How can we improve cooling sustainability for factory workers? Learning from the case of Bangladesh's ready-made garment industry

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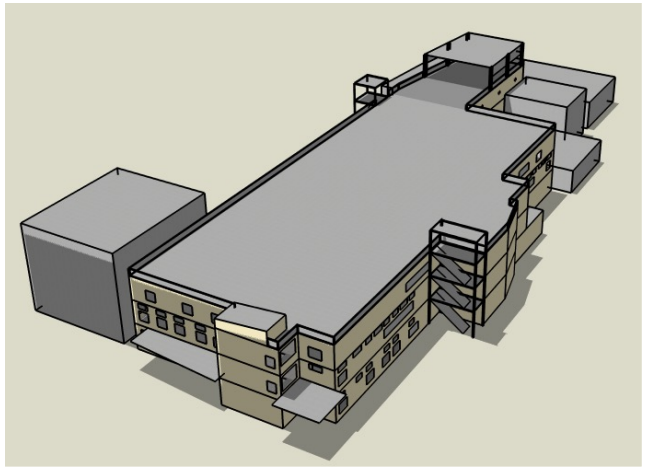

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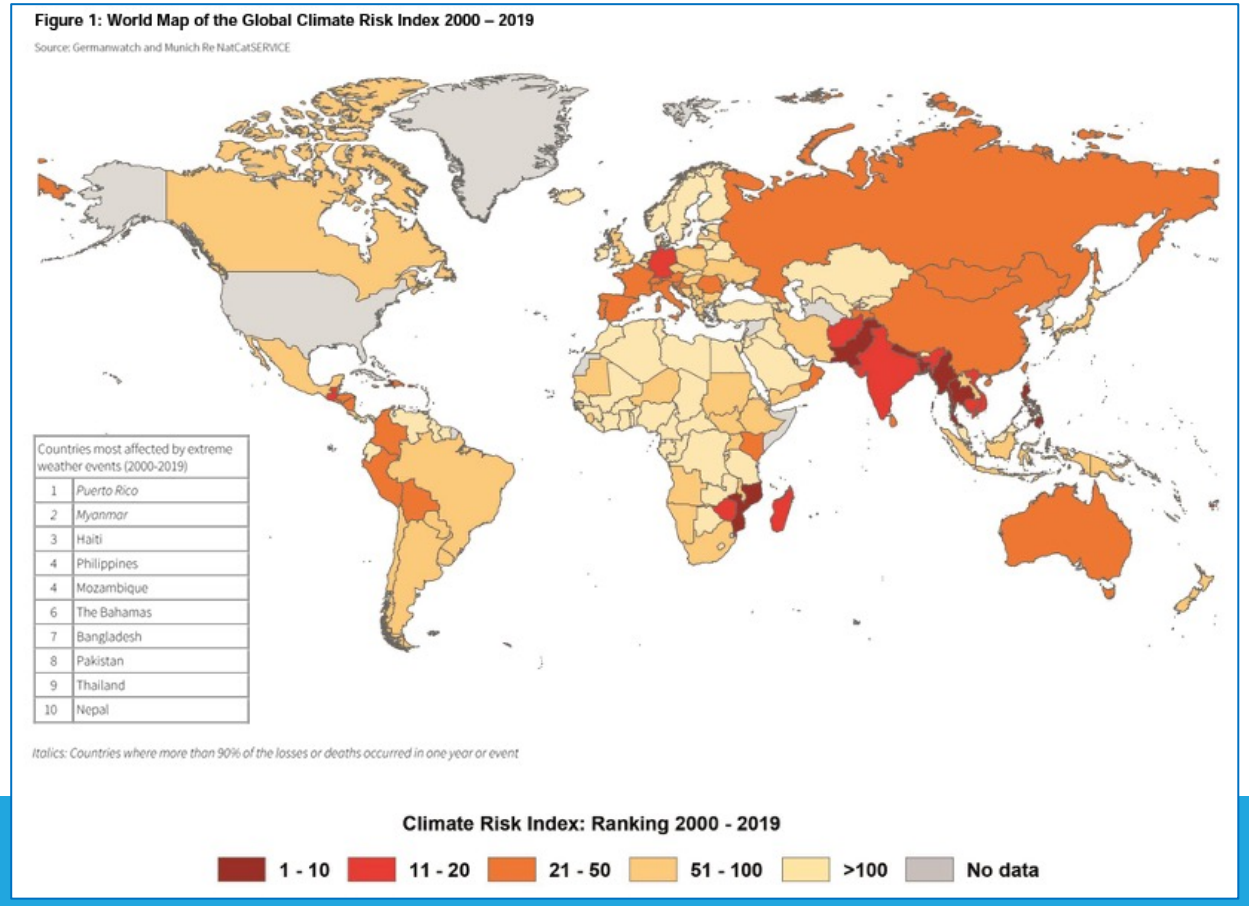
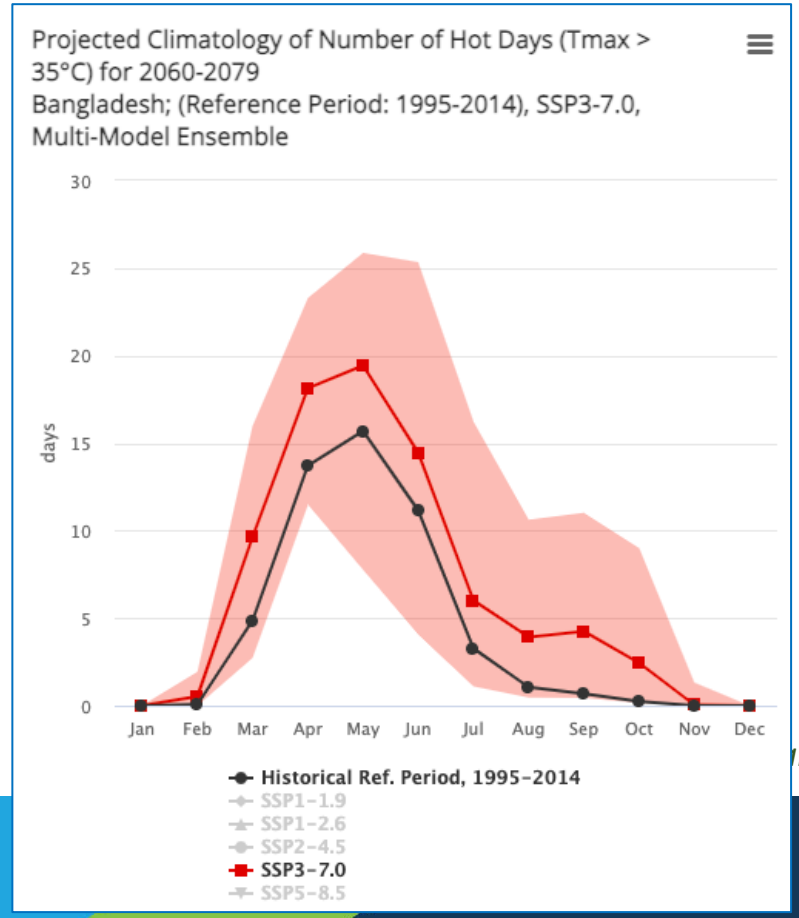
Why this project? Climate Change and Bangladesh

- Bangladesh is the 7th most impacted country by climate events between 2000 and 2019
  (Global Climate Risk Index, GermanWatch, 2021)



- Temperatures are expected to increase by around 4 °C by 2100 for a high emissions scenario (RCP8.5)
- Temperatures in urban areas may rise by an additional 4 °C *(Zhao et al. 2021)*



l, 2022)

Why this project? Bangladesh RMG Industry

- *The Ready-made garment* (RMG) industry is economically and socially vital:
  - Contributes 12-15% GDP and 84% exports by value *(BGMEA, 2022)*
  - Employs over 4 million workers (of which ~60% women)

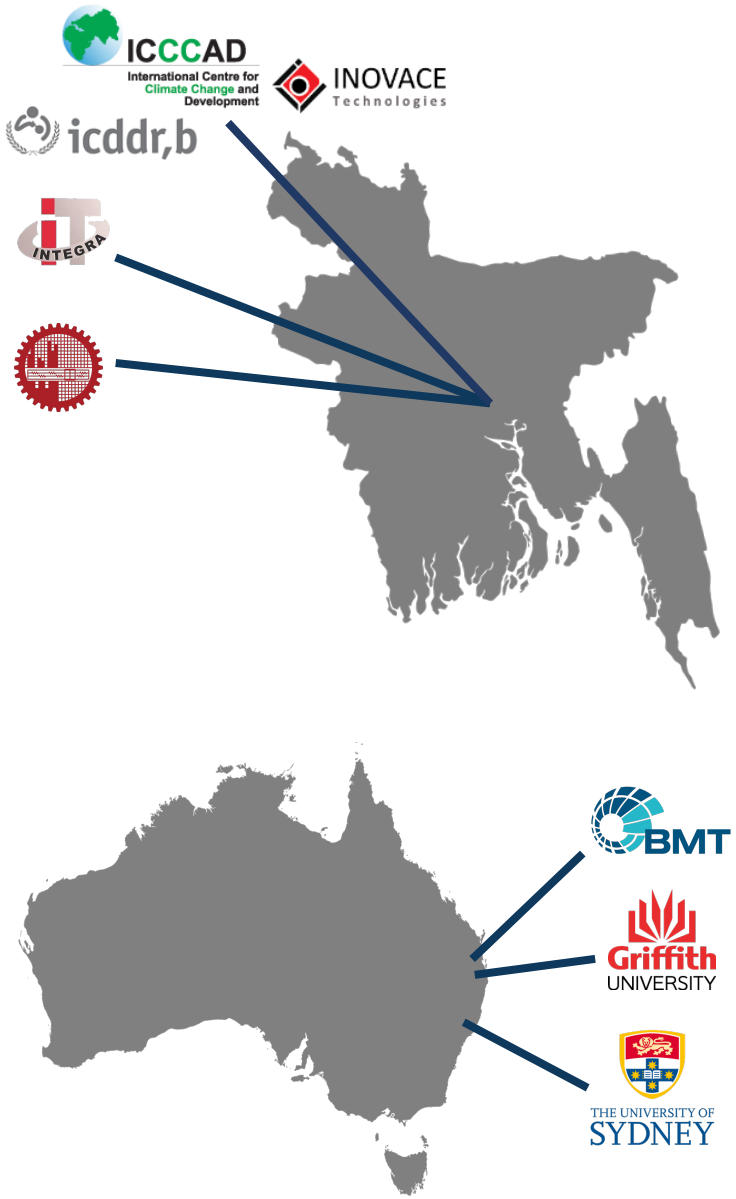
- **Around 77% Bangladesh electricity production is from fossil fuels**
- **Need to find sustainable solutions to already hot working conditions and future climate risks**
- **Further reliance on air-conditioning using fossil-fuel-generated electricity would be maladaptive**

Project outline

30-month project extended to three years funded under the Our Planet Our Health Program of Wellcome

The project is looking at heat stress among RMG factory workers in Dhaka

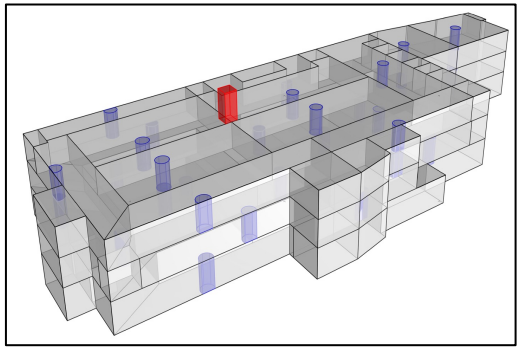
1. What are the present-day working conditions?
2. Do these conditions cause heat stress among RMG workers?
3. Can sustainable cooling strategies improve working conditions without adding to the GHG burden?
4. What will be the impacts of future climate change on factory working conditions?
5. Can the identified sustainable cooling strategies continue to contribute effectively under future worsening conditions?



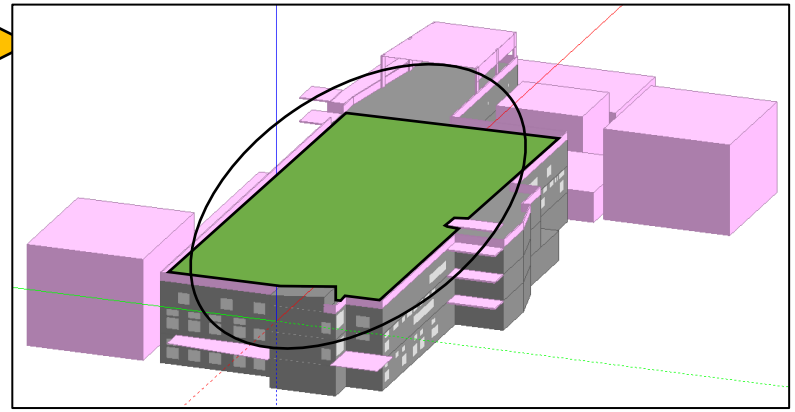
Project outline

Monitoring Indoor/outdoor conditions

Building factory model



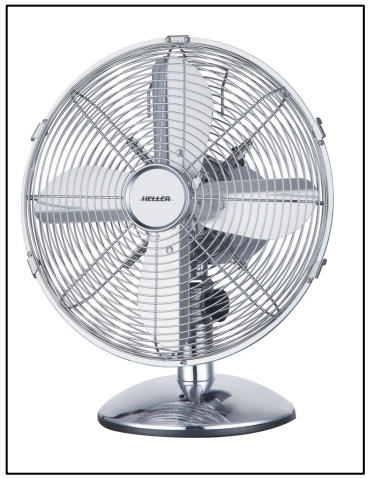
Factory interventions

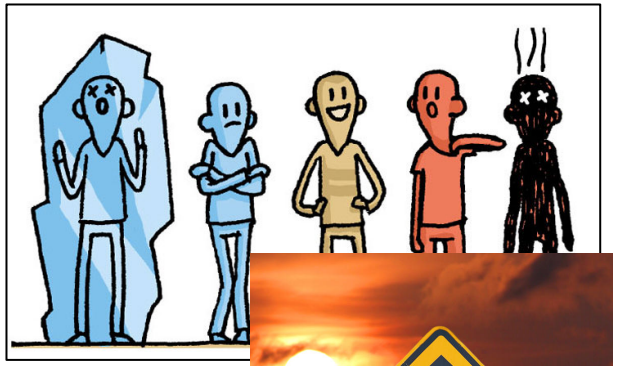


Thermal comfort surveys of workers

Replication in climate chamber

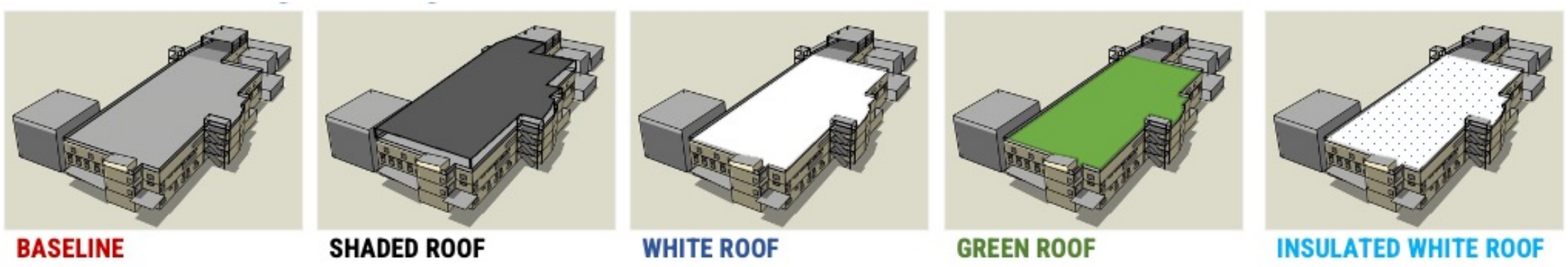
Personal interventions



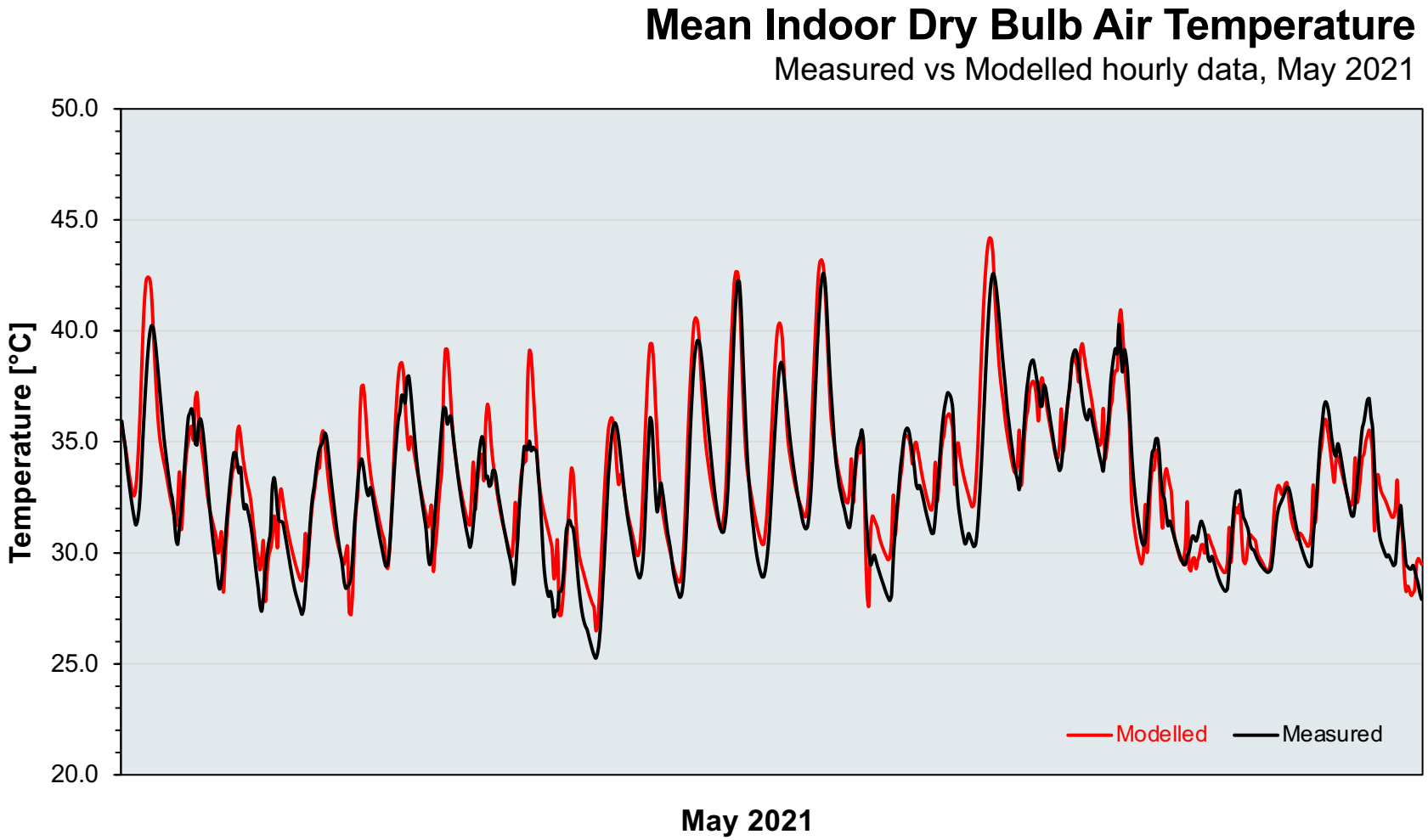


Factory interventions - Methods

1. Created a meteorological data set from our own and other observations
2. Used the data to build and validate an energy model of the factory using *EnergyPlus*
3. Generated and tested passive cooling solutions for reducing heat stress on the top floor for the present day
4. Generated future climate change scenarios (*2030-2100; RCP2.6, 4.5, 8.5*) using *Meteonorm*.
5. Tested the passive cooling solutions under the future climate change



Factory climate - Model vs Measured (top floor)



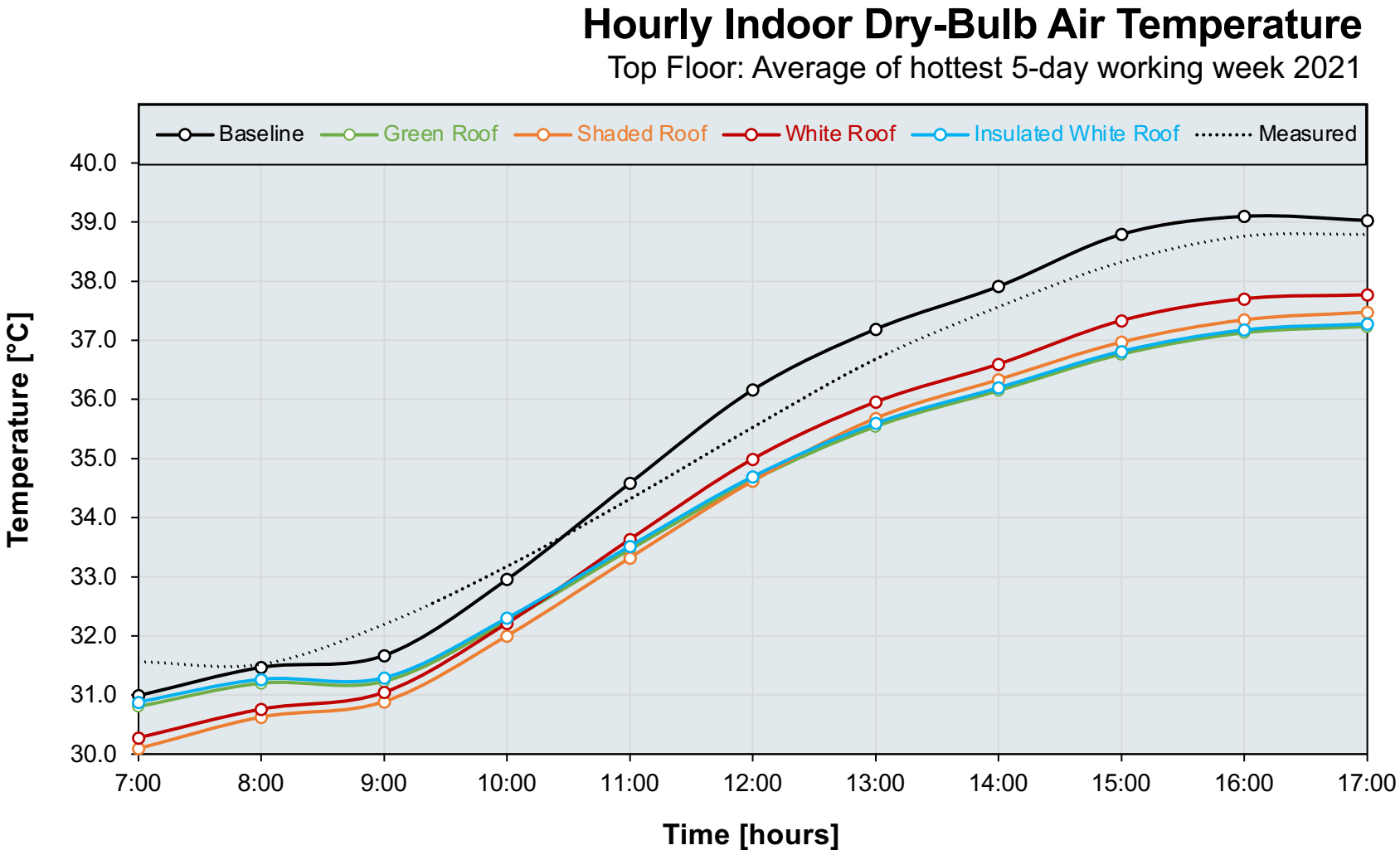
Cool Months (Jan, Feb, Nov, Dec)
NMBE: -0.25%
CV(RMSE): 6.00%

Hot-Dry Months (Mar, Apr, May)
NMBE: -0.23%
CV(RMSE): 5.21%

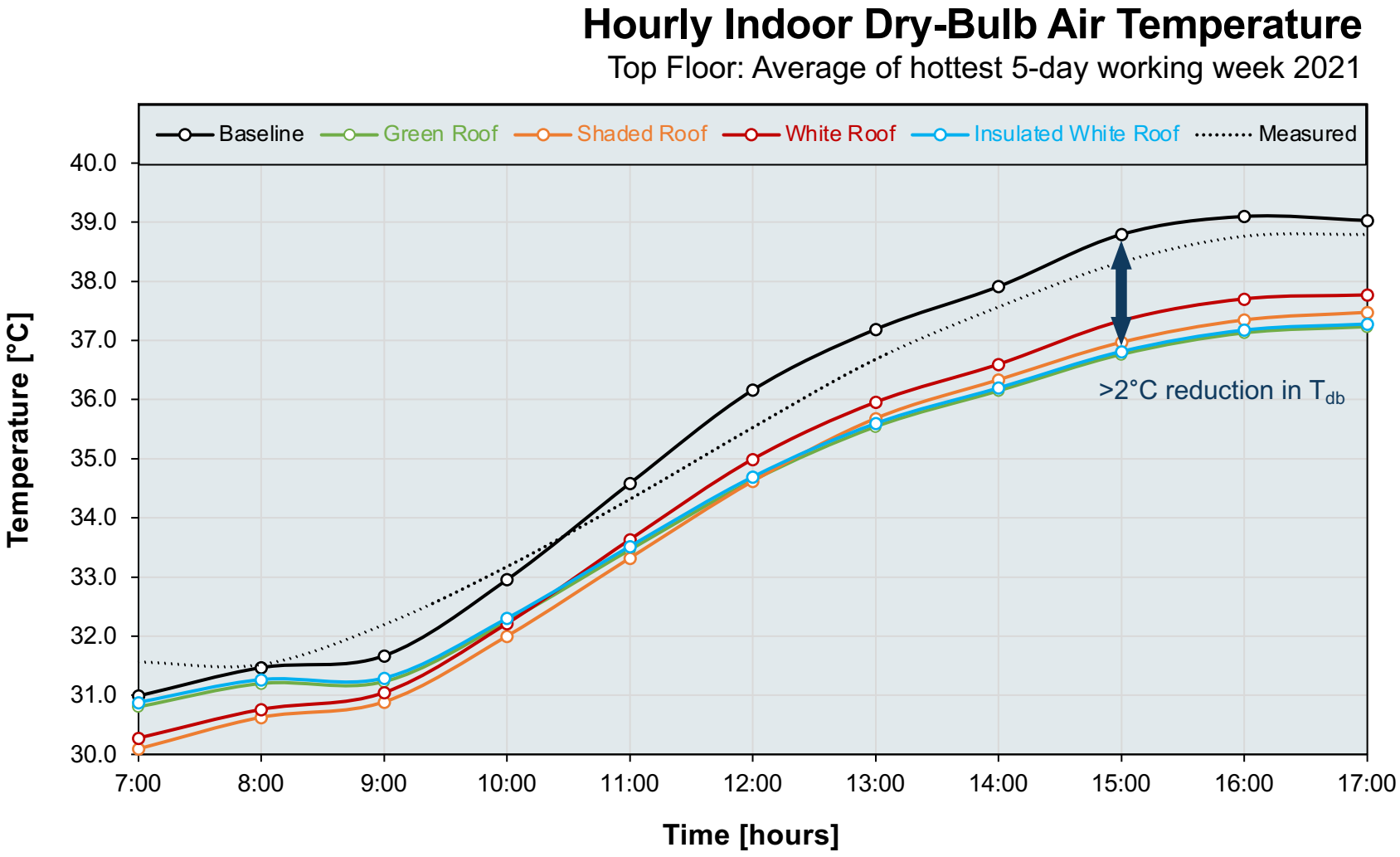
Hot-Wet Months (Jun, Jul, Aug, Sep, Oct)
NMBE: -0.08%
CV(RMSE): 3.98%

Acceptable NMBE for hourly data = ± 10%.
Acceptable CV(RMSE) for hourly data = ± 30%
(ASHRAE Guideline 14-2014)

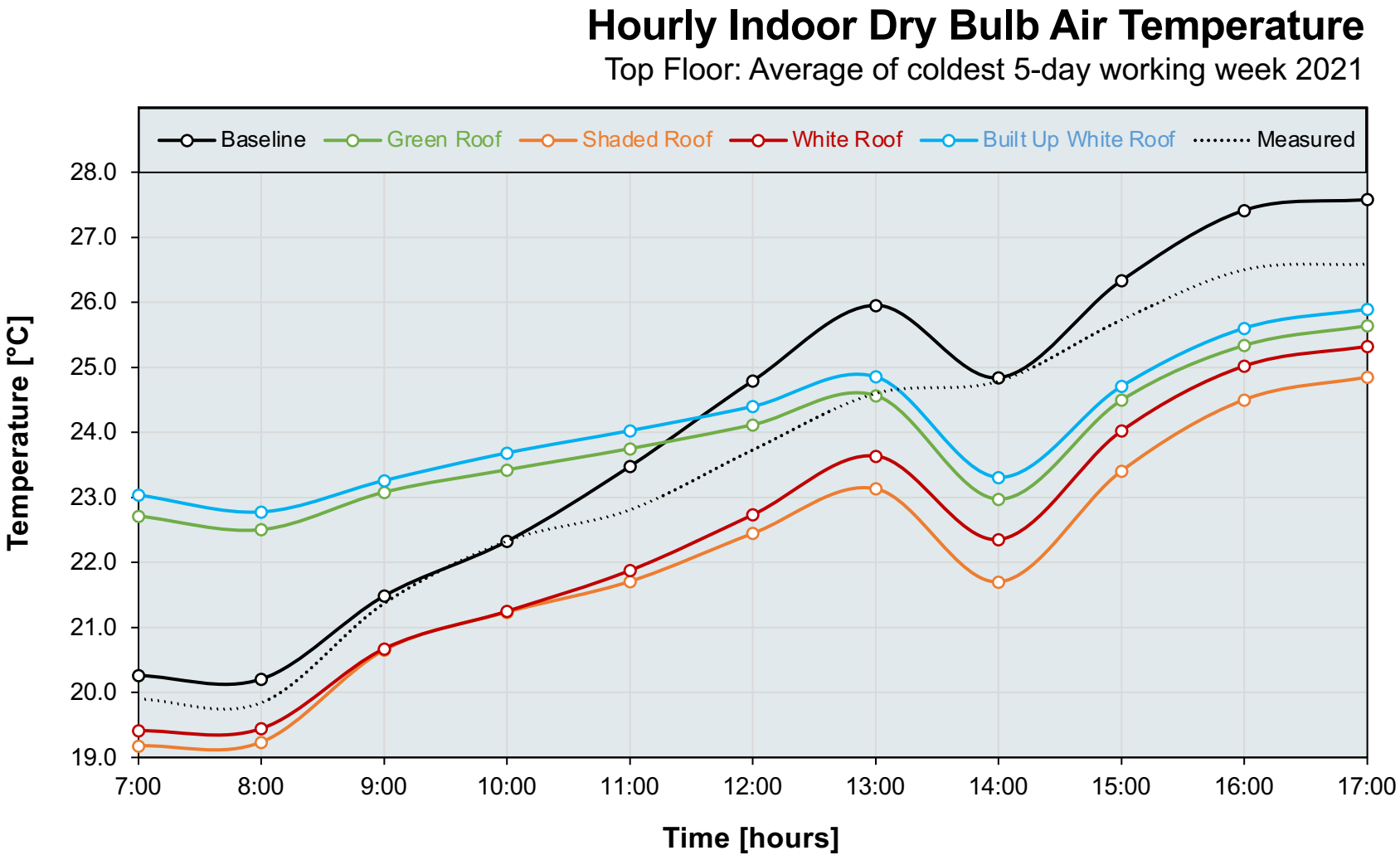
Factory climate - Modelled Strategies 2021



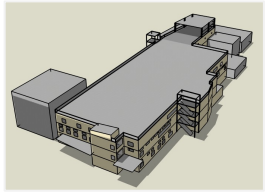
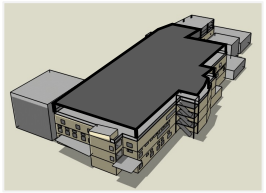
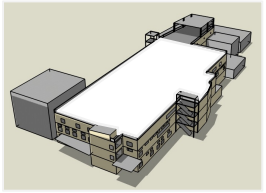
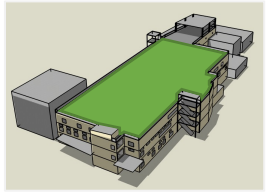
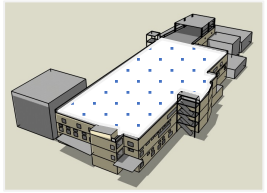
Factory climate - Modelled Strategies 2021



Factory climate - Modelled Strategies 2021

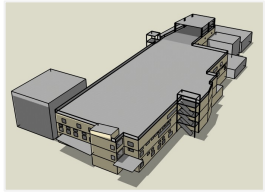
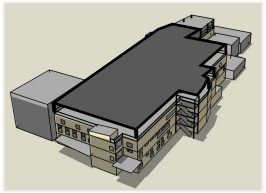
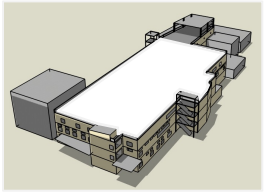
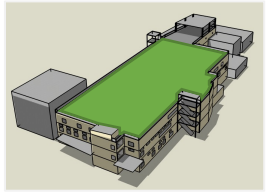
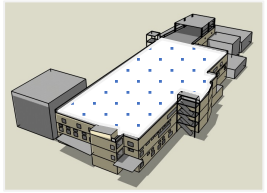


Factory climate - Present Day Performance

Heat Index Category	Baseline	Shaded Roof	White Roof	Green Roof	Insulated White Roof
Extreme Danger [>46°C]	217 h	**-61 (↓28%)**	-48 (↓22%)	-56 (↓26%)	-53 (↓24%)
Danger [≥39°C]	818 h	**-134 (↓16%)**	-117 (↓14%)	-95 (↓12%)	-96 (↓12%)
Extreme Caution [≥33°C]	1080 h	**-41 (↓4%)**	-38 (↓4%)	-4 (↓0.4%)	+6 (↑1%)
Caution [≥27°C]	1044 h	**-88 (↓8%)**	-64 (↓6%)	-2 (↓0.2%)	+25 (↑2%)
Low Risk [<27°C]	549 h	**+324 (↑59%)**	+267 (↑49%)	+157 (↑29%)	+118 (↑21%)

Factory climate - Present Day Performance

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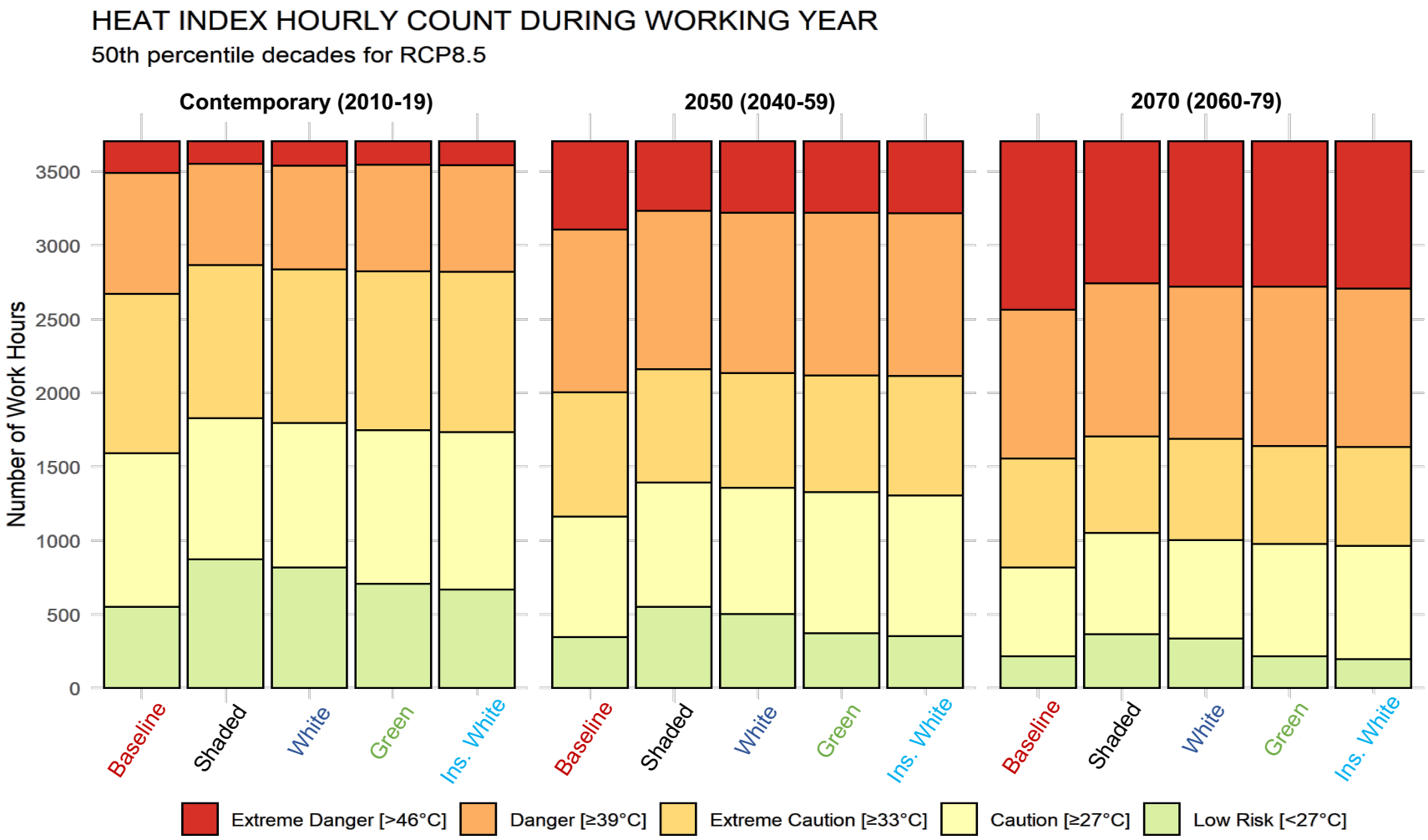
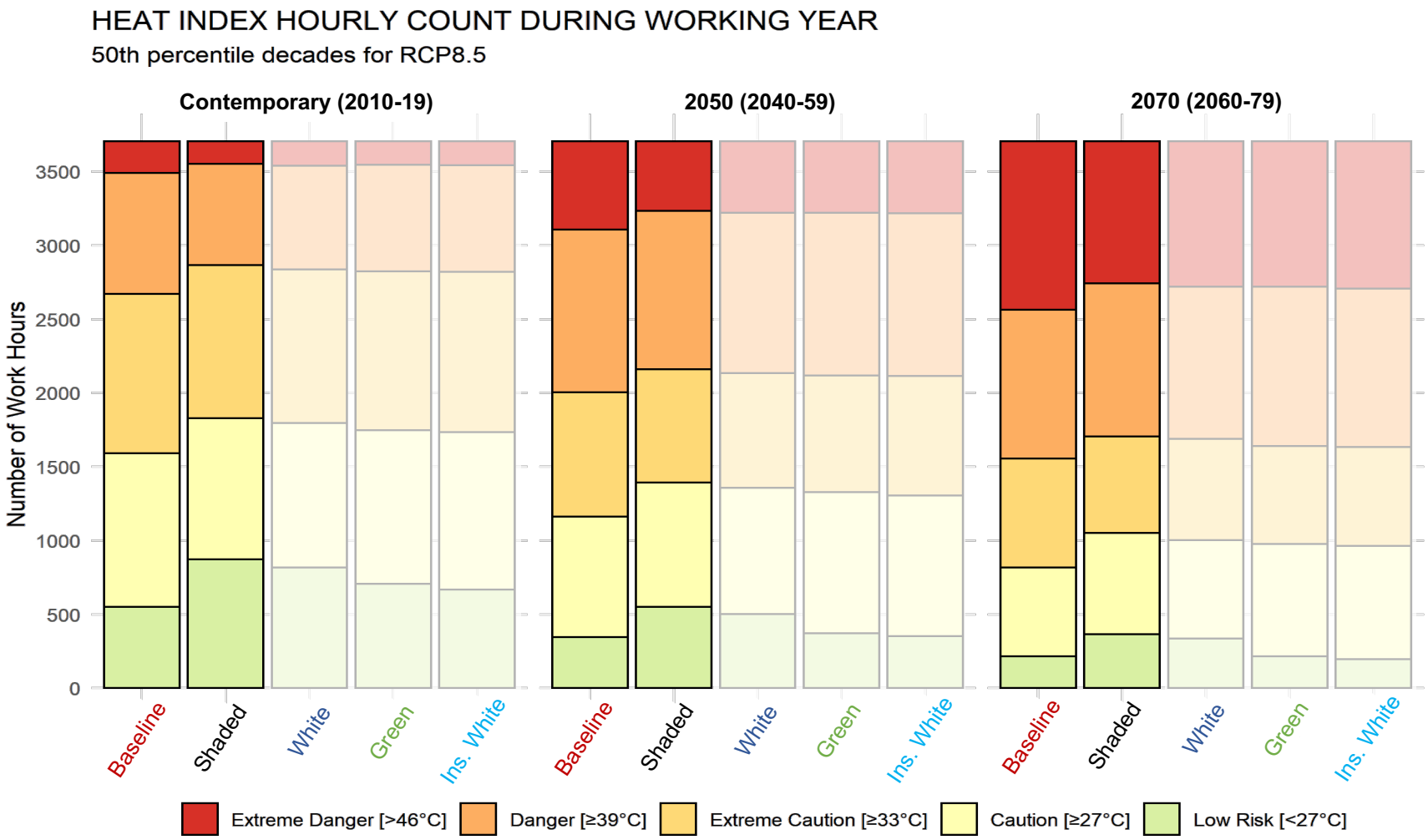
Reduction in highest risk hours equivalent to 3.9 fulltime (50h) work weeks

Overall shift to low risk hours equivalent to 6.5 fulltime (50h) work weeks

Interventions in the future



Interventions in the future



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Personal Cooling Interventions

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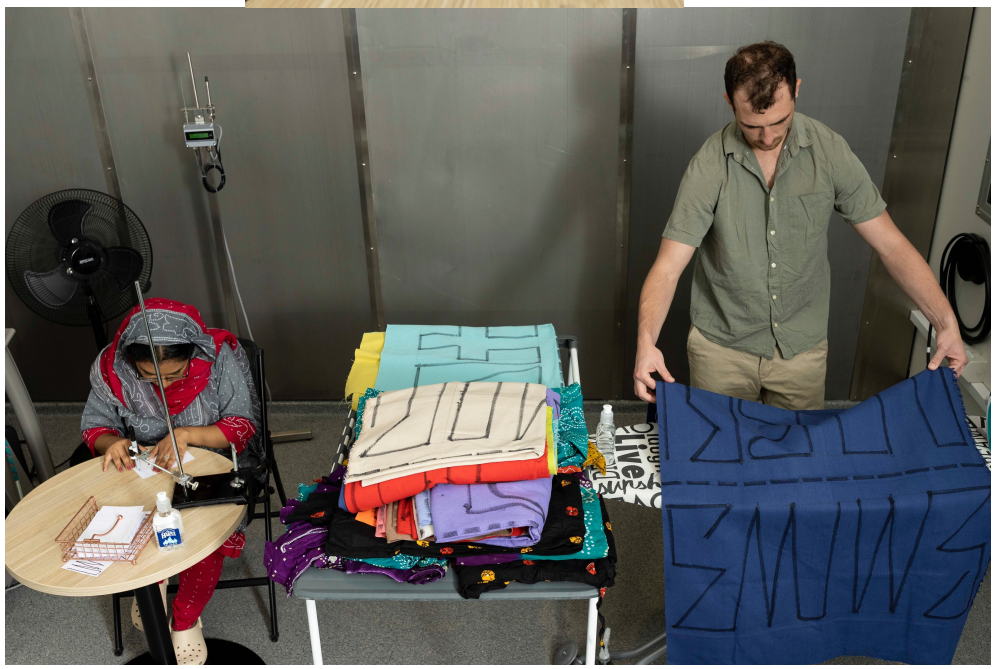
Replicating the average 3-hour temperature of the factory during the hottest week of the year

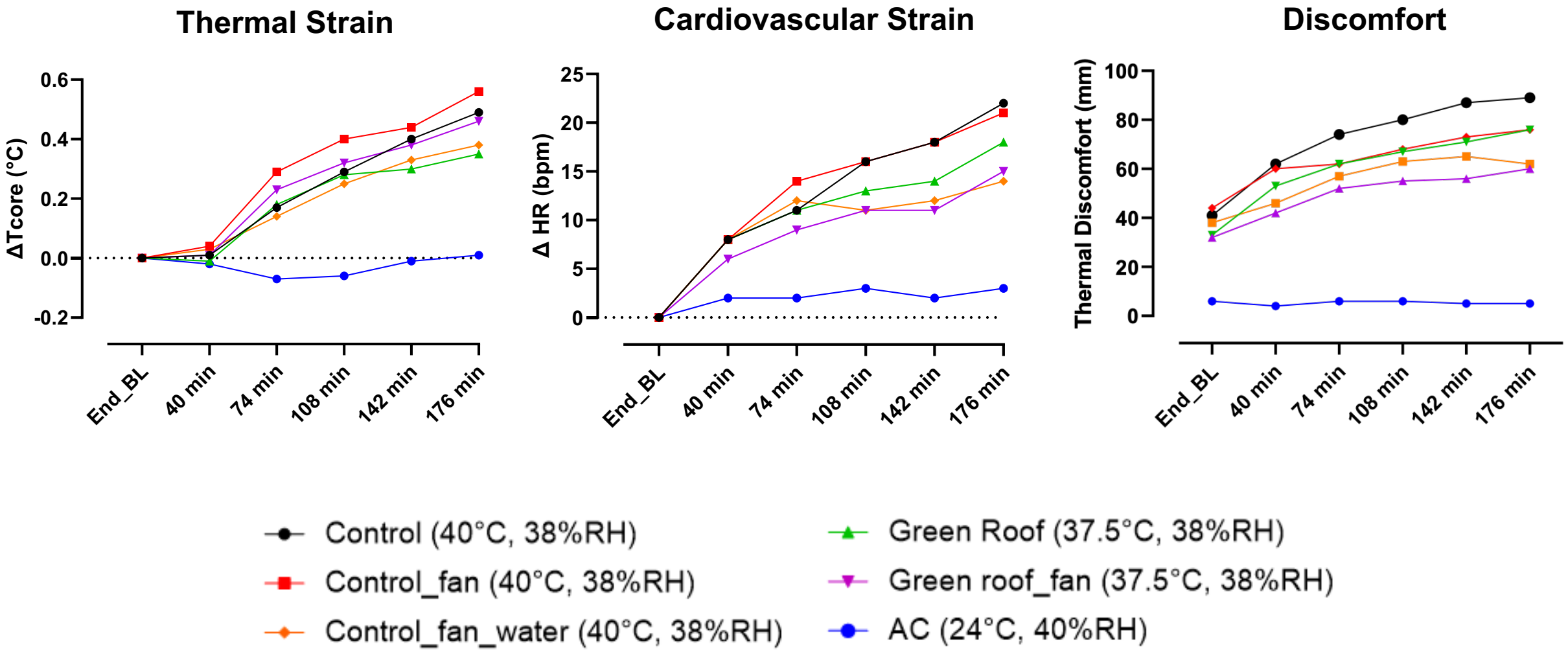
Testing the use of low-cost cooling interventions in various environments.

Low-Cost Cooling Interventions
- Fanning
- Fanning + Water Intake

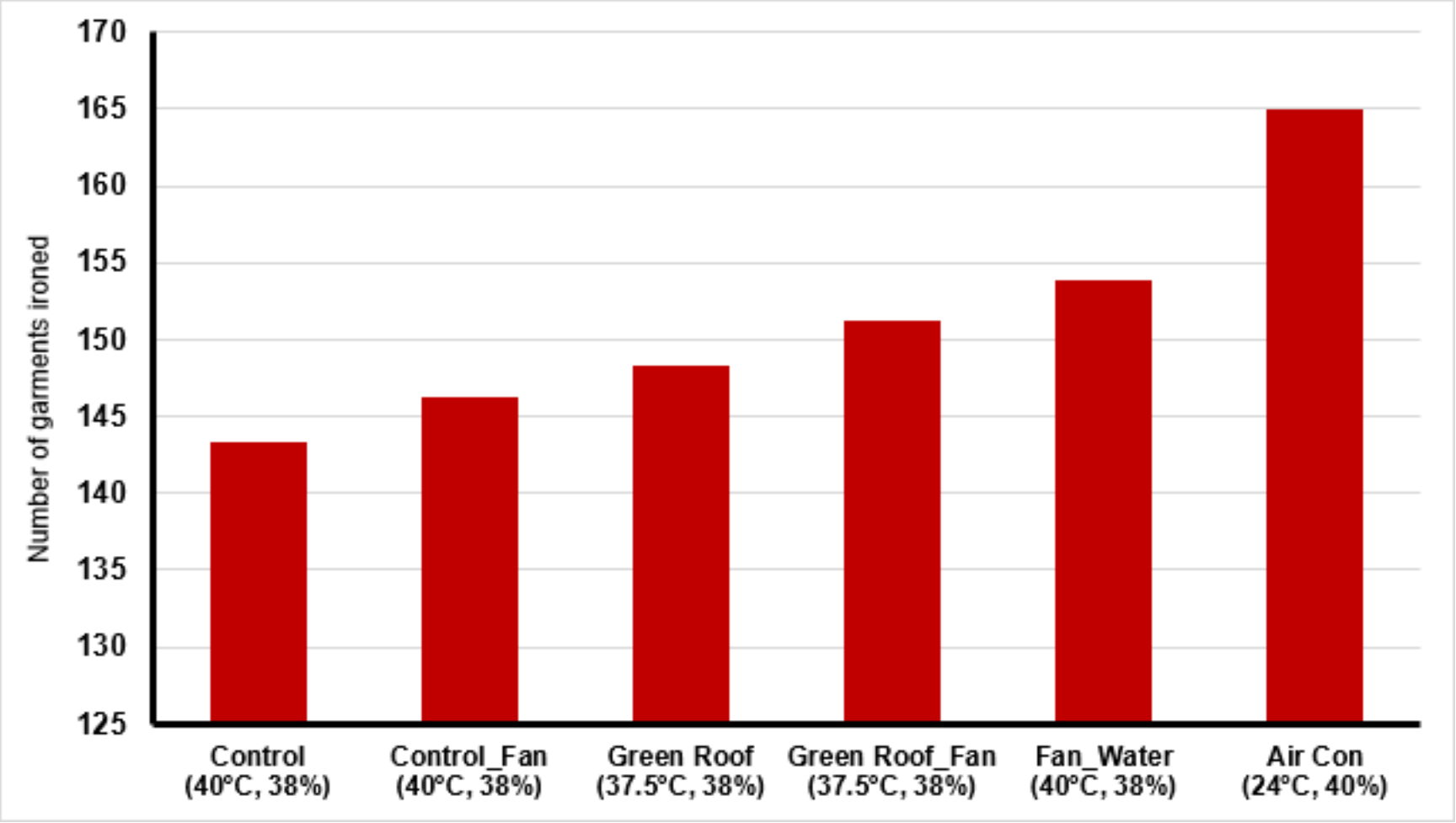
Environments
- Control i.e. Current Factory (40 °C)
- Green Roof (38 °C)
- Air-Conditioning (24 °C)

Outcomes
- Body temperatures (skin and core)
- Heart rate
- Thermal and Thirst Perceptions
- Productivity (Errors and Quantity)



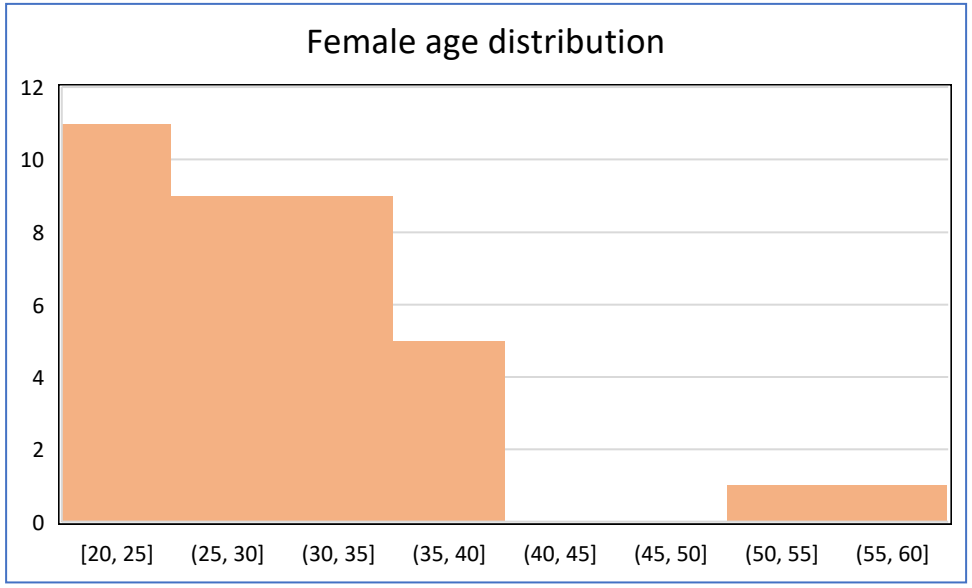

Thermal Strain
ΔTcore (°C)
0.6
0.4
0.2
0.0
-0.2
End_BL
40 min
74 min
108 min
142 min
176 min
Cardiovascular Strain
Δ HR (bpm)
25
20
15
10
5
0
End_BL
40 min
74 min
108 min
142 min
176 min
Discomfort
Thermal Discomfort (mm)
100
80
60
40
20
0
End_BL
40 min
74 min
108 min
142 min
176 min
Control (40°C, 38%RH)
Control_fan (40°C, 38%RH)
Control_fan_water (40°C, 38%RH)
Green Roof (37.5°C, 38%RH)
Green roof_fan (37.5°C, 38%RH)
AC (24°C, 40%RH)

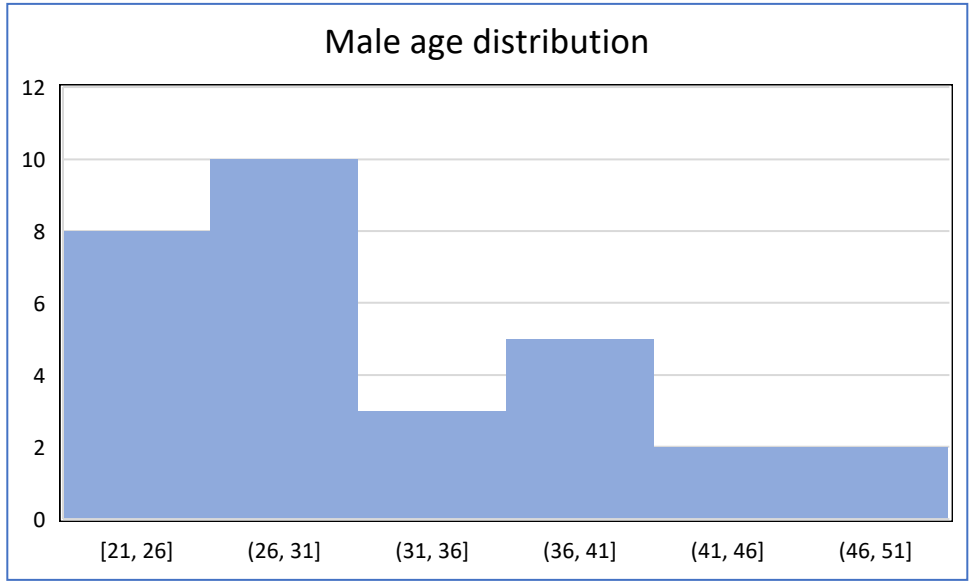
Work Productivity - Ironing



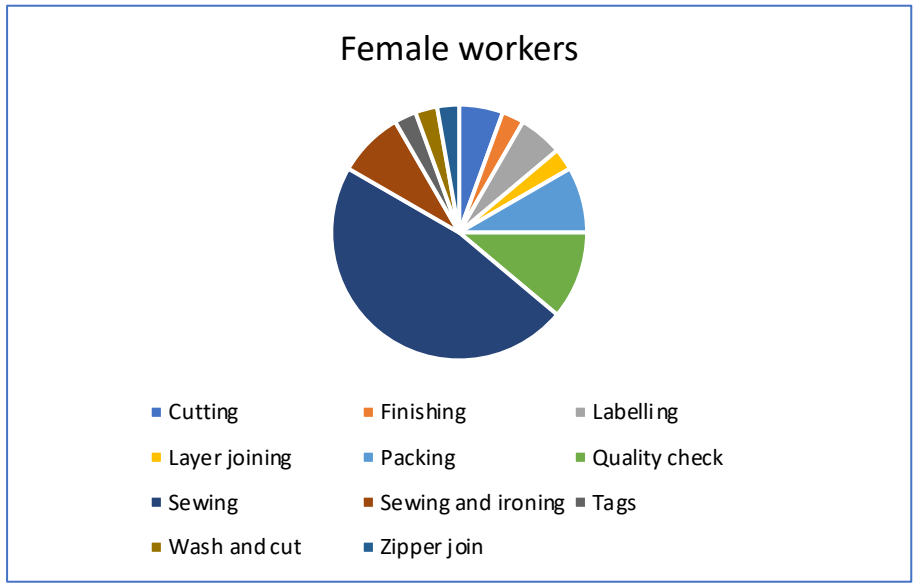
Worker surveys

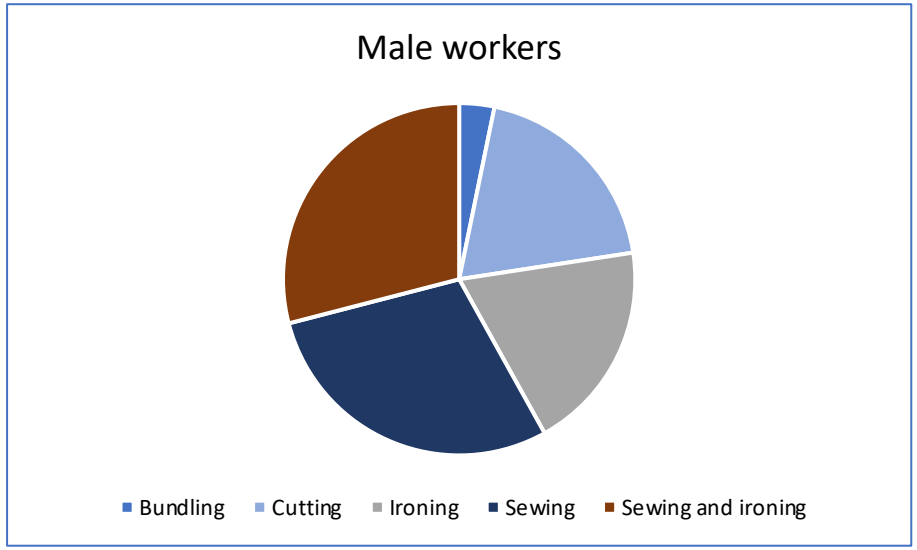
	n	Votes	Age (y)	Height (m)	Weight (kg)	BMI (au)
Male	31	911	32 ± 8	1.66 ± 0.06	59.1 ± 9.3	21.7 ± 3.4
Female	36	940	31 ± 8	1.52 ± 0.06	50.1 ± 10.3	21.7 ± 4.6
Total	**67**	**1851**	**31 ± 8**	**1.60 ± 0.08**	**54.3 ± 10.8**	**21.7 ± 4.2**





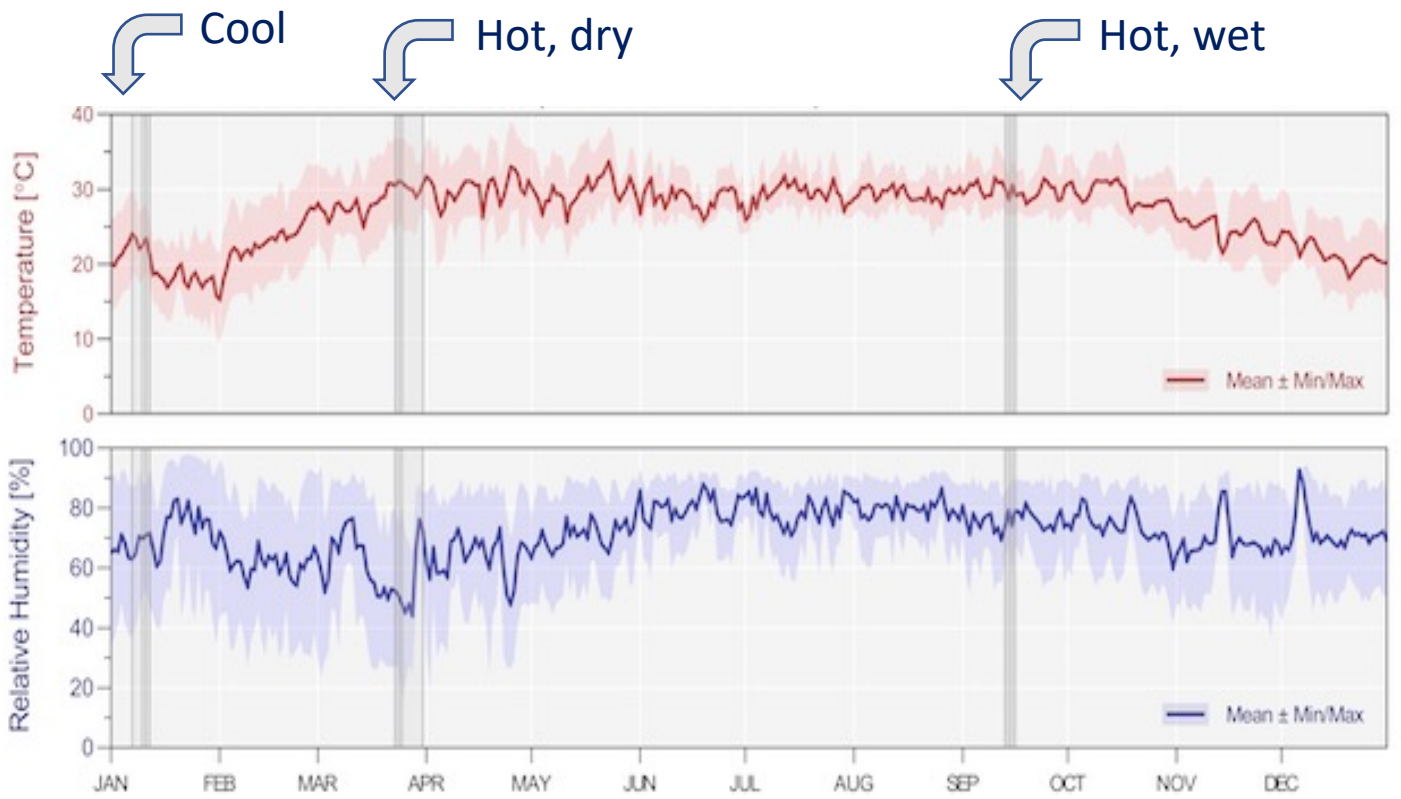
Worker surveys





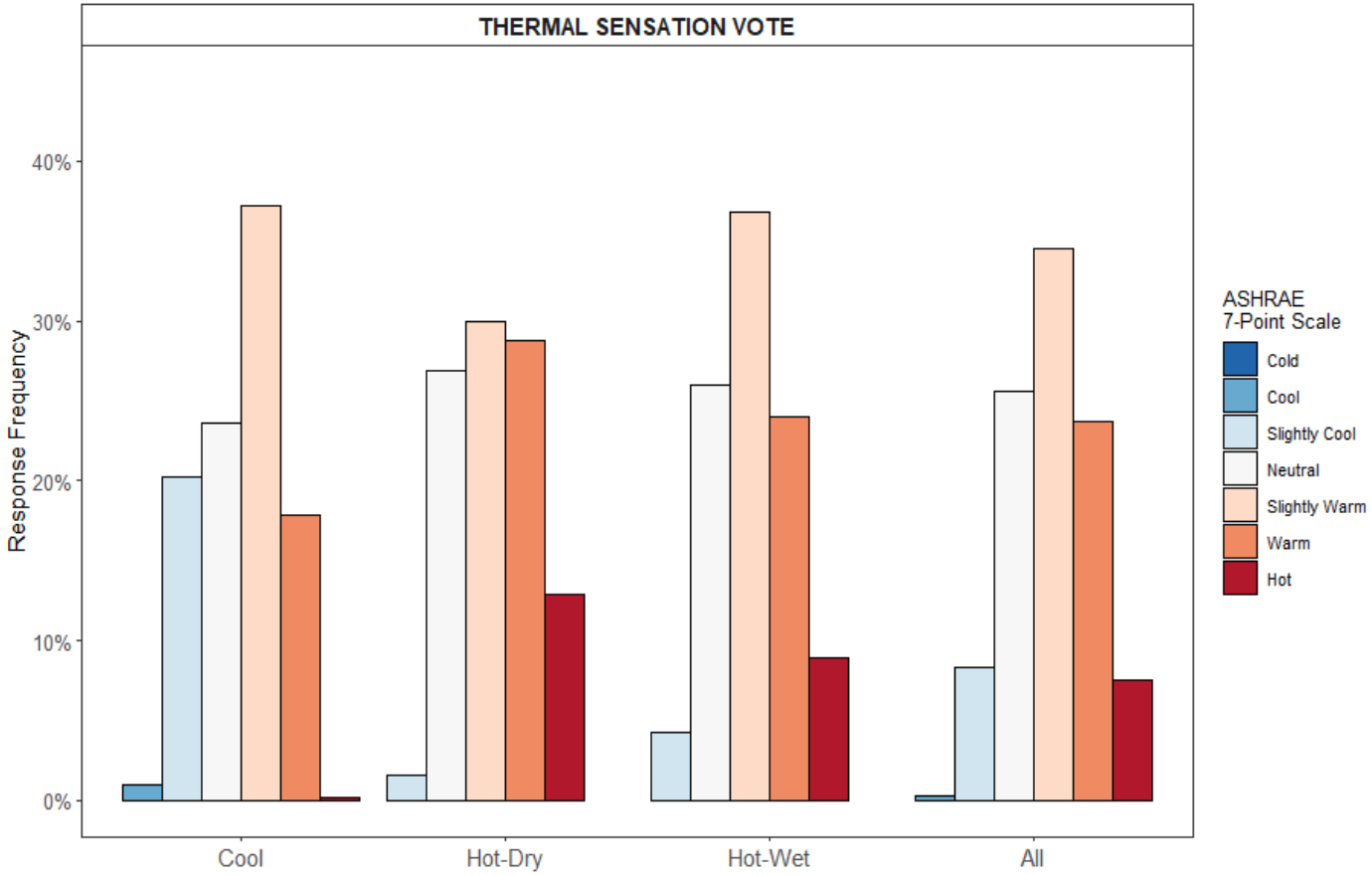
When did we survey:?

- three times,
- over 4-5 days each time,
- three times per day



How do you feel? Thermal Comfort

- In winter (January) surveyed workers were largely comfortable with their environment,
  - 58% desired no change with respect to temperature
  - 80% desired no change with respect to humidity.
- Even in winter 38% wished for a cooler environment
- In the hot, humid season (September), 78% wished for cooler working conditions, and 69% for less humid conditions.



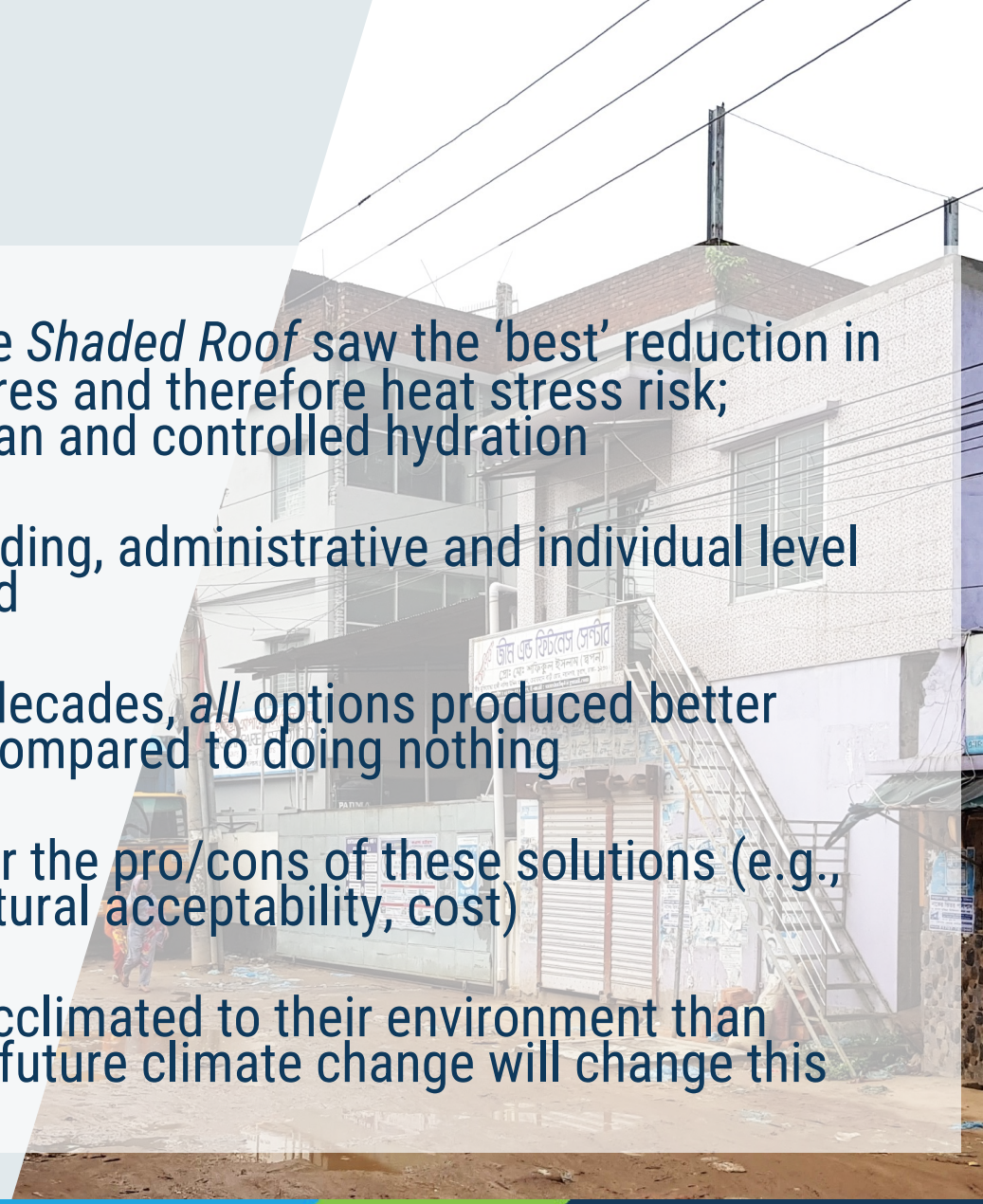
Future plans

- Dissemination events
- Journal papers in preparation
- We would like to explore the performance of the factory building and personal interventions in the real world
- To involve installing white, green and shaded roofs, and developing personal cooling regimes with workers using fans and hydration (and clothing changes where culturally appropriate)
- Using surveys and physiological measures (respiration, heart rate, blood pressure, kidney function) to evaluate comfort and stress levels
- A proposal has been submitted to the Wellcome Heat Health call led by icddr,b in Dhaka and with BUET, Griffith and University of Sydney participating

Take home messages

1. What are the present-day working conditions? *Severe*
2. Do these conditions cause heat stress among RMG workers? *They cause discomfort but no evidence of sickness*
3. Can sustainable cooling strategies improve working conditions without adding to the GHG burden? *Yes, from models/experiments*
4. What will be the impacts of future climate change on factory working conditions? *Depending on GHG trajectory and urban heat island , temperature increases of 2-4°C by mid-century can be expected*
5. Can the identified sustainable cooling strategies continue to contribute effectively under future worsening conditions? *Yes, from models/experiments*

- Simulations show the *Shaded Roof* saw the 'best' reduction in indoor air temperatures and therefore heat stress risk; improved by use of fan and controlled hydration
- Combinations of building, administrative and individual level strategies are needed
- Today and in future decades, *all* options produced better working conditions compared to doing nothing
- Important to consider the pro/cons of these solutions (e.g., lifespan, upkeep, cultural acceptability, cost)
- Workers are better acclimated to their environment than modelling suggests; future climate change will change this



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Thank you!

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- https://wellcome.org/news/heat-stress-climate-expert-explains

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- https://www.youtube.com/watch?v=XhhQUK0XaAs