Linking Environmental Conditions to Productivity

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(Abbreviated slideshow based on a presentation at the Eastern Ergonomics Conference and Exposition, New York, June, 2004)

IEQ Effects on Productivity

- Scattered studies that mostly show evidence of an association between indoor environment conditions and some measure of performance.
- Research issues:
  - Laboratory vs. field studies
  - Single vs. multiple contaminants/conditions
  - Surveys vs. interventions
  - Short-term vs. longer-term
  - Single exposure vs. multiple exposure
  - Time-lagged effects
  - Acute vs. chronic health effects

IEQ Effects on Productivity

System	Environmental experience	Productivity Impact
Heating, Ventilating and Air Conditioning System	• Thermal comfort • Indoor Air Quality • Background noise • Mechanical vibration • Personal control/stress	• Performance decreases when too cold • Performance decreases when too hot • Performance decreases in polluted air • Performance decreases when too noisy • Performance decreases when person/equipment vibrates • Performance decreases with no control (perceived or real)

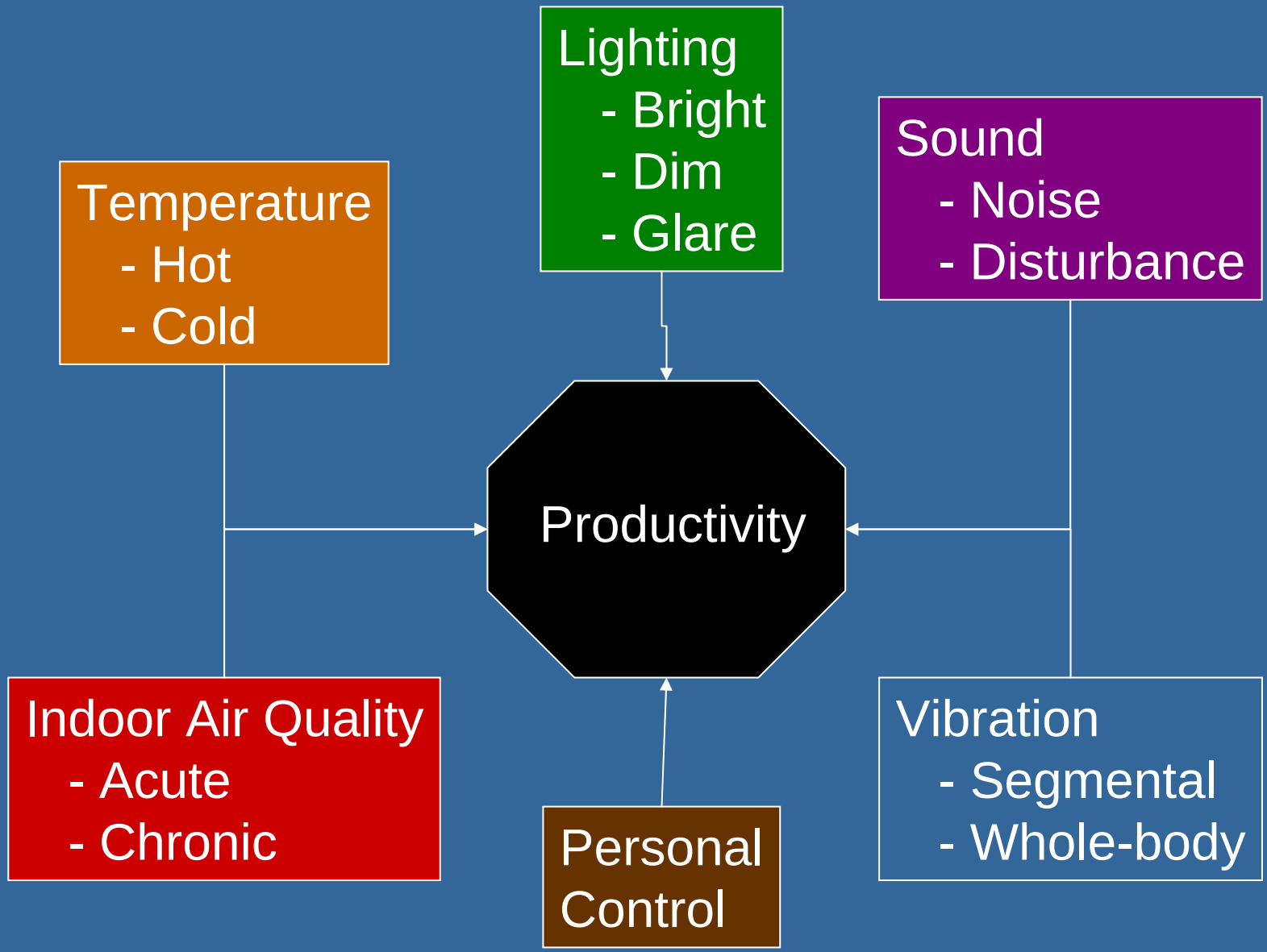
IEQ Effects on Productivity

System	Environmental experience	Productivity Impact
Lighting System	• Illumination level/ distribution • Glare • Ambient/task systems • Color • Room ambience (shadows) • Personal control/stress	• Performance decreases when too dim or too bright • Performance decreases when too glaring • Task demands and user age change light requirements • Affective changes in environmental desirability • Disrupts visual inspection/ interpersonal interactions • Performance decreases with no control (perceived or real)

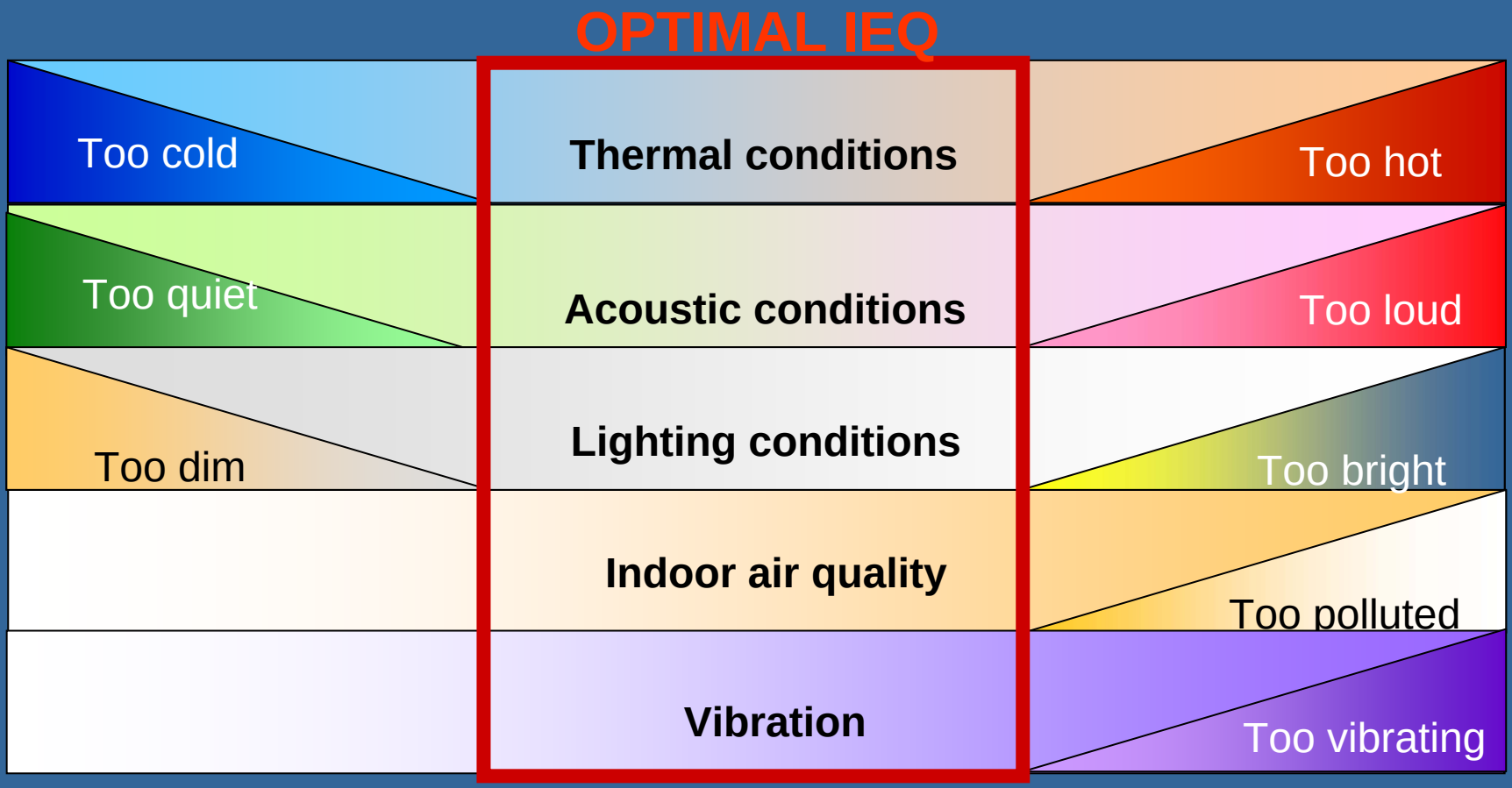
IEQ Effects on Productivity

System	Environmental experience	Productivity Impact
Sound conditioning system/ Acoustic design	• Background noise • Speech privacy/intelligibility • Noise stress • Personal control/stress	• Performance decreases with loud/annoying noise • Performance decreases with poor privacy • Performance decreases with noise stress • Performance decreases with no control (perceived or real)

IEQ factors and Human Performance



Optimal IEQ Conditions



(Source: Stanton, Hedge et al. (2004) Handbook of Human Factors and Ergonomics, CRC Press)

Productivity – Individual Work Performance

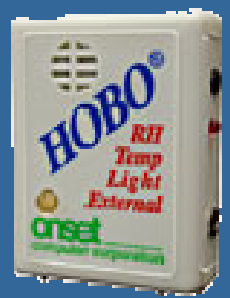
- Productivity research traditionally has focused at the coarse, aggregate level of the building and the occupants.
- Aggregate measures cannot define precise associations between IEQ conditions and individual productivity.
- Laboratory studies have investigated performance and exposure to specific pollutants and mixtures, but exposures are short-term, non-cumulative and use simulated work tasks
- Research need is to focus on the performance of the individual and the environment experienced by that the individual.
- Individual measures:
  - Self-reports
  - Task Performance (time, accuracy, quantity, quality)

IEQ and Productivity Research

- New Research Approach – Combining spatio-temporal IEQ and Productivity Datasets
  - IEQ measure needs to include air temperature and relative humidity because thermal conditions are known to influence work performance, and consequently could confound any associations with air pollutants.
  - Most HVAC systems are designed to regulate thermal conditions, and HVAC systems respond to thermostat controls.
  - Thermal conditions impact levels of VOCs and other pollutants
  - Thermal conditions are an indicator of ventilation quality. High temperatures can indicate poor ventilation which in turn can indicate high pollutant loads.

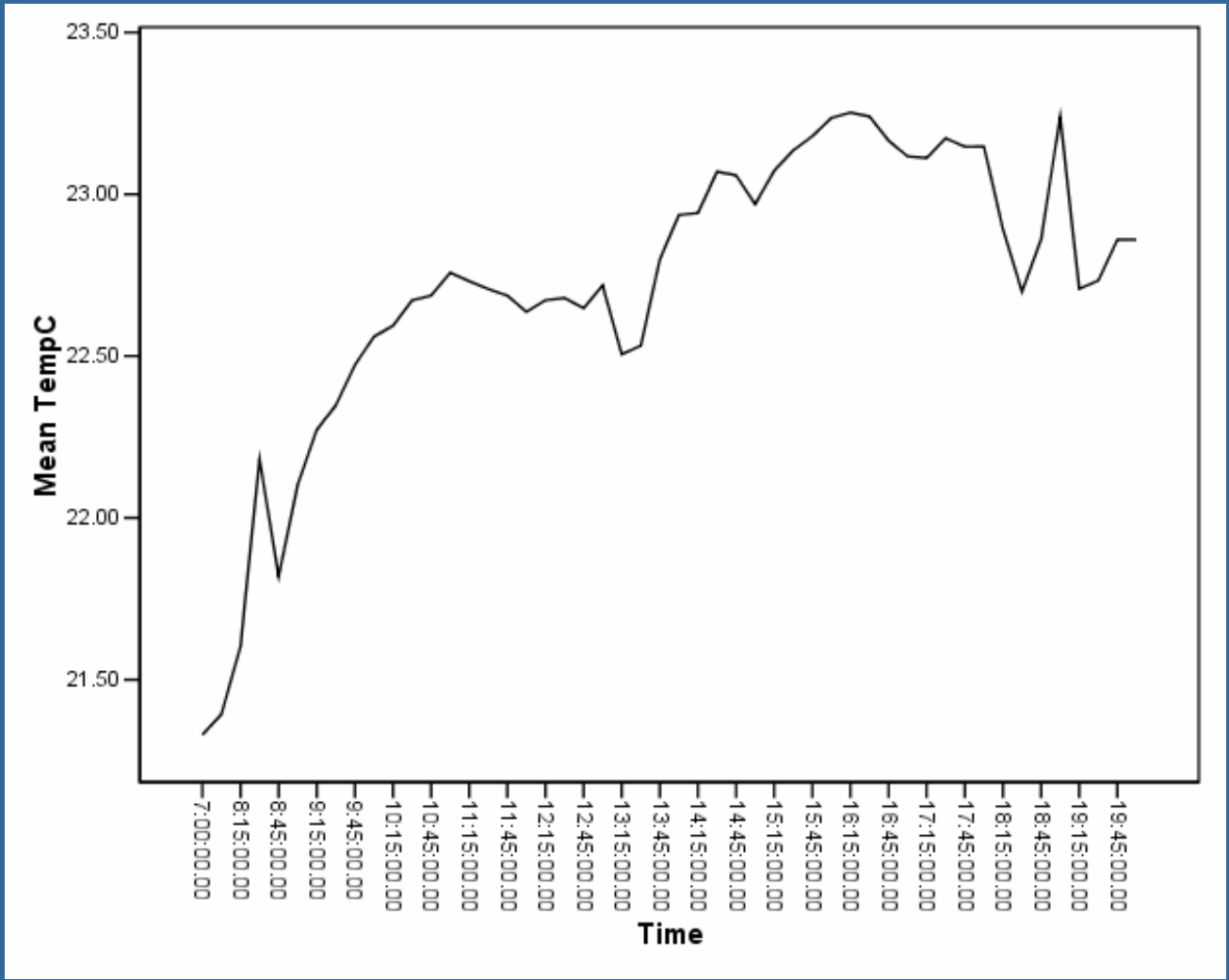
IEQ Data Logging

- IEQ logging units that can be:
  - Widely dispersed throughout a building
  - Small size
  - Silent operation
  - Self-powered
  - “Inexpensive”
  - Frequent logging/data storage capabilities
  - Ideally, work computer synchronized
  - Ideally, collect data on a wide array of IEQ variables.



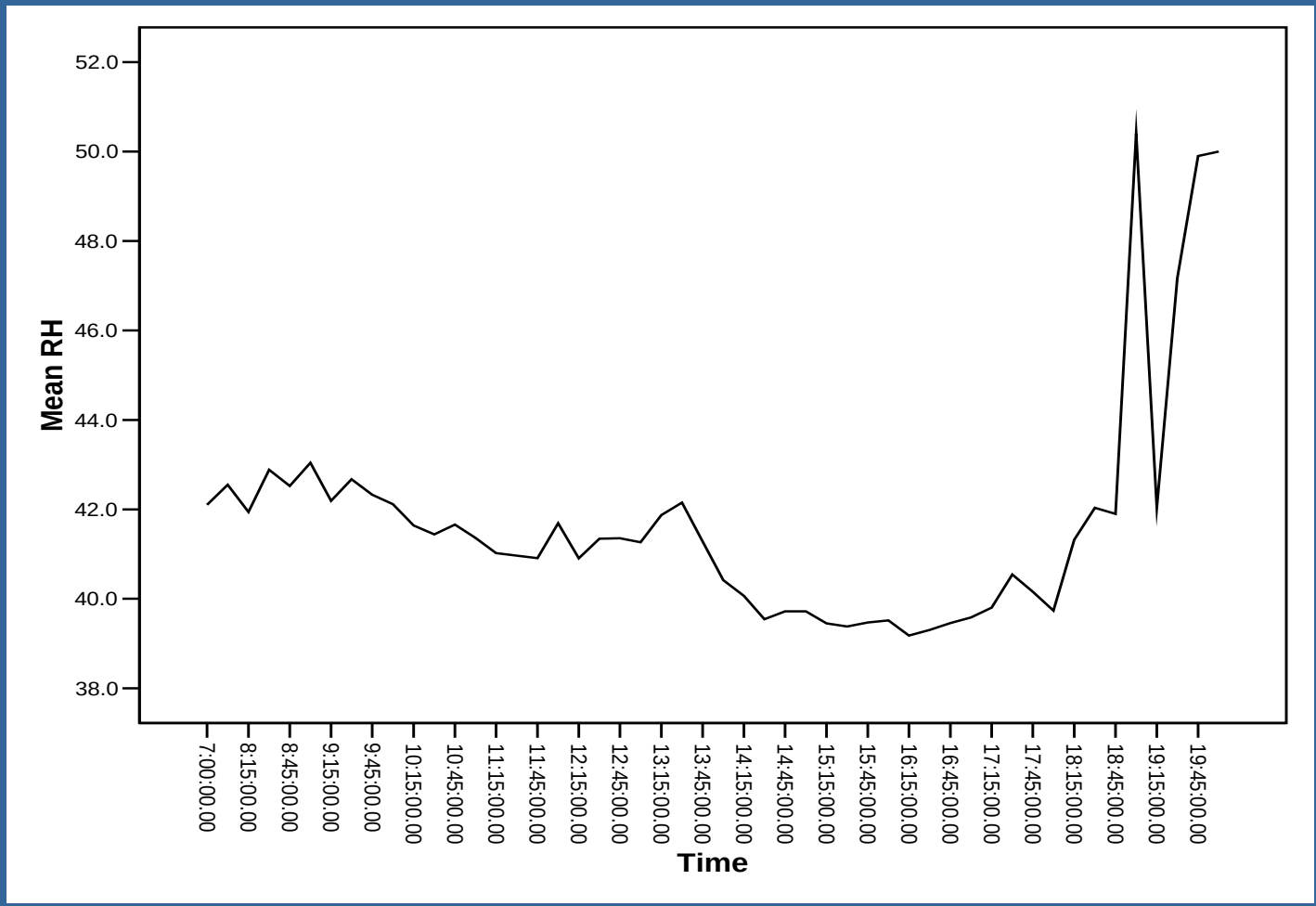
Average Daily Temperature Pattern

- Insurance company (Florida)
  - 9 workstations for 16 work days



Average Daily Humidity Pattern

- Insurance company (Florida)
  - 9 workstations for 16 work days

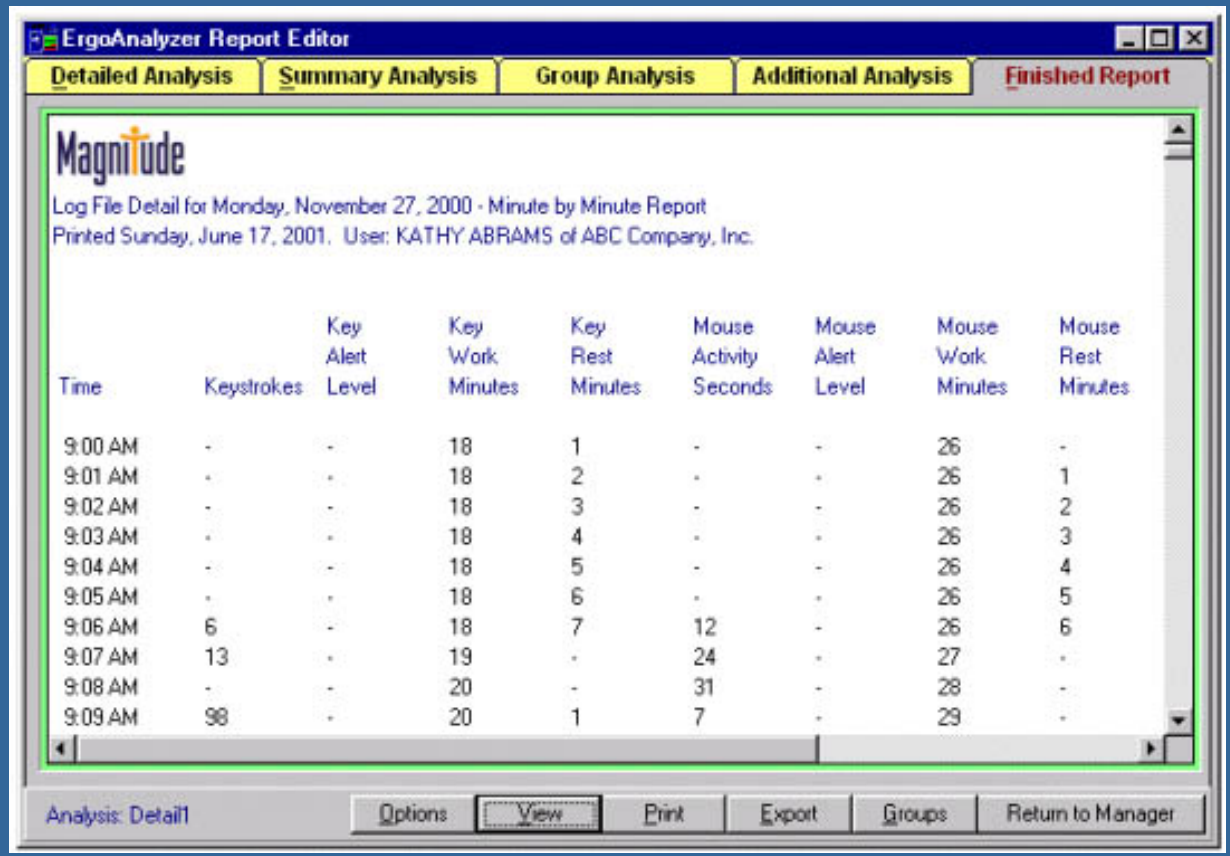


Electronic Productivity Measures

- Keystrokes/errors/mouse activity
- Utilize existing networked data collection software (EMS)
- Data file – every work minute the software records a count of:
  - Correct keystrokes
  - Errors
  - Mouse activity
  - Longitudinal data (e.g. every 15 minutes for 16 days)

Electronic Productivity Measures

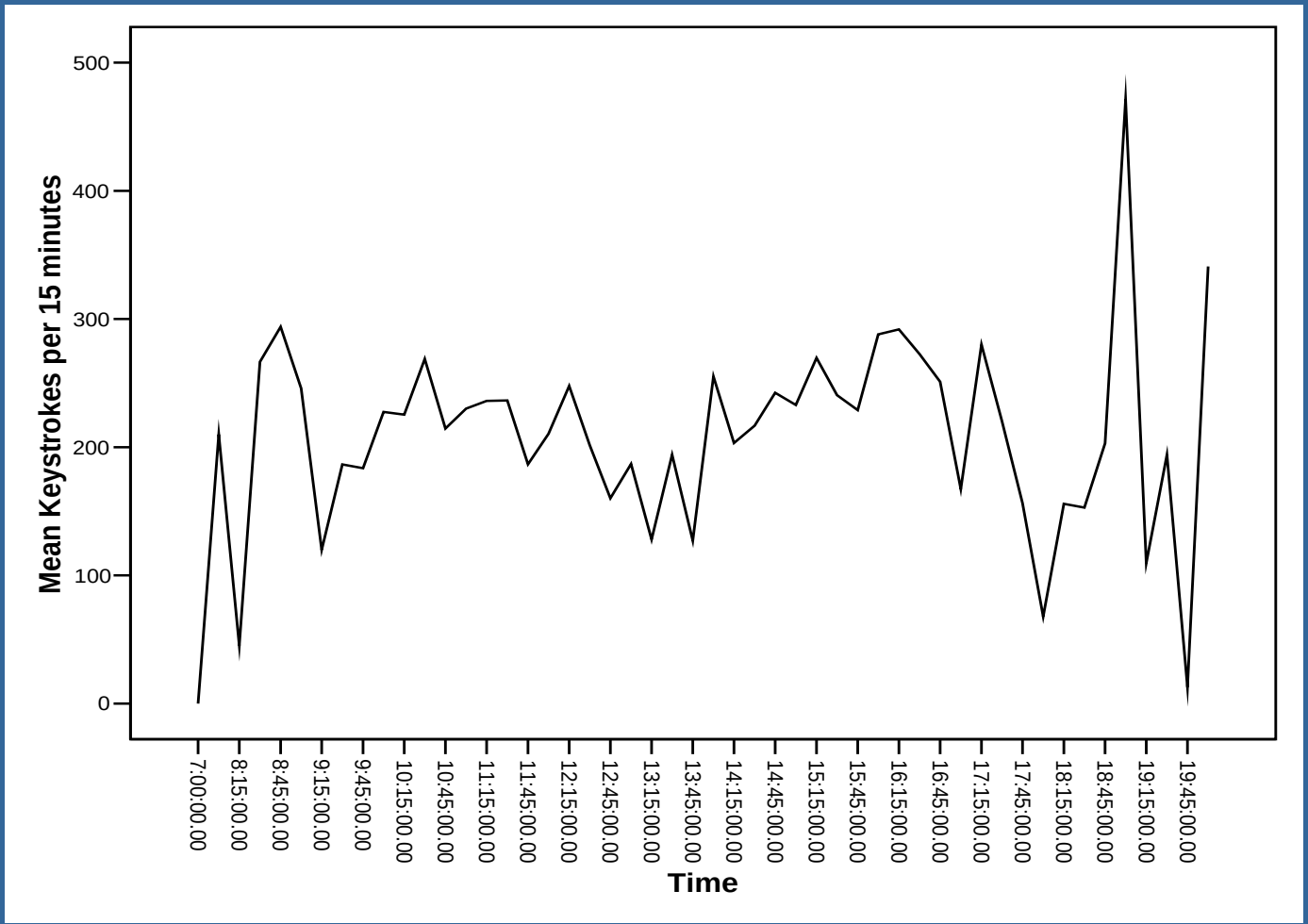
- Example of data structure (does not show errors column)



Time	Keystrokes	Key Alert Level	Key Work Minutes	Key Rest Minutes	Mouse Activity Seconds	Mouse Alert Level	Mouse Work Minutes	Mouse Rest Minutes
9:00 AM	-	-	18	1	-	-	26	-
9:01 AM	-	-	18	2	-	-	26	1
9:02 AM	-	-	18	3	-	-	26	2
9:03 AM	-	-	18	4	-	-	26	3
9:04 AM	-	-	18	5	-	-	26	4
9:05 AM	-	-	18	6	-	-	26	5
9:06 AM	6	-	18	7	12	-	26	6
9:07 AM	13	-	19	-	24	-	27	-
9:08 AM	-	-	20	-	31	-	28	-
9:09 AM	98	-	20	1	7	-	29	-

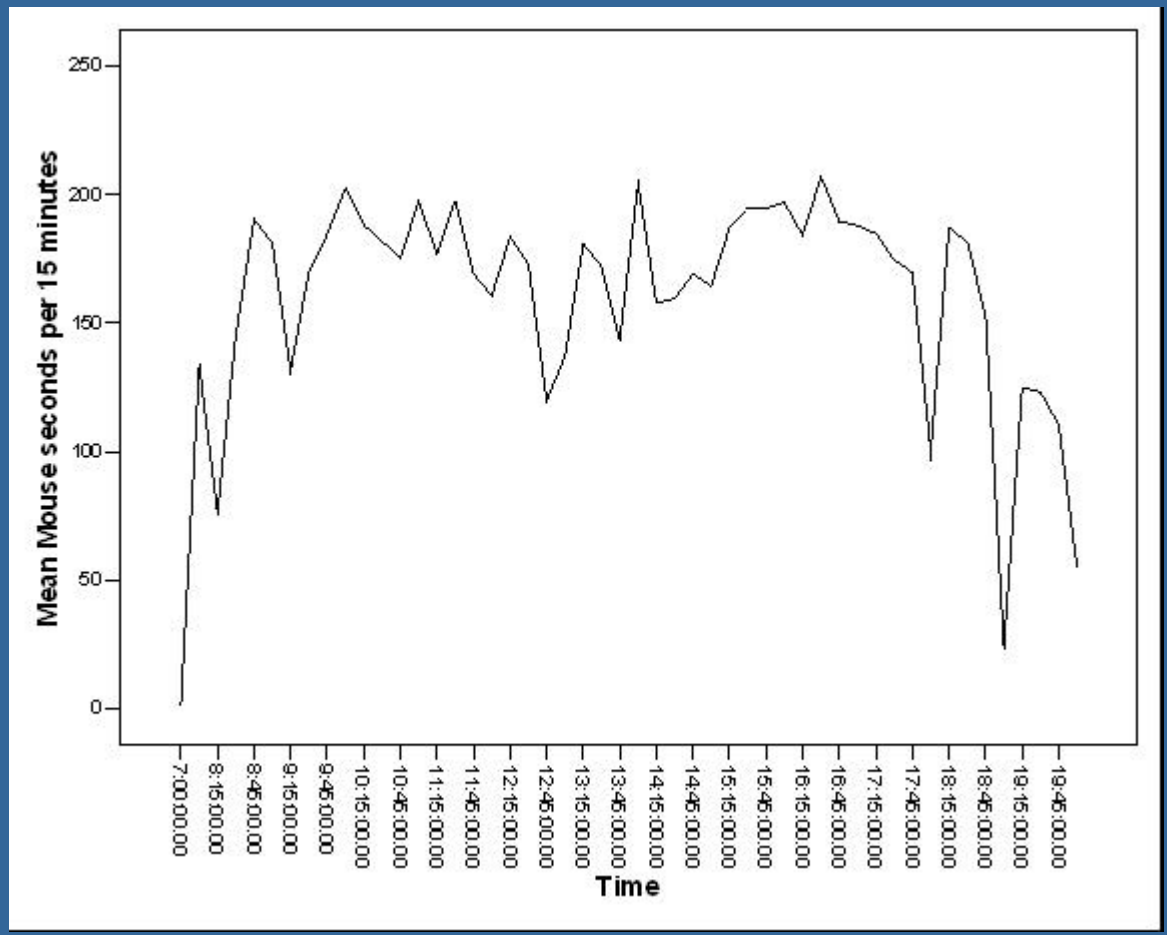
Average Daily Keying Pattern

- Insurance company (Florida)
  - 9 workstations for 16 work days



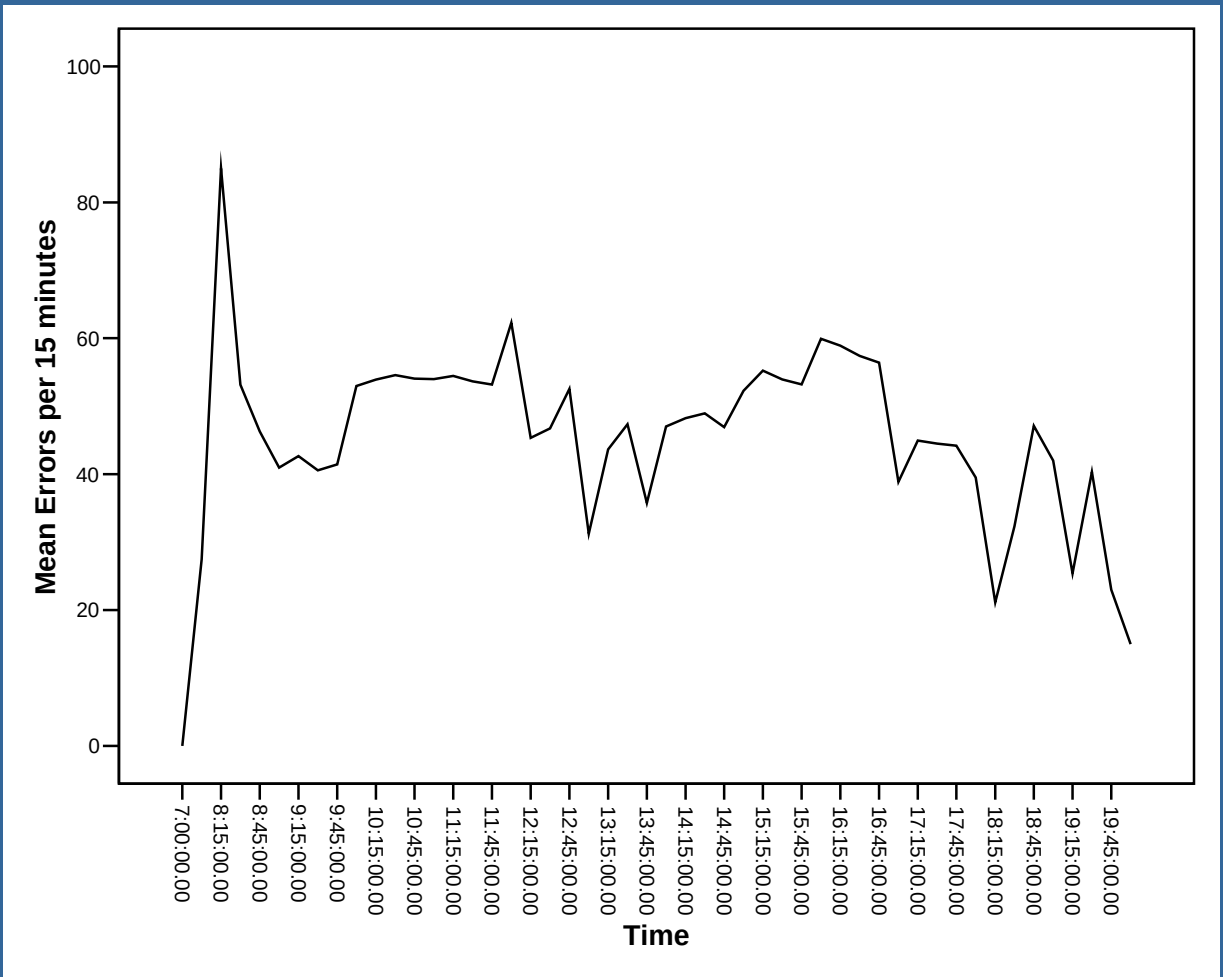
Average Daily Mousing Pattern

- Insurance company (Florida)
  - 9 workstations for 16 work days



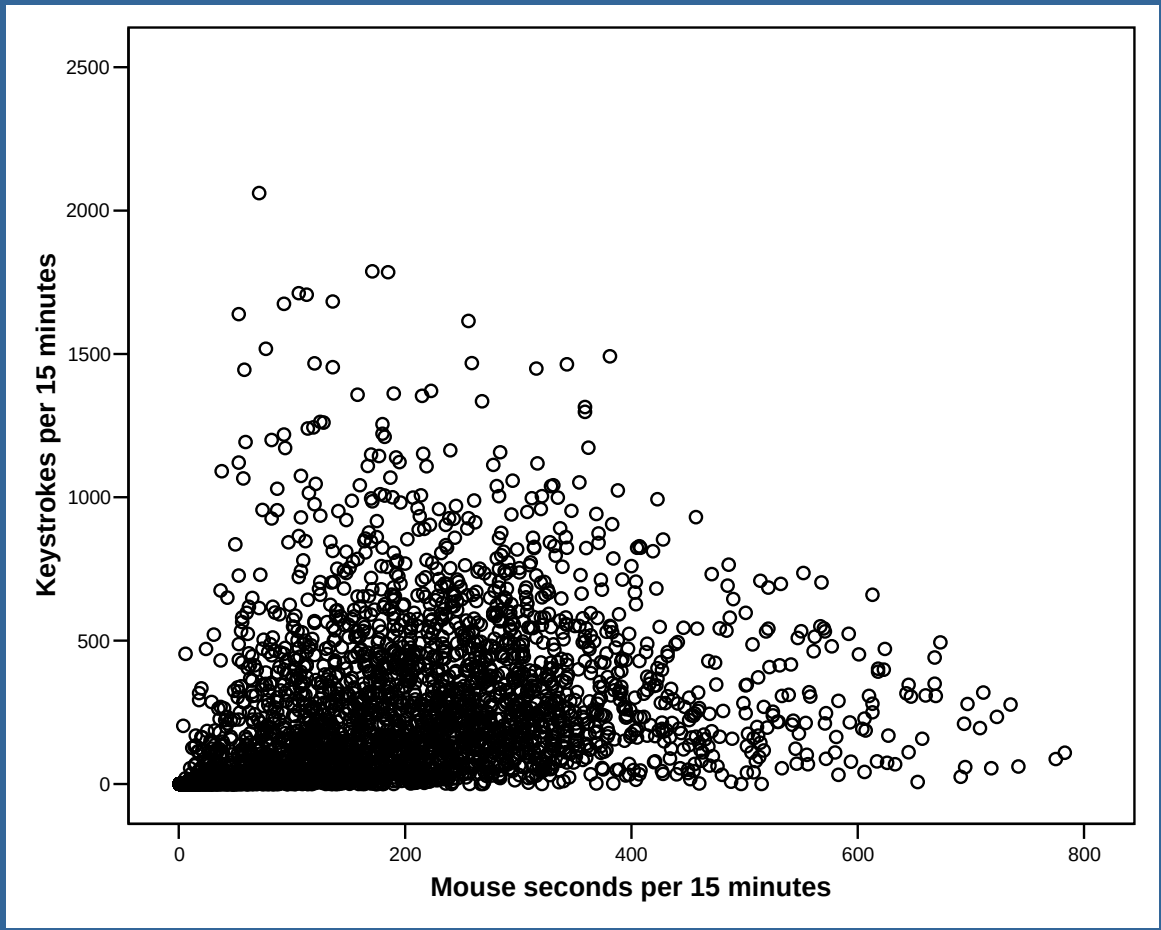
Average Daily Error Pattern

- Insurance company (Florida)
  - 9 workstations for 16 work days



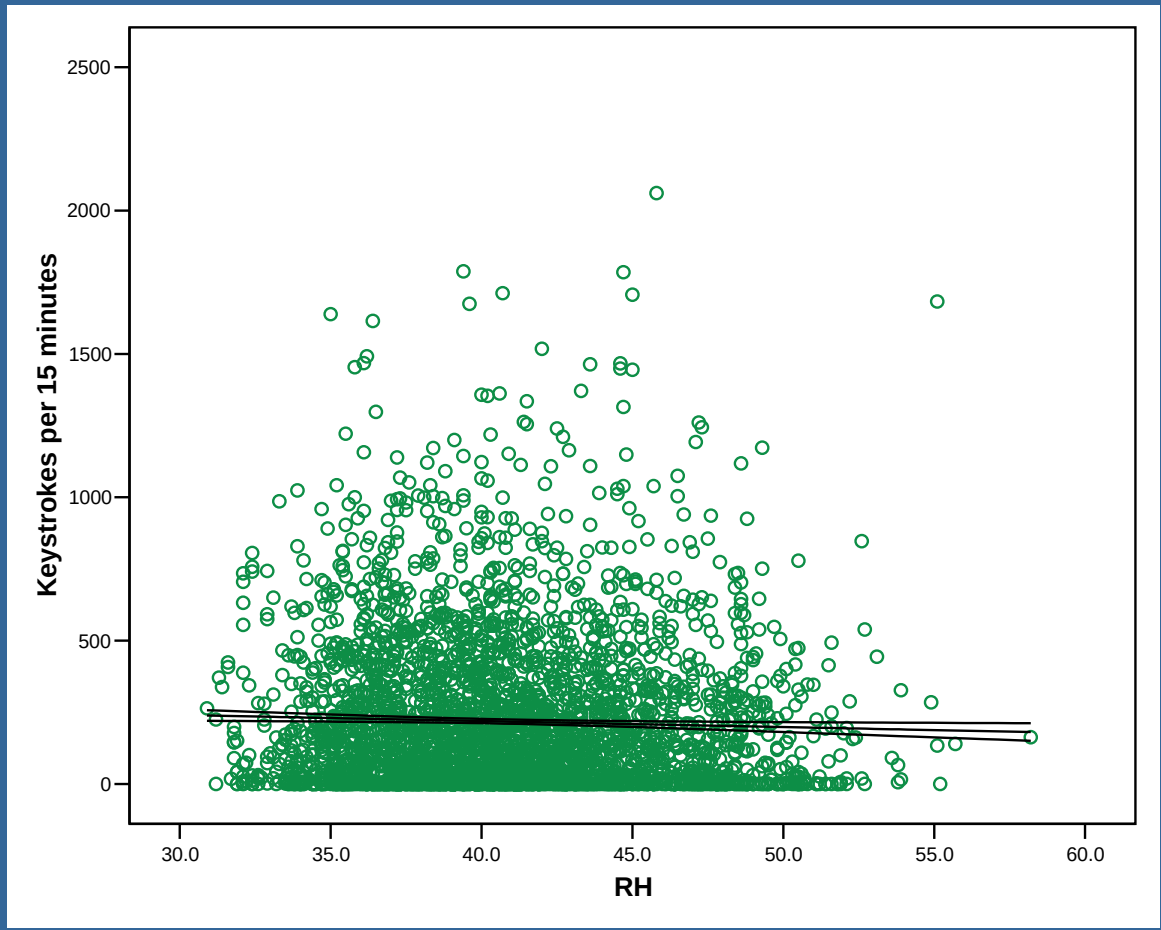
Keystrokes and Mousing

- Insurance company (Florida)
  - 9 workstations for 16 work days



Humidity and Keystrokes

- Insurance company (Florida)
  - 9 workstations for 16 work days



Light and Keystrokes

- Insurance company (Florida)
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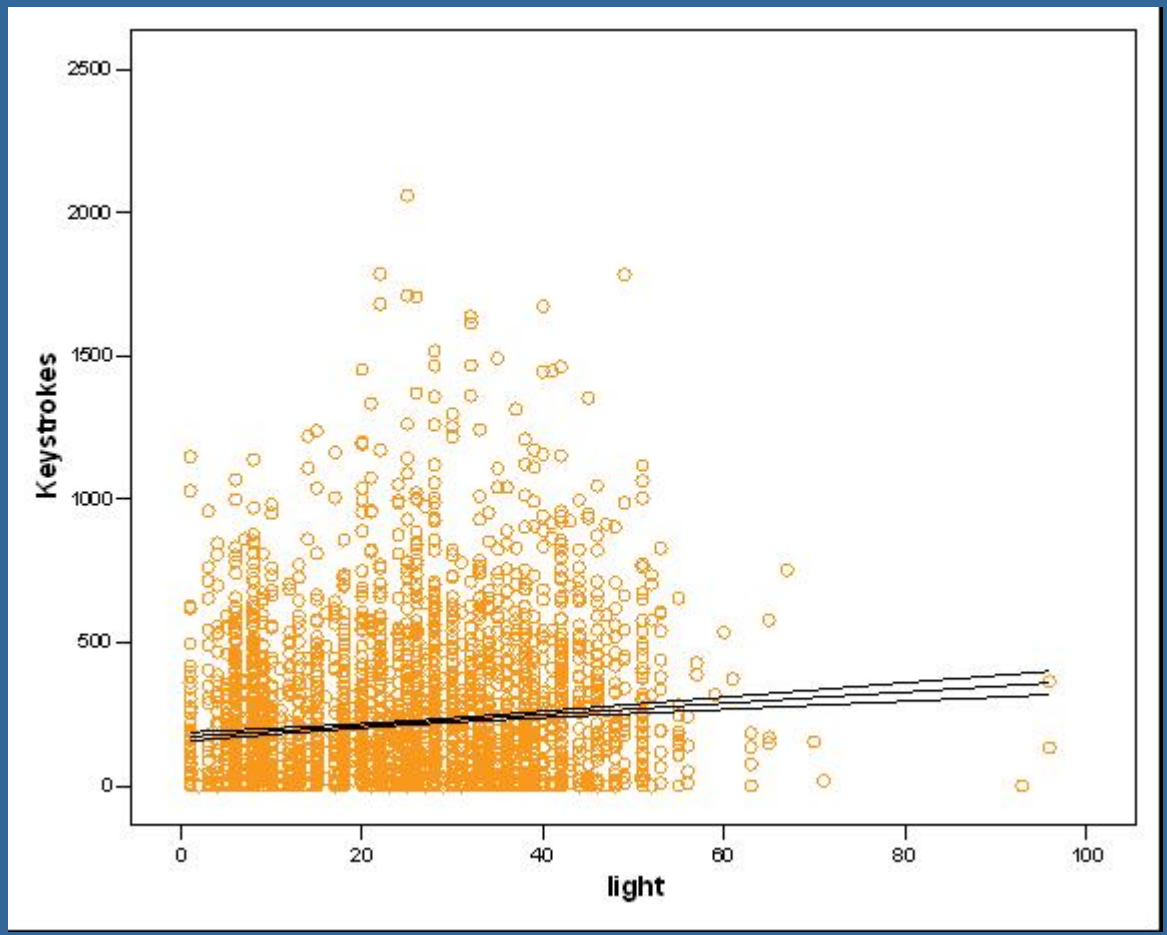
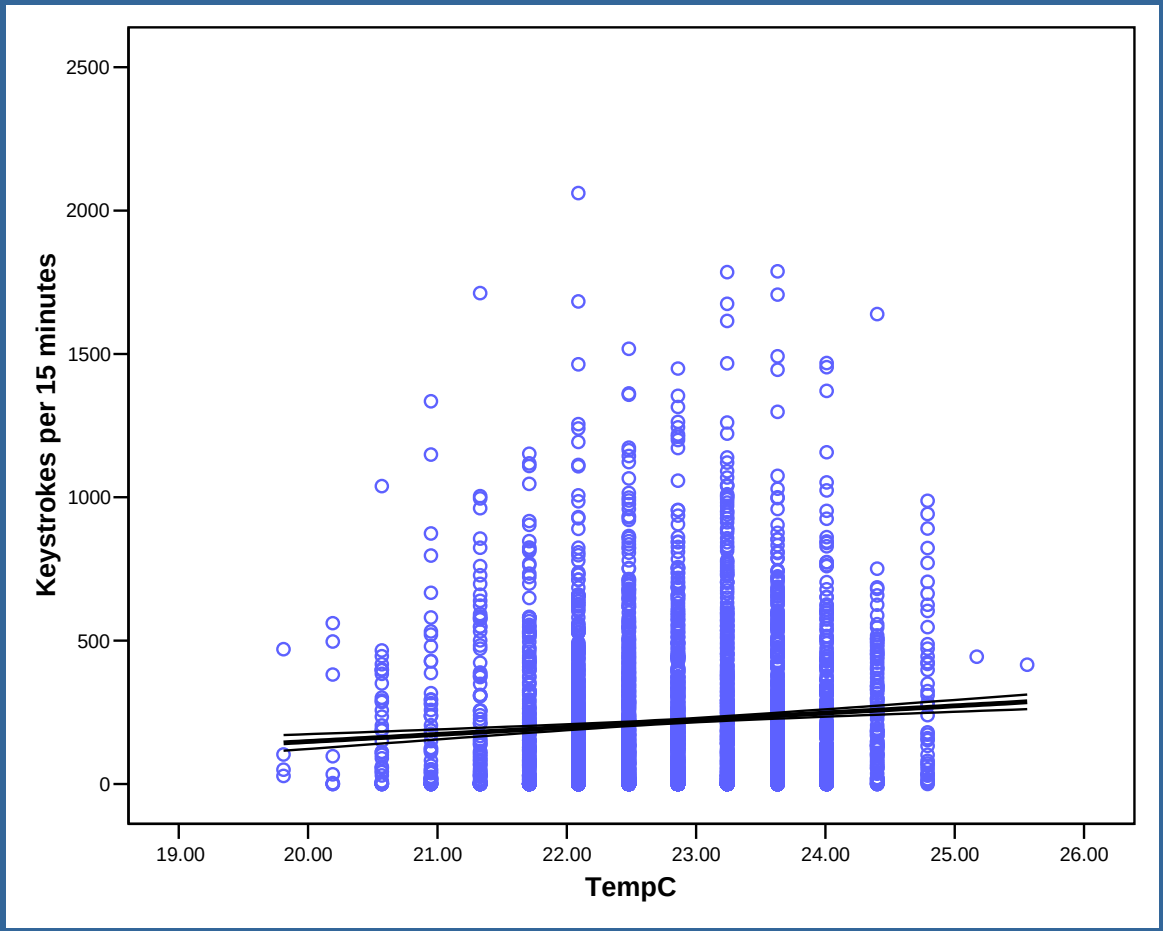


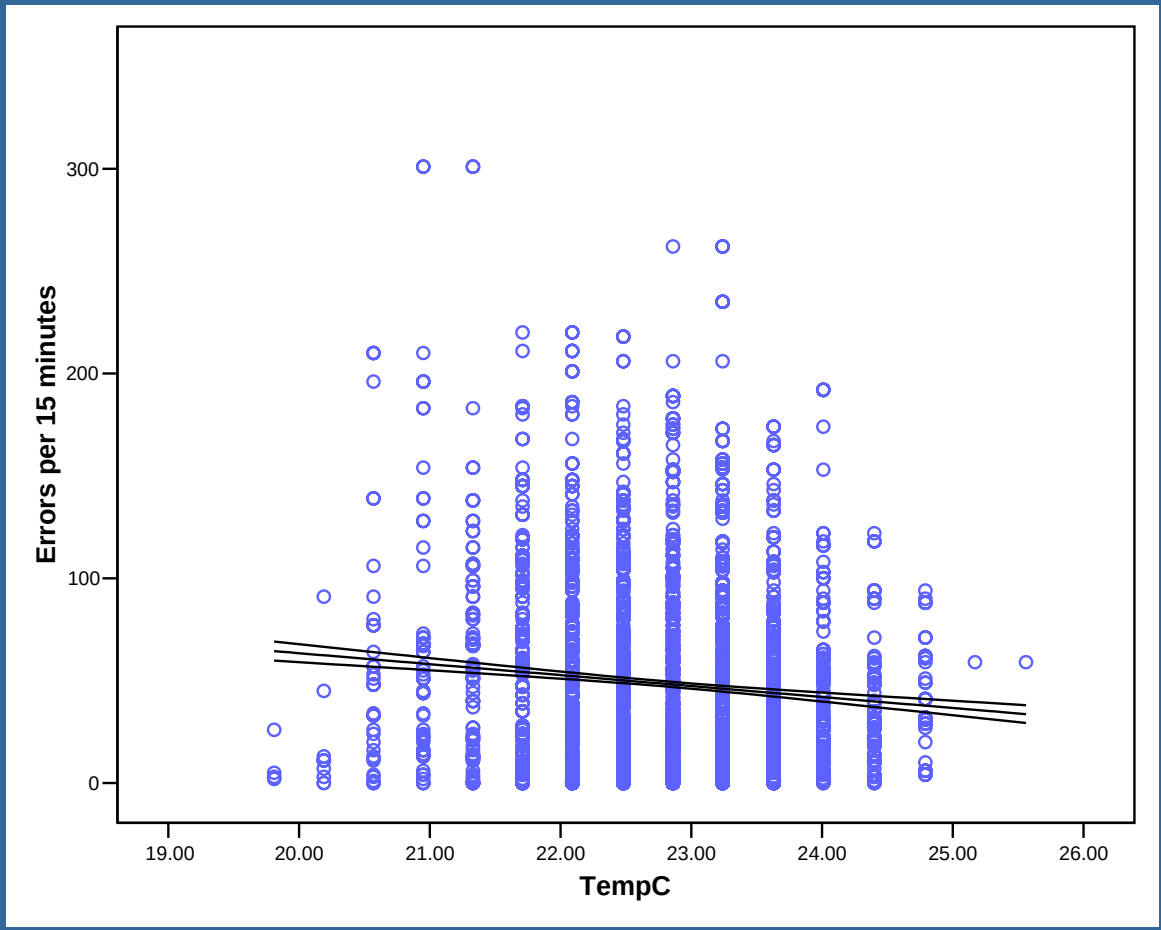
Temperature and Keystrokes

- Insurance company (Florida)
  - 9 workstations for 16 work days



Temperature and Errors

- Insurance company (Florida)
  - 9 workstations for 16 work days



Mouse Seconds

Dependent Variable: Mouse Seconds

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	176.333	3.505	50.308	.000	169.461	183.206
Temperature^2 (nTa°C)	5.325	2.301	2.314	.021	.814	9.836
RH^2 (nRH)	-.207	.101	-2.050	.040	-.405	-.009

Mouse seconds=176.33 + 5.33(nTa) ^{2} - .21(nRH)^2

Note: Environment variables normalized

Keystrokes

Dependent Variable: Keystrokes

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	204.522	5.411	37.798	.000	193.913	215.131
Light (nL)	2.446	.348	7.029	.000	1.764	3.128
Temperature (nTa°C)	33.087	5.444	6.078	.000	22.413	43.761
Temperature^2	19.306	4.373	4.415	.000	10.732	27.879

$$Keystrokes = 204.52 + 2.45(nL) + 33.09(nTa) + 19.31(nTa)^2$$

Note: Environment variables normalized

Error Keys

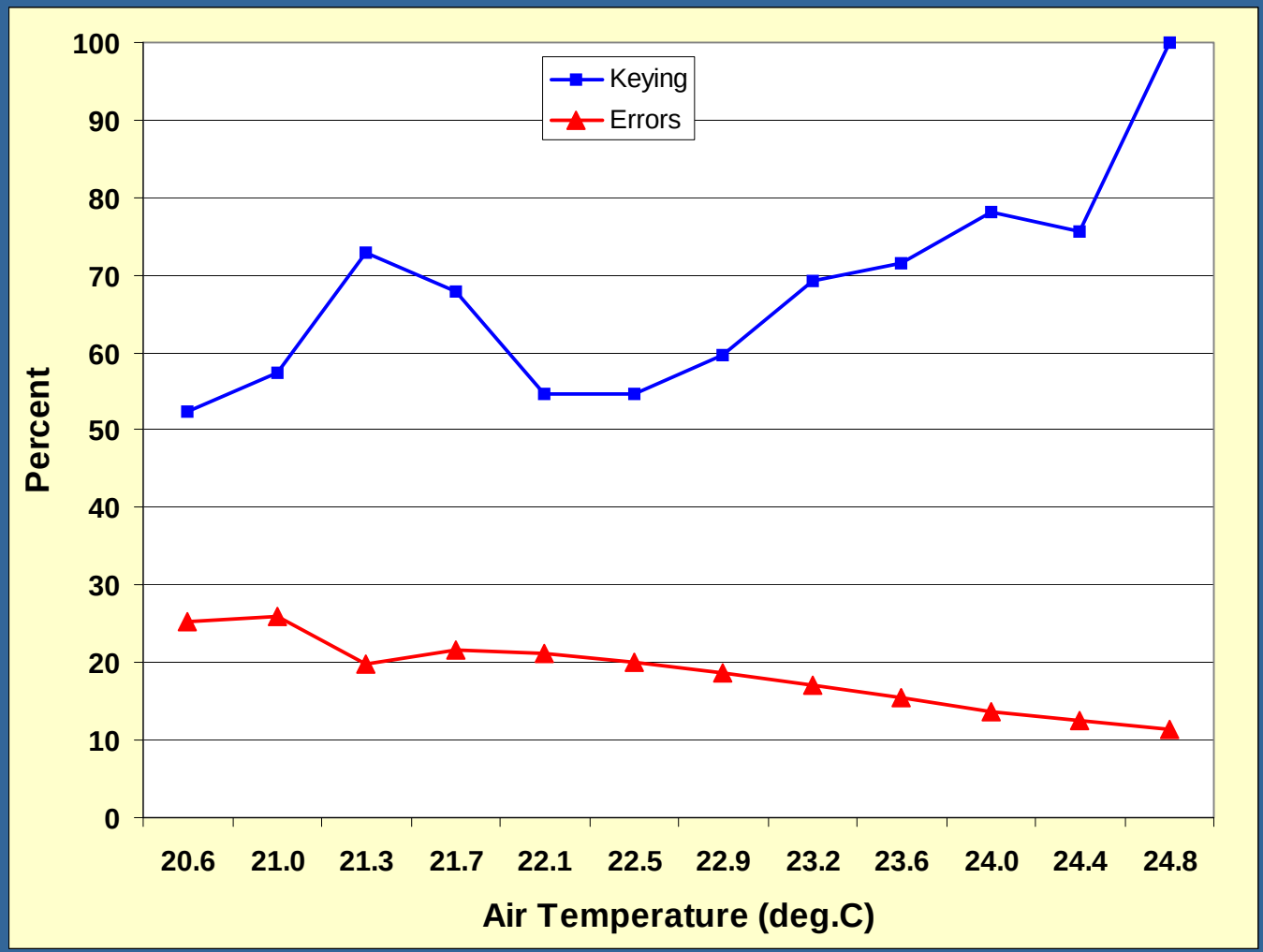
Dependent Variable: Error Keys

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	48.584	1.128	43.058	.000	46.371	50.796
Temperature (nTa°C)	-3.694	.937	-3.941	.000	-5.531	-1.856
RH (nRH)	.525	.188	2.800	.005	.157	.893
Light (nL)	.716	.059	12.165	.000	.600	.831
Temperature^2	2.021	.743	2.722	.007	.565	3.477
RH^2	-.082	.032	-2.515	.012	-.145	-.018

$$Errors = 48.58 - 3.69(nTa) + .53(nRH) + .72(nL) + 2.02(nTa)^2 - .08(RH)^2$$

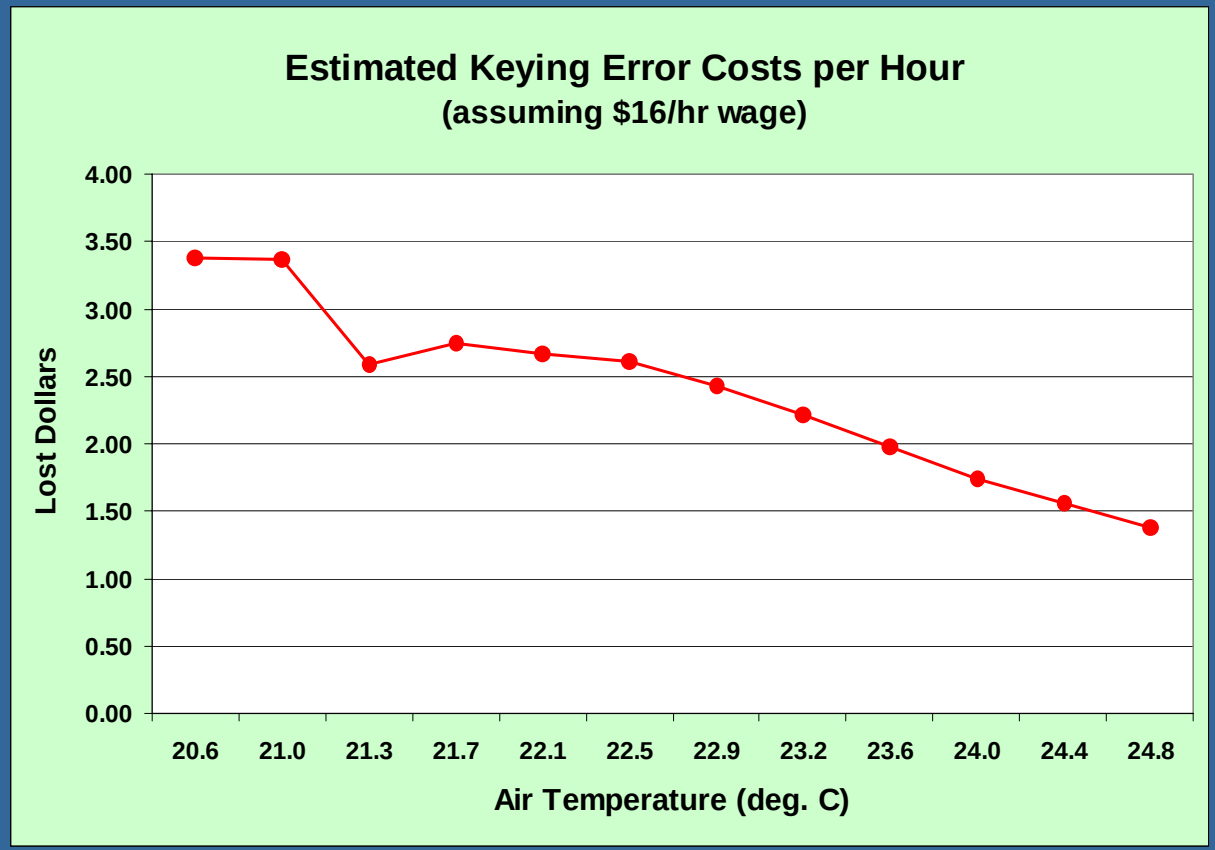
Note: Environment variables normalized

Temperature and Performance



Temperature and Cost

- Assumptions:
  - Employee earns $16 per hour
  - Keying time = 900-mouse time seconds
  - Total keys = correct + error keys
  - Cost/key = keying time/total keys
  - Error costs = error keys X costs per key
  - Hourly costs = 4 x error costs



Research Conclusions

- Results show clear associations between office work performance and indoor environment conditions
- Results suggest that performance improves as conditions approach a predicted thermal comfort zone
- Raising temperature from 20°C to 25°C:
  - Reduces energy consumption (less cooling)
  - Reduces costs
  - Reduces errors by 44%
  - Increases keying output by 150%
  - Saves ~$2.00 per worker in lost productivity
- With optimization of other environmental conditions the cost savings will be even greater!

Research Conclusions

- Study confirms the utility of this new metric for assessing the performance and financial impacts of IEQ changes.
- Associations between changes in specific indoor environmental variables and consequent productivity changes can now be investigated.
- The impact of IEQ changes (e.g. different lighting, different HVAC systems) on productivity can now be tested.
- The impact of any ergonomic changes (e.g. new chairs, new workstations, keyboard trays) on productivity can now be tested.
- Data for IEQ standards that can incorporate productivity impacts can now be gathered.

Questions