Implementation of a passive cooling strategy in an existing building using a simulation-based predictive control approach – a case study

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Abstract:

This paper presents an effort to implement a novel predictive control approach toward the utilization of passive cooling in an existing office building in Vienna, Austria. Three almost identical office rooms in this building were selected for the implementation. Two offices were used for simulation-based predictive control of window and blind operation, whereas the third office was used as a reference. In two years of testing a genetic algorithm was developed to generate control options (alternative positions of windows, shades, etc.). Numeric simulation is used to simulate and benchmark the best performing scenario. The paper describes the approach in detail and presents the results so far.

Keywords: passive cooling, simulation-based predictive control, thermal comfort

1 Introduction

In the past, low energy prices, low costs for (active) cooling devices, as well as increasing user demands led to the spread of energy-intensive mechanical systems for space cooling technologies particularly in areas with moderate climate. However, recent ecological and economical challenges such as climate change (IPCC 2007), urban heat island effect, and high energy prices have brought about, amongst other things, a renewed interest in energy-efficient alternatives for building controls. The intelligent use of passive methods combined with innovative materials as well as advanced sensory and actuating components and building controls have the potential to significantly decrease the energy consumption for space cooling (Lomas 2006). In new build structures instances of this approach have been implemented in the last years in different climate zones and continents (Garça et al. 2003; Krausse et al. 2007; Salmeron et al. 2009). For existing buildings the principle possibility to integrate natural ventilation in building controls was presented in previous publications (Mahdavi & Pröglhöf 2004, 2005, and 2006; Mahdavi 2008). The research presented in this paper focuses on the implementation of a passive cooling strategy in an existing, heritage-protected office building by using a simulation-based, predictive control approach (Mahdavi et al. 2009). The following measures were considered: i) natural (mostly night-time) ventilation using windows equipped with software-controlled actuators, ii) solar control via shading devices equipped with actuators, iii) thermal mass, iv) phase change materials (PCMs), and v) ceiling fans. The approach was implemented and tested in summer of 2009 and 2010.

2 Method

For the described approach an existing old university building in Wieden/Vienna was chosen. The building with its brick walls and wooden ceilings is typical for Vienna and its heritage protected structures. Three real, occupied and almost identical, south oriented office spaces (referred to as R1, R2, and R3) were specifically targeted for our study (Figure 1). One office (R1) was kept as is and used as a reference. This room was equipped with manually operated internal venetian blinds. The users could open the windows manually. The other two offices were equipped with window actuators, as well as internal (R2) and external (R3) window shades. Additionally, PCM elements as well as a ceiling fan were installed in R3. All rooms were equipped with sensors for measuring indoor parameters such as air, surface, and globe temperature, relative humidity, occupancy, illuminance at the ceiling and at the workplace, air velocity, and carbon dioxide in all three rooms. In addition, outdoor environmental data was collected at the façade in front of the offices (air temperature, relative humidity, wind speed, and precipitation) and on the rooftop (global horizontal radiation, and diffuse horizontal radiation). Shade position and door/window status were also monitored (Figure 2-4).

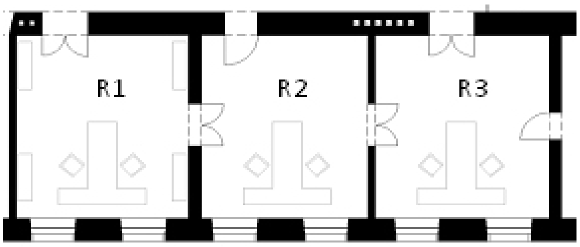

Figure 1: Floor plan of the three offices

Figure 2: Windows and shades of R3

Figure 3: Ceiling fan and suspended ceiling with PCM in R3

Figure 4: Workplaces in R2 with motorized window, internal venetian blinds and sensors for air, surface, and globe temperature, relative humidity, occupancy, illuminance, wind velocity and carbon dioxide

2.1 Predictive simulation-based control approach

R2 and R3 were run by a novel, predictive building control system (Mahdavi et al. 2009). This control approach uses the actual sensor values together with web-based weather forecast data (Weather.com 2010) for parametric simulations in the thermal and lighting domains. The objective is to arrive at an optimum control decision based on a set of performance functions and indicators. The first implementation of the predictive control started in 2009. The results of this season were promising, in the sense that the feasibility of the approach was clearly demonstrated. Given reliable simulation models (with calibrated input assumptions and boundary conditions) the approach reliably identifies preferable control options. The temperature differences between day and night were typically high enough to cool down the rooms overnight (Pröglhöf et al. 2010).

The approach was reinitiated and improved. In summer 2010 the simulation engine HAMBase (van Schijndel 2007) was used, integrated in a MatLab-routine. A genetic algorithm is used to generate best performing control scenarios based on simulation results. These scenarios are evolved every hour. The method uses extreme (e.g. all windows open; shades fully deployed) and randomly chosen initial settings for all actuators, as the starting point toward computing internal conditions for the next 24 hours. The genetic algorithm uses the results to optimize the scenarios (Schuss et al. 2010). The control method generates and evaluates alternative operation possibilities based on genetic algorithm and the multi-domain simulation results. Figure 5 illustrates the principle of this approach. This control procedure is executed on a regular basis (typically once every hour). The approach is described in detail in Schuss et al. 2011.

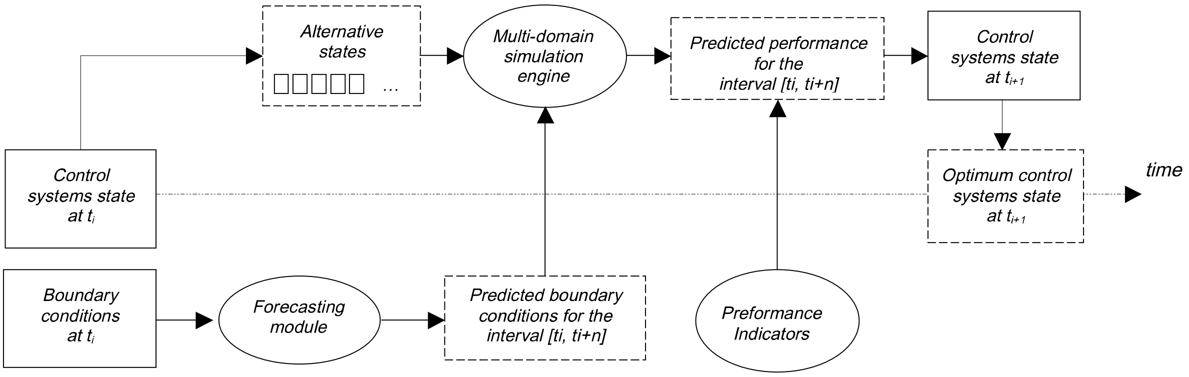

Figure 5: Illustration of the multi-domain simulation-assisted control method (Mahdavi et al. 2009)

Every user could overrule the control system using a graphical user interface (GUI) and directly control windows, shades, and the ceiling fan (Figure 6). The user interface was implemented in the programming language PHP to reach platform independence. The communication to the room controller was realized via Ethernet/IP.

Parallel to system operation, users in the offices were interviewed to obtain their evaluations of the indoor conditions and the operation of the systems.

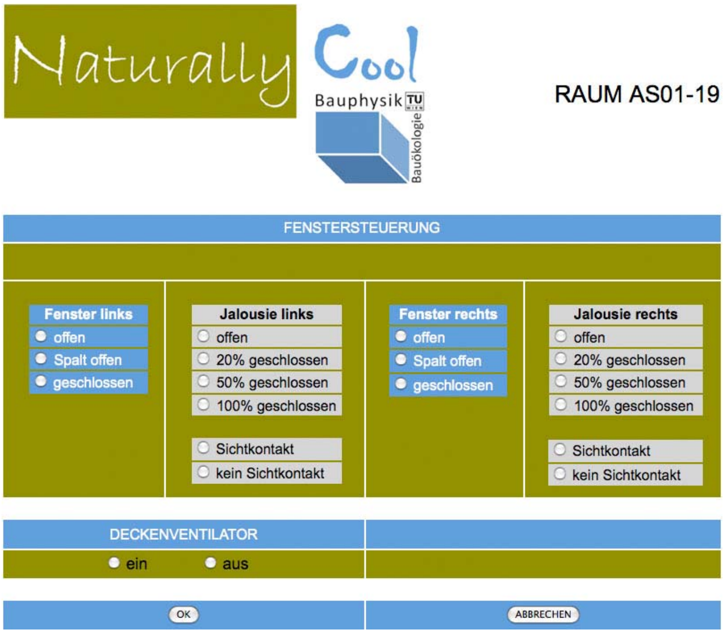

Figure 6: Graphical user interface for R3

3 Results and Discussion

To qualify the performance in terms of thermal comfort PMV was calculated for July and August (only working hours - 08:00-17:00). Figure 7 and 8 depict the PMVs as boxplot for R1, R2, and R3 for July, and August 2010. In both month R2 and R3 show better values for PMVs than R1. In August the difference between R1 and R3 is about 0.5 points. These results suggest the control system's cooling potential via utilization of night ventilation.

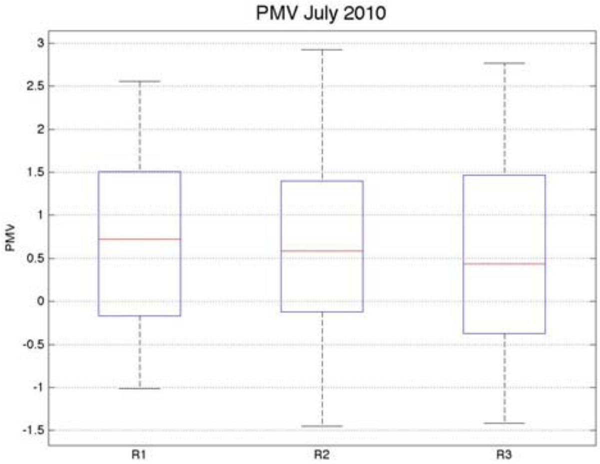

Figure 7: PMV values for working hours in July 2010

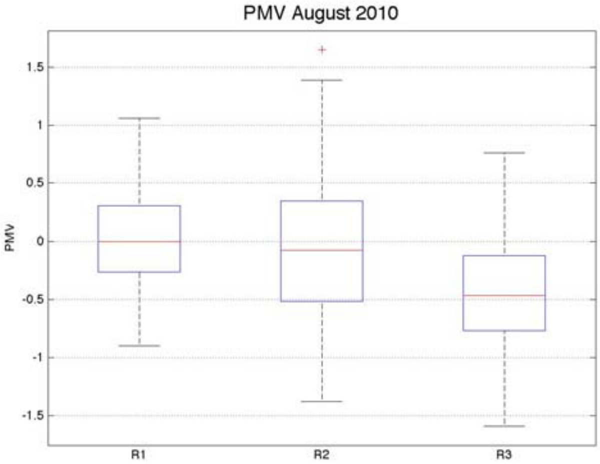

Figure 8: PMV values for working hours in August 2010

In addition to the PMV, the collected data was plotted in psychometric charts (Figure 9-14). This was done per room for July and August 2010 separately. The (red) dots represent mean hourly values (only working hours - 08:00-17:00). The (green) polygons show the applicable thermal comfort zone according to the adaptive thermal comfort theory (Schuss et al. 2011).

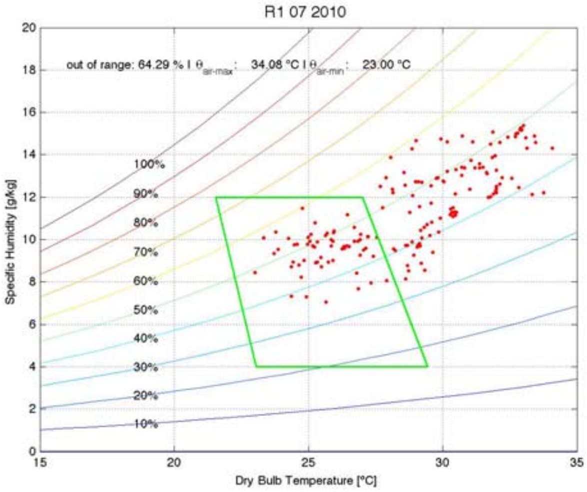

Figure 9: Measured temperature and humidity in R1 during working hours with comfort zone in July 2010

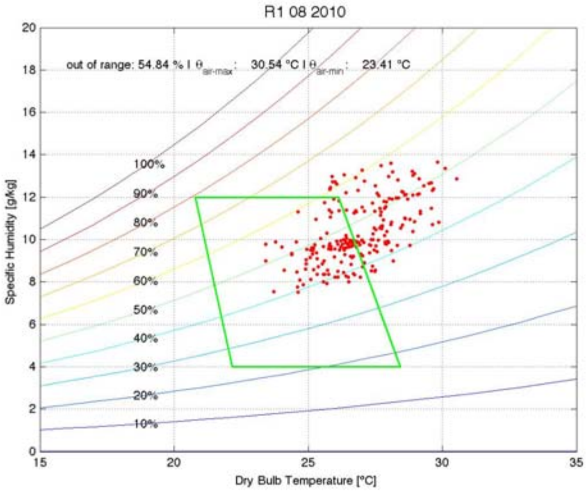

Figure 10: Measured temperature and humidity in R1 during working hours with comfort zone in August 2010

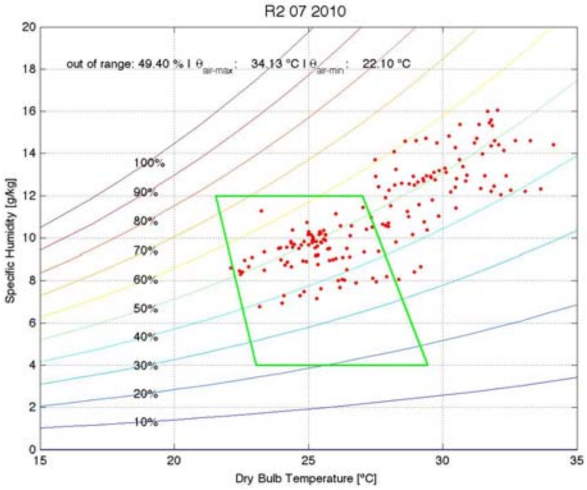

Figure 11: Measured temperature and humidity in R2 during working hours with comfort zone in July 2010

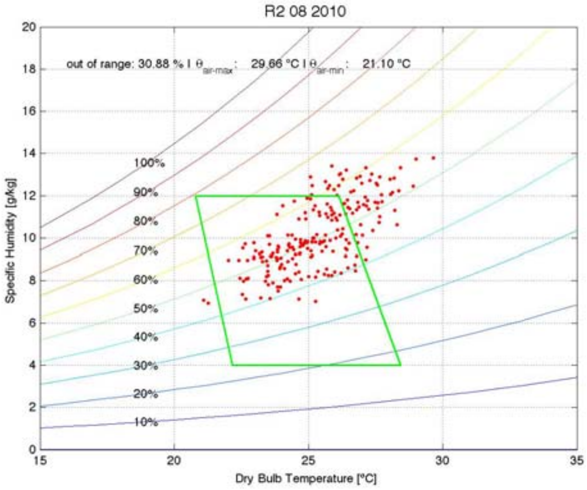

Figure 12: Measured temperature and humidity in R2 during working hours with comfort zone in August 2010

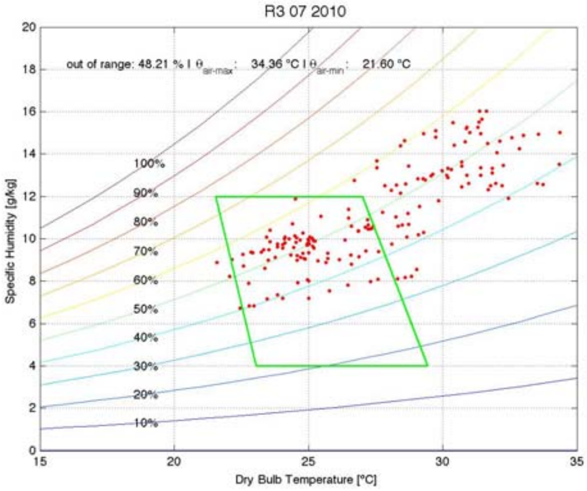

Figure 13: Measured temperature and humidity in R3 during working hours with comfort zone in July 2010

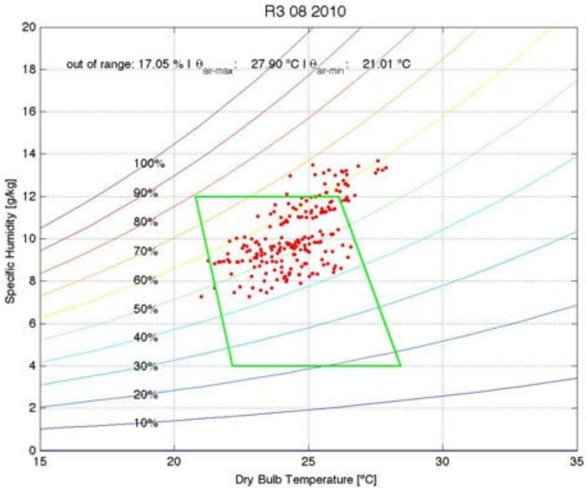

Figure 14: Measured temperature and humidity in R3 during working hours with comfort zone in August 2010

The results display similar trends compared to R1, R2 was ca. 15% less outside the thermal comfort zone in July and 24% less outside in August. R3 as the best equipped room was about 16% less outside the thermal comfort zone in July and 38% less in August.

Users in R2 and R3 stated that the air temperature in the offices was better in times with predictive control systems operation. Nighttime ventilation as well as the additional shading devices and the possibility to control the devices with the GUI was explicitly rated positive. The noise of the motorized windows and shades, while opening or closing, was found negative. Moreover, users criticized insufficient glare control (The automated control was based on the weather forecast only.).

4 Conclusion

The research results illustrate the potential of the proposed approach via the comparison of the differentially equipped offices. The day-night temperature differences appear to suffice the cooling requirement of the offices. The rooms with predictive control performed far better (in view of thermal comfort) than the reference room (see Figure 9 to 14).

Although the results are promising, there is of course potential for improvements:

- The minimization of internal loads: The installed power of the electric devices (computers, artificial lights, etc.) should be minimized. Devices should be switched off (or hibernate) when not in use.
- The importance of informing the users: Users should be instructed regarding the proper operation of building systems. Moreover, the users should be given proper feedback about their actions and behavior.
- The accuracy of input parameters for the predictions: The quality of the weather forecast is critical. Especially the prediction of solar radiation needs improvement.

Nonetheless, the results and the experiences with the implementation show that the proposed approach can be generally realized in existing structures with a reasonable degree of investment (effort, resources). The ultimate success of this novel approach to passive environmental controls depends on a well-orchestrated interaction of all influencing factors (building components, devices, climate, and the users).

5 Acknowledgement

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