SOUND ENERGY
thermo acoustic technology

NAG symposium "Geluid en energietransitie"

Woensdag 4 september

Geluid als medium voor energie conversie

kees de Blok

www.soundenergy.nl

Gewenst en ongewenst geluid

What is thermoacoustics?

How does heat create sound waves?

What can we do with thermoacoustics?

The practical embodiment

Were to apply thermoacoustic energy converters

Typical applications

The Products

Samenvatting en Conclusies

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Samenvatting en Conclusies

Forbes

192,750 views | Jan 18, 2019, 12:16pm

This Dutch Startup Converts Heat Into Cold Via A Stirling Engine, And Could Just Save The Planet

John Koetsier Contributor
Consumer Tech
John Koetsier is a journalist, analyst, author, and speaker.

Updated January 19 with expert commentary

By 2050, almost six billion air conditioners could eat 37% of global electricity, according to the International Energy

Gewenst en ongewenst geluid

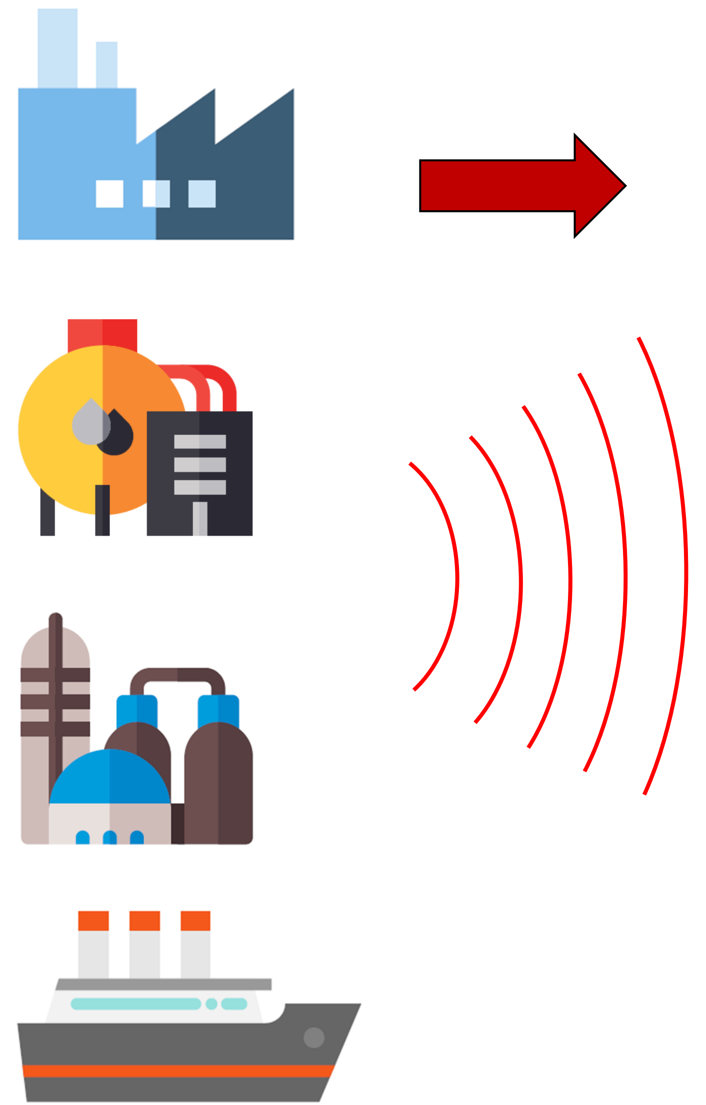
Bij de meeste natuurlijke activiteiten is het produceren van geluid het gewenste eindproduct als onderdeel van

- Conversatie
- Communicatie
- Oriëntatie
- Muziek
- etc.

Bij commerciële en industriële activiteiten is geluid vrijwel altijd een ongewenst bijproduct.

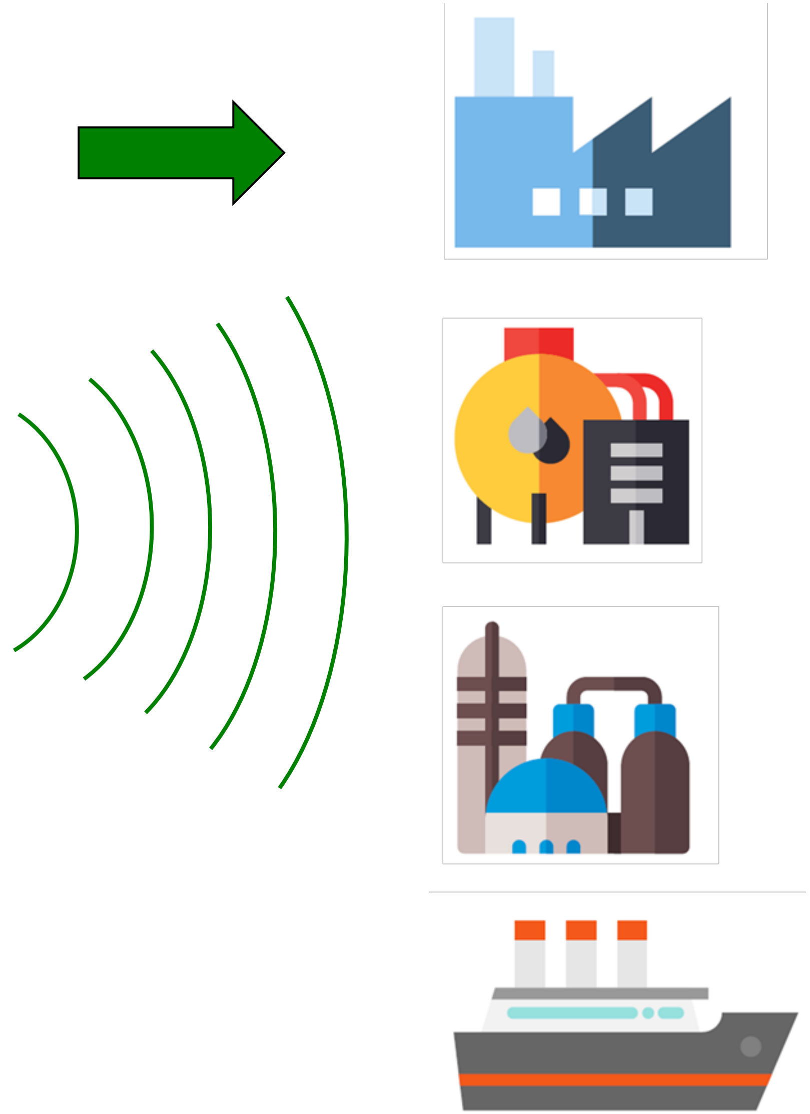
- Verkeer
- Warmtepompen
- Windturbines
- Industrie
- etc.

Geluid ontstaat in het algemeen bij de uitwisseling of omzetting van energie.



Gewenst en ongewenst geluid

Nuttig gebruik van geluid voor commerciële en industriële toepassingen



Relevante parameters hierbij zijn,

- Frequentie
- Intensiteit of golfamplitude

Hoog frequent

Ultrasoon

- Reinigen
- Bewerken
- Meten

Laag frequent + warmte

Thermoakoestische energie conversie

- **Benutten van zonne- en restwarmte**
- **Koude productie**
- **Genereren hoog akoestisch vermogen**
- …..

What is thermoacoustics?

Some history

Thermodynamics		
1656	Boyle	Ideal gas law
1763	Watt	Steam engine
1814	Carnot	Quality of heat
1816	Stirling	Stirling engine
1859	Rankine	Heat to work
1865	Clausius	Thermodynamic laws

Acoustics		
1850	Sondhausse	Heat driven oscillations
1859	Rijke	Heat driven oscillations
1878	Rayleigh	Theory of Sound

Cryogenics		
1940	Taconis	Oscillations in cryogen helium
1960	Gifford and Longsworth	Basic Pulse Tube Refrigerator

Related fields of science	
1831	Electricity (Farady)
1883	Fluid dynamics (Reynolds)
1900	Aerodynamics
1930	Radio & Microwaves
1960	Maser & Laser techniques

Over 150 years ago, Rayleigh understood that :

Lord Rayleigh, Theory of Sound, volumes 1&2

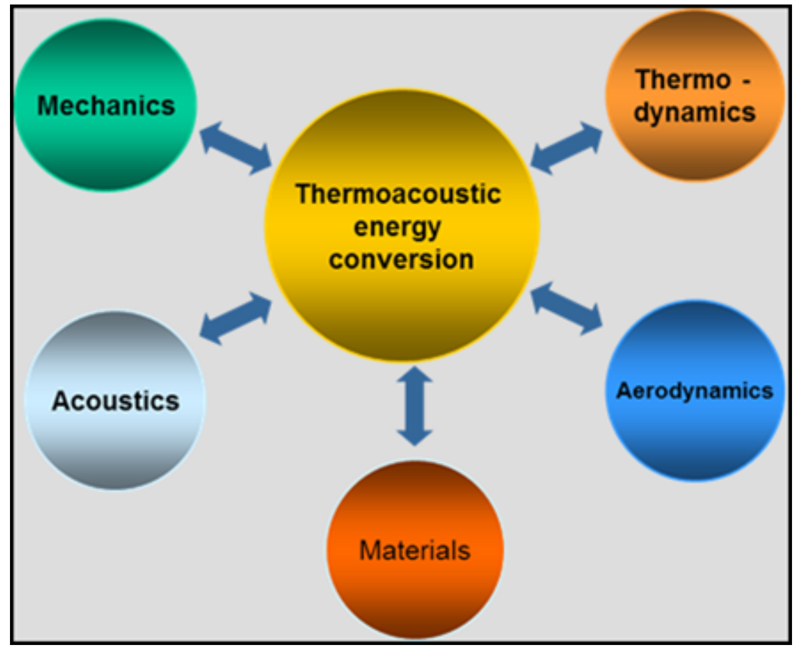
“if heat be given to the air at the moment of greatest condensation, or be taken from it at the moment of greatest rarefaction”, heating and cooling could create acoustic power

Rayleigh’s criterion is met in today thermoacoustic devices, converting heat into acoustic power (=mechanical power) and vice verse, converting acoustic power into a temperature lift.

What is thermoacoustics?

Energy conversion technology based on "classic" thermodynamic cycles in which compression, displacement and expansion of the gas is controlled by an acoustic wave instead of by pistons and displacers

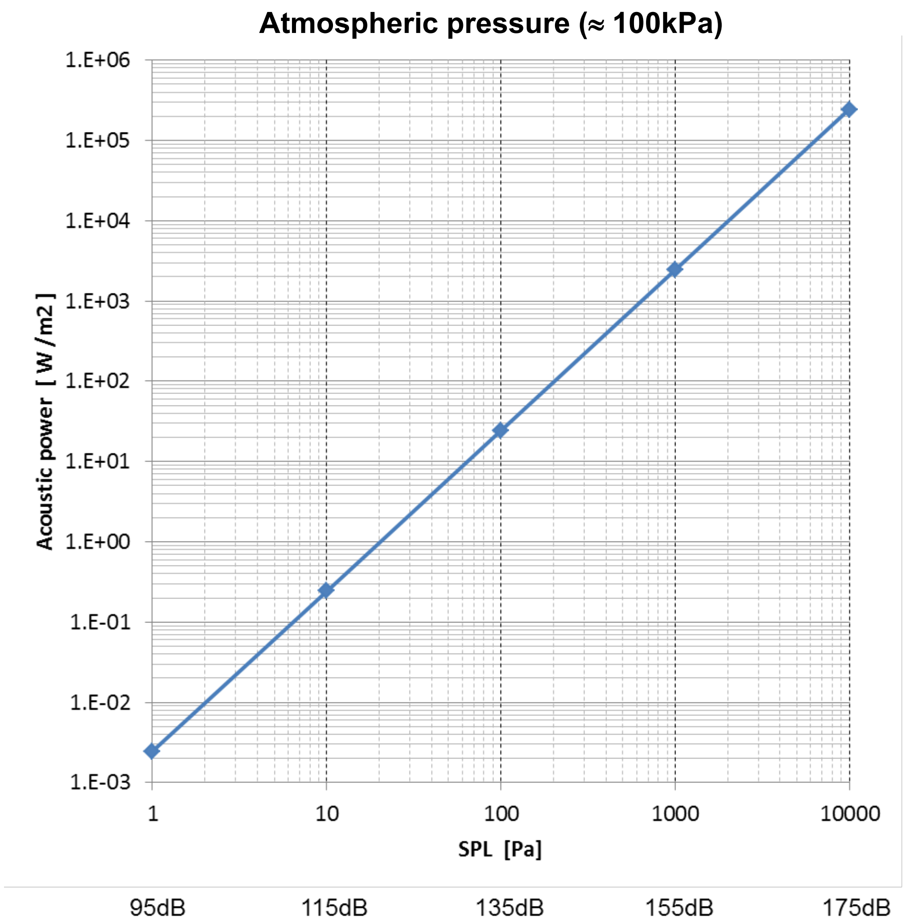
Involves multiple technology areas

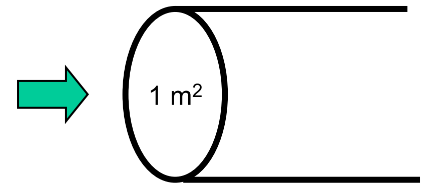


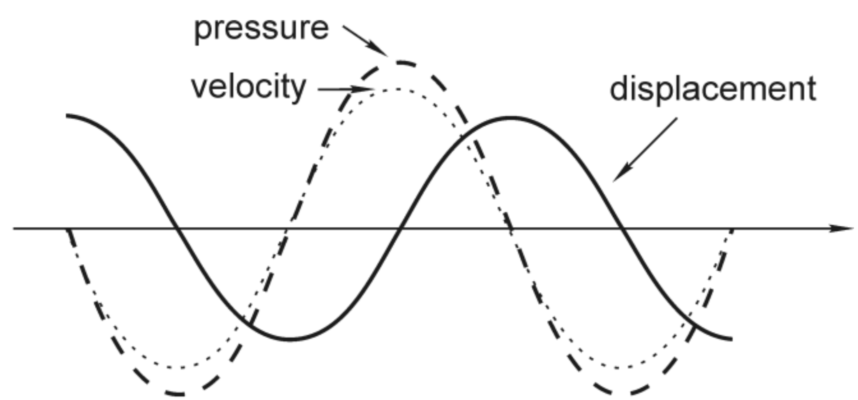
Typical characteristics

- No electricity
- No mechanical moving parts in the thermodynamic process
- Maintenance free
- Robust construction
- Large freedom of implementation
- Low noise
- High efficiency (>40% of the Carnot factor)
- Large temperature range
- Scalable from Watt's to MWatt's
- Inert gas like helium, argon or even air as working medium

Acoustic power ⇒ Pneumatic power ⇒ Mechanical power



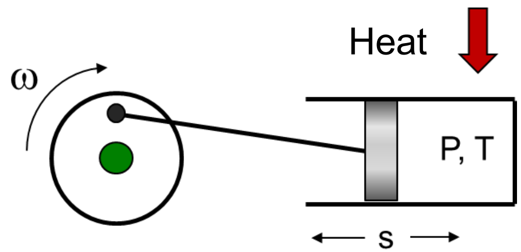




How does heat create sound waves?

The interaction between heat and sound is about cyclic compression and expansion with properly timed heat exchange.

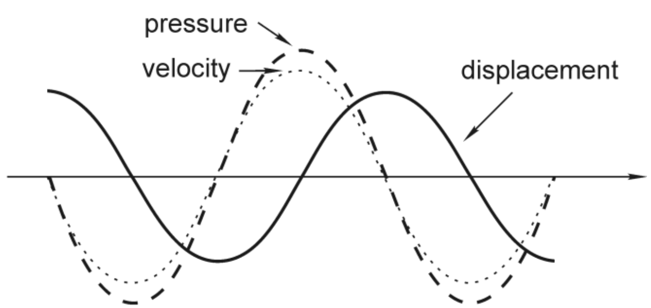
"Classic" by means of a classic by crank + piston

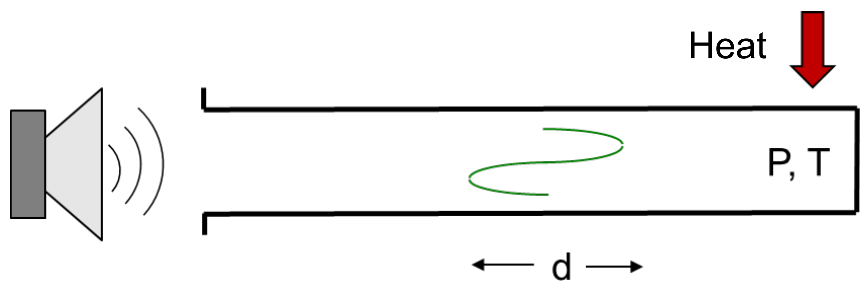


Heating the gas while compressed will raise pressure

- In the mechanical system this increases rotational output power
- In the acoustic system this increases acoustic output power

"Innovative" by means of gas motion in an acoustic wave



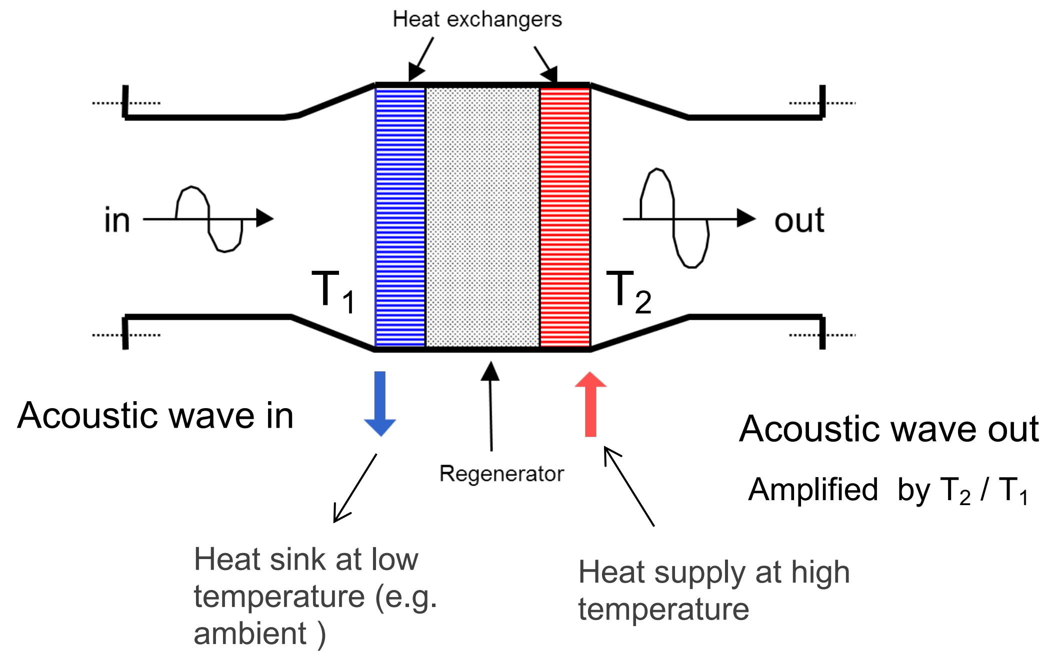


Gas displacement (d) in acoustic waves is similar to piston stroke (s) in mechanical compressors

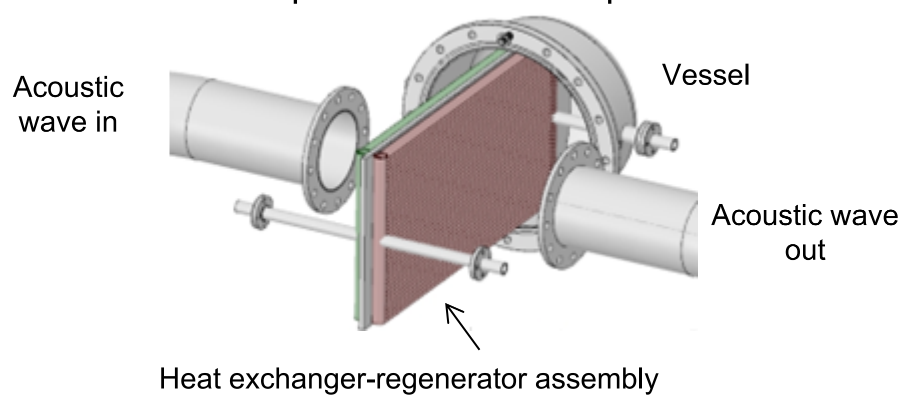
How does heat create sound waves?

Thermo Acoustic Energy Converter (TAEC) as Heat Engine

- Regenerator clamped between two heat exchangers
  - Heat supply at high temperature (T_2)
  - Heat rejected at lower temperature (T_1)
- Between heat exchangers there is a positive temperature gradient
- Acoustic power gain equals the ratio of the absolute temperatures of the heat exchangers $\Rightarrow T_2 / T_1$

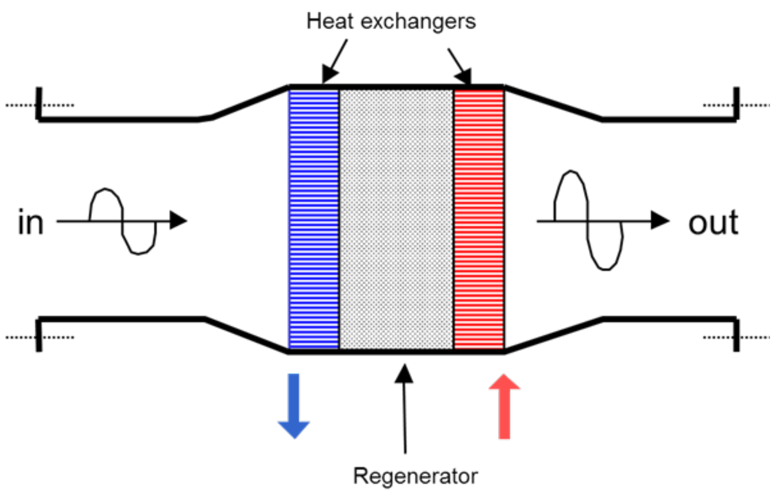


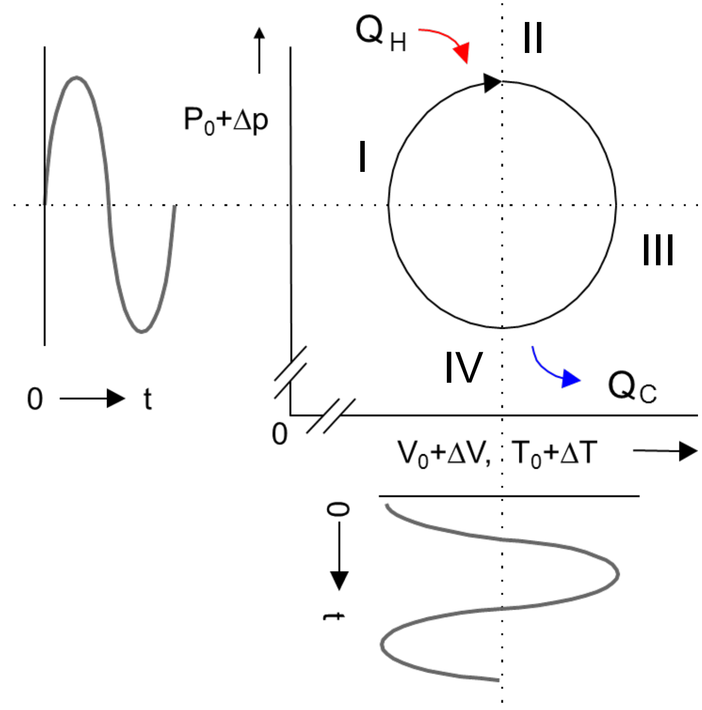
Implementation example



- **P-V diagram of a thermoacoustic engine**

  I compression
  II heat supply (Q_H) at high temperature
  III expansion
  IV heat sink (Q_C) at lower temperature





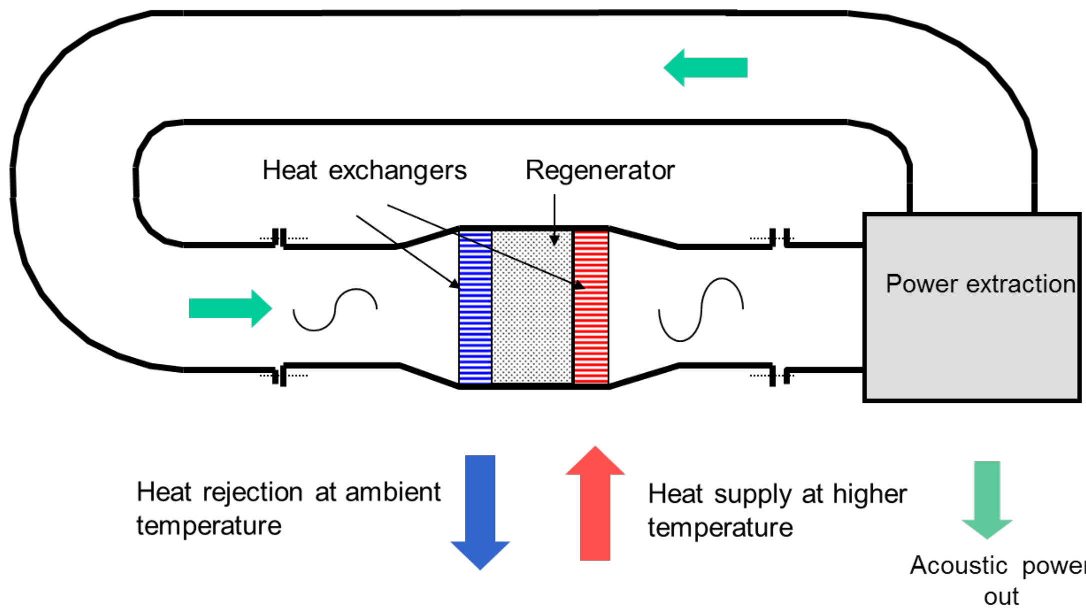
Timing (phase) between pressure, gas displacement and temperature is set by the local complex acoustic impedance inside the regenerator and the thermal response time.

How does heat create sound waves?

Basic geometry of a thermoacoustic heat engine

- In the heat exchanger-regenerator section, heat is converted into acoustic power in the feedback loop
- At a minimum (onset) temperature difference between both heat exchangers, natural disturbances (noise, Brownian movement) will start the oscillation at the fundamental frequency set by the (acoustic) length of the feedback loop
- Above this onset temperature, part of the acoustic power in the feedback loop can be extracted as useful acoustic (=mechanical) output

- Acoustic resonance and feedback circuit



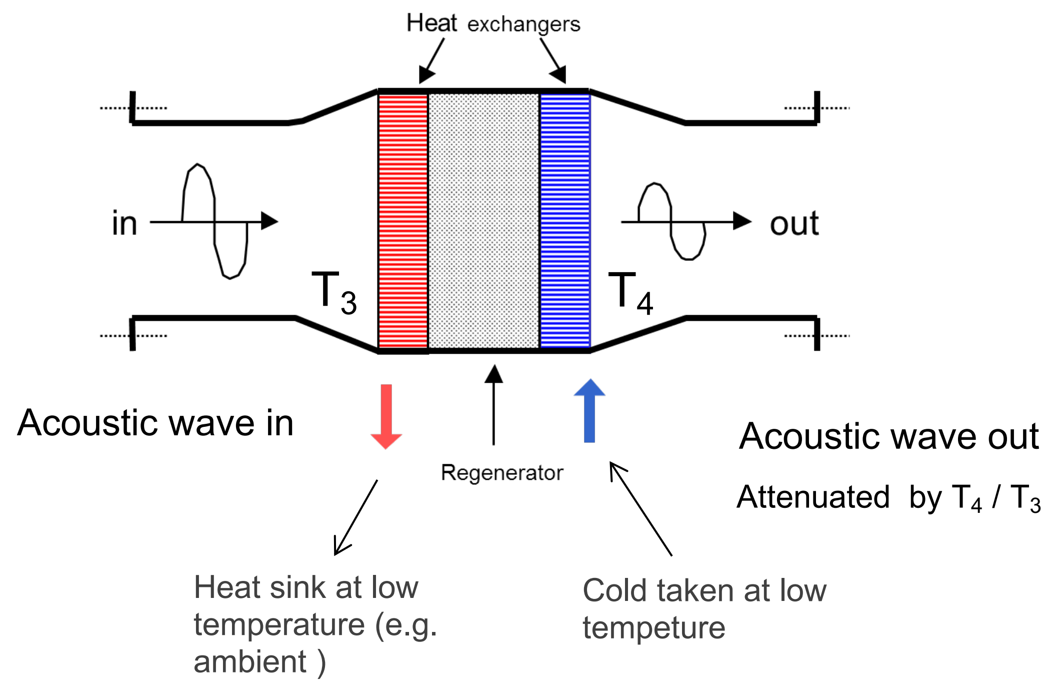
How does heat create sound waves?

Thermo Acoustic Energy Converter (TAEC) as Heat Pump

- Regenerator clamped between two heat exchangers
  - Heat absorption at low temperature (T_4)
  - Heat rejection at high temperature (T_3)
- Between heat exchangers there is a negative temperature gradient

⇩

- Acoustic attenuation equals the ratio of the absolute temperatures of the heat exchangers ⇒ T_4 / T_3



How does heat create sound waves?

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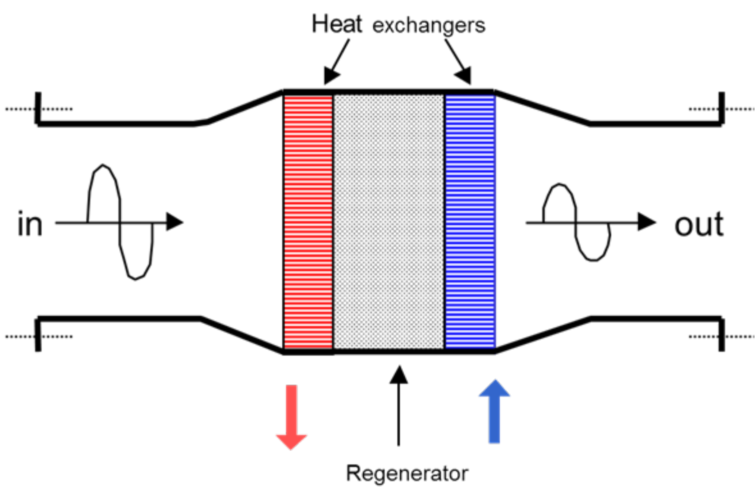
- **P-V diagram of a thermoacoustic heat pump**

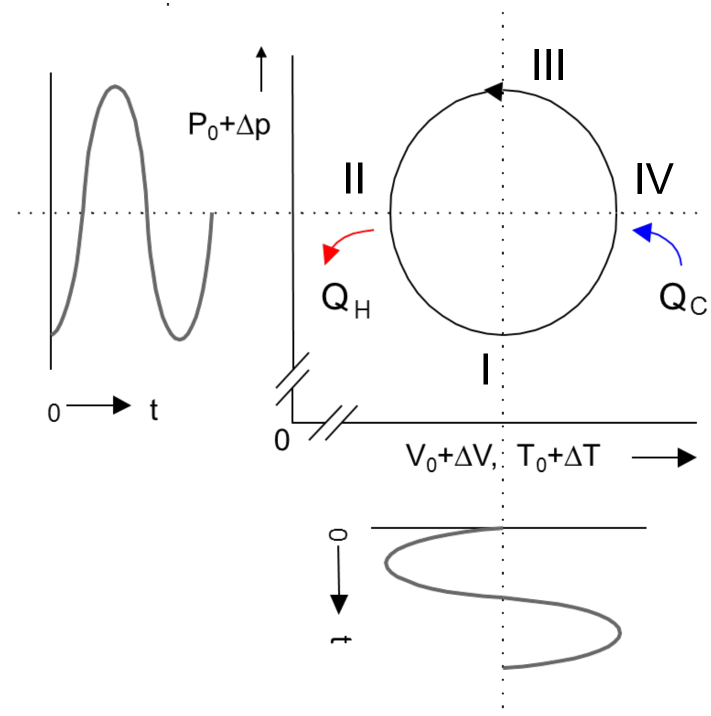
  I compression

  II heat rejection (Q_H) at high temperature left of the equilibrium position

  III expansion

  IV heat absorption (Q_C) at lower temperature rigth of the equilibrium position





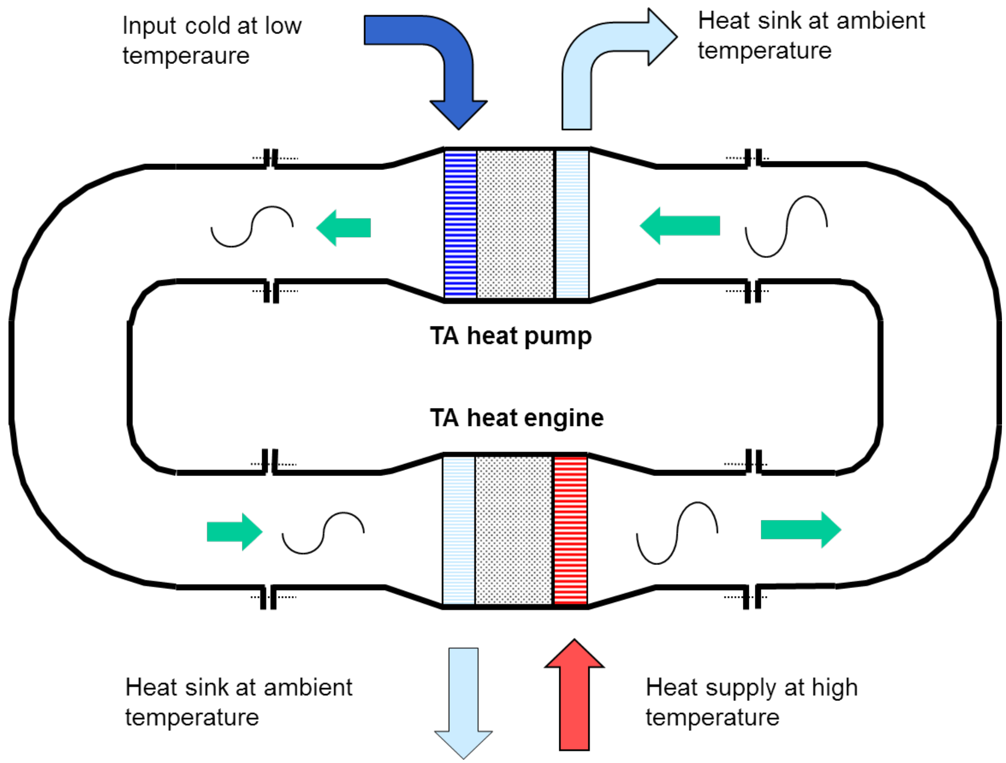
Timing (phase) between pressure, gas displacement and temperature is set by the local complex acoustic impedance inside the regenerator and thermal response time

How does heat create sound waves?

Basic geometry of a heat driven thermoacoustic heat pump

- Acoustic output power of the heat engine section is used to generate a temperature difference (temperature lift) between both heat exchangers of the heat pump section

- Cooling or heating is set by connecting the heat exchangers to the appropriate heat supply or heat sink circuit

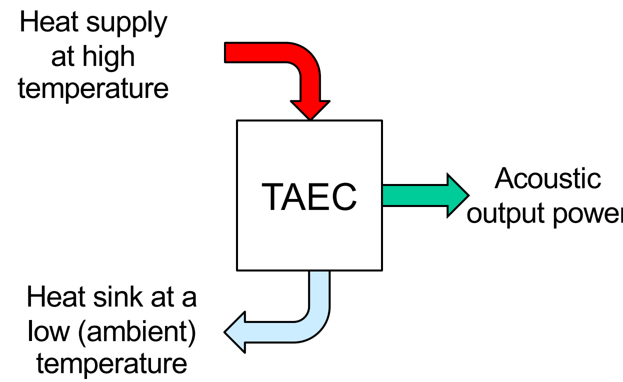


What can we do with thermoacoustics?

Converting heat into acoustic energy (= mechanical energy)

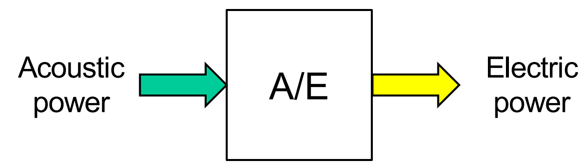
⇒ **Heat engine**

- Heat supply at high temperature from arbitrary heat source
- Onset temperature difference ≈ 30ºC
- Operating temperature difference 100ºC up to >300ºC



Converting the acoustic output power into electricity (optional)

- Linear alternator (loudspeaker)
- Bi-directional turbine

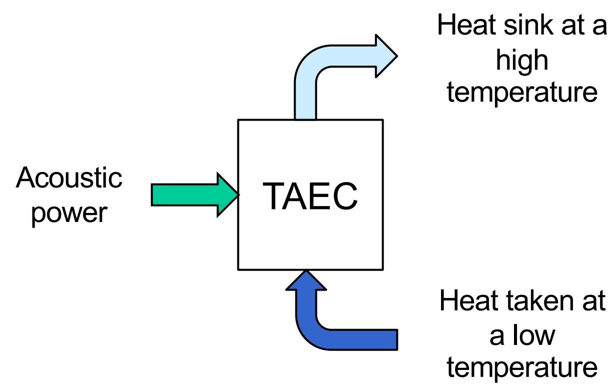


Converting acoustic energy into a temperature lift

(By reversal of the thermodynamic cycle)

⇒ **Heat pump or refrigerator**

- Temperature lift: > 80ºC
- Temperature range: -200ºC up to 250ºC



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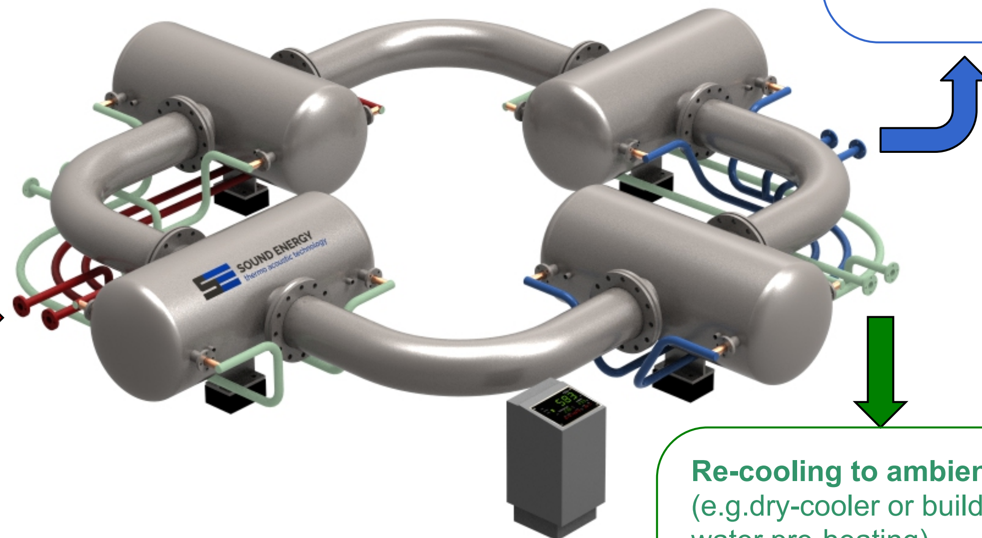
Converting solar heat directly into cold

Cold output
Typical temperature range for
- Cooling buildings: +8°C +12°C
- Cold storage: -8°C +8°C
- Ice production: < -20°C -5°C
- Water production: +15°C +25°C

Heat input from thermal solar collector array

Typical temperature range
100°C - 200°C



Re-cooling to ambient
(e.g.dry-cooler or building water pre-heating).

Typical temperature range
25°C - 50°C

Typical applications

Converting industrial or process waste heat directly into cold

Cold output

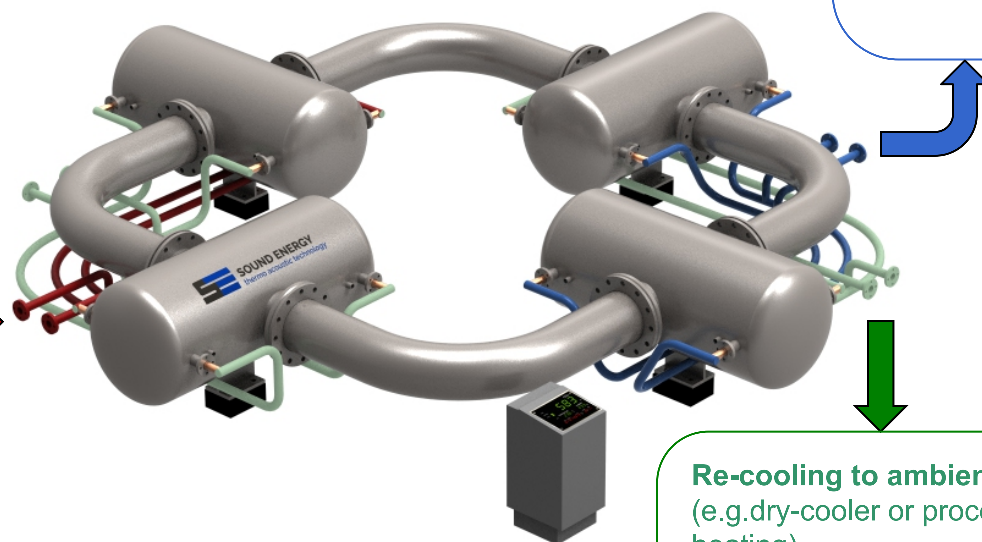
Typical temperature range for

- Buildings: +8°C +12°C
- Cold storage: -8°C +8°C
- Ice production: < -20°C -5°C
- Process cooling: < -20°C +15°C
- Gas liquefaction: -160 °C

Heat input from flue gas duct heat exchanger or directly from an industrial process

Typical temperature range

130°C - 300°C



Re-cooling to ambient
(e.g.dry-cooler or process pre-heating).

Typical temperature range

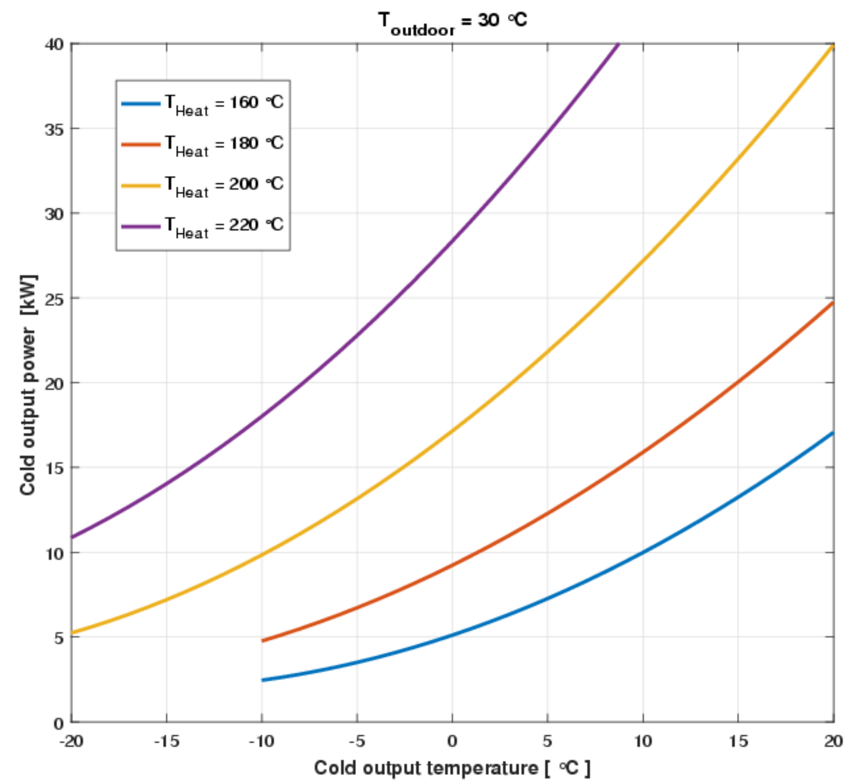
10°C - 50°C

The Product: THEAC-25-O

Sales THEAC-25-O

- Agriculture (UAE)
  - Solar heat powered water production
  - Solar heat powered storage cooling
- Coffee company (NL)
  - Flue gas heat powered air-conditioning
- School (NL)
  - Solar heat powered air-conditoning

Typical performance



The Product: THEAC-23-U (Container version)

Sales THEAC-23-U

- Bakery (NL)
  - Flue gas heat powered product cooling
- Supermarket (IT)
  - Tri-generation using genset exhaust gas
- Mobile cooling unit (NL/Mali)
  - Combined solar heat - flue gas cooling

Implementation example:

THEAC-23U + dry-cooler
Installed in 20ft container

Conclusie en Samenvatting

Geluid- of akoestische golven in gasmengsels kunnen worden toegepast voor

- **Het overdragen van energie**
  - Drukamplituden tot 10% van de gemiddelde gasdruk (10 - 40 bar)
  - Gassnelheden 1-30 m/s

- **Het besturen van thermodynamische kringprocessen**
  - Thermische responstijden < 1ms

Met als belangrijkste toepassing

- **Het direct omzetten van zonne- of industriële restwarmte in koude zonder elektrische of mechanische tussenstappen**