Environmental Product Declaration

Trane Centrifugal Chillers

CenTraVac® water-cooled chillers - Models CVHF and CDHH

Agility® water-cooled chiller - Model HDWA

CERTIFIED
ENVIRONMENTAL PRODUCT DECLARATION
UL.COM/EPD

EPD PROGRAM AND PROGRAM OPERATOR NAME, ADDRESS, LOGO, AND WEBSITE	UL Environment 333 Pfingsten Rd, Northbrook, IL 60062 www.ul.com www.spot.ul.com
GENERAL PROGRAM INSTRUCTIONS AND VERSION NUMBER	Program Operator Rules v 2.7 2022
MANUFACTURER NAME AND ADDRESS	Trane Technologies, 800-E Beaty Street, Davidson, NC 28036 USA
DECLARATION NUMBER	4790566295.101.1
DECLARED PRODUCT & FUNCTIONAL UNIT OR DECLARED UNIT	One (1) ton of chilling capacity
REFERENCE PCR AND VERSION NUMBER	UL PCR Part A: Life Cycle Assessment Calculation Rules and Report Requirements (2022 v 4.0) UL PCR Part B: Water Cooled Chiller EPD Requirements (2018 v2.0)
DESCRIPTION OF PRODUCT APPLICATION/USE	Water Cooled Chiller Systems
PRODUCT RSL DESCRIPTION (IF APPL.)	ESL (75 years); RSL (25 years)
MARKETS OF APPLICABILITY	Global
DATE OF ISSUE	Febuary 1, 2023
PERIOD OF VALIDITY	5 Years
EPD TYPE	Product specific
EPD SCOPE	Cradle to grave
YEAR(S) OF REPORTED PRIMARY DATA	2019, 2020, 2021
LCA SOFTWARE & VERSION NUMBER	SimaPro v.9.4.0.1
LCI DATABASE(S) & VERSION NUMBER	Ecoinvent 3.7.1
LCIA METHODOLOGY & VERSION NUMBER	TRACI 2.1 v1.06 ; IPCC 2013 v1.03 ; CML-baseline, v4.7
The PCR review was conducted by:	UL Environment PCR Review Panel epd@ul.com
This declaration was independently verified in accordance with ISO 14025: 2006. ☐ INTERNAL ☒ EXTERNAL	Cooper McC Cooper McCollum, UL Environment
This life cycle assessment was conducted in accordance with ISO 14044 and the reference PCR by:	Aspire Sustainability
This life cycle assessment was independently verified in accordance with ISO 14044 and the reference PCR by:	James Mellentine, Thrive ESG

LIMITATIONS

Exclusions: EPDs do not indicate that any environmental or social performance benchmarks are met, and there may be impacts that they do not encompass. LCAs do not typically address the site-specific environmental impacts of raw material extraction, nor are they meant to assess human health toxicity. EPDs can complement but cannot replace tools and certifications that are designed to address these impacts and/or set performance thresholds – e.g. Type 1 certifications, health assessments and declarations, environmental impact assessments, etc.

Accuracy of Results: EPDs regularly rely on estimations of impacts; the level of accuracy in estimation of effect differs for any particular product line and reported impact.

Comparability: EPDs from different programs may not be comparable. Full conformance with a PCR allows EPD comparability only when all stages of a life cycle have been considered. However, variations and deviations are possible". Example of variations: Different LCA software and background LCI datasets may lead to differences results for upstream or downstream of the life cycle stages declared.

1. Product Definition and Information

1.1. Description of Company/Organization

Trane Technologies®, is a world leader in heating and cooling systems, services and solutions. Together with our brands, Trane ® and Thermo King®, we bring efficient and sustainable climate innovations to buildings, homes and transportation.

Trane helps customers succeed by providing innovative solutions that optimize indoor environments through a broad portfolio of energy-efficient heating, ventilating and air conditioning systems, building, contracting and energy services, parts support and advanced controls for homes and commercial buildings.

Trane serves engineers, contractors and building owners on all continents and in an array of markets including education, healthcare, government, industrial/manufacturing, data centers, lodging, retail and commercial real estate. With more than 900 U.S. patents to date, Trane creates comfortable and energy-efficient environments around the world.

Trane systems and services have a reputation for reliability, high quality and advanced innovation; and are available through a powerful distribution network. Trane employees and distributors are respected industry-wide for their skills and performance in designing, manufacturing, marketing and supporting commercial and residential systems.

1.2. Product Description

Product Identification

A liquid cooled centrifugal chiller is a machine that moves heat from a source liquid loop to a sink liquid loop via a vapor-compression cycle. The source liquid can then be circulated through a heat exchanger to cool air or equipment as required. The heat in the sink liquid loop can be rejected to the atmosphere by a cooling tower. This study represents six individual chillers covering three product model lines manufactured in two regions, US and China.

CVHF [Product Family - CenTraVac® Water-cooled Chillers]

The low-pressure direct-drive multistage design delivers upward of 13.5% better efficiency as compared with other centrifugal chillers. CAPACITY: 120 to 2,000+ tons, 60/50 Hz.

- Semi-hermetic motor design, along with low-pressure refrigerant, provide low refrigerant leak rates
- Multiple stages of compression provide surge resistance and overcome high head-pressure conditions, ensuring more consistent comfort levels across a wide range of applications
- Efficiency-enhancing features, such as an integrated flash economizer, improve cycle efficiency by 5% to 7%, delivering industry-leading efficiency for low life-cycle costs
- Sustainability enhancing features, such as free cooling or heat recovery
- Connectivity, flexibility and serviceability enabled by factory installed Symbio 800 unit controller

CDHH [Product Family - Duplex® CenTraVac® Water-cooled Chillers]

With a series counterflow design and dual independent refrigerant circuits, the Duplex® chiller reduces energy consumption by up to 13% over a single-compressor unit. CAPACITY: 1,500 to 4,000+ tons, 60 Hz; 1,200 to 4,000+ tons, 50 Hz.

- Semi-hermetic motor design, along with low-pressure refrigerant, provide low refrigerant leak rates
- Multiple stages of compression provide surge resistance and overcome high head-pressure conditions, ensuring more consistent comfort levels across a wide range of applications
- Efficiency-enhancing features, such as an integrated flash economizer, improve cycle efficiency by 5% to 7%, delivering industry-leading efficiency for low life-cycle costs
- Sustainability enhancing features, such as free cooling or heat recovery
- Connectivity, flexibility and serviceability enabled by factory installed Symbio 800 unit controller

HDWA [Product Family - Agility® Water-cooled Chiller]

Combining efficiency, reliability and compact size, the Agility® chiller meets a wide range of rigorous conditions to improve building performance. CAPACITY: 175 to 425 tons, 60/50 Hz.

- Option to optimize with next-generation low-GWP refrigerant R-513A, which provides a 55% lower GWP than R-134a
- Fits through a standard double door (72 in. x 80 in.) fully assembled and can be separated into two sections that fit through a single door (36 in. x 80 in.), making it ideal for retrofitting existing buildings
- Utilizes oil-free magnetic bearings with optimized compressor speeds
- Operates at a medium pressure, which allows it to occupy a smaller footprint

1.3. Product Specification

The appropriate ASTM or ANSI product specification shall be provided, including additional pertinent physical properties and technical information.

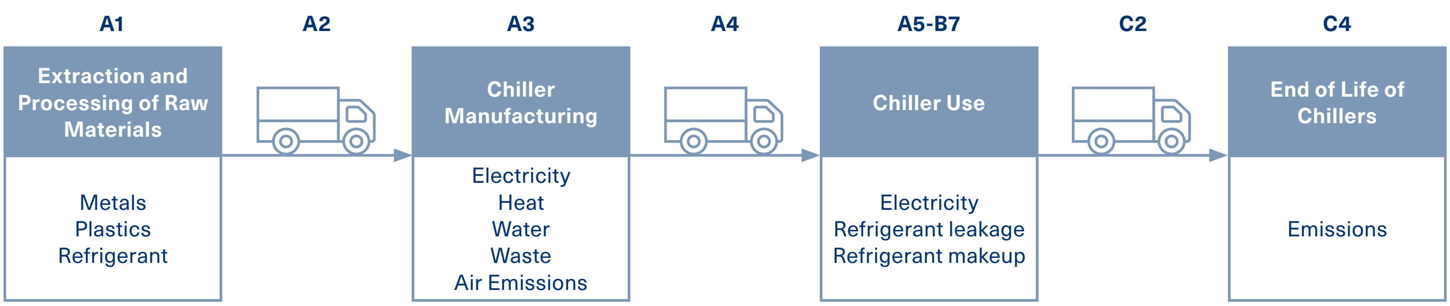
The rating and testing of chillers used in comfort cooling applications are governed by the following Standards:

- AHRI Standard 550/590 (I-P)-2020 with Addendum 3: Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle
- ANSI/ASHRAE Standard 147-2019: Reducing the Release of Halogenated Refrigerants from Refrigerating and Air-Conditioning Equipment and Systems
- ANSI/ASHRAE Standard 140-2017: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs
- ANSI/ASHRAE Standard 34-2019: Designation and Safety Classification of Refrigerants

Additional information on certifications: https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/equipment/chillers/water-cooled/centrifugal-liquid/CTV-PRC021C-EN_09062022.pdf

1.4. Flow Diagram

This flow diagram illustrates life cycle input/ output and activities for one water-cooled centrifugal chiller representative of the entire product family.



1.5. Product Average

The chiller models considered in the "average model" declared in this EPD are manufactured in the United States and China. This EPD is intended for business-to-business (B2B) communication in these markets. According to the guiding PCR this study is considered a manufacturer group declaration, as it is a declaration on an average product as an average from several manufacturing plants.

This is an EPD for three Trane chillers each manufactured in two locations including: **LAX CDHH 3050 Ton 50Hz with Starter, LAX CVHF 760 Ton 60Hz with AFD, LAX HDWA 400 Ton 60Hz with AFD, TC CDHH 3050 Ton 50Hz with Starter, TC CVHF 770 Ton 60Hz with AFD, TC HDWA 400 Ton 50Hz with AFD**. The chillers are manufactured in La Crosse, WI, USA (LAX) and Taicang, China (TC). The 3 models selected - CVHF, CDHH and HDWA represent the top selling units within the 3 major product families of Centrifugal water cooled chillers respectively - Simplex, Duplex and Agility. The 2 locations selected – La Crosse, USA and Taicang, China are the primary manufacturing locations for these 3 models. The overall result is a weighted average across all six chillers based on average production volumes from years 2019, 2020 and 2021.

1.6. Application

The function of the represented chillers is to provide chilled water for cooling a commercial building.

1.7. Declaration of Methodological Framework

This is a product specific EPD. Per PCR Part B specifications, a cradle to grave system boundary is considered in this study including life cycle stages A1-A5, B1-B2, B4, B6, C2 and C4. B3, B5, B7, C1 and C3 are not applicable for the chiller products and were excluded. The estimated service life is 75 years including replacement of the product at the reference service life of 25 years.

1.8. Technical Requirements

The cooling capacity of the weighted average chiller is 1,185 tons. Average annual energy usage for a given region or location was calculated using specific categories of performance. The four categories being evaluated are those defined by Air-Conditioning, Heating and Refrigeration Institute (AHRI) Standard 550/590-2019 (ASHRAE, 2019) and include energy efficiency as shown in the table below.

Table 1: Technical Data: Water Chilled Coolers

NAME	VALUE	UNIT
Chilled Capacity	1,185.62	tons of refrigeration (weighted average chiller)
Energy Efficiency	100% load at 85^{0}F 75% load at 75^{0}F 50% load at 65^{0}F 25% load at 65^{0}F	kw/ton at load % and entering condenser water temperature

In addition to the load percentages, the annual hours of operation were determined. This formula has been tested in compliance with (American National Standards Institute/ American Society of Heating, Air-Conditioning, and Refrigerating Engineers (ANSI/ASHARE) Standard 140-2020, 2020) and was approved for use by UL.

1.9. Properties of Declared Product as Delivered

Weighted average dimensions of the 6 chillers are as follow: width: 3.70 m (145.7 in); length: 4.11 m (161.8 in); height: 2.73 m (107.3 in).

1.10. Material Composition

Detailed material information was collected for every sub-assembly of each chiller down to individual components. This approach allows sub-assemblies to be modeled separately and to be used in different chiller models in order to understand the environmental impacts of a large portion of the existing chillers produced by Trane as well as potential new chillers.

When selecting representative unit processes from ecoinvent, cut-off library, flows were customized based on the type of alloy and recycled content, to represent the characteristics of actual input raw materials to the greatest extent possible. Recycled content of aluminum and steel were collected directly from the materials supplier for both manufacturing locations

Table 2: Chiller Weighted Average Bill of Materials by Subassembly

SUBASSEMBLY	TOTAL WEIGHT (KG)	ALUMINUM	BRASS	CAST IRON	COPPER	STEEL	OTHER MATERIALS
Compressor & Motor	5805.733	377.311	2.820	3647.017	76.152	1693.543	8.887
Condenser Copper Tubes	1938.281	0.0	0.0	0.0	1938.281	0.0	0.0
Condenser Shell & Waterboxes	2247.314	0.0	0.675	0.081	0.027	2244.742	1.26
Control Panel	383.7	0.0	3.5	0.8	103.1	173.8	102.4
Evaporator Copper Tubes	1769.5	0.0	0.0	0.0	1769.5	0.0	0.0
Evaporator Shell & Waterboxes	4381.6	0.0	0.3	0.1	4.9	4374.1	2.2
Economizer	472.9	0.0	0.1	0.0	0.2	472.3	0.3
Lubricant	56.3	0.0	0.0	0.0	0.0	0.0	56.3
Oil Tank	381.0	3.3	6.1	13.4	10.7	343.7	3.8
Purge	96.5	2.4	2.6	0.6	16.9	65.4	8.8
Starter	284.6	0.0	0.0	0.0	0.0	147.8	136.8
AFD	709.7	0.0	0.0	0.0	0.0	376.0	333.8
AFD Cooler	8.1	0.0	0.5	0.8	0.3	5.0	1.6
Unit Assembly	1462.2	0.7	10.6	1.5	77.6	1338.2	35.7

*Other materials include but are not limited to electrical elements, glass, nylon, plastics, rubber, lubricants.

Auxiliary Substances / Additives

In addition to the materials listed in the table above, chillers are charged with refrigerant at installation. Additional refrigerant recharges may also be required at a rate of 0.5-2% per year. Detailed information with regard to the type and amount per chiller type is found in table 14.

Material Explanation

The chiller heat exchangers are primarily made of carbon steel sheet with copper tubes used for heat transfer. The compressor is made of cast gray iron components that form the enclosure, with aluminum cast internal components and an electrical motor made from copper wire, electrolytic steel stampings, and a steel shaft.

Raw Material Extraction and Origin
The major components of the chiller are metals and metal parts that come from the global metal markets. All the materials used in the manufacture of this chiller are available in the earth's crust as non-renewable materials.

1.11. Manufacturing

The manufacturing locations (La Crosse, WI and Taicang, China) were modeled with a customized grid mix. The customized grid mix is matched to the specific power generation used at the manufacturing sites, however without specific supplier emission data, the emission factors use ecoinvent 3.7.1 as a proxy. The customized grid mix was collected directly from the utility supplier and is shown in detail in the table below.

Manufacturing inputs include the plant energy, utilities, air emissions, waste and recycling streams. Incoming electricity processes at each of the manufacturing sites were modified to best represent the impacts of the power generation. Trane purchases renewable energy for its manufacturing processes where possible and specific processes were created to represent the associated impacts.

Table 3: Manufacturing Electricity Grid Mix Including Renewable Energy

ELECTRICITY GRID MIX DETAIL | PROCESS [ECOINVENT 3.7.1)	FACTOR	UNIT
Electricity {LAX-RFC}| market for | Cut-off, U | Trane La Crosse, WI**		
Electricity, high voltage {RFC}| electricity production, hard coal | Cut-off, U	0.18	kwh
Electricity, high voltage {RFC}| electricity production, hydro, reservoir, alpine region | Cut-off, U	0.06*0.2	kwh
Electricity, high voltage {RFC}| electricity production, hydro, run-of-river | Cut-off, U	0.06*0.8	kwh
Electricity, high voltage {RFC}| electricity production, natural gas, combined cycle power plant | Cut-off, U	0.22*0.8812	kwh
Electricity, high voltage {RFC}| electricity production, natural gas, conventional power plant | Cut-off, U	0.22*0.1188	kwh
Electricity, high voltage {RFC}| electricity production, nuclear, boiling water reactor | Cut-off, U	0.27*0.3201	kwh
Electricity, high voltage {RFC}| electricity production, nuclear, pressure water reactor | Cut-off, U	0.27*0.6799	kwh
Electricity, high voltage {RFC}| electricity production, wind, <1MW turbine, onshore | Cut-off, U	0.23*0.0767	kwh
Electricity, high voltage {RFC}| electricity production, wind, >3MW turbine, onshore | Cut-off, U	0.23*0.0079	kwh
Electricity, high voltage {RFC}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	0.23*0.9154	kwh
Electricity, high voltage {RFC}| heat and power co-generation, biogas, gas engine | Cut-off, U	0.06	kwh
Electricity, low voltage {RFC}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, U	0.04	kwh
Electricity, {TC-SGCC}| market for | Cut-off, U | Trane Taicang, China**		
Electricity, high voltage {CN-JS}| electricity production, hard coal | Cut-off, U	0.8636/2	kwh
Electricity, high voltage {CN-JS}| electricity production, hydro, pumped storage | Cut-off, U	0.0053*0.5741	kwh
Electricity, high voltage {CN-JS}| electricity production, hydro, run-of-river | Cut-off, U	0.0053*0.4259	kwh
Electricity, high voltage {CN-JS}| electricity production, natural gas, combined cycle power plant | Cut-off, U	(0.8363/2)*0.9142	kwh
Electricity, high voltage {CN-JS}| electricity production, natural gas, conventional power plant | Cut-off, U	(0.8363/2)*0.0858	kwh
Electricity, high voltage {CN-JS}| electricity production, nuclear, pressure water reactor | Cut-off, U	0.0839	kwh
Electricity, high voltage {CN-JS}| electricity production, wind, <1MW turbine, onshore | Cut-off, U	0.0606*0.1130	kwh
Electricity, high voltage {CN-JS}| electricity production, wind, >3MW turbine, onshore | Cut-off, U	0.0606*0.2763	kwh
Electricity, high voltage {CN-JS}| electricity production, wind, 1-3MW turbine, offshore | Cut-off, U	0.0606*0.2831	kwh
Electricity, high voltage {CN-JS}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	0.0606*0.3278	kwh
Electricity, low voltage {CN-JS}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, U	0.0139	kwh

The main process steps occurring at Wisconsin and Taicang include cutting, rolling, machining, brazing welding and assembly. The chiller models made in La Crosse, WI incorporate electricity, natural gas, diesel, municipal water, air emissions, wastewater, solid waste and externally recycled materials. The chiller models made in Taicang, China incorporate electricity, liquified petroleum gas, diesel, municipal water, steam air emissions, wastewater, solid waste and externally recycled materials. The manufacturing input and output flows were allocated to each chiller model using weight and produced tonnage for each plant averaged over 2019, 2020 and 2021. The three-year average was used due to variations in manufacturing and production. The supporting report provides a list of manufacturing flows, quantities and representative unit processes used to model each flow.

During the entire production process, extra measures are taken to minimize the unintentional release of halogenated refrigerants. These measures are consistent with those identified in ANSI/ASHRAE Standard 147-2013, Reducing Release of Halogenated Refrigerants from Refrigeration and Air-Conditioning Equipment and Systems.

1.12. Packaging

Final product at installation site includes any installation inclusive waste treatment. Waste processing of product packaging waste and its transportation is listed in Table 4. In the absence of primary data, packaging disposal assumptions per region are included per UL PCR Part A: Life Cycle Assessment Calculation Rules and Report Requirements v 4.0 section 2.8.5 (UL PCR, 2022). The refrigerant is added to each chiller during installation, transportation of refrigerant has not been included with the model as distances per region vary by supplier.

Table 4: Product Packaging Waste at Installation Site of the Chiller (A5)

PRODUCT	INSTALLATION LOCATION	PROCESS (ECOINVENT 3.7.1)	INPUT VALUES	UNITS
CDHH 3050 CVHF 760 HDWA 400 CDHH 3050 CVHF 770 HDWA 400	North America North America North America Rest of World Rest of World Rest of World	Truck Transportation	6.72*100 3.33*100 34.14*100 7.13*100 3.44*100 2.01*100	kgkm
CDHH 3050 CVHF 760 HDWA 400 CDHH 3050 CVHF 770 HDWA 400	North America North America North America Rest of World Rest of World Rest of World	Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Cut-off, U	4*0.09 2.8*0.09 3.84*0.09 6.07*0.05 2.91*0.05 1.48*0.05	kg
CDHH 3050 CVHF 760 HDWA 400 CDHH 3050 CVHF 770 HDWA 400	North America North America North America Rest of World Rest of World Rest of World	Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U	2.72*0.68 0.53*0.68 (1.81+28.33)*0.68 1.06*0.05 0.53*0.05 0.53*0.05	kg
CDHH 3050 CVHF 760 HDWA 400 CDHH 3050 CVHF 770 HDWA 400	North America North America North America Rest of World Rest of World Rest of World	Municipal solid waste {RoW}| treatment of, sanitary landfill | Cut-off, U	2.72*0.2 0.53*0.2 (1.81+28.33)*0.2 1.06*0.95 2.91*0.95 0.53*0.95	kg
CDHH 3050 CVHF 760 HDWA 400 CDHH 3050 CVHF 770 HDWA 400	North America North America North America Rest of World Rest of World Rest of World	Municipal solid waste {RoW}| treatment of, sanitary landfill | Cut-off, U	4*0.68 2.8*0.68 3.84*0.68 6.07*0.95 2.91*0.95 1.48*0.95	kg
CDHH 3050 CVHF 760 HDWA 400	North America North America North America	Waste paperboard {RoW}| treatment of, municipal incineration | Cut-off, U	2.72*0.05 0.53*0.05 (1.81+28.33)*0.05	kg
CDHH 3050 CVHF 760 HDWA 400	North America North America North America	Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U	4*0.17 2.8*0.17 3.84*0.17	kg

1.13. Transportation

Transportation detail for each of the products included in the weighted average product are included in detail within the LCA report. The refrigerant is added to each chiller during installation, transportation of refrigerant has not been included with the model as distances per region vary by supplier.

Table 5: Transportation, Installation and Deconstruction Procedures

PRODUCT TRANSPORT FROM POINT OF PURCHASE TO BUILDING SITE	PRODUCT TRANSORTFROM BUILDING SITE TO WASTE PROCESSING	INSTALLATION AND DECONTRUCTION PROCEDURES
Weighted average chiller distance:1352.11 Mode: Diesel powered truck-/trailer	Weighted average chiller distance: 100 km Mode: Diesel powered truck-/trailer	Manual (no operational energy use)
Weighted average chiller distance: 863.19 Mode: Diesel powered container ship	n/a	n/a

1.14. Product Installation

Final product at installation site includes any installation inclusive waste treatment. The refrigerant is added to each chiller during installation, details including amount and type of refrigerant added are included in table 14. Individual refrigerant suppliers to charge chillers onsite vary by region.

The equipment, piping, flow balancing valves, gauges, thermostats, air vents and wiring are checked for proper installation. Pressure and leak testing, load condition verification, checks of ventilation and alarm systems within equipment room and provision of instructions around proper handling and use of refrigerant to the owner are also completed during the install.

1.15. Use

Major markets for the chillers are considered to be China and United States, however sales regions are world wide. This EPD is applicable for all markets. The use phase activities will be limited to consumption of energy during the defined reference service life (RSL) and maintenance and replacement over the estimated service life (ESL).

Operational Energy Use
In order to determine average annual energy usage for a given region or location, average weighting factors for specific categories of performance were calculated. The four categories being evaluated are those defined by Air-Conditioning, Heating and Refrigeration Institute (AHRI) Standard 550/590-2003 (ASHRAE, 2003) and include efficiency rates (kW/ton) at:

- 100% load at 85°F entering condenser water
- 75% load at 75°F entering condenser water
- 50% load at 65°F entering condenser water
- 25% load at 65°F entering condenser water

In addition to the load percentages, the annual hours of operation were determined. This formula has been tested in compliance with (American National Standards Institute/ American Society of Heating, Air-Conditioning, and Refrigerating Engineers (ANSI/ASHARE) Standard 140-2007, 2007) and was approved for use by UL.This procedure has been developed to determine the average energy usage for a given location, by manufacturer. The values resulting from the calculation are not intended to reflect actual energy usage but to provide the means of having a global and universal method to determine average energy consumption of chillers by manufacturer. For specific energy usage and life-cycle evaluation, a complete analysis must be completed for each and every application.

An average energy use value is calculated by the number of cities through estimated service life of 75 years. In order to reflect the chiller being used throughout the representative 55 cities, various electricity grid datasets were selected to best match the region or geographical proximity from within ecoinvent 3.7.1. The 55 cities cover each of the 17 different ASHRAE climate zones. They represent every climate in the world, and the larger chiller markets around the world. Efficiencies at the four categories of performance conditions and expected hours of use per year at each city, are used to calculate the total kWh of electricity expected over the estimated service life of 75 years for each model. The weighted average of these values was used to determine the average case. Therefore, the average energy use per ton of chilling capacity is not equal to the average of the calculated kWh per Ton chilling capacity for the individual chiller models.

The following 55 cities are considered in the calculation of the use phase energy use:

Atlanta, Bangkok, Beijing, Berlin, Boston, Buenos Aires, Cairo, Cancun, Capetown, Caracas, Chicago, Dallas, Denver, Dubai, Hanoi, HoChiMinh, Hong Kong, Houston, Jerusalem, Kansas City, London, Los Angeles, Madrid, Manila, Melbourne, Mexico City, Miami, Minneapolis, Moscow, Mumbai, New Delhi, Ottawa, Paris, Perth, Phoenix, Raleigh, Riyadh, Rome, San Diego, San Francisco, San Juan, Sao Paulo, Seattle, Seoul, Shanghai, Singapore, Sydney, Taipei, Tokyo, Toronto, Vancouver, Venice, Vienna, Warsaw, Washington DC

Refrigerant
The number of replacements of product expected during the building estimated service life of 75 years was determined by dividing the building estimated service life by the product reference service life and subtracting one. Using these assumptions for product reference service life and building estimated service life provided, two replacement cycles are calculated. It is assumed there are no resource inputs for installation. The corresponding impacts reported in module B4 will be approximately twice the total impacts of modules A1-A5. The weighted averages included all six chiller models and description of calculation is shown in the supporting LCA report.

The refrigerant impacts are spread out over several different modules and clarification of this is described below.

- A1: impacts of the refrigerant material used in the initial charge of refrigerant for one chiller.
- B2: emissions due to refrigerant leakage to the atmosphere that occurs over 75 years and the impacts from the production of the refill quantity of the leaked refrigerant that occurs over 75 years.
- B4: impacts associated with the production of the refrigerant material used in the initial charge of the two replacement chillers over 75 years.

Each Trane chiller has a specific amount of refrigerant that is charged into the chiller during the installation process. The amount of refrigerant varies by chiller type and size and this is specified by the Trane installation guide. The HDWA 400 Ton chiller models follow the PCR specified loss rate of 2% for medium pressure refrigerants as they operate between 200-300 psi and if there is a leak, the refrigerant will be discharged into the atmosphere. However, the CDHH 3050 Ton, CVHF 760 Ton, CVHF 770 Ton chillers use low pressure refrigerants as the machines operate at atmospheric pressure. The pressure inside is less than the air pressure outside resulting in negligible refrigerant leaks. The purge unit is needed to pull the air out of the chiller which does exhaust a small amount of refrigerant to the atmosphere. This low pressure system has been tested and verified by the engineering team at Trane over several years to have a leak rate of 0.5%. Replenishment of losses over the 75-year reference service life was included. Due to limited refrigerant data available in ecoinvent 3.7.1 (see detailed explanation in supporting LCA report), Table 13 in section 3 shows the refrigerant type representing each of the actual refrigerants.

The calculation of kg of replenished refrigerant per ton of chilling capacity is described below:

- divide the refrigerant charge amount (kg) by the chiller capacity (ton)
- multiply by the leakage rate (%)
- multiply by the RSL
- example calculation for LAX CDHH 3050 ton 50Hz
  - ((2586/3000) * 0.005) * 75 = 0.323 kg

1.16. Reference Service Life and Estimated Building Service Life

Table 6: Reference Service Life and Estimated Building Service Life

NAME	VALUE	UNIT
RSL (Reference Service)	25	years
ESL (Estimated Service)	75	years

1.17. Reuse, Recycling, and Energy Recovery

Re-use and energy recovery are not applicable to this product.

Due to the volume of metals within the product there is a possiblity for the metals to be recycled at the end of the products life. Data collection from Trane included collecting disposal and recycling details. For La Crosse, WI the facility recycling data is based on historical information from their third-party scrap providers. When the chillers are disposed of in the US at the end of the reference service life the disposal data is based on a Trane study among third-party scrap vendors who regularly recycle products removed from customer sites. For Taicang, China the facility recycling data is based on collected information from third party scrap providers. End of life recycling data is based on the reference PCR.

1.18. Disposal

Customer-provided data for products in the highest sales volume regions are summarized to common disposal pathways for each material within the chiller (including percent recycled, incinerated or sent to landfill). Main disposal pathways are shown in the table below. According to the PCR Part A requirements results for each of the individual options shall also be separately reported, as required by ISO 21930 Section 7.1.7.5 (ISO 21930, 2019) (i.e., if results are presented of a scenario that includes landfill, recycling, and incineration, then results must also be presented separately for 100% landfill, 100% recycling, and 100% incineration. Disposal scenarios are shown for each chiller in Appendix A of the supporting LCA report.

Table 7: Percentage of chiller materials to be disposed of to landfill, recycling or incineration

RAW MATERIALS	MATERIALS % SENT TO LANDFILL	MATERIALS % SENT TO RECYCLING	MATERIALS % SENT TO INCINERATION
Steel	15%	85%	-
Cast Iron	15%	85%	-
Aluminum	17%	83%	-
Copper	21%	79%	-
Brass	21%	79%	-
Cable/Wires	25%	75%	-
Mixed Plastics	87%	13%	-
Electrical Element+PCB	82%	18%	-
Paper	-	25%	75%
Rubber	74%	26%	-
Lubricant	50%	-	50%
Refrigerant	10%	90%	-

2. Life Cycle Assessment Background Information

2.1. Functional or Declared Unit

Functional unit defines the quantification of the identified functions (performance characteristics) of the product. In accordance with the PCR part B, the functional unit of the study is one of ton of chilling capacity. The estimated service life (ESL) is 75 years, and the reference service life (RSL) for one chiller is defined as 25 years. This functional unit is consistent with the goal and scope of this study, and Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) results are communicated based on this unit.

Table 8: Functional Unit

NAME	VALUE	UNIT
Functional Unit	1 ton chilling capacity	
Mass of one delivered product Service Life)	Weighted average by production volume – 19,966.01	kg
Conversion factor to 1 kg chilling capacity	16.84	kg/ton of chilling capacity

2.2. System Boundary

Per PCR Part B specifications, a cradle to grave system boundary is considered in this study including life cycle stages A1-A5, B1-B2, B4, B6, C2 and C4. B3, B5, B7, C1 and C3 were excluded. Detailed description of individual life cycle stages and their relevance to this study, is provided in the supporting LCA report.

Table 9: System Boundary Module

PRODUCT STAGE			CONSTRUCTION STAGE		USE STAGE							END OF LIFE STAGE			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
Raw Material Supply	Transport	Manufacturing	Transport from gate to site	Assembly/Install	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use During Product	Building Operational Water Use During Product Usae	Deconstruction	Transport	Waste Processing	Disposal
x	x	x	x	x	x	x	MND	x	MND	x	MND	MND	x	MND	x

Table 10: List of activities included and excluded from the system boundary

INCLUDED	EXCLUDED
• Raw material extraction	• Human labor
• Energy inputs in final assembly	• Employee commute and executive travel
• Inbound transportation to final assembly	• Repair and refurbishment over 75-year lifetime
• Installation of product	• Infrastructure
• Electricity consumption during use	• Capital goods
• Refrigerant charge and refilling over the 75-year lifetime	
• Refrigerant leakage	
• Disposal of non-recycled materials at the end of life	
• Replacement of unit after 25 years (3 total units)	

2.3. Estimates and Assumptions

The main limitation refers to the refrigerant datasets available. Refrigerant R134a is the most representative and complete refrigerant data set found in ecoinvent 3.7.1. Due to suppliers being unwilling to share proprietary ingredient information to properly modify and create datasets for refrigerants R514A and R-1233ZD, R134a is used to represent all refrigerants within the model.

According to ANSI/ASHRAE Standard 34-2019 R134a is a high GWP refrigerant (GWP - 1430) that will be phased out soon per upcoming regulations. While not a federal governance, many states are adopting SNAP 21 (policy originally created by the US EPA) which bans high GWP refrigerants in chillers starting in 2024. Alternative refrigerants include R513A (GWP of 573), R514A (GWP of 1.75), R-1233ZD (GWP of 1). While these modified refrigerants were not used in the modeling of the ingredients, the GWP adjustments were included for the use phase impact calculations. It is important to realize the significant reduction in use phase impacts these new refrigerants will have as chillers are modified to use the low GWP refrigerants.

The operational energy use was calculated by incorporating chiller efficiencies dependent on various use case conditions and weather information in the 55 cities as required by the guiding PCR. In lieu of measured data, it was assumed that use phase energy is representative of real-case operations in these locations.

Custom electricity datasets were created for the two manufacturing locations (La Crosse, WI and Taicang, China). The customized grid mix is matched to the specific power generation used at the manufacturing sites however without specific supplier emission data, the emission factors use ecoinvent 3.7.1 as a proxy. The customized grid mix was collected directly from the utility supplier and is shown in detail in Table 3.

2.4. Cut-off Criteria

The below procedure was followed for the exclusion of inputs and outputs:

- All inputs and outputs to a (unit) process shall be included in the calculation for which data is available. Data gaps may be filled by conservative assumptions with average or generic data. Any assumptions for such data shall be documented.
- In case of insufficient input data or data gaps for a unit process, the cut-off criteria shall be 1% of renewable and non-renewable primary energy usage, 1% of the total mass of that unit process. The total neglected input flows [per module A1-A5, B1-B7, C1-C4] shall be a maximum of 5% of energy usage and mass. Conservative assumptions in combination with plausibility considerations and expert judgement can be used to demonstrate compliance with these criteria.
- Particular care should be taken to include material and energy flows known to have the potential to cause significant emissions into air and water or soil related to the environmental indicators of this standard.

Conservative assumptions in combination with plausibility considerations and expert judgment can be used to demonstrate compliance with these criteria. All input and output flows are modeled in this study with no exclusion. No cutoff threshold was implemented, all value-add activities and processes were included to the best knowledge of the team involved in the study. No known flows are deliberately excluded from this EPD.

2.5. Data Sources

Primary data collected from Trane for their operational activities are representative for three 12-month averages including the calendar years 2019, 2020, 2021. All primary data was collected with the same level of granularity and consistency. 100% of value-added activities were considered and modeled.

The LCA model was created using SimaPro v.9.4.0.1 (SimaPro, 2020) software for life cycle assessment, developed by PRé Sustainability. Ecoinvent 3.7.1 (Wernet, et al., 2016) database contained in SimaPro provided the secondary LCI data for materials and processes used to model the background system.

The ecoinvent v3 cut-off library contains LCI data from various sectors such as energy production, transport, building materials, production of chemicals, metal production and fruit and vegetables. The entire database consists of over 10,000 interlinked data points, each of which describes a life cycle inventory on a process level. Detailed documentation of scope and references can be found on ecoinvent website.

2.6. Data Quality

Individual data points were reviewed before modeling and mass and energy balances were checked. If no primary data was available, secondary data from previous LCA studies and life cycle databases was used. Sources of the secondary data are documented.

The data used to create the inventory model shall be as precise, complete, consistent and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Temporal coverage was reviewed and matched with the scope of the study. Materials and manufacturing data was collected with the same level of consistency. An average of three calendar years of data was used to ensure variation in production was minimized. Detailed materials information was collected for each sub-assembly from each supplier. All value-added activities were considered and included within the model.
- The level of rigor exceeds the PCR requirement, however, will be beneficial to Trane when supporting design engineering teams in an effort to reduce material impacts for chillers.
- Datasets utilize most up to date versions for all generic and product specific data. Every effort was made to use representative and modified datasets to ensure accuracy.

Precision
The data used for primary data are based on direct information sourced from Trane. The energy and water usage data were collected directly from the utility meters and sub-meters, and the allocation was based on production volume during the time period of this study. Therefore, the precision for primary data is considered high; however, the uncertainty of the primary data has not been quantified.

Secondary data were sourced from the ecoinvent v3.7 database. Since the inventory flows for ecoinvent processes are very often accompanied by a series of data quality ratings, a general indication of precision can be inferred. Using these ratings, the data sets used generally have medium-to-high precision.

Completeness
The processes modeled represent procurement and manufacturing processes in both manufacturing locations. System boundaries and exclusions are clearly defined in above sections and no other data gaps were identified.

Consistency
Primary data were collected from the process experts at Trane. Supply chain data were sourced from product BOM and procurement datasets. Since most of the data used for this study are collected and reported annually, the consistency is considered high. Secondary data were consistently modeled using ecoinvent 3.7, cut-off library. Proxies were only identified and used if secondary data were not available in these or other databases. Using this approach, the consistency of the overall model is deemed to be high.

Representativeness
The representativeness of the datasets is chosen to be representative of North America and Asian average technologies.

2.7. Period under Review

The average chiller production is modeled based on a weighted average across all six chillers using production volumes from January 2019 through December 2021 (36 months).

2.8. Allocation

Primary data was collected for material inputs when possible and secondary data used to fill the gaps. Due to the significance of the use phase compared to the overall impacts this was deemed acceptable. Annual facility-wide manufacturing data was provided by Trane. Manufacturing stage, A3, is the only phase within this LCA where allocation of co-products is needed. The manufacturing inventories were allocated to each chiller using mass allocation approach based on production data from 2019, 2020 and 2021. The three-year average was used due to variations in manufacturing and production.

3. Life Cycle Assessment Scenarios

The tables represented in the Life Cycle Assessment Scenarios are shown for a weighted average chiller based on average production volumes from January 2019 through December 2021.

Table 10 shows transportation fuel use and capacity utilization for an average chiller. For liters of fuel the average fuel use per 100 km for both truck and ship were calculated from the ecoinvent datasets used. Average chiller transport distance was provided by Trane and was calculated by transportation mode as follows:

1. Transportation distance (km) * % of sales by product * production weighted average % by product = weighted average distance per product

2. Sum of weighted average distance per product (6)

The capacity utilization was pulled directly from the ecoinvent datasets used. The gross density of products transported is a weighted average for the six chillers modeled.

No known flows were deliberately excluded.

Table 11. Transport to the building site (A4)

NAME	VALUE	UNIT
Fuel type	Diesel	n/a
Liters of fuel	truck – 4.972 ship – 0.493	l/100km
Vehicle type	truck ship	n/a
Transport distance	truck – 1375.41 ship – 1016.78	km
Capacity utilization (including empty runs, mass based	truck – 27 ship – 70	%
Gross density of products transported	1128.02	kg/m^3
Weight of products transported (if gross density not reported)	n/a	kg
Volume of products transported (if gross density not reported)	n/a	m^3
Capacity utilization volume factor (factor: =1 or <1 or ≥ 1 for compressed or nested packaging products)	<1	n/a

Table 12. Installation into the building (A5)

NAME	VALUE	UNIT
Waste materials at the construction site before waste processing, generated by product installation	9.47	kg
Output materials resulting from on-site waste processing (specified by route; e.g., for recycling, energy recovery and/or disposal)	Landfill – 4.61 Recycling – 4.43 Incineration – 0.69	kg
Biogenic carbon contained in packaging	2.61E-02	kg CO_2

Table 13. Reference Service Life

NAME	VALUE	UNIT
RSL	25	years
Use condition – weighted average chiller hours of operational use	3231*25 = 80,775	hours/25 years

Table 14. Maintenance (B2) - Refrigerant type, annual leakage and total RSL replenishment per chiller model

PRODUCT	CHILLER CAPACITY (TON)	ACTUAL REFRIGERANT	REPRESENTATIVE REFRIGERANT	ESTIMATED GWP (KG CO_2E/LG)	REFRIGERANT CHARGE (KG)	REFRIGERANT CHARGE PER TON CHILLING CAPACITY (KG)	LEAKAGE RATE (%)	ANNUAL LEAKAGE PER TON CHILLING CAPACITY (KG)	REPLENISHMENT OVER 75 YEAR RSL PER TON CHILLING CAPACITY (KG)
LAX CDHH 3050 Ton 50Hz	3,000	R-1233ZD	R-134a	1	2,586	0.862	0.5%	0.00431	0.323
LAX CVHF 760 Ton 60Hz	700	R-514A	R-134a	1.75	521	0.686	0.5%	0.00343	0.257
LAX HDWA 400 Ton 60Hz	400	R-134A	R-134a	1,430	363	0.907	2.0%	0.01814	1.361
TC CDHH 3050 Ton 50Hz	3,000	R-1233ZD	R-134a	1	2,429	0.810	0.5%	0.00405	0.304
TC CVHF 770 Ton 60Hz	700	R-514A	R-134a	1.75	499	0.648	0.5%	0.00324	0.243
TC HDWA 400 Ton 50Hz	400	R-134A	R-134a	1,430	363	0.907	2.0%	0.01814	1.361
Weighted Average (ton)	**1,186**	-	-	-	-	**0.76**	-	**0.00665**	**0.498**

*LAX – La Crosse, WI; *TC – Taicang, China

Table 15. Replacement (B4)

NAME	VALUE	UNIT
Replacement cycle	2	Number/ ESL

Table 16. Operational energy use (B6) - Summary of electricity use per year, per ESL, per ESL per ton chilling capacity and weighted average of six chiller models

PRODUCT	kWh/YEAR	kWh/ESL (75 YEARS)	kWh/TON CHILLING CAPACITY OVER 75 YEARS
LAX CDHH 3050 Ton 50Hz with Starter	3,900,221	292,516,588	97,506
LAX CVHF 760 Ton 60Hz with AFD	802,874	60,215,533	86,022
LAX HDWA 400 Ton 60Hz with AFD	466,648	34,998,601	87,497
TC CDHH 3050 Ton 50Hz with Starter	3,590,379	269,278,412	89,759
TC CVHF 770 Ton 60Hz with AFD	831,260	62,344,526	89,064
TC HDWA 400 Ton 50Hz with AFD	468,863	35,164,690	87,912
Weighted average (1185.6 Tons)	**1,467,068**	**110,030,130**	**89,612**

Table 17. End of life (C2, C4)

NAME		VALUE	UNIT
Recovery (specified by type)	Reuse	0	kg
	Recycling	1.79E+04	kg
	Landfill	3.07E+03	kg
	Incineration	0	kg
	Incineration with energy recovery	0	kg
Disposal (specified by type)	Product or material for final deposition	2.10E+04	kg
Removals of biogenic carbon (excluding packaging)		0	kg/CO_2

4. Life Cycle Assessment Results

4.1. Life Cycle Impact Assessment Results

This section presents the life cycle impact assessment (LCIA) per ton of chilling capacity for a 75-year estimated service life. Note that the LCIA results indicate potential impacts only; they do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risk. For North American, these six impact categories are globally deemed mature enough to be included in Type III environmental declarations. For Rest of World, the five impact categories are globally deemed mature enough to be included in Type III environmental declarations. Other categories are being developed and defined and LCA should continue making advances in their development. However, the EPD users shall not use additional measures for comparative purposes.

This study assumes the selected chillers provide a representative overview of the types of chillers produced by Trane. The results represent potential impacts for an average chiller, estimated based on the weights and production volumes of individual chillers covered in this study. Individual results for each of the six chillers are also reported.

Considering the cradle to grave activities throughout the estimated service life of the chillers, the average results presented below highlight that a significant portion of the impacts in the majority of the categories are dominated by the operational energy use. The exception is with the ozone depletion potential category which is driven by the refrigerant charge and leakage replenishment.

It should be noted that while global warming potential (GWP) numbers were adjusted to reflect the lower impacts of more advanced refrigerants, the other impact categories are not representing the impacts of refrigerant fully and these results may get updated as better proxies become available in ecoinvent. It is of interest that the chillers using the refrigerant with reduced GWP have significantly lower impacts.

Table 18: Weighted average result for six chiller types manufactured in La Crosse, WI and Taicang, China per ton of chilling capacity

CATEGORY	A1-A3	A4	A5	B2	B4	B6	C2	C4
[NORTH AMERICA]								
IPCC GWP [kg CO_2 eq]	1.29E+02	1.80E+00	5.88E-03	4.16E+02	2.62E+02	5.59E+04	4.14E-01	6.11E+00
Ozone Depletion [kg CFC-11 eq]	1.34E-03	5.57E-07	4.99E-11	7.07E-04	2.69E-03	5.06E-03	1.54E-07	2.12E-08
Acidification [kg SO_2 eq]	2.04E+00	1.27E-02	2.27E-06	3.80E-02	4.10E+00	5.49E+02	2.70E-03	3.19E-03
Eutrophication [kg N eq]	1.77E-01	9.12E-04	1.00E-05	1.19E-03	3.56E-01	3.29E+01	1.83E-04	1.34E-02
Smog [kg O_3 eq]	1.20E+01	1.91E-01	3.65E-05	2.52E-01	2.43E+01	2.57E+03	2.83E-02	2.00E-02
Abiotic Depletion (fossil fuels) [MJ, LHV]	1.35E+03	2.48E+01	3.23E-03	4.27E+01	2.77E+03	6.72E+05	5.75E+00	1.40E+00
[REST OF WORLD]								
IPCC GWP [kg CO_2 eq]	1.29E+02	1.80E+00	5.88E-03	4.16E+02	2.62E+02	5.59E+04	4.14E-01	6.11E+00
Ozone layer depletion (ODP) [kg CFC-11 eq]	7.82E-04	3.16E-07	3.47E-11	4.99E-04	1.57E-03	2.15E-03	7.31E-08	9.48E-09
Eutrophication [kg PO_4 eq]	1.41E-01	1.17E-03	4.37E-06	1.48E-03	2.84E-01	2.60E+01	1.86E-04	5.74E-03
Acidification [kg SO_2 eq]	9.39E-01	8.34E-03	1.46E-06	2.15E-02	1.90E+00	2.29E+02	1.10E-03	1.06E-03
Photochemical Oxidation [kg C_2H_4 eq]	5.04E-02	2.56E-04	9.81E-07	4.56E-03	1.01E-01	9.25E+00	3.93E-05	1.31E-03

Table 19: LCIA Results - LAX CDHH 3050 Ton 50Hz with Starter (per ton chilling capacity)

CATEGORY	A1-A3	A4	A5	B2	B4	B6	C2	C4
[NORTH AMERICA]								
IPCC GWP [kg CO_2 eq]	1.12E+02	8.78E-01	1.23E-03	5.08E+00	2.26E+02	6.07E+04	3.69E-01	6.18E+00
Ozone Depletion [kg CFC-11 eq]	3.63E-03	8.86E-07	2.76E-11	1.35E-03	7.27E-03	1.37E-02	3.72E-07	5.53E-08
Acidification [kg SO_2 eq]	6.22E+00	1.99E-02	2.43E-06	9.86E-02	1.25E+01	1.86E+03	8.38E-03	1.05E-02
Eutrophication [kg N eq]	1.40E-01	3.88E-04	1.52E-06	7.53E-04	2.82E-01	3.61E+01	1.63E-04	1.36E-02
Smog [kg O_3 eq]	1.03E+01	6.00E-02	6.98E-06	1.59E-01	2.07E+01	2.79E+03	2.52E-02	2.02E-02
Abiotic Depletion (fossil fuels) [MJ, LHV]	1.17E+03	1.22E+01	4.72E-04	2.69E+01	2.37E+03	7.28E+05	5.13E+00	1.41E+00
[REST OF WORLD]								
IPCC GWP [kg CO_2 eq]	1.12E+02	8.78E-01	1.23E-03	5.08E+00	2.26E+02	6.07E+04	3.69E-01	6.18E+00
Ozone layer depletion (ODP) [kg CFC-11 eq]	8.45E-04	1.55E-07	4.98E-12	3.14E-04	1.69E-03	2.33E-03	6.52E-08	9.59E-09
Eutrophication [kg PO_4 eq]	1.17E-01	3.94E-04	6.73E-07	9.33E-04	2.34E-01	2.84E+01	1.66E-04	5.80E-03
Acidification [kg SO_2 eq]	8.15E-01	2.33E-03	2.52E-07	1.36E-02	1.63E+00	2.49E+02	9.78E-04	1.07E-03
Photochemical Oxidation [kg C_2H_4 eq]	4.35E-02	8.35E-05	1.48E-07	2.88E-03	8.71E-02	1.00E+01	3.51E-05	1.33E-03

Table 20: LCIA Results - LAX CVHF 770 Ton 60Hz with AFD (per ton chilling capacity)

CATEGORY	A1-A3	A4	A5	B2	B4	B6	C2	C4
[NORTH AMERICA]								
IPCC GWP [kg CO_2 eq]	1.39E+02	3.17E+00	3.43E-03	4.60E+00	2.85E+02	5.37E+04	4.22E-01	6.70E+00
Ozone Depletion [kg CFC-11 eq]	7.36E-04	7.43E-07	1.52E-11	2.72E-04	1.47E-03	2.84E-03	9.93E-08	1.40E-08
Acidification [kg SO_2 eq]	1.04E+00	1.80E-02	8.49E-07	1.14E-02	2.11E+00	2.19E+02	1.28E-03	1.51E-03
Eutrophication [kg N eq]	1.79E-01	1.67E-03	4.02E-06	6.50E-04	3.61E-01	3.15E+01	1.86E-04	1.47E-02
Smog [kg O_3 eq]	1.29E+01	3.68E-01	1.85E-05	1.37E-01	2.65E+01	2.47E+03	2.89E-02	2.19E-02
Abiotic Depletion (fossil fuels) [MJ, LHV]	1.48E+03	4.38E+01	1.14E-03	2.33E+01	3.05E+03	6.45E+05	5.87E+00	1.53E+00
[REST OF WORLD]								
IPCC GWP [kg CO_2 eq]	1.39E+02	3.17E+00	3.43E-03	4.60E+00	2.85E+02	5.37E+04	4.22E-01	6.70E+00
Ozone layer depletion (ODP) [kg CFC-11 eq]	7.33E-04	5.57E-07	1.18E-11	2.72E-04	1.47E-03	2.06E-03	7.45E-08	1.04E-08
Eutrophication [kg PO_4 eq]	1.47E-01	2.22E-03	1.78E-06	8.06E-04	2.98E-01	2.49E+01	1.89E-04	6.29E-03
Acidification [kg SO_2 eq]	1.02E+00	1.64E-02	6.59E-07	1.17E-02	2.06E+00	2.20E+02	1.12E-03	1.16E-03
Photochemical Oxidation [kg C_2H_4 eq]	5.22E-02	4.91E-04	3.91E-07	2.49E-03	1.05E-01	8.88E+00	4.01E-05	1.44E-03

Table 21: LCIA Results - LAX HDWA 400T 60Hz with AFD (per ton chilling capacity)

CATEGORY	A1-A3	A4	A5	B2	B4	B6	C2	C4
[NORTH AMERICA]								
IPCC GWP [kg CO_2 eq]	1.29E+02	2.20E+00	1.80E-02	1.96E+03	2.62E+02	5.47E+04	3.22E-01	4.27E+00
Ozone Depletion [kg CFC-11 eq]	8.93E-04	5.16E-07	1.91E-10	1.33E-03	1.79E-03	2.89E-03	7.57E-08	8.93E-09
Acidification [kg SO_2 eq]	9.16E-01	7.65E-03	6.61E-06	5.53E-02	1.85E+00	2.23E+02	9.73E-04	9.66E-04
Eutrophication [kg N eq]	1.94E-01	1.00E-03	3.02E-05	3.17E-03	3.91E-01	3.19E+01	1.42E-04	9.40E-03
Smog [kg O_3 eq]	1.15E+01	1.68E-01	1.36E-04	6.67E-01	2.32E+01	2.51E+03	2.20E-02	1.40E-02
Abiotic Depletion (fossil fuels) [MJ, LHV]	1.36E+03	3.05E+01	1.29E-02	1.13E+02	2.79E+03	6.57E+05	4.47E+00	9.79E-01
[REST OF WORLD]								
IPCC GWP [kg CO_2 eq]	1.29E+02	2.20E+00	1.80E-02	1.96E+03	2.62E+02	5.47E+04	3.22E-01	4.27E+00
Ozone layer depletion (ODP) [kg CFC-11 eq]	8.89E-04	3.87E-07	1.45E-10	1.32E-03	1.78E-03	2.10E-03	5.68E-08	6.63E-09
Eutrophication [kg PO_4 eq]	1.45E-01	1.08E-03	1.33E-05	3.92E-03	2.92E-01	2.53E+01	1.44E-04	4.02E-03
Acidification [kg SO_2 eq]	8.95E-01	6.78E-03	5.28E-06	5.71E-02	1.80E+00	2.24E+02	8.52E-04	7.41E-04
Photochemical Oxidation [kg C_2H_4 eq]	4.88E-02	2.32E-04	2.97E-06	1.21E-02	9.81E-02	9.05E+00	3.06E-05	9.19E-04

Table 22: LCIA Results - TC CDHH 3050T 50 Hz with Starter (per ton chilling capacity)

CATEGORY	A1-A3	A4	A5	B2	B4	B6	C2	C4
[NORTH AMERICA]								
IPCC GWP [kg CO_2 eq]	9.99E+01	6.01E-01	2.88E-04	4.77E+00	2.26E+02	5.59E+04	4.25E-01	6.16E+00
Ozone Depletion [kg CFC-11 eq]	7.96E-04	1.37E-07	4.65E-12	2.96E-04	1.70E-03	2.95E-03	1.00E-07	1.29E-08
Acidification [kg SO_2 eq]	7.97E-01	1.07E-02	1.14E-07	1.24E-02	1.66E+00	2.28E+02	1.29E-03	1.39E-03
Eutrophication [kg N eq]	1.39E-01	5.45E-04	6.03E-07	7.07E-04	2.82E-01	3.32E+01	1.88E-04	1.36E-02
Smog [kg O_3 eq]	9.84E+00	2.00E-01	2.07E-06	1.49E-01	2.07E+01	2.57E+03	2.91E-02	2.01E-02
Abiotic Depletion (fossil fuels) [MJ, LHV]	1.00E+03	8.04E+00	3.03E-04	2.53E+01	2.37E+03	6.71E+05	5.91E+00	1.41E+00
[REST OF WORLD]								
IPCC GWP [kg CO_2 eq]	9.99E+01	6.01E-01	2.88E-04	4.77E+00	2.26E+02	5.59E+04	4.25E-01	6.16E+00
Ozone layer depletion (ODP) [kg CFC-11 eq]	7.93E-04	1.03E-07	3.48E-12	2.95E-04	1.69E-03	2.15E-03	7.50E-08	9.57E-09
Eutrophication [kg PO_4 eq]	1.14E-01	1.11E-03	2.62E-07	8.76E-04	2.34E-01	2.62E+01	1.91E-04	5.79E-03
Acidification [kg SO_2 eq]	7.83E-01	1.00E-02	9.30E-08	1.27E-02	1.63E+00	2.29E+02	1.13E-03	1.07E-03
Photochemical Oxidation [kg C_2H_4 eq]	4.38E-02	2.57E-04	5.99E-08	2.70E-03	8.71E-02	9.24E+00	4.04E-05	1.33E-03

Table 23: LCIA Results - TC CVHF 760T 60Hz with AFD (per ton chilling capacity)

CATEGORY	A1-A3	A4	A5	B2	B4	B6	C2	C4
[NORTH AMERICA]								
IPCC GWP [kg CO_2 eq]	1.35E+02	1.08E+00	4.93E-03	4.40E+00	2.72E+02	5.56E+04	5.01E-01	6.87E+00
Ozone Depletion [kg CFC-11 eq]	7.04E-04	2.52E-07	1.87E-11	2.60E-04	1.41E-03	2.94E-03	1.18E-07	1.44E-08
Acidification [kg SO_2 eq]	1.03E+00	6.40E-03	1.22E-06	1.09E-02	2.08E+00	2.26E+02	1.52E-03	1.55E-03
Eutrophication [kg N eq]	1.94E-01	5.75E-04	1.08E-05	6.22E-04	3.89E-01	3.26E+01	2.21E-04	1.51E-02
Smog [kg O_3 eq]	1.30E+01	1.30E-01	1.85E-05	1.31E-01	2.62E+01	2.56E+03	3.43E-02	2.25E-02
Abiotic Depletion (fossil fuels) [MJ, LHV]	1.40E+03	1.49E+01	1.62E-03	2.22E+01	2.84E+03	6.68E+05	6.97E+00	1.57E+00
[REST OF WORLD]								
IPCC GWP [kg CO_2 eq]	1.35E+02	1.08E+00	4.93E-03	4.40E+00	2.72E+02	5.56E+04	5.01E-01	6.87E+00
Ozone layer depletion (ODP) [kg CFC-11 eq]	7.01E-04	1.89E-07	1.39E-11	2.60E-04	1.40E-03	2.14E-03	8.85E-08	1.07E-08
Eutrophication [kg PO_4 eq]	1.53E-01	7.84E-04	4.62E-06	7.71E-04	3.08E-01	2.58E+01	2.25E-04	6.46E-03
Acidification [kg SO_2 eq]	1.01E+00	5.84E-03	9.45E-07	1.12E-02	2.03E+00	2.28E+02	1.33E-03	1.19E-03
Photochemical Oxidation [kg C_2H_4 eq]	5.58E-02	1.74E-04	1.06E-06	2.38E-03	1.12E-01	9.20E+00	4.77E-05	1.48E-03

Table 24: LCIA Results - TC HDWA 400T 60Hzwith AFD (per ton chilling capacity)

CATEGORY	A1-A3	A4	A5	B2	B4	B6	C2	C4
[NORTH AMERICA]								
IPCC GWP [kg CO_2 eq]	1.22E+02	7.39E-01	3.00E-03	1.96E+03	2.46E+02	5.49E+04	3.83E-01	4.14E+00
Ozone Depletion [kg CFC-11 eq]	8.93E-04	1.73E-07	1.48E-11	1.33E-03	1.79E-03	2.91E-03	9.02E-08	8.64E-09
Acidification [kg SO_2 eq]	9.13E-01	3.32E-03	7.80E-07	5.53E-02	1.83E+00	2.24E+02	1.16E-03	9.35E-04
Eutrophication [kg N eq]	1.95E-01	3.60E-04	6.53E-06	3.17E-03	3.91E-01	3.21E+01	1.69E-04	9.09E-03
Smog [kg O_3 eq]	1.17E+01	7.00E-02	1.22E-05	6.67E-01	2.36E+01	2.53E+03	2.62E-02	1.35E-02
Abiotic Depletion (fossil fuels) [MJ, LHV]	1.27E+03	1.02E+01	1.19E-03	1.13E+02	2.57E+03	6.61E+05	5.33E+00	9.47E-01
[REST OF WORLD]								
IPCC GWP [kg CO_2 eq]	1.22E+02	7.39E-01	3.00E-03	1.96E+03	2.46E+02	5.49E+04	3.83E-01	4.14E+00
Ozone layer depletion (ODP) [kg CFC-11 eq]	8.89E-04	1.30E-07	1.11E-11	1.32E-03	1.78E-03	2.11E-03	6.77E-08	6.42E-09
Eutrophication [kg PO_4 eq]	1.46E-01	4.35E-04	2.80E-06	3.92E-03	2.92E-01	2.54E+01	1.72E-04	3.89E-03
Acidification [kg SO_2 eq]	8.91E-01	2.99E-03	6.11E-07	5.71E-02	1.79E+00	2.25E+02	1.02E-03	7.17E-04
Photochemical Oxidation [kg C_2H_4 eq]	4.98E-02	9.47E-05	6.40E-07	1.21E-02	9.99E-02	9.09E+00	3.64E-05	8.90E-04

The use stage electricity (B6) dominates most of the environmental impact categories. For example, when considering Global Warming Potential, the product use stage (B6) electricity for the 75-year expected service life represents 99% of the impacts.

In order to better understand the impacts from the other life cycle stages, product weighted average results as a percent contribution of each life cycle stage excluding the two additional replacement chillers (B4) and operational energy use (B6) are shown below. The percentages below include one chiller for the reference service life of 25 years.

Table 25: Weighted average chiller results as a percent contribution of each life cycle stage excluding operational energy use phase and replacements

CATEGORY	A1-A3	A4	A5	B2	C2	C4
[NORTH AMERICA]						
IPCC GWP [kg CO_2 eq]	47.5%	0.7%	0.0%	51.1%	0.1%	0.7%
Ozone Depletion [kg CFC-11 eq]	85.0%	0.0%	0.0%	14.9%	0.0%	0.0%
Acidification [kg SO_2 eq]	98.4%	0.6%	0.0%	0.6%	0.1%	0.2%
Eutrophication [kg N eq]	92.3%	0.5%	0.0%	0.2%	0.1%	7.0%
Smog [kg O_3 eq]	97.4%	1.6%	0.0%	0.7%	0.2%	0.2%
Abiotic Depletion (fossil fuels) [MJ, LHV]	96.7%	1.8%	0.0%	1.0%	0.4%	0.1%
[REST OF WORLD]						
IPCC GWP [kg CO_2 eq]	47.5%	0.7%	0.0%	51.1%	0.1%	0.7%
Ozone layer depletion (ODP) [kg CFC-11 eq]	82.4%	0.0%	0.0%	17.5%	0.0%	0.0%
Eutrophication [kg PO_4 eq]	94.9%	0.8%	0.0%	0.3%	0.1%	3.9%
Acidification [kg SO_2 eq]	98.2%	0.9%	0.0%	0.7%	0.1%	0.1%
Photochemical Oxidation [kg C_2H_4 eq]	94.2%	0.5%	0.0%	2.8%	0.1%	2.5%

Reviewing the weighted average results for one chiller for the reference service life of 25 years without the operational energy use, the chiller materials and refrigerant replenishment are significant contributors to the majority of the impact categories. The contribution of impacts from B2 are primarily driven by the HDWA chiller models due to the use of R134a. B2 impacts for the CDHH and CVHF chillers are noticeably lower due to the use of low-GWP refrigerants. Steel and copper are the main materials contributing to impacts, which correlates to the mass input in the bill-of-materials for each of the chillers modeled. The production of refrigerant charged at installation and the refrigerant leakage over the estimated service life of the chiller comprise the dominant portion of the Ozone Depletion impacts.

4.2. Life Cycle Inventory Results

The final results of this assessment are presented using the life cycle inventory indictors and life cycle assessment methodologies specified in the governing PCR. The life cycle inventory indicators cover renewable and non-renewable material resources, renewable and non-renewable energy sources, water, waste and biogenic carbon flows. Tables 26 through Table 28 summarize the indicators results for the weighted average chiller per ton of chilling capacity.

Table 26: Resource Use

PARAMETER	A1-A3	A4	A5	B2	B4	B6	C2	C4
RPRE [MJ, LHV]	2.06E+02	3.28E-02	9.88E-05	2.43E+00	4.17E+02	8.58E+04	7.41E-03	1.16E-01
RPRM [MJ, LHV]	1.96E-01	0.00E+00	0.00E+00	0.00E+00	3.93E-01	0.00E+00	0.00E+00	0.00E+00
NRPRE [MJ, LHV]	1.70E+03	2.71E+01	3.58E-03	5.14E+01	3.49E+03	8.30E+05	6.11E+00	1.67E+00
NRPRM [MJ, LHV]	1.66E+00	0.00E+00	1.66E-01	0.00E+00	3.32E+00	0.00E+00	0.00E+00	0.00E+00
SM [kg]	6.96E+00	0.00E+00	0.00E+00	0.00E+00	1.39E+01	0.00E+00	0.00E+00	0.00E+00
RSF [MJ, LHV]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF [MJ, LHV]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RE [MJ, LHV]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FW [m3]	1.40E+00	0.00E+00	0.00E+00	0.00E+00	2.80E+00	0.00E+00	0.00E+00	0.00E+00

Table 27: Output Flows and Waste Categories

PARAMETER	A1-A3	A4	A5	B2	B4	B6	C2	C4
HWD [kg]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NHWD [kg]	4.75E-04	0.00E+00	7.63E-03	0.00E+00	1.62E-02	0.00E+00	0.00E+00	1.04E+01
HLRW [kg]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ILLRW [kg]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CRU [kg]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MR [kg]	4.72E-03	0.00E+00	9.85E-03	0.00E+00	2.91E-02	0.00E+00	0.00E+00	4.37E+01
MER [kg]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EE [MJ, LHV]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 28: Carbon Emissions and Removals

PARAMETER	A1-A3	A4	A5	B2	B4	B6	C2	C4
Biogenic CO_2 products [kg CO_2]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Biogenic CO_2 packaging [kg CO_2]	2.61E-02	0.00E+00	0.00E+00	0.00E+00	5.21E-02	0.00E+00	0.00E+00	0.00E+00
Biogenic CO_2 calcination & carbonation [kg CO_2]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Biogenic CO_2 renewable waste combustion [kg CO_2]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Biogenic CO_2 non-renewable waste combustion [kg CO_2]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

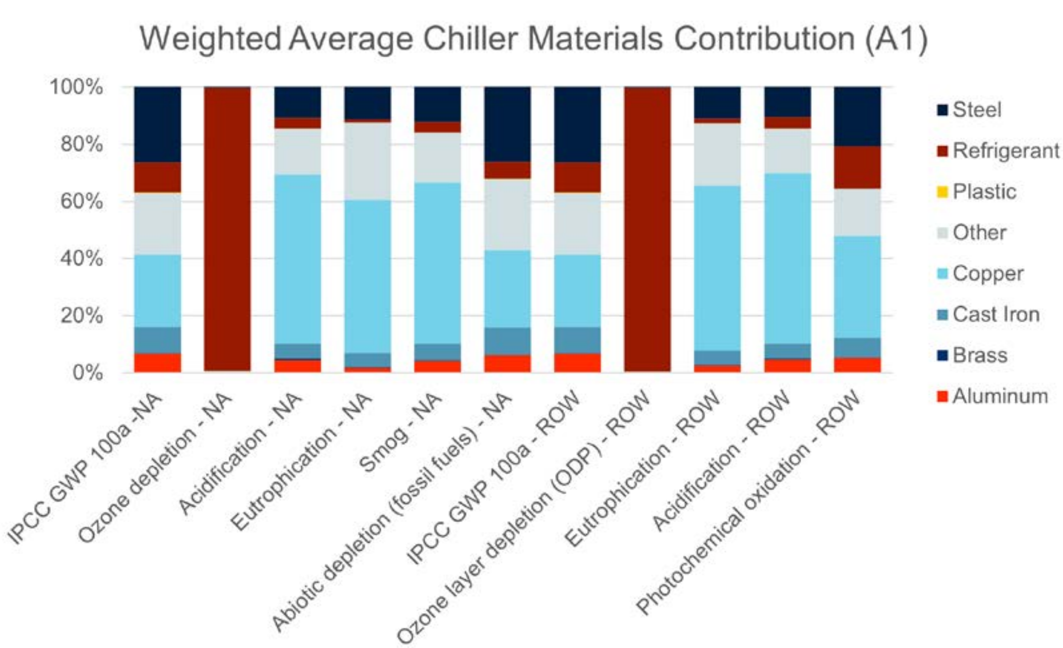
5. LCA Interpretation

Identification of relevant findings includes:

- Operational energy use is the dominant impact contributor to all categories except Ozone Depletion Potential. The use phase is the leading contributor as the product continues to use energy for the entire estimated service life of 75 years.
- Additionally, it is noted that reviewing the results without the operational energy use and for only one chiller with an estimated service of 25 years allows for more detailed understanding of areas of dominance to the impact contributions. The bulleted list below identifies comprehensive findings of the results without the operational energy use and for just one chiller (ESL 25 years).
  - The raw materials (A1) are the main impacts contributors. Those impacts are predominantly from steel, copper and refrigerant which correlates to the respective material weights for each chiller.
  - Production of refrigerant for the initial charge at installation and refills due to leakage are the main contributors to Ozone Depletion Potential. Given the test results for the improved refrigerant formula it is assumed that the impacts for Ozone Depletion Potential and Global Warming Potential could be reduced significantly if the chillers are charged with the alternative refrigerants. It would be necessary to build the alternative refrigerants with the ingredients in order to show this within the LCA results.
  - Manufacturing impacts are moderate across all categories and have improved accuracy relative to the electricity mix and product mix averages over a three-year period. There are minimal differences in the two different manufacturing locations and no trends that are consistent within the results of the three chillers made at each location.
  - For Acidification and Smog impact assessments, raw materials (A1) is the main contributor to the impacts
  - For Eutrophication, raw materials (A1) is the main contributor but product disposal (C4) also has a small impact.
  - For Abiotic Depletion, raw materials (A1) are again the driving factor with manufacturing (A3) being a medium impact.
  - For Ozone Layer Depletion, the results are driven by the refrigerant production, in line with the Ozone Depletion Potential impact factors
  - For Photochemical Oxidation, raw materials (A1) are the main contributor with Manufacturing (A3) and Maintenance, refill of leaked refrigerant (B2) contributing to a lesser extent.

Figure 1 shows the materials contribution for the weighted average chiller. As discussed previously, the refrigerant production comprises the dominant portion of ODP impacts. Copper and steel are the main materials contributing to impacts, which correlates to the mass input in the BOM. Production of refrigerants is also significant in non-ozone depleting impacts, such as GWP and PCOP.

Figure 1: Weighted Average Chiller Materials Contribution



6. Additional Environmental Information

6.1. Environment and Health During Manufacturing

During the entire production process, extra measures are taken to minimize the unintentional release of halogenated refrigerants. These measures are consistent with those identified in ANSI/ASHRAE Standard 147-2013, Reducing Release of Halogenated Refrigerants from Refrigerating and Air-Conditioning Equipment and Systems.

6.2. Environment and Health During Installation

Handling recommendations for refrigerants can be found in product and application literature, brocures and data sheets provided directly by the refrigerant suppliers and available from the internet:

https://www.trane.com/commercial/north-america/us/en/products-systems/chillers/water-cooled-chillers.html

6.3. Extraordinary Effects

Fire
Product is not flammable. The product is conformant to the International Code Council (ICC) and National Fire Protection Assocation (NFPA)

Water
The six chiller models referenced in this EPD are designed with NEMA 1 construction to prevent failure of components due to water contact. Additional NEMA 4 and NEMA 12 enclosures are an optional add-on for the CVHF and CDHH models.

6.4. Further Information

The chiller does not contain substances considered to be harzardous by Resource Conservation and Recovery Act (RCRA), Subtitle 3.

Maintenance for this product is described in the Annual Inspection Checklist and Report, which can be provided upon request. The checklist covers aspects relating to the compressor motor, starter, AFD, oil sump, condenser, control circuits, leak test chiller, and the purge unit.

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