Diagnosis of Window Opening Periods in a Large Building

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ABSTRACT

We describe the problem of detecting window opening periods from temperature measurements in a public administration building situated in North-Rhine Westphalia, Germany. A description of the building with special focus on the heating system and the available data is provided. The problem can be classified as a single time varying real world on-line fault diagnosis problem with external disturbances.

1 INTRODUCTION

We provide a real-world example with measured noisy and sometimes corrupted data. The goal is to detect whether windows in some reference rooms of a five-story building are open or closed to improve the performance of the heating system. For this example, an open window can be considered as a fault.

Temperature measurements in some reference rooms are used to control the supply temperature of the heating system. Without fault detection, the temperature in all rooms will increase whenever the window in one of the reference rooms is opened during a heating phase in the winter time. This is because the controller assumes an undersupply of the heating, which does not happen in reality. Currently, there is no diagnosis system and thus, the indoor temperatures often lies outside the comfort interval, which frequently leads to costumer-induced openings of other windows.

The situation reverses in summer, when the same system is used for cooling. Of special interest are periods in spring and autumn where the decision whether the system is operating in cooling or heating mode may depend on a correct fault detection. This motivates to look for the best solution to diagnose the status of the windows.

To show that fault detection methods which use real on-line data lead to a better overall performance than predictions by models of user behaviour as given in (F.Haldi, 2010) or (Herkel *et al.*, 2008) is one of the challenges. Application of AI methods for predictive control of buildings is a field of current research, see (Mady *et al.*, 2011), and (Privara *et al.*, 2011). An overview of fault diagnosis for the application domain of building systems can be found in (Katipamula and Brambley, 2005).

Relevant running projects in this field are: Stochastic Control Optimization of Mixed-Mode Buildings for U.S. Climates (ASHRAE Research project number 1597-RP), ITOBO - Information and Communication Technology for Sustainable and Optimised Building Operation (University College Cork, Ireland), ModQS - Qualitätssicherung des energetischen Gebäudebetriebs (German Federal Ministry of Economics and Technology).

2 BUILDING DESCRIPTION

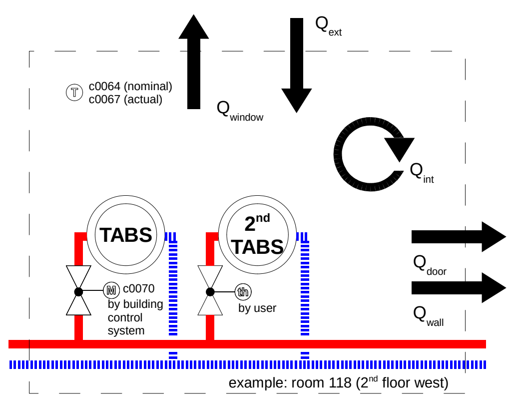

Figure 1: Schematic Diagram of a Reference Room

2.1 Structure

The building under investigation was built in the years 2003 to 2005 and is mainly used as an office. The face of the five-story building consists of glass and aluminium. The ground level is mainly covered by glass whereas in the second to the fifth floor aluminium is also employed. Here the insulated glass windows have the height of the rooms. All non-window areas are highly thermally insulated. For airing it is possible to open some clacks - where different opening degrees can be chosen. To prevent direct solarization perforated vertical window blinds are installed.

2.2 Heating System

Heating and cooling of the building is performed by a thermo-active building system (TABS), the concrete core of the ceiling is used for heating or cooling. The system is similar to a floor heating system, but since the thickness of the active mass is larger than in floors, the latency is larger as well. Individual temperature control can be performed by manually adapting the thermostatic valve position of the secondary TABS circuit in each room (see Figure 1).

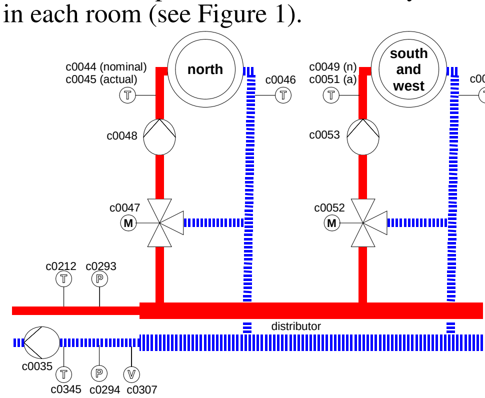

Figure 2: Scheme of the TABS System

The entire TABS system consists of two circuits shown in Figure 2 with individual setpoint temperatures chosen as a function of the ambient temperature. Each floor has three heating zones (north, west, south), which can be opened and closed individually. Note that the secondary circuits is not controlled automatically but manually by the user. A legend for the symbols used in Figures 1 and 2 can be found in Figure 3.

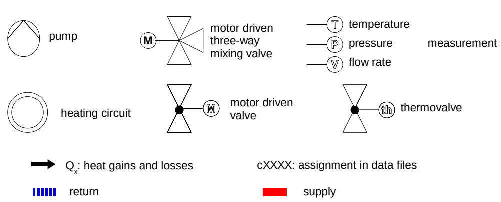

Figure 3: Symbols in Heating Systems

2.3 Available Data

Table 1: Measured Signals

Measurement	Comment
Supply temperature	For both circuits
Return temperature	For both circuits
Valve position	Not for the secondary circuits
Pressure	On distributor and collector
Flow rate	On distributor
Room temperature	For 16 reference rooms
Ambient temperature	-

The measurement signals presented in Table 1 are available for that building over a period of one year and sampling interval of one minute at *http://modqs.de/dx2011*.

3 PROBLEM DESCRIPTION

3.1 Diagnostic Task

The diagnostic task is to detect at every sample time in less than one minute calculation time which windows are currently open with the help of the (past) measurements given in Table 1.

3.2 Further Noise Sources and Disturbances

The following disturbances and uncertainties have impact on the real measured data:

- Internal heat sources as computers or humans,
- Utilization of the window blinds and doors,
- Valve settings of secondary TABS circuit,
- Solar radiation on temperature sensors,
- Different degrees of window openings,
- Irregular sampling times of up to five minutes.

4 EXAMPLES

In this section some examples of one and seven day measurements are provided.

- Figure 4: A simple example with temperatures taken from reference rooms on the west side of the building in the 2nd to 5th floor. The temperatures are constant during the night and rise in the morning due to solar radiation or internal heat sources. In the following night the temperatures drop back to the level of the night before. One can see from the measurements, that the window in the 4th floor is opened at 7am, which leads to a drop in the temperature of about 3K. A short time later the window is closed again, such that the temperature rises back.
- Figure 5: In this example, data for the south side of the building are shown for a period of one week. On Monday 01/10/2011, windows of all reference rooms - except the 4th floor - were opened in the morning by the users as soon as they start to work. In the 3rd and the 5th floor the windows were closed when the temperature dropped to approximately 21^{o}C. The window of the 2nd floor remained open. When the window is open for a longer period, the correlation of ambient and room temperature can be seen.

  On Tuesday morning, the windows in 3rd and 5th floor were opened. The 2nd floor window was closed due to the cold room temperature, opened again when the temperature raised to 27^{o}C, and left open. This is a repeated behaviour also from Wednesday to Friday. On Saturday 15th and Sunday 16th of January 2011, there are no users in the building and temperature profiles of each room are very similar. The peak on Sunday afternoon is likely to be caused by solar radiation.

- Figure 6: Here the measurements of a day in January are shown to illustrate the influence of solar radiation. On the north side of the building the room temperatures are nearly constant whereas on the south side the room temperature increases about 4K at noon time and decreases again in the afternoon. In the 4th floor on the west side the window is opened frequently starting at 12pm. The effect of solar radiation on floor temperatures can be seen - especially the delay of the west compared to the south side.

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FIGURES

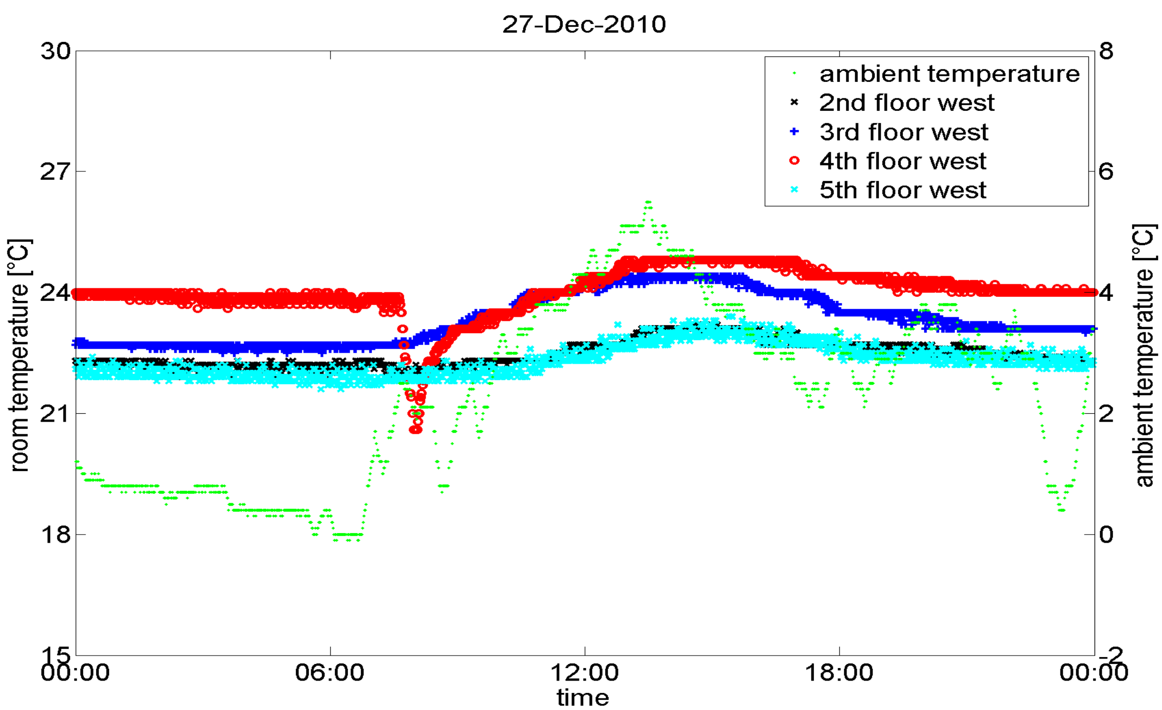

Figure 4: Simple example: 4th floor west, window is opened at 7am

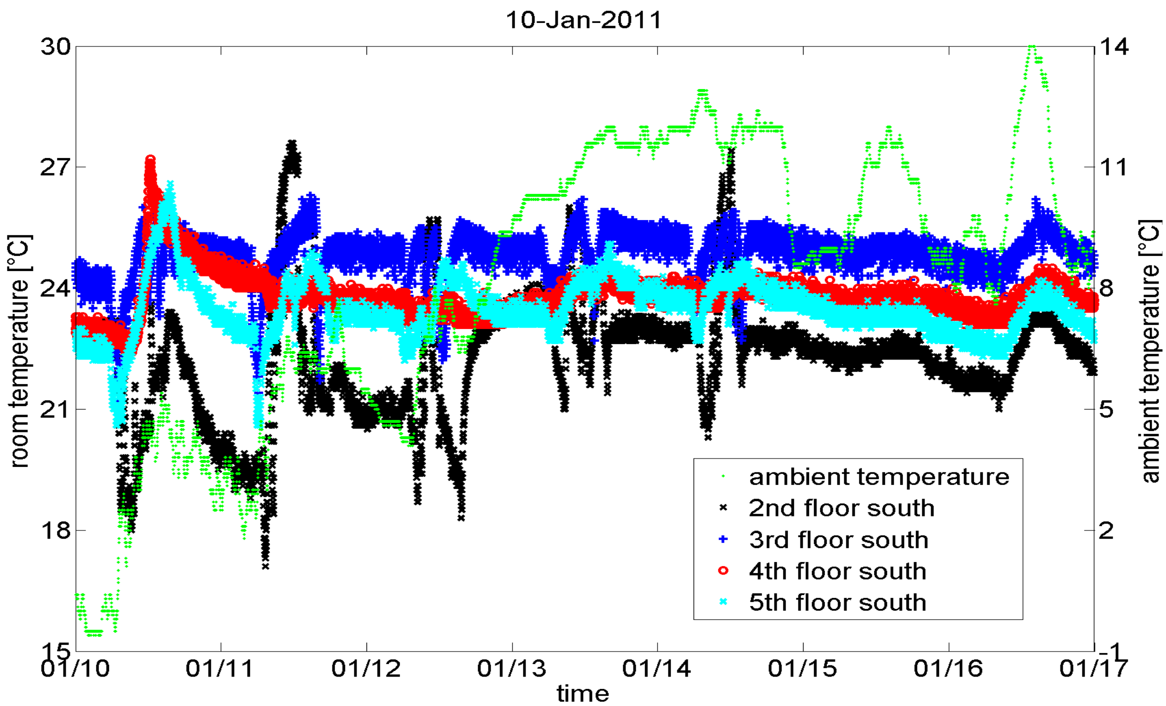

Figure 5: User behaviour: window openings at start of work, no changes on weekends

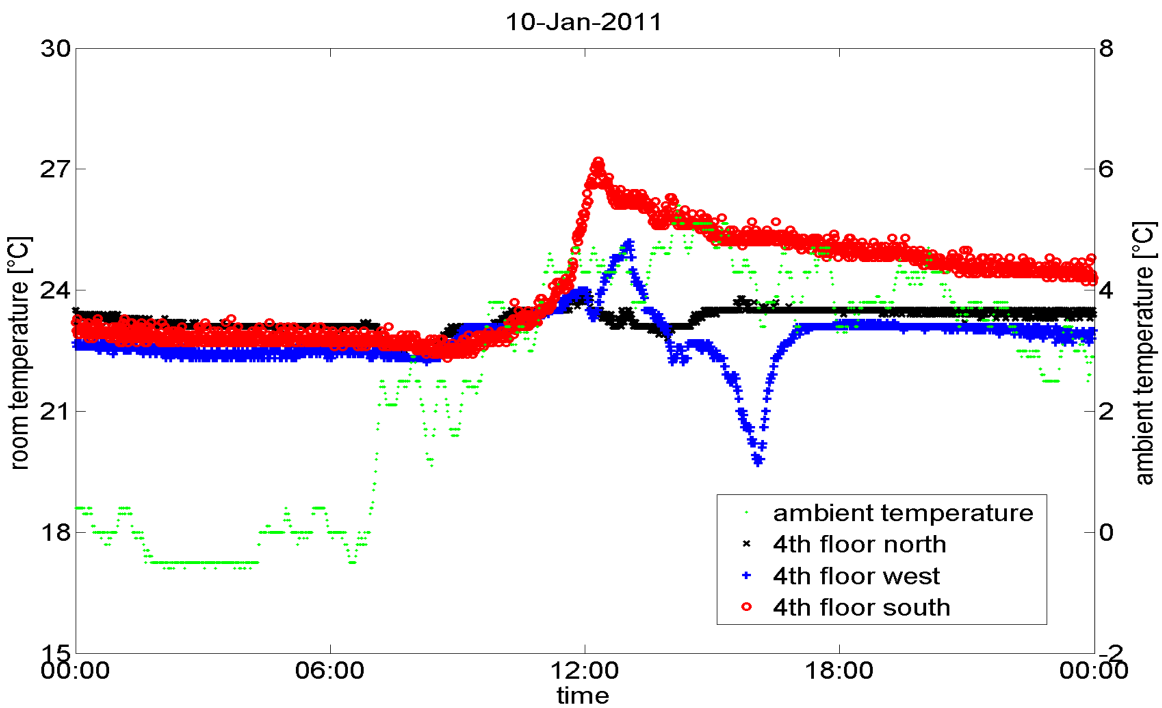

Figure 6: Influence of solar radiation in dependence of the orientation