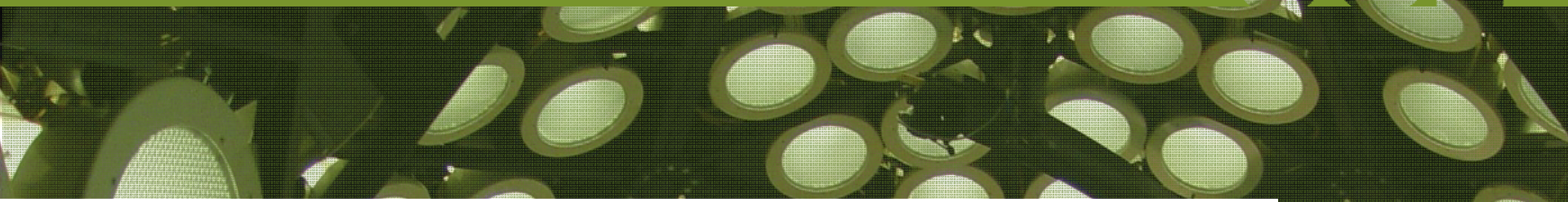


HVAC Sector Challenges Ahead
REHVA Annual Meeting 2017, London, 03-04 April 2017

The Impact of Temperature Ventilation Rates and Indoor Air Quality on Student Performance

Professor Dejan Mumovic

REHVA Seminar

03-04 April 2017, London, UK

1. **T and Ventilation Rates/CO2 as a Cognitive Performance Driver**
2. **What Do We Know?**
3. **Education in the Context of HVAC Challenges**

Architectural Education at UCL
1841-2016

"WANDERING IN A LABYRINTH OF EXPERIMENTS"

Thomas Leverton Donaldson,
Inaugural lecture, UCL, 1842

175

bit.ly/Bartlett175
#Bartlett175

Feilden Clegg Bradley Studios Islington Academy

"IMAGINE A SCHOOL WHERE THE *INDOOR AIR QUALITY* REDUCED THE RISK OF EXPOSURE TO DISEASE, WHERE THE ACOUSTICS WERE SUCH THAT LEARNING WAS ENHANCED, WHERE THE QUALITY OF FINISHES AND ARCHITECTURE MADE YOU *FEEL WELCOMED*, VALUED AND NURTURED, WHERE THE QUALITY OF LIGHT MADE YOU FEEL MORE ALERT AND YOU DID NOT HAVE TO TURN ON ELECTRIC LIGHTS, WHERE YOU FELT CONNECTED TO THE OUTSIDE WORLD, WHERE YOU GENERATED THE MAJORITY OF YOUR NEEDS *ON SITE*, WHERE YOU PROMOTED, TAUGHT, AND PRACTICED ENVIRONMENTAL RESPONSIBILITY, WHERE THE SCHOOL HELD A PROMINENT AND IMPORTANT *PLACE IN COMMUNITY*, WHERE TESTS SCORES IMPROVED, WHERE TEACHER RETENTION INCREASED AND *ABSENTEEISM* DROPPED, WHERE THE SCHOOL ACTUALLY BECAME A TEACHING TOOL."

FORD, A. (2007) DESIGNING THE SUSTAINABLE SCHOOL, IMAGES PUBLISHER

DESIGN CONFLICTS

CIBSE TM57: Integrated School Design

DESIGN FOR PERFORMANCE

TOTAL DESIGN FOR PERFORMANCE

REHVA Seminar

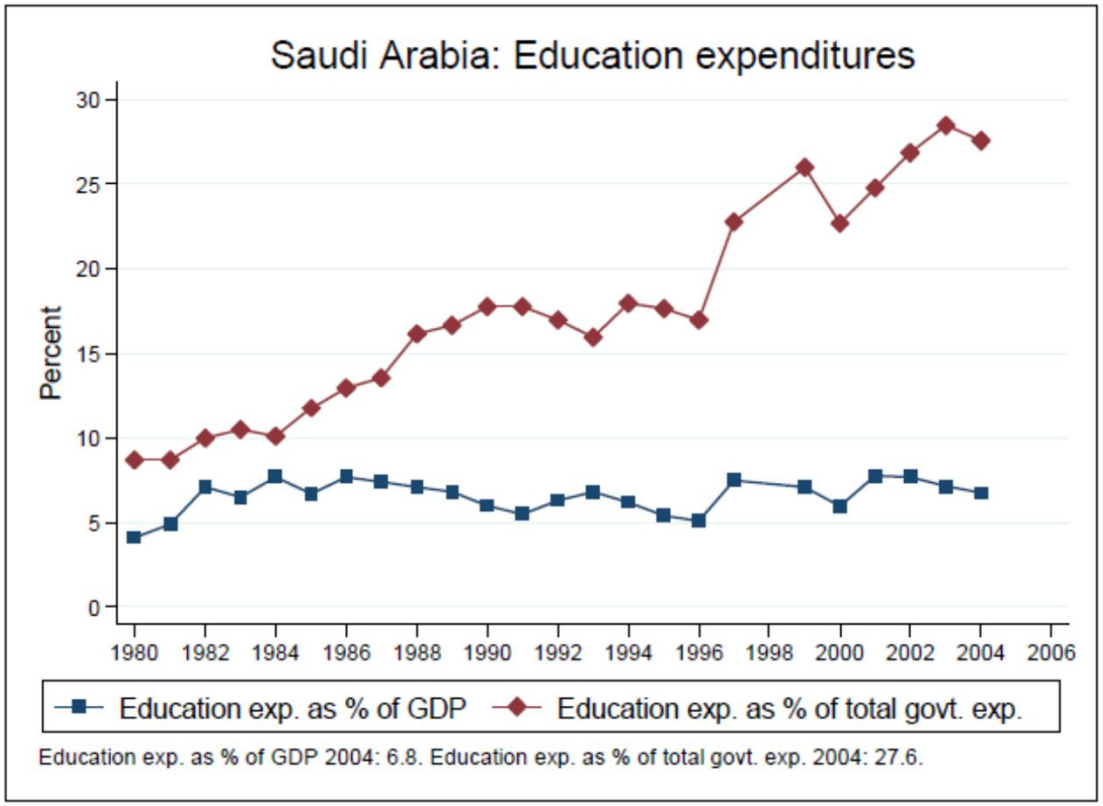
03-04 April 2017, London, UK

T and Ventilation Rates/CO_2 as a Cognitive Performance Driver

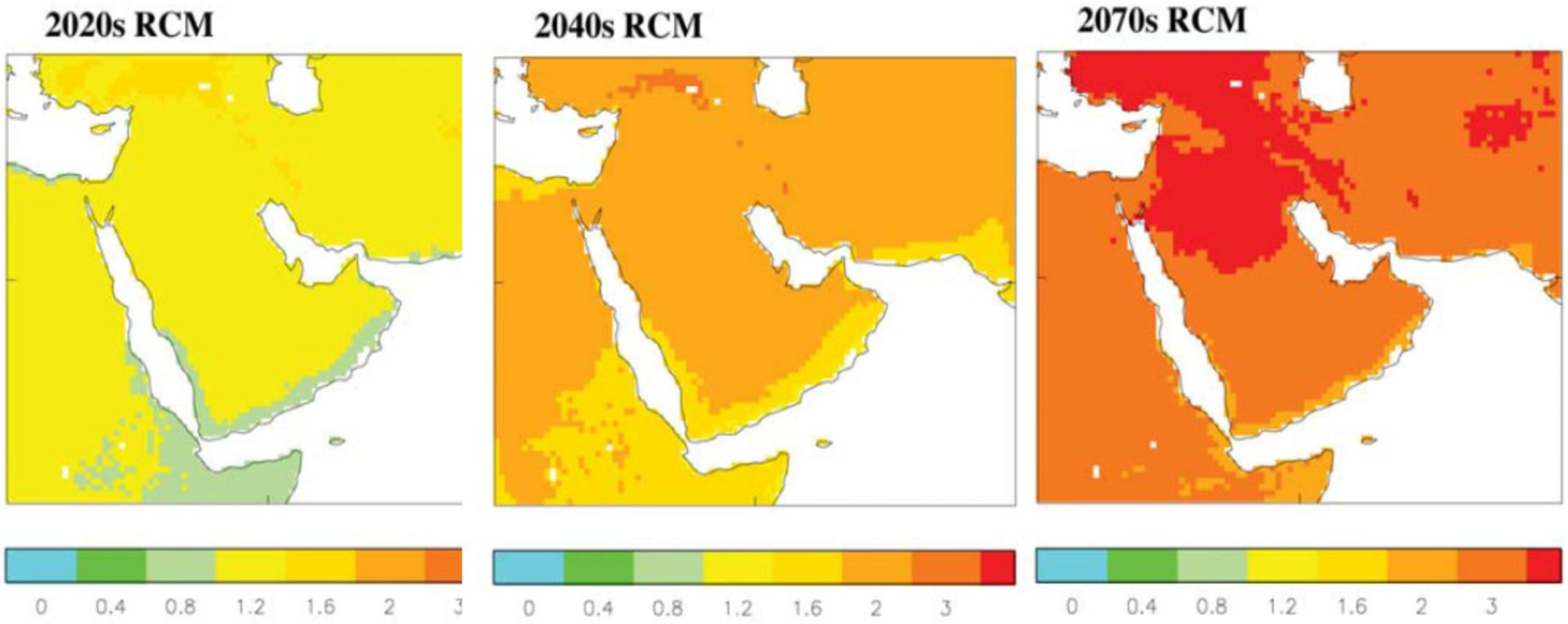
Researcher: **Riham Gaber Ahmed**

Prof Dejan Mumovic & Dr Marcella Ucci

Government budget on education expenditures in Saudi Arabia. Source: Education: UNESCO Institute for Statistics, Data Centre [Online].



Regional climate model projections of average temperature changes (ºC) across the Gulf region for the 2020s, 2040s and 2070s, relative to the 1990s (Brown and Crawford, Online)



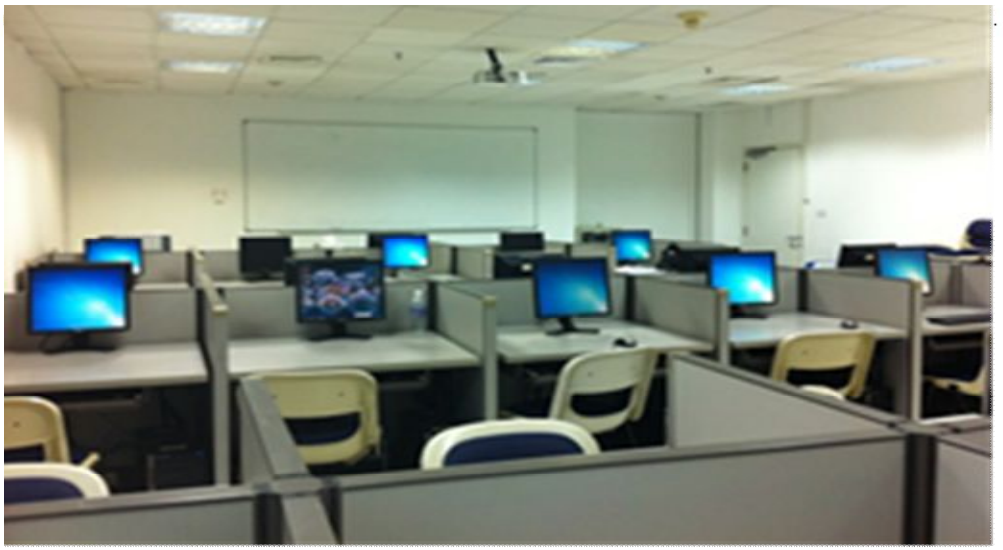
Environmental Exposure and Physical Monitoring/Measurements

Conditions of exposure:	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20C, CO2: 600PPM	T1: 20C	CO2/PPM 1: 600PPM
Condtion 2: Temp: 20C, CO2: 1000PPM	T2: 20C	CO2/PPM 2: 1000PPM
Condtion 3: Temp: 20C, CO2: 1800PPM	T3: 20C	CO2/PPM 3: 1800PPM
Condtion 4: Temp: 23C, CO2: 600PPM	T1: 23C	CO2/PPM 1: 600PPM
Condtion 5: Temp: 23C, CO2: 1000PPM	T2: 23C	CO2/PPM 2: 1000PPM
Condtion 6: Temp: 25C, CO2: 1800PPM	T3: 23C	CO2/PPM 3: 1800PPM
Condtion 7: Temp: 25C, CO2: 600PPM	T1: 25C	CO2/PPM 1: 600PPM
Condtion 8: Temp: 25C, CO2: 1000PPM	T2: 25C	CO2/PPM 2: 1000PPM
Condtion 9: Temp: 25C, CO2: 1800PPM	T3: 25C	CO2/PPM 3: 1800PPM

Baseline condition

Environmental Exposure and Physical Monitoring/Measurements

Parameter	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6	Condition 7	Condition 8	Condition 9
Temperature (°C)	20.0 ± 0.2	20.0 ± 0.2	20.0 ± 0.2	23.0 ± 0.2	23.0 ± 0.2	23.0 ± 0.2	25.0 ± 0.2	25.0 ± 0.2	25.0 ± 0.2
CO_2 Concentration Levels (ppm)	600 ± 30	1000 ± 40	1800 ± 60	600 ± 30	1000 ± 40	1800 ± 60	600 ± 30	1000 ± 40	1800 ± 60
Relative Humidity (%)	40 ± 3	40 ± 3	40 ± 3	40 ± 3	40 ± 3	40 ± 3	40 ± 3	40 ± 3	40 ± 3
Air Velocity (m/s)	0.1 ± 0.02	0.1 ± 0.02	0.1 ± 0.02	0.1 ± 0.02	0.1 ± 0.02	0.1 ± 0.02	0.1 ± 0.02	0.1 ± 0.02	0.1 ± 0.02
Light Intensity (Lux)	400	400	400	400	400	400	400	400	400
Noise Levels (dB(A))	34 ± 2	34 ± 2	34 ± 2	34 ± 2	34 ± 2	34 ± 2	34 ± 2	34 ± 2	34 ± 2
Outdoor Temperature (°C)	36.0 ± 0.5	39.0 ± 0.5	36.0 ± 0.5	39.0 ± 0.5	38.0 ± 0.5	36.0 ± 0.5	38.0 ± 0.5	37.0 ± 0.5	36.0 ± 0.5
Outdoor Relative Humidity (%)	32.0 ± 3	30.0 ± 3	32.0 ± 3	30.0 ± 3	30.0 ± 3	32.0 ± 3	30.0 ± 3	31.0 ± 3	32.0 ± 3



Neurobehavioral tasks: **B**ehavioural **A**ssessment and **R**esearch **S**ystem battery

BARS tests (http://www.nweta.com/bars/tests/)

Test	Symbol	Function
Continuous Performance	(CPT)	attention
Match-to-Sample	(MTS)	visual memory + delay
Simple Reaction Time	(SRT)	response speed
Reversal Learning	(RL)	learning, coordination between right and left hemispheres of the brain
Serial Digit	(SDL)	Digital memory + learning
Symbol Digit	(SDT)	complex function
Digit Span	(DST)	Attention+ memory
Alternative Tapping	(Alt TAP)	response speed, coordination between right and left hemispheres of the brain

significant role in learning and education in pedagogy

responding to teachers in classrooms and interacting with their questions involves:

- perception (hearing and understanding the question)
- memory skills (recalling and collecting information from the memory)
- problem solving skills (thinking about the answer)
- decision taking (answering or not)
- motor skill (raising the hand)
- language skills (talking and understanding language).

The nature of the information being mentally manipulated (e.g., numbers, design concepts) and the operation (e.g., comparing, abstracting, ordering) define the category of thinking.

Neurobehavioral tasks: **B**ehavioural **A**ssessment and **R**esearch **S**ystem battery

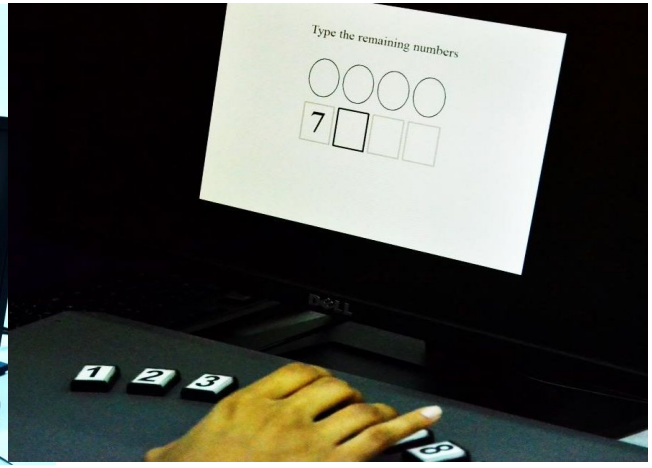
All students from the different departments were invited in order to widen the scope of students' contribution to the experiment with different intellects and thoughts and thus minimise cognitive performance test bias.

To increase their motivation to perform the tests seriously, community service hours were offered to the participants every time they contribute depending on their performance.

To ensure that the learning effect was removed, a wash-out period was kept between the conditions (rest time interval between conditions)

30 minutes before performing the cognitive test to allow time to adapt to the classroom adjusted conditions of exposures.

only 8 participants contributed at a time



Socio-Demographic Characteristics of the Study Population and Participants' Responses to Questionnaire

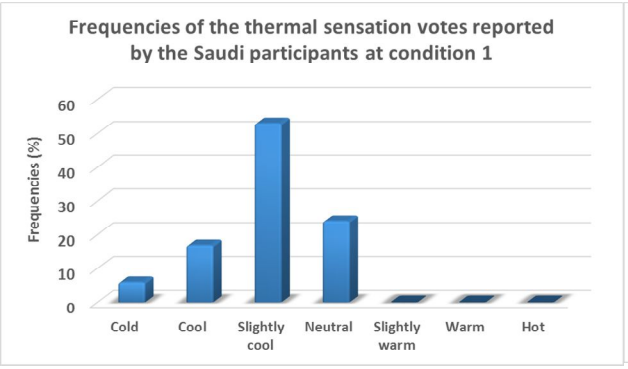
No. Participants: 600-499-386 (95%CI)
Sleeping hours: 7+/99%
Breakfast: Yes/99%
Caffeine within 2 hours: No/99%
Stress due to personal reasons: Yes/1%
0.8-0.9 clo: 98%
Ambient Noise Levels: 2% dissatisfied

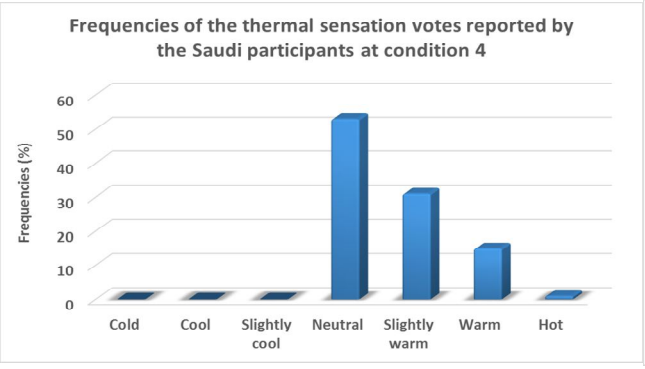
CO_2 levels of ~600 ppm or ~1000 ppm :5% of the participants have reported symptoms of dizziness, headache and heaviness on head.

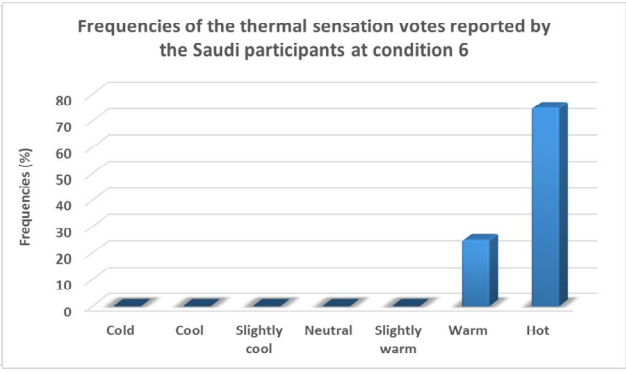
CO_2 levels of ~1800 ppm :95% of the participants have reported symptoms of dizziness, headache and heaviness on head.

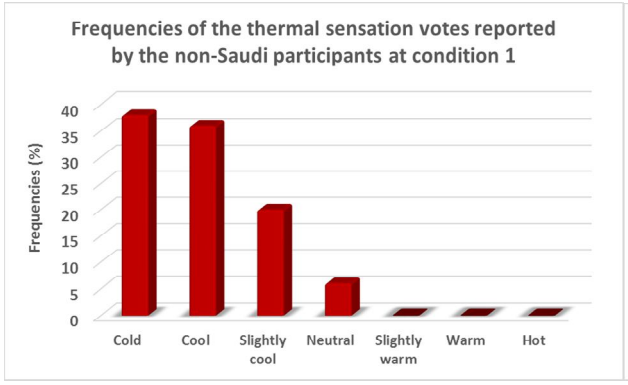
Variable	Frequency	Percentage
Age:		
15	60	12.0%
16	64	12.8%
17	66	13.2%
18	68	13.6%
19	62	12.4%
20	59	11.8%
21	65	13.0%
22	55	11.2%
Gender:		
Females	499	100%
Marital Status:		
Single	480	96.2%
Married	19	3.8%
Ethnicity:		
Bangladeshi	13	2.6%
Egyptian	15	3.0%
Indian	71	14.2%
Iraqi	1	0.2%
Lebanese	10	2.0%
Libyan	1	0.2%
Pakestani	49	9.8%
Palestanian	19	3.8%
Saudi	320	64.2%
Number of years spent in KSA for non-Saudis		
1, or less	10	5.6%
2	11	6.1%
3	7	3.9%
4	7	3.9%
5	9	5.0%
6	11	6.1%
7	13	7.3%
8	10	5.6%
9	8	4.5%
10	11	6.1%
11	9	5.0%
12	12	6.7%
13	10	5.6%
14	11	6.1%
15	10	5.6%
16	9	5.0%
17	10	5.6%
18	11	6.1%
Smoking and drinking alcohol profile		
non-smokers	499	100%
not drinking alcohol	499	100%
General fitness status		
regularly physically active	14	2.8%
not physically active	485	97.2%
General health status		
diabetic	0	0%
having any health issue or coronic disease	0	0%

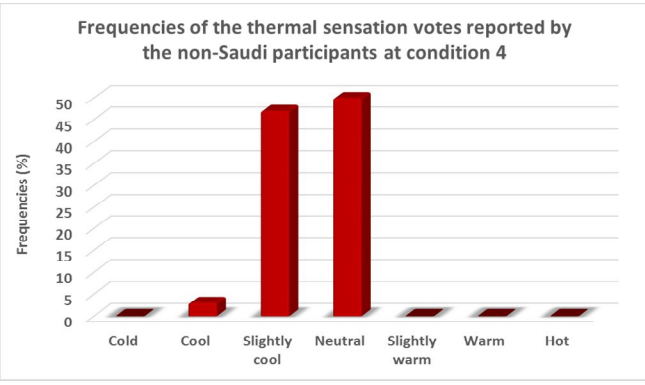
Participants' Thermal Sensation by Ethnicity

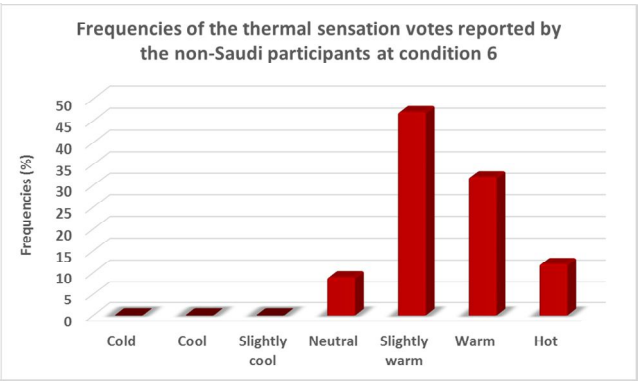




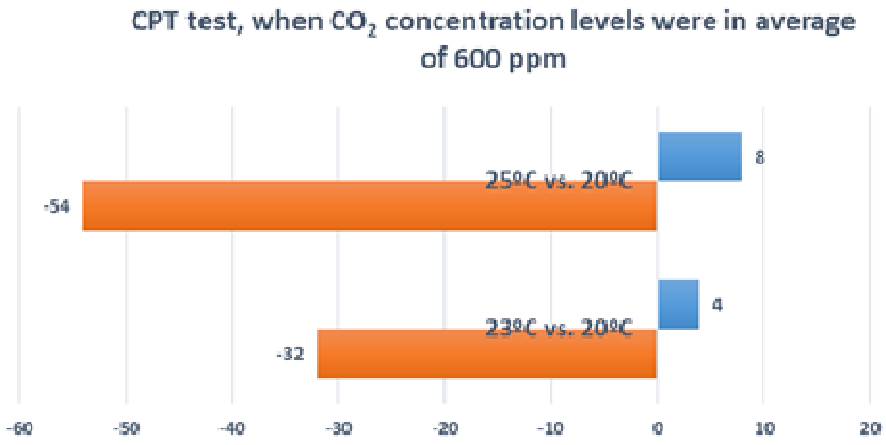


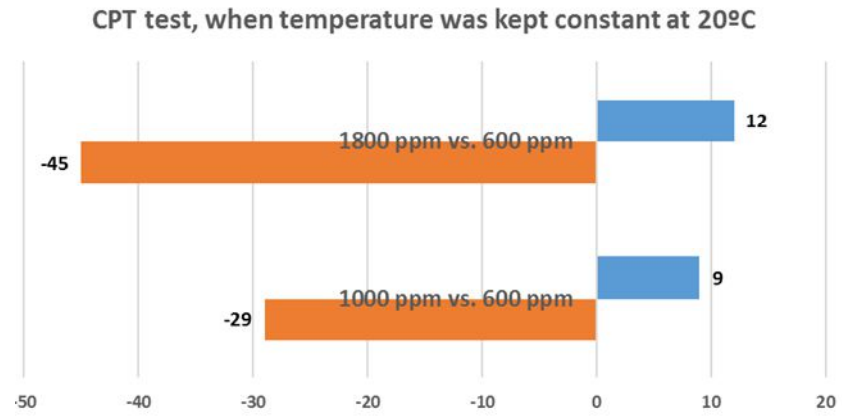






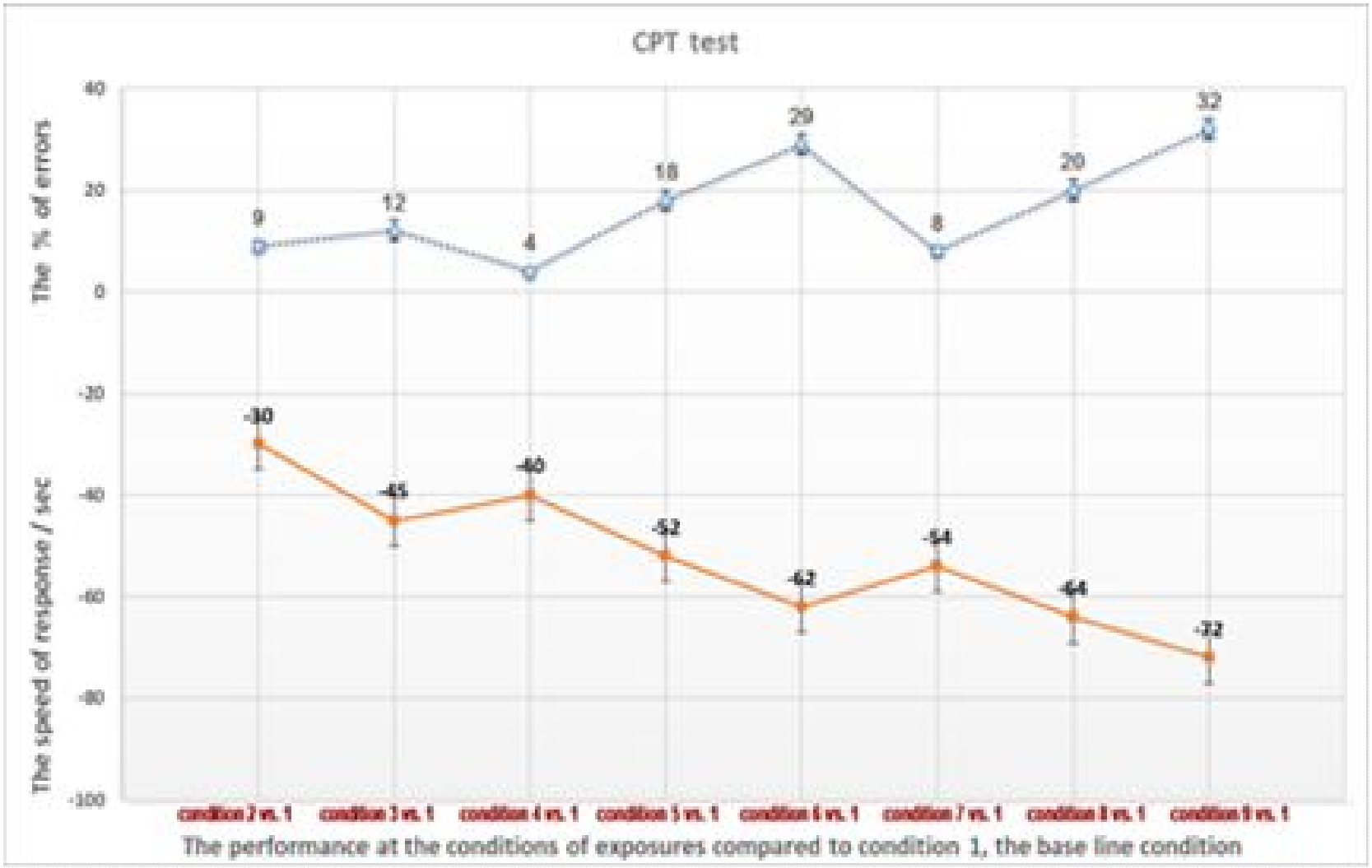
Continuous Performance Test (CPT) Results (compared to the base line condition)



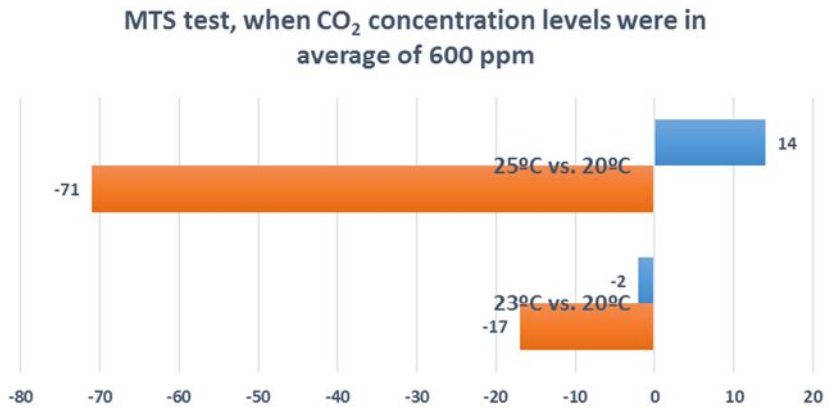


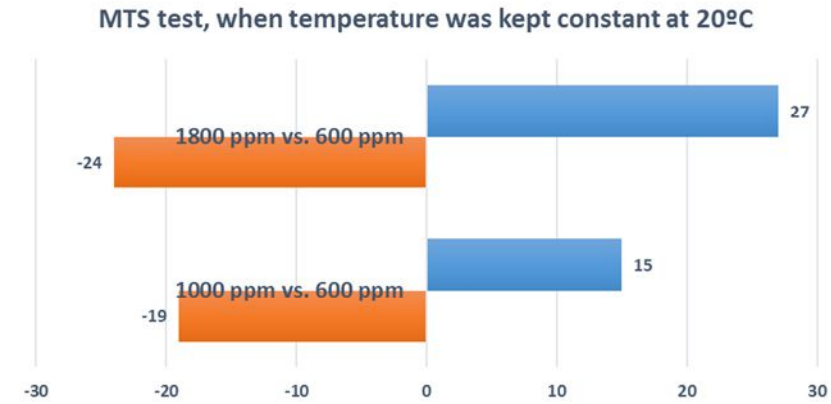
Tornado diagrams showing the trend of change in the % of errors (blue) and speed of response (orange) at the CPT test relative to the baseline conditions.

Continuous Performance Test (CPT) Results (compared to the base line condition)



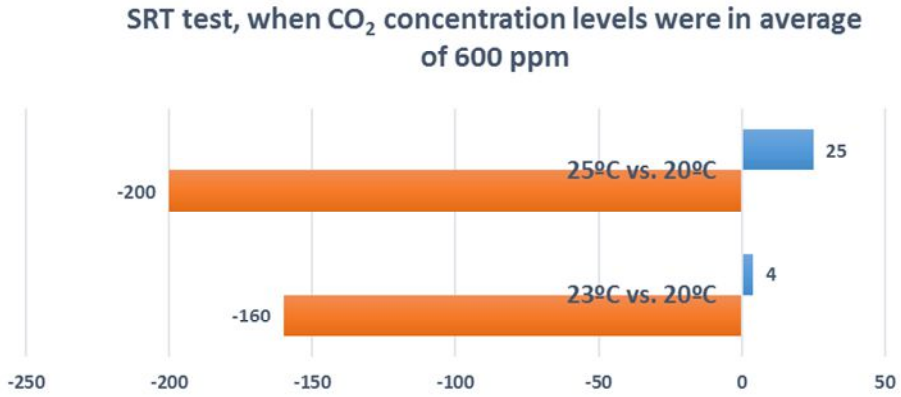
Match To Sample Test (MTS) Results (compared to the base line condition)

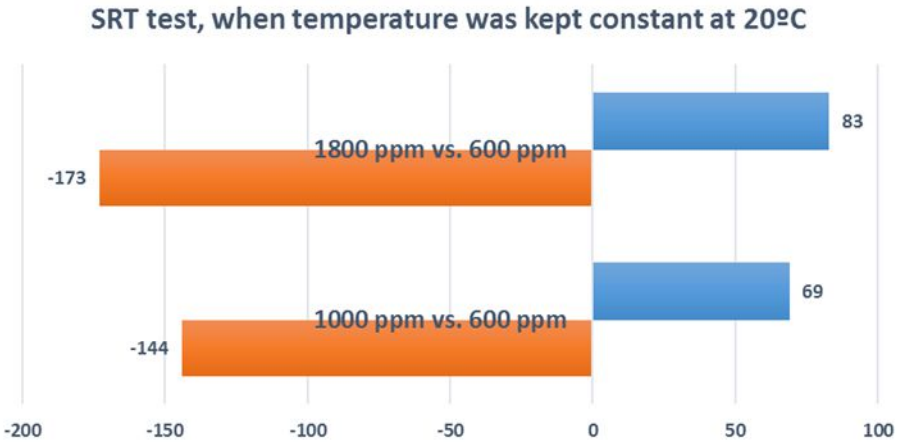




Tornado diagrams showing the trend of change in the % of errors (blue) and speed of response (orange) at the MTS test relative to the baseline conditions.

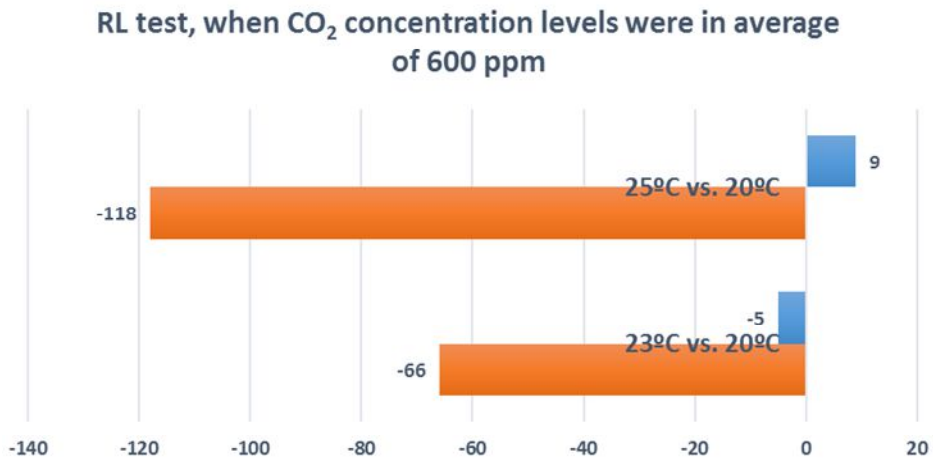
Simple Reaction Test (SRT) Results (compared to the base line condition)

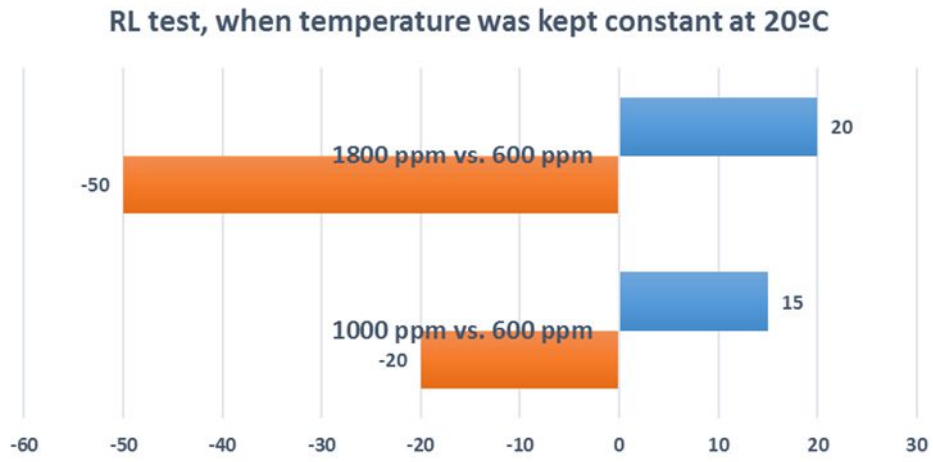




Tornado diagrams showing the trend of change in the % of errors (blue) and speed of response (orange) at the SRT test relative to the baseline conditions.

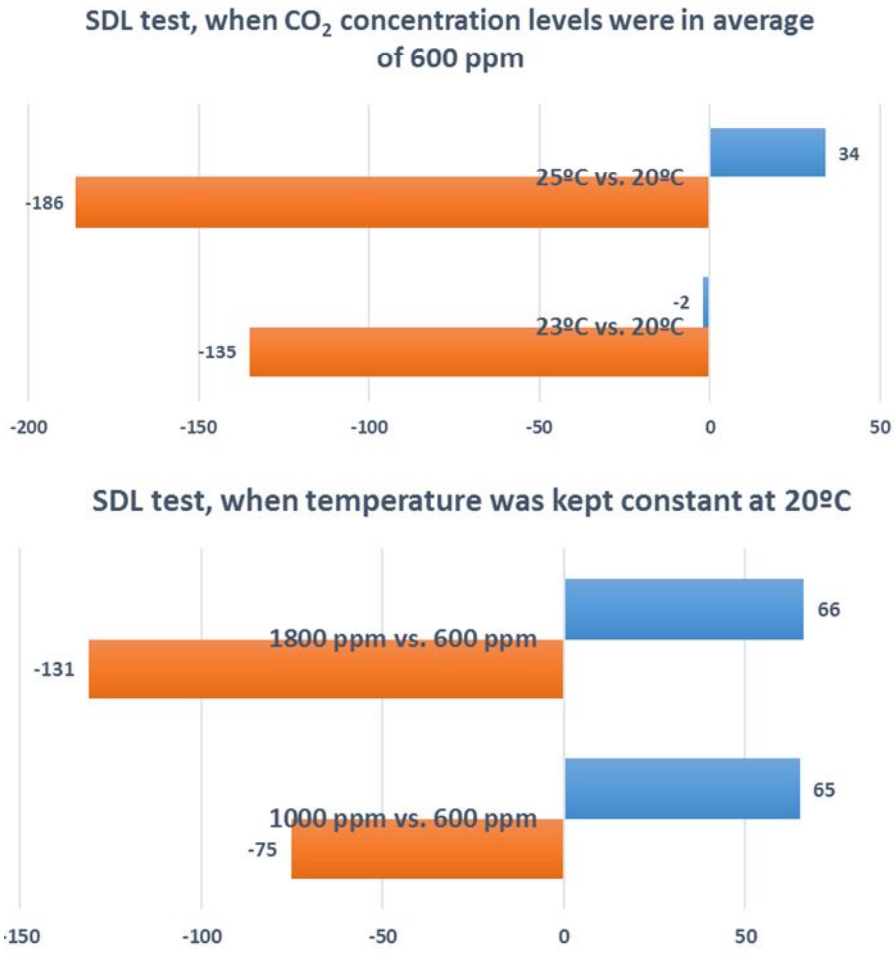
Reversal Learning Test (RL) Results (compared to the base line condition)





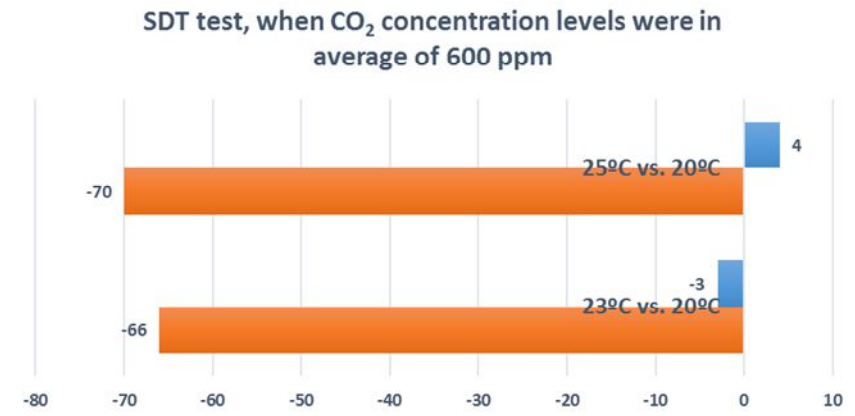
Tornado diagrams showing the trend of change in the % of errors (blue) and speed of response (orange) at the RL test relative to the baseline conditions.

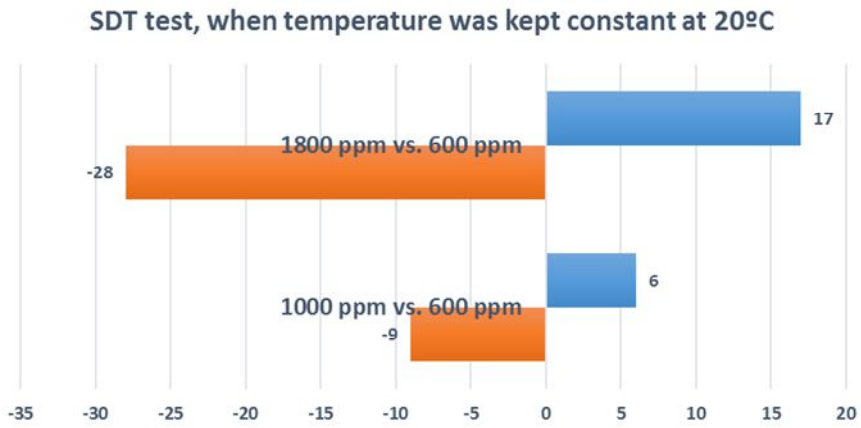
Serial Digit Test (SDT) Results (compared to the base line condition)



Tornado diagrams showing the trend of change in the % of errors (blue) and speed of response (orange) at the SDT test relative to the baseline conditions.

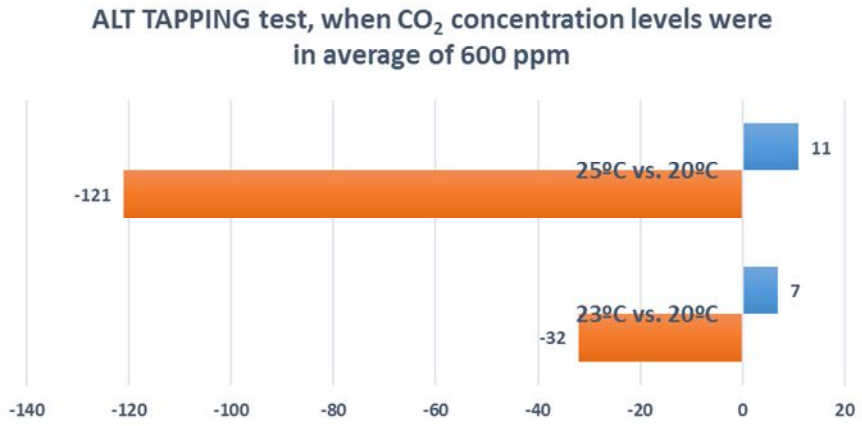
Symbol Digit Test (SyDT) Results (compared to the base line condition)

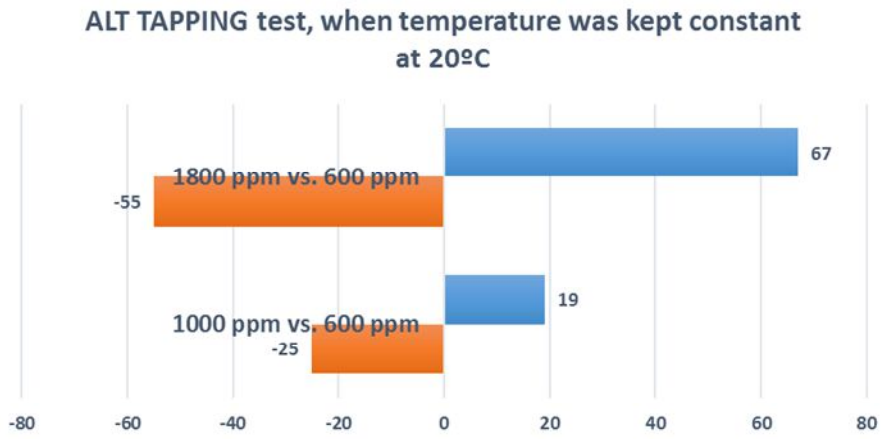




Tornado diagrams showing the trend of change in the % of errors (blue) and speed of response (orange) at the SyDT test relative to the baseline conditions.

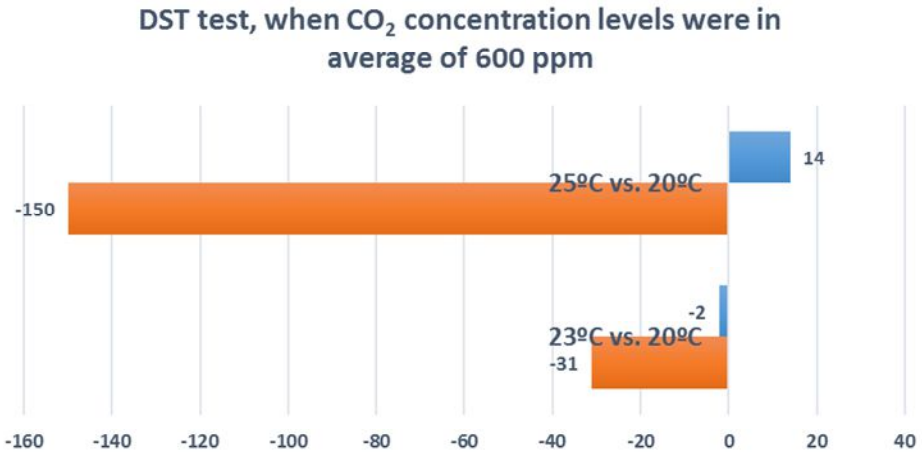
ALT Tapping Test (ALT) Results (compared to the base line condition)

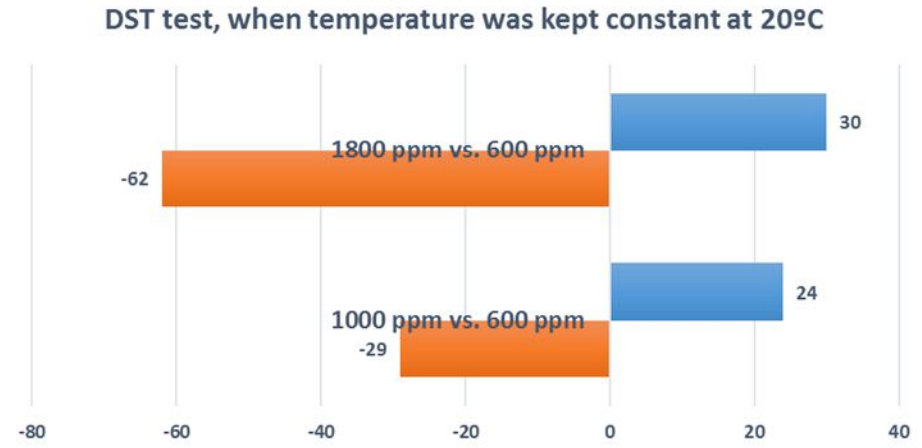




Tornado diagrams showing the trend of change in the % of errors (blue) and speed of response (orange) at the ALT test relative to the baseline conditions.

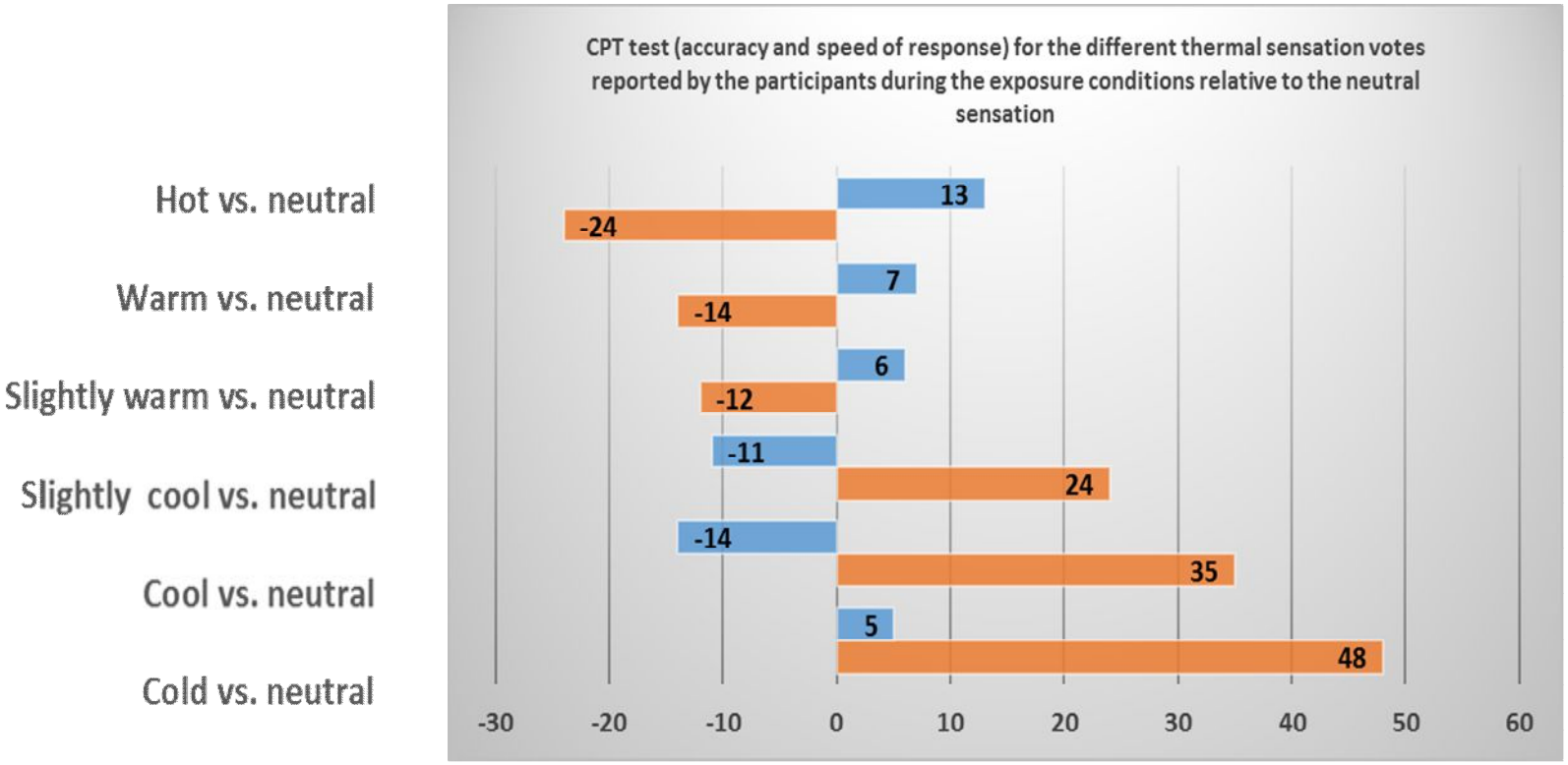
Digital Span Test (DST) Results (compared to the base line condition)





Tornado diagrams showing the trend of change in the % of errors (blue) and speed of response (orange) at the DST test relative to the baseline conditions.

Continuous Performance Test (CPT) Results vs. Thermal Sensation



Tornado diagram showing the trend of change in the % of errors (blue) and speed of response (orange) at the CPT test for the thermal sensation votes reported by the participants relative to the neutral sensation conditions

REHVA Seminar

03-04 April 2017, London, UK

What Do We Know?

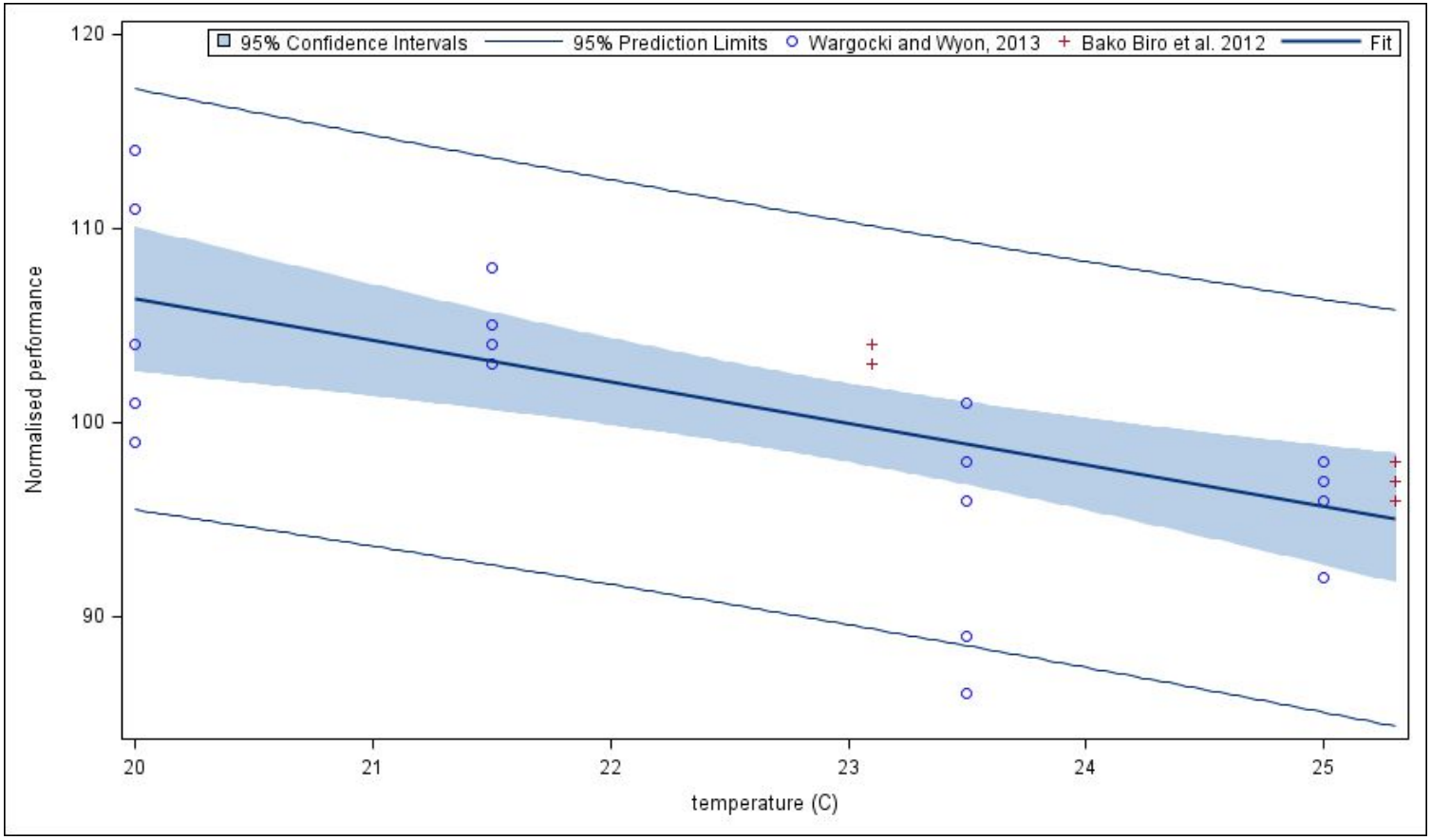
Researcher: **Dr Lia Chatzidiakou**

Prof Dejan Mumovic & Prof Julie Dockrell

Summary of the studies assessing the effect of temperature on academic performance indicators, health and comfort of children in school settings

Study	Population	Country	Design	Outcome measure	Authors' findings
Cognitive performance and IAQ perception					
Wargocki and Wyon, 2013 [6]	Meta-analysis study from seven intervention studies Ns=5 primary schools Nc= 380 Age: 10-12	Denmark	Cross-sectional blind intervention study	Performance in school associated tasks including language and mathematical skills	For every 1 °C reduction academic performance in terms of speed was improved by 2 to 4 %. No improvement in terms of accuracy.
Bako Biro et al, 2012 [44]	Ns=8 primary schools Nc=332 Age: 9-10	England	Cross-sectional blind intervention study	Computer-based software - VISCoPe (Ventilation in Schools and Cognitive Performance)	Cognitive performance of pupils improved by 6% to 8% when lowering the temperature from 25.3 ^{o}C (sd:0.4) to 23.1 ^{o}C (sd: 0.8) in terms of speed.
Health outcomes					
Mi et al, 2006 [45]	Ns=10 secondary schools Nc=1414 Age:13-14	China	Simultaneously controlling for a large number of indoor pollutants	Asthma, asthmatic and respiratory symptoms	Lower temperatures were associated with reduced breathlessness.
Zhang et al, 2011 [46]	Ns=10 secondary schools Nc=1143 Age:11-15	China	Longitudinal study Simultaneously controlling for a large number of indoor pollutants	SBS	T, RH and CO_2 levels were negatively related with SBS symptom.
Ns= number of schools, Nc= number of children					

Normalised performance as a function of classroom temperature. Graph synthesised from two peer-reviewed publications



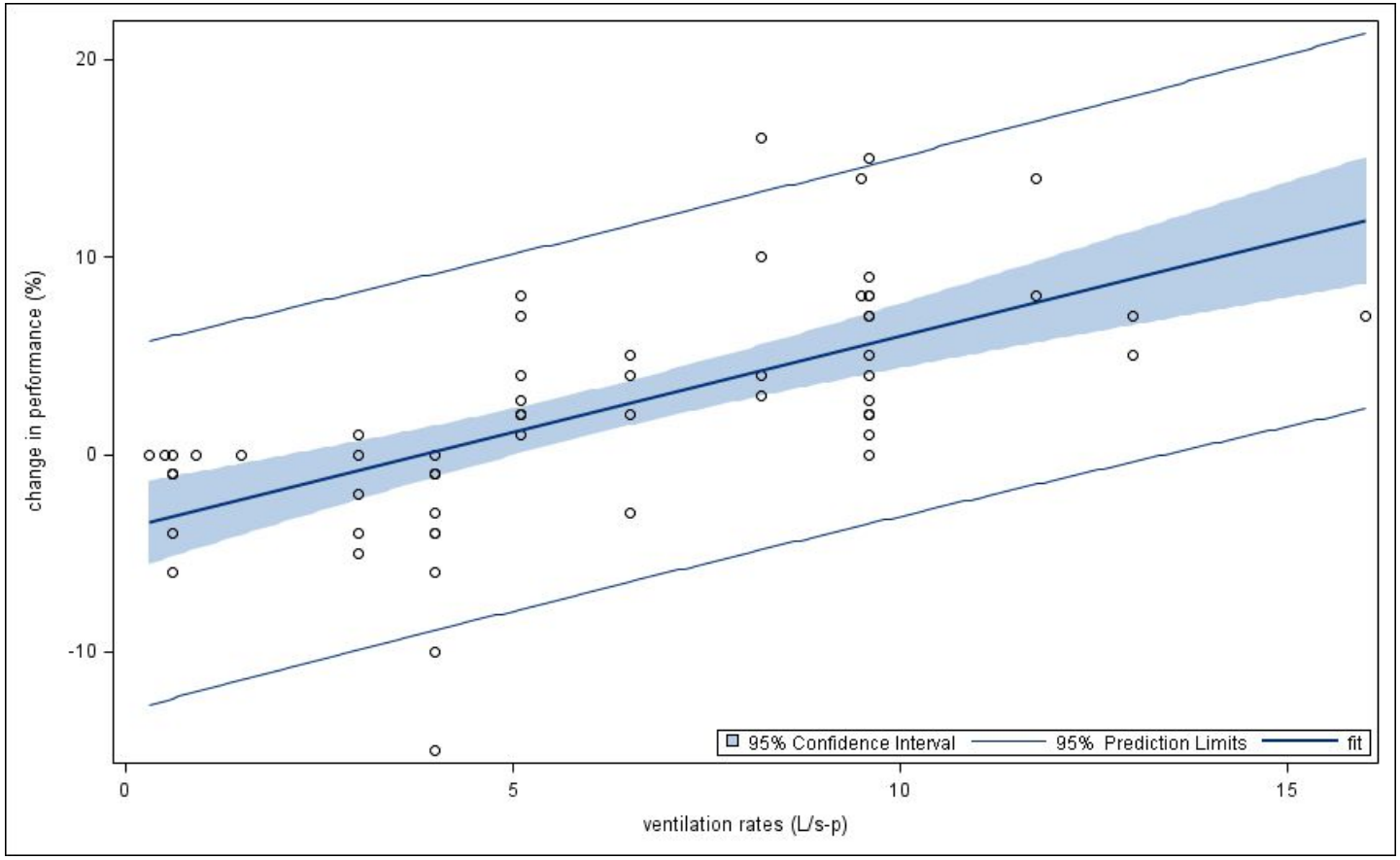
Synthesised relationship shows that an improvement of meta-OR: 11.0 % (95% CI: 10.0 % to 11.2 %) in cognitive performance may be expected when temperature drops from 25 ^{o}C to 20 ^{o}C

Summary of the studies assessing the effect of ventilation on performance indicators of children in school settings

Study	Setting	Ventilation rates (L/s-p)	CO_2 concentrations (ppm)	Design	Outcome measures	authors' findings
Coley and Greeves, 2004	Ns=1 primary school Nc=18, age: 10-12	intervention: 13 control: 1.5	Intervention: 690 (sd: 122) (range 501-983) control: 2909 (sd:474) (range: 2096-4140)	Cross-sectional intervention studies (not blind)	Cognitive Drug Research (CDR) computerised cognitive assessment system (10 minutes to complete)	Increased speed by 5% but not accuracy
Bako Biro et al, 2012	Ns=8, primary school Nc=332, age 9-10	Control:0.3-0.5 Intervention :13-16	No data	Cross-sectional blind interventions. Controlled for comfort, personal factors, airborne particles ($PM_{2.5}$) and noise levels.	Computerised assessment tests software VISCOPE	Increased pupils' speed ~7% in maths (addition, subtraction). No significant effect on accuracy
Wargocki and Wyon, 2013	Ns =5 primary schools Nc=380 age:10-12	3.0 to 9.5		Cross-sectional blind intervention studies (2 weeks)	Numerical and language based tests	Improve Speed: 8% No effect on accuracy.

Nc= Number of children, Ns= number of schools

Percentage change in performance vs. average ventilation rate, fitted with a linear regression model derived from six studies



This synthesis suggests that an increase of ventilation rates from 5 L/s-p to 15 L/s-p will result in an improvement in performance by 10.8 % (95 % CI: 7.9 to 13.0 %).

REHVA Seminar

03-04 April 2017, London, UK

Education in the Context of HVAC Challenges

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Start: September 2017

Website: www.ucl.ac.uk/bartlett/environmental-design/

We are part of The Bartlett: UCL's Global Faculty of the Built Environment

Term One

- Health, Comfort & Wellbeing in the Built Environment
- Methods of Environmental Analysis
- Wellbeing in Buildings: Theory & Practice
- Integrated Building Design for Health, Comfort & Wellbeing

Term Two

(Optional Modules: choose 2 out of 3)

- Indoor Air Quality in Buildings
- Health & Wellbeing in Cities: Theory & Practice
- Light, Lighting & Wellbeing in Buildings
- Building Acoustics
- Designing Inclusive Places

Term Three

- Research project (Dissertation)


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CEGE ENGINEERING A BETTER WORLD

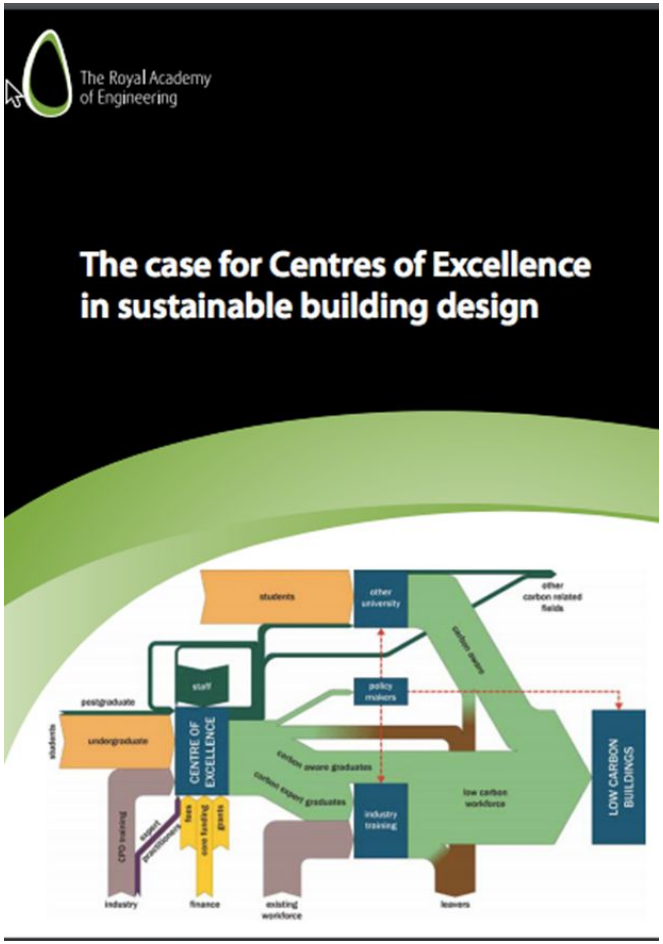
UCL Institute for Environmental Design and Engineering

THE ROYAL ACADEMY OF ENGINEERING (2007-2013)

Key documents:

- Educating Engineers for the 21st Century (2007)
- Pathways to Success in Engineering Degrees and Careers
- The Case for Centres of Excellence in Sustainable Building Design

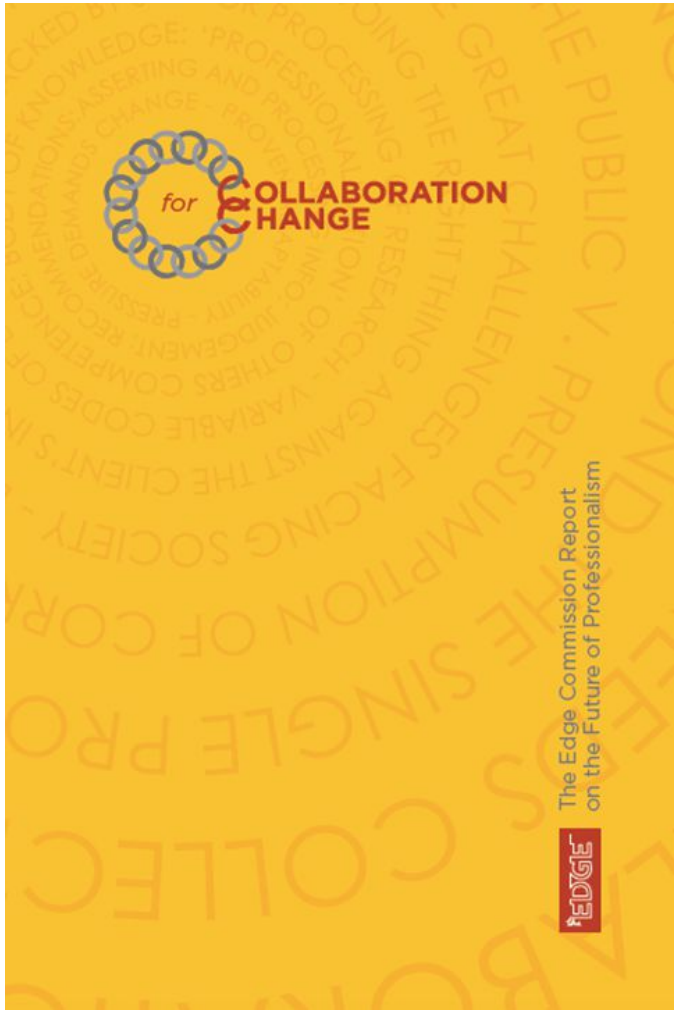
The Bartlett & UCL Engineering Centre of Excellence in Sustainable Building Design



THE EDGE COMMISSION REPORT: FUTURE OF PROFESSIONALISM

EDGE Debates:

- Edge Debate 66: Is it a Problem that Practice and Research do not Connect?
- Debate 63: Edge Commission of Inquiry on Future Professionalism Session 4: Future Value
- Debate 62: Edge Commission of Inquiry on Future Professionalism Session 3: Society
- Debate 61: Edge Commission of Inquiry on Future Professionalism Session 2: The Economy.
- Debate 60: Edge Commission of Inquiry on Future Professionalism Session 1: The Environment
- Debate 54: A New Professionalism?
- Debate 46: What does it mean to be a building professional in the 21st century?



MENG ENGINEERING AND ARCHITECTURAL DESIGN

MEng Engineering and Architctural Design Integrated masters degree, 4 years, 16 Course Units 16/01/16 V0

Year 1	Course Units	Year 2	Course Units	Year 3	Course Units	Year 4	Course Units
Core Module 1 **Materials and Making**	0.5	Core Module 9 **Structural Analysis and Foundation Design**	0.5	Core Module 14 **Mechanics of Buildings**	0.5	Optional Module 1 **Range of options**	0.5
Core Module 2 **Mechanics of Structures and Soils**	0.5	Core Module 10 **Mathematical Modelling and Analysis**	0.5	Core Module 15 **Sense, Sensing and Controls**	0.5	Optional Module 2 **Range of options**	0.5
Core Module 3 **Mathematical Solutions**	0.5	Core Module 11 **Urban Physics**	0.5	Core Module 16 **Practice and Project Management**	0.5	Core Module 19 **MEng Dissertation**	1
Core Module 4 **Building Physics and Energy**	0.5	Core Module 12 **Environmentally Responsible Building Systems**	0.5	Core Module 17 **Making Buildings**	0.5		
Core Module 5 **Building Physics and Environment**	0.5	Core Module 13 **Design Lab 1** Design studio	2	Core Module 18 **Design Lab 2** Vertical design units	2	Core Module 20 **Design Lab 3** Vertical design units	2
Core Module 6 **History and Theory of Design**	0.5						
Core Module 7 **Making Information**	0.5						
Core Module 8 **Design Make Live** 'Live' project	0.5						

MENG ENGINEERING AND ARCHITECTURAL DESIGN

UNIQUE SELLING POINTS 1

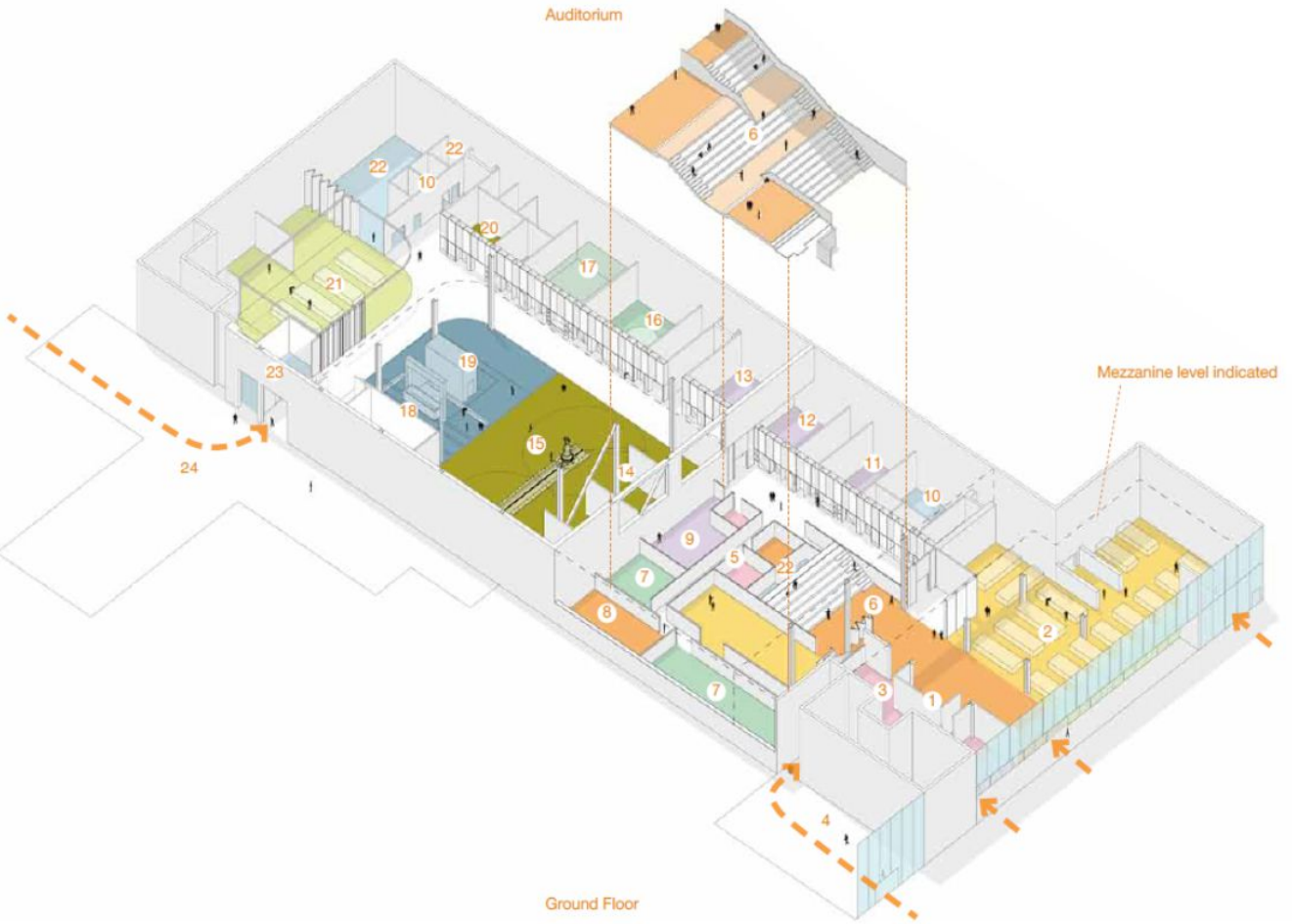
harness and evolve the design studio model to utilise engineering tools in creative design development and to augment the design studio to incorporate advanced fabrication facilities and engineering laboratories in order to put experimentation and prototyping at the heart of the 'design labs'

MENG ENGINEERING AND ARCHITECTURAL DESIGN

UNIQUE SELLING POINTS 2

Key

1. Reception / Exhibition / Social
2. Studios
3. Shared Offices
4. Atrium
5. Teaching / Social
6. Auditorium
7. Human Chamber
8. Waiting Room
9. ISH Sample Store
10. WC's
11. Human Robotics
12. Micro/Nano Robotics
13. ISH Lab
14. Specialist Workshop Bays
15. 3D Tracked Robot Zone
16. Lighting Lab
17. Thermal Lab
18. Robotics Testing
19. Stuctural/Enviro Chamber
20. Waterjet
21. Fabrication Zone
22. Storage
23. ISH Garage
24. Loading Bay



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MENG ENGINEERING AND ARCHITECTURAL DESIGN

UNIQUE SELLING POINTS 3

outward facing to the architectural, engineering and design community

- AKT II
- Atelier One
- Arup
- Buro Happold
- Feilden Clegg Bradley
- Foster + Partners
- Hoare Lea Consulting Engineers
- Knight Architects
- Laing O'Rourke
- Max Fordham
- Price & Myers

THANK YOU