



Daylight-Informed Exploration of Window Configurations in Modular Temporary Shelters Using Machine Learning

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Model performance, data visualization, analysis, reflection

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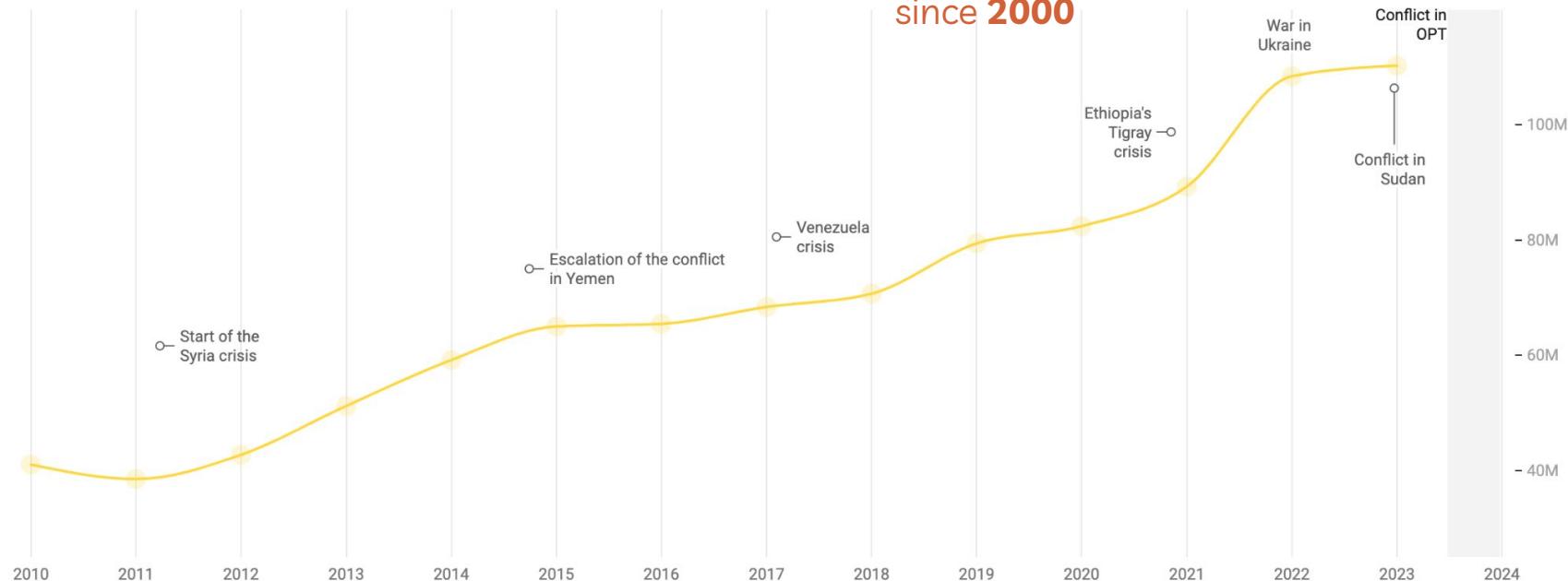
Results and Discussion

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110 MILLION DISPLACED BY 2023



Highest number
since 2000



1 in 124 people
forcibly displaced

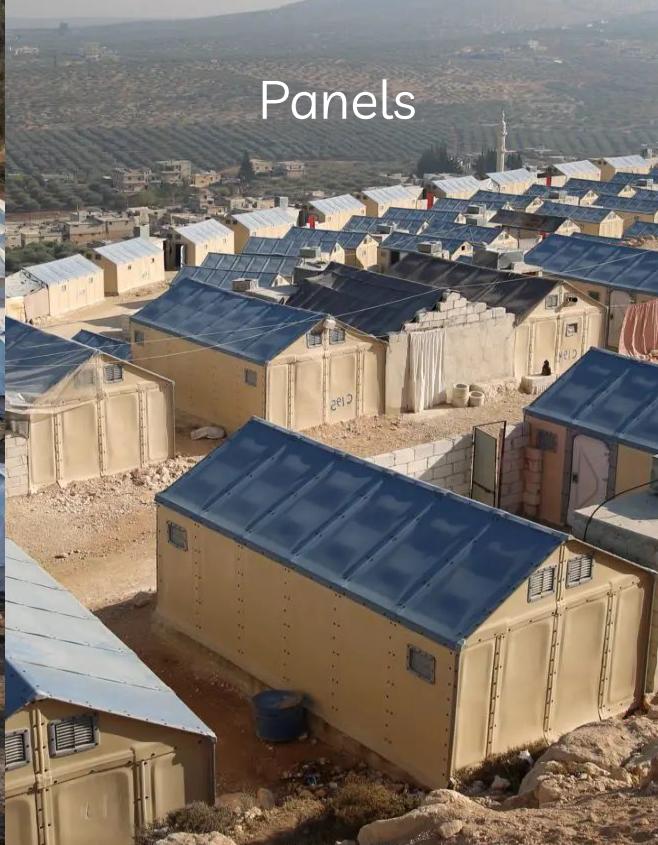
1 in 73 people
forcibly displaced

Mass deployed temporary shelters

Tents



Panels



Ex-containers



Relief Housing Unit (RHU)

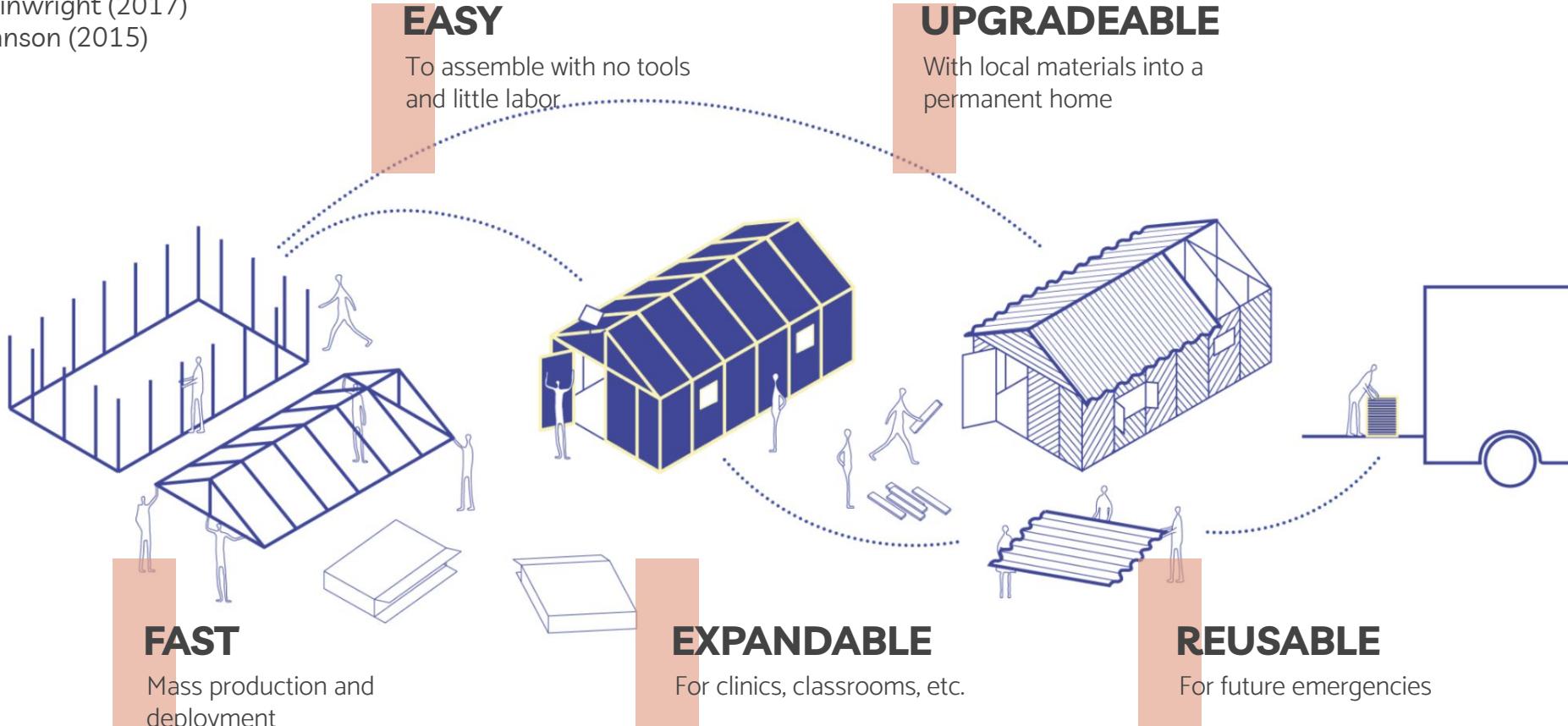


- Long-term and modular
- 190,000 deployed since 2015
- IKEA x UNHCR



Better Shelter (2013)
Cerini (2023)
Peters (2021)
Snow (2013)

Better Shelter (2013)
Szondy (2013)
Wainwright (2017)
Johnson (2015)



PROBLEM

Criticized for not meeting indoor **daylight** needs



Dunn (2015)
Fairs (2017)
Scott-Smith (2017)
Jahre et al. (2018)

PROBLEM

Uniform assembly
in camps despite
interchangeable
panels and different
unit orientations



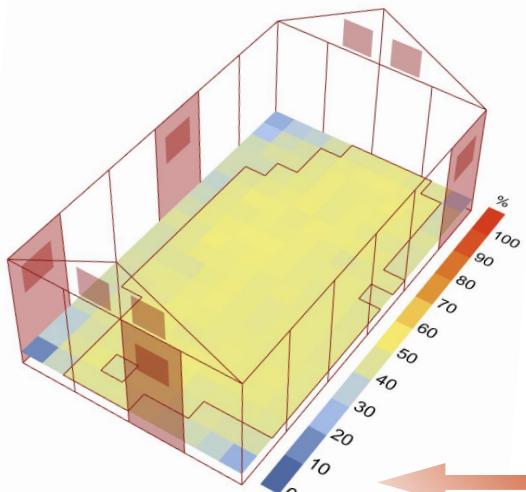
PROBLEM

Uniform assembly
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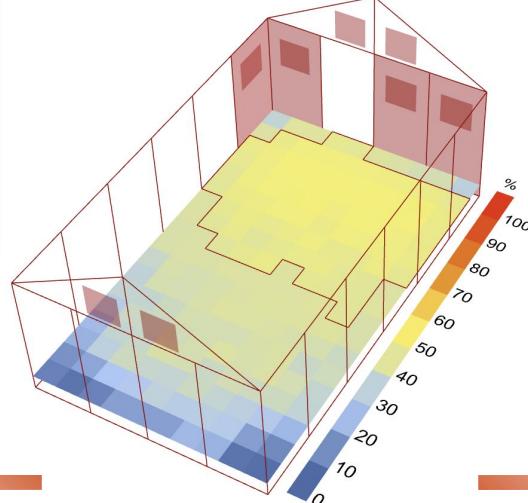
PROBLEM

Window configuration and orientation can affect annual daylight significantly...

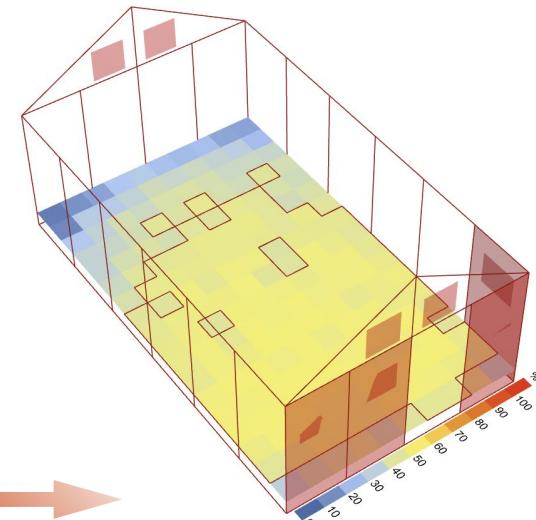


76%
of total area

Different window
configuration



42%
of total area



65%
of total area

Different
orientation

PROBLEM

...but **iterative**
daylight analysis can
take **DAYs** to
compute!

Objective

Use machine learning to **explore** the
RHU's modular design, **develop** daylight
insights, and **improve** analysis tools

Scope

Setup daylight analysis and RHU model

Collect and **visualize** initial data

Run surrogate model to simulate instantaneous results

Run generative model to predict good window configurations

01

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Key concepts, setup, workflow, data
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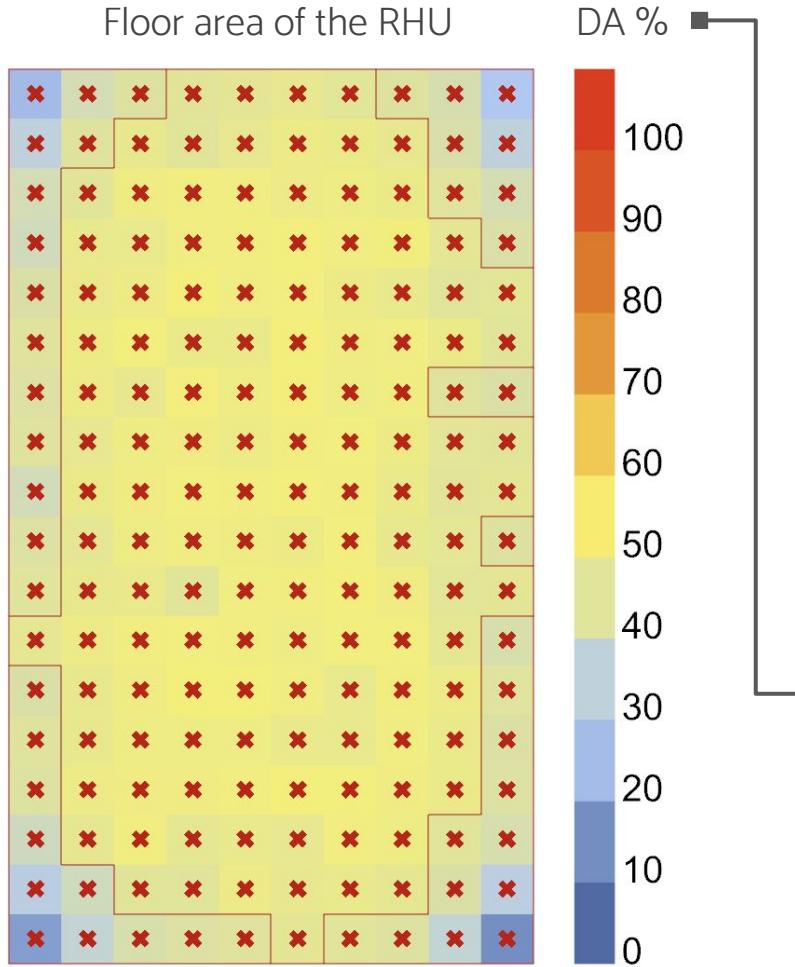
Results and Discussion

Model performance, data
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% of Total Area =

72%

Floor area of the RHU



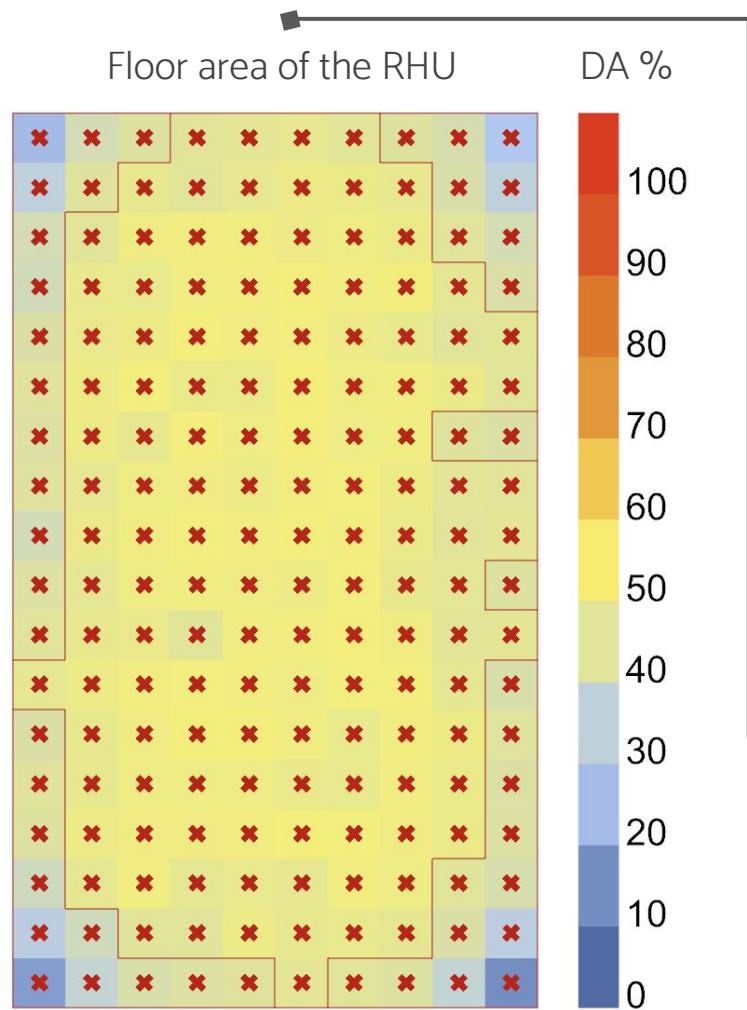
Daylight Autonomy (DA)

% of time when a **threshold of illumination** is reached

Annual (9am-5pm each day)

Illumination measured by **lux**

% of Total Area =
72%



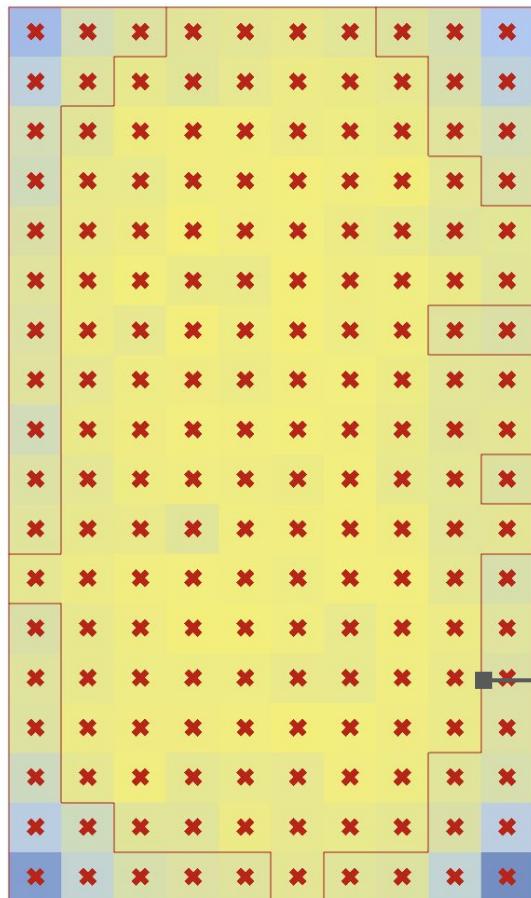
Daylight Autonomy (DA)

All **180** sensors have their **own DA value**

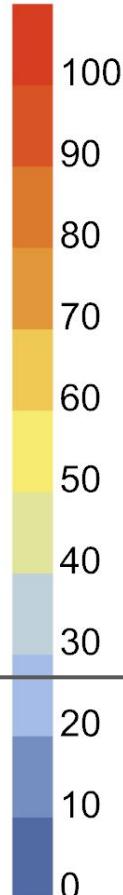
% of Total Area =

72%

Floor area of the RHU



DA %



Daylight Autonomy (DA)

Outlined sensors have a DA value **larger than 40%**

Represented by **% of total area**



Home

>150 lux

SETUP



Classroom

>300 lux

Lux threshold:
>150 lux

Location:
Syria

Unit geometry:
Standard kit

Design variable #1:
Window
configuration

Design variable #2:
Orientation



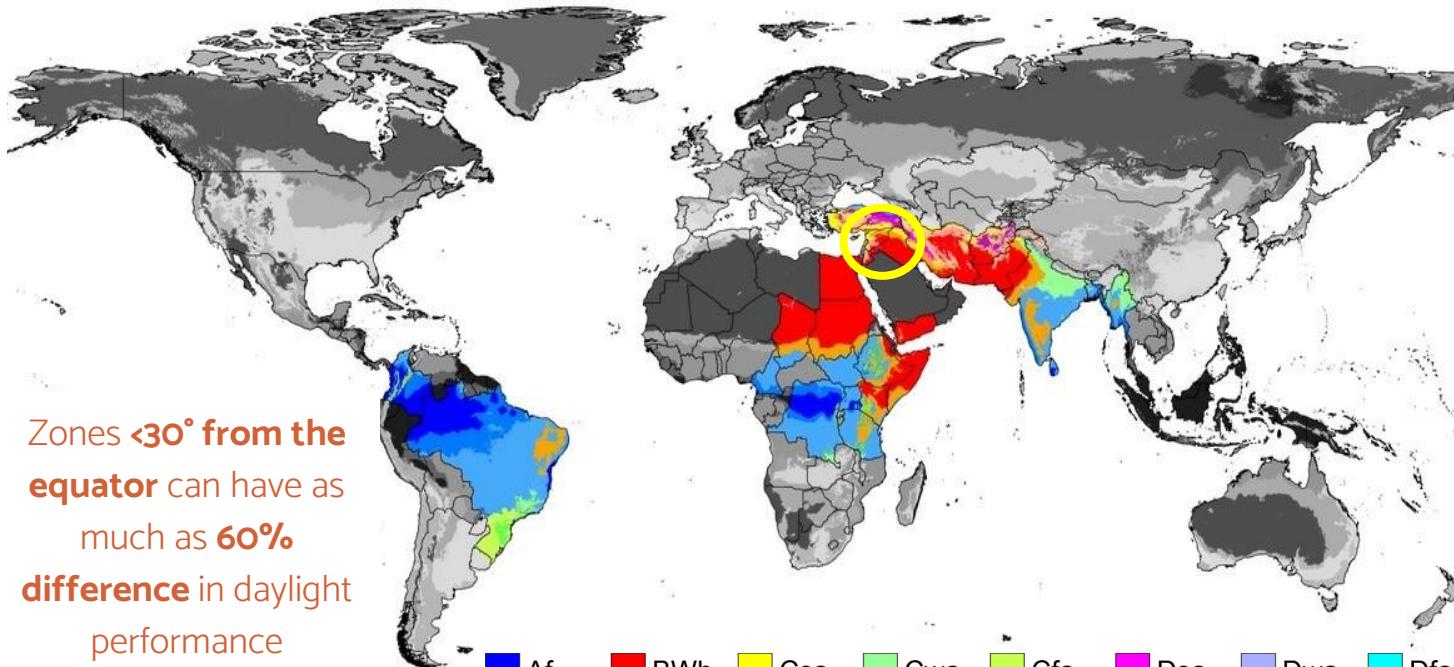
Clinic

>500 lux

General treatment

Köppen climate zones of countries with the most populated refugee camps

SETUP



Lux threshold:
>150 lux

Location:
Syria

Unit geometry:
Standard kit

Design variable #1:
Window configuration

Design variable #2:
Orientation

Terne (2022)
Köppen (1936)
Dyvik (2023)

Munoz et al. (2014)

SETUP

Lux threshold:
 >150 lux

Location:
Syria

Unit geometry:
Standard kit

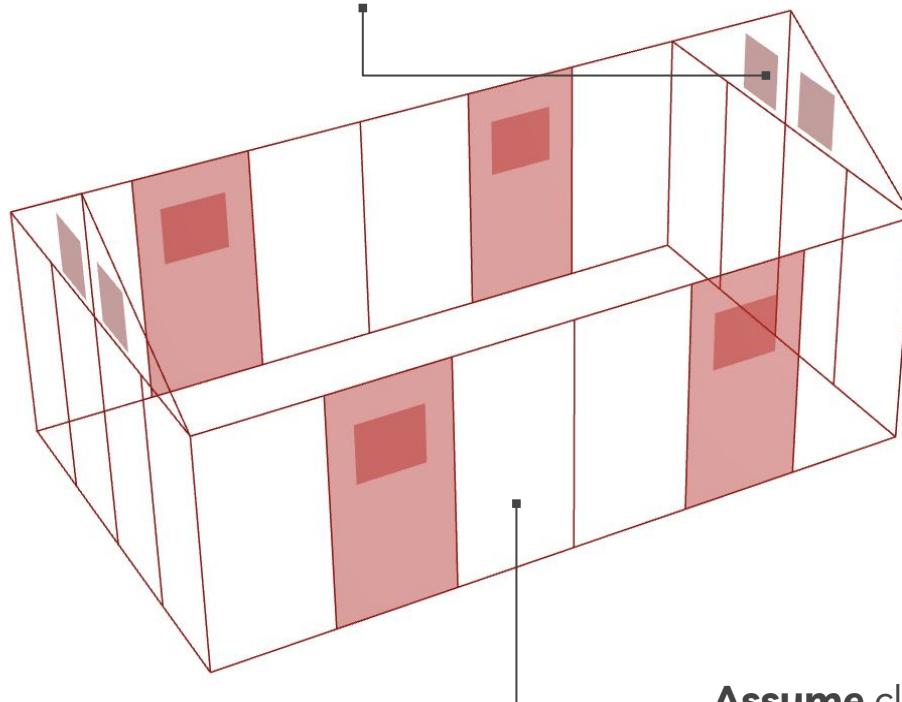
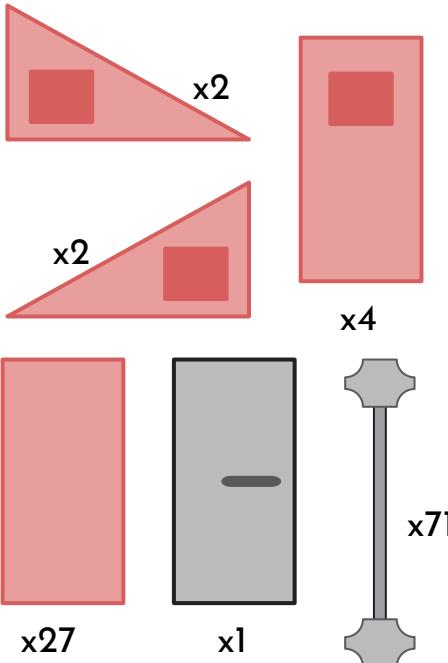
Design variable #1:
Window
configuration

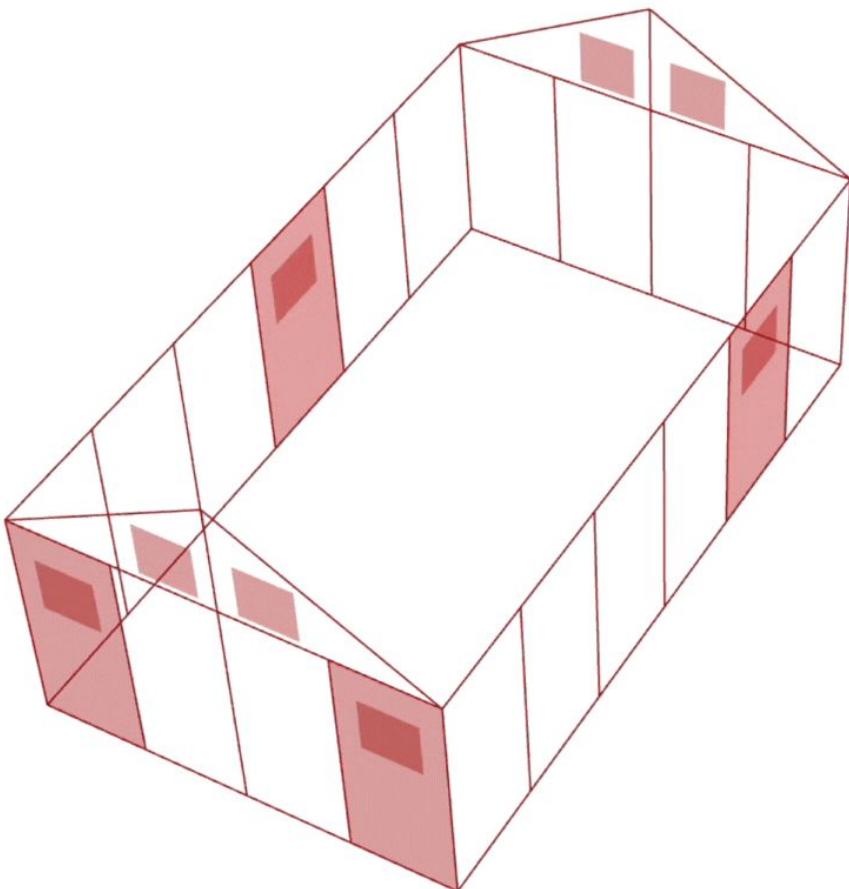
Design variable #2:
Orientation

Assume high windows
for ventilation

Assume closed door
for security and privacy

Standard kit





SETUP

Lux threshold:
 >150 lux

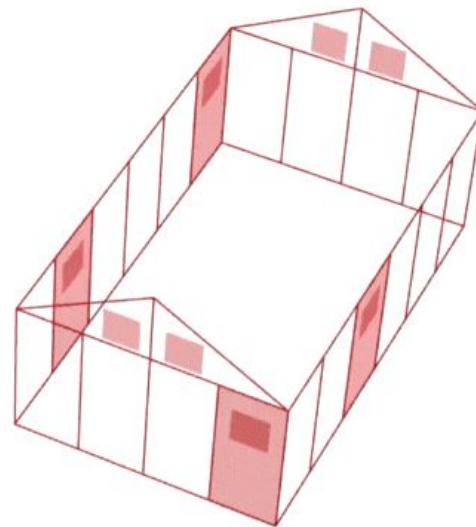
Location:
Syria

Unit geometry:
Standard kit

Design variable #1:
Window configuration

Design variable #2:
Orientation

SETUP



Lux threshold:
>>150 lux

Location:
Syria

Unit geometry:
Standard kit

Design variable #1:
Window
configuration

Design variable #2:
Orientation

Workflow:

Data collection

$n = 4$



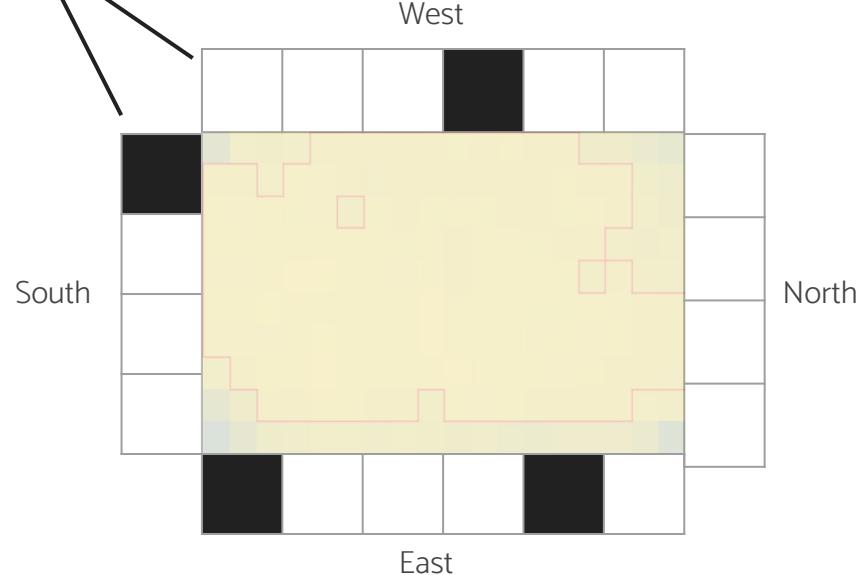
1. Panel binaries



Window



Window

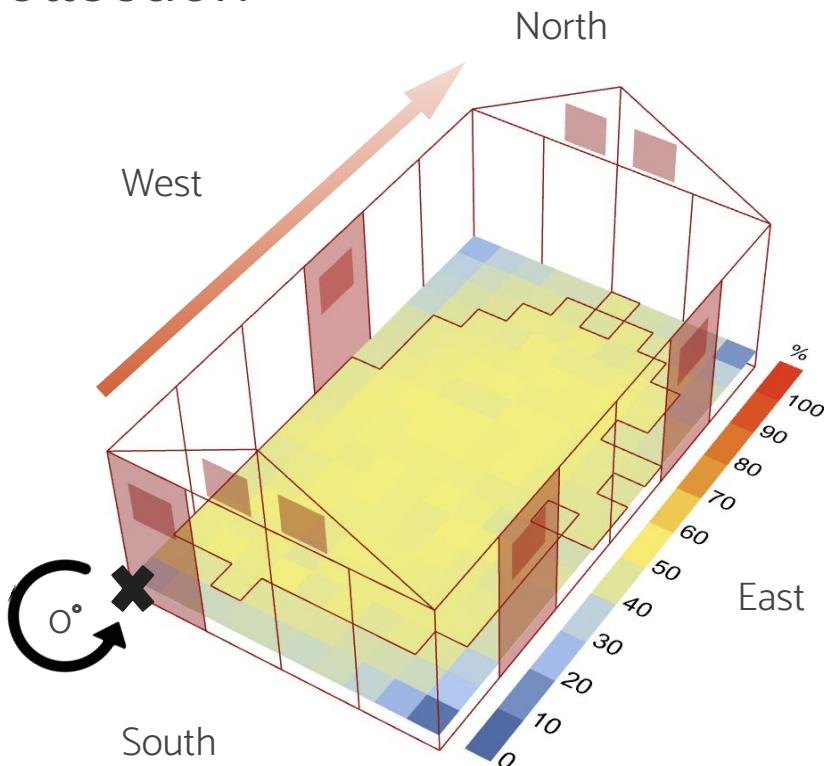
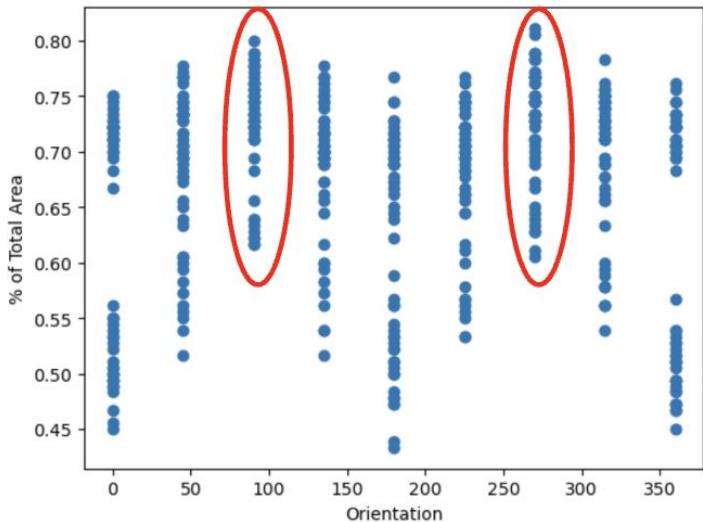


Workflow:

Data collection

2. Orientation

To track direction of windows in **15 degree rotation intervals** from 0-180°



Workflow:

Data collection

3. Individual sensors

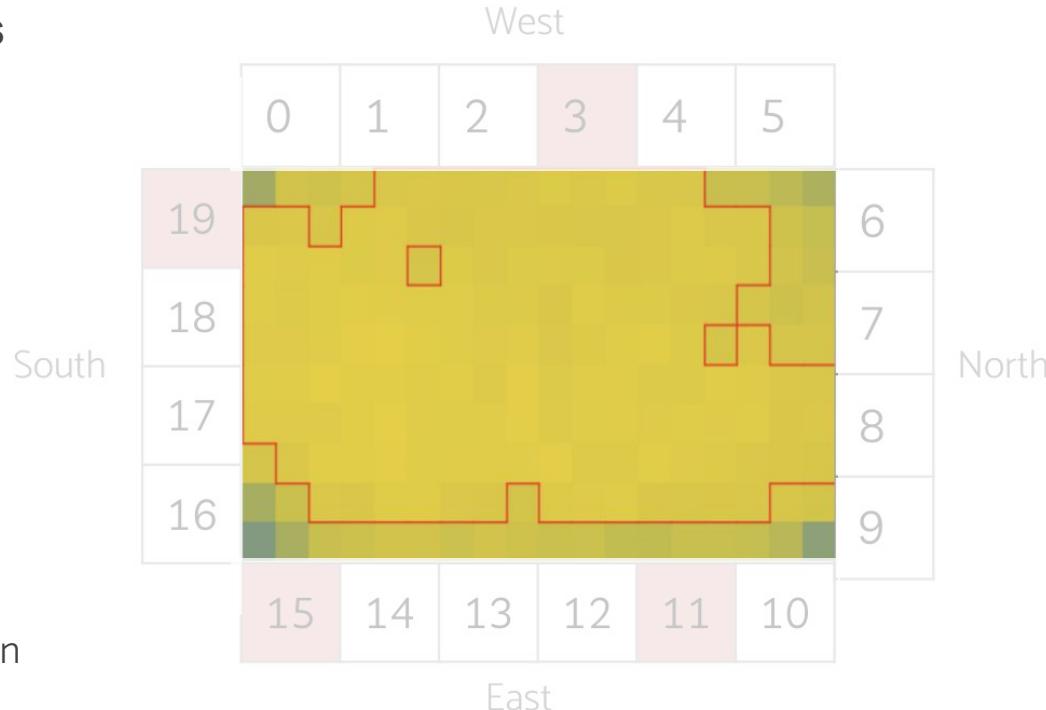
To simulate DA values

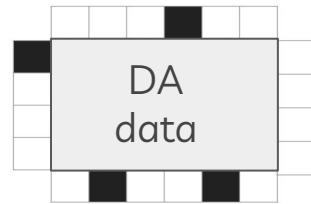
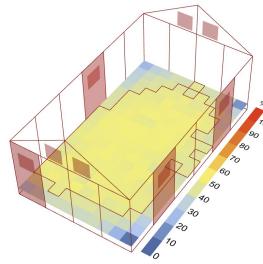
4. % of total area

To assess DA maximization

5. Average sensor

To account for dark corners/even distribution



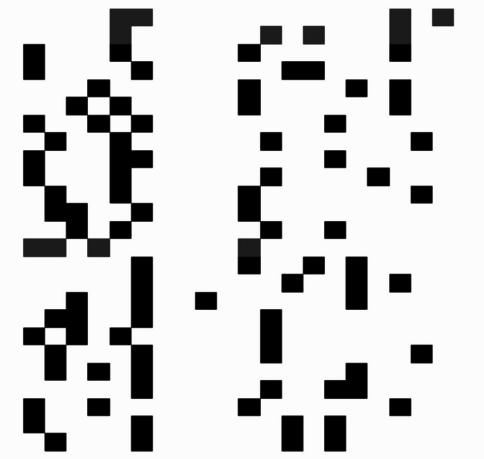


Workflow: ML Models

Generative



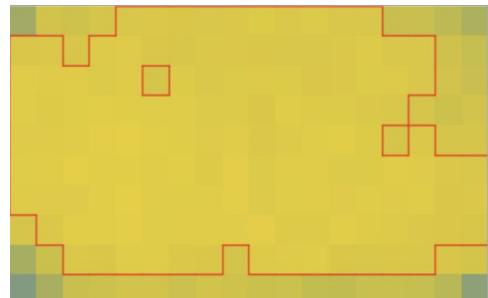
Good window configurations



Instantaneous predictions

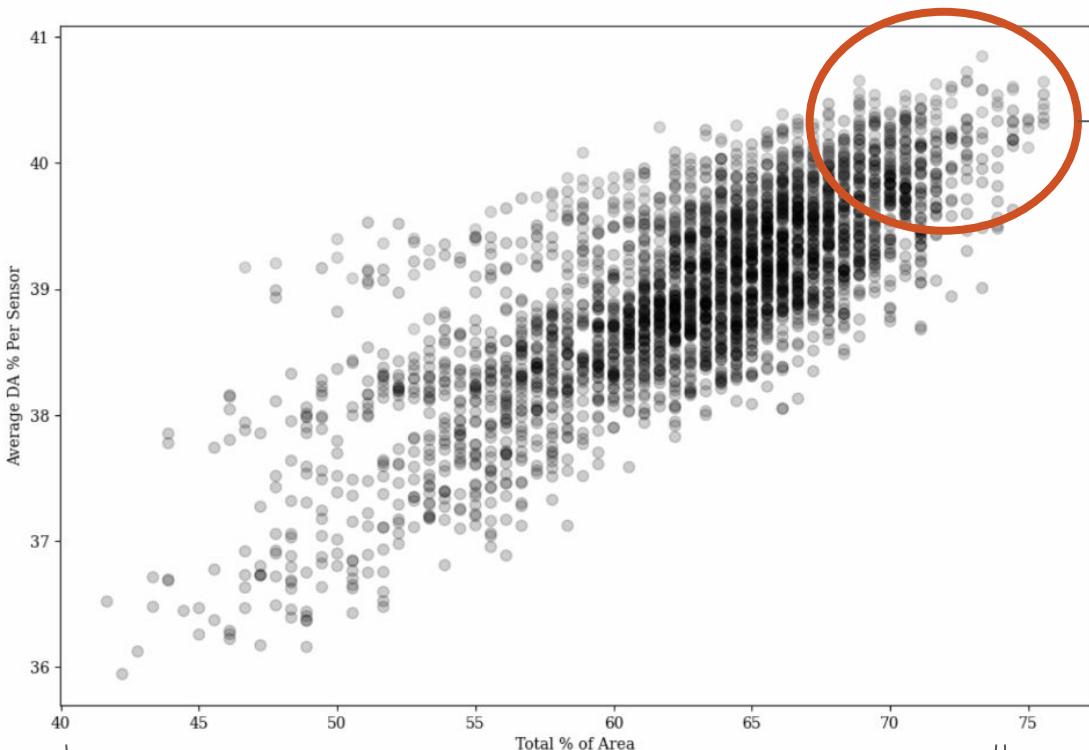


Surrogate



3000 window configurations
(orientation control: 0°)

Workflow: ML Models

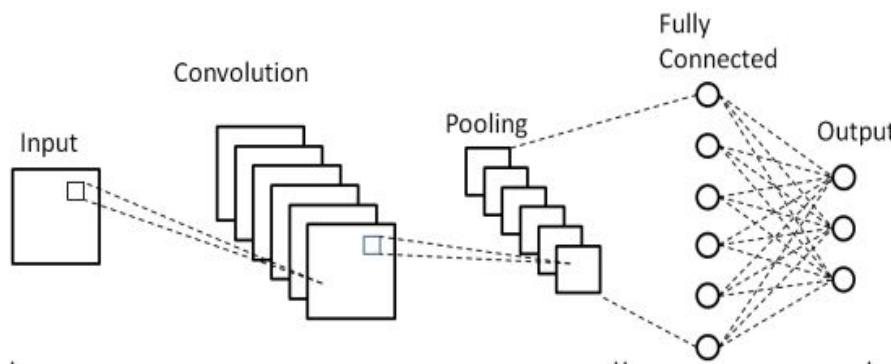


Train generative model
with best performing only

Train surrogate model

Test surrogate model

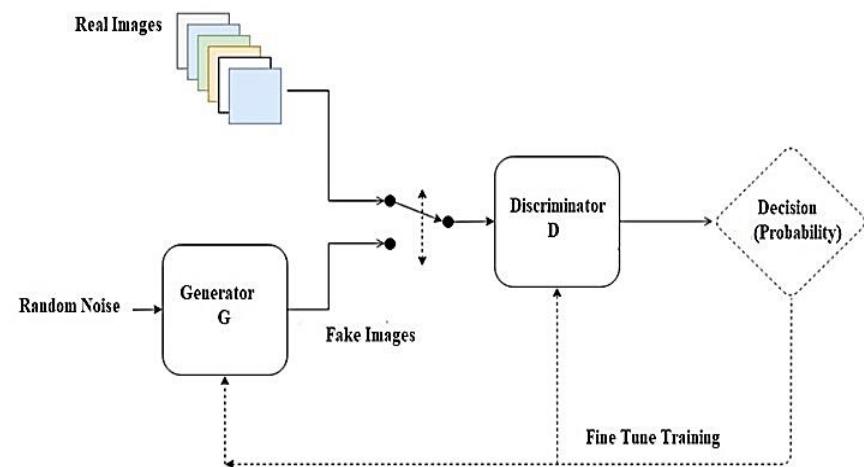
Workflow: ML Models



Convolutional
neural network



Surrogate model
(regression)



Generative
model

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Test Dataset: Average DA Per Sensor (Truth)



Test Dataset: Average DA Per Sensor (Model Prediction)



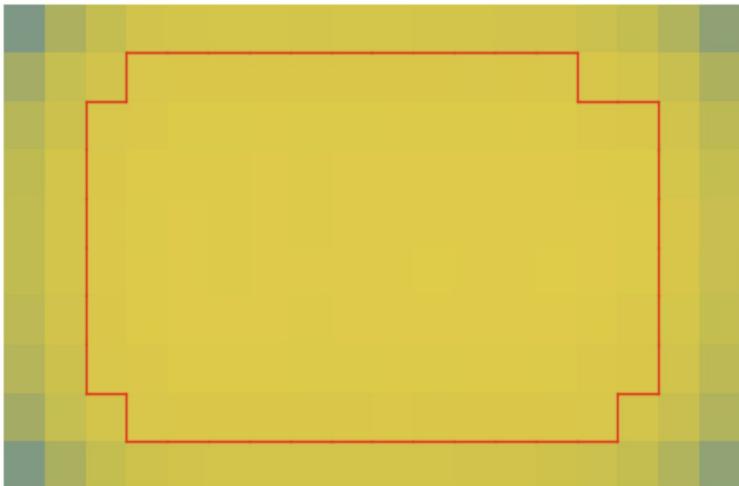
Prediction is very similar to test data!

*Absolute error between truth
and prediction*



Minimal average error per sensor!

Average truth

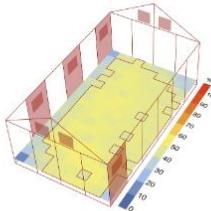
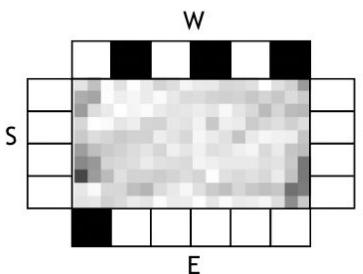
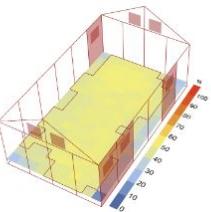
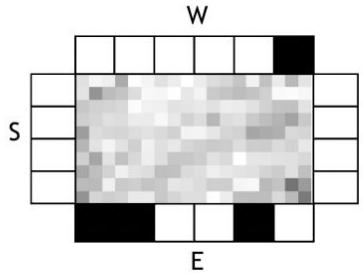
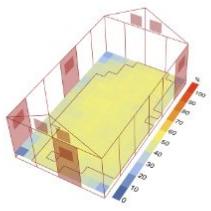
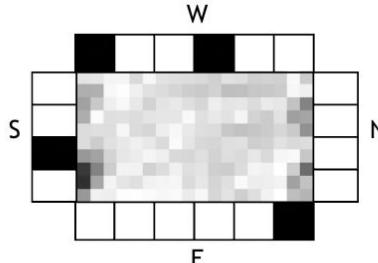


Average prediction

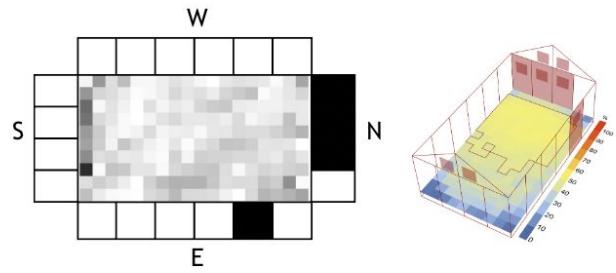
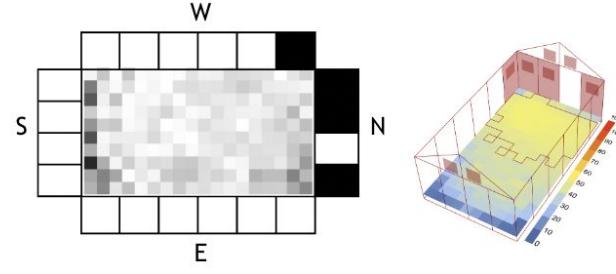
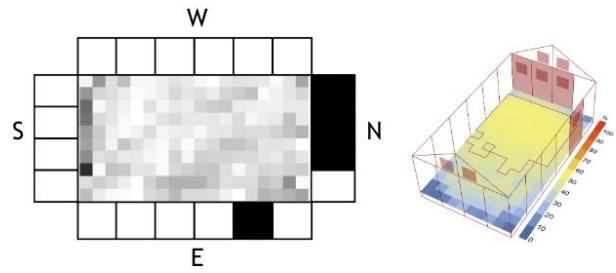
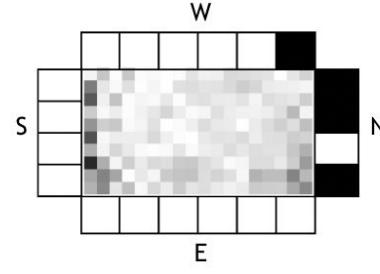
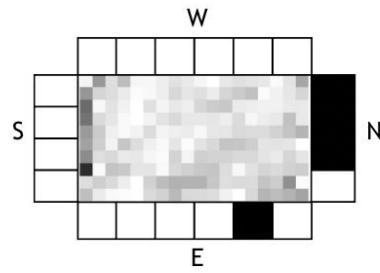
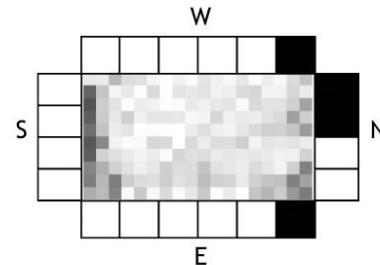


...but small errors can interfere with **threshold selection**

Most DA



Least DA



Higher error with
less DA = harder to
predict

Most error found
around **edges** of
the room

*normalized

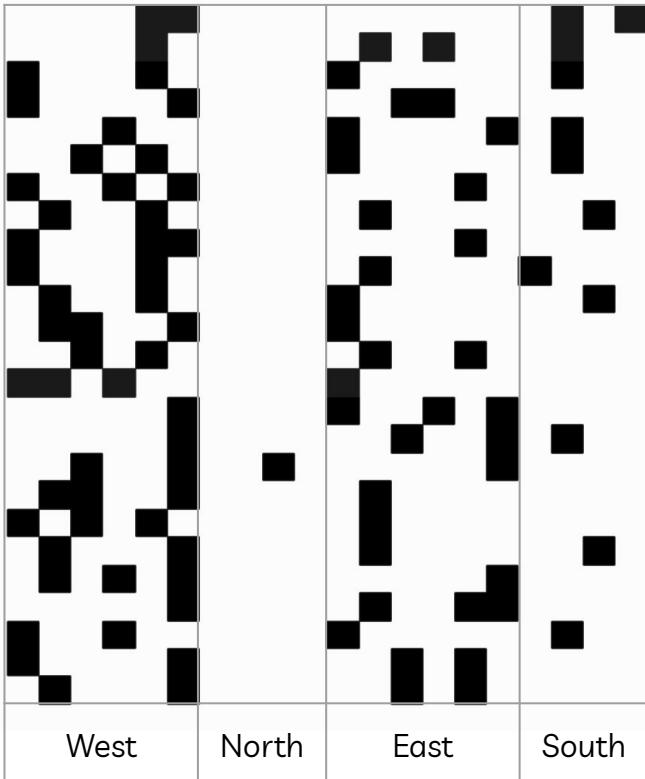


Frequency of Each Window Panel



Corner window panels
versatile?

Window configurations with most DA

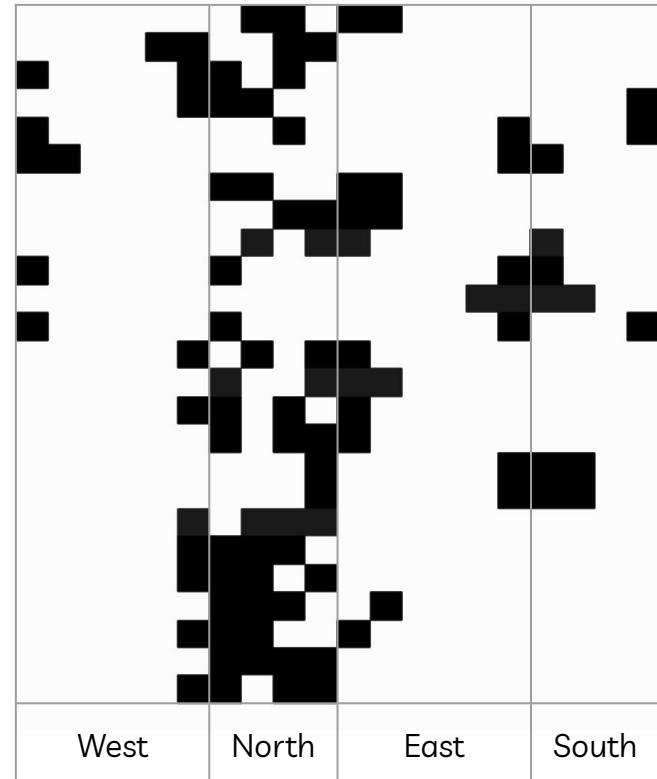


North-facing
windows have
significant effect

Spacing is
important

but...

Window configurations with least DA



Window configurations with most DA

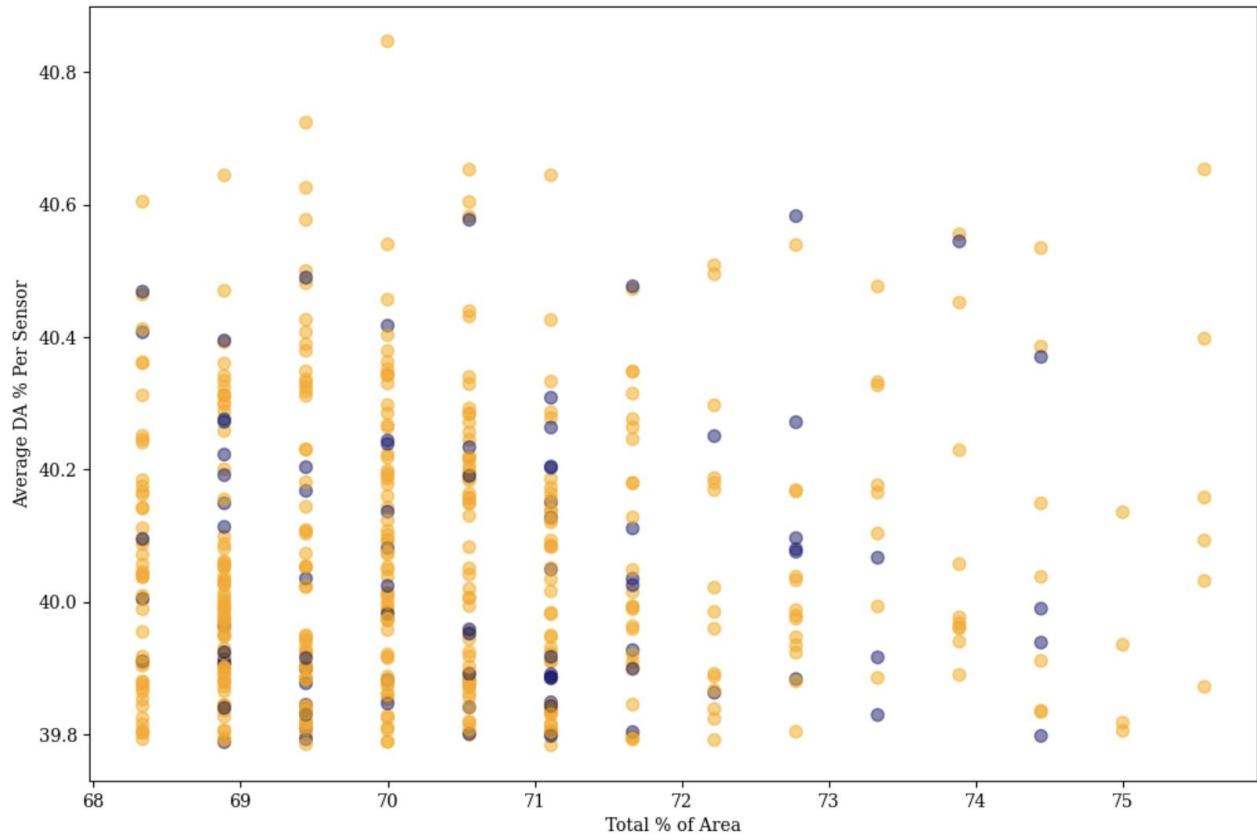
83%

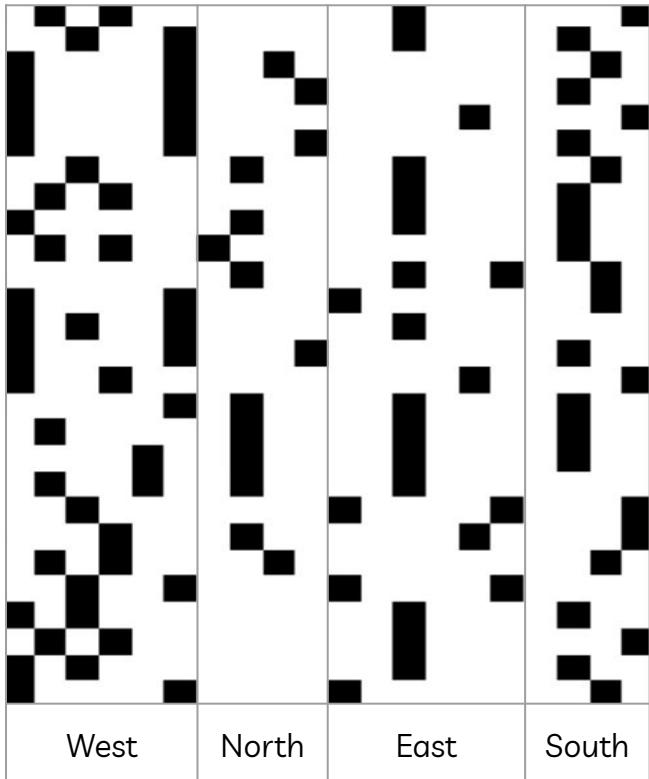
With consecutive windows

17%

Without consecutive windows

...majority have consecutive windows





Performance of generated window configurations

75th percentile (>67%)

29%

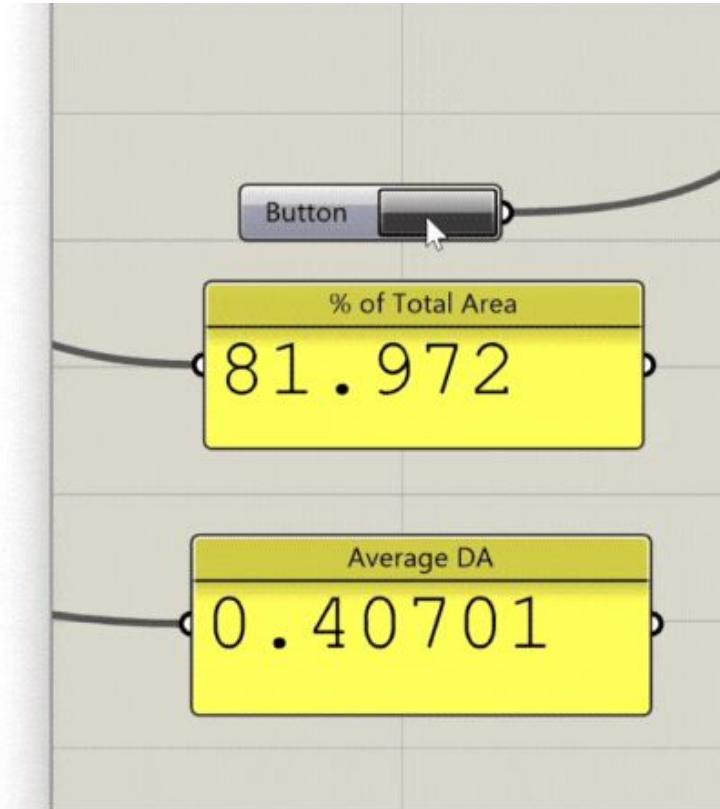
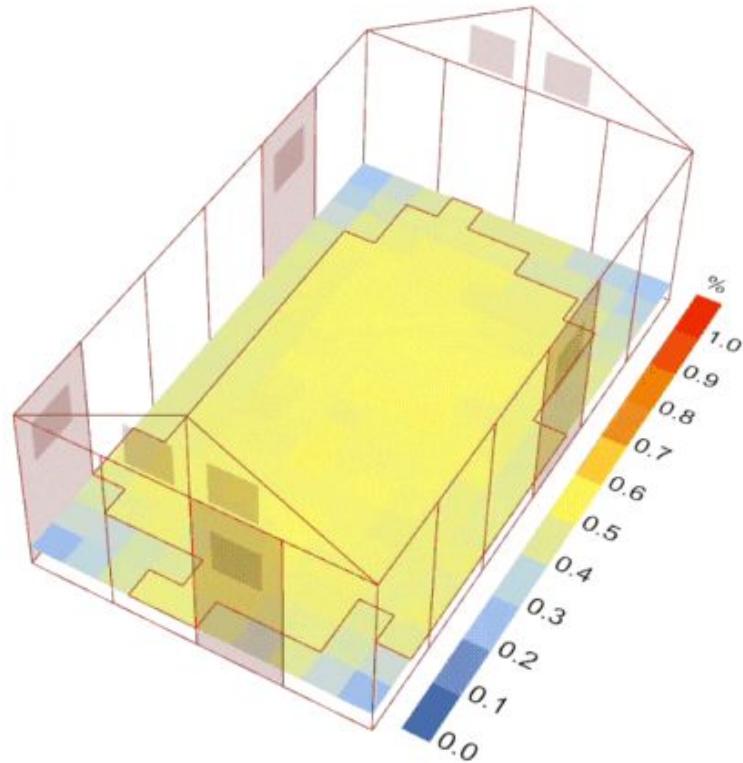
Above average
(>62%)

43%

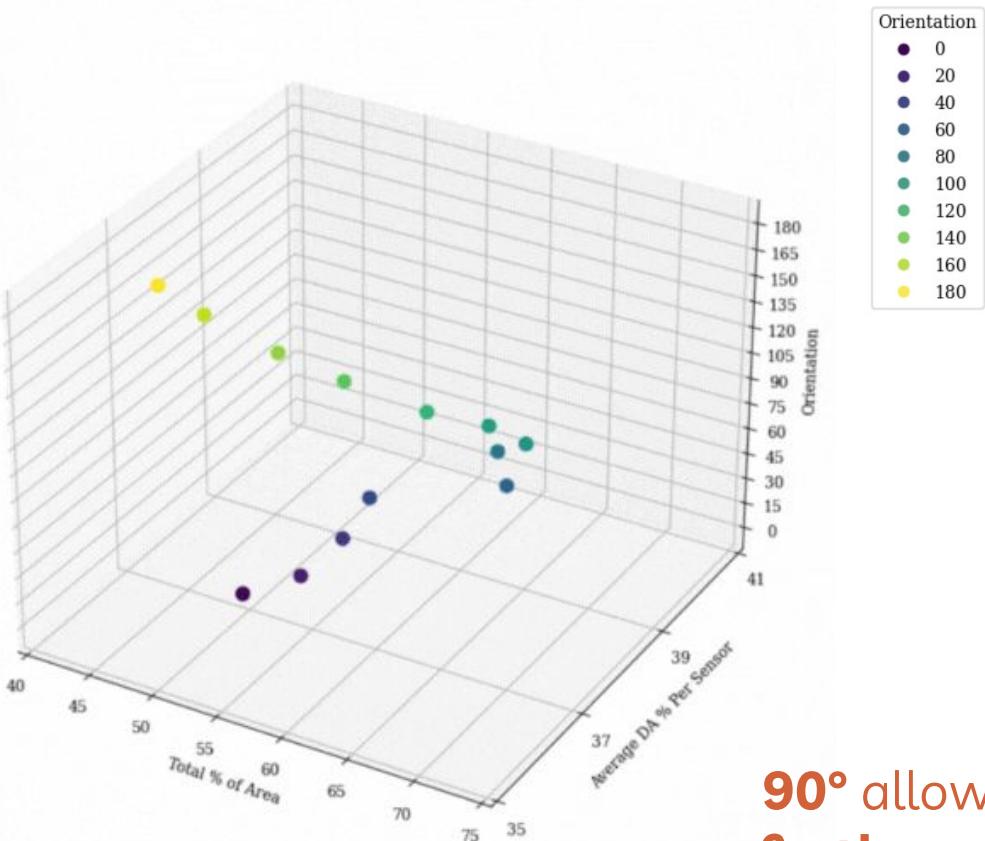
Underperformed

28%

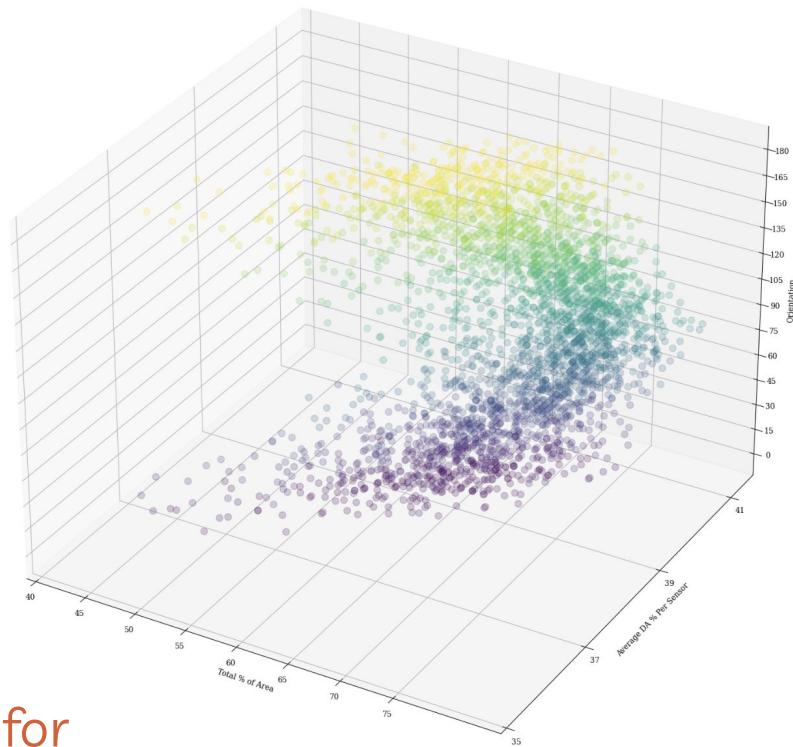
Generated **no consecutive windows** and **lots of north/south facing windows...**

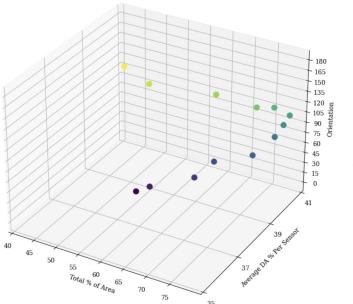
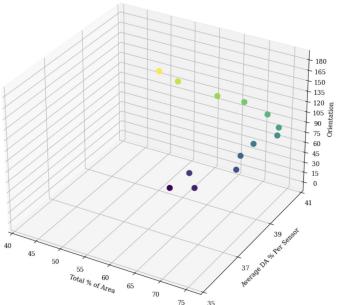
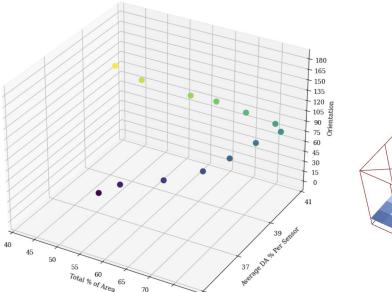
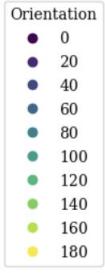


Improved! Gets good results **30x** faster!



90° allows for
further reach

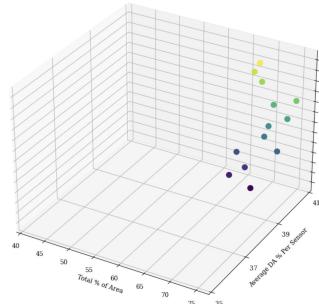
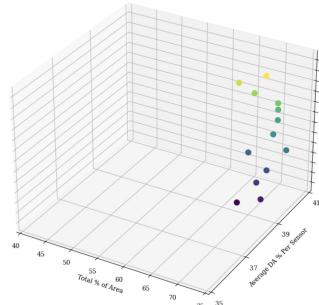
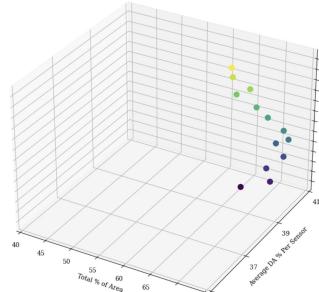




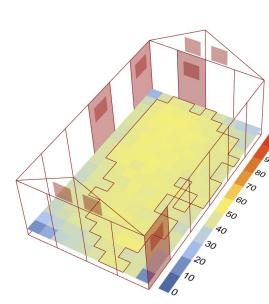
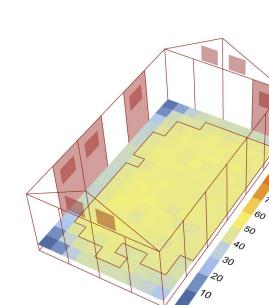
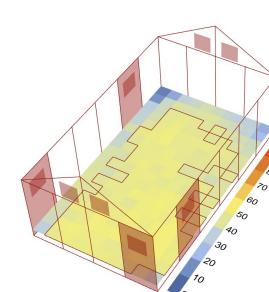
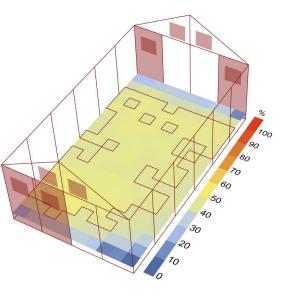
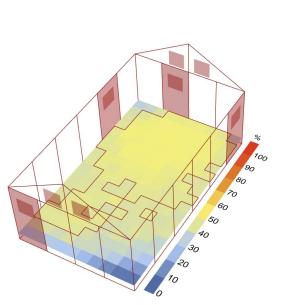
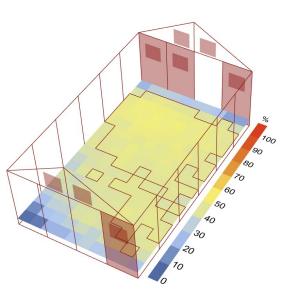
More variable



Number of north/south windows influences orientation effect on performance variability



Less variable



Insights

Window configuration

Minimal effect on even distribution/dark corners

Windows **do not need** to be **evenly spaced**

Consecutive and **corner windows** can be effective

Orientation

Winter sun decreases DA **significantly**

Unit length is better aligned with **east/west windows**

Number of north/south windows affect performance **variability**

Limitations

First experiences with
daylight analysis and
machine learning

Lack of expertise

Time constraint

Limited data collection
Trial and error takes
time

Outlook

More data

For **extensive** design exploration

Lots of **factors**
compound

Interactive system

User-friendly system for
practical use

Can be **applied** to other types of modular shelters

Significance

Decrease dependence
on solar panels

Leverage modularity for
future-proof design

Avoid unit disuse
through quality control

Improve response to any
given emergency

Ensure health, safety, and
productivity

Enhance efficiency of
daylight analysis tools

Thank you!

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