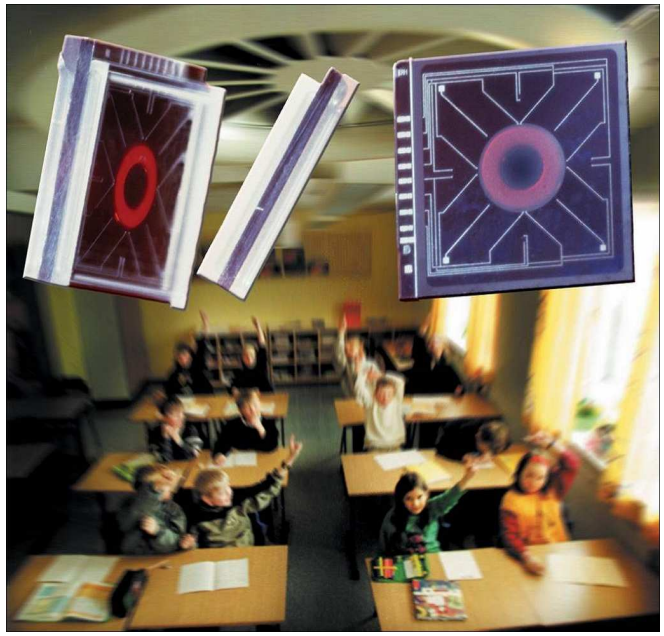
# Innovations in HVAC



**Workshop at VVS-Dagene**

**Wednesday 18 October 2006**

Andy Drysdale, Danish Technological Institute
VVS-Dagene 2006
Lillestrøm. Norway, 18 October 2006

Nordic Innovation Centre

Multisensors and Other New Technology for Improved indoor Environment in buildings

# Workshop agenda

**Welcome and introduction (and a little background about the MONTIE initiative)**
*Peter Østbø, SINTEF and Andy Drysdale, Danish Technological Institute*

**Trends and drivers for innovating HVAC installations and control techniques**
*Andy Drysdale, Danish Technological Institute*

**Future requirements for the indoor environment in living and working spaces**
*Jørn Toftum, Technical University of Denmark / International Centre for Indoor Environment and Energy*

**The challenge of future HVAC installations – facing a paradigm shift ?**
*Jens Møller Jensen, Danfoss A/S*

**IAQ (indoor air quality) sensorics today and tomorrow**
*Bertil Hök, Hök Instrument AB, Peter Østbø, SINTEF and Per Gløersen, Infineon Technologies SensoNor AS*

**Questions and discussion**

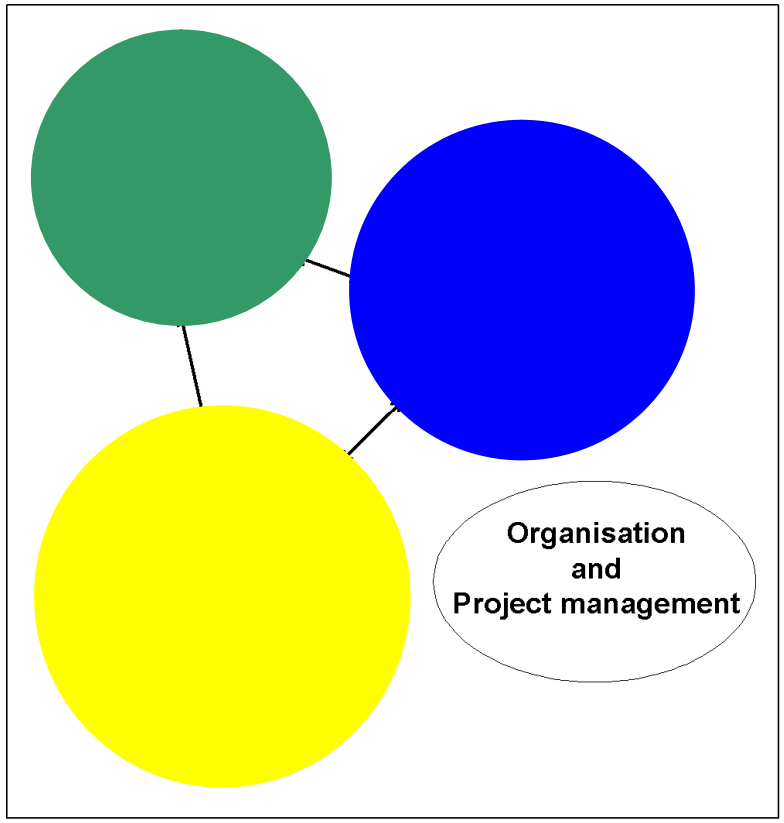
A little background about the MONTIE initiative

# What is the MONTIE initiative?


**M**ulti-sensors and **O**ther
**N**ew **T**echnology for
**I**mproved indoor
**E**nvironment in buildings

- A consortium of Nordic partners
- Funding from the Nordic Innovation Centre 2004 - 2006
- Increase focus on Indoor Air Quality (IAQ). Spread knowledge about its importance
- Address the current, and future uses, of advanced multi-sensors
- Initiate technological developments to support improved HVAC systems
- Encourage the conversion of expert academic knowledge into practical applications and use.

# What are the goals of the MONTIE initiative?




## Main activities

Information dissemination about:

- The importance of IAQ
- The advantages gained from using micro-sensors and other new technology

Increased information/awareness will:

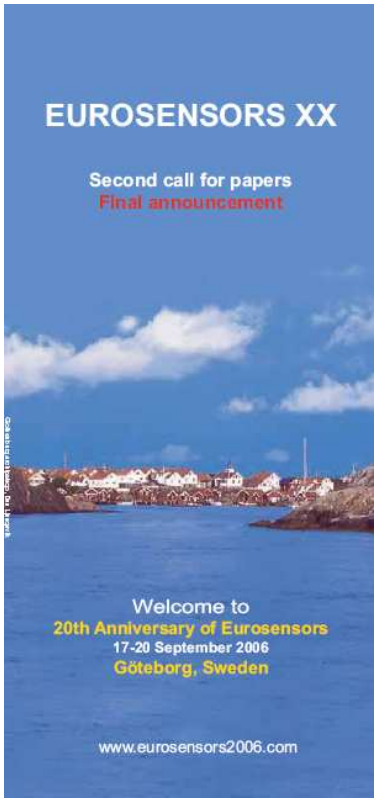
- Initiate coherent efforts to increase the level of knowledge about IAQ
- Initiate and boost the number of IAQ – and IAQ related - development activities
- Increase business and commercial export opportunities

# The partners in MONTIE

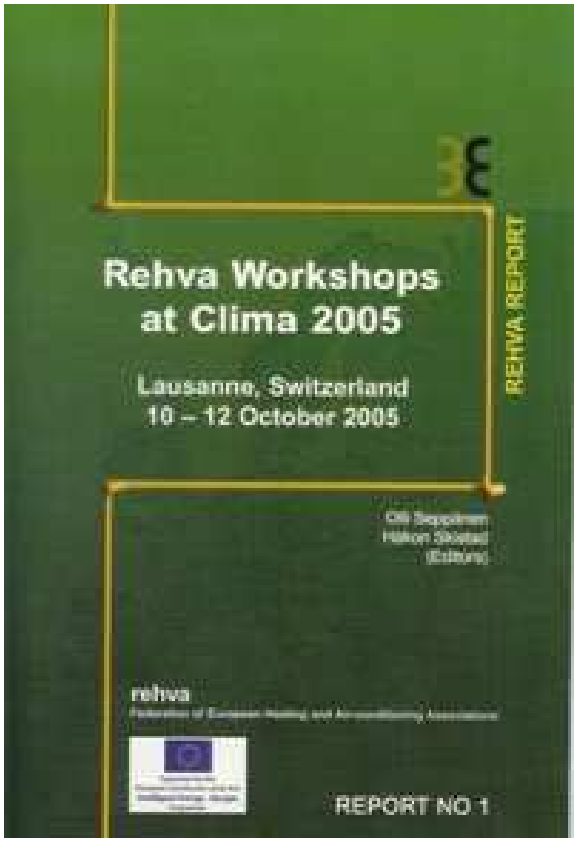
- Danfoss A/S (DK)
- Hök Instrument AB (SE)
- Infineon Technologies SensoNor A/S (NO)
- The Finnish Association of HVAC Societies (FINVAC) (FIN)
- Finnish Society of Indoor Air Quality and Climate (FiSIAQ) (FIN)
- SINTEF IKT (NO)
- The Technical University of Denmark
  International Centre for Indoor Environment and Energy (DK)
- Danish Technological Institute (DK)
- Nordic Innovation Centre

# Main activities so far



# Main activities so far - 1




**Clima 2005**

- Key-note and short presentations, poster sessions and workshops on scientific trends and practical developments in HVAC technologies
- Included a MONTIE workshop presenting MONTIE ideas and ambitions

MONTIE workshop programme

- Summaries of state-of-the-art (Nordic) technology on sensors
- Applications of these sensors for the measurement and demand based control of IAQ
- Discussion forum (more than 40 participants) to discuss the future needs for development and dissemination.

www.rehva.com/workshops/index.html

# Main activities so far - 2


**"MONTIE" conference on Technological advances for controlling indoor environment**

- Focus on "State-of-the-art" technology
- Key-note presentations on user-driven issues and invited presentations on technology-driven issues

**Programme**

- IAQ, sensors and measurements, wireless communication and other new technology
- Intelligent HVAC installations and installation technology, including the use of sensors and coupling with Facility Management issues and security aspects
- New business opportunities and challenges
- Innovative solutions

www.teknologisk.dk/montie

# Main activities so far - 3

**MSW 2006**

**Micro Structure Workshop · 9-10 May · Västerås · Sweden**

**General information**

Log on to our website **www.minst.nu/msw2006** for more details on:

· Registration
· Call for papers
· Practical details

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**MSW** is a forum for those interested in MEMS and MST. Our mission is that MSW will be a creative catalyser and a place to meet for industry, suppliers, financiers and researchers, and that it will be the seed to a network between the most important national actors. An informal atmosphere and many opportunities for discussions and to form new contacts characterize MSW.

**MSW** will show the dynamics and width in applications of the MEMS area. Innovators can show their new ideas, SMEs can demonstrate their new products, applications and processes, and researchers can present their interesting new results.

**MSW** is intended not only for those working actively in the area, but equally well for those in both industry and academy that have a general interest in MEMS/ MST. We expect that more than half the participants will come from industry. Participants from all countries are welcome.

**MSW**'s programme will have a strengthened industrial profile in order to represent the general trends and maturity of the area. **Welcome to MSW 2006!**

**Micro Structure Workshop**

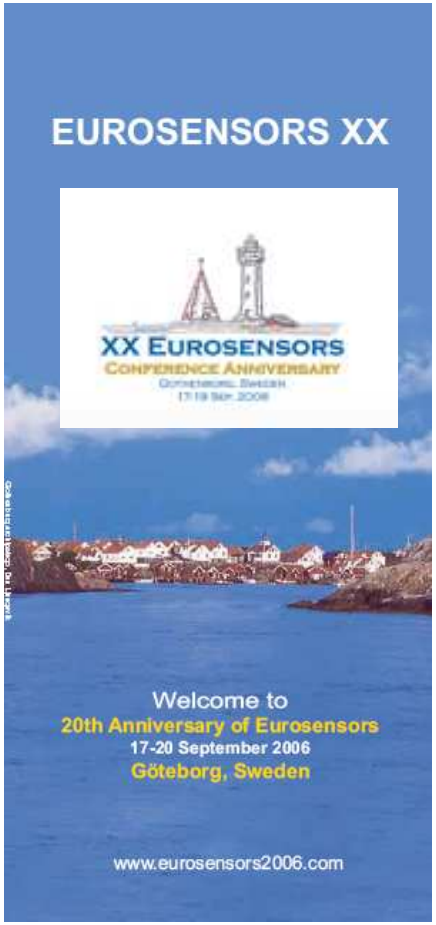
- A forum for those interested in MEMS and MST. Aimed at acting as a catalyst and a place to meet for industry, suppliers, financiers and researchers.
- Key-note presentations and invited presentations on a wide range of topics. Posters and exhibition.
- Strong industrial participation.

**Programme**

- MEMS and MST
- A “thematic overview” during a session on “industrialisation” aimed at presenting the current status for the MONTIE initiative, and to inspire innovative thoughts for possible new applications for (MEMS) sensors!

www.minst.nu/msw2006

# Main activities so far - 4




**Eurosensors 2006**

- Major European conference – the only one covering the entire field of sensors, actuators and microsystems. Aimed at scientists and engineers from academy, national research institutes and industry
- Key-note presentations and invited presentations on a wide range of topics. Comprehensive poster session.
- Included a MONTIE workshop

**MONTIE workshop programme**

- Future sensorics for indoor environment measurement and control applications
- Presentations focusing on “the user perspective” to discuss with the “sensor research community” representatives present at the workshop.
- Discussion forum with about 40 participants

- www.mc2.chalmers.se/conferences/EUROSENSORS2006/

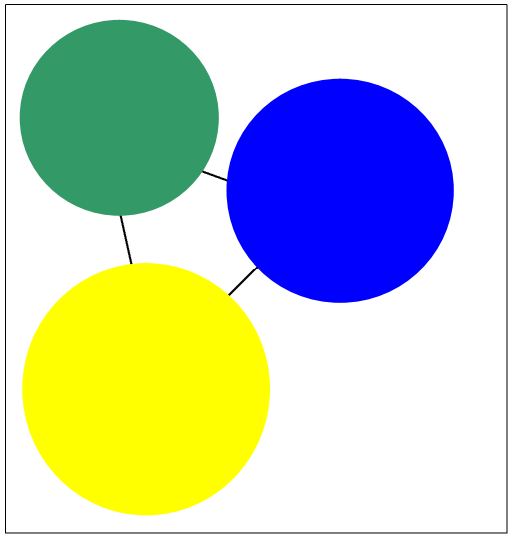
# Background

- The importance of indoor air quality (IAQ) in buildings is indisputable
- IAQ significantly impacts occupants' comfort, health and productivity
- Potential savings and productivity gains are enormous
- Traditional building HVAC control strategies are often insufficient

# New control strategies for indoor environment

- New, promising control strategies are emerging
  - reliable, accurate and inexpensive sensors to measure key IAQ parameters are becoming widely available
  - Processes such as “Constant Commissioning”, an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits

- They need to be combined with methods of using these measurements in HVAC control strategies.



## The goal of this workshop at


- To summarise state-of-the-art technology on sensors and their application for the objective measurement and demand based control of indoor air quality.
- Speakers will focus on presenting **“the user perspective”** to the representatives from the HVAC industry participating in VVS-Dagene
- To initiate discussions about the future needs for development work and information dissemination activities.

# TRENDS AND DRIVERS FOR INNOVATING HVAC INSTALLATIONS AND CONTROL TECHNIQUES

**Andy Drysdale**

**Danish Technological Institute**

## VVS-Dagene

**Wednesday 18 October 2006**

# Agenda

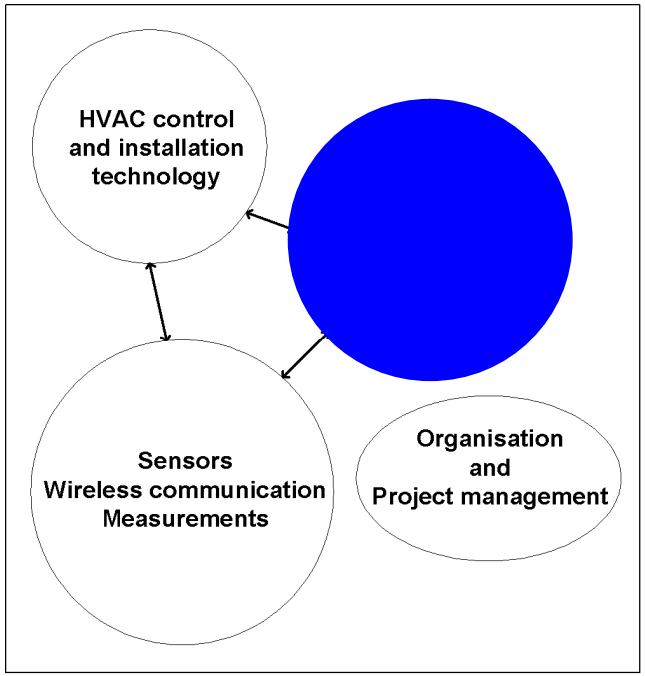
- The benefits of improved indoor environment (IAQ)
- The link between IAQ, HVAC (Heating, Ventilation and A/C) and sensors
- More about sensors for better IAQ
- Barriers and challenges

**The aim of this presentation is to present the current status of the MONTIE initiative**

**....and to inspire innovative thoughts for possible new sensors solutions in HVAC applications**

# THE BENEFITS OF IMPROVED INDOOR ENVIRONMENT

**AIR QUALITY**
**THERMAL**
*(ACOUSTIC)*
*(LIGHT)*



# The benefits of improved indoor environment (IAQ)

The importance of indoor air quality (IAQ) in buildings is indisputable.

People spend about 90% of their time indoors (at work, at home, transport)

Intake for a person per day:

- 1 kg food
- 2 kg liquid
- **15** kg air

Comfort-Productivity costs:

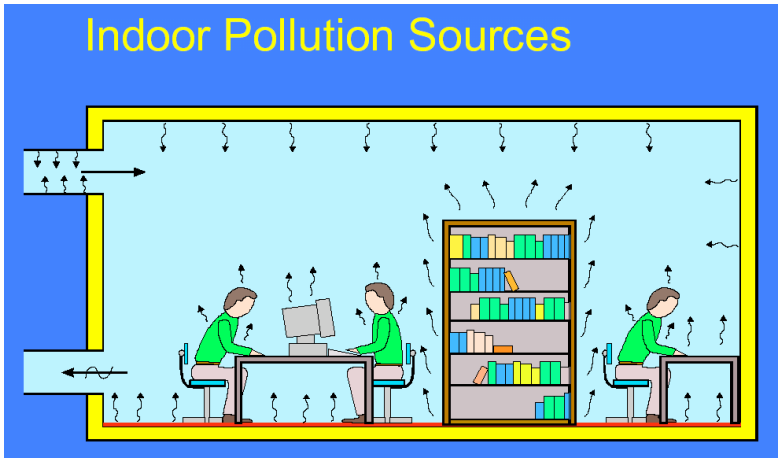
- People 100
- Maintenance 10
- Financing 10
- Energy 1

In typical office buildings
20 – 40 % of occupants have SBS symptoms
20 - 40% find the IAQ unacceptable (even though existing ventilation standards are met)

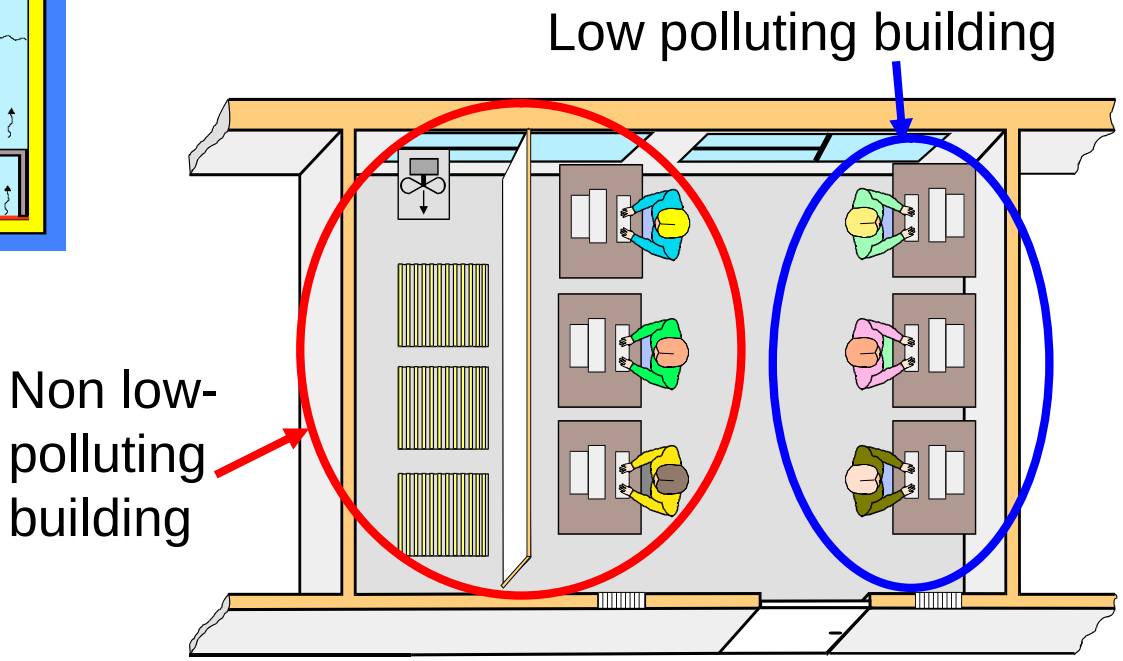
Field studies show substantial rates of dissatisfaction in practice

# The benefits of improved indoor environment (IAQ)

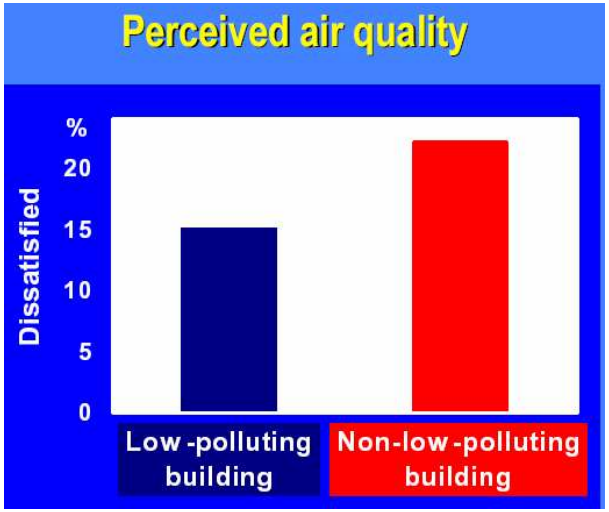
IAQ impacts occupants' comfort, health and performance

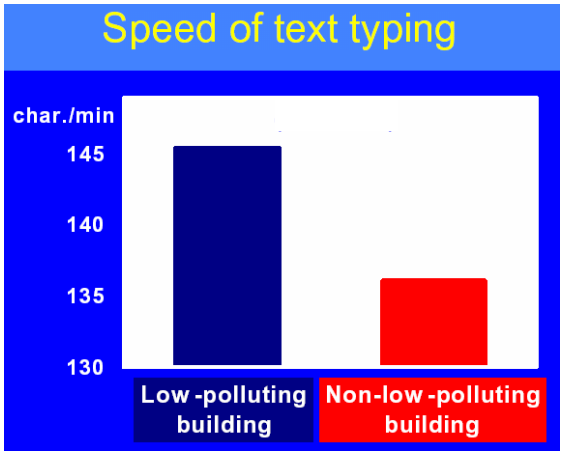


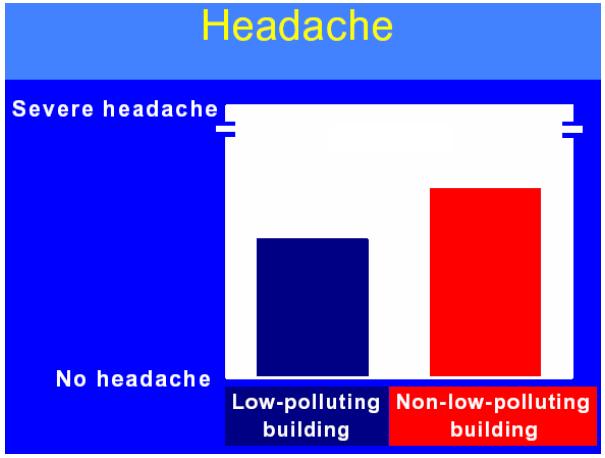

Experimental set-up at
Tech. Uni. of Denmark (DTU)



# The benefits of improved indoor environment (IAQ)



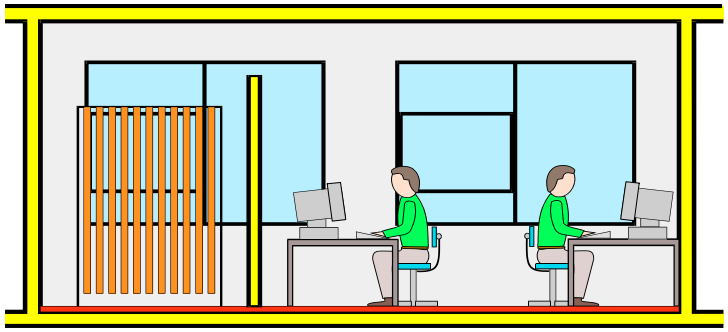



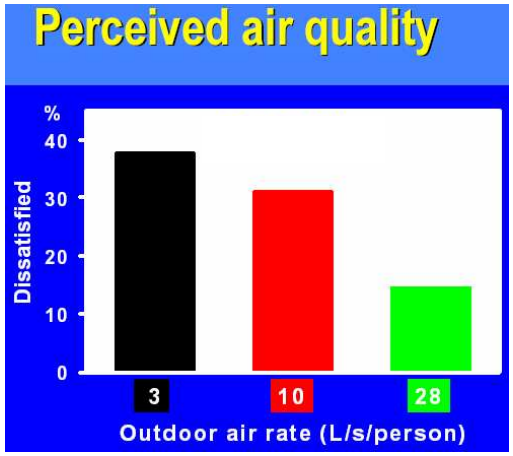
# The benefits of improved indoor environment (IAQ)

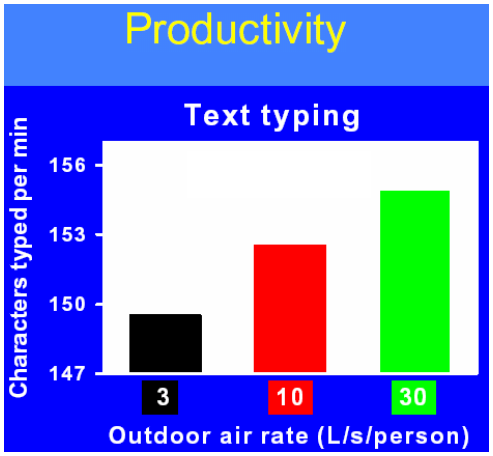
Outdoor air rates:

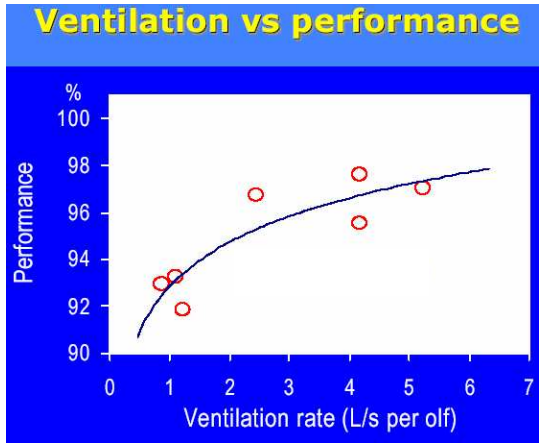
3 L/s/person (0.6 $h^{-1}$)
10 L/s/person (2 $h^{-1}$)
30 L/s/person (6.0 $h^{-1}$)

Experimental set-up at DTU





# The benefits of improved indoor environment (Thermal)

## General thermal comfort

Personal factors
- Clothing
- Activity

Environmental factors
- Air temperature
- Radiant temperature
- Air velocity
- Humidity

## Local thermal comfort

- Floor surface temperature
- Vertical air temperature difference
- Draught (mean air velocity, turbulence, air temperature)
- Radiant temperature asymmetry (heated/cooled ceiling, warm/cool wall)

**10 % decrease in dissatisfied will increase performance by 1.5 %**

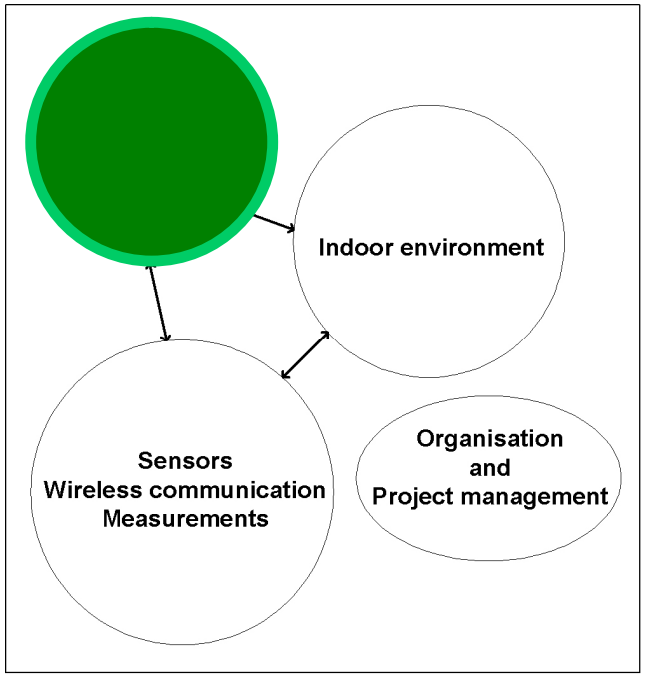
# The benefits of improved indoor environment (IAQ)

Potential savings and productivity gains are enormous

Macroeconomic estimation of productivity gains of improved IEQ

| Source of productivity gain | Potential annual health benefits | Potential US annual savings or productivity gain (1996 USD) |
|---|---|---|
| Reduced respiratory illness | 16 – 37 mill avoided cases of common cold or influenza | **6 – 14 billion USD** |
| Reduced allergies and asthma | 18% to 25% decrease in symptoms for 53 million allergy sufferers and 16 million asthmatics | **1 – 4 billion USD** |
| Reduced SBS symptoms | 20% to 50% reduction in SBS symptoms experienced by 15 mill workers | **10 – 30 billion USD** |
| Improved worker performance from changes in thermal environment and lighting | | **20 – 160 billion USD** |
| Total cost of energy in US commercial buildings | | **70 billion USD** |

# THE LINK BETWEEN
# IAQ
# HVAC (Heating, Ventilation and A/C)
# AND SENSORS



# The link between IAQ, HVAC and sensors

Traditional building HVAC control strategies are often insufficient to provide a satisfactory indoor environment

Intelligent buildings with new, promising strategies are emerging .....

- Reliable, accurate and inexpensive sensors to measure key IAQ parameters are becoming available
- Processes such as **"Constant Commissioning",** an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits

..... they need to be combined with methods of using these measurements in HVAC control strategies.

Legislation, i.e. the EU Energy Performance of Buildings Directive may help

- Integrated built-in sensors for diagnostics and inspection purposes
- Continuous calculation of energy consumption
- Explicitly specifies that reduction of energy consumption should not compromise occupants comfort, health and productivity.

# Future needs for HVAC control strategies

- Improvements to existing sensors and some features of new sensors:
  - Low cost, small size sensors integrated into HVAC/IAQ system components
  - Self-calibrating, self-testing, self-diagnosing, and self-reporting sensors
  - Sensors that automatically detect the need for a measurement
  - Low power consumption
  - Built-in algorithms for diagnostics, service and inspection routines
  - Reliable. Low-drift,
  - Running calculation of energy consumption
  - Incorporation of low-cost processing and memory on sensor elements to generate information from raw data and to store that information, reporting data only when anomalies occur
  - Easy to implement (plug-and-play). Better system integration
  - Communication (including a wireless option to reduce installation costs)
  - Feedback to user regarding energy consumption and indoor environment status
  - Long life (> 10 years)
  - Documented system effects and pay-back

  - ….the list is long ……

All these aspects are related to sensors and measurements …….

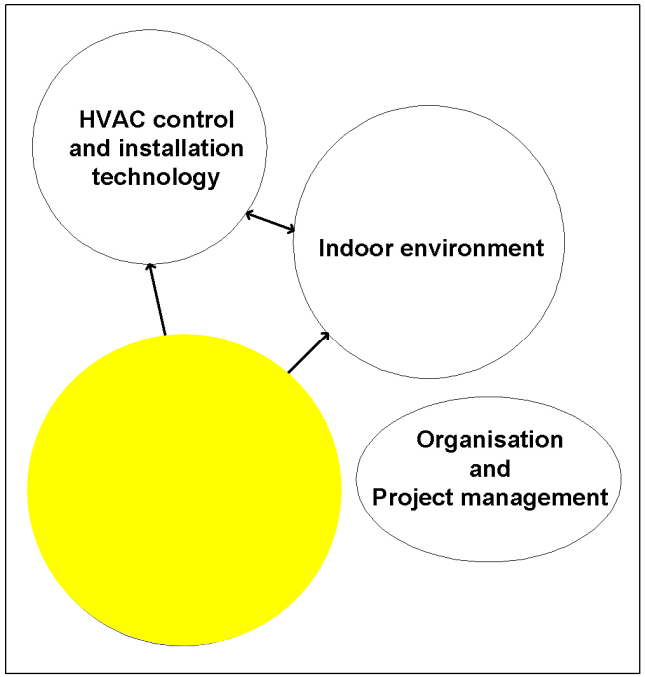
# Future needs for HVAC control strategies

Technology drivers:

- Automotive industry
- Aerospace industry
- Military applications
- High end buildings
  - concert halls, conference rooms….

But comfort and prestige in buildings and homes could also be a driver

# MORE ABOUT SENSORS FOR BETTER IAQ



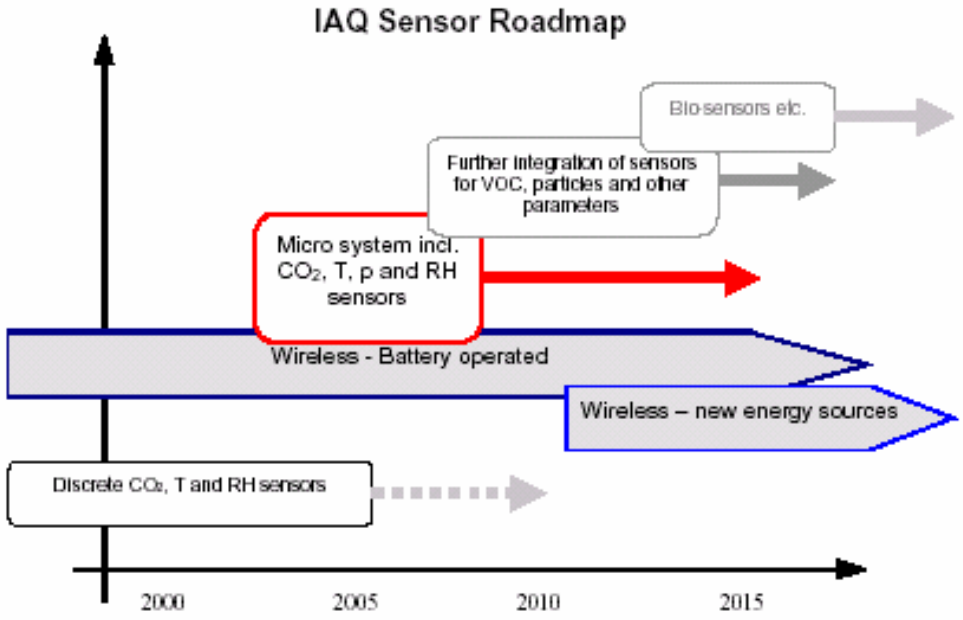
# What do we want to measure – and how well?

Main IAQ parameters:

- Temperature
- Carbon dioxide concentration
- Relative humidity
- Pressure variations

Next step

- Particles (dust, pollen ...)
- Volatile organic compounds (VOC's)
- Other gases

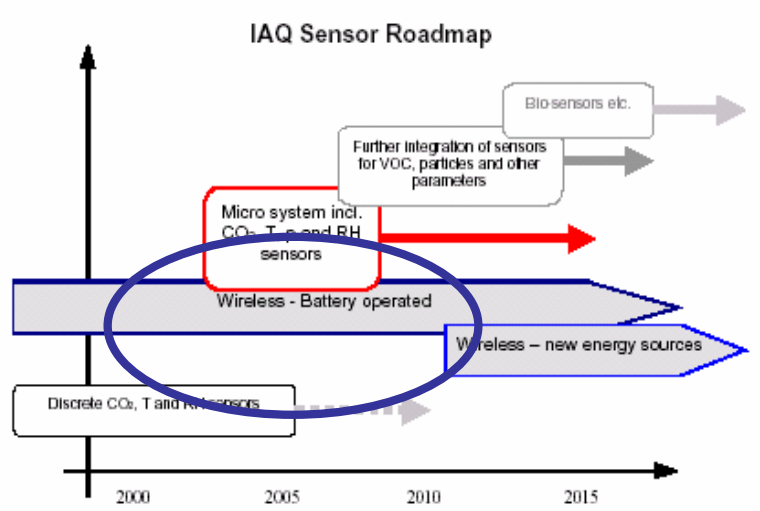



| | $CO_2$ concentration (ppm) | Relative humidity (%) | Temperature (°C) | Pressure variations (Pa) |
|---|---|---|---|---|
| Operating range | 0-3000 | 10-90 | 0-40 | 0-1000 |
| Overall accuracy | +/- 50 | +/- 5 | +/- 0.5 | +/- 100 |
| Resolution | 5 | 1 | 0.1 | 1 |
| Cross sensitivity | <2-3% | <2-3% | <2-3% | <2-3% |
| Response time | 60 sec | 120 sec | 60 sec | 0.01-10 Hz |

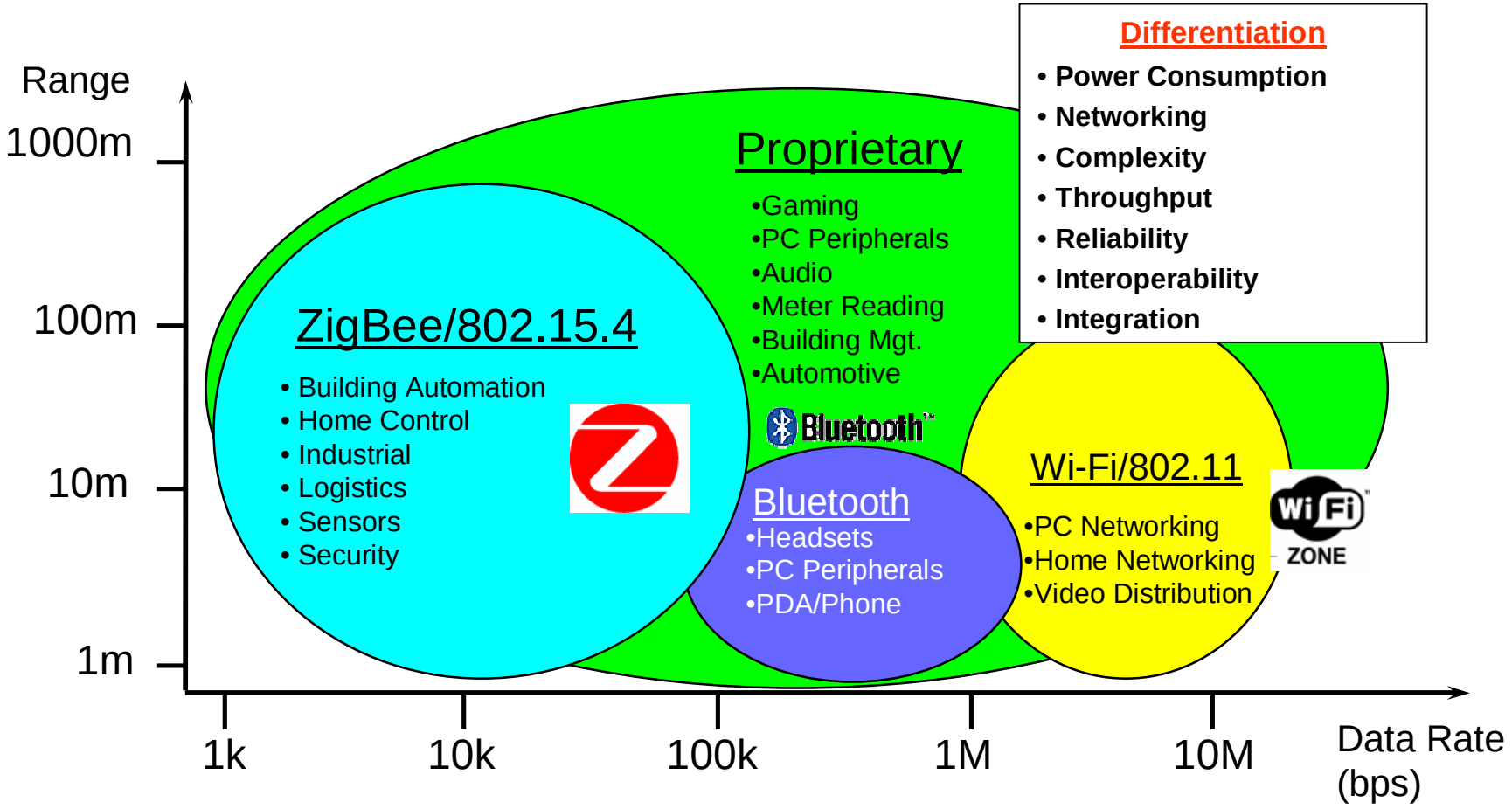
Tentative specifications of the multi-sensor in terms of measurement performance

# Wireless monitoring and control systems

- Large number of nodes → wireless solutions are required
- Low-complexity and low power protocol
- Low system cost
- Sensor nodes have typically only limited amount of data to send
  - Very low raw data rate (few kBits/s)
  - Very small amount of data (couple of Bytes)
- Short to medium ranges (meters / tens of meters)
- Sensor nodes remain “quiet” in long periods of time
- Very long lifetime requirements
  - up to several years
  - unattended operation



# A note about short range communications



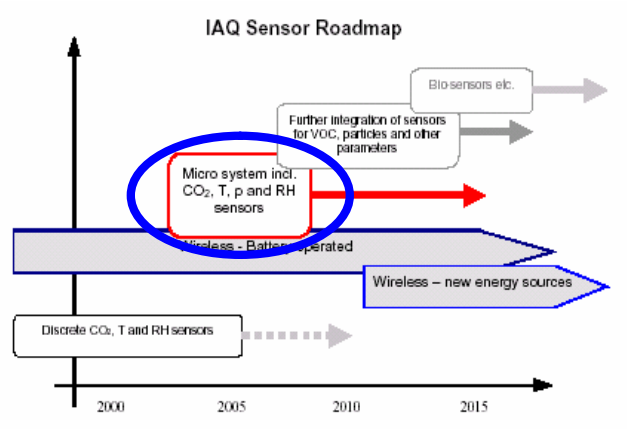
# Wireless monitoring and control systems

ZigBee as a suitable candidate ?

| Standard | ZigBee™ / IEEE 802.15.4 | Wi-Fi™ / IEEE 802.11b | BlueTooth™ / IEEE 802.15.1 |
|---|---|---|---|
| Application focus | Monitoring & Control | Web, Email, Video | Ad hoc cable Replacement |
| Stack Size (kBytes) | < 128 | 1000 + | 250 + |
| Battery Life (days) | 100 – 1000 + | 0.5 - 5 | 1 - 7 |
| Network Size (#nodes) | ~Unlimited (65536) | Many | 7 |
| Bandwidth (kbps) | 250 | 11 000 | 1000 |
| Range (meters) | 100 + | 100 | 10 + |
| Target BOM costs | < $ 3 | $ 9 | $ 5 |

# Examples of what sensor technologies are available

- **IR** technology offers highly sensitive, selective and reliable gas sensors
  - MEMS based IR sources, IR detectors, tunable optical filters, and complete gas and humidity sensors are available
  - IR gas sensors are still expensive due to large size, expensive components, packaging, and drift compensation. Higher level of integration is required
- A **DOE** (Diffractive Optical Element) based $CO_2$ sensor
- A MEMS based **photo-acoustic** gas sensor for $CO_2$
- **Electro-acoustic** MEMS-implemented $CO_2$ sensors



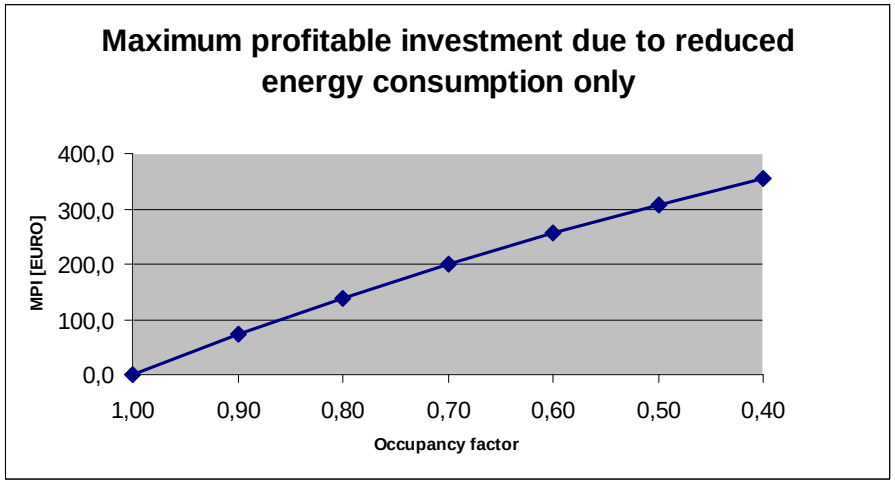

Why **MEMS** for multi-sensors?

- MEMS based sensors are by their small size and fabrication and packaging technology potentially suitable for multi-sensor integration
- Temperature sensors are easily implemented as an integral part of standard electronics
- Multi sensors are often based on integration of several sensors at the same electronic boards
- MEMS devices are potentially easy to integrate since the are small and often based on the same principles (piezoresistive, capacitive and optical)
- MEMS also opens for a higher degree of monolithic integration
  - Temperature sensors as part of the gas sensor chip

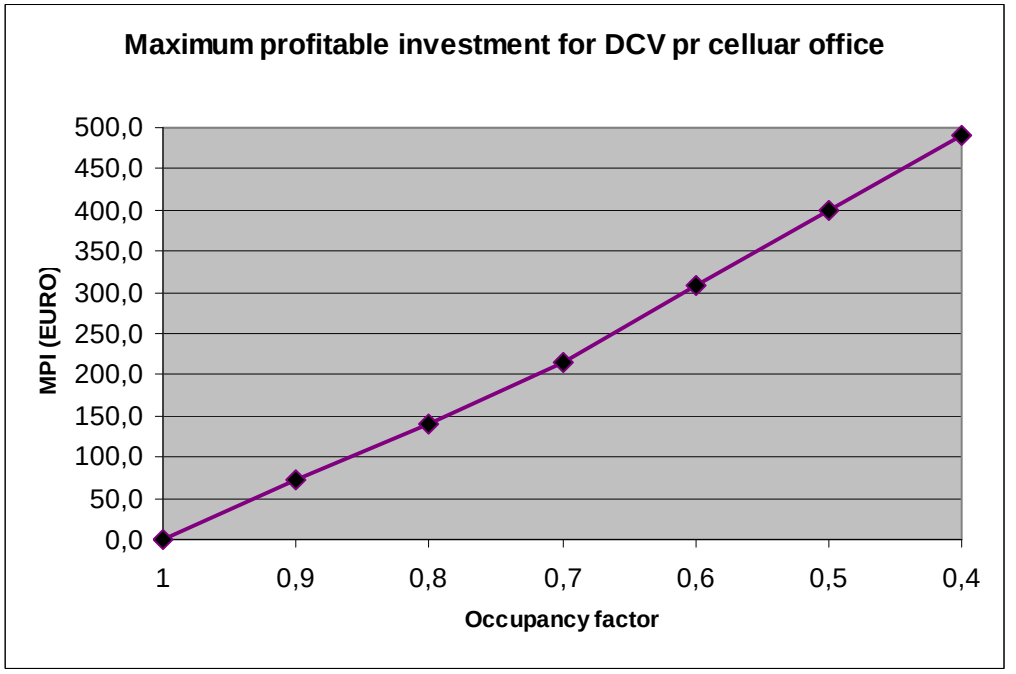
# Is ”demand controlled ventilation” the solution

Possible to calculate the maximum profitable investment:

- **Due to reduced energy use only**
- **Due to reduced energy use, installation cost and reduction of technical area**




**Energy use, installation cost and reduction of technical area**



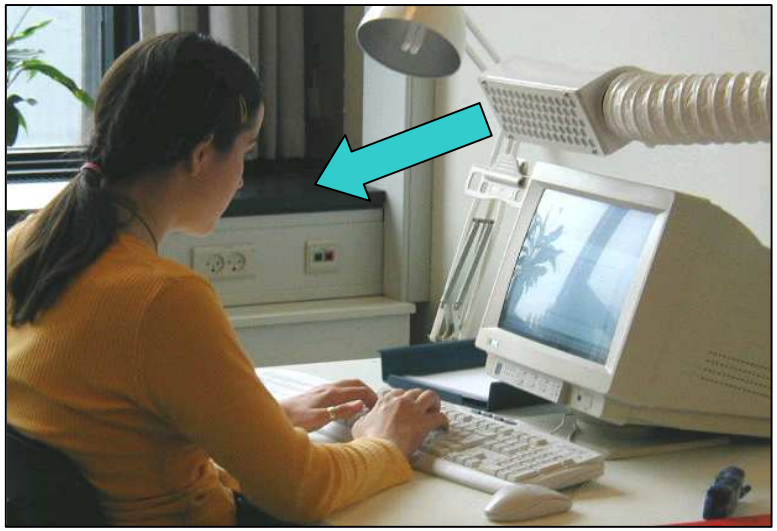

The impact increases with increased electrical energy cost

- Electrical energy cost of 0.25 EURO/kWh
- MPI is 700 EURO per celluar office

# Is ”Personalised ventilation” the solution

Large differences between occupants in regard to:

- **Preferred Temperature**
- **Air movement sensation**
- **Clothing insulation level**
- **Activity level**
- **Air quality perception**



Personalized ventilation

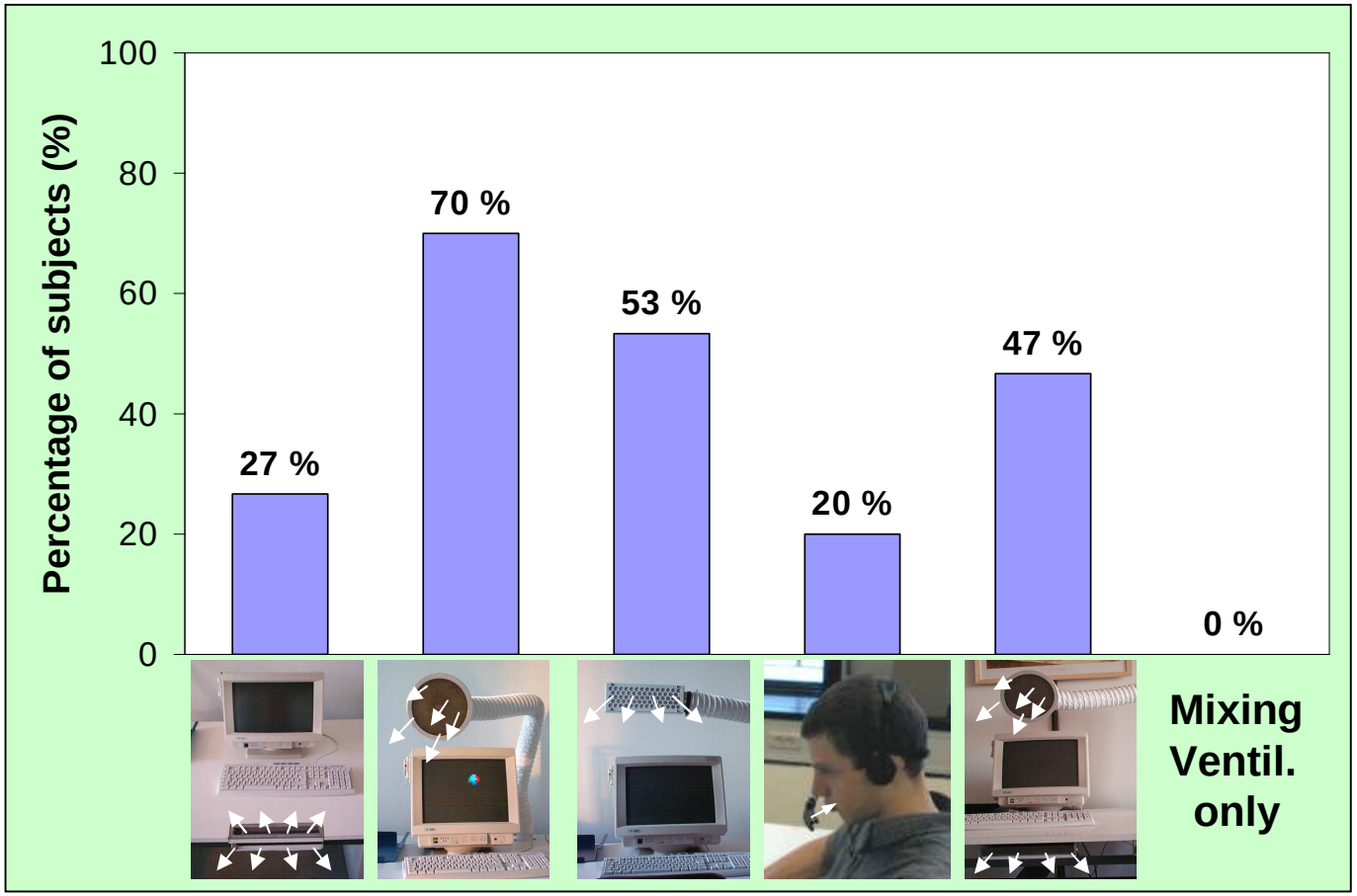
**Clean air is supplied to the breathing zone**

**Individual control & preferred environment:**

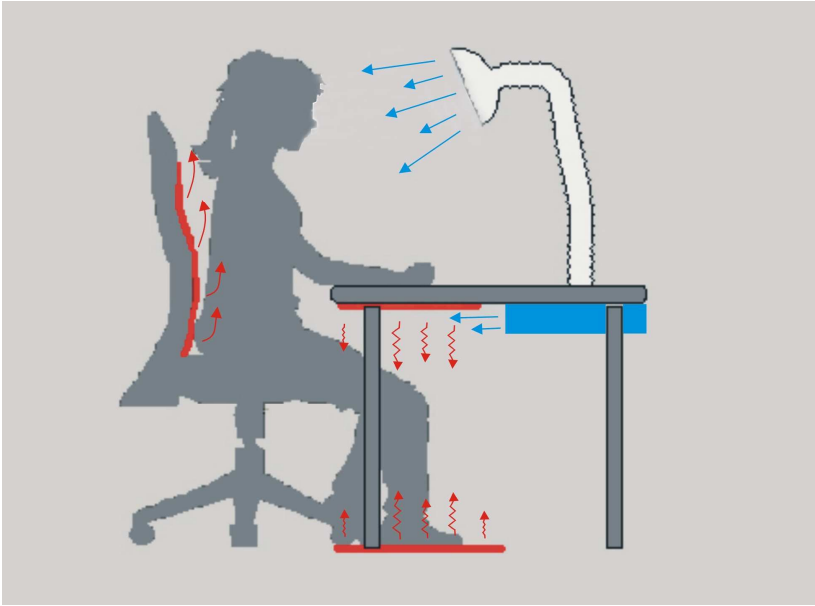
- **airflow direction**
- **preferred temperature**
- **preferred velocity: 0.2 m/s – 1.8 m/s**

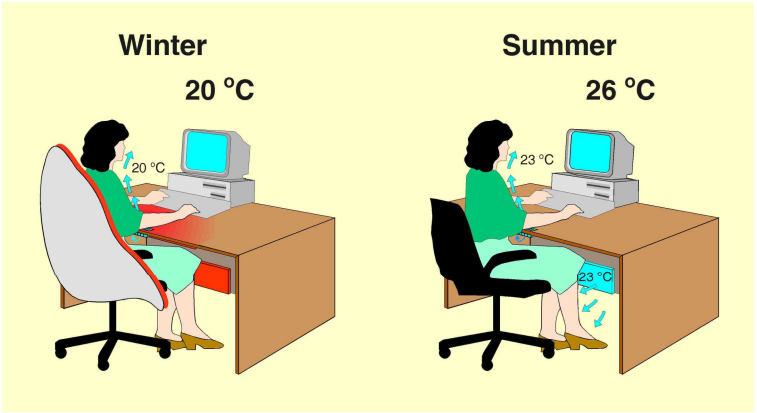
# Is ”Personalised ventilation” the solution

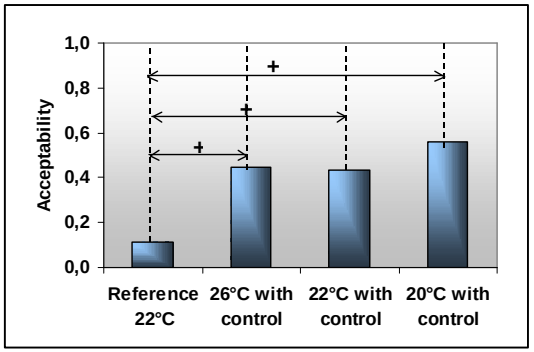
Which system(s) would you like to have on your desk?



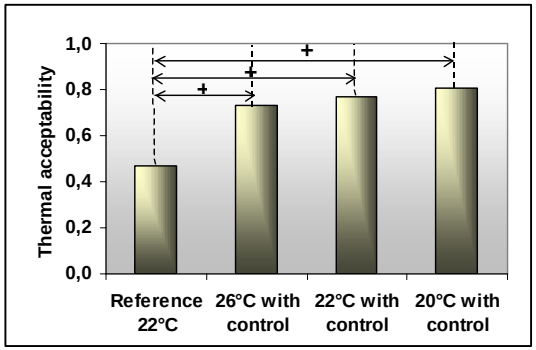
# Next step ”Personalised heating and ventilation”



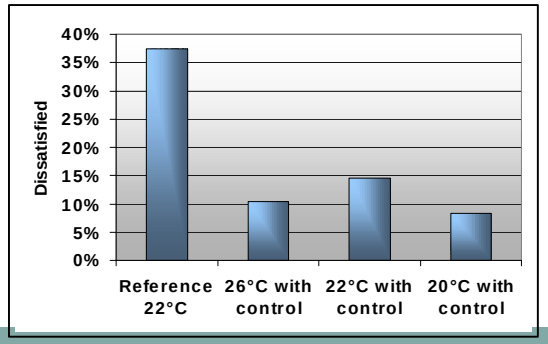



Perceived Air Quality

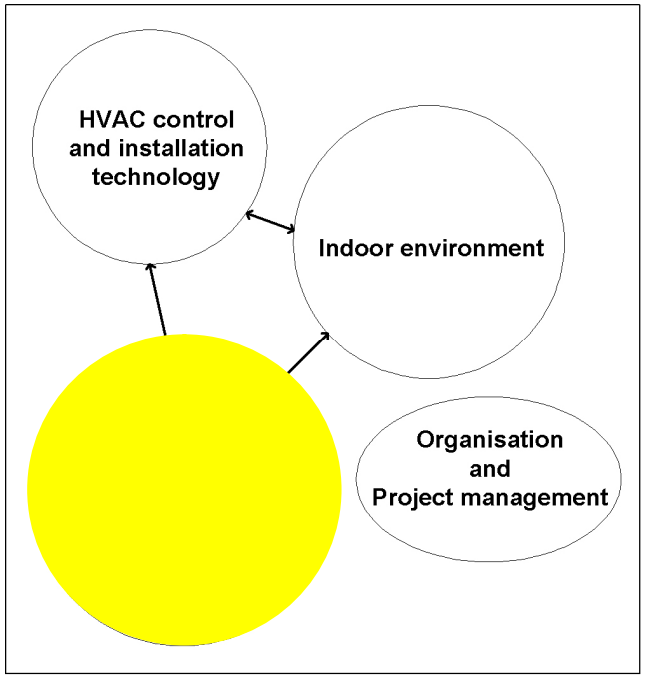



Thermal Comfort




General satisfaction

# EXAMPLES OF IAQ SENSORS THAT HAVE BEEN IDENTIFIED DURING THE PROJECT

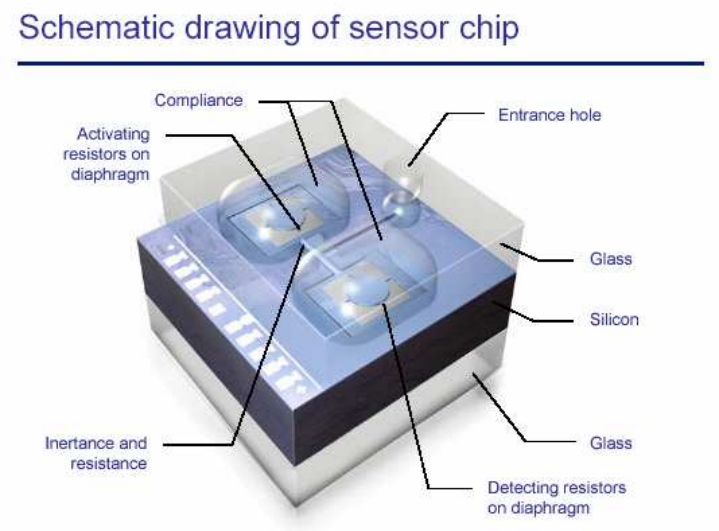


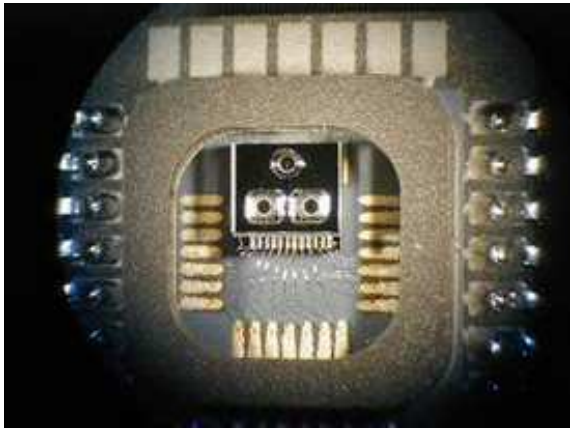
# Example – IAQ sensors in the Nordic area

Hök Instrument Q-AIR wall-mountable sensor for measuring $CO_2$, temp, RH


SenseAir infrared $CO_2$ sensor for embedded solutions

# Other examples of IAQ sensors



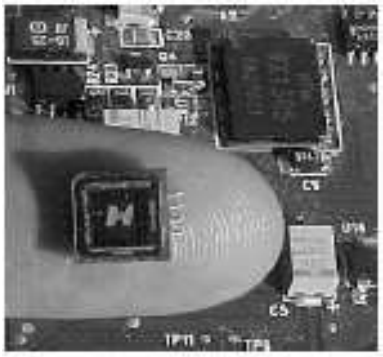



Sensor chip area: 3 x 3 mm.
Packaged in a standard ceramic package

MASCOT - Micro-Acoustic Sensors for CO2 Tracking.

The MASCOT project was co-financed by the EU IST programme

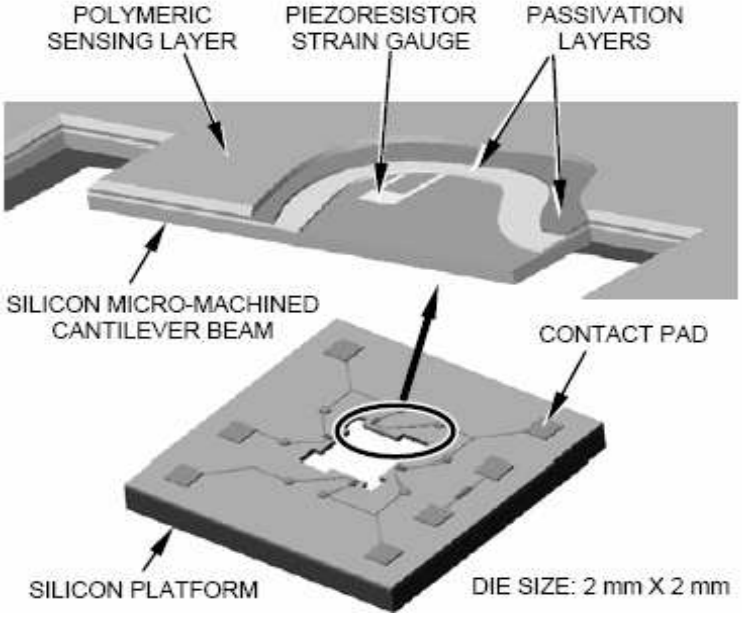
# Other examples – MEMS multisensor from the aerospace and industry sector

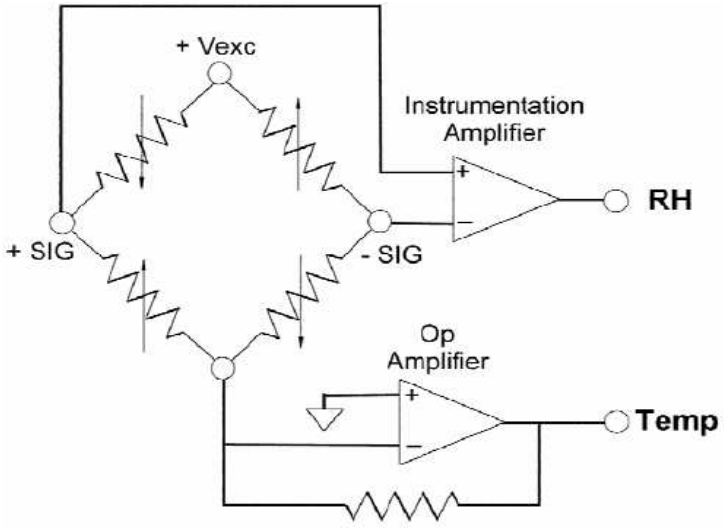


HYGROMETRIX

The Hygrotron

http://www.hygrometrix.net



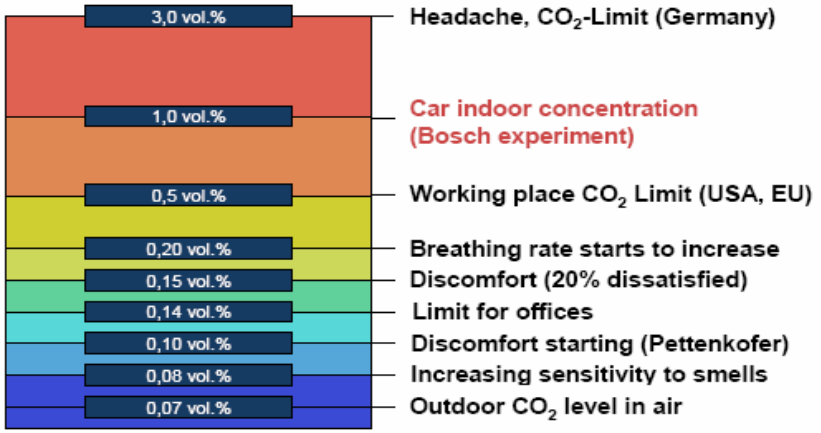




## Applications

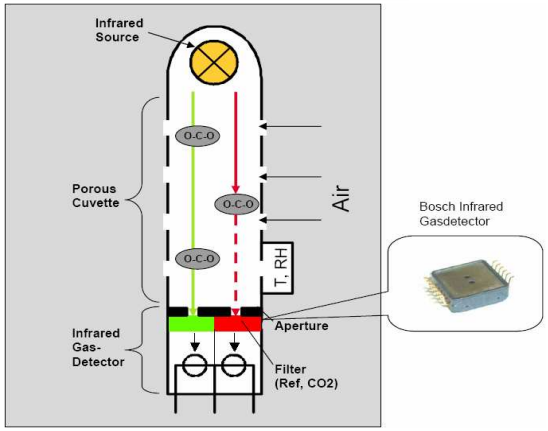
- Environmental monitoring and control
- Avionics and aerospace
- Dehumidification, industrial drying
- HVAC
- Precision instrumentation

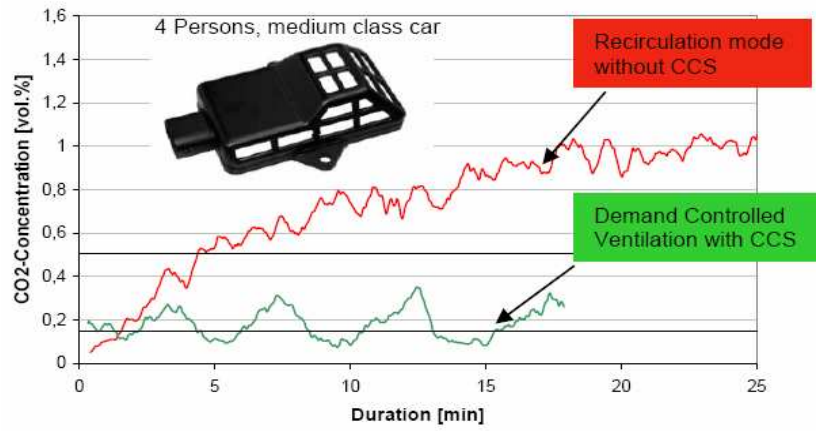
# Other examples – from the automotive sector


Source: Bosch Medical Service




The Climate Control Sensor by Bosch
(http://rb-k.bosch.de)



# Other examples – from the automotive sector



**Introduced att the Las Vegas Automobile Accessory Fair, Nov.1-4, 2005**


***$CO_2$ Engine -LO***

*AA-950* ***BLACK***

# Other examples of IAQ sensors – in consumer products

Plug-in CO2 sensor modules

Korea is catching up…

Clock radio +
demand controlled ventilation
from Korea…


Clean Air Tec Fair,
Korea Oct.5-7, 2005

# Future needs for HVAC control strategies

## Barriers:

- Conservatism about technical installations in buildings – HVAC components and installations traditionally have a long lifetime
- A lack of understanding of how complex building automation systems interact with their environment
- Degree of adoption and implementation is slow
- Often limited to flagship buildings. Demonstration projects are important but specific business cases are better
- Unclear commercial potential and costs. Is it possible to provide convincing evidence to investors and end users ?
  - (Can investments be justified? How do we calculate/document payback time?)
- Can you provide value for money to the end users?

# “Better” sensors and solutions are necessary

## There is a worldwide interest and future market for IAQ multisensors

### Some challenges

- Low cost – will enable several sensors even in one room, reducing difficulties in the selection of sensor location
- Low power will fulfill battery demands – or alternatives to batteries
- On-chip diagnostics of system function and performance is important
- Measurement aspects: Cross sensitivity (influences from temperature, humidity, dust), poisoning, long term drift

## Thanks to the following for most of the information in these slides

**Indoor environment**
Bjarne Olesen, Jørn Toftum, Arsen Melikov, DTU/ICIEE

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Peter Østbø, Ralph Bernstein, SINTEF
Jan Nielsen, DTI

**HVAC systems, wireless communication etc.**
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Jens Møller Jensen, Peter Gravesen, Danfoss
Mads Mysen, SINTEF Bygforsk
Per Anker Jensen, DTU/BYG

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