AUSTRIAN INSTITUTE OF TECHNOLOGY
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1D MODELLING OF HEAT PUMPS INCLUDING ACOUSTICS

Sound Source Extension Library

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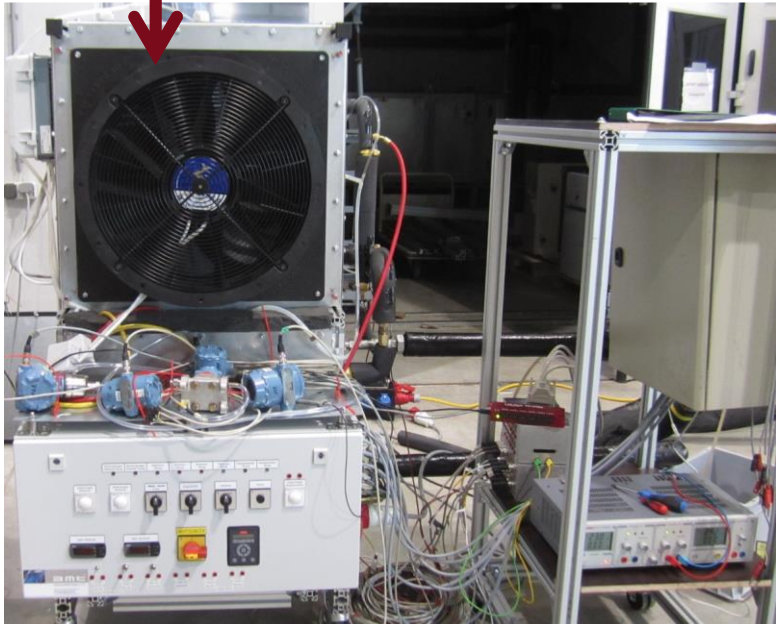
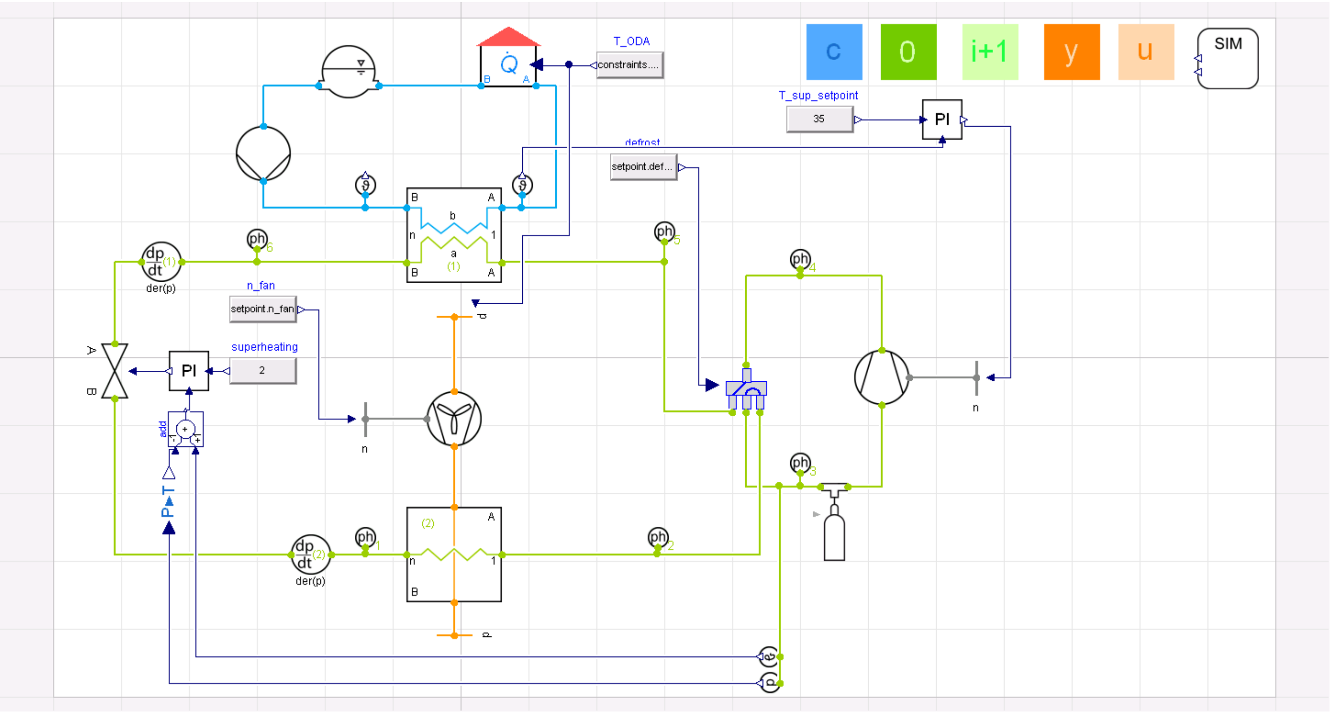
Why do we need do consider sound sources in system modeling?

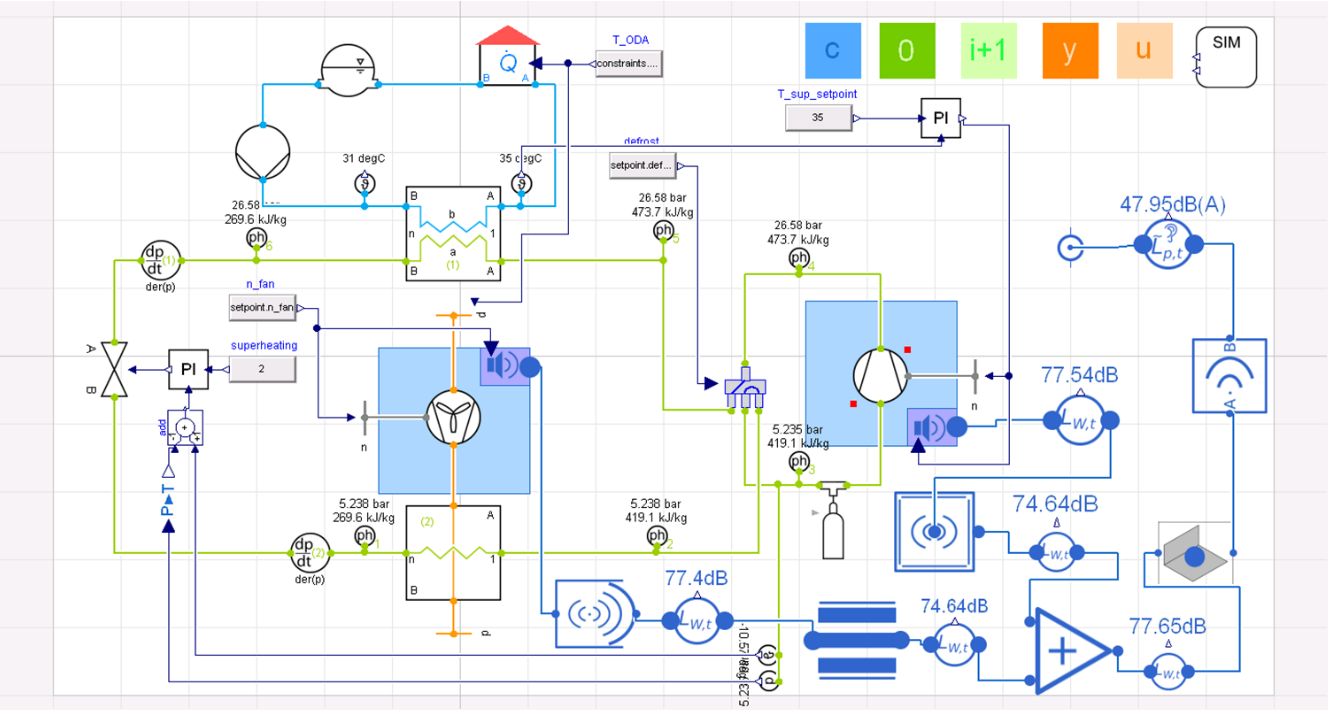
fan



compressor



Energetic heat pump heat pump cycle



Energetic heat pump heat pump cycle **extended** with sound characteristics

Agenda

- Theory of Sound Propagation in the SSElib
- Implementation to Modelica
- Examples
- Summary

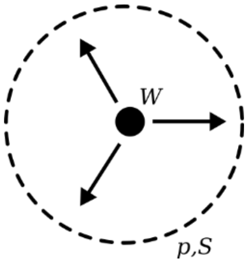
Theory of Sound Propagation in the SSElib

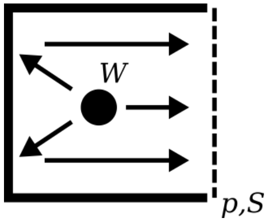
…let’s have a look at the equations

Assumptions

- All sound sources are independent point sources.
- The sound fields considered in the SSElib are assumed to be diffuse and incoherent in all frequencies.
- The discussed methods will be used as a first approximation of insertion losses in an enclosure even if the requirements are not always fulfilled

Theory of Sound Propagation in the SSElib





Spherical and 1-D sound propagation:

$$W = \overbrace{\frac{1}{\rho\, c}\; p_{rms}^{2}}^{\text{sound intensity}}\, S$$

sound power

enclosed surface

sound pressure

Theory of Sound Propagation in the SSElib

Spherical and 1-D sound propagation:

$$W = \overbrace{\frac{1}{\rho\ c}\ p_{rms}^{2}}^{\text{sound intensity}}\ S$$

sound power

“flow (conservation of energy)”

sound pressure

enclosed surface

“depend on location”

Theory of Sound Propagation in the SSElib

Sound properties are commonly used with logarithmic units:

$$L_W(\mathrm{dB}) = 10 \log \left(\frac{W}{W_0} \right) \qquad L_p(\mathrm{dB}) = 20 \log \left(\frac{p}{p_0} \right)$$

threshold of human ear

- In the SSElib, decimal units are used to describe the sound power in order to circumvent problems with negative logarithmic values.

  Negative logarithmic values have also positive decimal values. Hence the description of a reverse sound flow would had lead to the introduction of a flow direction variable.

- The logarithmic units are still accessible over sensors in the library.

Theory of Sound Propagation in the SSElib

Sound can be described in frequency bands (Fourier).

Therefore, sound power and sound pressure are described as vectors in the SSElib:

$$\boldsymbol{W} = \begin{pmatrix} W_1 \\ \vdots \\ W_i \\ \vdots \\ W_n \end{pmatrix}$$

Belongs to i-th center frequency

e.g. Center frequencies of the one-octave band:

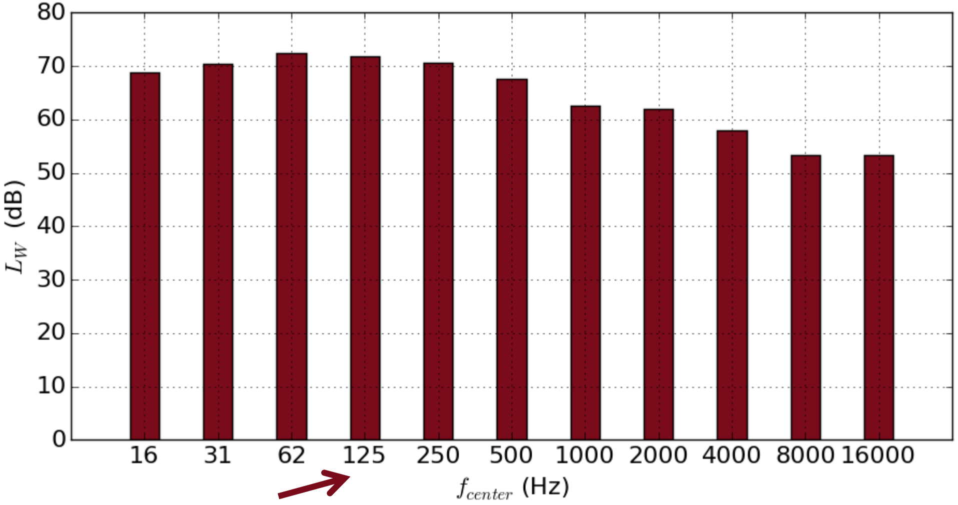
$$\boldsymbol{f_c} = (16{,}31.5{,}63{,}125{,}250{,}500{,}1000{,}2000{,}4000{,}8000{,}16000)^T$$

Sound is often analyzed in frequency bands as this information contain information about the human **perception**.

Theory of Sound Propagation in the SSElib

Sound power level of an experimental heat pump in the one-octave band

- Sound data as recorded with a microphone

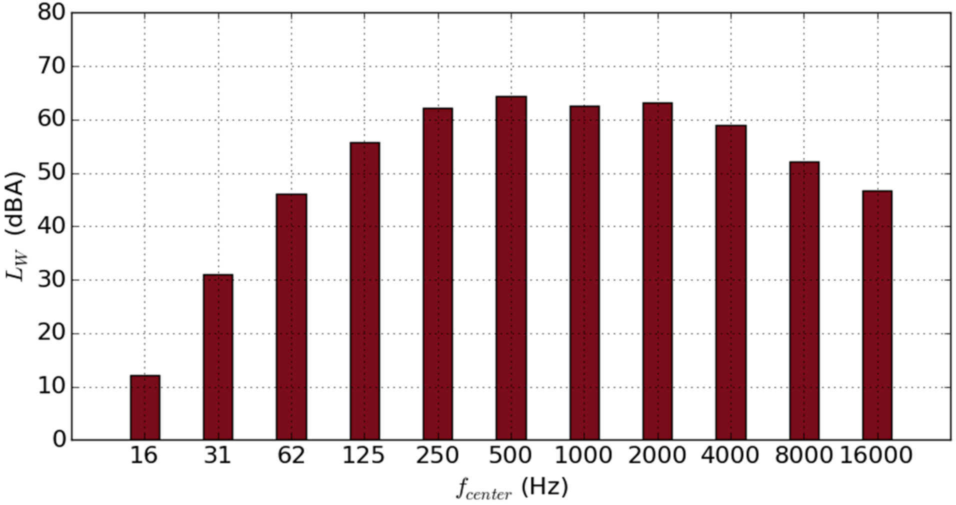


one octave band resolution

Theory of Sound Propagation in the SSElib

Sound power level of an experimental heat pump in the one-octave band

- Sound data was filtered to match the perception of the human ear

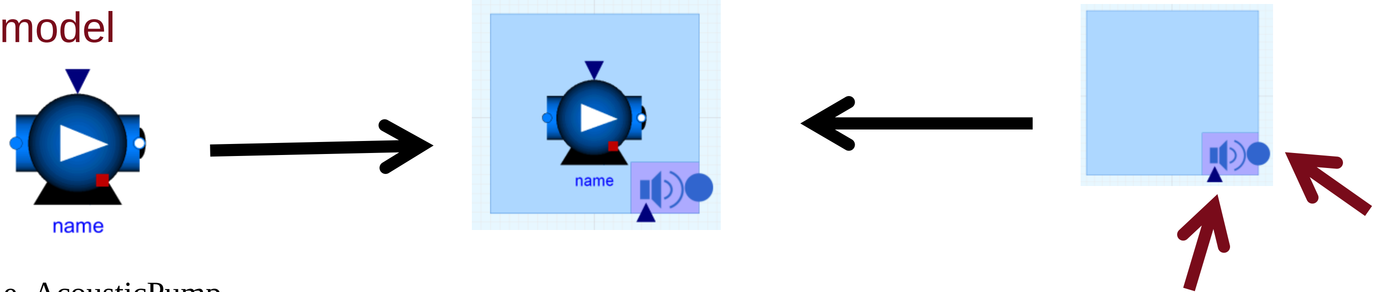


Implementation to Modelica

…let’s get it running

Implementation to Modelica

1. Create a new model for you acoustic component and extend it with the existing model and the acoustic extension



Existing model

Acoustic extension

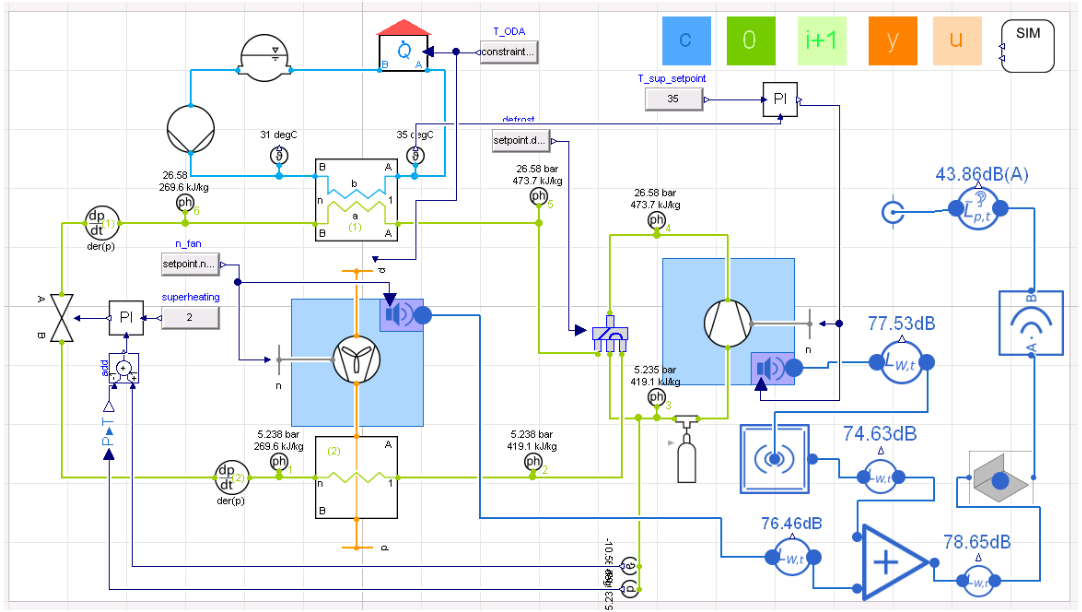
sound port

Independent sound input e.g. rotational speed

```
model Example_AcousticPump
  extends SSElib.SoundSourceExtension.AcousticExtensionOneOctave;
  extends Modelica.Fluid.Machines.PrescribedPump;
end Example_AcousticPump;
```

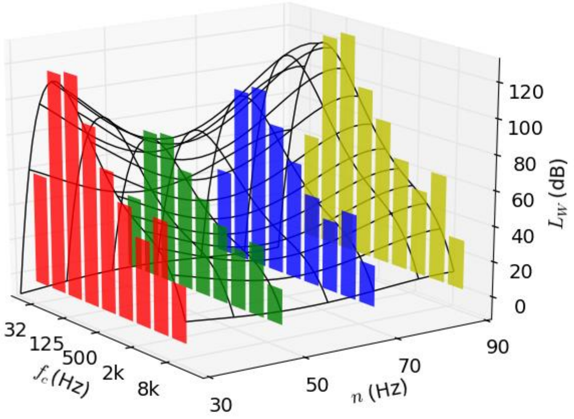
Implementation to Modelica

2. Use the new model instead of the existing model and connect the independent sound input and the sound port to the environment



Implementation to Modelica

3. Add your characteristic sound date to your components

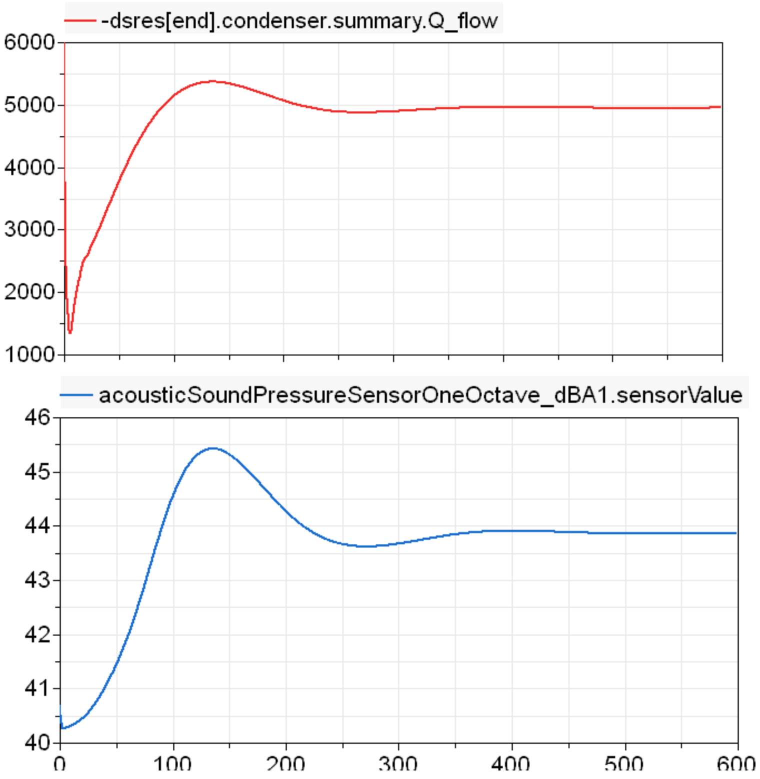


3rd or 4th order polynoms are used in the SSElib to describe the frequency dependent sound behavior. Their coefficients are parameters of the sound source.

Implementation to Modelica

Where we want to go:

Simulate realistic dynamic behavior



Summary

- We wrote a library to include acoustic behavior to existing models
- Priority was given to simplicity and fast computation
- Frequency dependence of sound was considered in the one-octave band
- Published under Modelica 2.0 licence

More information:

http://www.ep.liu.se/ecp/132/067/ecp17132605.pdf

(DOI: 10.3384/ecp17132605)

Download of SSElib:
https://2017.international.conference.modelica.org/proceedings/html/authors/author_66.html

Thank you for your attention!

Acknowledgement

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