Final report

1.1 Project details

Project title	EUDP-11-II, Fremtidens Chiller Teknologi
Project identification (program abbrev. and file)	EUDP, journal number 64011-0329
Name of the programme which has funded the project	Energiteknologisk Udviklings- og Demonstrations Program (EUDP). Området: Energieffektivitet Energy Technology Development and Demonstration Area: Energy efficiency
Project managing company/institution (name and address)	Johnson Controls Denmark Chr. Den X´s Vej 201 DK-8270 Hoejbjerg
Project partners	Johnson Controls Denmark LEGO Rambøll
CVR (central business register)	19056171
Date for submission	May 15, 2018

1.2 Short description of project objective and results

The project objective has been to demonstrate application of new chiller technology in real field application. The technology is based on 10 years of research on a unique, competitive, energy efficient and nonpolluting chiller unit using water as refrigerant. The project has demonstrated this successfully with a water vapor chiller up running at LEGO facility in Billund, Denmark. The chiller has a cooling capacity of approximately 850 kW, cooling water around +9ºC. The key challenge in using water as primary refrigerant is the low density and thereby required high swept volume of the compressor. The heart of the chiller is a unique, axial multi-stage compressor, developed solely for this purpose. The compressor, driven by a 160 kW high speed motor, has shown performance (capacity and efficiency) as expected and has the potential to be on level with best of conventional technologies. Compared to best available current technology, a Sabroe ChillPAC112L ammonia based chiller, current as-is efficiency of the water vapor chiller is somewhat lower but potential for optimization has been clearly identified with the potential to bring it up to same level.

Selecting a fair baseline for a COP comparison is an open discussion. Some conventional technologies may become obsolete over the next years due to restrictions on refrigerants for reasons of greenhouse impact (HFC) or safety issues (toxicity or flammability). In some applications, this may leave water vapor as the technology with the highest efficiency.

In addition, heat exchanger design, evaporator and condenser deviates substantially form conventional technology by its “falling rain” direct evaporating/condensing principles. The project has demonstrated feasibility of the heat exchanger designs.

The control system is also completely new as the control parameters and algorithms deviate substantially from conventional chillers. Operation of a multistage turbo compressor close to the stall limit is required for optimum performance but also a challenge not resolved this way before in refrigeration industry. The control system has proven capability to ensure safe, reliable and fully automated operation of the chiller.

Durability has also been a focus area for the demonstration chiller. Though a number of pauses of operation has been required to upgrade the design of the chiller a total of 3,000 hours has been achieved by May 2018.

Manufacturing cost of the demonstration chiller was obviously much higher than what is expected to for a mature product manufactured in a significant volume. However, to change the water vapor chiller from a niche product into a mainstream product further cost reduction by design changes are required.

1.3 Executive summary

Refrigeration and Air-Conditioning amounts a steadily increasing share of global energy consumption and thereby contributes significantly to global warming. Besides impact from energy consumption, the use of synthetic refrigerants with high greenhouse effect (GWP) may contribute with as much as 0.5C of total warming in year 2100. The Kigali agreement sets targets for phase down on HFC usage and the search for safe, natural and low GWP refrigerants and technologies has become even more intense since the project started. As the project overall has been successful Johnson Controls intend to take the water vapour technology further into the market for refrigeration, heat pumps and eventually derived applications like process drying outside our usual business.

1.4 Project objectives

The particular objective of projects has been to bring the water vapour technology out of the laboratory into a real field application. This to demonstrate the practical feasibility and reliability of the technology. During the test period a number issues has been encountered and resolved:

Compressor focus has in particular been on below topics:

- Vibration. The rotor is to some extend flexible and combined with high rotational speed requirements for dynamic balancing is extremely demanding. Vibration and related issues has been the major cause for delays in operation.
- Bearings are water lubricated as avoidance of oil or other substances has been a key design objective. However, viscosity of water is low and requires high precision of bearings. A modified version with advanced surface treatment has been installed to ensure durability.
- Erosion of rotor blades has been a concern from the design phase. Some damage to first stage rotor was observed, mainly caused by water droplets entering during the commissioning phase. The issue has to some extent, been resolved though long-term erosion remains to be observed.

Chiller:

- Pressure of water vapour at operation conditions is below 0.05 bar, i.e. the entire chiller is under high vacuum and air contamination must be kept on a low level. A patented air purge system has proven capable of keeping air content low. However, some operational issues with vacuum pumps and water traps has been found and will be modified in the next builds of water vapour chillers.
- Water treatment. The direct evaporating concept eliminates fouling issues on heat exchangers. However, in a closed loop system it also imposes a concentration of minerals on the evaporator side where a distillation of the water takes place. Therefore monitoring of water condition is important for the reliable operation of the chiller. Valuable experience has been gained during the test.

1.5 Project results and dissemination of results

Overall, the project results has met expectations. The chiller is now operating at full capacity and is approaching 3,000 working hours. Energy efficiency is as expected on level with state-of-art alternatives adding the benefits of water being a safe, natural, non-toxic, non-flammable, non-pressurized refrigerant. However, manufacturing cost of the chiller still exceeds conventional alternatives.

1.6 Utilization of project results

Due to the yet higher cost of water vapour, technology will initially be seen as a niche technology. Application within heat pump segment seem especially interesting right now and next installations will target this segment.

1.7 Project conclusion and perspective

The project has demonstrated the feasibility of the water vapour technology and our believe in its potential remains undiminished.

Annex

Water vapour EUDP presentation

Dansk resume:

Projektets formal har været at demonstrere vanddamp som kølemiddel i en praktisk anvendelse. Vanddamp har som kølemiddel helt unikke egenskaber i kraft af at være miljø- og klimaneutralt, ikke-brændbart og under de givne driftsforhold trykløst. Målet har været at eftervise energieffektivitet såvel som at opnå driftserfaring. Den opnåede systemvirkningsgrad (COP) er på linje med mange gængse teknologier, men pt. dog lidt lavere en den mest effektive reference, en ammoniakbaseret Sabroe ChillPAC chiller. Der er i projektet identificeret energioptimeringspotentiale så vanddamp teknologi med den rette udviklingsindsats vil kunne opnå samme høje virkningsgrad som bedste referenceteknologier.

Vanddamp chilleren har per maj 2018 opnået cirka 3000 driftstimer efter installationen hos LEGO i 2016. Der har undervejs været driftspauser for at modificere anlægget ud fra driftserfaringer. Særligt vibrationer omkring den centrale komponent, en nyudviklet high-speed flertrins aksial kompressor, har givet udfordringer. Disse ser nu ud til at være løst så anlægget kan køre fuldautomatisk ved højeste kapacitet.

Kostprismæssigt er vanddamp teknologien stadig umoden og derfor er den aktuelle kostpris for en vanddamp chiller markant højere end gængse alternativer. Johnson Controls forventer dog på sigt at kunne bringe kostprisen ned på et konkurrencedygtigt niveau. Og set i lyset af voldsomt pres for udfasning af syntetisk kølemidler, jævnfør Kigali aftalen, forventer vi at vanddamp teknologien gradvist vil bevæge sig fra et nichemarked til at blive ét af kerneprodukterne i Johnson Controls Denmarks portefølje af løsninger baseret på naturlige kølemidler.