### REAL-LIFE OPERATION OF **SOLUS SYSTEM**: A FOCUS ON THERMAL COMFORT

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#### ALESSANDRO MACCARINI, POSTDOC



DANISH BUILDING RESEARCH INSTITUTE AALBORG UNIVERSITY COPENHAGEN

### Agenda

- Concept behind the SOLUS system
- Energy performance (simulations)
- Thermal comfort (measurements)

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Simultaneous heating and cooling demand can occur in the same building



Conventional four-pipe systems



SOLUS system (two-pipe system)



SOLUS system (two-pipe system)

### Active beams are used as terminal units



Active beams are used as terminal units

SOLUS system (two-pipe system)







Advantages of SOLUS

 In situations of simultaneous heating and cooling demand in a building, excess heat from warm rooms can be transferred to cold rooms



 Operating temperatures of about 22 °C in the water circuit facilitate the integration of sustainable energy sources



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How to study the energy performance of SOLUS?

## When this project started (2013), no building was equipped with SOLUS



Simulations using **MODELICA** 



Modelica is a free object-oriented language for modeling of complex systems

#### **Multi-domain**

Systems belonging to different physical domains can be modeled (mechanical, electrical, thermal etc)

#### **Equation-based**

The mathematical code behind the graphical models consists of differential and algebraic equations

#### Library-structured

Modelica models are usually structured into libraries, both commercial and free







#### Modelica model of SOLUS system



Modelica model of SOLUS system

![](_page_15_Figure_2.jpeg)

#### Modelica model of SOLUS system

![](_page_16_Figure_2.jpeg)

![](_page_17_Figure_0.jpeg)

![](_page_18_Figure_0.jpeg)

![](_page_19_Figure_0.jpeg)

![](_page_20_Figure_0.jpeg)

Results – Annual energy savings

![](_page_21_Figure_2.jpeg)

Annual primary energy savings of about 18%

Combination of three effects:

- Heat transfer among rooms
- Higher free cooling potential
- Higher heat pump COP

Heat transfer among rooms – influencing parameters

![](_page_22_Figure_2.jpeg)

parameter on the energy savings

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(Jönköping)

- First building equipped with SOLUS
- 16 floors (offices, gym, restaurant)

- 8500 m<sup>2</sup>
- 550 beams

![](_page_24_Picture_6.jpeg)

Thermal comfort measurements

![](_page_25_Picture_2.jpeg)

#### Unoccupied double-office room

Objective:

-vertical air temperature difference? -draught rate?

![](_page_25_Picture_6.jpeg)

#### Occupied open-office room

Objective:

-how do occupants perceive the thermal environment?

Thermal comfort measurements

![](_page_26_Picture_2.jpeg)

#### Unoccupied double-office room

Objective:

-vertical air temperature difference?-draught rate?

![](_page_26_Picture_6.jpeg)

#### Occupied open-office room

#### Objective:

-how do occupants perceive the thermal environment?

#### Unoccupied room

![](_page_27_Figure_2.jpeg)

![](_page_27_Picture_3.jpeg)

![](_page_27_Picture_4.jpeg)

![](_page_27_Figure_5.jpeg)

#### Summer

Unoccupied room

![](_page_28_Picture_2.jpeg)

#### **IC-meters**

Air temperature (±0.3 °C)

![](_page_28_Picture_5.jpeg)

**Probes** Air velocity

(±0.02 m/s)

![](_page_28_Figure_8.jpeg)

Unoccupied room – vertical air temperature difference / winter

![](_page_29_Figure_2.jpeg)

According to ISO standard 7730 the vertical air temperature difference between head level (1.1 m, seated) and ankle level (0.1 m) should be **less than 2 °C** 

Unoccupied room – vertical air temperature difference / summer

![](_page_30_Figure_2.jpeg)

Unoccupied room – air velocity

![](_page_31_Figure_2.jpeg)

Thermal comfort measurements

![](_page_32_Picture_2.jpeg)

Unoccupied double-office room

Objective:

-vertical air temperature difference?-draught rate?

![](_page_32_Picture_6.jpeg)

#### Occupied open-office room

Objective:

-how do occupants perceive the thermal environment?

Occupied open-office space

1. Measurements of physical parameters

![](_page_33_Figure_3.jpeg)

#### 2. Survey delivered to occupants

Runda Huset - Floor 13 Questionnaire about thermal comfort This questionnaire is part of a research project conducted by the Danish Building Research Institute - Aalborg University. The study is undertaken for scientific purposes. Participants will remain anonymous. The guestionnaire will be delivered twice, once in the morning and once in the afternoon. I have worked in this building since ...... Date ..... On average, how many hours per week Gender (M/ do you work in this building? 1. Please tick the scale below at the place that best represent how you feel at this moment Cold Slightly Cool Neutral Slightly Warm Hot cool warm 2. Do you find this... (tick the box) Very Comfortable Just Uncomfortable Verv Just comfortable comfortable uncomfortable uncomfortable 3. You would prefer the room temperature to be... Much Cooler Slightly No change Slightly Warmer Much cooler cooler warmer warmer 4. How acceptable is the thermal environment at this moment? Highly Just Just Highly acceptable acceptable unacceptable unacceptable 5. In terms of air movement, you would like to have... Less air movement No change More air movement

Air temperature

![](_page_34_Figure_2.jpeg)

#### WINTER

SUMMER

Air velocity

![](_page_35_Figure_2.jpeg)

WINTER

![](_page_36_Figure_1.jpeg)

WINTER

SUMMER

![](_page_37_Figure_1.jpeg)

Comfort

![](_page_38_Figure_2.jpeg)

![](_page_38_Figure_3.jpeg)

![](_page_38_Figure_4.jpeg)

SUMMER

Air movement

![](_page_39_Figure_2.jpeg)

![](_page_39_Figure_3.jpeg)

![](_page_39_Figure_4.jpeg)

### Munksjötornet - Conclusions

#### **Unoccupied room**

- The room is well-mixed, and there is no significant thermal stratification in the space.
- The draught rate was below 10% for most of the cases

#### **Occupied room**

- The SOLUS system maintains a quite constant air temperature (between 21-23°C all year round)
- According to the survey, the thermal environment in winter seems to be slightly too cold. The thermal environment in summer seems to be almost neutral

![](_page_41_Picture_0.jpeg)

- Concept behind the SOLUS system
- Energy performance (simulations)

#### **Real-life monitoring**

• Thermal comfort (measurements)

### Real-life monitoring (energy performance)

![](_page_42_Figure_1.jpeg)

# Thank you!

Any questions?