Heat Pump Systems Adapted to Energy-Flexible and Highly Insulated Buildings in Cold Climate

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Research idea

- Investigate heating systems which maximize *energy efficiency* as well as *energy flexibility in view of the electrical grid* and which optimize the *heat pump cycle length*

- **Approach:**
  - Investigate the characteristics of highly insulated buildings and hence the challenges that come with a super-insulated envelope
  - Set up a numerical model of a residential nZEB in IDA ICE (Living Lab)
  - Validate and calibrate the model with field measurements
  - Determine and define flexibility parameters
  - Test the performance of different control strategies for the energy system using IDA ICE
    → finding an optimal system integration for obtaining a zero energy balance
  - Implement and test the control strategies in a real nZEB

Characteristics and challenges of highly insulated envelopes

- **Typical characteristics:**
  - High thermal insulation
  - Air-tight envelope
  - Use of mechanical balanced ventilation with HRU
  - High-performance windows

  → Low space heating demand

- **Challenges:**
  - Power oversizing for SH and SC

  - Shortened SH season → affects cost-effectiveness measures
  - Thermal losses from pipes and storage tanks may have to be considered
  - Time constant of the building is increased → good storage and use of thermal losses
  - Reduced number of heat emitters
  - DHW/SH ratio increases

  - Influence of occupant´s behavior on the building performance increases (internal gains, SH needs, DHW consumption, opening of windows and doors)

Energy flexibility of nZEBs

- **What is «energy flexibility»?**
  - Building-to-grid «energy flexibility» often reduced to the electricity consumption for heating
  - Amount of electricity that can be shifted to off-peak hours by activating thermal energy storages

- **Flexibility parameters:**
  - Related to services that a building can offer to the power grid
  - Example: Le Dréau (2016):

$$Flexibility\ factor = \frac{\int_{low\ price\ time} q_{heating} \cdot dt - \int_{high\ price\ time} q_{heating} \cdot dt}{\int_{low\ price\ time} q_{heating} \cdot dt + \int_{high\ price\ time} q_{heating} \cdot dt}$$

Flexibility factor:

- Ability to shift the energy use from high to low price periods
- Similar heating use in low price and high price periods leads to a factor of 0
- Factor 1 or -1 represent cases of no heating during high price periods or no heating during low price periods, respectively

- Increasing energy flexibility by improving **control strategies for heat pump systems**
  - Time/price dependent grid interaction
  - Increased self-consumption
  - Model-predictive control in combination with thermal storages show great opportunity for peak shaving and reducing operational costs (Afram (2014))

Model of the Living Lab in IDA ICE

- **Goal:**
  - Setting up a numerical model of the Living Lab
  - Validating and calibrating the model with measurement data from field tests

- **General challenges:**
  - How detailed is detailed enough?
    - → Difficult to know which assumptions and default settings give good results
  - Getting sufficient input data

- **Energy system:**
  - Ground heat exchanger (1)
  - Solar thermal collectors (2)
  - Ground source heat pump (3)
  - Hot water storage tank [SH tank (4) integrated in the DHW tank (5)]
  - Two auxiliary electric heating coils in the water storage tanks (6)
  - Ventilation distribution network / AHU (7)
  - Photovoltaic panels

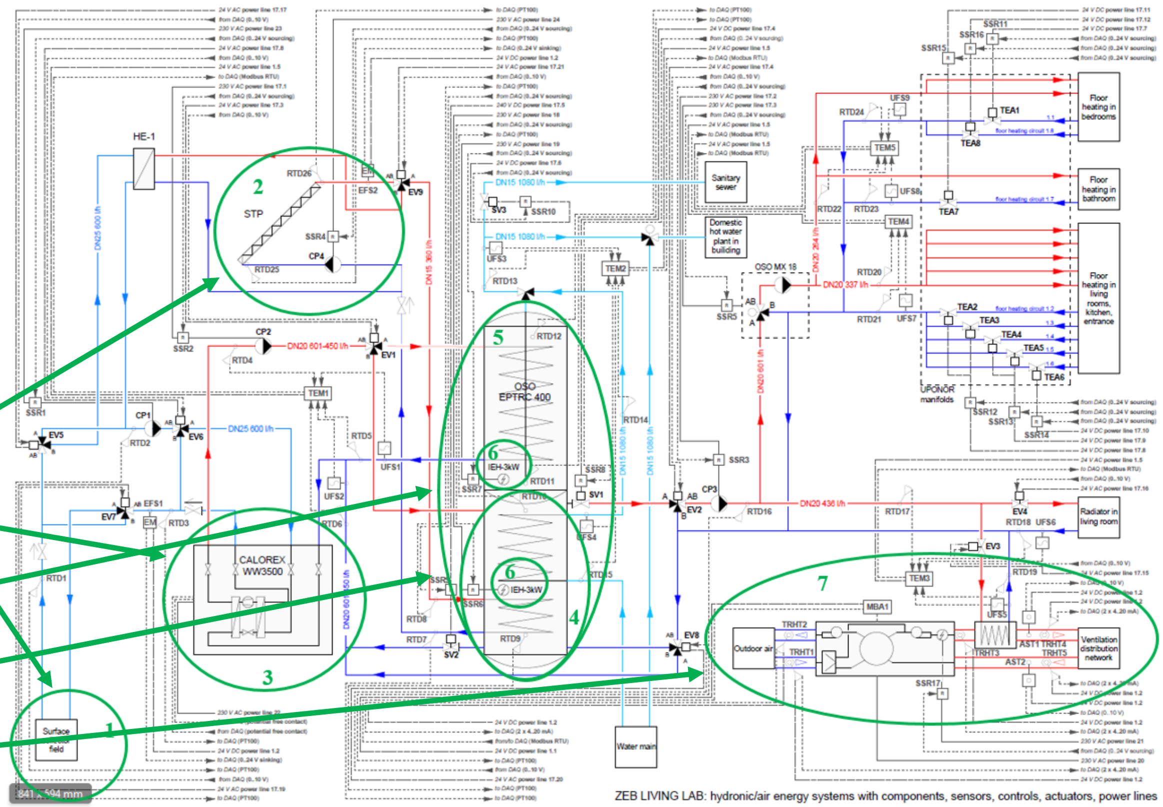

Figure 1 – *Sketch of the energy system of the Living Lab*

Model of the Living Lab in IDA ICE

- **Current modeling challenges:**
  - GSHP: Minimizing the error between the manufacturer data and the simulation results from IDA ICE
    → B, C, E, F can be optimized doing parametric runs
  - Setting up the tank-in-tank model → use of appropriate assumptions and simplifications
  - Setting up the connections between the water tank and the two different heat distribution systems
  - Design of the total heating power → flow rates of the FH do result in a very high design power (120 W/m^2)
  - Ground properties for the horizontal GHE
  - Control of all the components and system integration
  - Modeling of the PCM

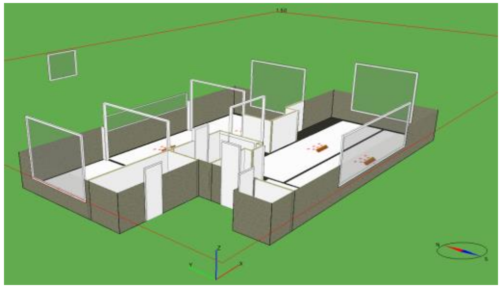

***Figure 2** – Sketch of the LL in IDA ICE*

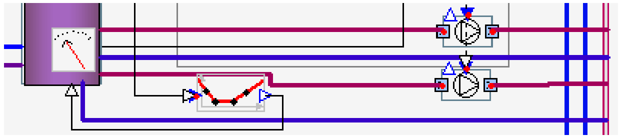

***Figure 4** – Implementation of a second HDS*

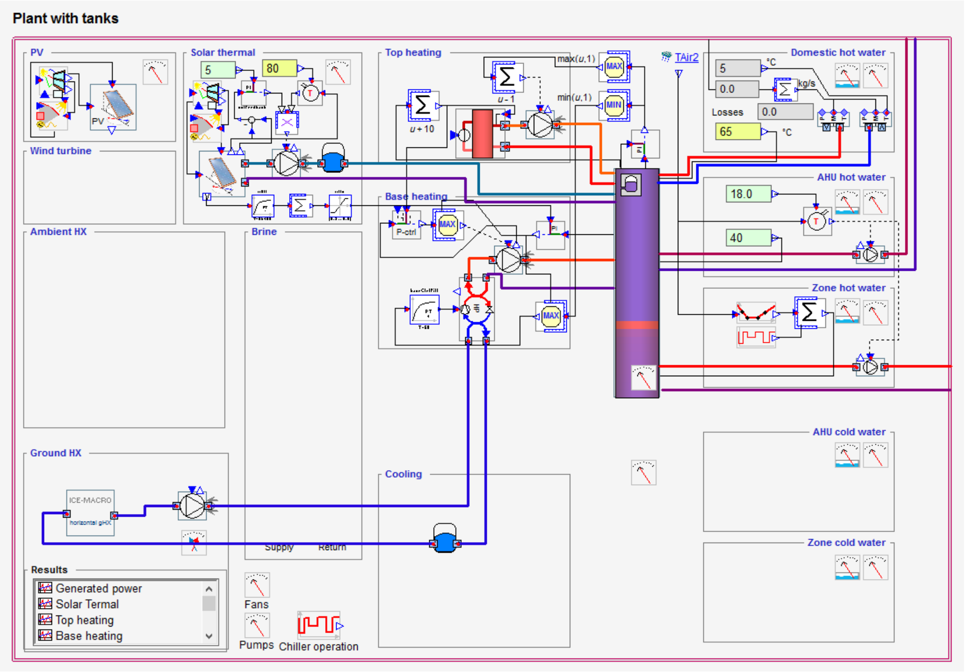

***Figure 3** – Simplified sketch of the energy system of the Living Lab in IDA ICE*

Control strategies for the heat pump system

- Evaluation of the heating system based on *energy efficiency* as well as *energy flexibility in view of the electrical grid* and based on *heat pump cycle length*

- **Rule-based control strategies:**
  - Setting different pre-defined conditions for indoor thermal comfort (indoor temperature variation, CO_2 level)
  - Use of schedules

- **Model-predictive control:**
  - = A dynamic model that tries to find a control strategy over a sliding planning horizon so that a chosen performance criterion is minimized
  - Combines a prediction and a control strategy to automate a target system
  - Can consider fluctuations of energy prices or load profiles of renewable energy sources
  - Storage devices can be operated in a cost-efficient way and therefore increase energy savings (Arnold and Andersson (2011))

Prospects and expected outcomes

- **Prospects:**
  - Validation and calibration of the IDA ICE model
  - Setting up an MPC in IDA ICE
    → Coupling MATLAB with IDA ICE is possible, but difficult right now → most problably new developments from EQUA next year
  - Evaluating the performance of different control strategies

- **Expected outcomes:**
  - *More accurate prediction of heating needs* of highly-insulated buildings during the design phase of the energy systems
  - *Improved energy efficiency* of the energy system of a building
  - Determination of the potential services that the building can offer to the grid (*building grid impact*)
  - Implementation of a model-predictive control is expected to lead to *energy savings*
  - New insights on *favorable design choices* of heat pump systems and their control
  - *Improved knowledge base* and understanding of the influences of the control of the heat pump

Thanks for your attention! ☺

References

- LeDréau, J. (2016). Energy flexibility of residential buildings using short term heat storage in the thermal mass. *Energy*, 991-1002.

- Arnold, M., Andersson, G. (2011). Model Predictive Control of Energy Storage including Uncertain Forecasts. *Power System Computation Conference* 2011 Stockholm, Sweden

- Afram, A. (2014). Theory and applications of HVAC control systems - A review of model predictive control (MPC). *Building and Environment*, 343-355.

- Picture on first page:
  http://www.zeb.no/index.php/pilot-projects/13-laboratories/158-living-lab-trondheim