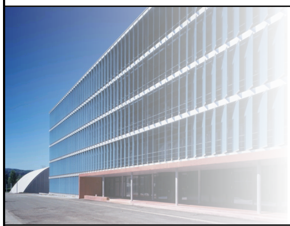
Building Energy Management

Weather Forecasts
Enhance Comfort and Save Energy



Manfred Morari

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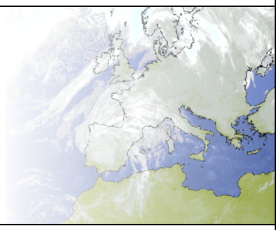
ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich



Outline

- Motivation
- Utilizing Weather Forecasts
  - Siemens
  - ETH and partners
- Ventilation Control
- External Collaborations
- Some Caveats
- Conclusions

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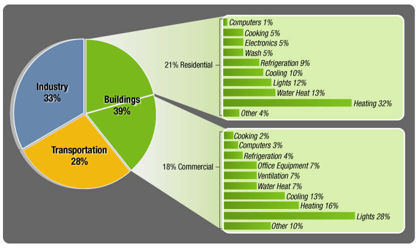
Building Energy Demand Challenge in U.S.

Buildings consume:
39% of energy
71% of electricity
54% of natural gas

Buildings produce:
48% of carbon emissions

Energy Breakdown by Sector

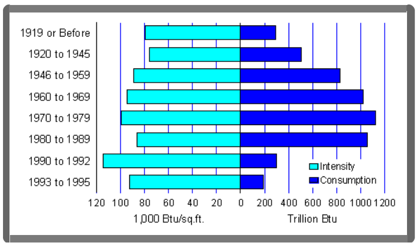


Sources: Ryan and Nicholls 2004, USGBC, USDOE 2004

Commercial building annual energy bill:
$120 billion

The *only* energy end-use sector showing growth in energy intensity:
17% growth 1985 – 2000
1.7% growth projected through 2025

Energy Intensity by Year Constructed

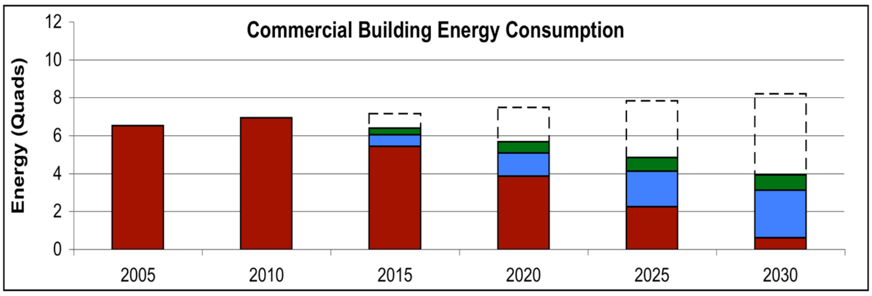


Source: EnergyInformation Administration
1995 Commercial BuildingsEnergyConsumptionSurvey

Vision of DOE Sponsored Project HiPerBRIC

Enable transformation of U.S. Commercial buildings sector in 20 years, starting NOW

– Save >4 Quads of energy and reduce >400 million tons of CO_2 annually
– Reduction in energy consumption: 90% in new buildings; >50% in retrofits
– Enhance health, comfort, safety/security and water usage while gaining energy efficiency



Can the required technology be developed and implemented in this time frame?

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Example: Forum Chriesbach, EAWAG, Zurich

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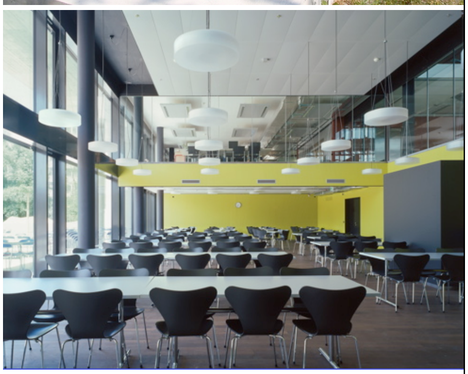
Building Data

- Area (EBF) ~10’000 m^2
- Cost: ~ CHF 33 Mill (2006)

- Offices: work areas for 150 people
- Lecture hall: 140 seats
- Seminar and meeting rooms: 180 seats
- Cafeteria: 150 seats
- Book and multimedia library
- Atrium and communication zones
- Exhibition areas

Architecture

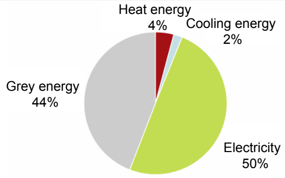


Energy Audit for First Year of Operation

Energy audit

3-PLAN HAUSTECHNIK

„1.4 liter building"



	Final energy[1]	Weighting	Primary energy[1]	Fraction
Heat energy	2.1	1.3	2.7 kWh/m²a	4%
Cooling energy	1.1	1.1	1.2 kWh/m²a	2%
Electricity	10.8	3.0	32.4 kWh/m²a	50%
Grey energy			28.6 kWh/m²a	44%
Total	14.0 kWh/m²a		64.9 kWh/m²a	

[1]relating to theenergyreferencearea (11 170 m²)

Bob Gysin + Partner BGP, Zürich
3-Plan Haustechnik, Winterthur

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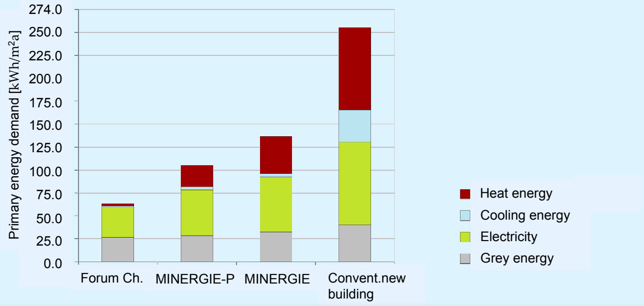
Energy Comparison

Energy - comparison

3-PLAN HAUSTECHNIK



The **primary energy demand** of Forum Chriesbach is less than **one quarter** that of a conventional new building.

Bob Gysin + Partner BGP, Zürich
3-Plan Haustechnik, Winterthur

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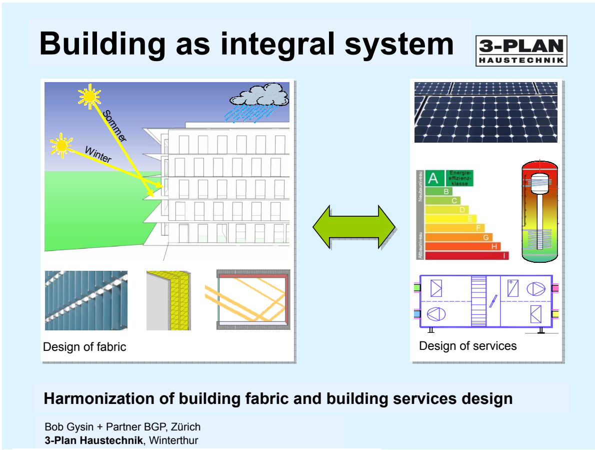
How was it done?

- Pushing the limit of what is technically feasible
- Combine many known elements into functioning complete system



Research at ETH, EMPA and Siemens

ETH

Control of heat pump heating system

Building autarky for extreme locations

Novel ventilation concepts

Siemens

Combined heating and power

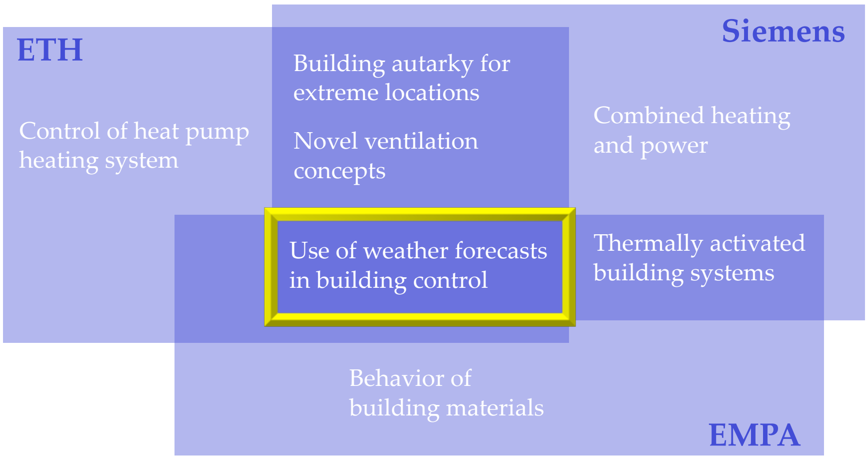
Use of weather forecasts in building control

Thermally activated building systems

Behavior of building materials

EMPA

Research at ETH, EMPA and Siemens



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What should Building Automation Systems do with Weather Forecasts?

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Some options:

1. **Rule-based methods**
   i.e. applying rules of the form "If …….. then …….“
2. **Replace measurements by forecasts**
3. **Model predictive control (MPC)**
4. **Stochastic methods**

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1. Rule-based Methods Illustrated with New Monte Rosa Cabin

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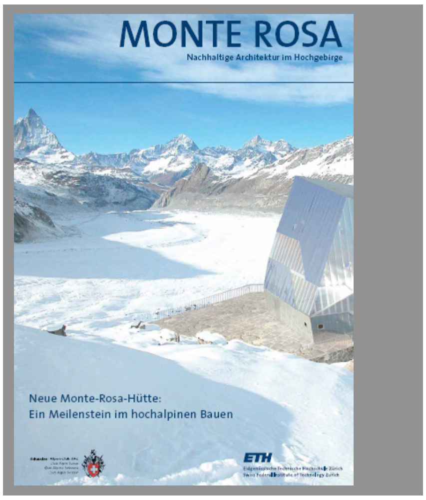
New Monte Rosa cabin

A project of the Swiss Federal Institute of Technology Zurich (ETHZ) on the occasion of its 150th anniversary.
Contribution by Siemens Building Technologies.



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1. Rule-based Methods Integrated Energy, HVAC and Water

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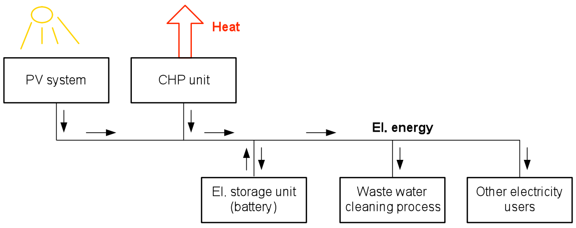
When should the controller switch on the waste water cleaning process?



Rule based control strategy:

- **If** the battery is half full **and** the waste water tank is half full **and** a lot of sunshine is predicted for the near future **then …**
  …the controller switches on the cleaning process, **(to reduce the risk that solar energy will have to be rejected because the battery will be fully loaded)**
- **If** the battery is half full **and** the waste water tank is half full **and** no sunshine is predicted for the near future **then …**
  …the controller switches off the cleaning process, **(to reduce the risk that battery will get empty and therefore the CHP-unit has to be switched on to supply the other electricity consumers with energy)**

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2. Replacing Measurements by Forecasts: Control of TABS

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Controller for Thermally Activated Building Systems (TABS) using weather forecasts from MeteoSwiss

- **Established practice:**
  The supply water temperature is varied with the **measured** outdoor temperature
- **New option (implemented):**
  The supply water temperature is varied with the **one day forecast** of the outdoor temperature
- **Argument for the use of forecasts:**
  Due to the high thermal mass of the slabs the room temperature reacts very slowly on control actions

Leonardo office building in Zurich

Sunrise Tower in Zurich

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3. Model-based Predictive Control
Predictive Heating Controller

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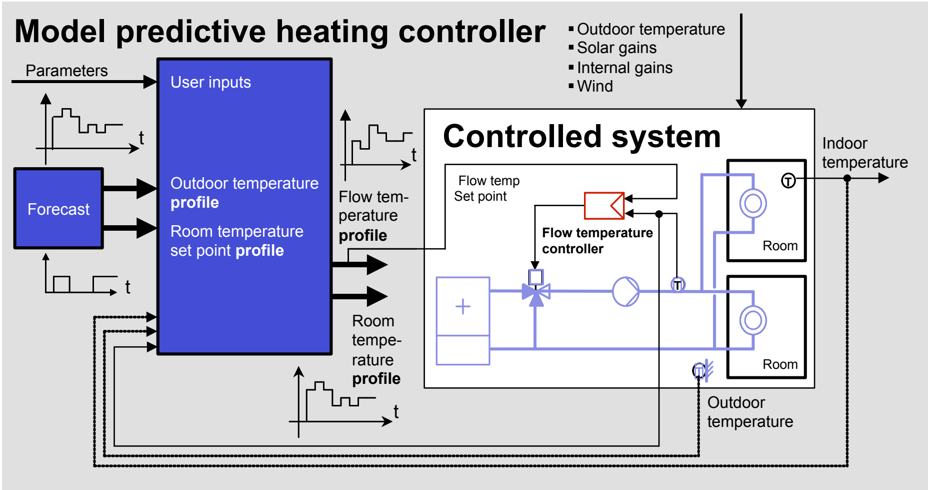

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3. Model-based Predictive Control
Predictive Heating Controller

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Implementation and Benefits

Test sites:

- Residential building in Garmisch (G. Lehnerer)
- Office building in Vienna (RC Austria)

Customer benefit:

- Adaptive version of controller requires only little tuning.
- Fast reaction to room-temperature set-point changes.
- Automatic exception handling, e.g. change of heating strategy on exceptionally cold days

Literature: 'Predictive Control for Heating Applications', Gruber, M. Gwerder, J. Tödtli, CLIMA 2000, Napoli, 2001

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3. Model Based Predictive Control Another Promising Application

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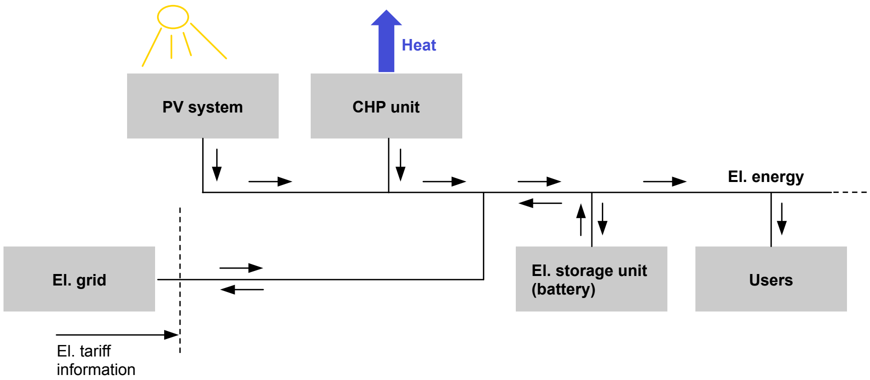
A building with PV panels, CHP-unit, etc. connected to the public electricity supply net and with variable or even dynamic electricity prices.



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4. Stochastic approaches

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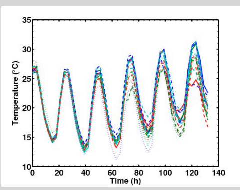
They take uncertainty in the weather forecasts explicitly into account, by using probabilistic models

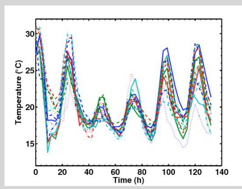
Forecast for Zürich Kloten with COSMO-LEPS
(LEPS = Local Ensemble Prediction System)

Forecast at 5.06.2006:



Low uncertainty

Forecast at 5.06.2006:



High uncertainty

Source: MeteoSchweiz

These approaches can reduce the risk that comfort requirements are violated, in applications where a false prediction of the weather leads to such violations

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Expected Benefits:

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- Energy or energy cost savings
- Better indoor environment
- The benefit with regards to energy and indoor environment is obvious for many people.
  This might lead to a broader use of predictive controllers.
- The control actions of controllers using weather forecasts are plausible for many people.
  This will lead to a higher acceptance of the controller and to a better user interaction with the system, and therefore to a better overall performance.

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Use of Weather and Occupancy Forecasts for Optimal Building Climate Control

Research project OptiControl

Project partners:

- ETH Zurich, Terrestrial Systems Ecology (Project lead)
- ETH Zurich, Automatic Control Laboratory
- EMPA Building Technologies (ETH domain)
- MeteoSwiss, Federal Office of Meteorology & Climatology
- Siemens Building Technologies

Duration:

- 2007 to 2010

Funded by:

- Swisselectric Research
- CCEM (Competence Center for Energy and Mobility, ETH domain)
- Siemens Building Technologies

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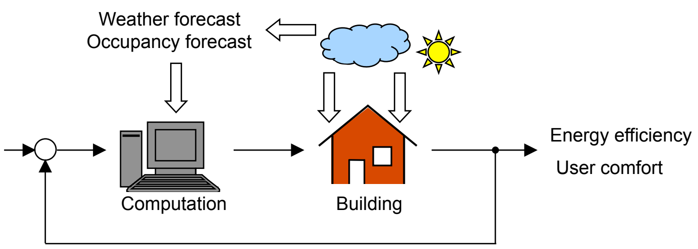
Use of Weather and Occupancy Forecasts for Optimal Building Climate Control



Standards: Keep room temperature in comfort range with a given probability

Goal: Satisfy constraints with a minimum amount of energy

Idea: Low carbon energy sources and building dynamics are slow and intermittent – use weather forecast for planning

Method: Model Predictive Control using weather and occupancy forecasts

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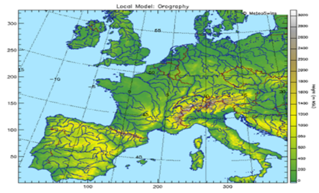
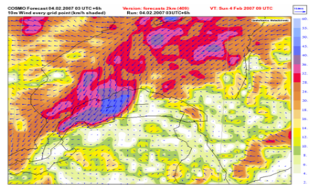
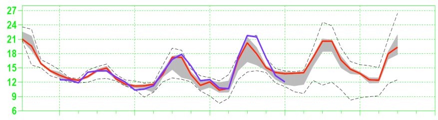
Weather Forecasts

- **Extrapolation**: assume persistence or extrapolate from the past
- Weather forecasts by MeteoSwiss
  1. **Cosmo 7** (deterministic forecast)
     - 2x daily 72 hour forecast
     - Region of Europe
     - 385 x 325 grid points, 7km mesh
     - 45 terrain following altitudes
  2. **Cosmo 2** (deterministic forecast)
     - 8x daily 18 hour forecast
     - 2.2 km mesh
     - region around the Alps
  3. **Cosmo-Leps** (ensemble forecast)
     - uncertainty information
     - 16 sample predictions
     - 2x daily 132 hour forecasts
     - southern and central Europe
     - grid-spacing 10 km, 40 altitudes







Source: MeteoSwiss

Use of Weather and Occupancy Forecasts for Optimal Building Climate Control

Integrated room automation means:

Integrated control of the heating and cooling system, the blinds and the electrical lighting of a room

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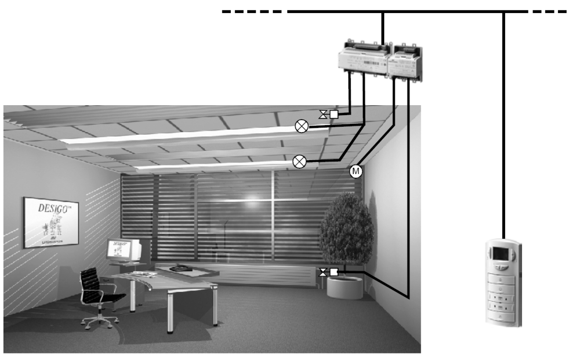


Using Weather Forecasts for Building Control The Size of the Prize

Sites: 9 locations representing the different weather conditions in Europe

Weather inputs:
- **Data:** Hourly measurements from 2006
- **Predictions:** Perfect forecast, i.e. equal to weather realization

Occupancy inputs:
- **Data:** Standard profile, cellular office
- **Predictions:** Perfect forecast, i.e. equal to occupancy realization

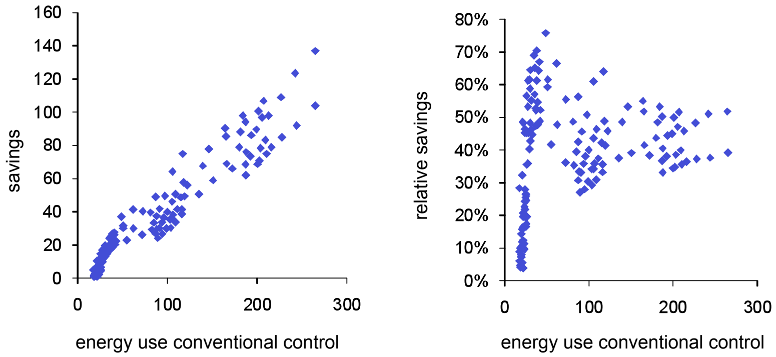
Buildings:

- **Facade orientation**	Southwest	
- **Thermal insulation level**	Swiss average	Passive house
- **Construction type**	Heavyweight	Lightweight
- **Window area fraction**	30%	80 %
- **Internal gains level**	low	high

Case study: 16 buildings x 9 locations = 144 scenarios

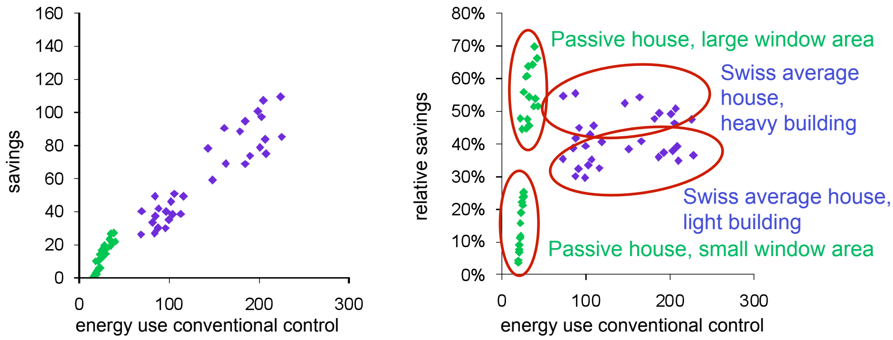
Integ. Room Automation - Size of the Prize 144 Scenarios

Savings: Control with perfect weather forecast vs. conventional control



Integ. Room Automation - Size of the Prize Swiss sites

Savings: Control with perfect weather forecast vs. conventional control



For passive houses: more potential with large window areas
For Swiss average houses: more potential with heavy buildings

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Size of the Prize - Summary

Potential **maximum** savings from integrated room automation using weather forecasts are substantial but depend strongly on particular situation, e.g.,

- 30-40% for Swiss average light house
- < 60% for Swiss average heavy house
- < 70% for passive house with large windows

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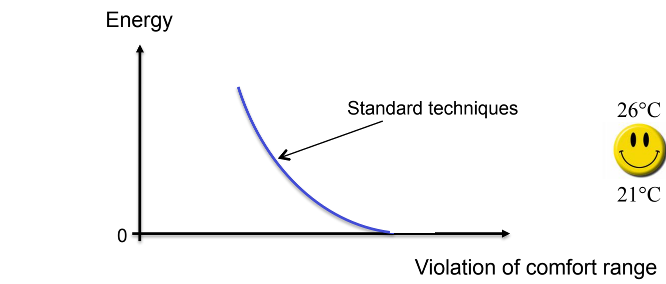
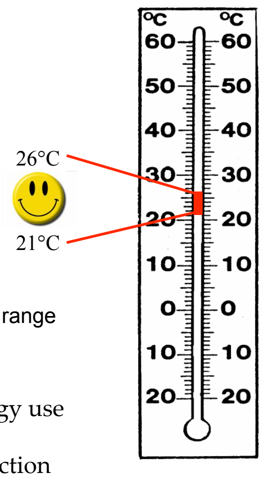
Power of Modern Control Techniques: Trade-off between Comfort and Energy





- Every control technique trades off comfort and energy use
- Often large energy savings from small comfort reduction

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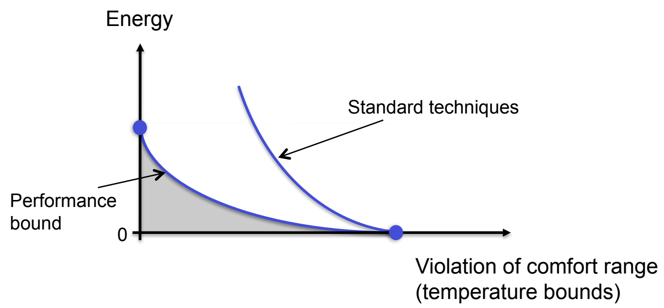
Power of Modern Control Techniques: Trade-off between Comfort and Energy



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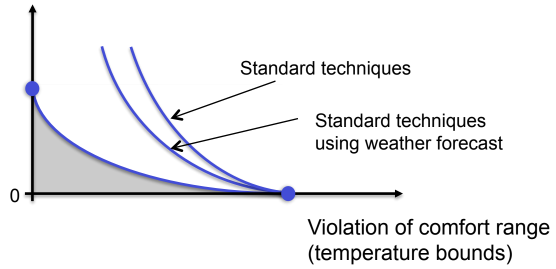

- More information ⇒ More savings
  e.g. weather forecast, occupancy sensors
- Potential savings significantly outweigh 'sensor' costs

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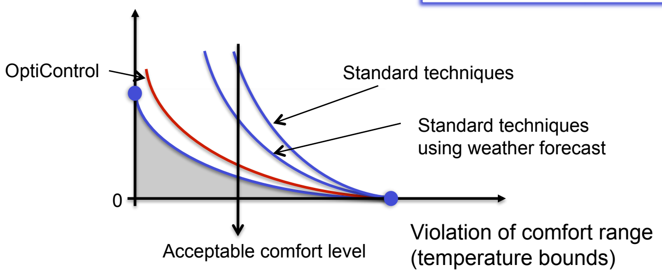
Power of Modern Control Techniques: Trade-off between Comfort and Energy

The trouble with weather forecasting is that it's right too often for us to ignore it and wrong too often for us to rely on it.
- Patrick Young



- Wrong forecast ⇒ Wrong control ⇒ Poor comfort
- **OptiControl:** Account for forecast uncertainty in control
- Uncertain forecast ⇒ Cautious control ⇒ Improved comfort

Difficult to use uncertainty in control: Active area of research

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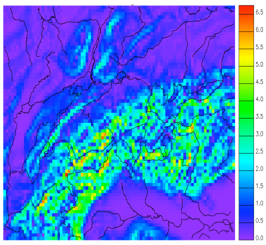
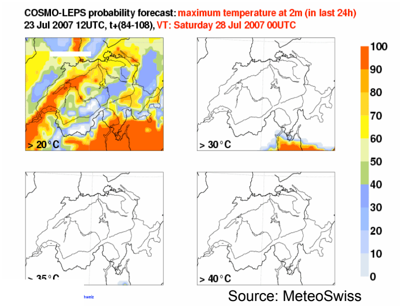
Potential Advantages of Using Predictive Control Using Weather Forecasts

- Comfort improvements and/or cost/energy savings
- Simple adjustment by user to effect desired comfort level
- Plausible strategy leads to good acceptance





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Novel ventilation concepts

Use of weather forecasts in building control

Siemens

Combined heating and power

Thermally activated building systems

Behavior of building materials

EMPA

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Ventilation
Energy Efficient HVAC Systems

P. Rostalski[1], M. Morari[1], A. W. Woods[2]

[1] Automatic Control Laboratory, ETH Zurich, Switzerland
[2] BP Institute, University Cambridge, UK

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BP Institute University of Cambridge

Berkeley Lab

Lucerne University of Applied Sciences and Arts HOCHSCHULE LUZERN

ifa Automatic Control Laboratory, ETH Zürich
www.control.ethz.ch/~building

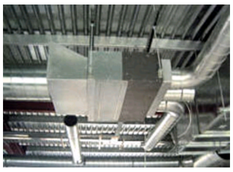
ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Energy Consumption: - Ventilation

Why do we care about Ventilation?

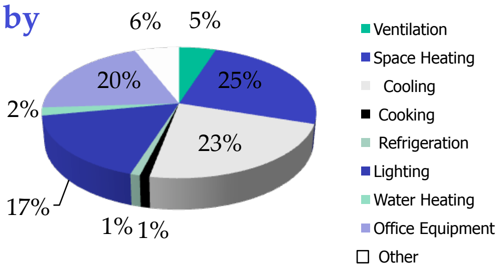
- Affects human health
- Consumes energy
- Influences heating and cooling performance

⇒ Trade-off between air quality and energy consumption



Total energy consumption by end-user in the US :

- 5% of total energy used for ventilation
- 48% of total energy directly influenced by ventilation (heating/cooling)



Source: US Environmental Protection Agency (adapted from E-source 2006)

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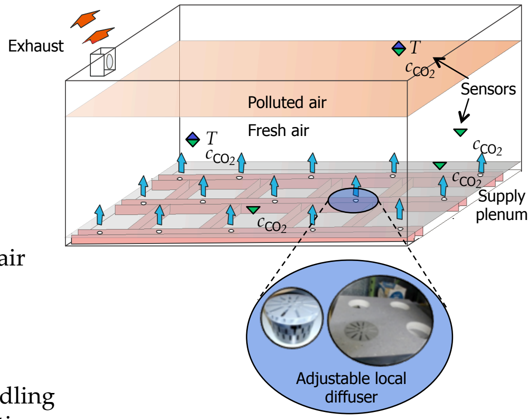
Energy Efficient Ventilation - Concept: Underfloor Ventilation

Key Elements:

- A single exhaust at ceiling level (driving the flow)
- Adjustable local diffuser
- Supply plenum
- Temperature and CO_2 sensors



Advantages:

- Air quality: (almost) inlet air
- Energy efficiency

Challenges?

- Contaminant handling
- Disturbance rejection
- Prevention of recirculation

→ Dynamic estimation and control

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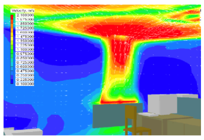
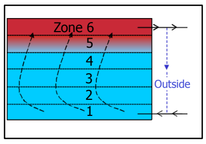
Energy Efficient Ventilation - Model-based Approach

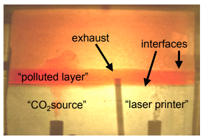
Dynamical model:
- Describing air flow dynamics
- Capturing stratification
- Suitable for real-time computation


a) CFD simulations



b) Simplified dynamical model

Procedure:
- Steady state modeling
- Dynamic modeling
  (k-ε - Model, CFD)
- Simplified dynamic model
  (POD + Galerkin Projection)



c) Small-scale experiments


d) Large scale experiments

Employment:
- Model-based sensor positioning
- Dynamic estimation
- Predictive control

Sponsored by NCCR MICS (Mobile Inf. and Comm. Systems)

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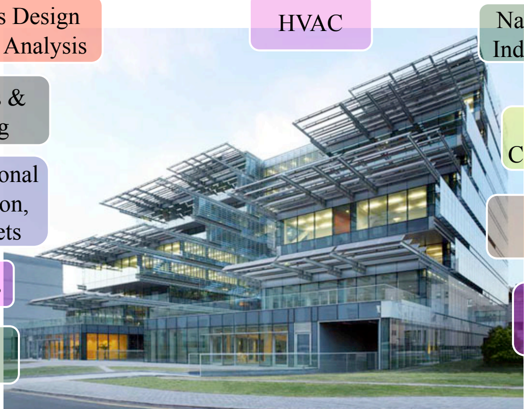
Collaboration with Some Other Projects

High Performance Buildings Research & Implementation Center HiPerBRIC (DOE sponsored)

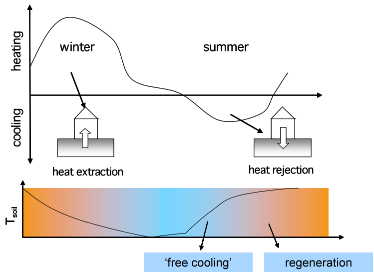
Simulations of thermal systems - K.U.Leuven

HiPerBRIC Role and Differentiation: Systems of Systems

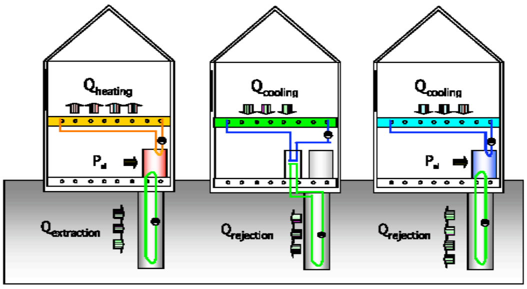
“Prius of Buildings: Exploiting the Interfaces between Sub-systems”



Simulation of Thermal Systems – K.U. Leuven



Ground coupled heat pump systems in office buildings



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Outline

- Motivation
- Utilizing Weather Forecasts
  - Siemens
  - ETH and partners
- Ventilation Control
- Some Caveats
- Conclusions

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Some Caveats:
Building Construction

Design → Bid → Build

- Owner wants a single, general contractor to hold responsible
- Controls subcontractor is several tiers down in the contractual hierarchy
- Cost pressures at each tier result in low margins for controls work
- Minimum first-cost mindset precludes lower-cost investment options based on life-cycle performance
- Commissioning is often not done well and sometimes not at all

Result: Poor quality of installed systems

Source: S.T. Bushby, NIST, 2007

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Some Caveats:
Building Operation

- Building maintenance staff are often poorly trained
- Contract maintenance based on trouble calls is common
- Overrides or temporary fixes often stay in place preventing the control system from doing its job
- Facility budgets are often seen as a potential place to cut when money is tight

Result: System performance degrades over time

Source: S.T.Bushby, NIST, 2007

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Conclusions

- Advances in information technology enable major changes in building (energy) management
- Energy savings from control utilizing weather forecasts can be large, but are highly situation dependent
  ⇒ need for assessment tool
- Realization of savings will require not only technological advances but changes in the processes for implementation and operation of technology

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OptiControl

Project Leader: D. Gyalistras, ETH Zurich

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EMPA Materials Science & Technology

SIEMENS Building Technologies

MeteoSwiss
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
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