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Educated commissioning and operation of a complex nearly zero energy office building with the help of dynamic thermal HVAC-simulations - a best practice report from the Austrian postal service headquarter Post am Rochus

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Abstract. This paper presents lessons learned from practice focusing on planning, commissioning and first year of operation of the Austrian Post AGs' new headquarter "Post am Rochus", a nearly zero energy building with 49.300 m^2 gross floor area. The execution phase was supported by a research project aiming for a significant reduction of the commissioning phase. Based on the positive experience of this Austrian lighthouse project, general conclusions are drawn focusing on which activities and recommendations can be applied to similar projects, and which parts need further improvement or adaption. The question of how and when building energy performance simulations of complex HVAC-systems can be used to increase the energy efficiency, room comfort and operational stability of modern office buildings is investigated from a practical perspective. The challenge, and an outlook of how to reduce the information gap between the various disciplines involved in a complex multi-stakeholder process and the conclusions from the building owner are discussed and summarized in the conclusions.

1. Motivation and Objectives

Current changes in weather and climate again fuel the discussion on future building standards like net or nearly zero energy (nZEB/NZEB). On the one hand harsher weather conditions lead to an increased climate awareness, and in return to political/regulatory targets regarding energy efficiency. On the other hand the changes also affect the capabilities and expectations of modern office buildings when it comes to (thermal) comfort. In order to master these challenges with technical means, the processes of planning, construction, commissioning and operation play an enabling role and thus require a high quality themselves. In reality, buildings often operate in sub-optimal conditions due to various technical and non-technical barriers resulting in inefficiencies and discomfort, in other words "dissatisfaction" for domestic buildings and "loss of productivity" (mainly) for commercial buildings. One reason is the common practice to design and size the system for peak-load operation (which is often legally required to be granted permission to build), even though this scenario might never occur during the whole building lifecycle. In order to fully exploit the high efficiencies of the different components (compression chillers, inverter driven heat pumps, free cooling loops, etc.) it is necessary to thoroughly analyse, design and document all relevant operational modes (part-load behaviour, transition period behaviour, etc.). Another barrier to overcome is the often insufficient commissioning phase, which should primarily guarantee/check the physical presence and correct operation of all sensors and actuators but also test the correct implementation of the various control strategies within the building automation system. The aim of this publication is to report from the Austrian project PEAR providing

recommendations and improvements for future similarly ambitious building construction projects with a specific focus on extending the usage of simulation models/ results especially during the first years of a buildings' life cycle. The evaluation of monitoring data as well as the innovative "controller in the loop" methodology are not part of this report. A summary of the complete activities can be found at the Austrian research and development agencies' website[1]

2. Building and process description

2.1. The "Post am Rochus" building

The aim of the owner was to obtain a modern comfortable building with very high standards regarding sustainability and energy efficiency not only in the operational phase but also during the execution phase

Figure 1. Rendering of the Post am Rochus building (source: Post AG).

and commissioning. Therefore, the opportunity to frame the building construction project with a research project was highly appreciated and also supported. The goal was to shorten the commissioning phase by a very detailed study and optimization of control strategies of the HVAC systems along with the involved planning, construction and operational project team of the "Post am Rochus" project (PEAR). The results should not only be documented in a clear manner, moreover the developed strategies should be tested with the real hardware well in advance and thus avoiding/reducing time-and cost intensive bug-fixing. The contractor was actively involved in the research project as well, mainly contributing to the control strategy implementation. The following chapter briefly describes the control strategy development process.

Regarding the energy and HVAC system, notable highlights of this project are:

- three highly efficient compression chillers with 1 MW capacity each,
- the option for heat recovery during cooling season (reheat-coil during dehumidification),
- the utilization of a 320m^3 sprinkler water basin as cold temperature storage for free-cooling (via recoolers)
- concrete core activation for cooling, and
- major air handling units are equipped with latent and sensible recovery (enthalpy rotor with bypass).

The heating energy for concrete core activation and fan coils is supplied by the local district heating grid. Service hot water is prepared decentralised by electric heaters.

2.2. The planning process during the execution phase

The ambitious aim was to drastically shorten the commissioning phase. In order to achieve this, all relevant parties (HVAC planner, measurement and control engineers, owner and operator) were involved from the very beginning, which in this case was almost two years prior to commissioning. This should ensure that the commissioning happens in an "educated" manner, with a very high degree of system understanding, minimal "confusion" and a well-documented description of functionalities, operational phases and control rules/set points as well as specific performance targets. In order to have a quantifiable basis, building performance energy simulations (BEPS) have been used in a broad manner extending their application to the domains of control engineering and building automation.

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[1] https://nachhaltigwirtschaften.at/en/sdz/projects/pear-test-facility-for-energy-efficient-automation-and-control-of-buildings.php

2.3. System integration and control strategy development

Within the project nine different operational modes have been identified, see **Figure 2**. Cost-optimized control strategies have been defined for each mode by using parameter variations of i.e. set points, hysteresis, time schedules, cross-dependency curves (i.e. power cascades), etc. The aim was to describe all modes in a way that the control engineers and the operators/facility managers obtain a practical guidance for programming, operation and bug-fixing. Furthermore, it should ensure that all involved parties refer to the same data basis, i.e. a "functional manual" including controller set points, times schedules etc.

Once the control engineers finalized the control strategies, certain parts of their implementation in the building automation software have been tested using the "controller-in-the-loop" approach. This allows to test the control strategies on the actual controller hardware to be implemented in the building. Functionality-checks were performed for all operational modes prior to their implementation in the building and thus independently of the actual weather during commissioning, which is an important benefit, as cooling systems can hardly be fully tested in heating season. This approach reduces commissioning time, since bugs could be found before the soft- and hardware was finally implemented in the "Post am Rochus" building, further details see e.g. [1]
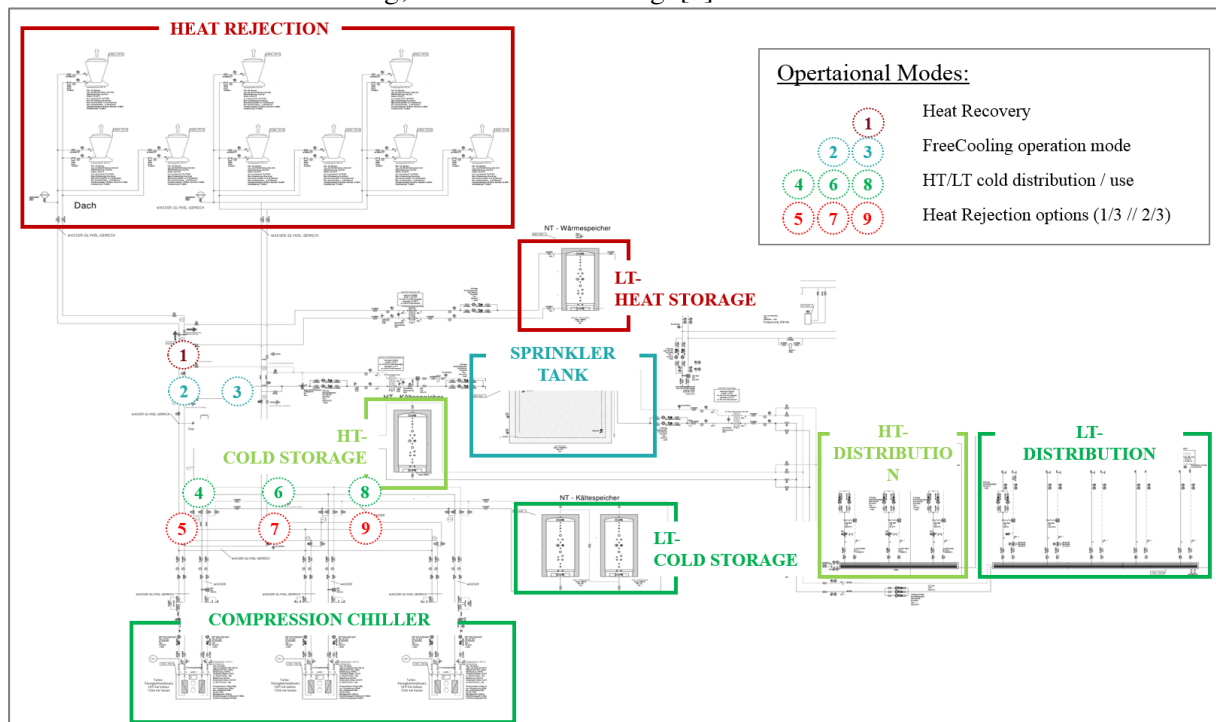

Figure 2. Overview of the major thermal system components and operational modes.

3. Simulations

For BEPS the software TRNSYS 17.02 has been chosen, as it was used by all involved simulation parties and thus the most straightforward choice. Due to the high complexity of the simulation tasks and for unhindered workflows in the different offices the overall HVAC model has been split into three independently functioning decoupled sub-models (the following investigations are based on the second part model):

    1. Multizone building model
    Optimization of the envelope, control strategy development of concrete core activation, calculation of heating and cooling loads (input for thermal system)
    2. Thermal (cooling) system
    Control strategy development and optimization of all operational modes (see **Figure 2**)

3. *Ventilation system*
Control strategy development and optimization for various operational modes of the air handling units

The results of the sub-models have been validated individually and have been taken as input for the thermal model. This model used the load curves for high temperature cooling (concrete core activation) and low temperature cooling (fan- and cooling coils) that have been calculated in the building and ventilation model as an input. The load curves of the supermarket and server rooms have been estimated according to standards (SIA2024[2]).

3.1. Component model validation
As a first step within the model generation process the tendered main components have been modelled and validated against manufacturers' data sheets. An example of the chiller[3] and the recooler[4] is shown in **Figure 3**. The four standard storage tanks (3m^3 capacity each) have been implemented with multi-layer stratified storage models (TRNSYS Type 4b). The two sprinkler basins with a volume of 170m^3 each (dimensions: 6 x 6 x 5 m) have been modelled with the TRNSYS Type 531[5].
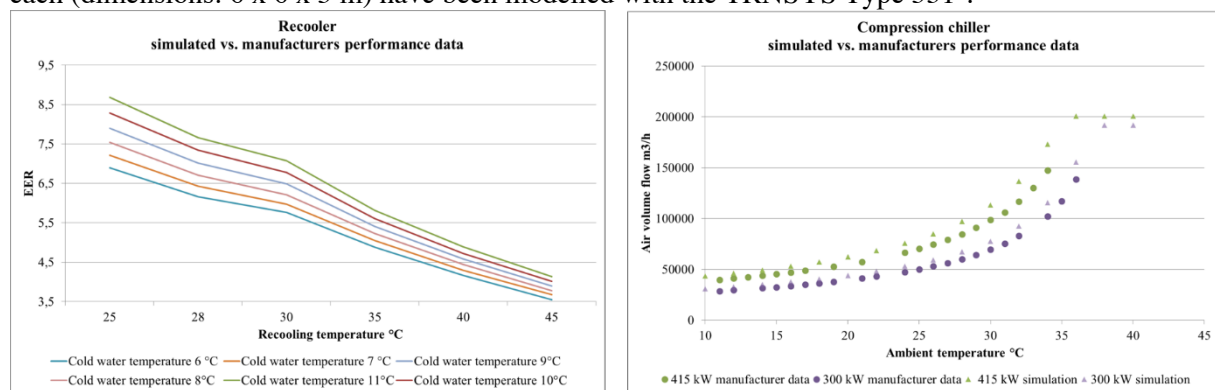

Figure 3. Simulated performance vs. manufacturers' data of the recooler (left) and the compression chiller (right).

The simulations have been used for two purposes: on the one hand to analyse typical/potential failures that the facility management reported from similar components/systems with the specific system, on the other hand for further optimization of the control strategies.

3.2. Subsystem models
The individually validated component models have been connected to subsystem-models with the purpose to optimize the layout (hydraulic connections and temperature levels of each individual component) of the overall HVAC model. Therefore parameter variations regarding temperature levels of the high and low temperature loop, cooling curves for fan coils, server rooms and concrete core activation as well as operating/charging conditions for storages, recoolers and all three compression chillers have been conducted in order to find the cost-optimal configuration. To quantify the influence of major assumptions like the cooling demand for the server rooms sensitivity analysis have been carried out.

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[2] http://shop.sia.ch/normenwerk/architekt/sia%202024/d/2015/D/Product
[3] Cofely Quantum X135-E3E-LH modeled with TRNSYS Type 666.
[4] Güntner GFD 090.1D/2x6-EJ1C/4P.E modeled with TRNSYS Type 511.
[5] Rectangular tank with immersed heat exchanger.

4. Conclusions and recommendations

4.1. The commissioning phase

One of the main goals was to drastically shorten the commissioning phase, however due to delays in the construction process the trial-operation could not take place as planned, as the building has been occupied rapidly. Based on the experiences of the project, a successful commissioning phase is supported by the following factors:

- Functional quality management on component level
- Correct functionality of the whole hydraulic system including extensive hydraulic balancing
- Provision of a clear documentation for the commissioning phase of all major components (building automation, energy efficiency/performance targets, set points, etc.)
- Definition of suitable overall control strategies and operational modes for the whole system.

In order to guarantee an efficient operation of the system it is further recommended to install a quality management scheme for the trial operation phase. Therefore, major operational modes and procedural steps to be tested must be clearly defined together with the control engineers.

4.2. Owners' perspective

The Austrian Post AG was actively involved in the research project contributing as well as demanding based on her experience within various professional units like the internal technical facility management and the group real estates. The overall feedback was very positive as costly problems/failures could be identified and avoided in an early stage. Maintaining an interdisciplinary approach throughout the construction and commissioning phase and actively integrating the research results into practice were major pillars to obtain efficient building operation. The owner's quality management needs to involve as well as demand and promote the technical facility management. The integral process and the results from simulations, discussions and agreed-upon targets are extremely helpful and a basis for that. The periodic workshops with various experts and professionals build the communication basis for the whole process. These workshops definitely need to be continued in a higher frequency during the first weeks of operation, as the overall system knowledge that has been built up during the previous years should be exploited to the fullest extent possible. Doing so potential faults can be identified rapidly and improvements or necessary adjustments can be discussed immediately in an "educated" manner. Even though it's often a time critical process (which is frequently skipped or delayed in reality), enough time should be reserved for the acceptance, handover and trial operation of the whole building technology and automation system (including all sensors, actuators and data handling/visualization). Those processes need to be conducted and documented in a well-structured and coordinated manner. Therefore, special attention must be put on the legal/contractual side already in the early planning stage, as the majority of all the efforts during planning and construction culminate in this crucial point.

4.3. Research and general

The project has proven to be very successful, still there is a long way to go when it comes to establishing integral planning practices and "educated commissioning" procedures in highly complex nZEB. The extension of the usage of dynamic-thermal simulations into the building automation and control domain should become common practice, as it really plays an enabling role for the successful realisation of high quality and comfortable nZEB. One barrier is the lack of information in the early planning phases during execution as some components will be fixed on quite short notice. This results in a high number of assumptions that all might affect the quality and reliability of the obtained results. The time needed to set up such complex models[6] including bug-fixing, plausibility check and adequate visualization of the results might be problematic, as decisions are often time-critical and of course time means costs which is always a problem in building construction processes.

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[6] Estimation: 2 man month to set up the system model, 2 weeks implementation of the control strategies in MATLAB, 2 weeks for plausibility checking, 1 week to set up the visualization routines in python (might be not necessary in other software environments).

The decoupling of building and system model (even in the same software) by choice has proven to be a good approach for the specific research questions. The system could be dealt with independently as the loads were always matched and in return (thermal) comfort guaranteed. For scenarios where the building mass should be included in the optimization, i.e. in order to reduce storage capacity, a coupling of building and system is inevitable.

As it turned out, hydraulic problems that occurred during the handover and commissioning phase were in fact the reason for the suboptimal operation of free-cooling and on/off cycling of the chiller. In the specific case the mechanical flaps could not open the circuit for free-cooling, as the pressure in the pipe was so high due to the level difference between roof (recoolers) and basement (chillers). For certain key components it might be beneficial to conduct some kind of hydrodynamic evaluation, either by very experienced experts or preferably on the long run by data driven methods i.e. dynamic simulations of the hydraulic network (including geometrical information like pipe length and differences in elevation) to accurately determine and influence flow patterns especially in transitional periods. Therefore, the digitalisation of all relevant data is a prerequisite which, with the rapid development of the building information modelling (BIM) industry, hopefully will take some advances in the coming years. This would also overcome/reduce the problem of data loss that typically happens at all interfaces like e.g.:

- planning ←→ construction ←→ operation

but also between the different disciplines for example

- HVAC planner ←→ control engineer or
- building automation ←→ facility management.

From a legal perspective it must be clearly regulated how to deal with the simulation results in the context of the construction project, i.e. are they merely additional information or in fact changes to the functional technical description. Another legal issue is the operators' contract. Often it contains "energy saving targets" which are mostly measured in relative savings compared to previous period over the first 3-5 years of operation. This is obviously not the best solution! The usage of the design values as target might not always be feasible as assumptions might change during the planning and construction phase, i.e. lower internal gains due to new technologies like LED. This calls in return for a recalibration of the design models with as-built values that should be validated by monitoring data. This would provide a dynamic up-to-date baseline over the whole building lifecycle. Moreover it can be used for automatic fault- and inefficiency-detection and thus further improve the buildings' quality and ensure to meet the energy and comfort targets that the owner paid for in the first place.

Acknowledgments

References

[1]   F. Judex, S. Hauer, und K. Eder, „"Post am Rochus" as case study for accelerated testing of building automation systems", in *Zukunft der Gebäude, digital-dezentral-ökologisch*, Pinkafeld, 2017, S. 47–52.