Quality Control for HVAC Systems in Residential Buildings with IoT-based Fault Detection and Diagnostics

Stella Joos
Daniel Buchmiller
Andreas Gerber
Sebastian Herkel

University of applied sciences
Biberach

Fraunhofer ISE

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Introduction

- Residential buildings have a high potential of energy saving
- Performance gap: Mismatch of designed and measured performance
- Components vs. System
- Complex systems
  - Small faults increase primary energy consumption
- Increase efficient by quality control and optimization, therefore saving energy
- Find cost-efficient, easy, practicable approach by using IoT
- Is it possible to find faults before they increase consumption or decrease comfort?
Actors in an ideal process during the life cycle of buildings

- Owner
- Planner/Engineer
- Technician/Craftsman
- Operator/Maintainer
- Facility Manager
- Operator/Maintainer
- Occupant

- Design
- Build
- Commissioning
- Operation
Actors and faults in a process during the life cycle of residential buildings

<table>
<thead>
<tr>
<th>Owner</th>
<th>Operator/ Maintainer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technician / Craftsman</td>
<td>Operator/ Maintainer</td>
</tr>
<tr>
<td>Design</td>
<td>Build</td>
</tr>
</tbody>
</table>

### Faults

**Design**
- Missing or faulty calculations
- Wrong components
- Wrong design/incompatible components

**Build**
- Faulty assembling
- Wrong positions of components

**Commissioning**
- Wrong parameterization
- Missing hydraulic balancing
- Wrong set points
- Wrong controller settings

**Operation**
- Components
- Missing service
- New terms of use
Quality in HVAC systems in residential buildings

- **Problems**
  - Planning process is not in focus
  - Human caused faults
  - No monitoring

- **Specific features**
  - Systems are simple and similar, means methods should be easily replicable
  - Low-cost solutions required
  - Closed systems
State of the art and science

- Quality of single HVAC components (ErP)
- “Energy labelling of residential ventilation units”
- “Ecodesign requirements for ventilation units”

Checklists for installation and commissioning

<table>
<thead>
<tr>
<th>Beschreibung</th>
<th>OK</th>
<th>Bemerkungen</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Kontrolle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 Allgemeine Installationskontrolle:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Anschlüsse korrekt</td>
<td></td>
<td></td>
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<tr>
<td>• Flussrichtung</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Sekundärseite gefüllt</td>
<td></td>
<td></td>
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<tr>
<td>• Wärmedämmung komplett</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Fühler eingebaut und angeschlossen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Elektroinstallationen Regelung, Pumpe, Sicherungen definitiv angeschlossen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2 Installationskontrolle der Kollektoren, unmittelbar nach deren</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation (vor Abbau Gerüst, vor Schliessen Installationsischächte)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3 Dichtheitskontrolle durchgeführt und protokolliert?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4 Entlüftungs- und Entleerhahnen geschlossen?</td>
<td></td>
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<tr>
<td>1.5 Expansionsgefäss installiert, Vordruck gemäss Anlagehöhe eingestellt?</td>
<td></td>
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<tr>
<td>1.6 Sicherheitsventil auf Kollektorseite nicht absperren</td>
<td></td>
<td></td>
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<tr>
<td>1.7 Abblaseleitung in Auffanggefäss geführt?</td>
<td></td>
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</tr>
<tr>
<td>1.8 Ansprechdruck Sicherheitsventil überprüft?</td>
<td></td>
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<tr>
<td>1.9 Rückschlagventil (Schwerkraftbremse) installiert?</td>
<td></td>
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<tr>
<td>1.10 Füllvorrichtung mit Gefäß (Fass/Kanister) komplett und ausreichend</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dimensioniert?</td>
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</tbody>
</table>
Promising approaches

- Building Information Modelling (BIM)
  → Information can be shared between all actors in all phases of life cycle

- IoT based data generation (Monitoring)
  → All data in a centralized place with same format

- Fault detection and diagnostics (FDD)
  → Faults can be detected and the cause can be found
Use of BIM for operation supervision of HVACs
Design process - boiler and hot water loop
Internet of Things (IoT)

- All physical sensors, devices and actors have a unique identity in the internet
- They can communicate via the same protocols with each other
- Parameters can be changed remotely with smart end devices

- QR-Codes/ RFID
  - Prepare information
  - Digital device informations → Digital system information
Internet of things (IoT)

- Energy supply
- Range vs. data rate: e.g. LoRaWAN® with high range but low data rate
- Different protocols
- Different topologies

Data rate

- WiFi
- Bluetooth
- NFC/RFID
- ZigBee
- 5G
- 4G
- 3G
- 2G
- LPWAN

Range

End Device / Sensor Node
Sensor Node / Routing
Gateway Node
Fault detection and diagnostics

Based on:

- Expert knowledge
- Classified data
- Machine learning
  - Prediction
  - Outlier detection
  - Classification

Fault diagnostics
An example of a system with boiler, hot water tank and buffer storage

- Additional sensors were added
- Faults could be detected
Results of case study

Fault detection rules

(i) If $T_{top} < T_{center}$ → fault or (ii) If $T_{bottom} > T_{center}$ → fault
(iii) If $T_{top} < T_{bottom}$ → fault

$T_{top} < T_{center}$

missing stratification
or faulty sensor
Conclusion and Outlook

Conclusion

- Quality of installation and operation of small supply systems is needed to close the performance gap
- Fault detection methods using Artificial Intelligence algorithms could be applied even in small systems
- IoT is a promising technology to enable economical quality control solutions in residential buildings during all phases (building, commissioning and operation)

Outlook

- Demonstration on HVAC systems in existing residential buildings
- Benchmarking for quality in small residential buildings
- Simulation for validation and further investigations
Thank you for your attention!

Stella Joos, M. Sc.

Hochschule Biberach
Institut für Gebäude- und Energiesysteme (IGE)

Fraunhofer-Institut für Solare Energiesysteme ISE
Stella.joos@ise.fraunhofer.de