Model selection and identification for (MB) CCx in office buildings

- **Intro**
  - HVAC & BEMS
  - Energy use & Related cost(s)
  - Nomenclature: (MB) CCx?
  - CCx subtasks
  - Research questions?
- HVAC & HVAC control
  - Common practice
  - State of the art (SoTa)
  - In the pipeline
- Results & Discussion
  - Model selection, identification
  - Evaluation criteria
  - Reusability
- Conclusion

Intro:
HVAC & BEMS

Building Automation Behind the Scenes
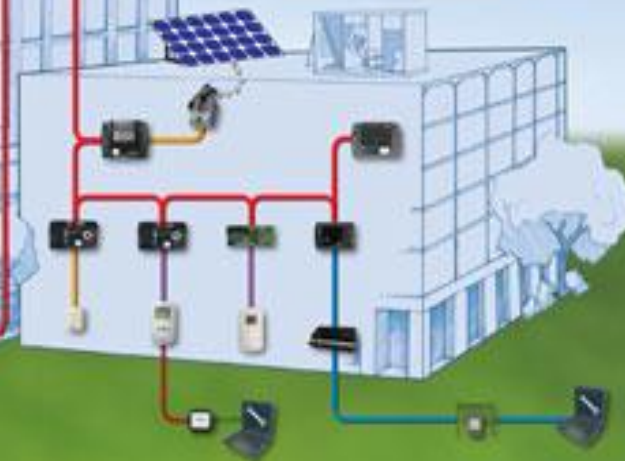
Basic Building Automation Controls
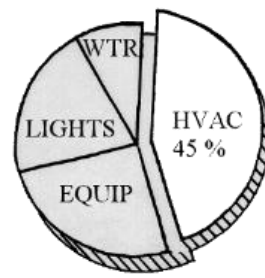
BACnet Network
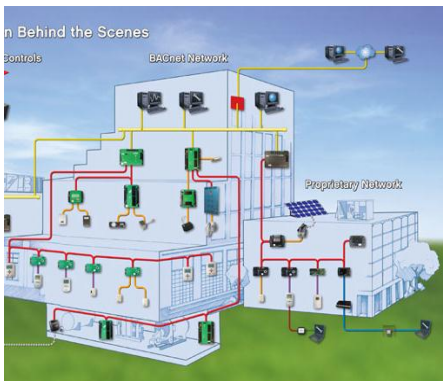
Mixed Networks

Proprietary Network

Intro:
Energy use & related costs

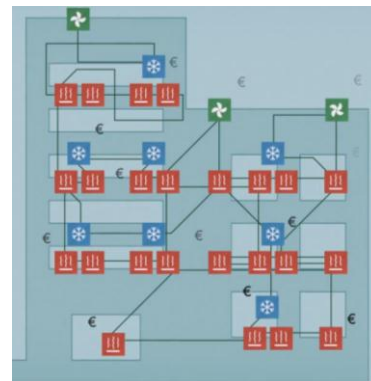Indoor thermal comfort (& IAQ) in offices
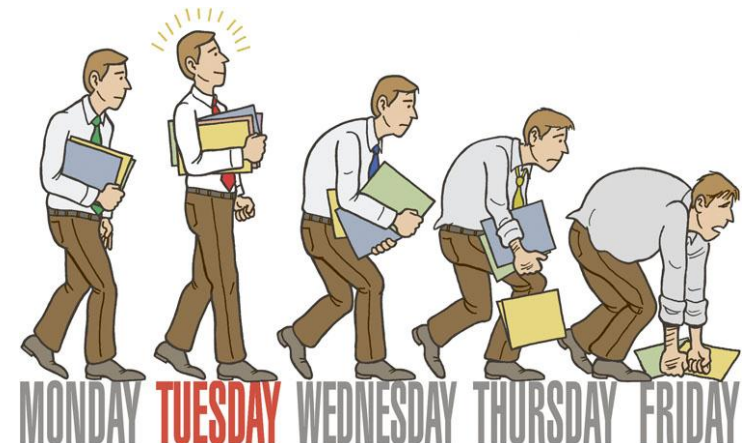
- Comes with a large (often hidden) cost!
  - HVAC equipment: ~10% construction c.
  - HVAC control: ~3% construction cost
  - HVAC energy cost: ~40% of prim. En. Use
  - Maintenance cost: ~3 €/y/m²
  - Discomfort cost: ~5 €/Kh²/y/m²

http://www.kmccontrols.com/   *http://www.tibucon.info*   *http://greenberg-art.com/.Illustrations*

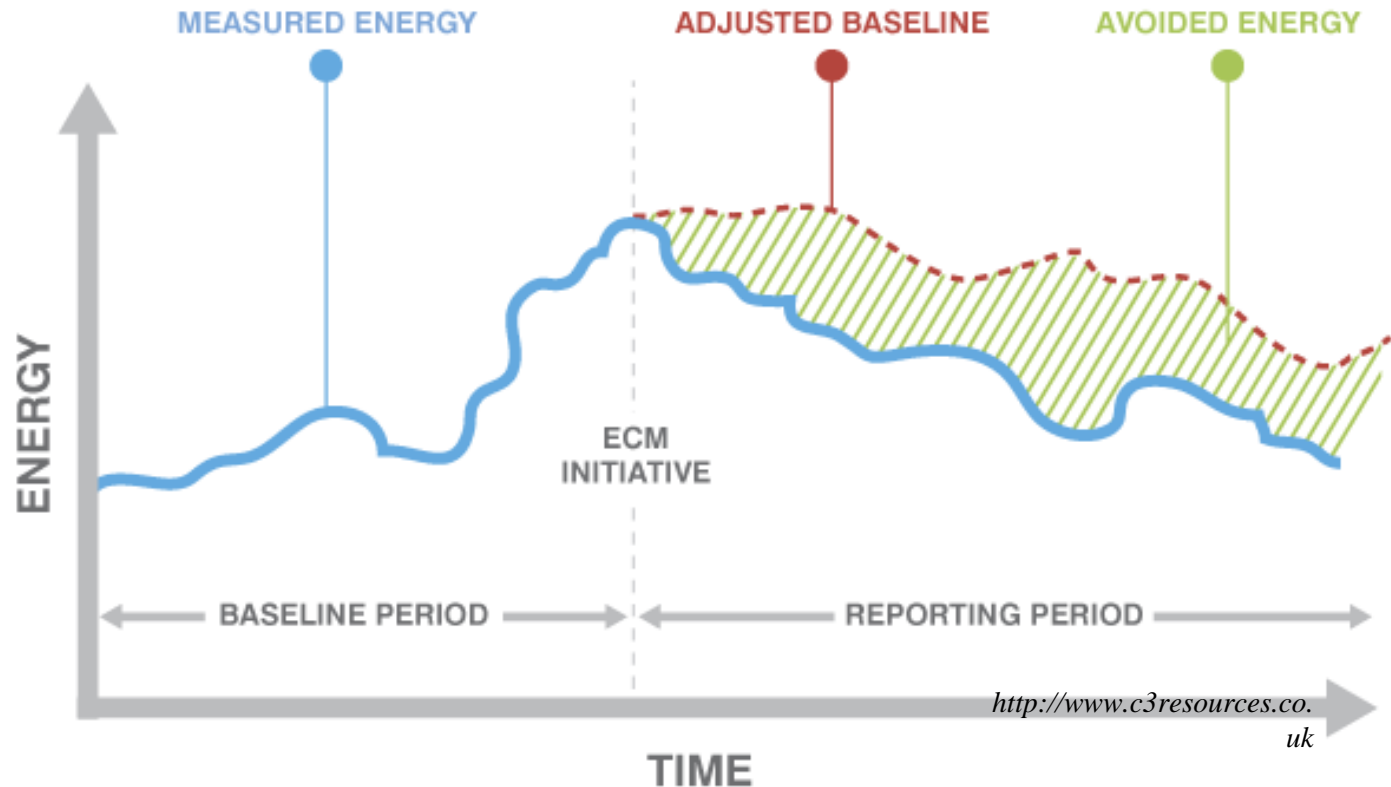# Intro: Nomenclature (MB)CCx?

- Commissioning   *Cx*
- Continuous Commissioning   *CCx*
- Re(tro)-commissioning   *Re(tro)- Cx*
- Monitoring based / Model based   *MB*

MEASURED ENERGY   ADJUSTED BASELINE   AVOIDED ENERGY

ENERGY

ECM INITIATIVE

BASELINE PERIOD   REPORTING PERIOD

http://www.c3resources.co.uk

TIME

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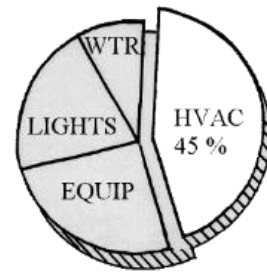
Intro:
CCx subtasks

- Efficiency Improvement?

  A. Baselining, Benchmarking, Energy conserving opportunities — ECO

  B. Fault detection, diagnosis — FDDe

  C. Improved Control — AdvC

➔ **Right models may assist in these sub-tasks!**

Plan / Act / Do / Check

DEFINE   MEASURE   ANALYZE   IMPROVE   CONTROL

Which models? (1/2)

PHYSICAL
(PDEs, ODEs, etc.)
(*state-space*)

LUMPED PHYSICAL
(ODEs, etc.)
(*state-space, parametric*)

GRAY BOX
(Transfer Fcns, ARMA, etc.)
(*parametric*)

BLACK BOX
(AR, ARMA, MA, polys, etc.)
(*parametric , non-parametric*)

SIMPLE
(transforms,non-parms, etc.)
(*non-parametric*)
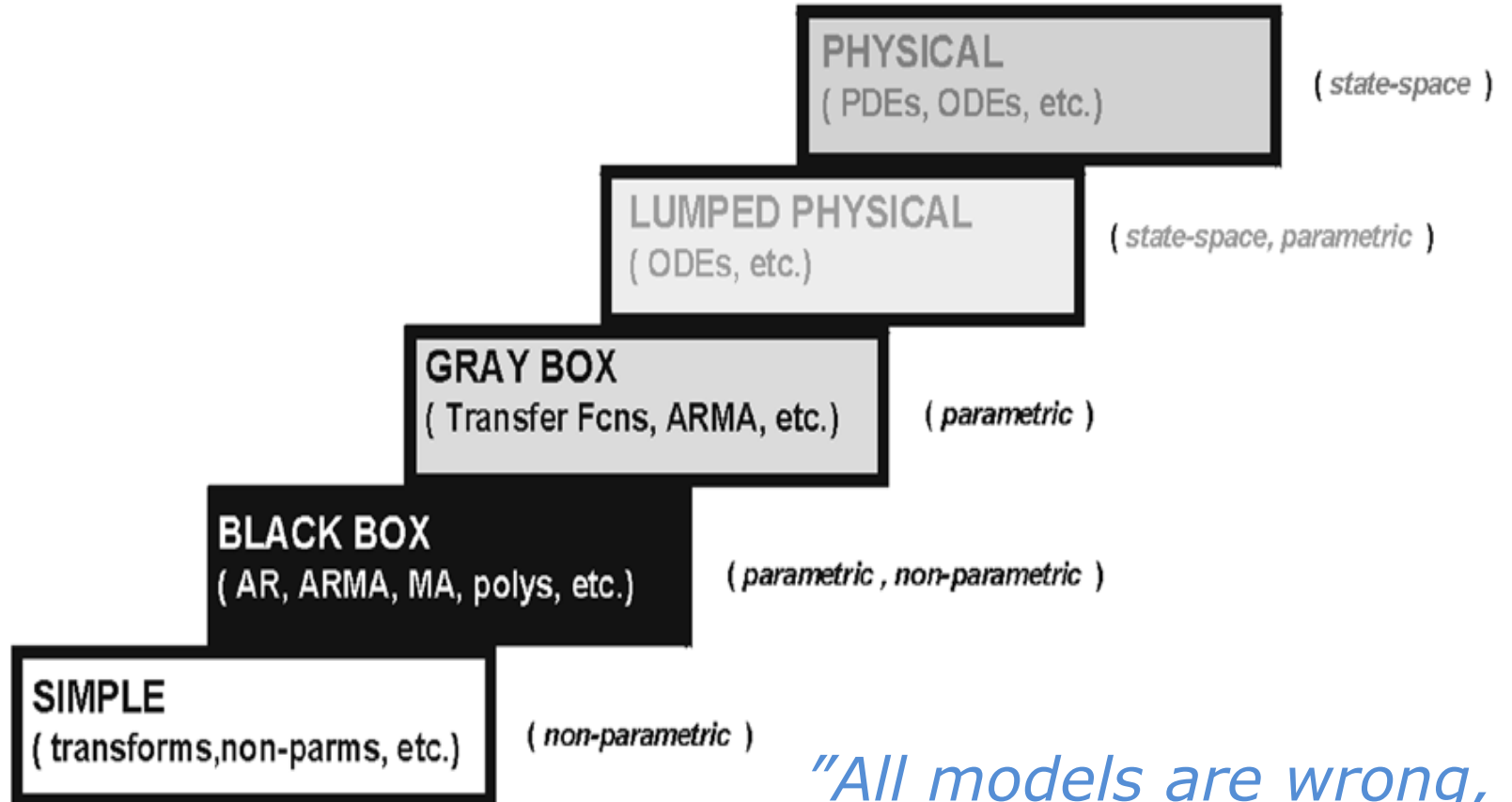
"All models are wrong, but some are useful."
~ George E.P. Box

Simplicity

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Which models? (2/2)

- What "choices" are there?
  - System: Building, HVAC, users,…
  - Type: WB/GB/BB, det./stoch,…
  - Structure: SS/TF, cont/discr,…
  - Domain: time/freq
  - Order: #y,s,u,d,p
  - Software: Modelica, …
  - Parameter identification:
    - Methods
    - Training and validation data
    - Performance criteria
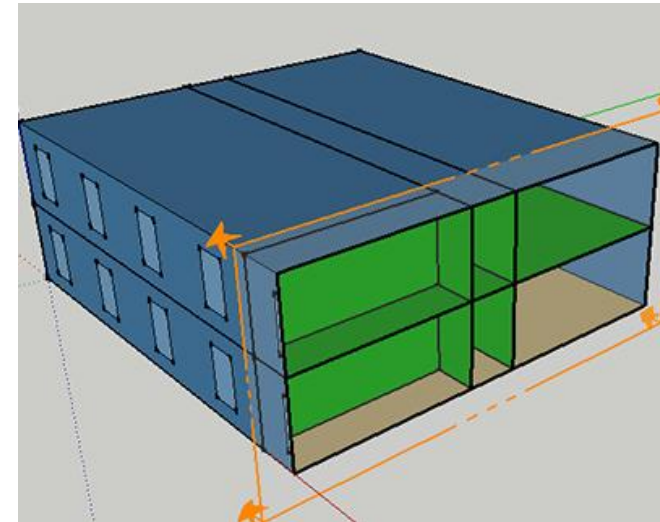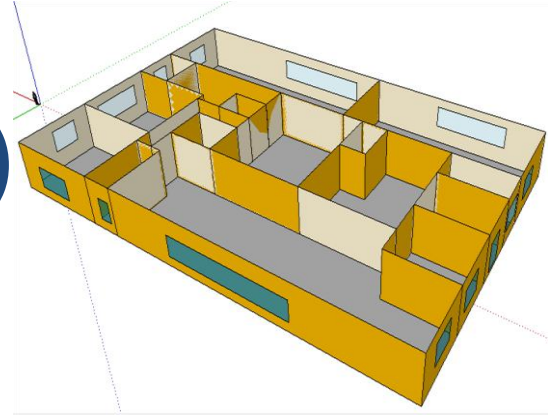
Research questions?

1. What CCx measures are implemented (& how)?
2. Data & calculation requirements?
3. Which parts can be re-used?

➔ Focus on:

- **Model based control (MBC)**
- **Hydronic (water based) HVAC**
- **In office buildings**

http://www.damuth.com/

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Hydronic HVAC and MBC: Common practice
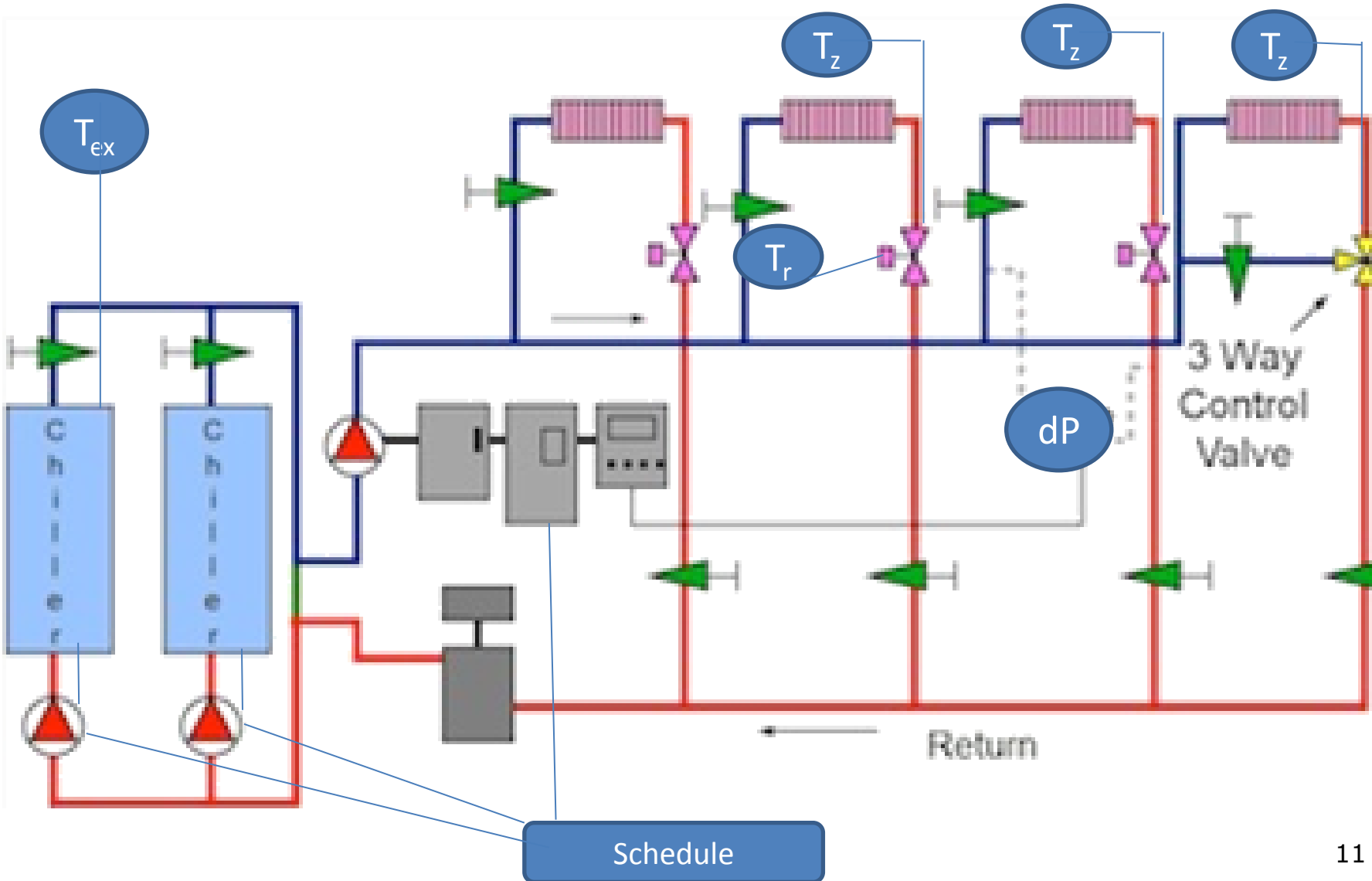
Hydronic HVAC and MBC: State of the art (SotA)?

Integrated building energy management system (BEMS)

Comfort conditions
Feeling comfortable

LT-terminal units, TABS

LT & HT production

HP & Free cooling

Storage
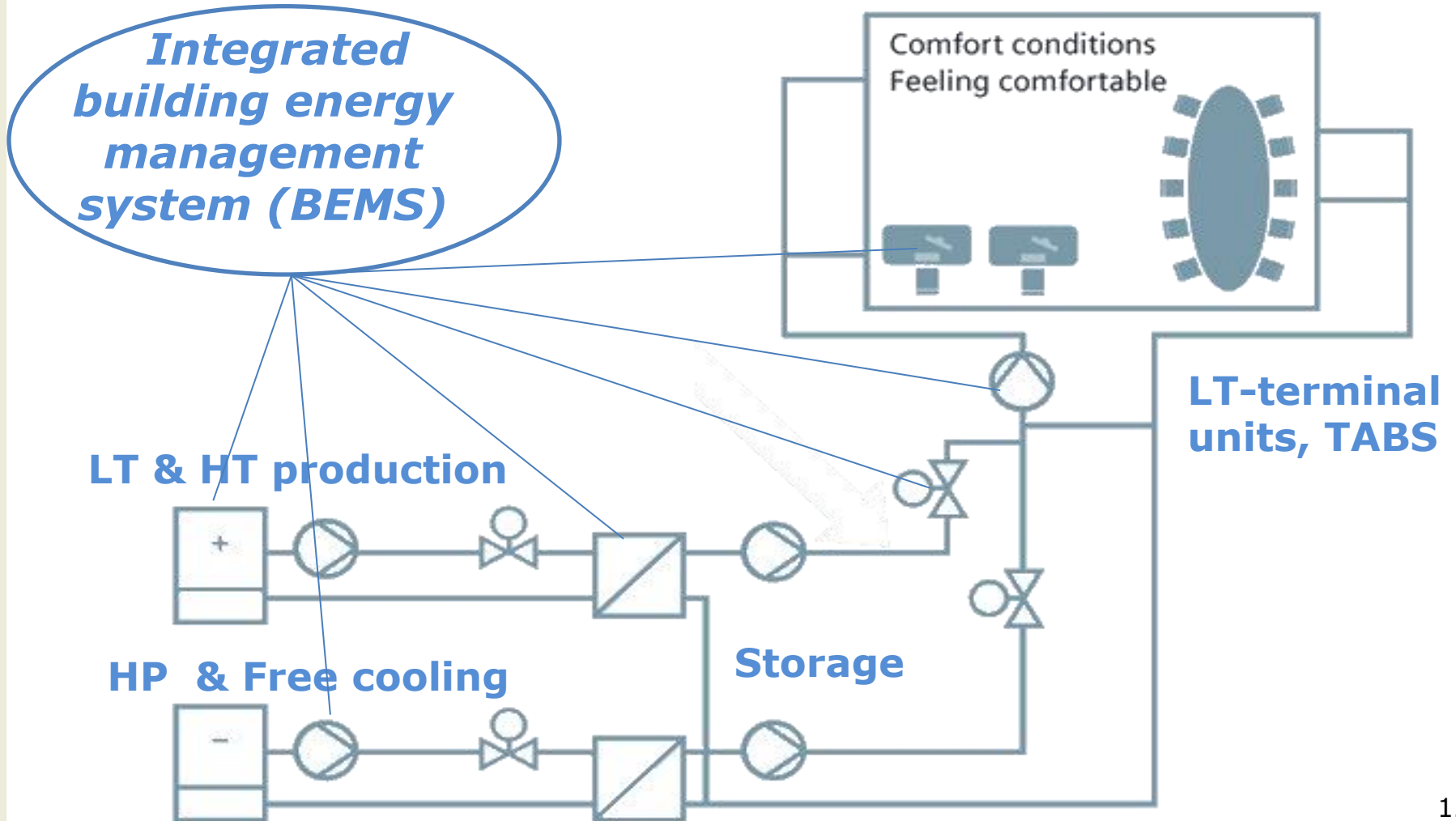
Hydronic HVAC and MBC: In the "pipeline"? (1/4)

- Emerging MPC for HVAC (Model predictive control):
  - At **plant level**:
    - Czech Republic (Siroki, 2011), coop with **Honeywell**
    - Sweden (Gruber, 2014)
    - Spain (Castila, 2014)
    - Australia (West, 2014)
    - …
  - At **building level** (plant + room level):
    - Oklahoma, (Dong, 2010)
    - France, (Lamoudi, 2011), coop with **Schneider Electric**
    - Berkeley (Bengea 2013)
    - Philadelphia (Pengfei, 2013)
    - Switzerland (Oldew.,2013), coop with **Siemens**
    - Belgium (Soubron, 2014)
    - Belgium (De Koninck, 2014)
    - …

Active field, coop. W. BEMS manuf.!

Hydronic HVAC and MBC: "Pipeline" model structures (2/4)

- Different *flavours* of MPC
  - At plant level:
    - Czech republic (Siroki, 2011)   **WB-SS (NL)**
    - Sweden (Gruber, 2014)   GB-SS (NL)
    - Spain (Castila, 2014)   WB-SS (NL)
    - Australia (West, 2014)   GB-TF (Lin)
    - …
  - At building level (plant + room level):
    - Oklahoma, (Dong, 2010)   WB-SS (NL, stoch.)
    - France, (Lamoudi, 2011)   **GB-SS** (NL, distr.)
    - Philadelphia (Pengfei, 2013)   BB-SS (Lin, ARX)
    - Switzerland (Oldew.,2013)   **GB-SS** (bi-lin, MI)
    - Belgium (Soubron, 2014)   **GB-SS** (NL)
    - Belgium (De Koninck, 2014)   **GB-SS (NL)**
    - …

> Historically: WB!
> Now: GB!

MBC implementations: "Pipeline" model orders (3/4)

- Model orders: low # states & medium (1-3) #inputs!
  - At plant level:
    - Czech republic (Siroki, 2011)   1y 2(4)s (2)u 1d
    - Sweden (Gruber, 2014)   2y, (2)s, (2)u, 5d
    - Spain (Castila, 2014)   1y, 5(2)s, (1)u, 14d
    - Australia (West, 2014)   5(7)y, 4(4)s, (3)u 0d
    - …
  - At building level (plant + room level):
    - Oklahoma, (Dong, 2010)   (1)y, (3)s, 1(1)u, 2d
    - France, (Lamoudi, 2011)   11(?)y, 3s, ?(?)u, 3d
    - Philadelphia (Pengfei, 2013)   9(1)y 2s 6(1)u 2d
    - Switzerland (Oldew.,2013)   32(2)y,15(1)s, 9(1)u, 6d
    - Belgium (Soubron, 2014)   8y, 3(2)s, (3)u, 5d
    - Belgium (De Koninck, 2014)   …
    - …

Low # of states & outputs.
Typical order: 2-3 /temp reading

MBC implementations: "Pipeline" ident. methods (4/4)

- Wide variety of identification methods!
  - At plant level:
    - Czech republic (Siroki, 2011) MPC Relevant Ident. (N4SID)
    - Sweden (Gruber, 2014)   Unspecified
    - Spain (Castila, 2014)   Adaptive (unspecified)
    - Australia (West, 2014)   Unspecified
    - …
  - At building level (plant + room level):
    - Oklahoma, (Dong, 2010)   Subspace trust region solve
    - France, (Lamoudi, 2011)   Prediction Error Minimisation (PEM)
    - Philadelphia (Pengfei, 2013)   LS-estimation
    - Switzerland (Oldew.,2013)   Hankel-norm reduction
    - Belgium (Soubron, 2014)   MPC Relevant ident.
    - Belgium (De Koninck, 2014) …
    - …

Much variation, no "standard"

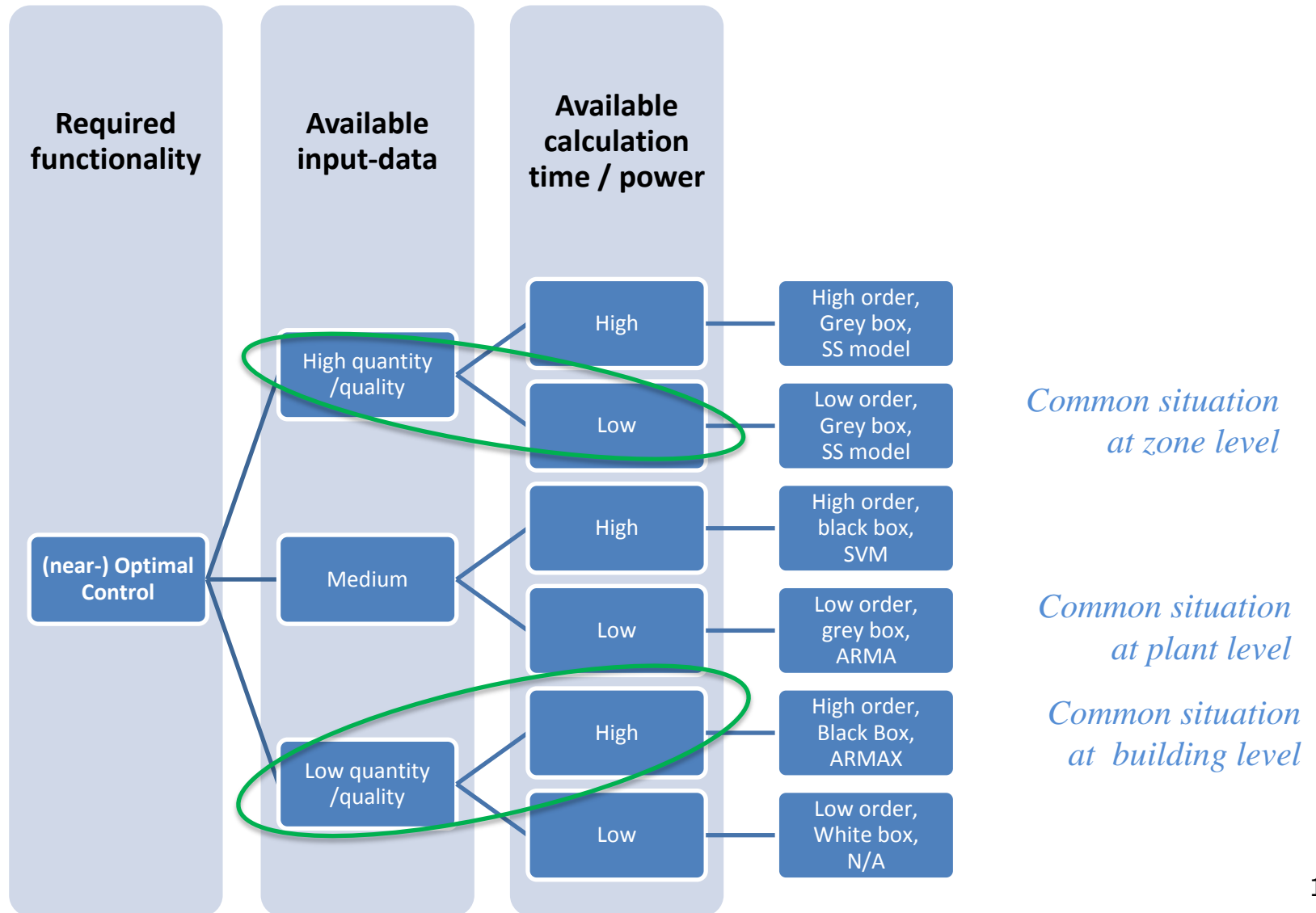# Model selection and identification for (MB) CCx in office buildings

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Control model-, identification- and structure-selection

Required functionality	Available input-data	Available calculation time / power	
	High quantity /quality	High	High order, Grey box, SS model
		Low	Low order, Grey box, SS model
(near-) Optimal Control	Medium	High	High order, black box, SVM
		Low	Low order, grey box, ARMA
	Low quantity /quality	High	High order, Black Box, ARMAX
		Low	Low order, White box, N/A

Common situation at zone level

Common situation at plant level

Common situation at building level

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MBC Evaluation criteria

- **Model quality criteria (MQC)**
  - short-term prediction accuracy
  - short-term state estimation
  - Suitable temporal resolution
  - Robustness

- **Evaluation criteria:**
  - Open loop, 1-step-ahead prediction RMSE
  - Closed loop MSE, MAE,RMSE, cv(RMSE)
  - In-operation KPI-performance vs theoretical
  - Modeling requirements
  - Computational requirements
  - Input data requirements

-

Reusability for MBC

- **WITHIN** a subtask: **Model orders** are often **similar** :
  - In ECO: Low #inputs in ECO, #1-2 states/zone
  - **For MBC: Medium #inputs in MBC #3-5 states/zone**
  - For FDDe: High #inputs, #10-20 states / system

- **BETWEEN** subtasks:
  - Large diversity:
    - Long term, integrated pred. performance for ECO
    - **Short term, dynamic pred. perf. for MBC**
    - Short term, static perf for FFDe
  - Large variety of models type and structures:
    - For ECO: White/Grey box (mostly static, multizone)
    - **For MBC: (dynamic multizone) white/grey/black box**
    - For FDDe: Black box (mostly dynamic, multizone)
- Why? Different Evaluation criteria!

Few opportunities for full model exchange between CCx subtasks.   *(GB structures), ident. techniques and datasets may be shared!*

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MB-CCx Conclusions:

- On model selection:
  - **Take available calculation power & data quality/quantity into account!**
  - No model structure suitable for multiple subtasks
  - Large diversity in used (usefull?) models between and within MBC-subtasks
  - Model order diversity small within MBC subtask

- On model identification:
  - **Resource & technology sharing between MB CCx-subtasks can mean a costdown for:**
    - Calculation power (hardware)
    - Obtaining (high quality) identification data
    - Applying parameter identification techniques

- **Future work** & more details:
  Journal paper (under construction), titled:
  "Review of model selection and identification for (MB) CCx implementations in office buildings"

Questions?

"YOU NEVER CHANGE THINGS BY FIGHTING THE EXISTING REALITY. TO CHANGE SOMETHING, BUILD A NEW MODEL THAT MAKES THE EXISTING MODEL OBSOLETE."

- BUCKMINSTER FULLER

taniaannmarshall.wordpress.com