TOWARDS AN OPTIMAL THERMAL COMFORT AND ENERGY EFFICIENT WORKPLACE
PART I: INTRODUCTION
Spend 80 – 90% of the lifetime indoors;

Buildings → Protect + Comfort

Comfortable indoor environment = Challenge!
1.1 PROBLEM FIELD

**Differences among users:** age, gender, body mass, activity and position in building

**Building Energy Systems:** maintained on steady level | fixed schedule & average values;

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**ENERGY SYSTEMS**

**40% primary energy consumption** → 50% energy consumption by HVAC systems.

**High expenditure** for building owners

**Energy transition:** Reduce Green House Gas (GHG) emission by 40% before 2030
Thermal comfort

= essential factor in worker productivity & satisfaction

Building energy system

= cannot satisfy all users + significant source of energy consumption + high expenditure for building owners

1.2 Problem Summary

Challenges

Providing a solution, which creates an appropriate balance between thermal comfort and energy performance of buildings
PERSONAL COMFORT SYSTEM =
Improvement thermal comfort + Energy saving

1.3 POSSIBLE SOLUTION = PCS

USER INTERFACE

LIGHTING
VENTILATION
TEMPERATURE
1.3 Personal comfort system | Climate work desk

**VENTILATION**
Fan offering extra air flow

**HEATING**
Local temperature can be adjusted (Top & Bottom heating)

**LIGHTING**
The light intensity and light color is adjustable

**INTERFACE**
Personal settings can be adjusted through an interface

**COSTS**
The average price:
1.4 Case: ING building, Amsterdam

"Personal comfort system can increase comfort of users & provide energy savings"

PROPERTY MANAGER (PM)

“So fitting out the whole building with Personal Climatization Desk will maximize the building performance”

FACILITY MANAGER (FM)

“This will save me huge amount of, since maintaining a comfortable work climate will shift to the building user itself”

ME = ADVISOR

“Okay, lets conduct a research if the both managers are right”
1.5 APPROACH

“How can the application of personal comfort systems in existing office buildings improve the thermal comfort of the individual building occupants and provide energy savings in the meantime?”

TOOLS

1. KNOWLEDGE
   - Thermal comfort
   - Energy consumption
   - Personal comfort systems

2. ANALYZE EXISTING DATA
   - Climate work desks tested at ING;
   - Period: May to September 2018
   - Data collected and stored

ADVICE
PART II: KNOWLEDGE
2.1 THERMAL COMFORT

Thermal comfort

One of the important aspect of IEQ → it is based on the thermal adaptation of the individual and is dependent of:
• Gender, Age, Race, Local climate, Geographic Locations

37 °C

Human body tries to keep body temperature around 37 °C → heat exchange between the human body and surrounding environment

Thermal comfort requirements = standards ISO 7730 and ASHRAE 55

ISO 7730 & ASHRAE 55

average values for a large group of people; +

Do not take into account individual differences
2.1 THERMAL COMFORT

**PREDICTION THERMAL COMFORT**

**Personal comfort model:** Predicts an individual’s thermal comfort response, instead of the average response of a large population

**Individual focus**

**BENEFITS**

1. Improvement of accuracy of predicting thermal comfort on an individual level
2. Possibility in obtaining a diversity of data regarding occupant feedback
2.2 ENERGY CONSUMPTION

40% primary energy consumption $\rightarrow$ 50% energy consumption by HVAC systems.

Discrepancy between actual energy consumption and predicted energy consumption: (1) underestimation of predicted values, (2) deviation in construction and (3) wasteful use of resources during operation.

Factors affecting building energy consumption: Climate, Building characteristics, Building energy systems, Building operation, Indoor thermal & environmental quality & Occupant behavior

Key player in energy consumption $\rightarrow$ the building energy system has a bad response to patterns of occupancy behavior.
Besides computer desk, chair and screen the current workplace is not adjustable to personal needs;

Limitation of HVAC systems → resulted in rise of personal comfort systems;

PCS

Average setting

Individual setting

POTENTIAL

Improvement thermal comfort

Energy saving

NO FLEXIBILITY
3.4 THEORETICAL FRAMEWORK

Contextual Factors
- Local Climate
- Geographic Location
- Building Characteristics
- Building service system
- Building operation
- Indoor thermal & environmental quality

Personal Factor
- Race
- Age
- Gender
- Socio-demographic background

Thermal comfort → Occupancy behavior → Energy performance

Personal Comfort System (PCS)
PART IV:
CASE STUDY
Climate work desk offering users the possibility to regulate heating, cooling or light preferences locally at the work desk. Temperature, humidity, light intensity, CO2 concentration, Presence, Artificial lighting & Weather data on hour basis.

**VENTILATION**
Fan offering extra air flow

**HEATING**
Local temperature can be adjusted (Top & Bottom heating)

**LIGHTING**
The light intensity and light color is adjustable

**INTERFACE**
Personal settings can be adjusted through a interface

**COSTS**
The average price:
The interaction with the desk was recorded with different sensors integrated in the work desk + surveys → measure experience of users

**Database + Survey**

**ZERO MEASUREMENT**

Covers the period between June 2016 and March 2017;

**TEST PERIOD**

Covers the period between May 2017 and September 2018;

Potential energy savings: increasing the bandwidth default indoor temperature

**Inside temperature**

**SUMMER** +1 °C

**WINTER** -0.5 °C
Temperature is less constant → varies between summer & winter

Winter period:
The default temperature is lower than the lower limit of the comfort class B (Isso-74)

→ So it is colder inside than usual.
VENTILATION

The CO2 concentration is mainly around 400 and 500 ppm.
- Co2 = <1000 ppm

⇒ Building is sufficiently ventilated
TEST PERIOD

Covers the period between May 2017 and September 2018;

Identify the added value of Personal climatization system:
Thermal comfort + Energy consumption

Follow users in different seasons

Alignment of Data:
• Qualitative data: Survey
• Quantitative data: Database
TEST PERIOD

Moderate Summer
September 2017
Respondents
6/9/2017
7/9/2017
13/9/2017
14/9/2017

Hot Summer
July & August 2018
Users work desk + Weather
24/7/2018
6/8/2018

Winter
February 2018
Respondents
6/2/2018
9/2/2018
13/2/2018
16/2/2018
PART IV: FINDINGS & ANALYSIS
Context | Thermal comfort | Occupancy behavior | Energy consumption
Context factors
Inside temperature | Outside temperature | Cloudiness | Air humidity

21.7 °C | 15.4 °C | Rainy days | 59% - 87%

Average days

Satisfaction ratio

Satisfied

17 users

Unsatisfied

2 users

Moderate summer Period | September 2017
Hot summer Period | July & August 2018

Inside temperature

Outside temperature

Air humidity

24.4 °C

27.9 °C

36% - 47%

Satisfaction ratio

Satisfied
4 users

Unsatisfied
3 users

→ Hot days
Winter Period | February 2018

Inside temperature
Inside temperature
Outside temperature
Outside temperature
Cloudiness
Cloudiness
Air humidity
Air humidity

20.17 °C
1.72 °C
Cloudy days
Cloudy days
63% - 87%
63% - 87%

Cold days
Cold days

Satisfaction ratio
Satisfaction ratio

Satisfied
Satisfied
Unsatisfied
Unsatisfied

9 users
9 users
9 users
9 users
Thermal Comfort
Moderate summer Period | September 2017

Unsatisfied

2 users

Desk usage

1 user

Comments

“?”

Satisfied

17 users

Desk usage

10 users

Comments

“Additional heating/cooling not needed”

Default indoor temperature

Increased bandwidth

SUMMER

+1 °C

Thermally acceptable
Hot summer Period | July & August 2018

Unsatisfied

3 users

Satisfied

4 users

Comments

“Most respondents experienced the overall indoor climate as too hot”

Default indoor temperature

Increased bandwidth

SUMMER

+1 °C

Thermally Unacceptable
Winter Period | February 2018

Unsatisfied

9 users

Desk usage

4 user

Comments

All the unsatisfied users are unsatisfied, because of the lower indoor temperature.

Satisfied

9 users

Desk usage

6 user

Comments

Users are happy with the possibility to adjust settings regarding thermal comfort.

Default indoor temperature

Increased bandwidth

Thermally Unacceptable

-0.5 °C
Occupancy behavior
Moderate summer Period | September 2017

Unsatisfied
1 users

Used features

Satisfied
10 users

Mainly

Used features

ADJUSTED SETTINGS

4x Changes in setting

1 x

1 x

2 x

3 out of 10
Hot summer Period | July & August 2018

13 Users

Used features

13 out of 13

11 out of 13

9 out of 13

Heating + ventilation
8 out of 13

ADJUSTED SETTINGS

Additional cooling is needed → More changes = High interaction

13 out of 13

11 out of 13

9 out of 13

31x Changes in setting

11 x

17 x

3 x

9 out of 13
Winter Period | February 2018

Unsatisfied

4 users

Used features

4 out of 4

4 out of 4

ADJUSTED SETTINGS

Additional heating is needed ➔ More changes = High interaction

9x Changes in setting

4 x

5 x

2 out of 4 users
Winter Period | February 2018

- Satisfied: 6 users
- Used features: 6 out of 6
- 4 out of 6

ADJUSTED SETTINGS

Additional heating is needed → More changes = High interaction

- 9 x Changes in setting
- 6 x
- 3 x
- 4 out of 6 users

4 out of 6
ENERGY CONSUMPTION
Energy consumption
3.56 Wh / table

- Light: 80%
- Ventilation: 6%
- Heating: 14%
Ventilation covers the largest part of energy consumption in the Hot summer period.

Energy consumption
4.72 Wh / table

- Light: 43%
- Ventilation: 56%
- Heating: 1%
Winter Period | February 2018

- Heating covers the largest part of energy consumption in the winter period.

Energy consumption
20,18 Wh / table

Light
20%

Ventilation
-

Heating
80%
### User Profiles: Different Periods

#### Winter Period

<table>
<thead>
<tr>
<th></th>
<th>Satisfied</th>
<th>Unsatisfied</th>
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</thead>
<tbody>
<tr>
<td><strong>20%</strong></td>
<td><strong>40%</strong></td>
<td><strong>20%</strong></td>
</tr>
<tr>
<td><strong>10 users</strong></td>
<td><strong>Unactive</strong></td>
<td><strong>Active</strong></td>
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#### Summer Period

<table>
<thead>
<tr>
<th></th>
<th>Satisfied</th>
<th>Unsatisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>31%</strong></td>
<td><strong>69%</strong></td>
<td><strong>31%</strong></td>
</tr>
<tr>
<td><strong>13 users</strong></td>
<td><strong>Unactive</strong></td>
<td><strong>Active</strong></td>
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#### Moderate Summer

<table>
<thead>
<tr>
<th></th>
<th>Satisfied</th>
<th>Unsatisfied</th>
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</thead>
<tbody>
<tr>
<td><strong>43%</strong></td>
<td><strong>43%</strong></td>
<td><strong>14%</strong></td>
</tr>
<tr>
<td><strong>7 users</strong></td>
<td><strong>Unactive</strong></td>
<td><strong>Active</strong></td>
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</tbody>
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#### Hot Summer

<table>
<thead>
<tr>
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<th>Satisfied</th>
<th>Unsatisfied</th>
</tr>
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<tbody>
<tr>
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PART IV: CONCLUSIONS
Conclusion

“How can the application of personal comfort systems in existing office buildings improve the thermal comfort of the individual building occupants and provide energy savings in the meantime?”

1. Personal climate work desk is useful for improving thermal comfort, especially for unsatisfied users, and generally does not result in energy savings. **possibility to regulate thermal comfort locally when needed.**

2. Energy saving is mainly possible by increasing the bandwidth of the default indoor temperature.

Thereby increasing the bandwidth is only possible if the acceptable temperature limits are higher than the default indoor temperature.
PART IV:
PRACTICAL GUIDELINES
Personal climate work desk is especially effective for improving thermal comfort and not to realize energy savings.

Advice:
Fit out only a part of the office building, or a part of every department since fitting out the entire building is very costly.

To define the right amount of tables:
1. Acquire insights regarding the thermal comfort status of the actual office users.
2. Map out the occupancy rate in the office building throughout the work week for every different department among the building.
Practical guidelines | Thermal Comfort

Personal climate system help reducing thermal comfort complaints

But under extreme weather conditions, the personal climate work desk is not sufficient to meet the needs of the unsatisfied office users.

So, features provided by the climate work desk are not sufficient → More features needed

Advice:

1. Create an work desk 2.0 → offering the possibility to expand current features with additional heating/cooling modules which can be plugged in by the office users itself, such as modules for the back, neck, and feet.

2. Analyze thermal comfort complaints and react on it by providing additional modules for the users who need additional cooling or heating.
Practical guidelines | Energy consumption

Thermal comfort is mainly influenced by outside weather conditions.

Weather is complex and dynamic → acceptable temperature limits continuously change.

So the central systems need to adapt to changing weather conditions.

Advice:
Climate system has to meet the following technical requirements:
Sensor: collect data about outside weather conditions

Network and connectivity: Enables data transfer from the sensor to a central server.

Central server:
Analyzing real-time weather information and acceptable temperature limits: check if the acceptable temperature limits are higher/smaller than the default temperature settings

Send instructions to the controllers of the central climate system

Controller: Adapt the extension settings of the central climate system
Energy savings only possible by extending the default indoor temperature and not by the desk.

Advice:
Possible energy savings $\Rightarrow$ define acceptable temperature limits of the users. The needed steps:

1. Measure inside & outside temperature for a one year;
2. In the meantime periodical surveys need to be conducted;
3. Compare the collected data measurements $+$ Survey $\Rightarrow$ the acceptable temperature limits (bandwidth) can be defined for different seasons.

Facility Manager
Perspective: Guarantee a healthy and comfortable workplace
THE END...
Discussion

Research complements existing literature on occupant behavior → provide managers insights about how users interact with the buildings.

→ Appropriate measures can be taken to improve thermal comfort & optimize energy consumption

Limitations representative user profiles
• The number of respondents filled in the survey is low → decreased over time
• From the users who have filled in the survey, not all users made use of the desk in that period;
• The climate work desk did not function properly in the beginning, in particular, the inability to log in