Novel

3 participants responded: The Benchmark

Experiment II: Discussion

Tasks - Productivity

Not a sufficient amount of people

Too short experiment

Lux Sensor

Different Angles

Obstacle

Occupant response

Regarding level of discomfort

Scoring system

Experiment II: Discussion

More data:

(i) gathering the occupant's response in real time,

Imperceptible, Perceptible, Disturbing, Intolerable (make image for these things)?

(ii) investigate each individual

via machine learning, statistical analysis

(iii) the light should be measured via more sensors in different places

Light sensor at eye level

(iv) The experimental set up mirrors an actual office building

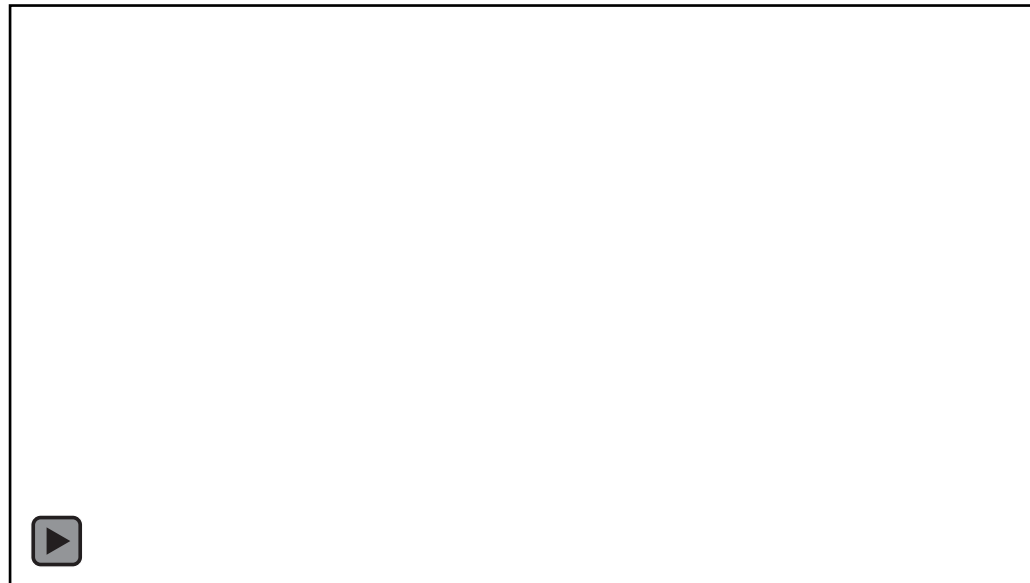
To enhance correlation and with real sun light is important

Conclusion

Main question:

“How can an automated system, consisting of switchable glazing and a system that can sense the needs of the occupant, be used to control glare in an effective manner?”

By taking the occupant in the loop; by adding Facial Action Units to the control system, with emphasis on the Eyebrow Movement



Conclusion

Main question:

“How can an automated system, consisting of switchable glazing and a system that can sense the needs of the occupant, be used to control glare in an effective manner?”

After **evaluating** the key indicators for **effectiveness**

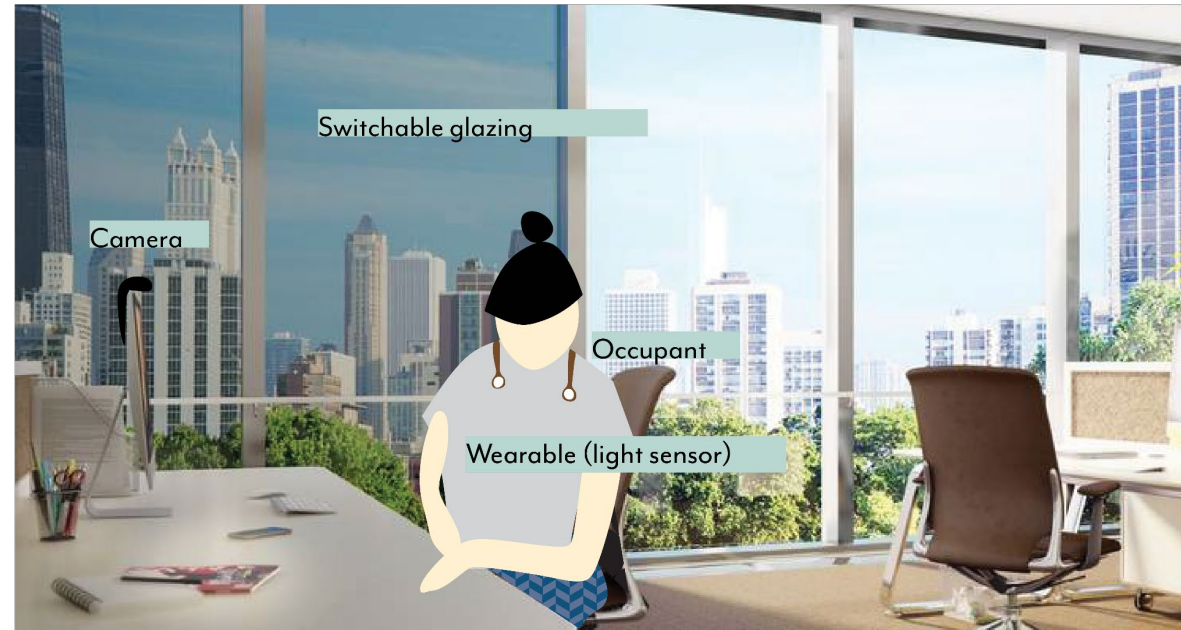
At current stage Novel system appears to be no worse, then the Benchmark system

More data is needed

Translating the system into real offices



Translating the system into real offices



Privacy concerns:

1. not recording when there is no occupant
2. not via internet
3. delete recording after several minutes

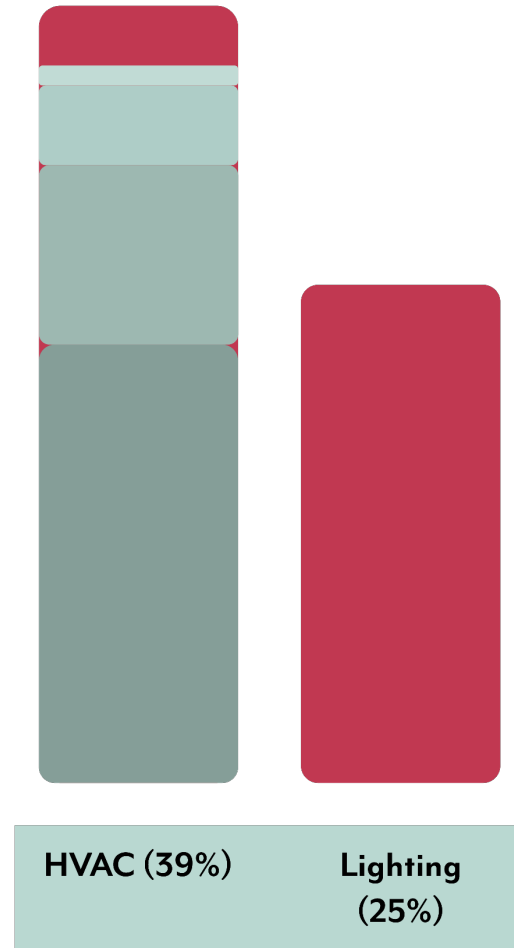
Multiple occupants:

Interesting to explore: who is controlling the glazing

Thank you for listening

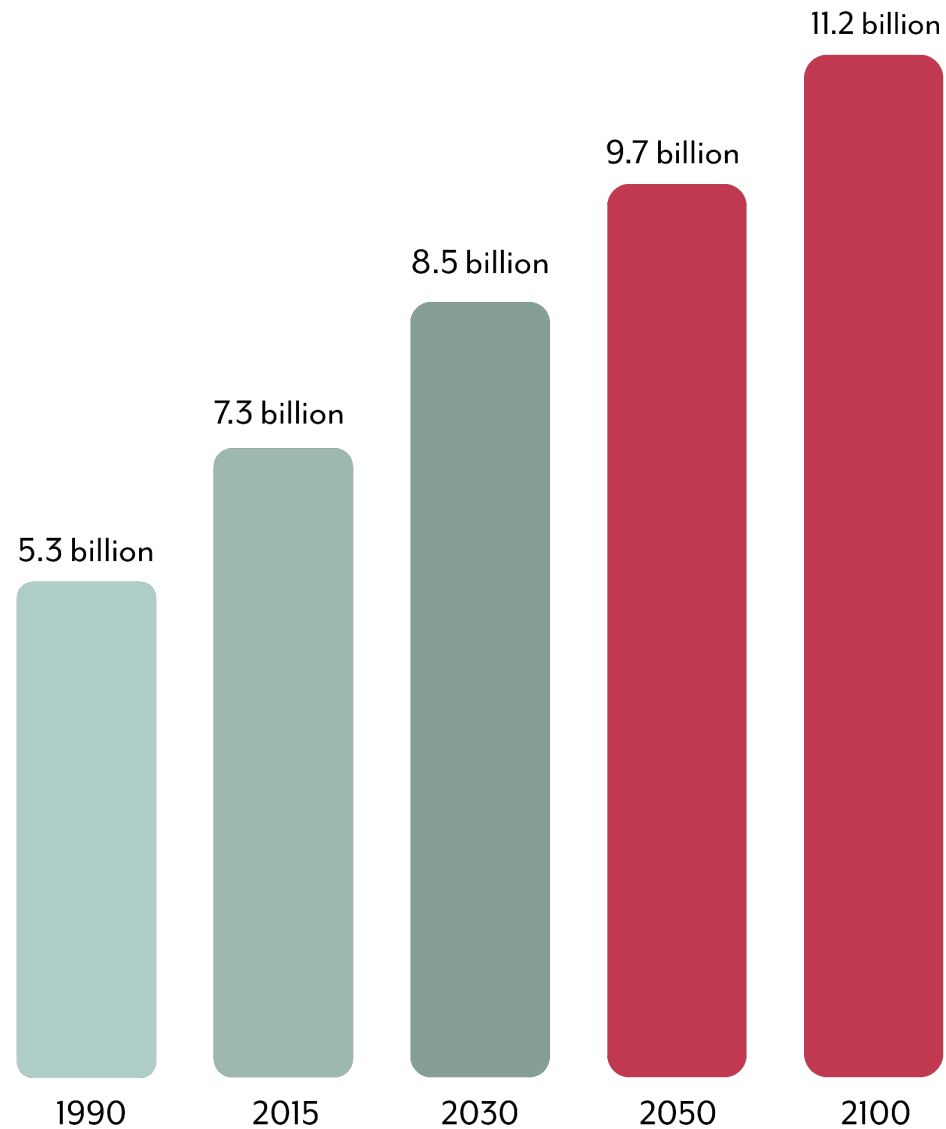
Any questions?

Energy consumption breakdown

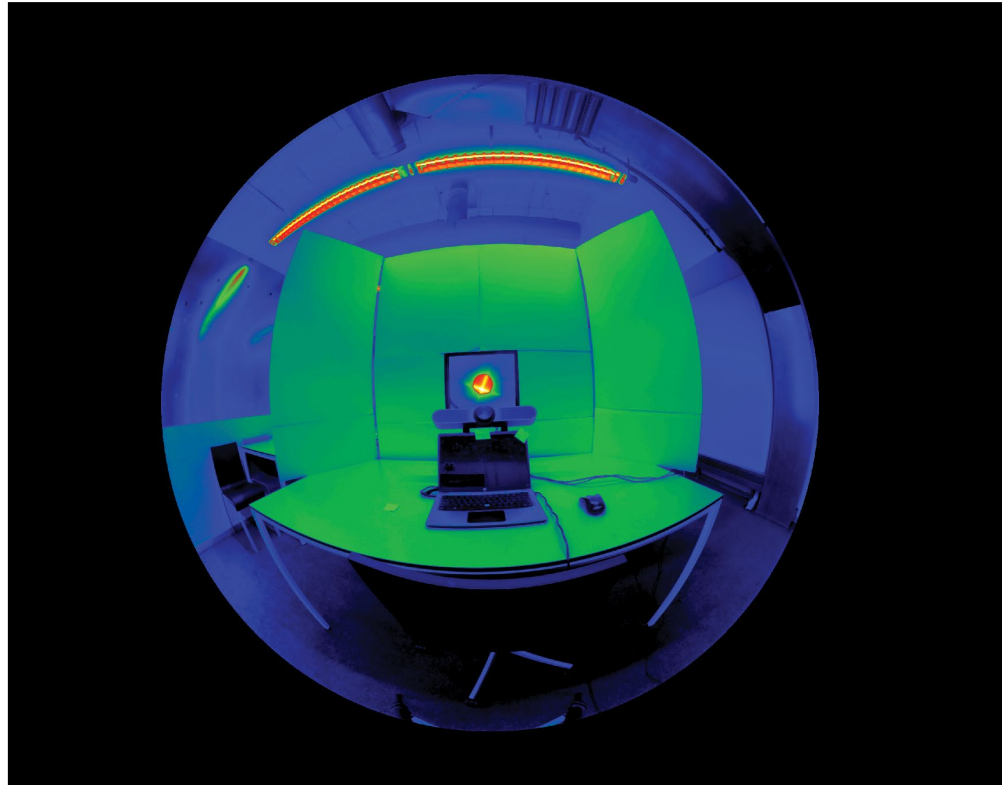


Typical energy distribution

Population growth



Glare Assessment



Daylight Glare
Probability

0.257

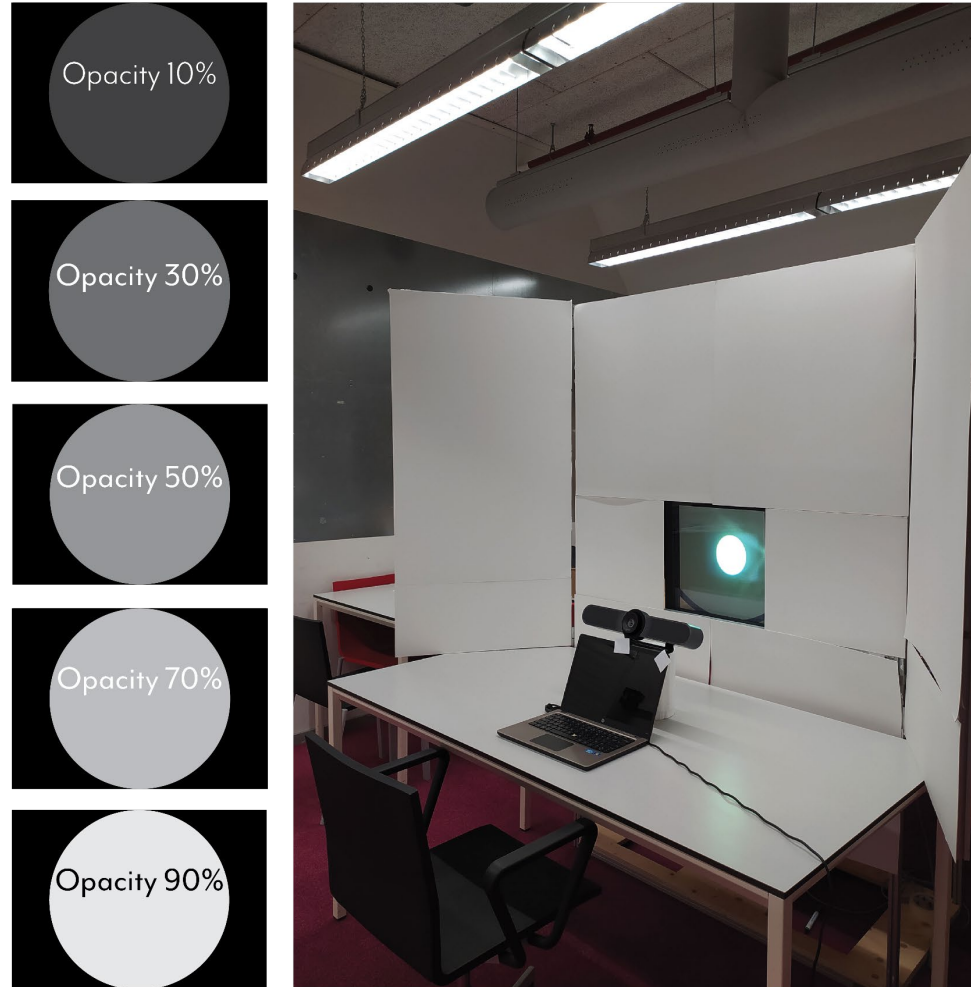
Daylight Glare Index

22.37

**Unified Glare
Rating**

26

Experiment I: Procedure



Increasing brightness of artificial glare source

Glass state: always bright

Experiment II: Results

