

# HVAC monitoring in commercial buildings using Anomaly Detection

TinyAI Forum on  
PdM and Anomaly Detection  
(05.12.2023)



 soundsensing

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Jon Nordby [jon@soundsensing.no](mailto:jon@soundsensing.no)

# Commercial Buildings



- Offices
- Hotels
- Restaurants
- Retail shops
- Schools  
etc...



## Clean air



## Heating

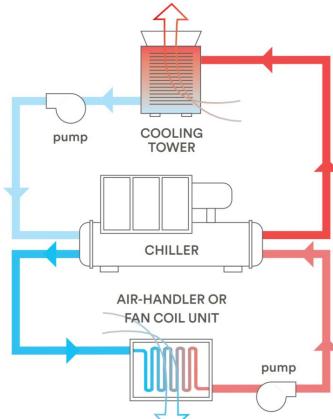
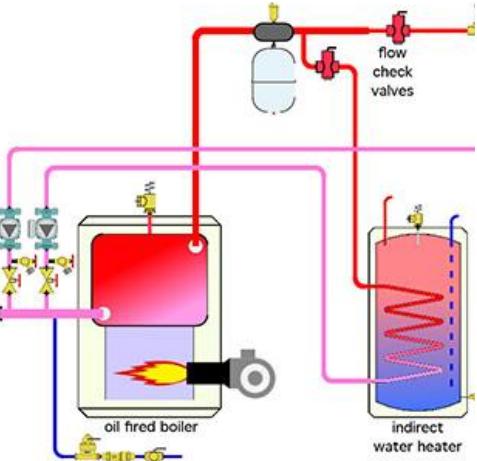
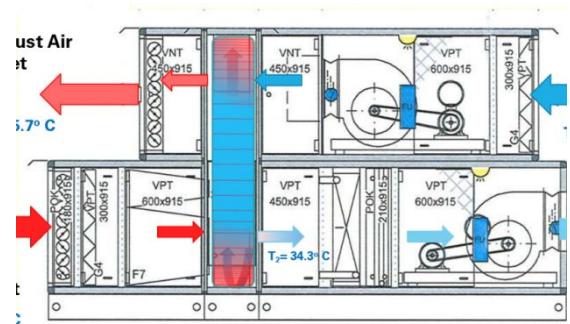


## Cooling

Tenants



# HVAC



Building Operations Manager



Building Maintenance Technician



HVAC Technician



# Manual inspections

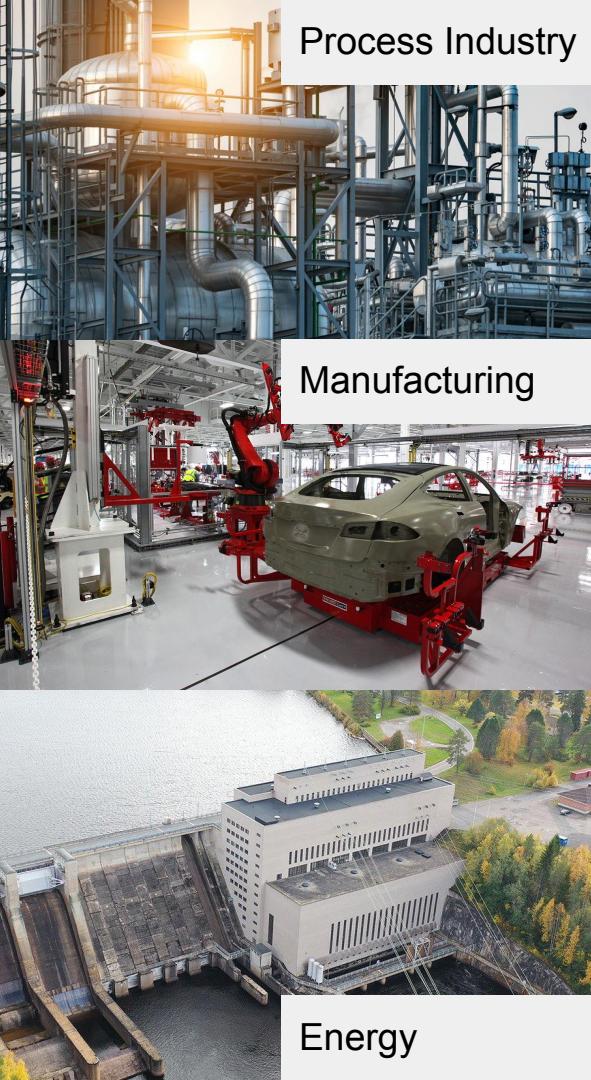
Every 1-2 weeks by operations team  
+ Every 6-12 months by service technicians

Majority of the time: nothing found  
- but issues still happen between checks

**= inefficient strategy  
for preventing incidents**



*See, touch, smell, hear*



Process Industry

Manufacturing

Energy

# Remote Condition Monitoring

## Benefits of **Condition Monitoring**

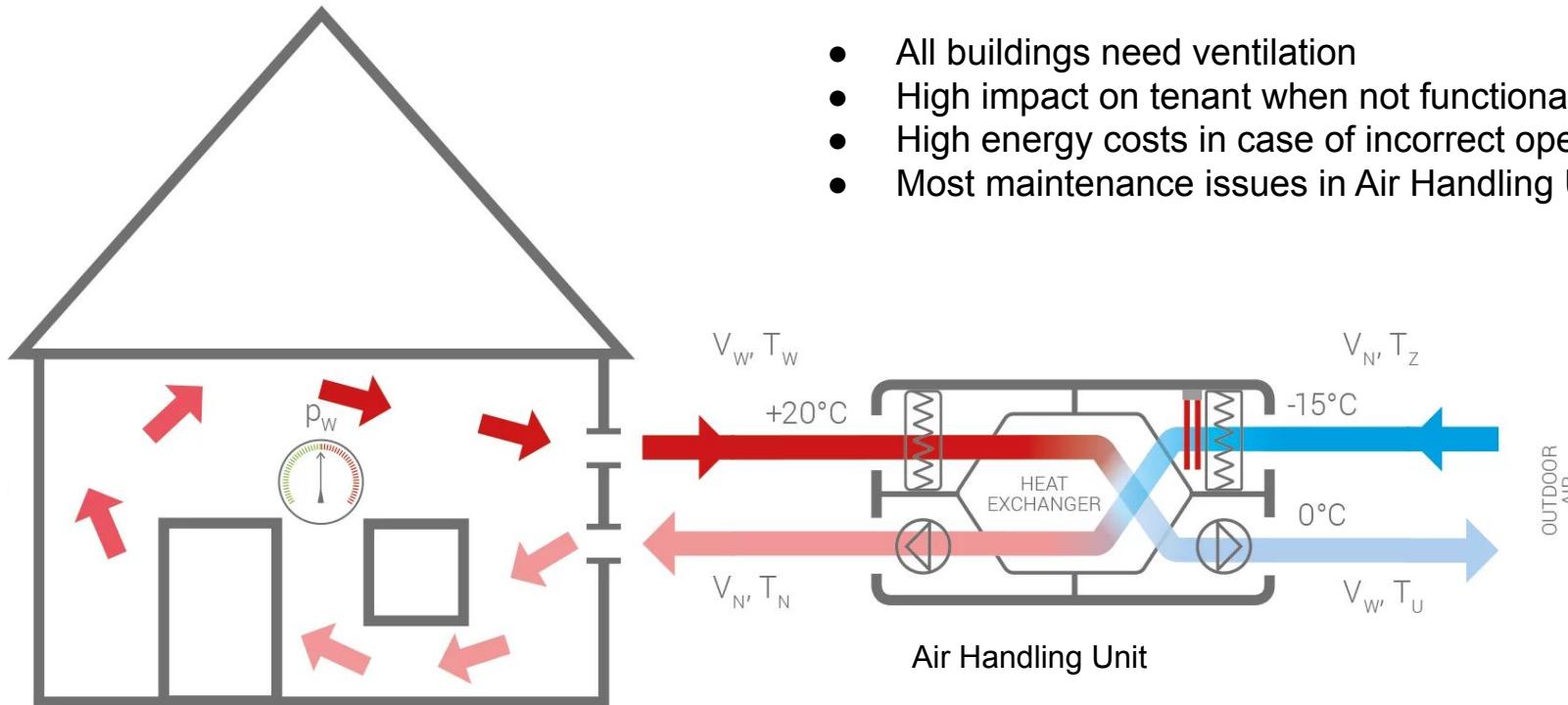
- Improved ability to plan activities  
More efficient use of time
- Reduction in unplanned downtime
- Faster recovery from downtime

## Benefits of **Remote monitoring**

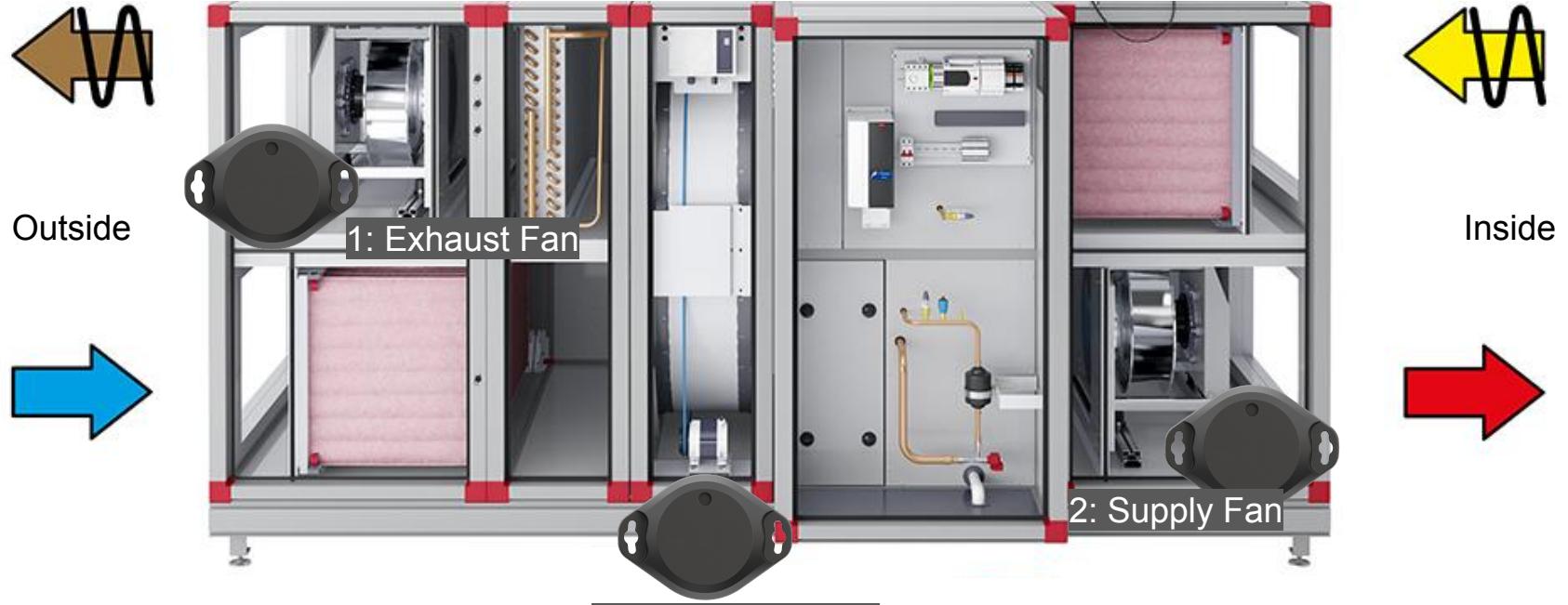
- Less time spent on travel
- Monitor larger geographic area

# Air Handling Units

**Valuable place to start**  
when applying Condition Monitoring  
for commercial buildings



# Vibration Monitoring for Air Handling Unit



MEMS accelerometer  
Battery powered  
Bluetooth Low Energy  
IoT gateway, 4G/Ethernet uplink

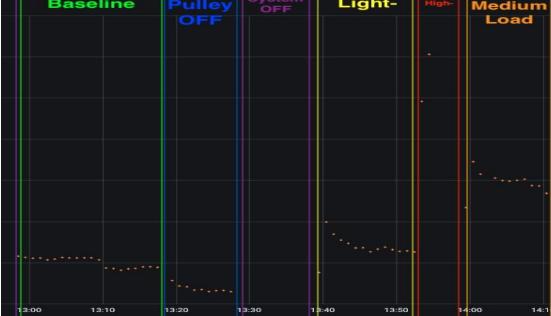
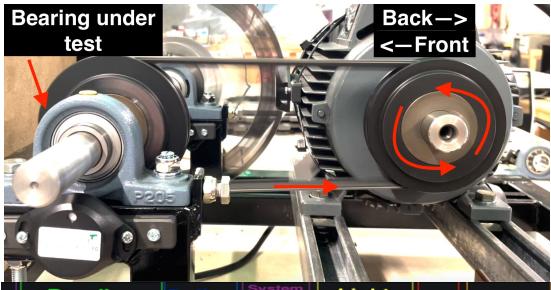
Vibration level XYZ  
RMS + Peak2Peak  
Sampled **1 second every 1 minute**

# Validation of sensor data quality

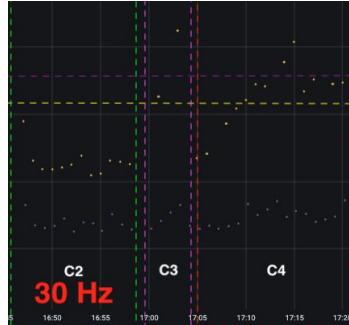
>1000 USD Industrial sensors: Documented performance (on large motors)

<100 USD MEMS accelerometer: Insufficient data found on performance, tests needed

Lab test example:  
Increasing loads



Lab test example:  
Remove lubrication



Field test example: Increasing airflow



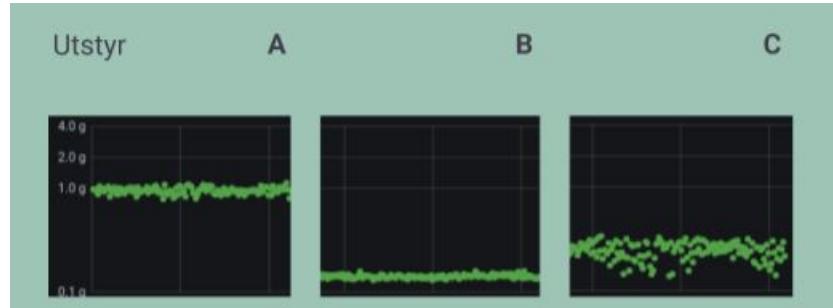
Field test example: Blocking airflow



# What is “normal” machine condition?

Differences in physical properties

- Equipment type and brand/model
- Existing equipment condition (unknown)
- Sensor placement and attachment method (which has to be practical)



Different operating patterns

- Constant on
- Weekday schedules
- Demand-driven ventilation
- Irregular



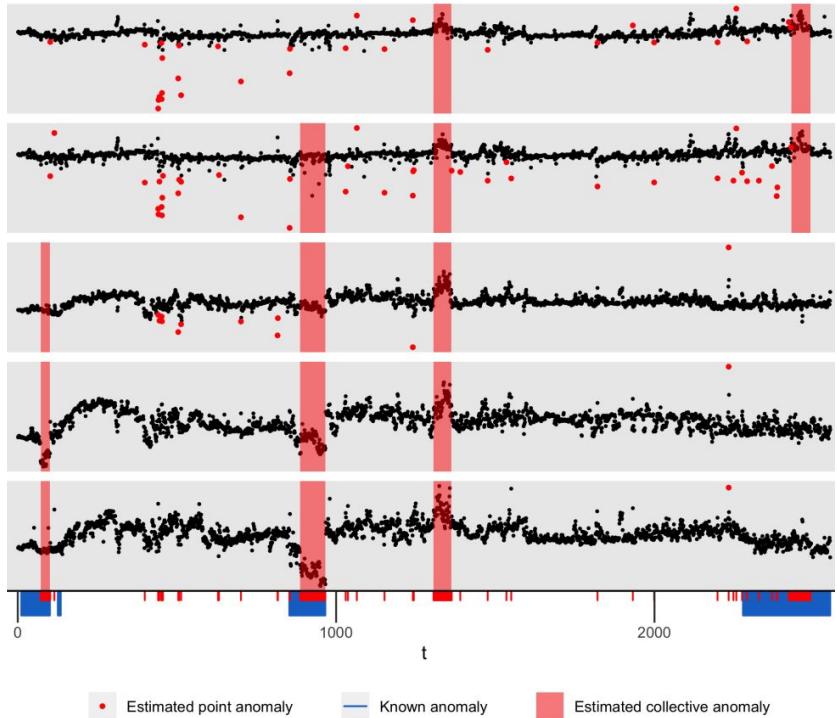
**Strategy: Learn from data with Unsupervised Anomaly Detection**

# Anomaly Detection

Any significant changes from normal = Anomalous

Severe anomaly = Alarm

Custom models  
based on *Collective And Point Anomalies (CAPA)*[1]



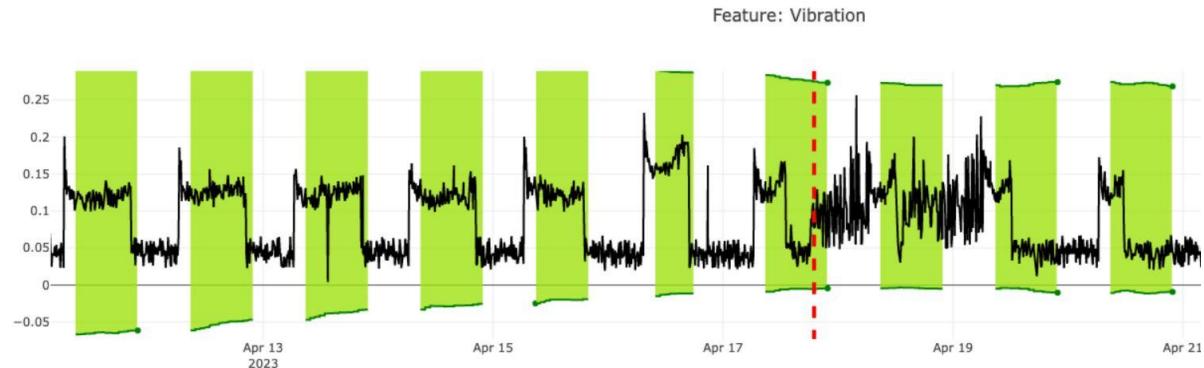
1. A linear time method for the detection of point and collective anomalies (Fisch et al, 2018) - <https://arxiv.org/abs/1806.01947>
2. Scalable changepoint and anomaly detection in cross-correlated data with an application to condition monitoring (Tveten et al, 2021) <https://arxiv.org/abs/2010.06937>
3. <https://github.com/NorskRegnesentral/streamchange>

# Example 1: Heat Exchanger breakdown

360.002 Varmeveksler

Devices f5f3c2c1e3c5

Model Vibration Conditional Model



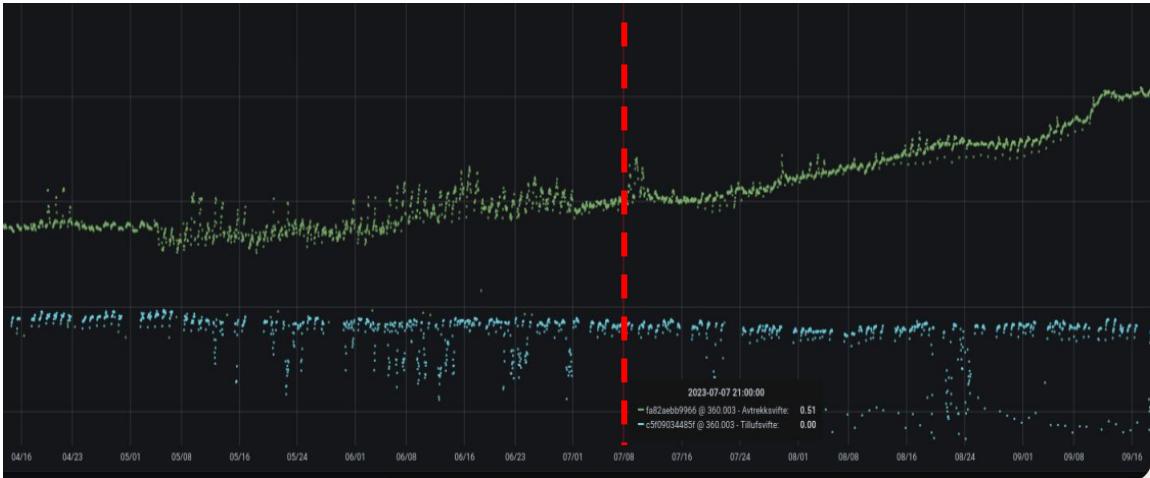
- Erratic vibration levels in heat exchanger motor
- Building manager confirmed motor was failing
- !! Service technician had done a full service 1 week prior - did not find the issue

**Predictive**

0-4 weeks before functional failure (estimated)



# Example 2: Worn out bearing



- Vibration levels started increasing over time
- Compared to flat levels for the other fan
- Service technician confirmed bearing was worn out

**Predictive**  
4-12 weeks before functional failure (estimated)

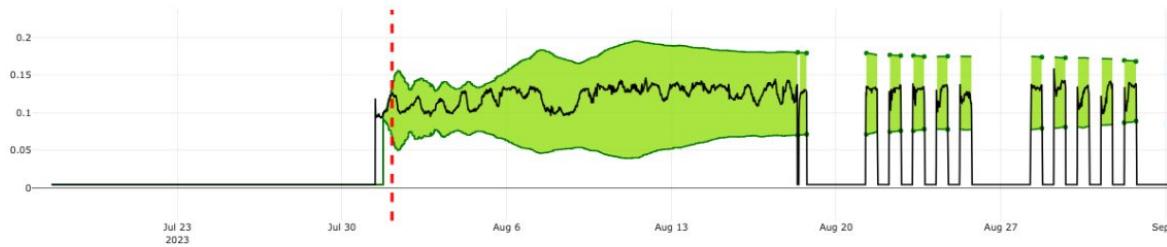
# Example 3: Ventilation always on

Avtrekksvifte - 36.01

Devices e37634889f2a

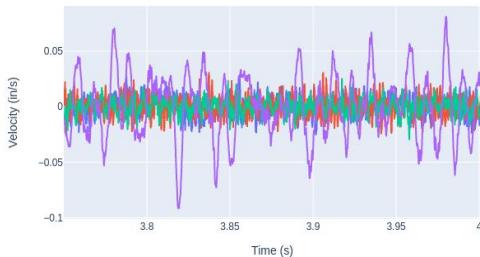
Model Vibration Conditional Model

Feature: Vibration

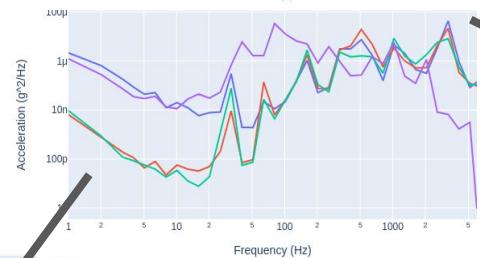


- Vibration levels indicated constant ON
- This case was identified upon installation
- No BMS in place, would have not been caught for weeks
- Operations team estimated savings of 10'000+ NOK
- System also raises alarm if stop following schedule

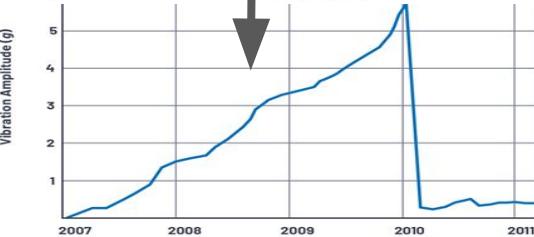
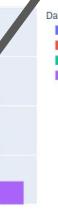
Raw vibration waveform



Power Spectral Density (PSD)



Sum of PSD frequency bands

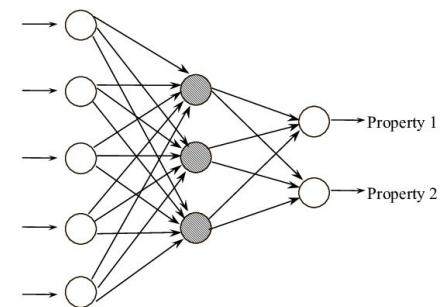


**Classic**  
Vibration level  
as machine health indicator

# TinyML opportunity

Better machine health data  
using on-device estimation

**TinyML**  
Learned features  
for machine health



- Rotation speed
- Spectral change
- Start/stop detection

# Summary

**Benefits of Condition Monitoring** known from industry and transfer well to ventilation in buildings

**Vibration monitoring** with wireless MEMS sensors can **effectively detect many common problems**

**Air Handling Units** are a valuable target for CM in commercial buildings

**Anomaly Detection** is key for automated detection of problems and enable alarms with early warning of failures



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# Bonus

# User Experience

We have detected an anomaly.

## Email

Building	None
Room	Teknisk rom 3 (ventilasjonsrom) B-fløy
Asset	360.003-Avtrekksvifte
Time	04.02.2023 16:18

Vibrasjonsnivå tilsier at utstyret er på kontinuerlig, hele dagen og natten. Utstyret tidligere kun på fra 05:00 til 14:00.

[See Alarm Details In App](#)



## Alarm Overview

## Webapp

### All Alarms

Search



Organization

OsloBygg



### Filter

Building All

Room All

Asset All

Clear

### Alarms

Status

Date

Type

Device

Asset

Room

Building



Unresolved

Nov 17,  
2023 11:  
50

B

dbb81df  
dbc9

Tilluftsvifte  
– 36.02

Ventilasjon  
srom Vest

Ole Brumm  
barnehage



Unresolved

Nov 1, 2  
023 0  
9:10

B

da4b181  
debd3

Motor varm  
egjenvinner

Ventilasjon  
sanneks

Humlebakk  
en barneha  
ge



## Management, Operation and Maintenance (MOM) system

### #1158.7 Ventilation system not started on

Seen by Jon Nordby

Overview

Checklist

Costs

Time tracking

#### General

##### Reported by:



Soundsensing Dev Explore

Soundsensing HQ

Reported 26. nov. 2021, 17:55

Status: Not started

##### Description:

Normal starting period 0900-1000, soundlevel 75 dB.  
Current soundlevel 50 dB: machine not on.

Detected by Soundsensing Acoustic Condition Monitoring.

See more details:

<https://app.soundsensing.no/#/device/c7140b9c-36b6-4c20-8dfb-780a5907f569>

Edit alerting setting:

<https://app.soundsensing.no/#/device/c7140b9c-36b6-4c20-8dfb-780a5907f569/settings>

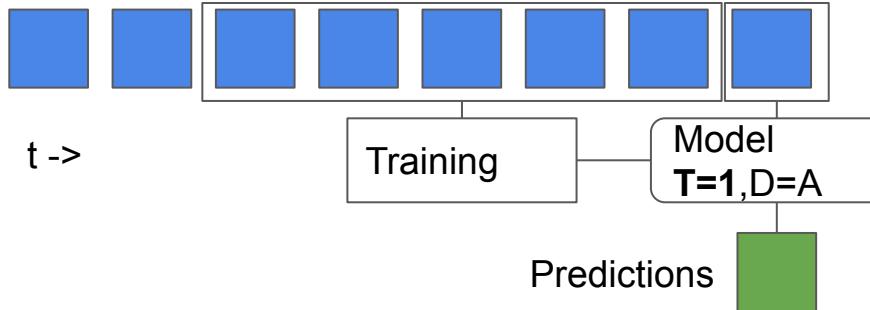
Propely

FAMAC

FDVweb  
CuroTech

# Continuous learning

Input data stream. Device A at **Time 1**



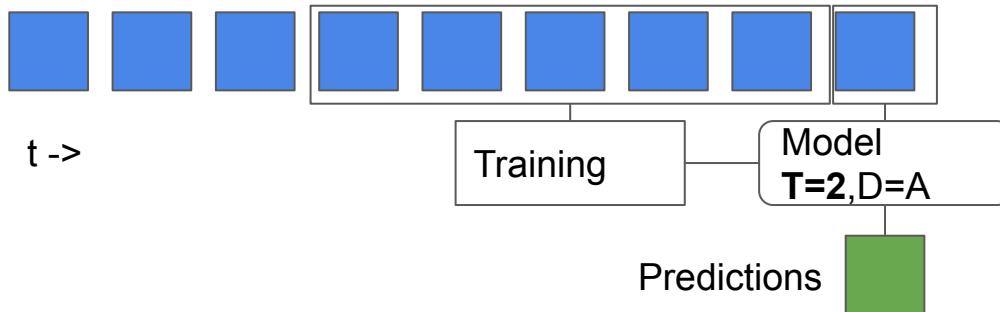
New Anomaly Detection models trained regularly, looking back a fixed time period.

Process repeated for each device.

Typical training interval: 1 days

Typical lookback: 30 days

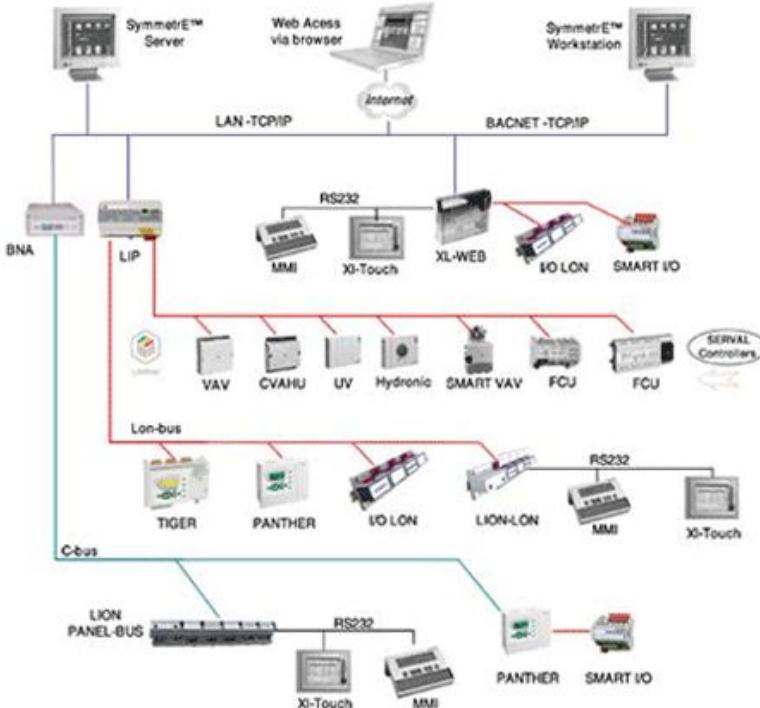
Input data stream. Device A at **Time 2**



# Building Management System for monitoring

## Limitations

- Many buildings still do not have a BMS (!)
- Limited coverage in equipment / failure modes
  - Many components missing feedback
  - Many components missing alarms
  - No mechanical sensing
- Different systems in different buildings
- Very expensive to upgrade
- Not always available remotely



# Differences to heavy industry

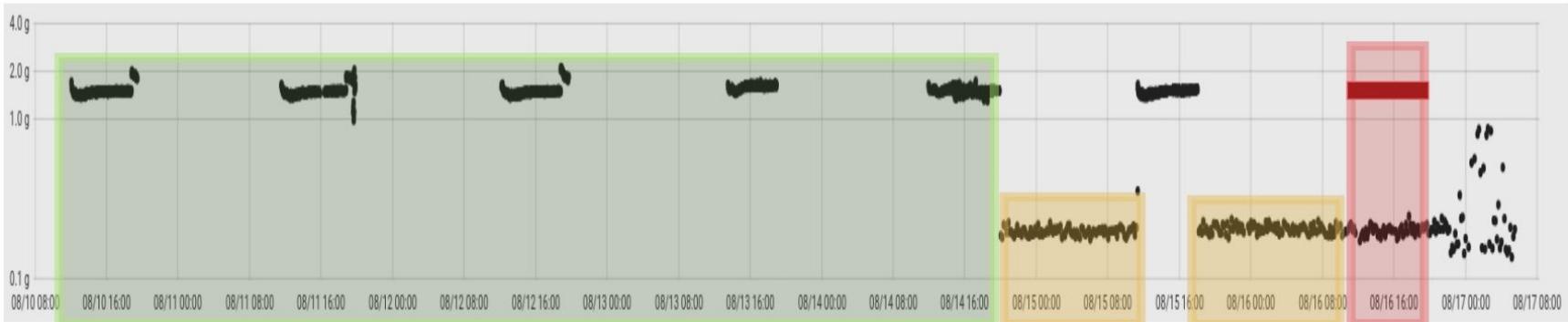
- Lower consequence/cost of failure/downtime
- Many fewer assets per site
- Much smaller maintenance teams
- Less time available for maintenance activities
- Few to no maintenance specialists in organization

## Consequences

- System install and operational cost must be much lower
- Must not require extensive site-specific configuration
- Must not require extensive training or specialized skills

# Case 4: Air Handling Unit does not start on time

Was due to corrupted configuration



# Customers



# Development partners

