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19. November 2024

Bosch Home Comfort Group

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Questions

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https://www.menti.com/

Code: 1134 5026

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01

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Heat pumps acoustics: When is quiet quiet enough?

The Bosch Home Comfort Group Experts:

Alexander Merzkirch
Group Leader Noise, Vibration & Harshness

Jürgen Herbst
Acoustic Expert

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Agenda

- Challenges from Industry Perspective
- Legislation in Europe
- Sound Prediction Tools and Online Sound Comparisons
- Acoustic Development of Heat Pumps
- Source Characterization & Selection of Components
- Sound Visualization & Optimization
- Psychoacoustics
- Q&A

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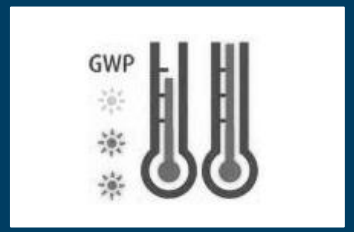
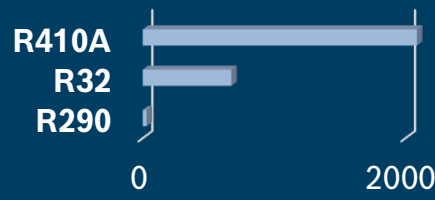
Trends that effect heat pump business



Usage of alternative refrigerants

- usage of refrigerants with high GWP is affected by EU's F-Gas regulation
- develop new refrigerant fluids with both, high thermal performance and low environmental impact

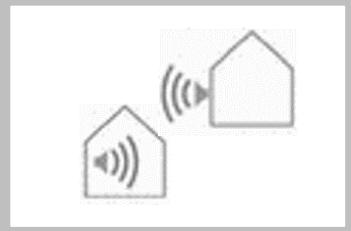


Connectivity – HP as system component

- energy management: maximize usage of self-produced energy
- system landscape: develop components, accessories, apps and portals to integrate HP in extended systems
- Easy installation (plug & play) and integration in systems

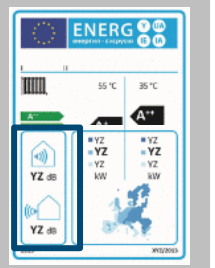
Increase maximum flow temperature

- HPs work best with surface heating due to higher efficiency on lower flow temperatures
- increasing the maximum flow temperature will strengthen HPs position in retrofit use-cases where mainly radiators are used
- keep efficiency and COP strong while providing higher temperature output



Reduce in-/outdoor noise emissions

- sound of HP outdoor units perceived as potential conflict issue with neighbors
- EU directive and local legislation limits maximum noise level and requires information on energy label
- Innovation driver: development of noise prevention measures, noise insulation and adjustment of fan design



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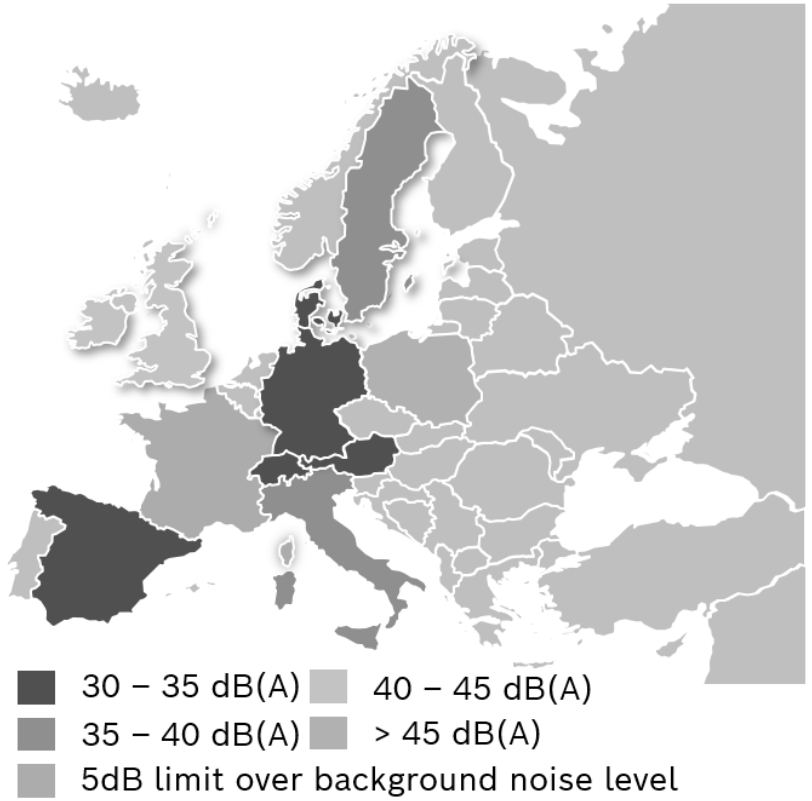
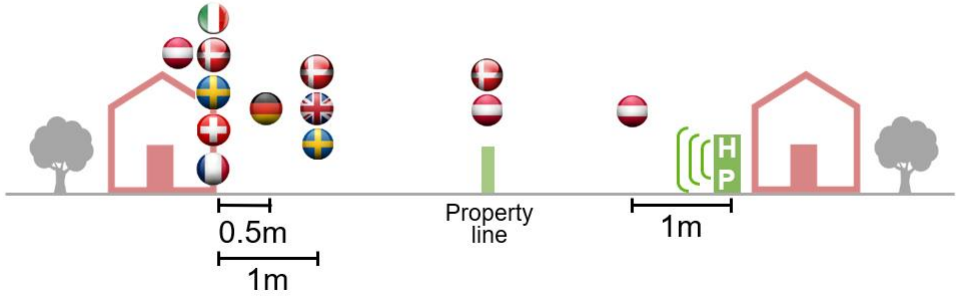
Legislation in Europe

Sound pressure level limit (night)



Measuring location for defining the maximum permissible sound pressures



- Country specific, sometimes region-specific requirements. Limit values in Austria partly not achievable with reasonable effort (Vienna, Salzburg)
- **Very heterogeneous legislation in Europe**
- Countries with individual regional legislation usually change legislation faster compared to national or European standards
- DACH & DK: lowest limit values for noise emissions (D: TA Lärm)
- Different requirements in Germany depending on the classification in the development plan: e.g. purely or general residential area, mixed area, ...
- ErP value is measured at 35% of maximum power – not representative

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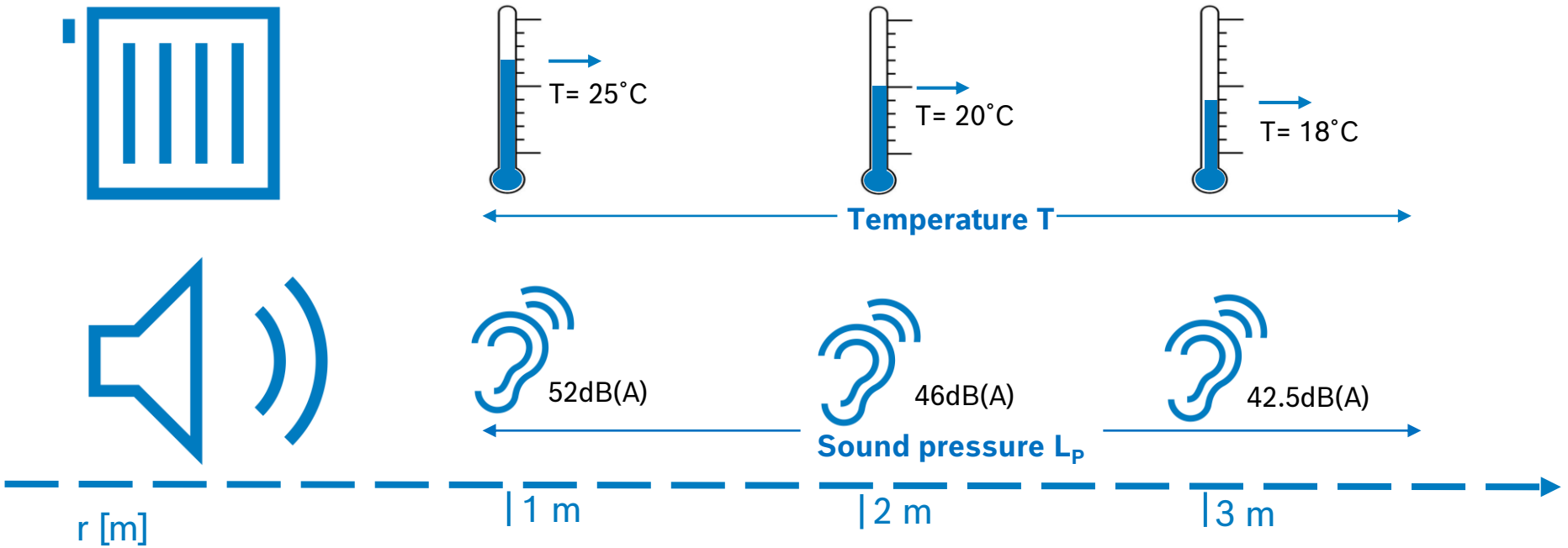
Comparison of Sound Power & Sound Pressure

- **Similarities between heating power and sound power in terms of distance**



- **Sound power level describes the source Sound**
- **Pressure level varies with the position of the microphones**

- Sound power is measured in Watts – small energies result in high sound power levels: $L_{W,0}$ = 10−12W ≡ 0dB, 1W = 120dB, regardless of distance
- Sound pressure is measured in Pascal, reference sound pressure: $L_{P,0}$ = 20 µPa = 2 · 10^{-5} Pa ≡ 0dB, static air pressure: 1013hPa = 101 325 Pa

→ Sound power describes the sound source, sound pressure is meaningless without location and source reference

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TA Lärm: Impact of National Noise Protection Regulations

Noise Limit Values:

Sound pressure levels L_P measured 0.5m in front of an open window of a living room or bedroom

Development Goals:

Translating sound limit of e.g. L_P = 35dB(A) into a development goal of L_W < 50dB(A)(sound power)

Guidance for Professionals:

Builders, architects, installers and end customers prefer distance limits to the neighbor's window:

3m distance to protected windows requires L_W = 49.5dB(A) and covers ~90% of all installations

2m distance can be reached with L_W = 46dB(A) and covers ~98% of all installation cases.

TA Lärm (German Regulation) Challenges:

- Sound generated by already installed heat pumps need to be considered or else a 6dB lower sound power limit to be achieved
- Tonality penalty to be added, but not a reliable process defined to assess tonality (no correlation between subjective evaluation and DIN45681 found)

TA Lärm goes beyond what is necessary:

- Heat pumps with L_W < 50dB(A) are virtually inaudible at a 2m distance.
- Sound power levels L_W < 50dB(A) are sufficient to meet the need for quiet.

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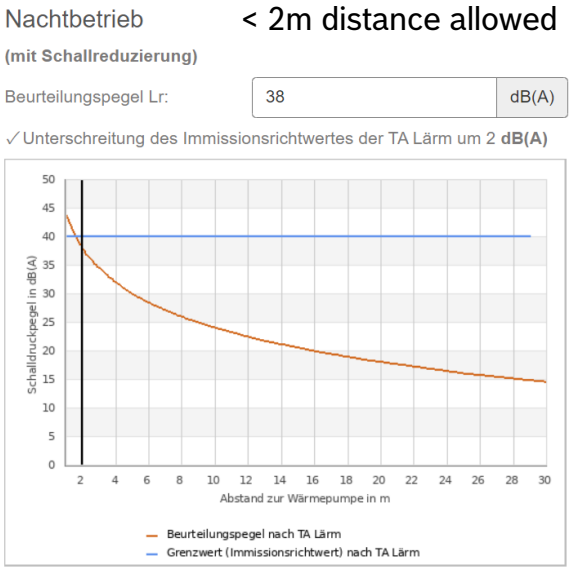
Sound Simulation & Calculation Tools

- **Sound & Distance Calculator (e.g. BWP Schallrechner)**

https://www.waermepumpe.de/schallrechner/



- **Sound Simulation**

https://www.bosch-homecomfort.com/de/de/wohngebaeude/wissen/heizungsratgeber/waermepumpe/waermepumpe-lautstaerke/

- **Virtual Reality (3D simulation of HPs)**

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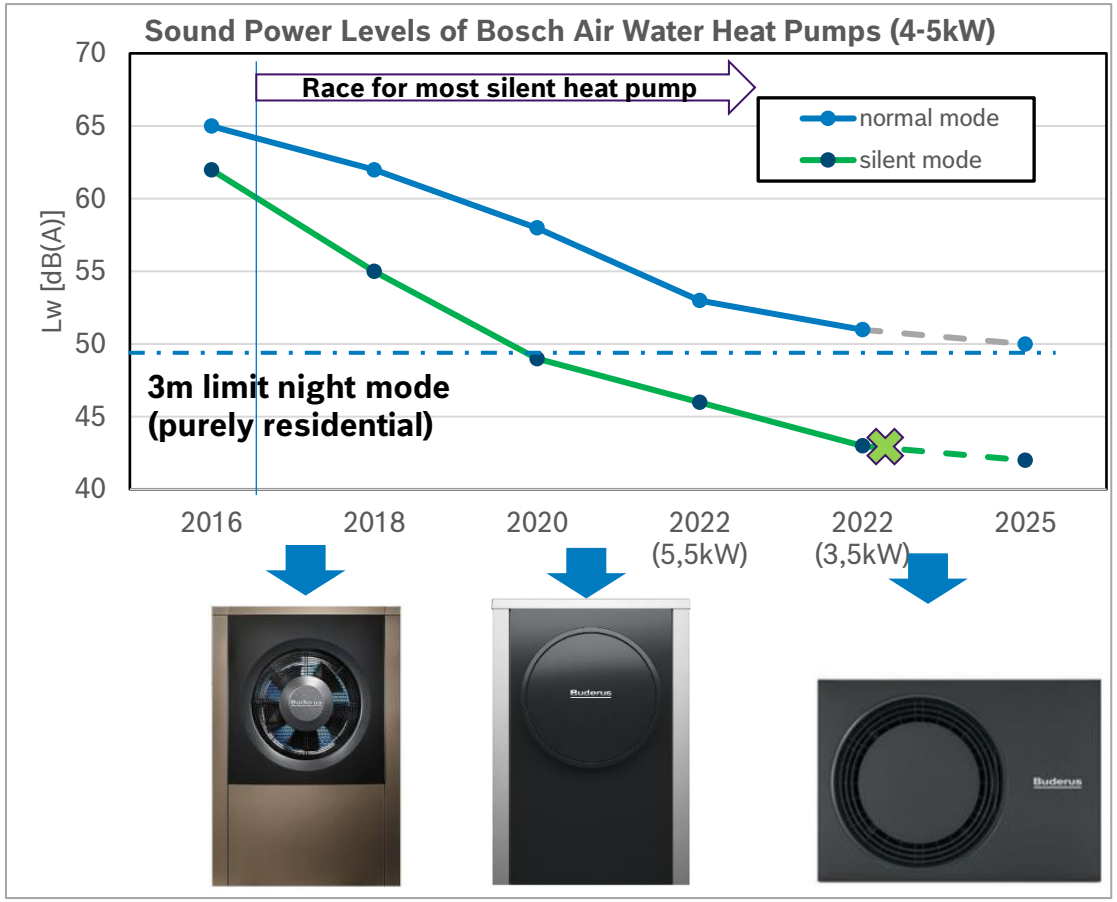
Reduction of Sound Power

Noise reduction

- 14 – 19dB sound power reduction over last 6 years
- "Best in class" – 4dB/1dB quieter than the best competitor (Bosch AW5800 & Buderus WLW176i 3,5kW/5,5kW variant)
- Further sound reductions
  - require high development effort + costs
  - are not required, unless required by law

Why?

- No known noise complaints with Bosch AW7400i or Buderus WLW196i.2-4 and 2-6 (49 / 51dB(A) in night mode)
- Psychoacoustics play a greater role in perception than the sound power value



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Engineering

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Development steps for noise reduction

- **Selection of quietest components**

  Compressor & Fan

- **Optimization of air flow:** Finger ingress grid, fan motor mount, shroud
- **Diffusor:** Reduction of sound radiation to the front, invisible fan
- **3-fold encapsulation of the compressor**

  Compressor Jacket (recycled absorber material)

  “box in the box” concept for the ref-circuit components (3-layer barrier with recycled absorber material)

  Design covers

- **Transfer path optimization**

  Housings: Solid & stamped base plate, reinforced frame, design covers including vibration damping…

  Compressor Decoupling: Two stage vibration isolation

  Vibration Damping: added to copper pipes and metal parts to reduce noise and extended lifespan.

  Cable Routing: Optimized layout.

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Source Characterization Compressor

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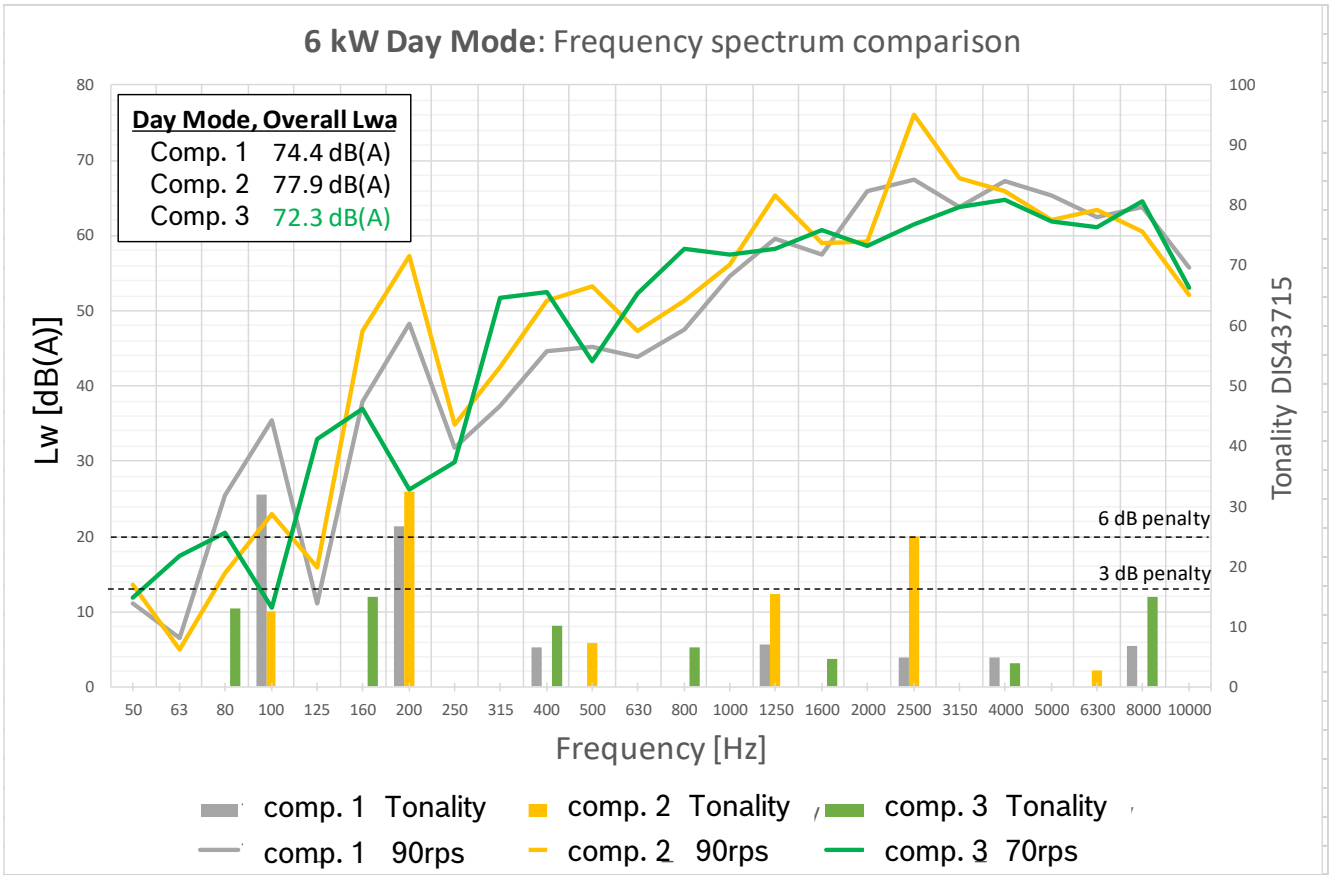
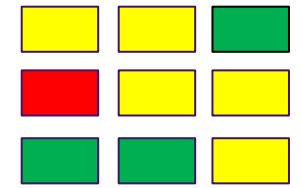
Compressor Selection: Sound Power Tests & Tonality



- **Compressor Components Test**
- **Acoustically relevant selection criteria**
  - >20 operating points
  - Sound power (absolute value)
  - Sound power (frequency spectrum)
  - Vibrations (absolute values)
  - Vibrations (frequency spectrum)
  - Tonalities
  - Cost, performance, size…

6 kW (4 kW) Overview: Day / Night / ErP



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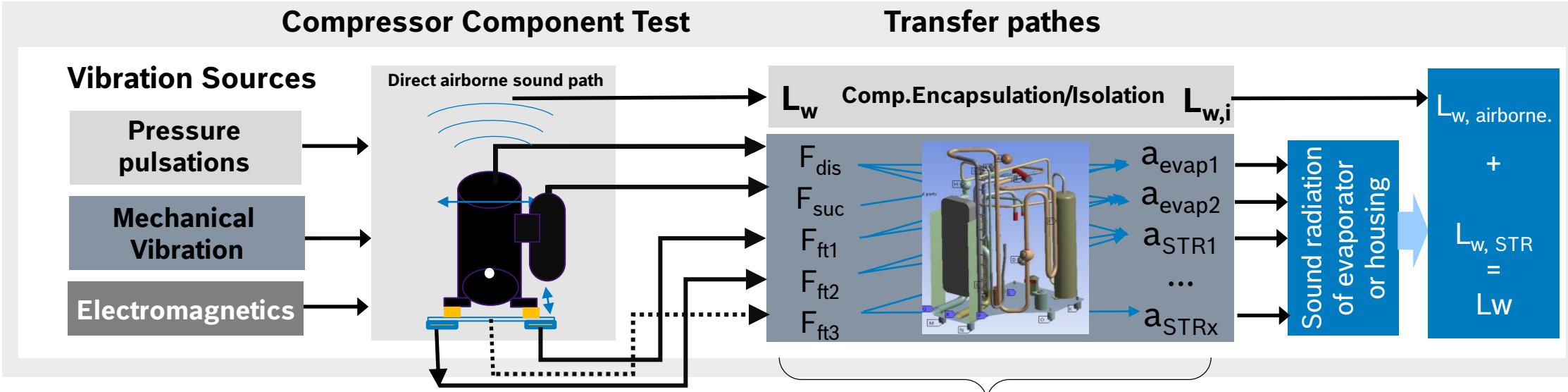
Overview – Cause-Effect Relationships / Transfer Paths



Transfer Path Optimization

- **Structure/Housing** (base plate, frame, design panels, reduction of sound radiation and resonances)
- **Refrigeration circuit** (pipe routing, decoupling strategy, component placement, encapsulation & sealing measures)
- **Direct airborne sound** (fan: shroud, diffusor, protective grid/fins; compressor: encapsulation & sound barriers)

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Simulation

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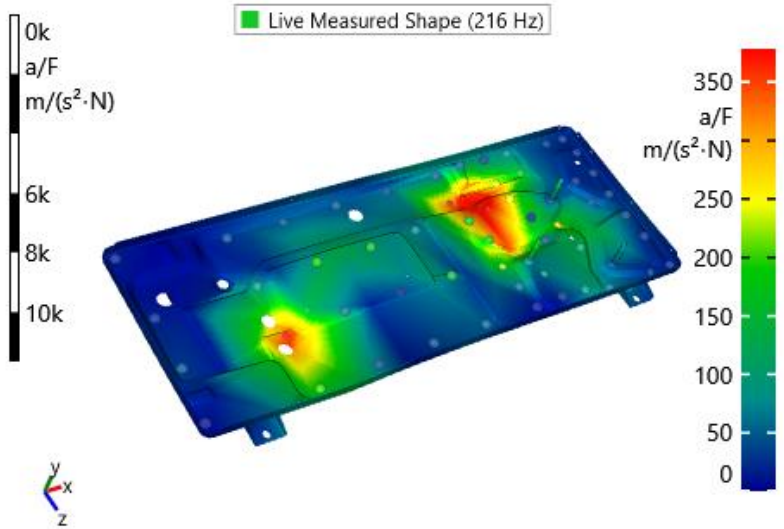
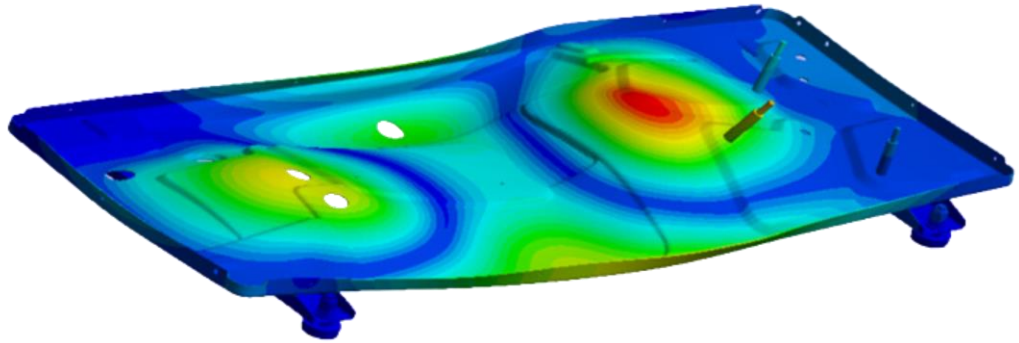
Validation of FEM Simulations of the HP Baseplate

- **Base plate of the heat pump – matching measurement and simulation**



Experimental Modal Analysis (ArtemiS®)

211 Hz



FEA Modal Analysis (ANSYS)

Good match of frequency and vibration shape → simulation model validation!

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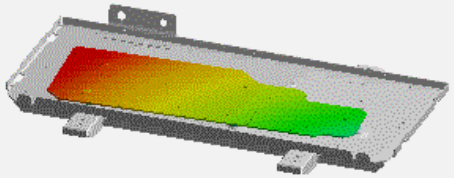
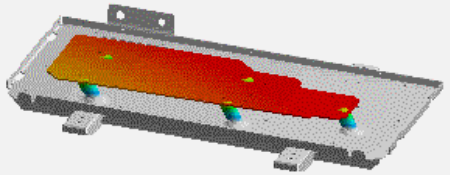
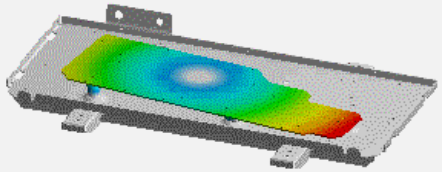
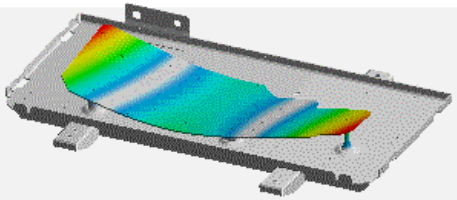
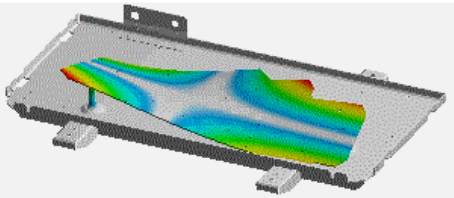
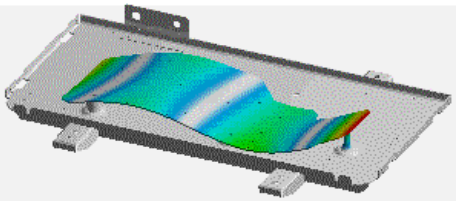
Vibration Modes #1..3 + #7..9 | Rigid Body & Bending Modes

- **Base Plate and Compressor Base Plate – Design and Optimization**

mode shape n.1	mode shape n.2	mode shape n.3
		
18,4 Hz	**18,6 Hz**	**21,6 Hz**
mode shape n.7	**mode shape n.8**	**mode shape n.9**
		
64,2 Hz	**99,6 Hz**	**121,3 Hz**

Goal:

Shift Rigid Body Mode frequency below compressor excitation

Goal:

increase stiffness to move bending modes like this to high frequencies

- **Optimization of decoupling based on simulations**

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Sound Visualization

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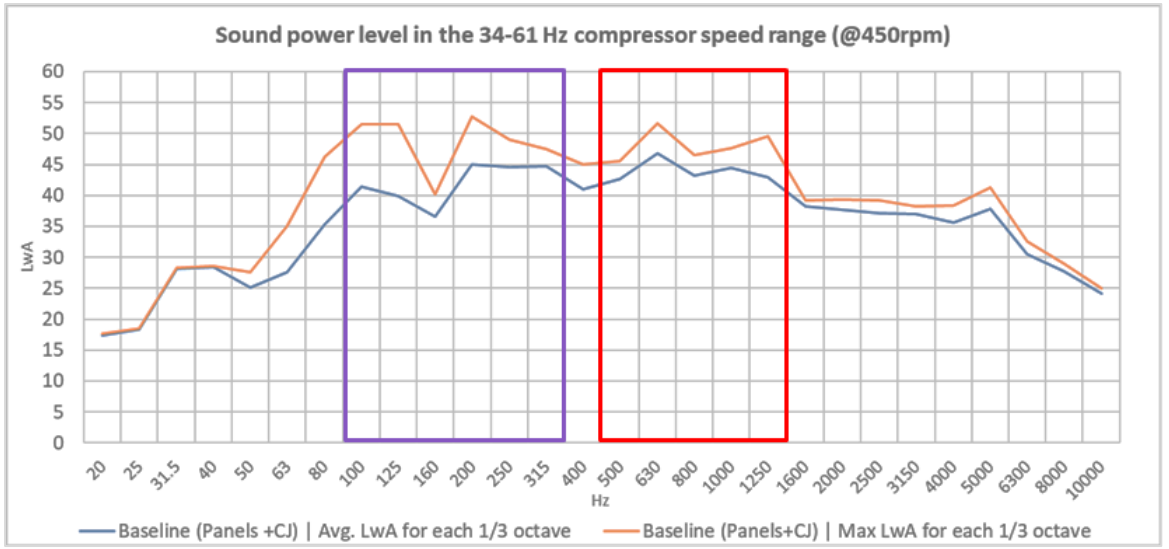
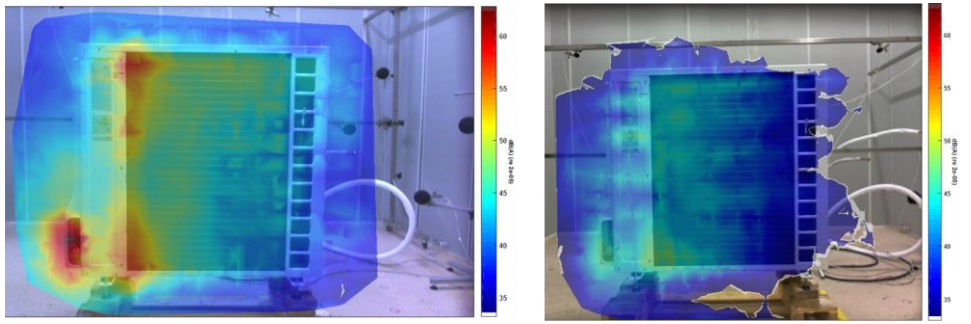
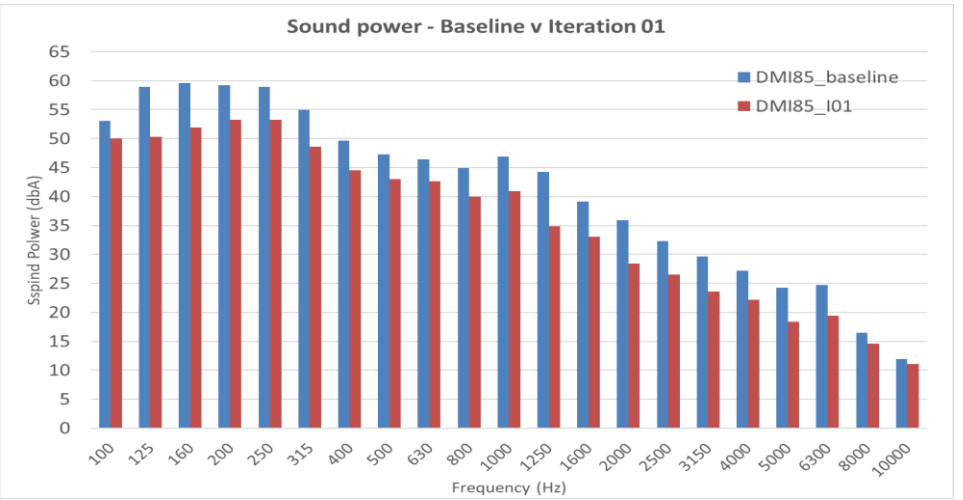
Airborne Sound “Leak Detection" using Sound Visualization

- **Task:** Detection of “sound leaks" & evaluation of measures
  Result: Measures developed and implemented







- “Sound leak” detection is an efficient tool to identify weak spots
- **~5dB airborne noise reduction achieved by sealing “sound leaks”**

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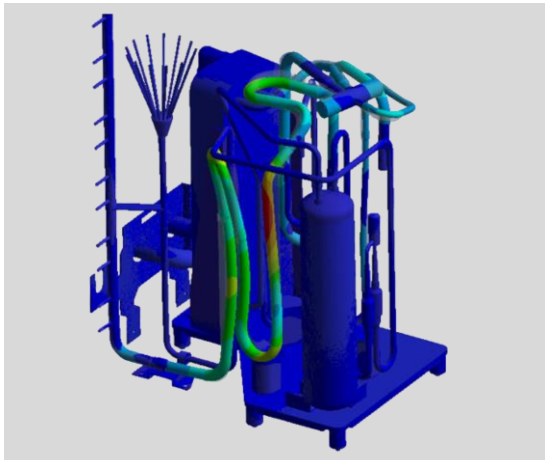
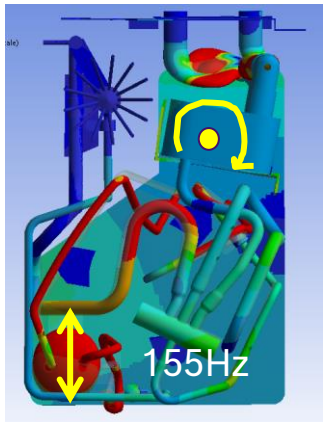
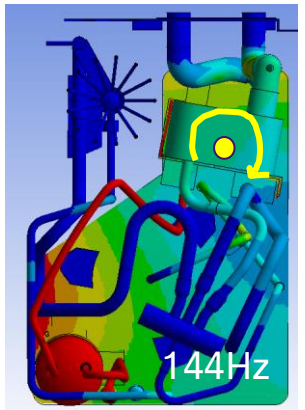
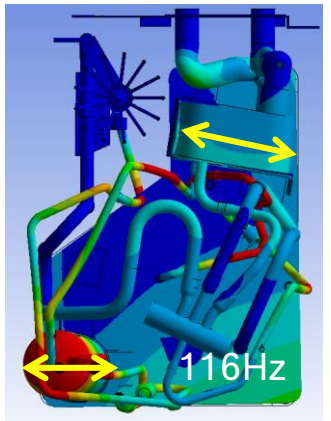
Comparison of the oscillating shapes of the refrigerant circuit

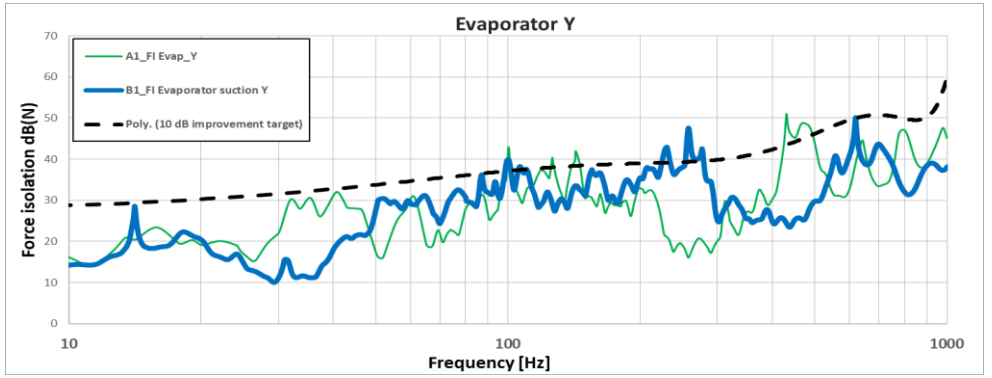
- **Resonances visualized**
- **Critical frequencies & vibration modes identified**
- **Countermeasures derived:**
  - Receiver geometry & fixation (height, diameter, etc..)
  - Torsional stiffness of the plate heat exchanger bracket











- **Lower vibration amplitude for dominating resonances achieved**

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Psychoacoustic

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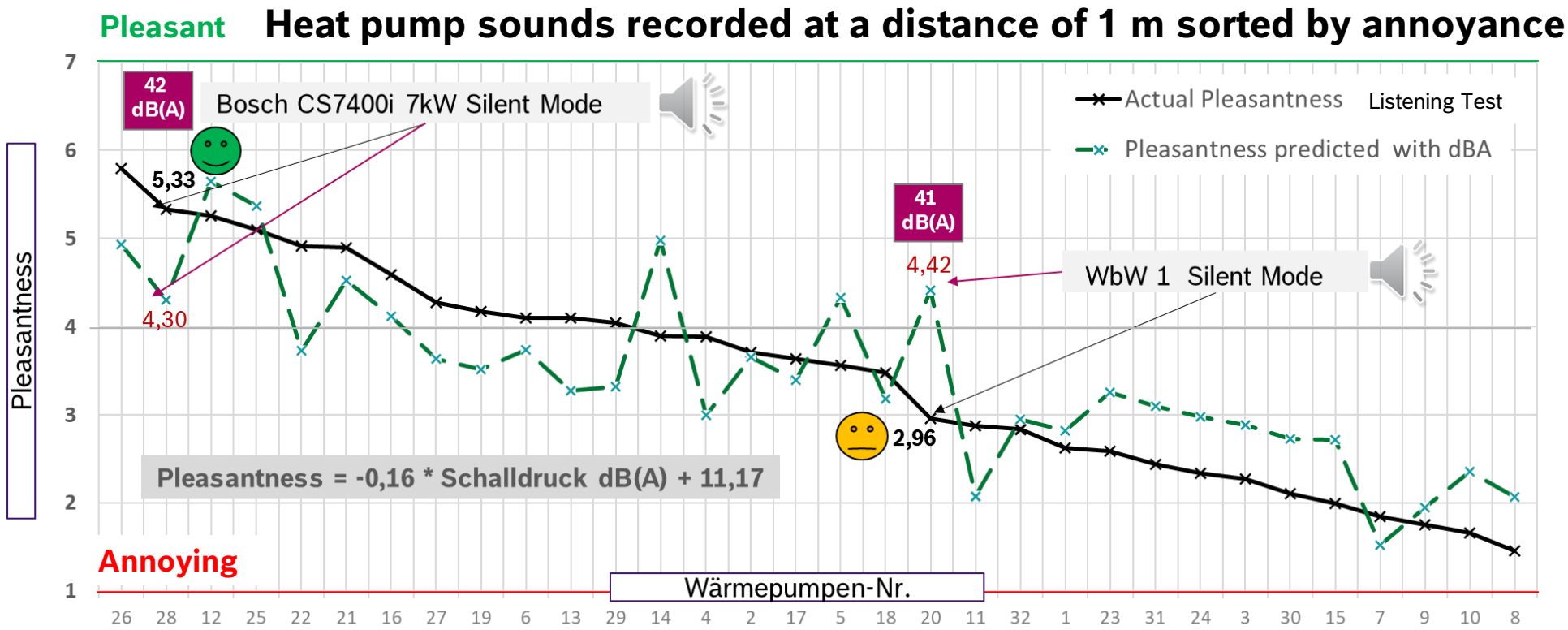
Motivation



- **Evaluation of the annoyance of 30 heat pump noises by 105 participants of listening study**
- **The annoyance of a product can vary greatly from its sound level**

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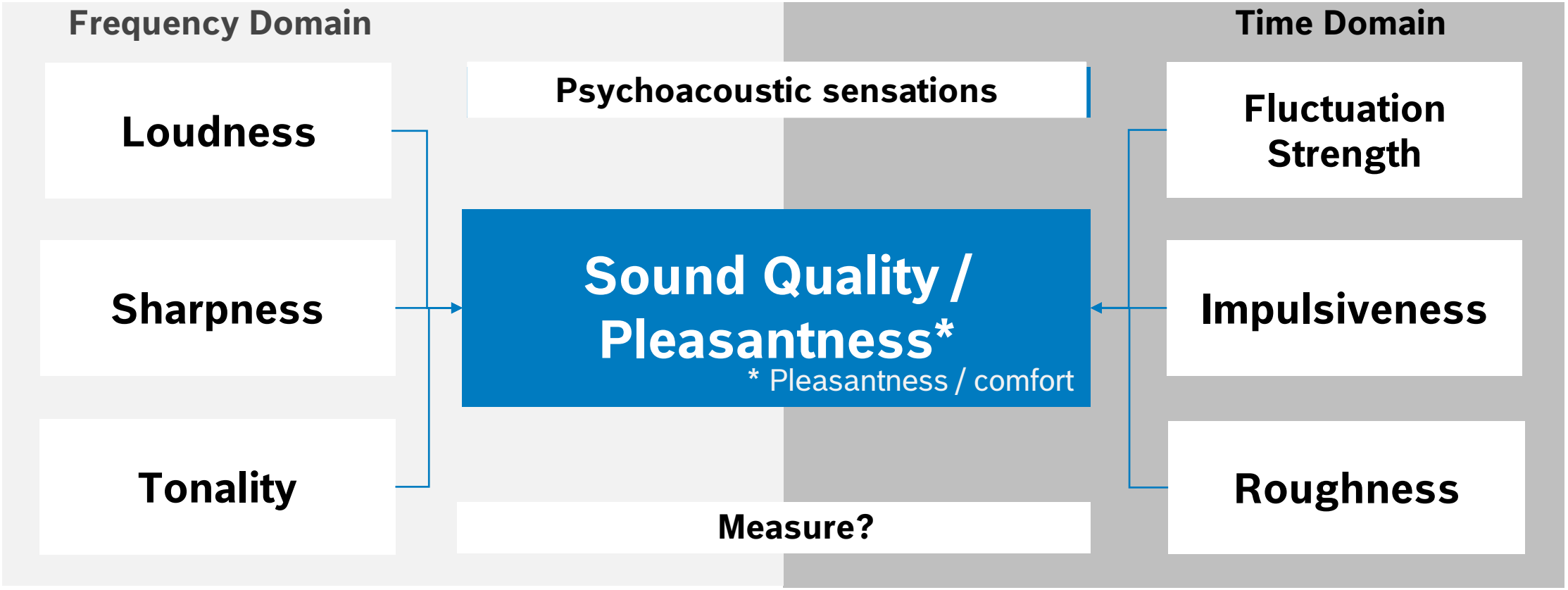
Sound Quality / Pleasantness



- **Can a 'sound quality' or annoyance model be based on measurable quantities?**

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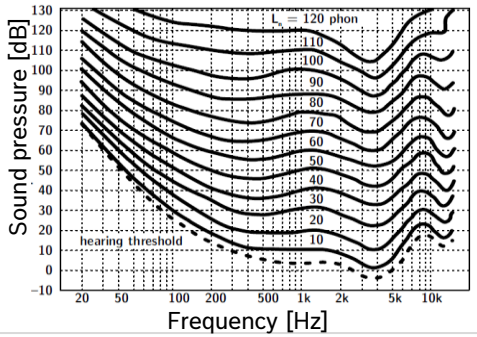
Psychoacoustic Metrics – Relevant Parameters

Loudness



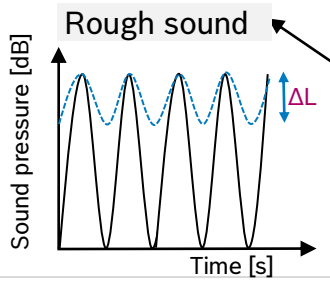
Unit: [sone]

Loudness linearizes perception

10dB difference is perceived twice as loud, therefore a doubling of loudness in sone equals human perception

Roughness and modulation

Unit: [asper]



Maximum at: delta ~70 Hz

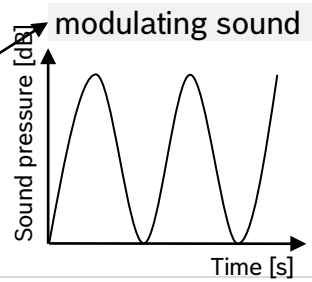
20-300 Hz

Amplitude Modulation

Maximum at: delta ~4 Hz

< 20 Hz

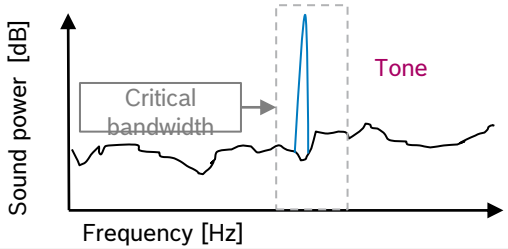
Unit: [vacil]



Tonality

Level difference between tonal & broadband frequencies

Unit: [tu]

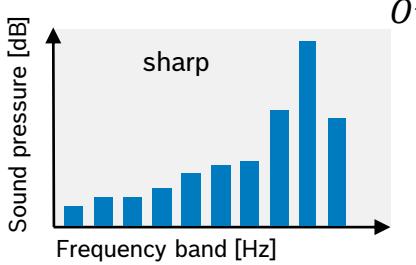


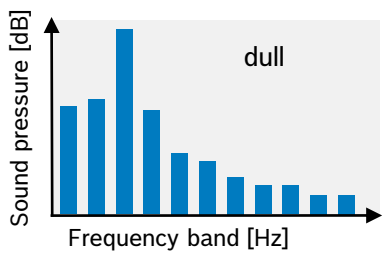
Up to 6dB penalty on declared sound power value for tonal noise components

Sharpness

$$\frac{Loudness\ of\ high-frequency\ components}{Overall\ loudness}$$

Unit: [acum]





- **Relevant Psychacoustic Metrics: Loudness, Tonality, Roughness, and Sharpness**

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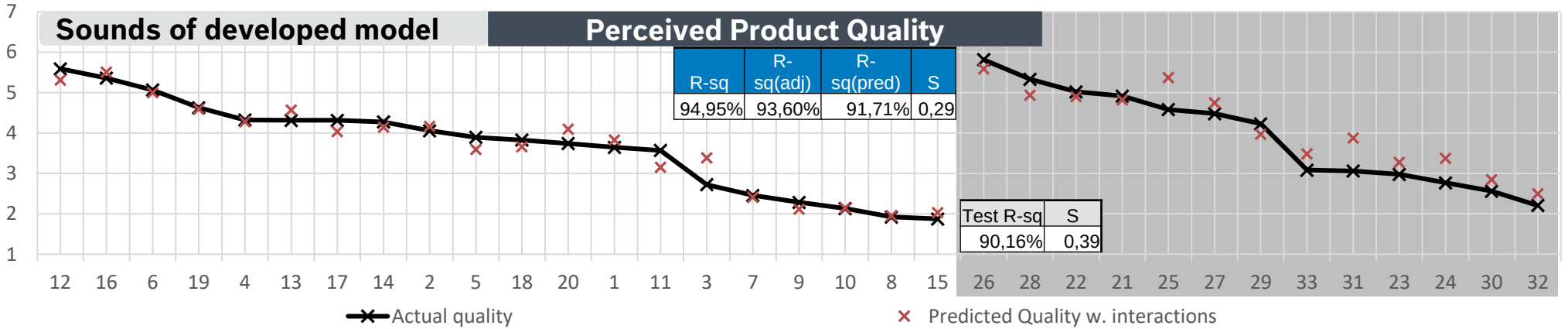
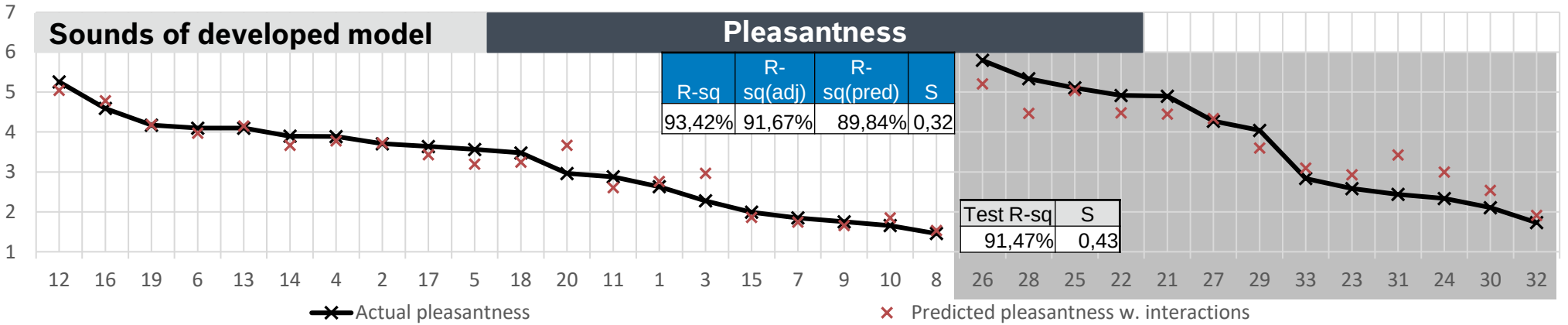
Final Model Checked by 13 Test Sounds





- **Pleasantness model for heat pumps tested and validated**

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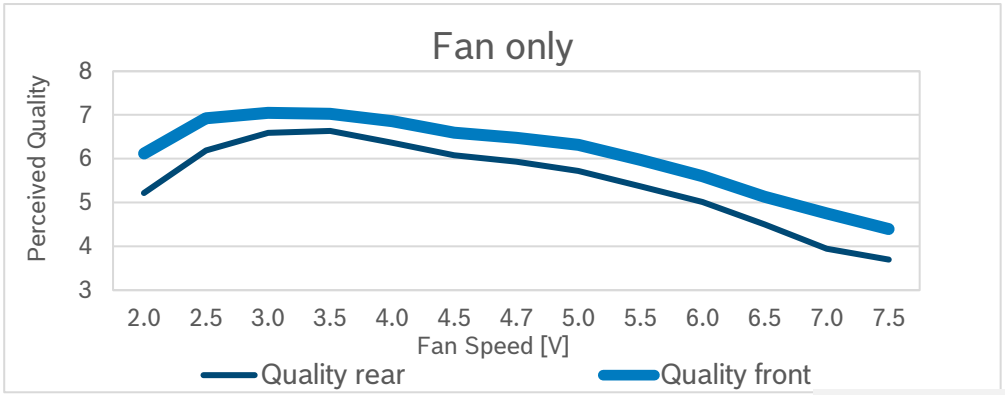
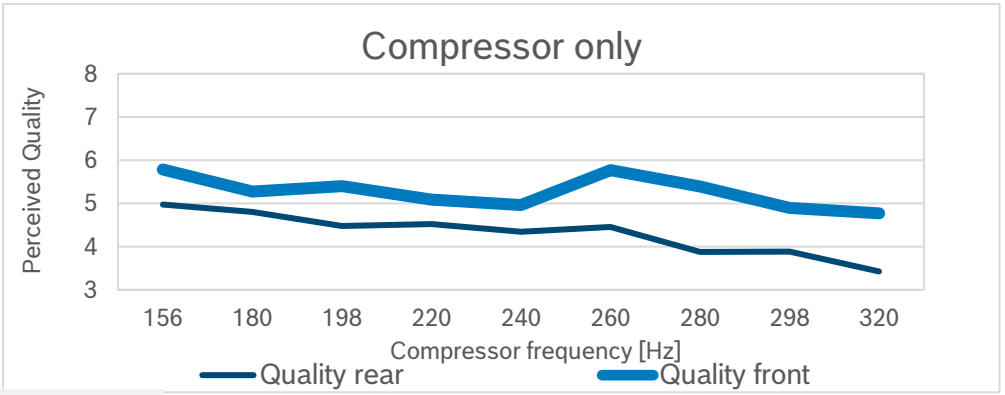
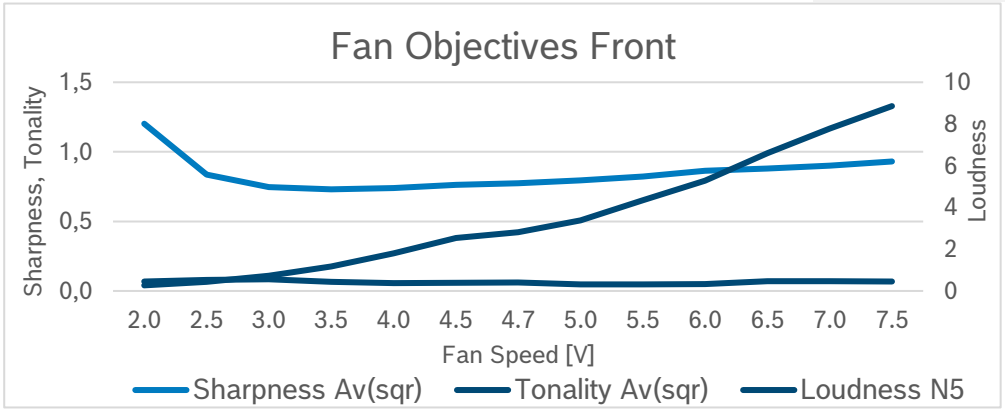
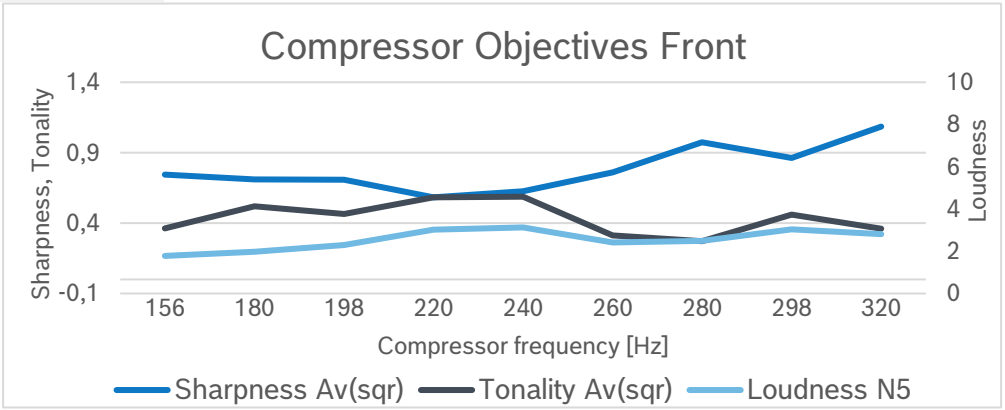
Analysis of Operating Conditions of CS7400AW - 4kW A7W35





Quality = 9,4 - 2,4 S -3,7 T - 0,3 L + 0,3 XY





- **Sound radiation at the back of the appliance is more annoying than at the front**

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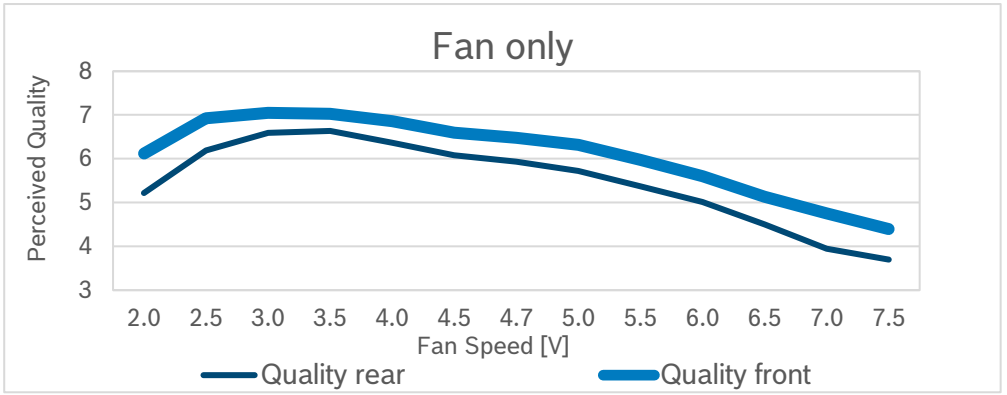
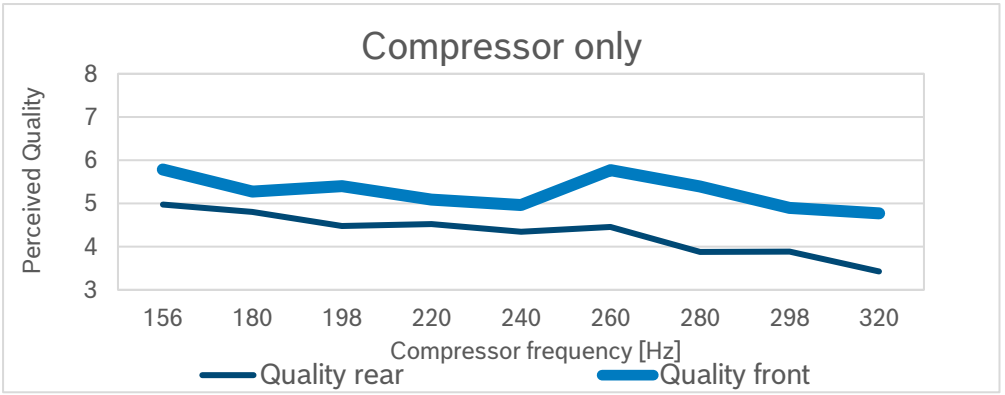
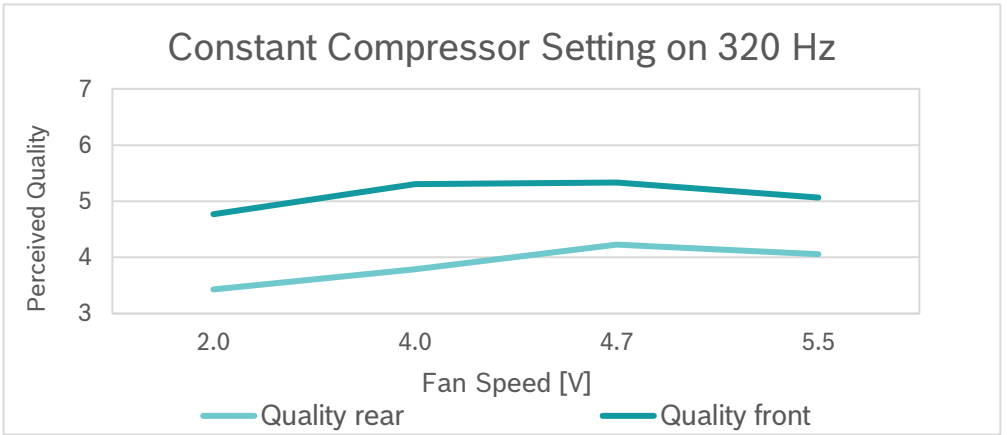
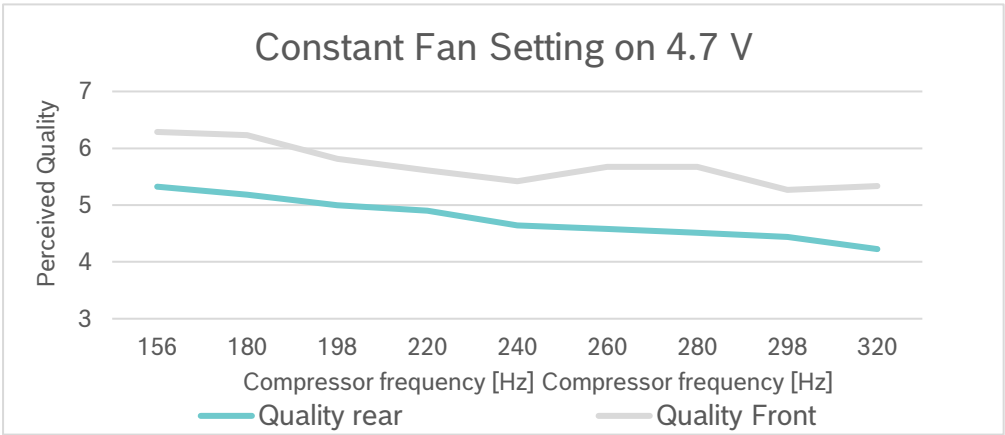
Analysis of Operating Conditions of CS7400AW - 4kW A7W35









- **Optimization of operating points possible (optimal fan/compressor speeds)**

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Summary / Key Messages

- **Four Major Challenges** for the heat pump industry
- **Acoustics Development** is significantly influenced by the TA Lärm
- **Acoustic Tools** available for installers and end customers
- **Acoustic Development of Heat Pumps**:
  - **Great progress** has been made in the past 5 years: 10 – 15dB sound reduction
  - **Meaningful lower limit reached**: Sound power at night <50dB(A)
  - **Psychoacoustics** considered during the development of heat pumps!
- **Advances in Psychoacoustics**: Annoyance model with good correlation (>90%)
- **Modern Heat Pumps** are already a useful solution for many old buildings.

- **Goal achieved: Heat pumps can be very quiet and sound pleasant**

Q&A

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Now it’s time for your questions!

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Thank you!

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