Spatial analysis of thermal and daylight simulation data with Mr.Comfy

Max C. Doelling, Dipl.-Ing. | IBPSA NYC Chapter, 16 04 2014

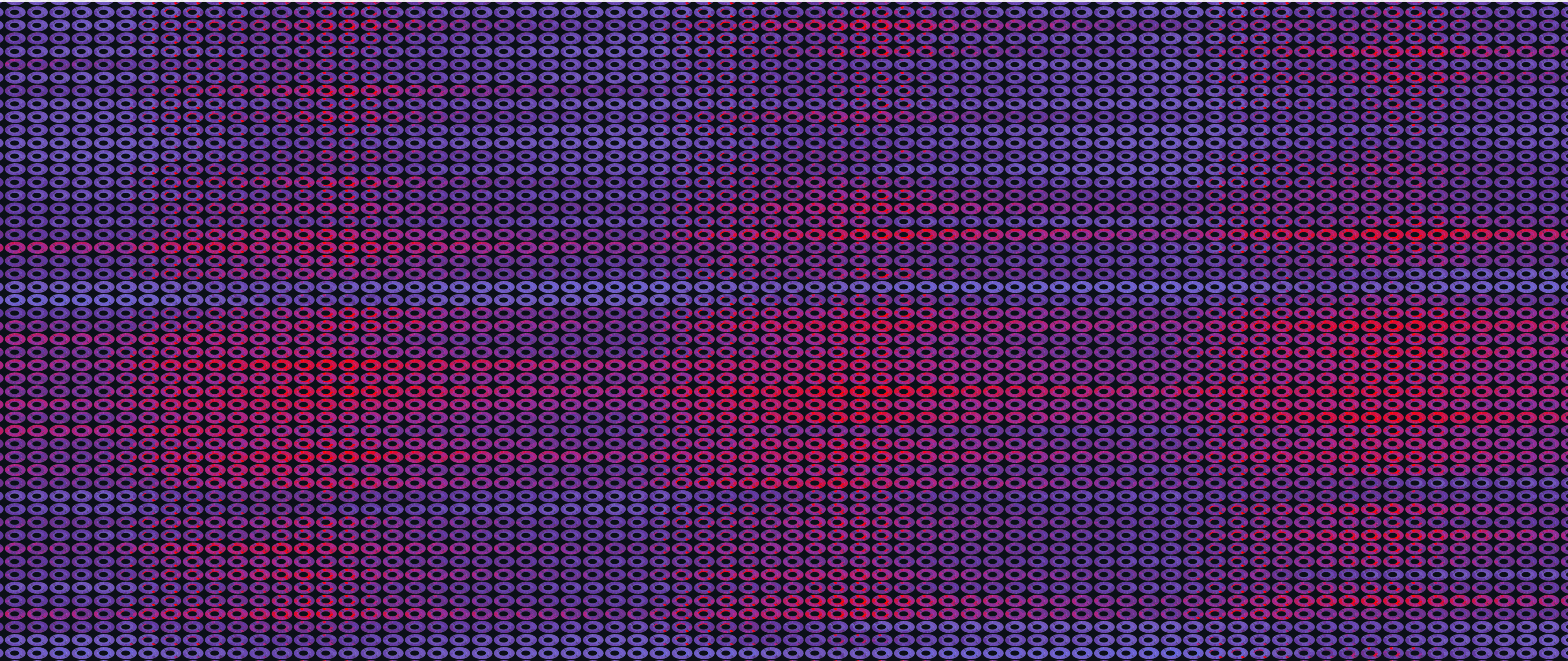
p. 1 | Introduction + Presentation Structure

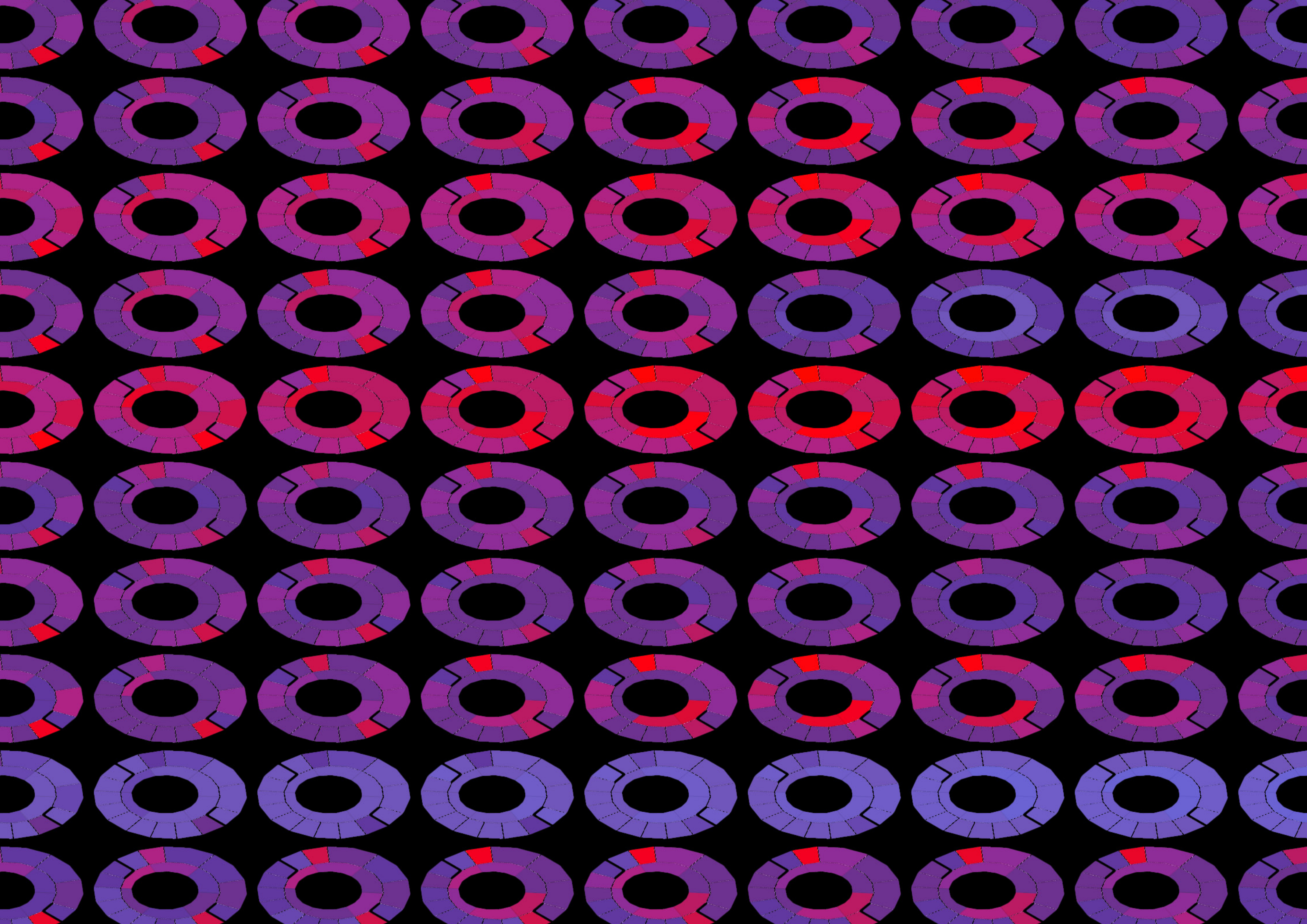
1 Tool development context: integrated design + pedagogy

2 Mr.Comfy features + design cognition

3 Academic case studies: discovery + optimization

4 User survey + outlook





DEVELOPMENT CONTEXT
INTEGRATED DESIGN + PEDAGOGY

p. 3 | Interdisciplinary Classes 2011 - 2014

- Three years of teaching design-integrated thermal and daylight simulation to MArch students at the TU Berlin, Germany

- Formed procedural, cognitive and representational basis for spatial analysis and visualization ideas found in Mr.Comfy

- Education & research project goals:
  - *Investigate the design-led use of current simulation technologies*
  - *Derive an integrated process model through empirical research*
  - *Investigate modes of design/performance representation*
  - *Develop design/simulation support technologies (Mr.Comfy)*

- Design-centricity has strong side effects:
  - *Simulation is science but seen as part of architectural craft*
  - *Design processes are fluid, not procedurally constrained*
  - *Knowledge repositories are primarily spatial models*
  - *The overruling driver is usually global design intent*

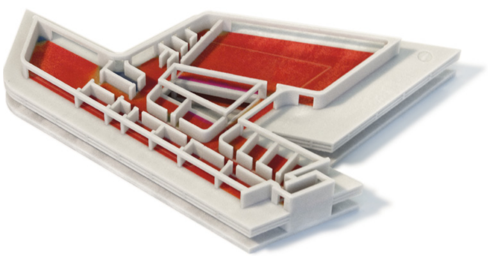
Background/Opposite:
Students R. Georgieva + C. Castillo presenting Community Center Design + Simulations
Parametric Design Class, Winter 2011/2012

DEVELOPMENT CONTEXT
INTEGRATED DESIGN + PEDAGOGY

p. 4 | Class Types 2011 - 2014

A : Parametric Design Climates : 1, 2, 4

Community Center & Offices
(mechanically conditioned)

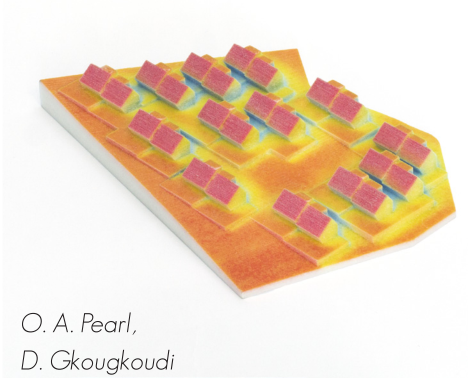


R. Canihuante,
M. El-Soudani
Office Bldg. (FL site)

Strategies:
Geometric optimizations
Fixed materials & setpoints
Balance thermal & daylight

B : Performative Design 1, 3, 4

Housing Units & Urban Design
(passive & mechanical conditioning)

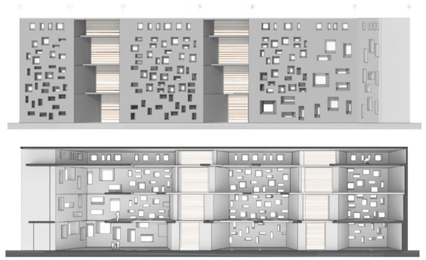


O. A. Pearl,
D. Gkougkoudi
Housing units (SWE site)

Geometric & material optimization
Fixed setpoints & U-Val., custom mat.
Thermal performance focus

C : 'Robust' Studio Integration 5

Multi - Use Exhibition & Office building
(mechanically conditioned)

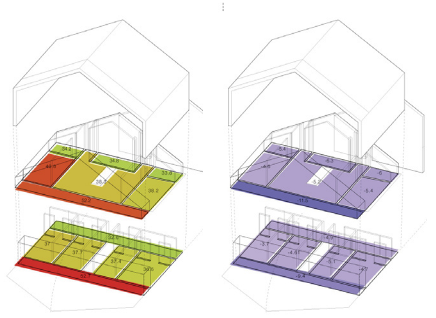


B. Suazo, M. Silva
Mixed-Use Exhibition Building (Berlin site)

Geometric & material optimization
Custom setpoints, mat. & behavior
Individualized performance tests

D : Performance Mapping 1 - 5

Spatial Thermal Performance Visualization
+ Optimization with Custom Software



F. Wich, B. Wittik
Housing Development (SWE site)

Comfort and energy use behaviour discovery & optimization visualization of new and previous class designs

Design Climate Zones

1 Hollywod, FL, USA
Climate.: Am (Köppen class)

2 Hashtgerd, Iran
Climate: BSk

3 Yazd, Iran
Climate: BWk

4 Östersund, Sweden
Climate: Dfc

5 Berlin, Germany
Climate: Dfb

DEVELOPMENT CONTEXT
INTEGRATED DESIGN + PEDAGOGY

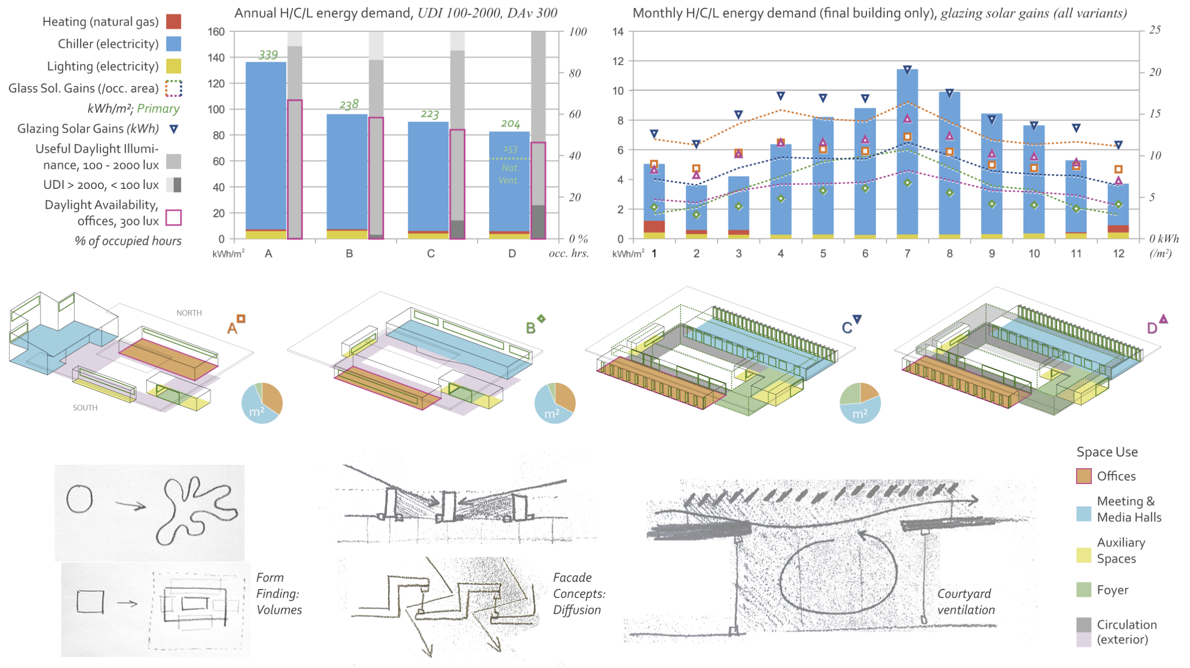
p. 5 | Performance Representations, Process Models

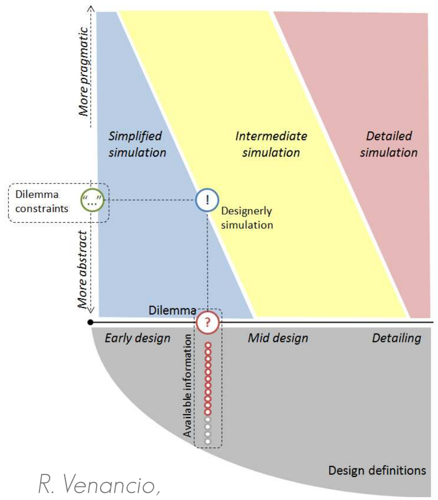
- Discourse on process models has in part moved away from a purely iterative and deterministic understanding
  - *See e.g. Bleil de Souza & Tucker, 2013; Venancio et al., 2011; Doelling & Nasrollahi, 2013; Fioravanti et al., 2011*

- Class design observations showed:
  - *Dynamic process fields better represent what actually happens when design meets performance exploration*
  - *Performance states are often encoded by multi-domain representations that express knowledge states*
  - *Hybrid drawings, models spatially show geometry, intended properties, behaviours and contextual factors at once*

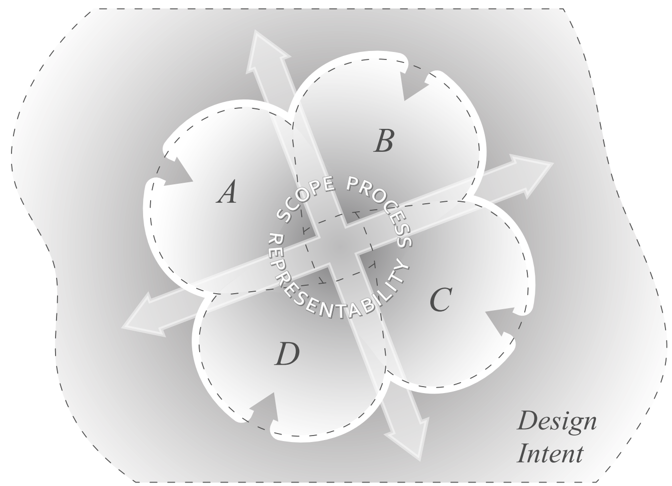
- Process and representation mediate cognition, which shapes design/simulation support tool requirements:
  - *Support dynamic, customized analysis, don't obstruct it*
  - *Improve design behavior pattern recognition*
  - *Synthesize disparate knowledge domains into a whole*

- "Tacit" knowledge through enhanced cognition becomes "explicit" (or "experience") (Friedman, 2003)





R. Venancio, A. Pedrini, A.C. van der Linden, E. van den Ham & R. Stouffs: Think Designerly! Using Multiple Simulation Tools to Solve Architectural Dilemmas (BS '11)



M. C. Doelling & F. Nasrollahi: Dynamic Field Design/Simulation Process Integration Model (Building Simulation '13)

Opposite, top: Florida Community Center Performance Development, I. Crego, D. Cepeda
bottom: Integrated Process Models, R. Venancio / M. C. Doelling

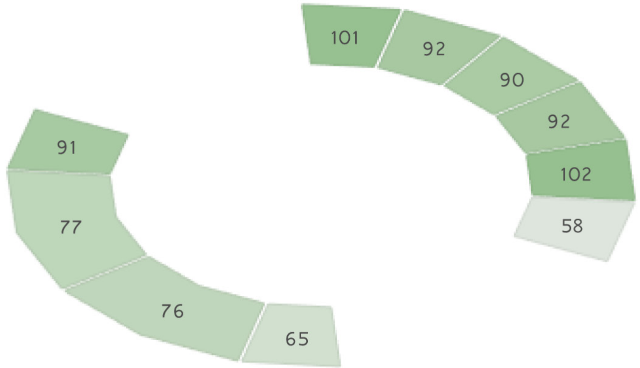
MR.COMFY FEATURES + DESIGN COGNITION

p. 6 | Development Rationale, Capabilities Overview

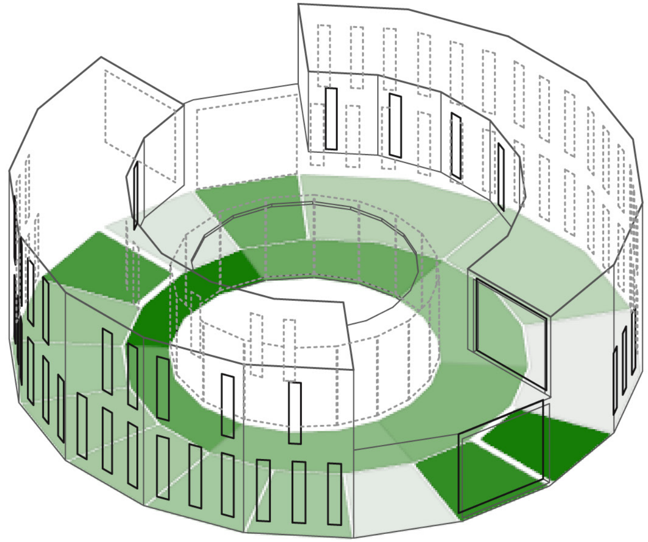
"[...] one's ability to think is extremely limited without external props and tools" (Ware, 2004 p. xix)

"What is happening in a design, when do the behaviours occur, where do they occur, and how do they compare to simultaneous states in other parts of the intended building?" To answer these questions enables designers to find out why patterns exist, and through contextual cognition to influence them.

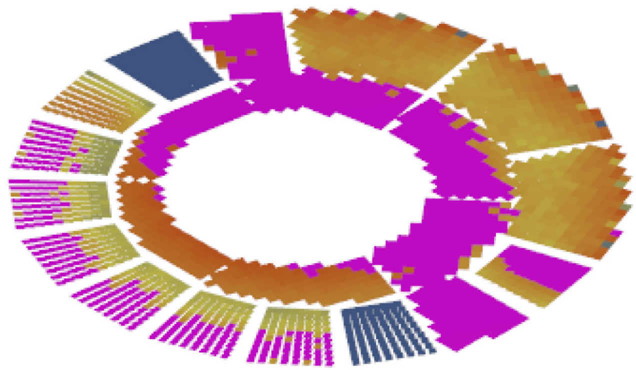
- Influenced by Shneidermann's Information Seeking Mantra:
  - *"Overview first, zoom and filter, details on demand" (S., '96)*
- To aid cognition, Mr.Comfy has dedicated functionality:
  - *Zone-based, spatial display of E+ thermal, Daysim daylight results*
  - *Dynamic color mapping for pattern recognition in design space*
  - *Custom metrics creation through GH component instantiation*
  - *Scales for large & geometrically complex models (+states)*
- Visualization precedents (publicly available, only thermal):
  - *Ecotect (similar internal, non-GUI exposed functionality)*
  - *OpenStudio, IDA ICE (zone boundary color mapping)*



Sample Office Building (2 floors)
Climate: Berlin, Germany
Fully conditioned
Core occupancy: 8 - 20 hrs.



Annual Total Heating + Cooling Energy Use, kWh/m²
Schedule: 24 hrs., fit bounds
Sum mode, annual custom metric



Daylight Availability, 500 lux
Meshed DIVA metrics output
Schedule: 8 - 20 hrs.

Annual Total Heating + Cooling 50 kWh/m² 182

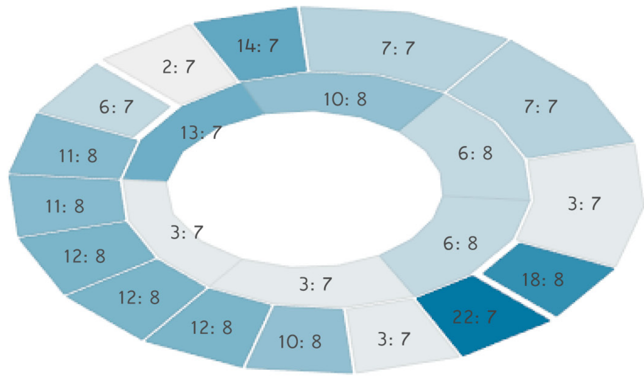
Daylight Availability (500 lux) 0 % occ. hrs. 100

MR.COMFY FEATURES + DESIGN COGNITION

p. 7 | Search, Mapping Modes, Multi-Metric Display

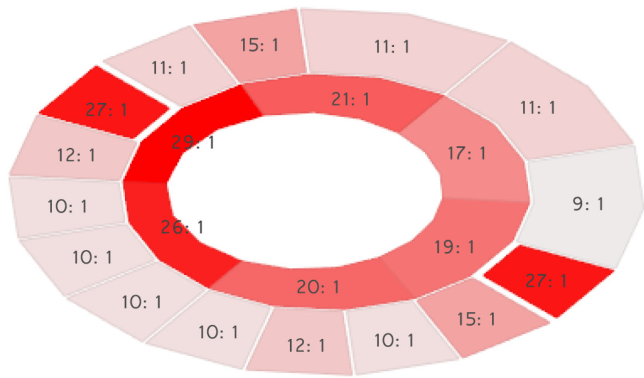
- Comparative display of several metrics enhances analysis
  - "What is happening in a design?" *answerable by cross-mapping*
- Zone min. or max. peak state search aids discovery
  - *Peak mapping to find minima/maxima of mode permutations*
  - *"When do the behaviours occur?", filtered by sum/avrg. mode*
  - *(A)synchronous display of overall zone maxima/minima hierarchy*
  - *"Which spaces use the most heating in winter, and when?"*
  - *Create "sensitivity maps" for e.g. zone transmitted solar*
- Time, calc. and display mode permutations "zoom & filter":
  - *Hourly, daily, monthly, annual range or point in time mode filter*
  - *Sum, average or frequency calculation for custom daily schedules*
  - *"How hot do the west offices get in summer afternoons?"*
- Similar functionality for daylight & thermal display
  - *Schedule/range-synched by default, can be decoupled*

Cooling Energy Use	*2.22*	*kWh/m²*	*22.17*
Heating Energy Use	*8.54*	*kWh/m²*	*28.7*
Avrg. of Total Internal Lat. Gains	*3.93*	*kJ/m²*	*9.32*
Log. of Avrg. Illuminance	*382*	*log(lux)*	*6733*



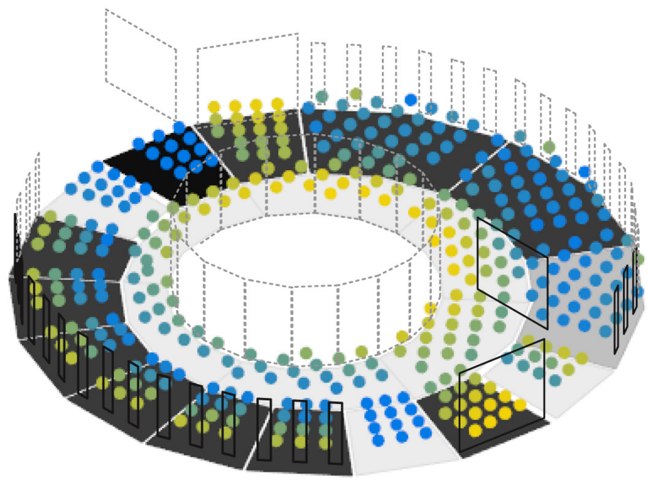
Custom Search, Zone Highest Monthly Cooling Energy Use kWh/m²: month timecode
Sum, max. peaks modes, annual
Schedule: 24 hrs., fit bounds

Max. cooling use in July + August, asynchronous zone peaks



Custom Search, Zone Highest Monthly Heating Energy Use, kWh/m²: month timecode
Sum, max. peaks modes, annual
Schedule: 24 hrs., fit bounds

Heating peaks in January, for all zones (synchronous)



Average of Total Daytime Zone Internal Latent Gains, kJ/m²
Average mode, annual

Illuminance Distribution, log(lux)
Average mode, annual
Schedules: 8 - 20 hrs., fit bounds

Pinpoint zones with highest combined internal and external gains

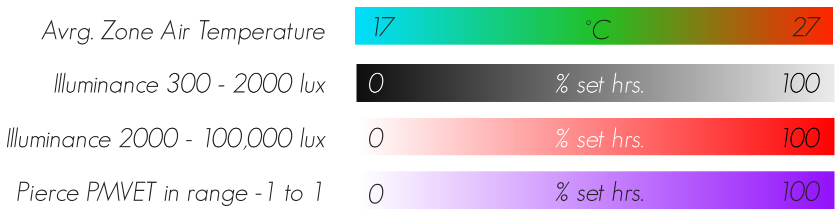
M R . C O M F Y F E A T U R E S +
D E S I G N C O G N I T I O N

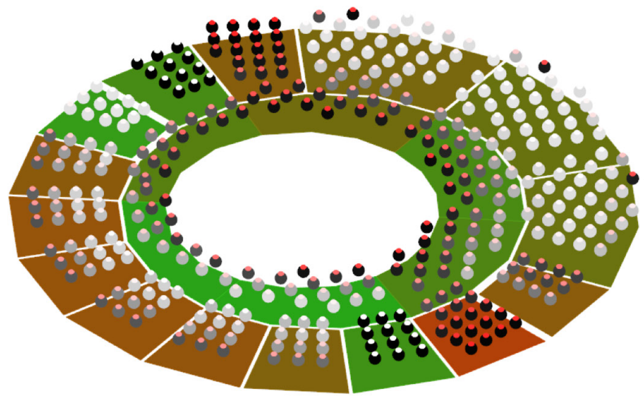
p. 8 | Custom Display Bounds, Daylight Co-Mapping

- Daylight co-display designed as secondary data overlay
  - *Scalable dithered "dot" display to always view thermal context*
  - *Good semantic interpretability even if few sensors used*
  - *Currently no formal metrics but filtered raw data display only*

- Gradient bounds can be fit to current or custom ranges
  - *Fit color range magnifies even small zone value differences*
  - *Custom color ranges to "look ahead" (in a very limited sense):*
  - *Switch from temporally "local" to a "global" reading, and vice versa*
  - *Animation over time steps shows seasonal variable progression*

- Retain aspects of traditional data representations to increase robustness, improve both design and engineering cognition:
  - *Frequency vs. average mapping (catch variable oscillation)*
  - *Numeric values usually co-displayed (prevents "color bias")*
  - *Instantiate components to create custom metric (cross)maps*
  - *Zone-based overview improves simulation error checking*



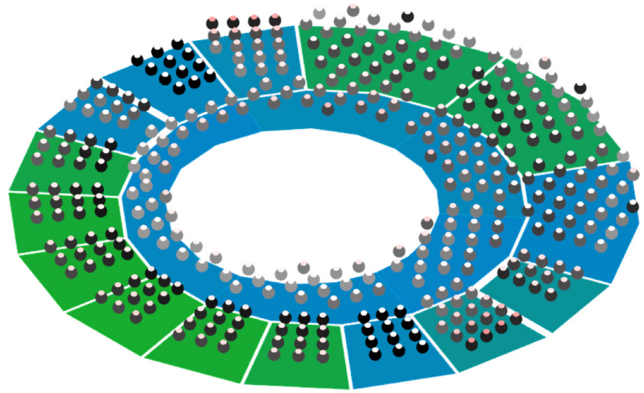


Apr.-Sep. Avrg. Air Temperatures, °C

Nested Illuminance Frequencies,
300 - 2000 lux, % of set hours,
› 2000 lux, , % of set hours (small dots)

Schedule: 8 - 20 hrs., annual bounds

Semi-adequate office daylighting,
tendentially overlit (as in DAv 500);
south offices + yard warmest

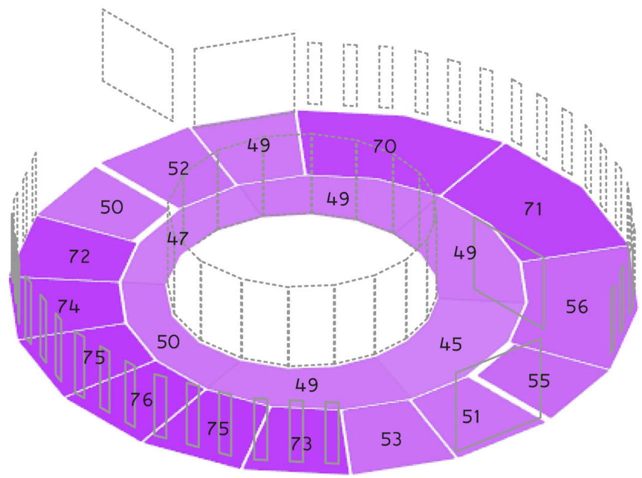


Oct.-Mar. Avrg. Air Temperatures, °C

Nested Illuminance Frequencies,
300 - 2000 lux, % of set hours,
› 2000 lux, , % of set hours (small dots)

Schedule: 8 - 20 hrs., annual bounds

Offices tendentially underlit,
yard circulation spaces coldest



Frequency of Pierce PMVET
Thermal Comfort Index
-1 to 1, % of set hours

Frequency mode, annual
Schedule: 8 - 20 hrs., fit bounds

PMVET distribution mirrors energy
use and temperature mapping

MR.COMFY FEATURES + DESIGN COGNITION

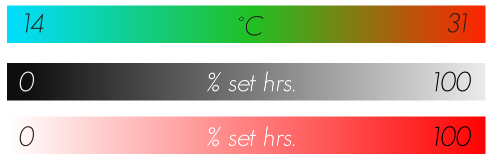
p. 9 | Animation, Multi-Timestep Mapping

- Annual vis. bounds combined with slider animation to create e..g monthly multi-metric maps with individual calculation modes (here average radiant temperature + nested daylight frequencies)

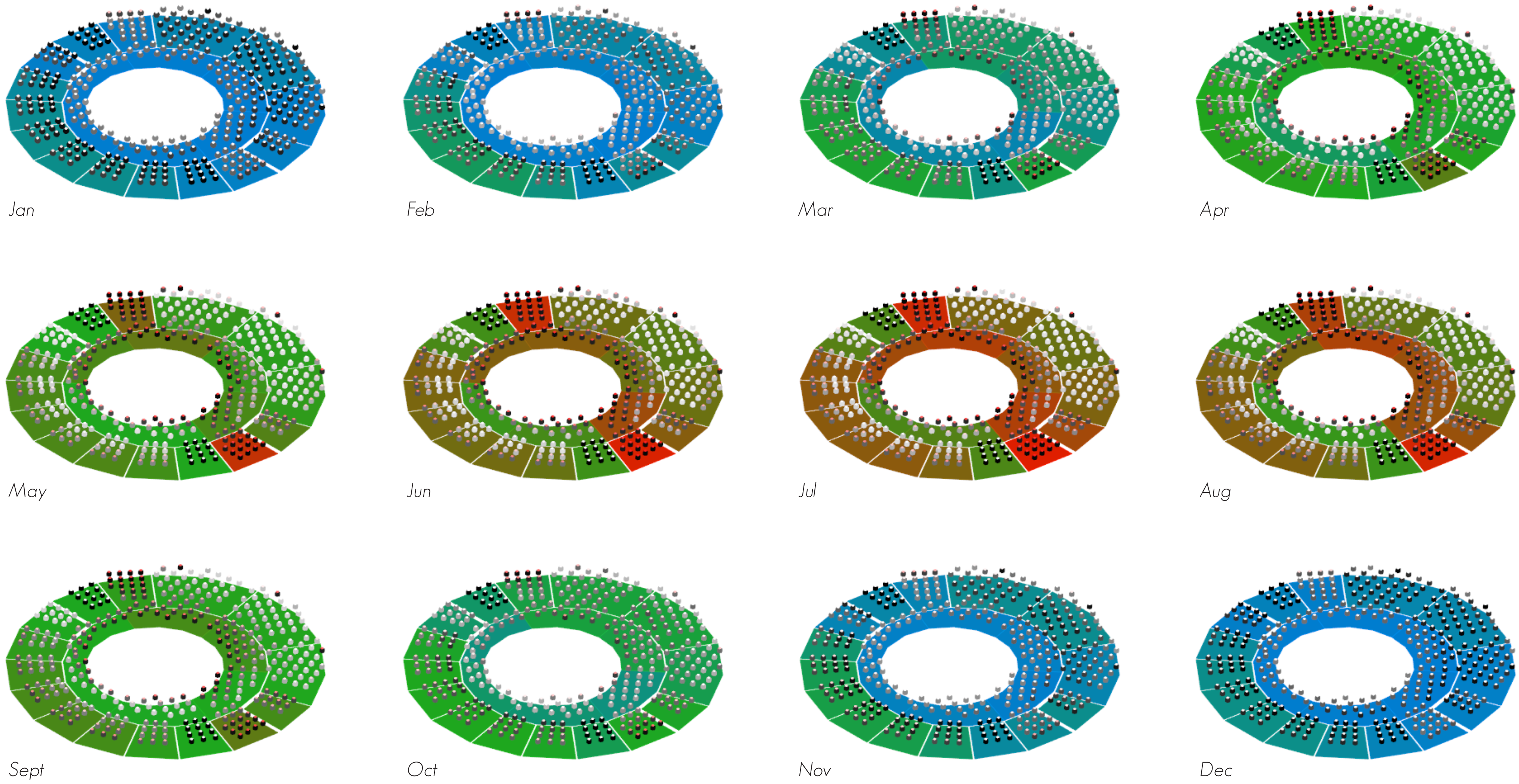
Avrg. Zone Radiant Temperature

Illuminance 300 - 2000 lux (large dots)

Illuminance > 2000 lux (small dots)



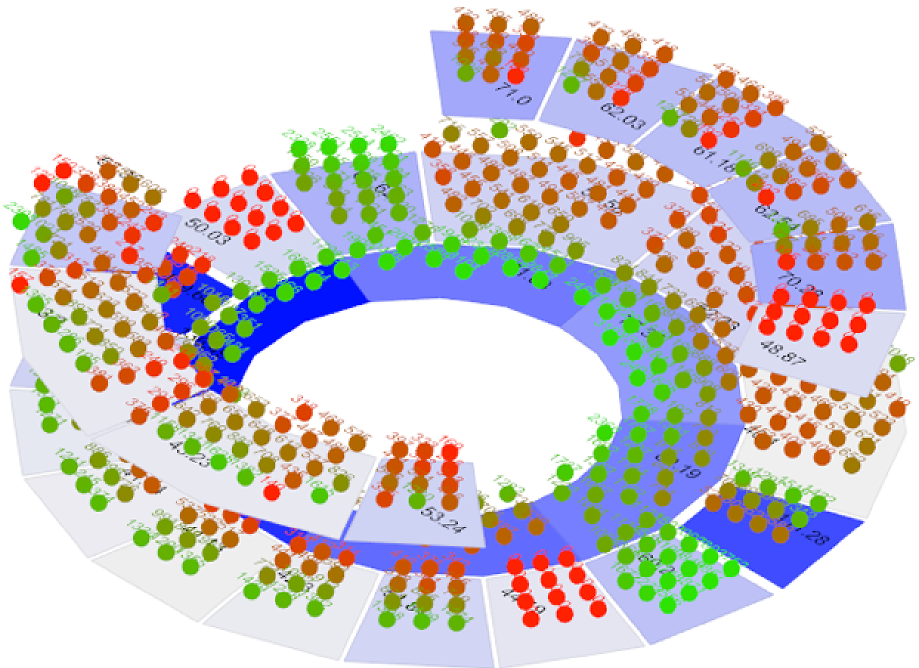
Zone Radiant Temperature, Illuminance Frequencies (daylit vs. overlit), °C / % set. hrs., Average / frequency mode, monthly, schedule 8 - 20 hrs., annual (global) bounds

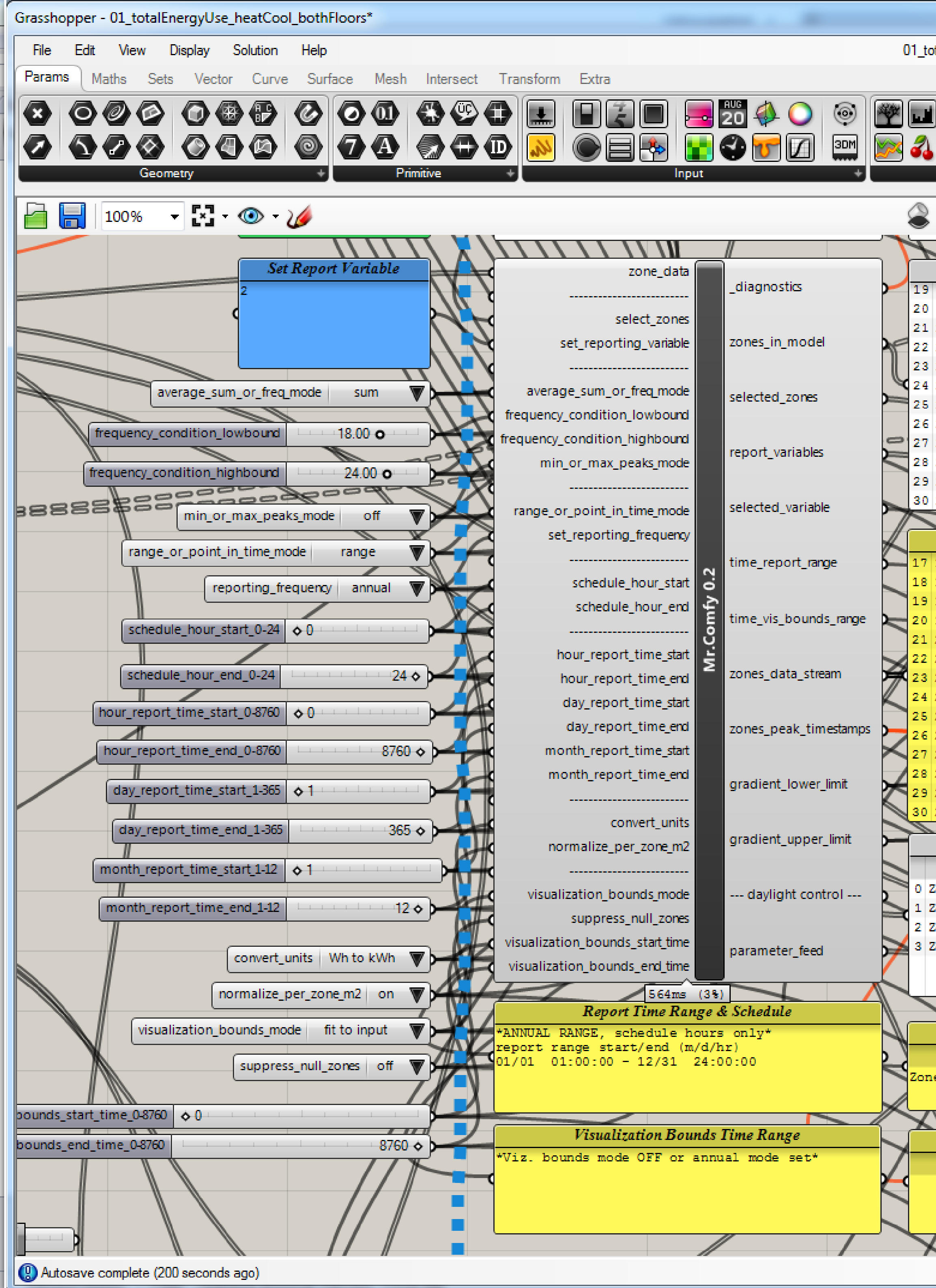


MR.COMFY FEATURES + DESIGN COGNITION

p. 10 | Grasshopper Component Interface

- All time, calculation and output modes directly exposed
  - *Makes interface "heavy", but eases component instantiation*
  - *Exposure of "analogous" input sliders for Grasshopper animation*
  - *Only custom bounds selector interpolates from hourly input*
- On-screen display also shows numeric values by default
- Contrast colors or color vs. monochrome for best results





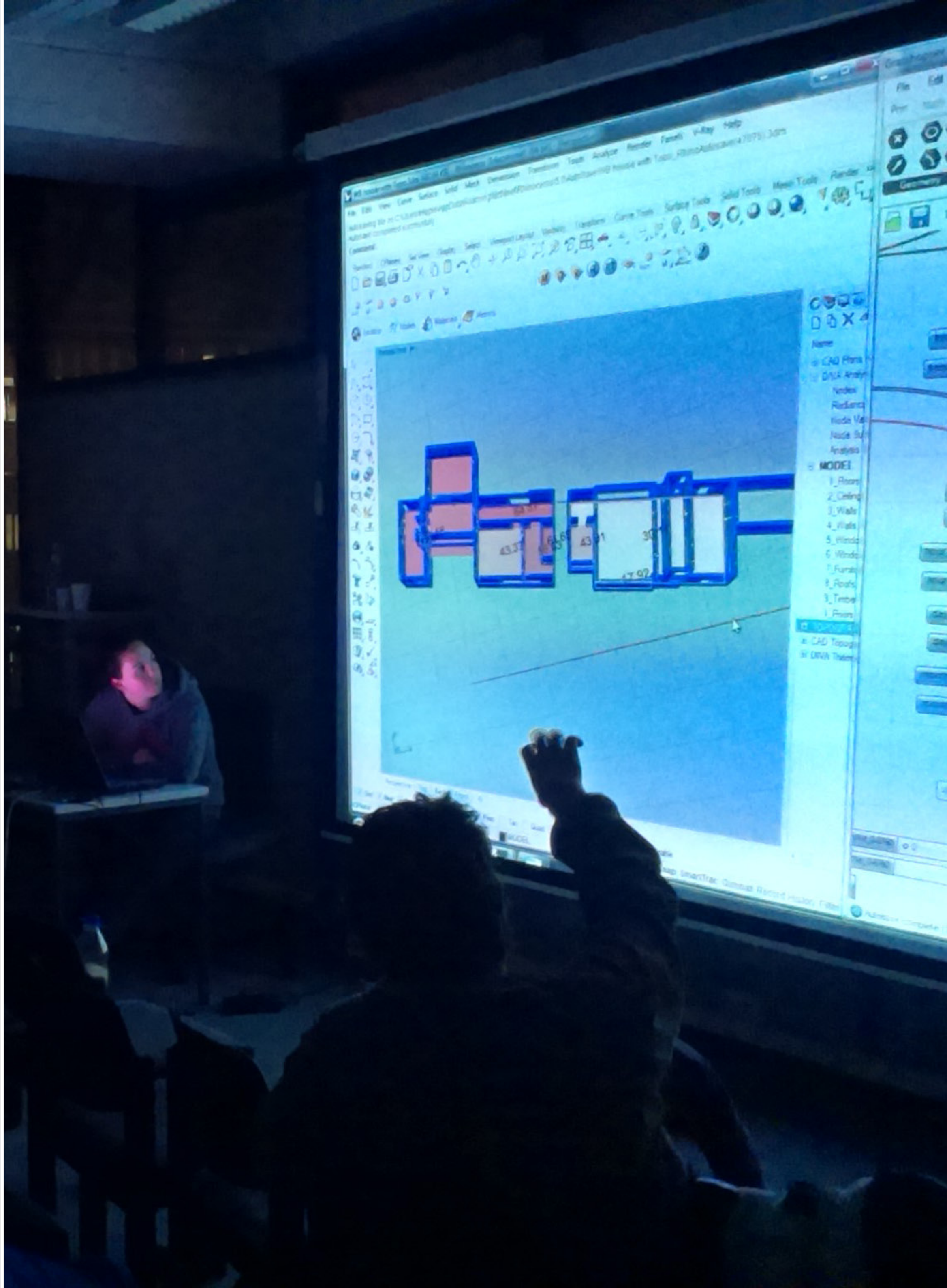
p. 11 | Performance Visualization of Student Designs

- Mapping + optimization class to test tool principles
  - *Check if advanced visualization improves optimization work*
  - *Discover how simulation data interpretation is impacted*

- Re-optimize students' existing, energy-conscious designs
  - *Visualize performance data behaviour in a variety of climates*
  - *Find previously hard to spot errors in (large) simulation models*
  - *Compare cognitive with actual performance picture*

- Gather data through design observation, user survey
  - *Implement new features, improved interaction design, bug fixes*
  - *Observe design/optimization process impacts caused by tool*

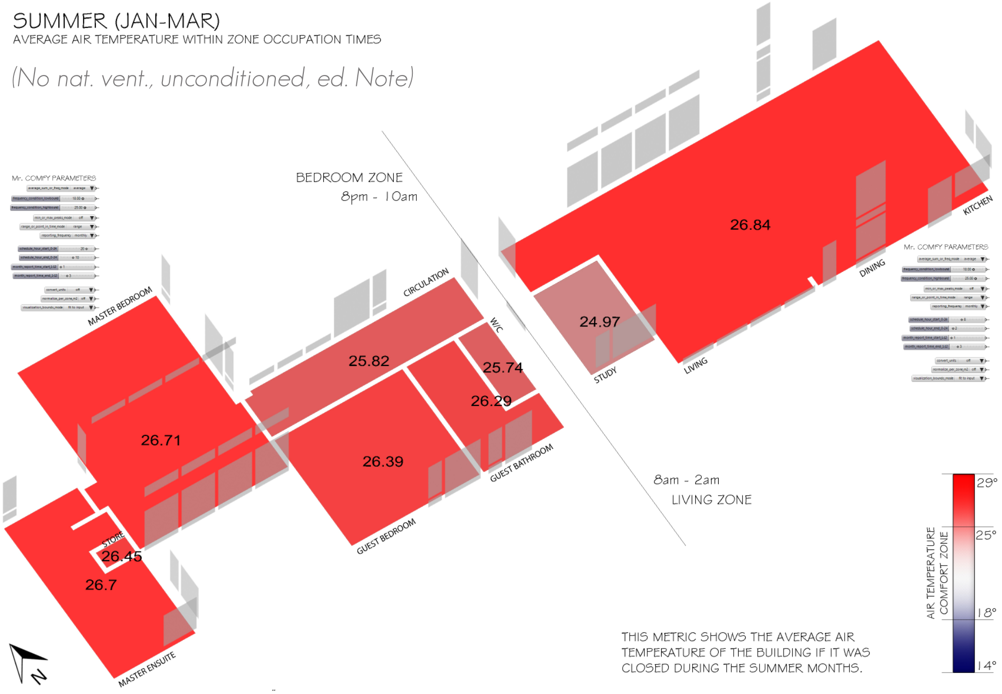
Background/Opposite:
Student Sophie Barker presents Mapping Case Study of Waratah Bay House, Winter 2013/2014, TU Berlin, Germany

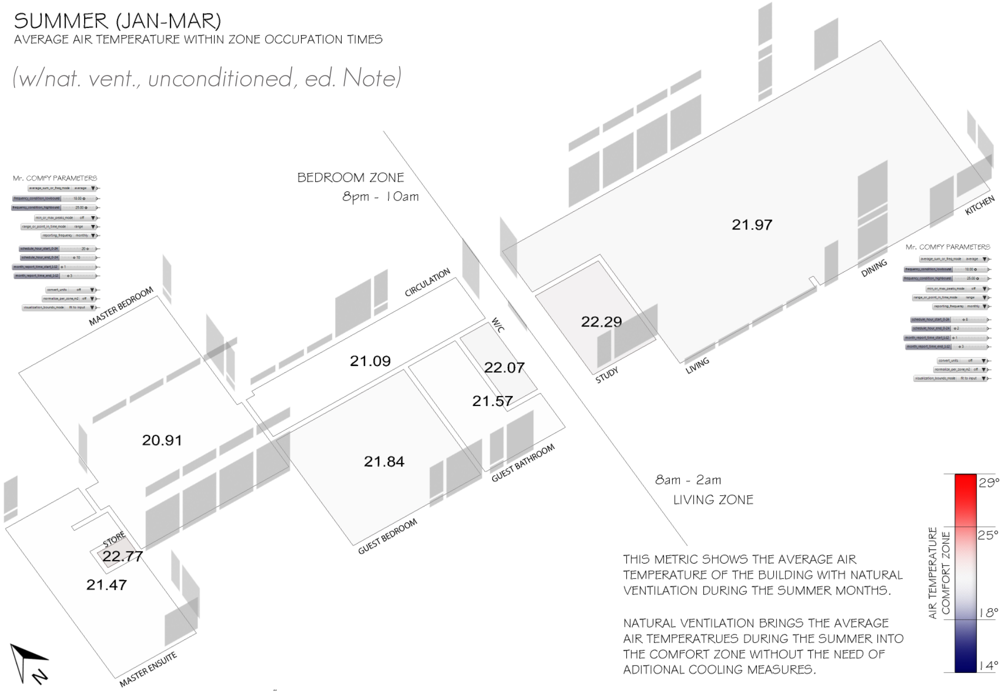


ACADEMIC CASE STUDIES DISCOVERY + OPTIMIZATION

p. 12 | Waratah Bay House Analysis, Sophie Barker

- Built structure; compare sim. to subjective assessements
- Site: Waratah Bay, Australia (Köppen Cfb, temp. oceanic)
- Map seasonal (un)conditioned building performance
  - *First "live" tool use ever in a non-test space scenario*
- Natural ventilation vs. infiltration only comparisons
  - *If nat. vent, summer air temperatures within acceptable limits*
  - *Air temperature as (over)simplified comfort index, for test purposes*





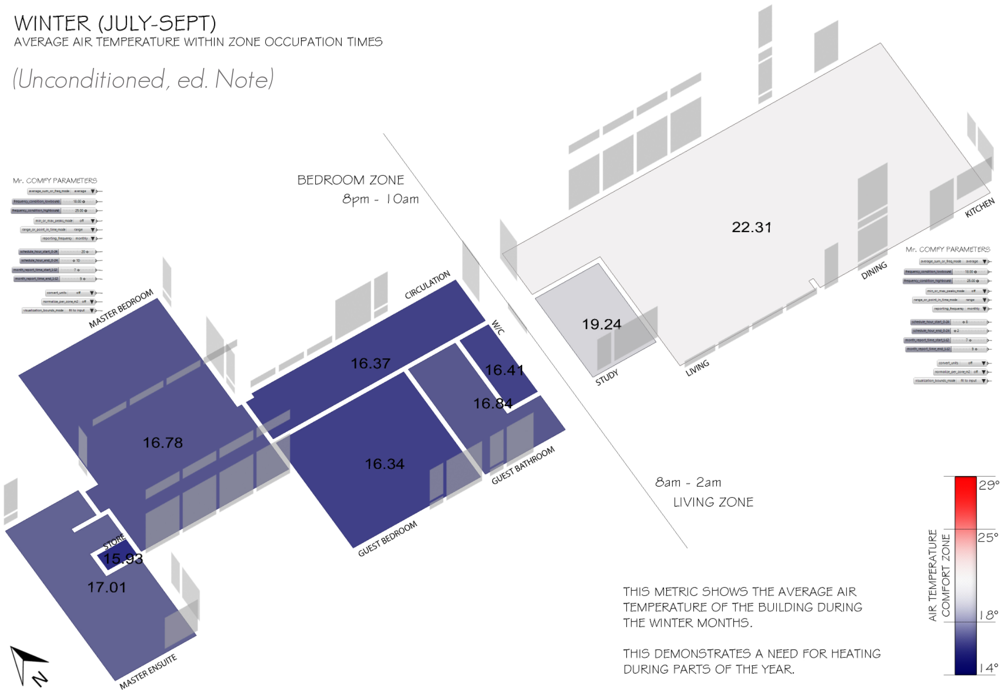
ACADEMIC CASE STUDIES
DISCOVERY + OPTIMIZATION

p. 13 | Waratah Bay House Analysis, Sophie Barker

- Temporal/spatial split bedroom vs. living room block
  - *Combination of schedules, seasonal range calibrates analysis*
  - *Peak display shows predicted heating wattage needs*
- Seasonal display shows winter heating need
  - *Air temperatures towards uncomfortable range*
  - *Corresponds with live observations, experiences per zone*

WINTER (JULY-SEPT)
AVERAGE AIR TEMPERATURE WITHIN ZONE OCCUPATION TIMES

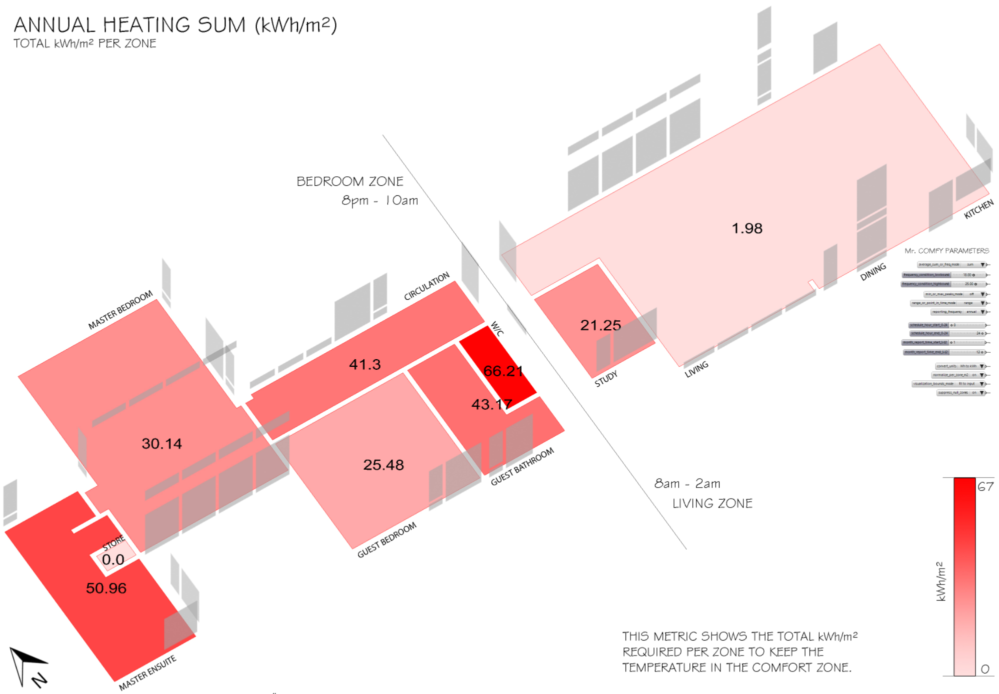
(Unconditioned, ed. Note)



THIS METRIC SHOWS THE AVERAGE AIR TEMPERATURE OF THE BUILDING DURING THE WINTER MONTHS.

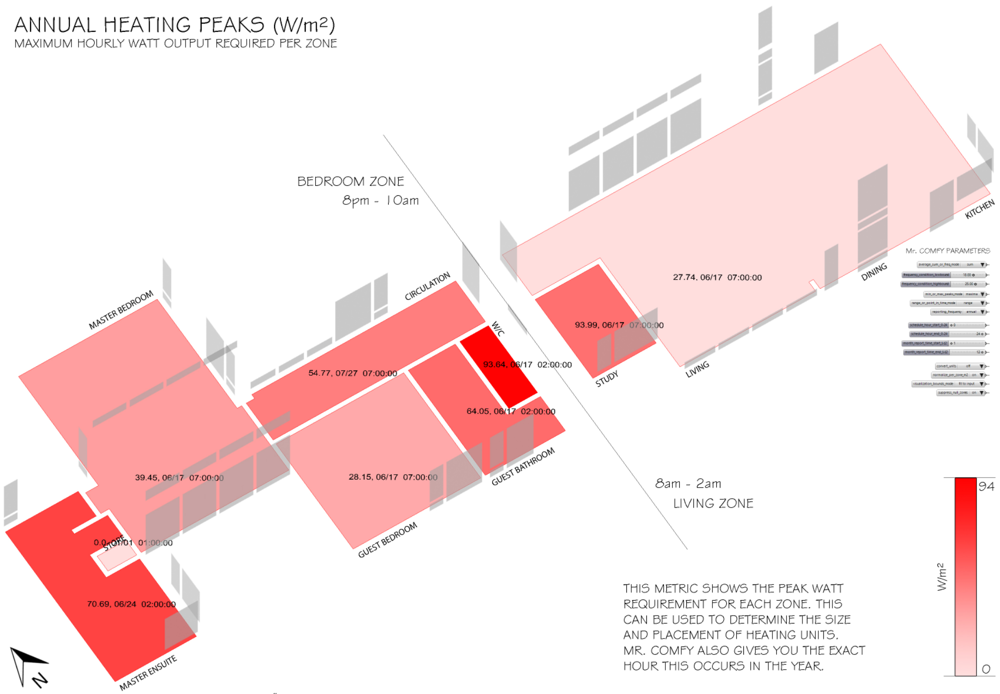
THIS DEMONSTRATES A NEED FOR HEATING DURING PARTS OF THE YEAR.

ANNUAL HEATING SUM (kWh/m2)
TOTAL kWh/m2 PER ZONE



THIS METRIC SHOWS THE TOTAL kWh/m2 REQUIRED PER ZONE TO KEEP THE TEMPERATURE IN THE COMFORT ZONE.

ANNUAL HEATING PEAKS (W/m2)
MAXIMUM HOURLY WATT OUTPUT REQUIRED PER ZONE

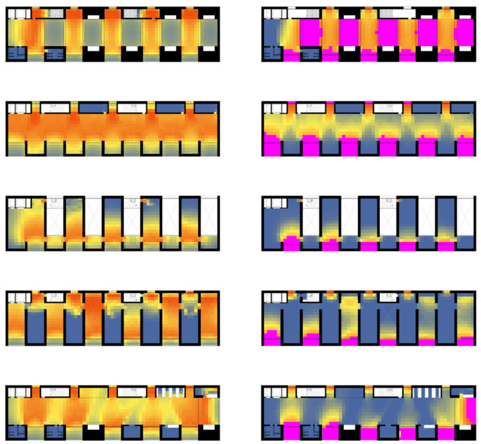


THIS METRIC SHOWS THE PEAK WATT REQUIREMENT FOR EACH ZONE. THIS CAN BE USED TO DETERMINE THE SIZE AND PLACEMENT OF HEATING UNITS. MR. COMFY ALSO GIVES YOU THE EXACT HOUR THIS OCCURS IN THE YEAR.

ACADEMIC CASE STUDIES
DISCOVERY + OPTIMIZATION

p. 14 | ROBUST Studio Design Reoptimization
Design: Christopher Sitzler, Laura de Pedro

- Mixed-use office + exhibition spaces, 50 zones
  - *Created in simulation-integrated (light, thermal) studio*
  - *Already highly energy and daylight-conscious design*
  - *Infra-lightweight concrete envelope study*
- Site: Downtown Berlin, Germany
  - *Köppen climate classification: Dfb, continental*
  - *Heavily overshadowed lot, especially in winter*
- Re-analyze & optimize building in mapping class



04 Research, Administration

03 Multi-Purpose

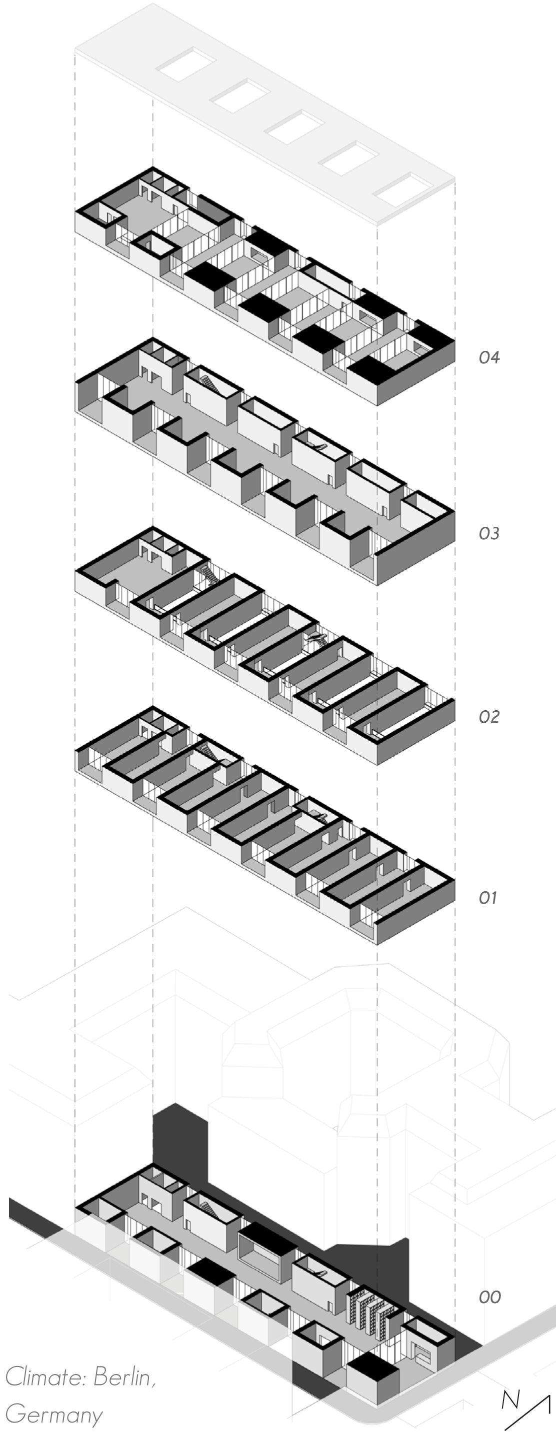
02 Exhibition

01 Exhibition

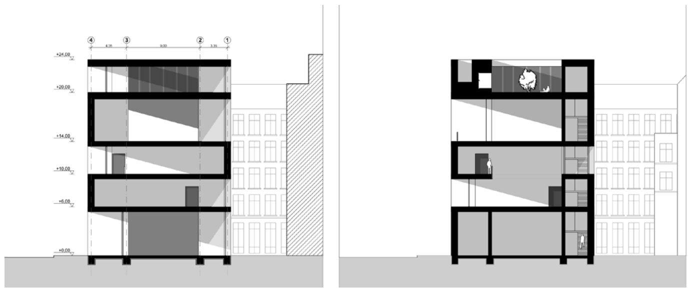
00 Events

UDI 100 - 2000 Lux   D. Availability 500 Lux

Daylight studies for alternating contrast situations

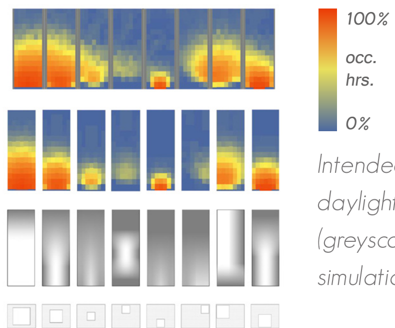


Climate: Berlin, Germany

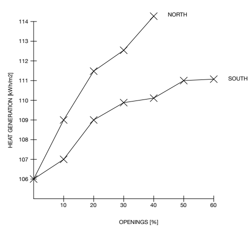


Cross Sections

Lateral Section



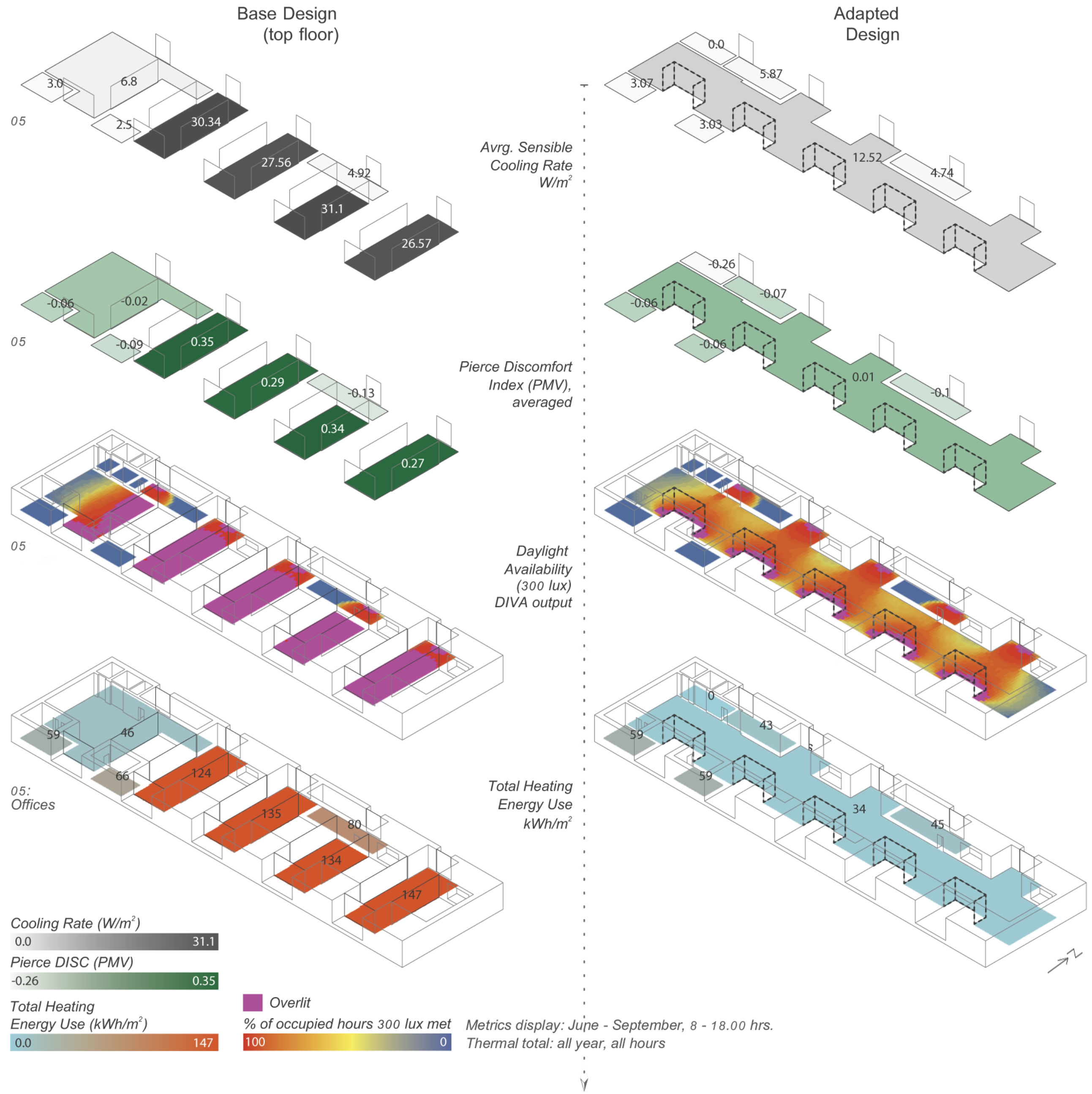
Intended interior daylight volumetrics (greyscale) vs. simulation results



Window to wall ratio effect on heating energy use studies

p. 15 | ROBUST Studio Design Reoptimization
Design: Christopher Sitzler, Laura de Pedro

- Highest energy use on top floor (heat, cool)
  - *East/west-facing plate glass overdimensioned*
  - *High thermal exposure due to discontinuous spaces*
  - *Shading was tested, spaces still performed badly*
  - *In-model display made problem hard to ignore*
- Summer PMV (Pierce) slightly uncomfortable
  - *Would probably be much worse than indicated*
- Spaces heavily overlit, esp. in summer
- Design changes performed, based on map:
  - *Merge top floor into one continuous space*
  - *Orient glazing south, shielded by balconies*
  - *Improve north-facing glazing U-value*
- Large heating, cooling energy use reduction
  - *Comfort improved, with a still slightly warm trend*
- Summer daylight utilization improved

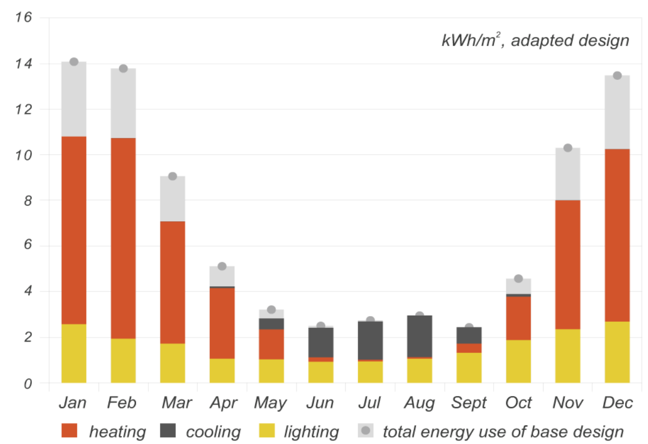


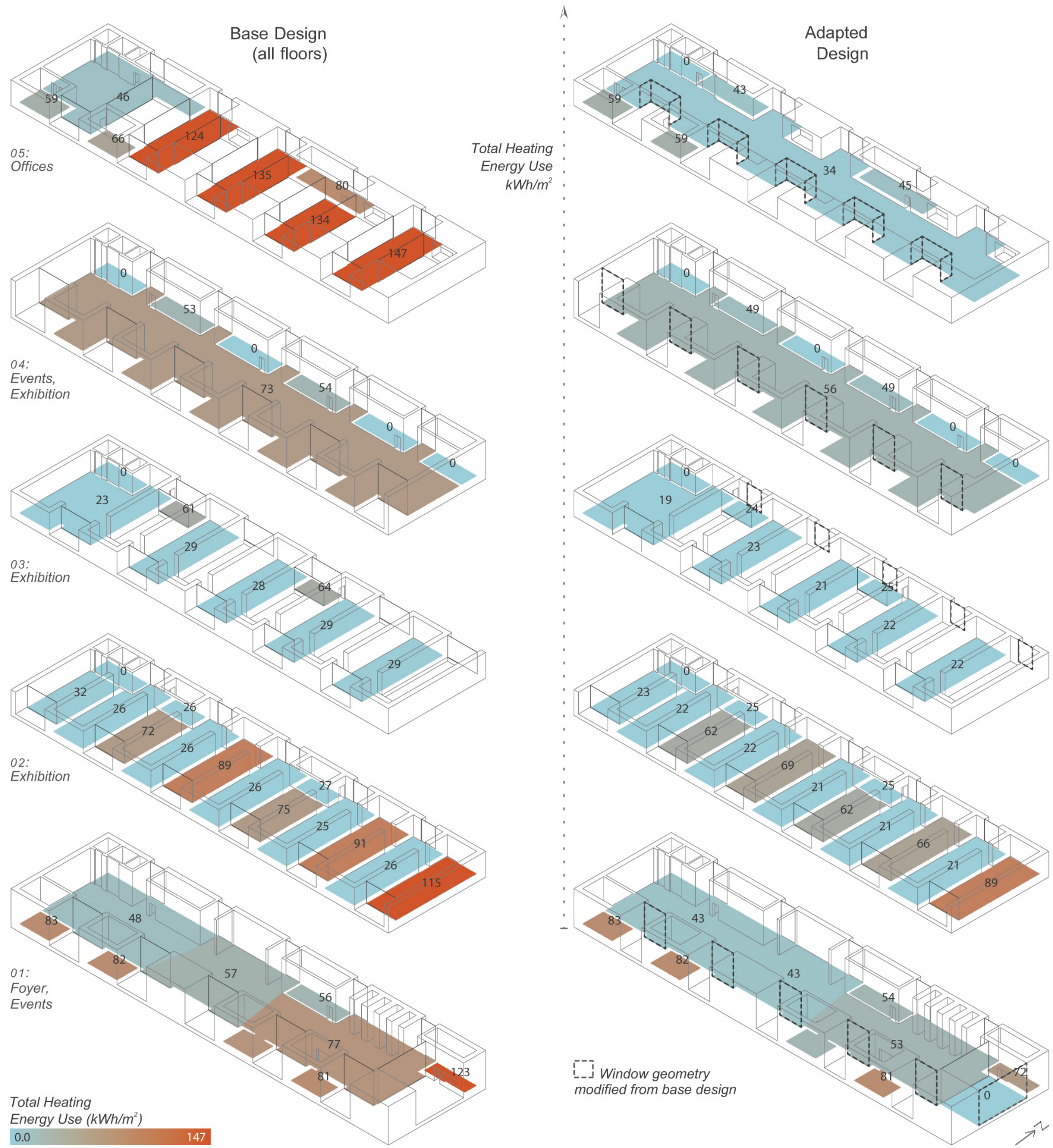
Opposite: Top Floor Multi-Metric Performance Map;
Next page: Annual Total Heating Energy Maps, All Floors;
'ROBUST' Studio Design. Graphics: Author

ACADEMIC CASE STUDIES
DISCOVERY + OPTIMIZATION

p. 16 | ROBUST Studio Design Reoptimization
Design: Christopher Sitzler, Laura de Pedro

- Further improvement of heating energy use:
  - *Reduce ground floor lobby glazing area*
  - *Add unconditioned lobby buffer space*
  - *Reduce north window area, improve U-Values*
- Changes in U-Values read linearly
- Geometry mods have largest visible effect
- Compound changes become readable
  - *Are one recurring feature of free process design*
  - *Zone cross-influences more easily diagnosed*
  - *Localized reading of performance effects*
  - *Simulation errors (if any) easily spotted in context*





ACADEMIC CASE STUDIES
DISCOVERY + OPTIMIZATION

p. 17 | Sweden Urban Housing Design Exploration
Design: Franziska Wich, Björn Wittik

- Energy-conscious, (sub)urban row housing design

- Site: Östersund, Sweden
  - *Köppen climate classification: Dfc, subarctic*

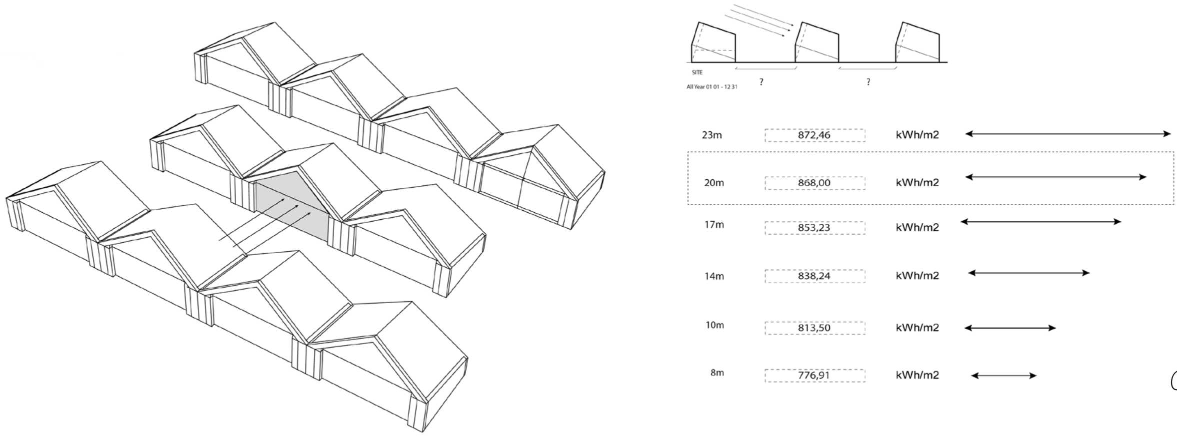
- Design created, adapted during two classes
  - *Performative Design & Mapping Seminars*
  - *Simulation focus, no "true" zero-energy design class*

- Simplified exploration hierarchy:
  - *Create locally inspired housing design language/intent*
  - *Analyze housing unit overshadowing & facade irradiance*
  - *Develop conceptual passive conditioning idea (sunspace)*
  - *Test designs performance when conditioned (class 1)*
  - *Experiment with passive performance (class 2)*

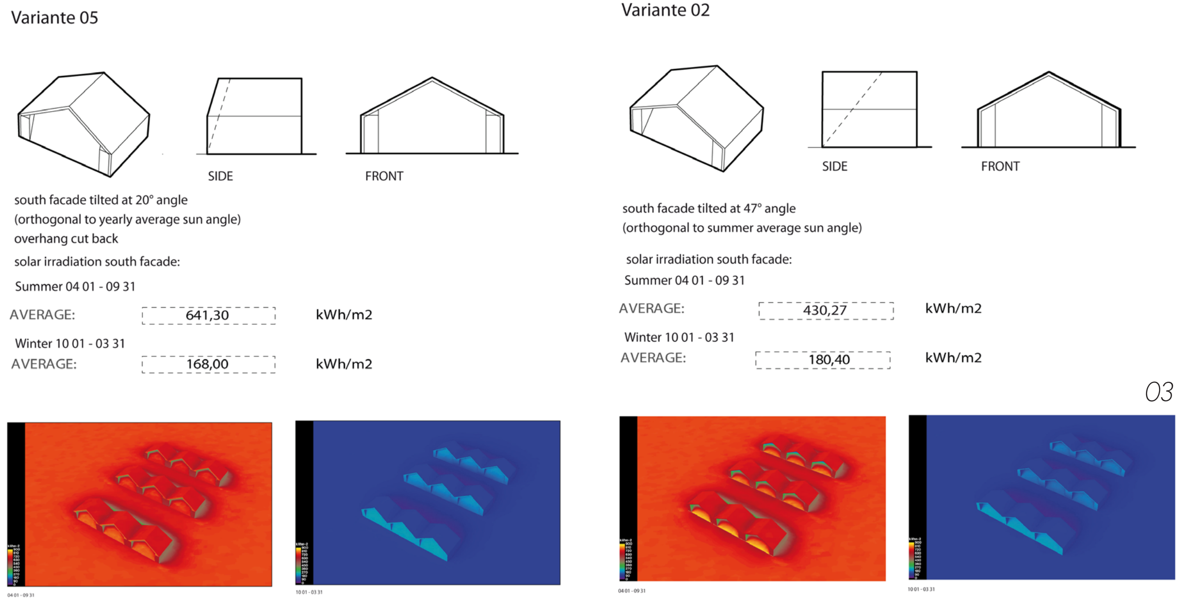
- Mapping class goals:
  - *Detailed performance exploration & typology modifications*
  - *Create clear narrative to test visual storytelling*
  - *Check how processes might change in "passive" design*

Opposite:
01 Design Development Phasing, Final Iteration Site Plan
02 Row Housing Overshadowing Distance Study
03 Combined Overshadowing + Facade Tilt Irradiation Studies

01



02

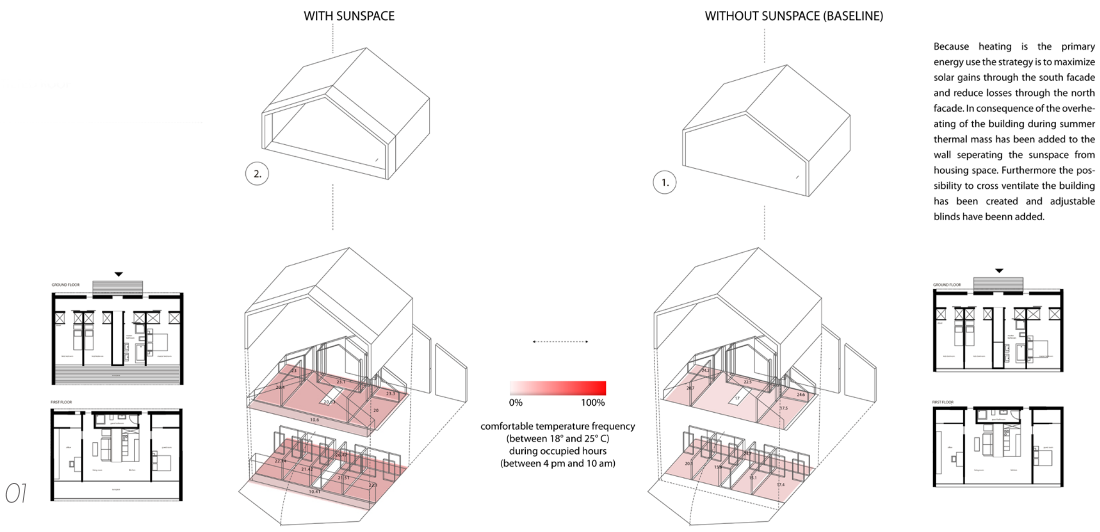


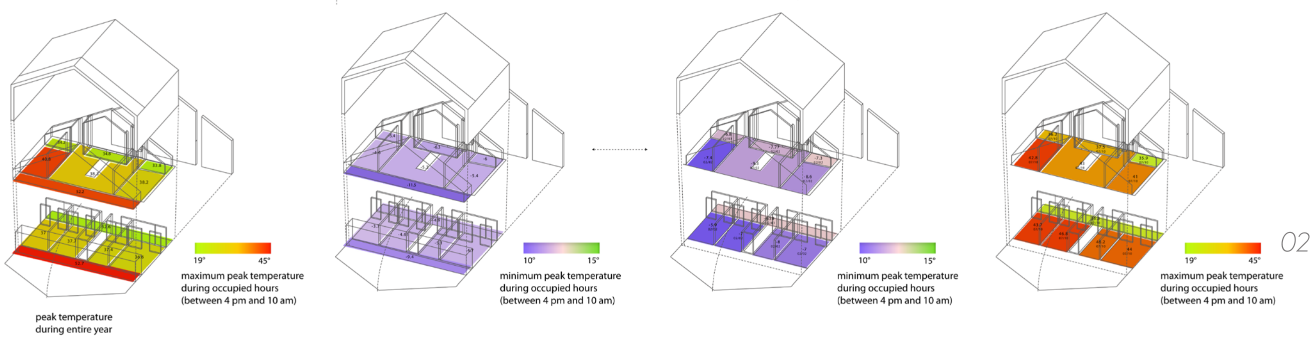
03

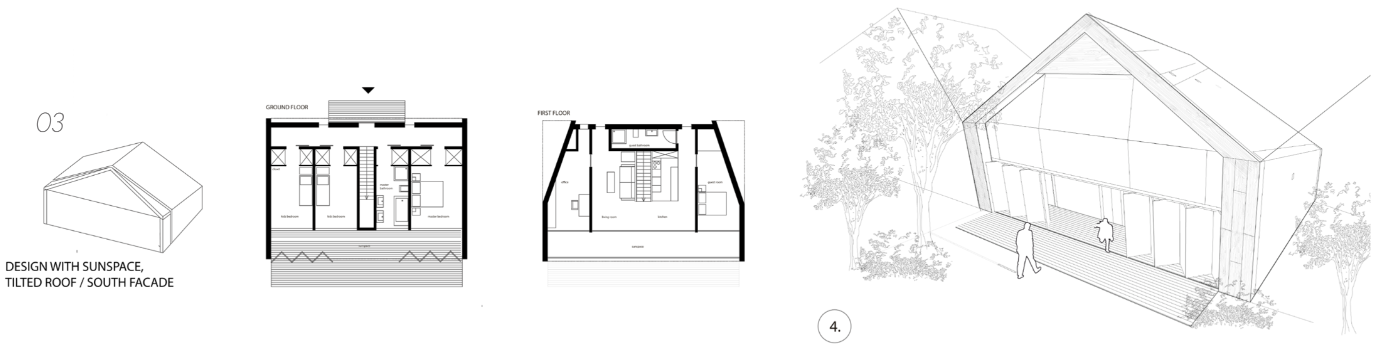
ACADEMIC CASE STUDIES
DISCOVERY + OPTIMIZATION

p. 18 | Sweden Urban Housing Design Exploration
Design: Franziska Wich, Björn Wittik

- Base state vs. sunspace typology visualized
  - *Sunspace addition has greater performance potential*
- Highly simplified metric: zone air temperature
  - *"Intuitive", coarse sensitivity metric as workflow test*
  - *Most tests performed on unconditioned building*
  - *Explore impact of geometric changes only*
- Frequency, peak mapping combined use
  - *Increased frequency of acceptable air. temp. band*
  - *Reduced severity of hourly max./min. peaks*
- Summer overheating discovered as problem
  - *Additional steps taken for partial mitigation*







Opposite:
01 Base Type with vs. without Sunspace Comparison, Frequency Maps of Hours Zone Air Temp. 18° - 25° C

02 Base vs. Sunspace Type Comparison, Peak Hourly Minima / Maxima Zone Maps

03 Synthesized Design State with Sunspace, incl. Envelope Modifications (improved SV ratio)

ACADEMIC CASE STUDIES
DISCOVERY + OPTIMIZATION

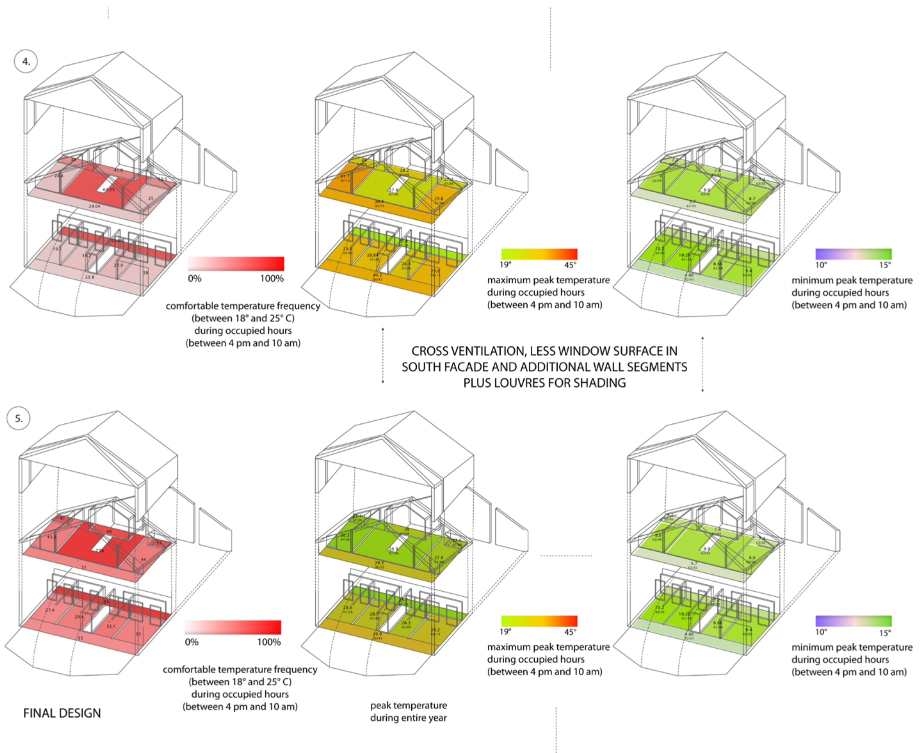
p. 19 | Sweden Urban Housing Design Exploration
Design: Franziska Wich, Björn Wittik

- Adapted sunspace house iteration adjusted for seasonal balancing
  - *Stepped reduction of sunspace glazing areas, increased thermal mass*
  - *Zone air temperature-triggered dynamic shading enabled during summer*
  - *Natural sunspace and cross-ventilation tested (incl. new north windows)*

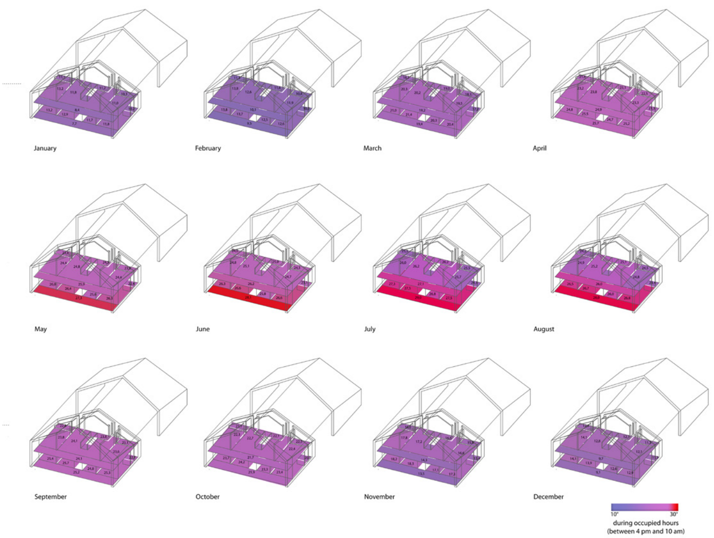
- Increases in acceptable frequency, reduced peaks (esp. maxima)

- Improved daylight utilization (especially reduction of overlit areas)

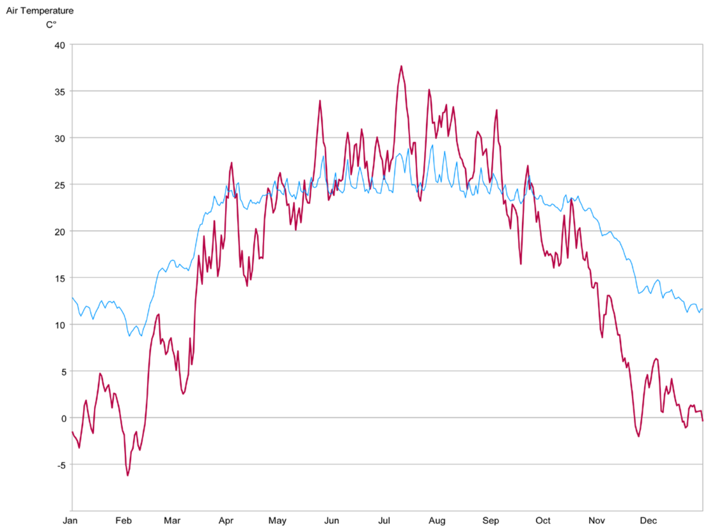
- Not all performance issues fully resolved until class ended
  - *Comfort/sensitivity mapping narrative found promising (tested on architects!)*



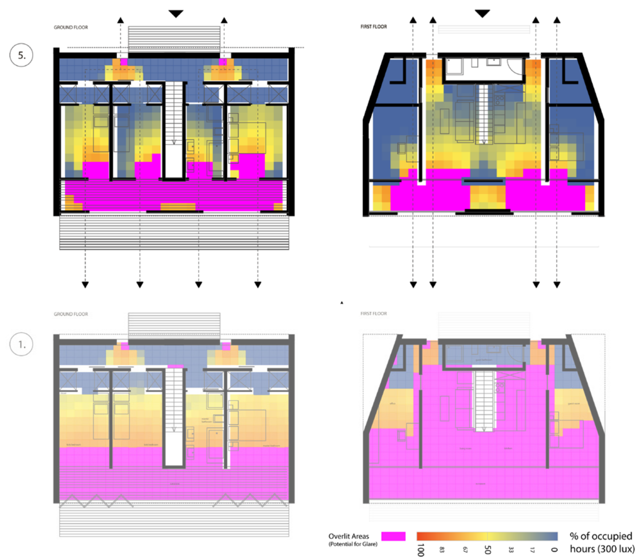
Sunspace Base Typology vs. Nat. Vent, Dynamic Shading added, reduced Glazing Area



Monthly Average Air Temperatures., Final Adapted Design State

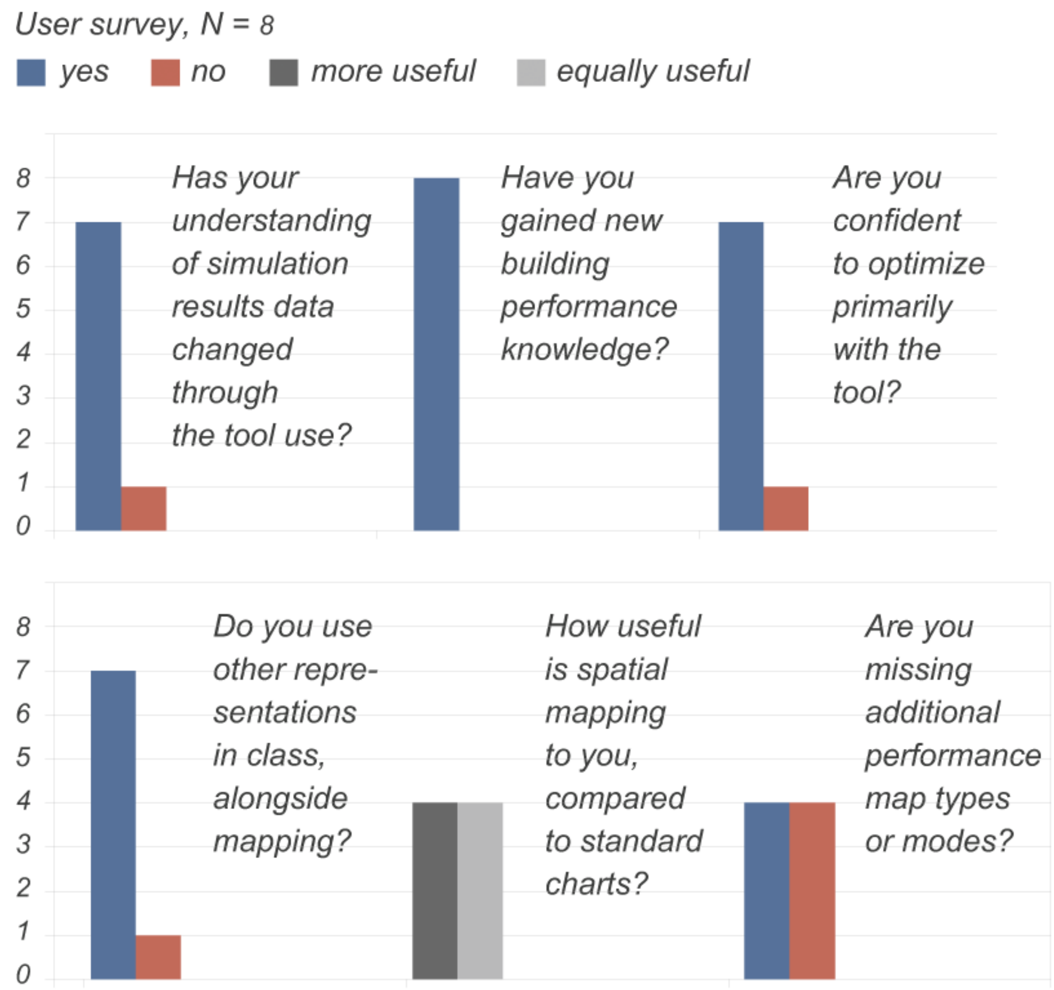


Daily Average Air Temperatures., Final vs. Baseline Design State



Annual Daylight Availability (300 lux), Base vs. Final (top) *p. 20 | Class User Survey + Design Observation Study Results, Winter '13/'14 Mapping Class*

- Can tool's mere use as "illustration device" be discounted?
  - *Achieved to further optimize designs from previous classes*
  - *Class observations, survey show new insights generated*
- Does method improve analysis, communication, workflow?
- Case studies reveal analysis improvement effects:
  - *Easier discovery of local performance states (confirmed by survey)*
  - *Overall building performance pattern recognition benefits*
  - *Filtering, zooming are used to think in (temporal) scenarios*
- Survey shows positive participant experiences:
  - *Gained new building performance knowledge*
  - *Confident to use tool as main optimization aid (but not alone)*
- Tool is not seen as an isolated helper, but in context:
  - *Additional representations for holistic perf. appraisal were used*
  - *Not all saw method as intrinsically superior, but complementary*
- Additional qualitative user observations:
  - *Seeing multi-metric, spatial relationships helps raw data analysis*
  - *Embeddedness in design space improves performance cognition*
  - *Analysis improves through flexible, custom component use*

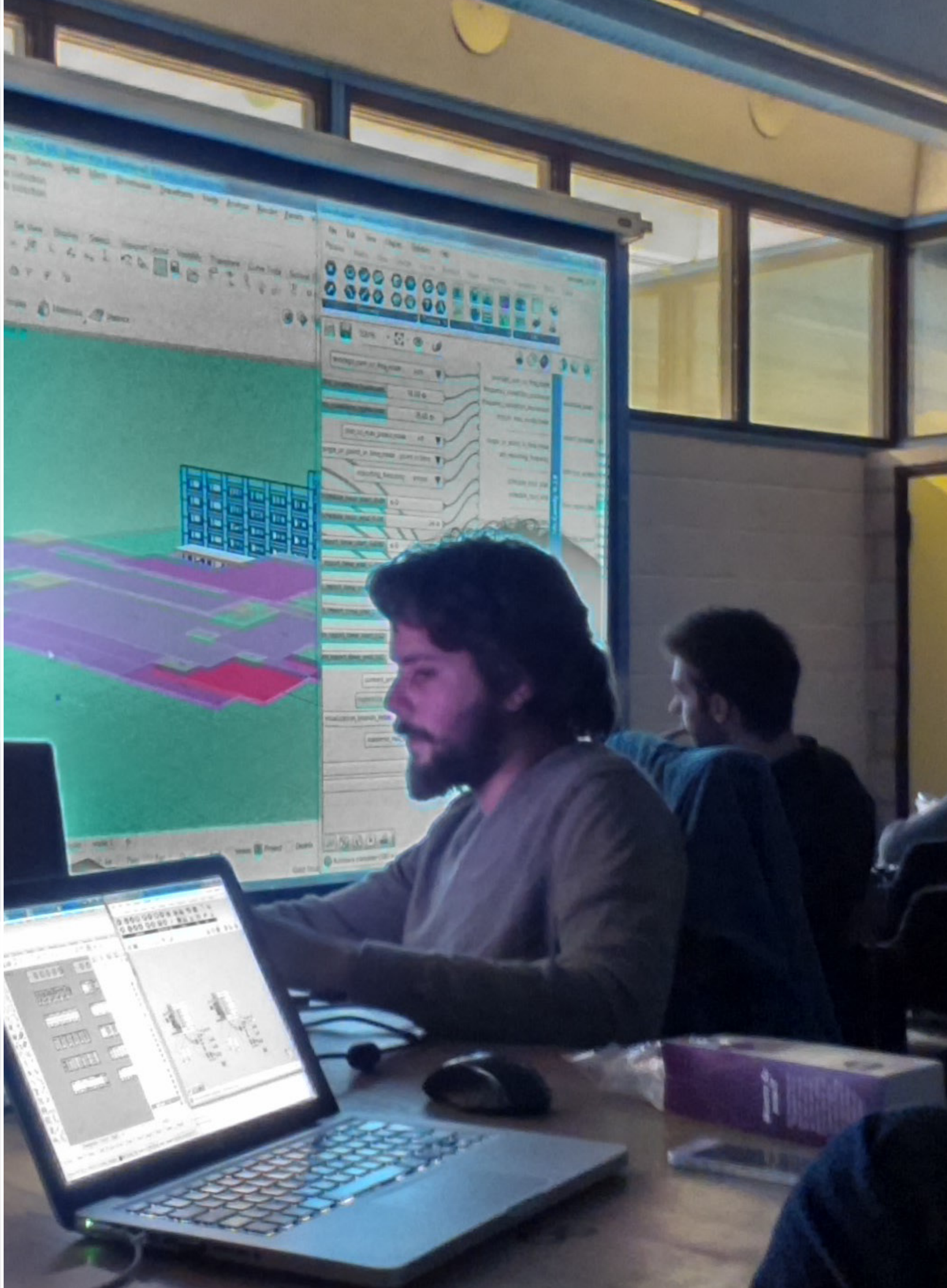


p. 21 | Outlook, Acknowledgements

- Develop “hybrid” thermal (comfort) metrics to aid cognition
  - *Consider addtional multi-metric cross-mapping types*

- Implement metrics prototyping directly in tool
  - *Custom metric “expressions”, nested conditionals etc.*
  - *Strengthen daylight visualization (formal metrics)*

- Anything you would like to see?



Background/Opposite:
Student Alan Patrick presents Mapping Case Study of ‘ROBUST’ Design,
Winter 2013/2014, TU Berlin, Germany

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Thank you for having me!

With deep gratitude to all past class participants- you're the best.

Thanks to cherished colleagues + friends:

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Cecilia, Irena, L., J. & C. Doelling, A.J. Jakubiec

visit http://mrcomfy.org :: max@spacesustainers.org

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