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Configuration and Change Management Approach in Product Variant Design of Chillers

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Abstract

The objective of the research presented in this paper is to present an approach to Configuration and Change Management (CCM) in product variant design of chillers. According to today's requirements requested from manufacturers to rapidly introduce new products and update existing ones while reducing their costs and improving their quality for the purpose of maximizing the market opportunities, a satisfactory system option/solution must be offered. In this case, configuration and change management for products is a very common option, which can deliver a competitive advantage on the market. Due to very high demands in cooling plant design set in recent years, chillers have grown in size and complexity. Chiller manufacturers must be able to offer in their product ranges more customizable products with multiple options of product variants (based on a known product platform), which make changes to product design highly complicated. The main objective of proposed approach is to achieve optimal system architecture for the observed product variants, including feedback in the phase of changing product properties (this sometimes requires several iteration steps). "Optimal architecture" refers to an architecture that is optimal based on several criteria: its performance (in terms of an energy efficient product with minimum electricity consumption, minimum levels of sound power and pressure, minimum required dimensions (with the lowest possible weight)) and minimum price of the product. The approach presented was primarily developed to assist all mechanical designers engaging in the composition of industry-specific product configurations (chillers) and provide them with guidance when selecting appropriate product alternatives. It helps them focus on these essential properties, which gives them a competitive advantage over other manufacturers. It is presented graphically as a flowchart diagram. The approach was verified against two examples of chillers: an air cooled chiller and a water cooled chiller, including the results obtained and their discussion.

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Keywords: Approach; Configuration and Change Management (CCM); Product Variant Design; Optimal System Architecture; Chiller

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1. Introduction

Cooling systems with chillers are often found in practice, specifically in the area of cooling and air conditioning engineering, both for comfort purposes and for industrial uses [1]. Considering the high and complex requirements presently defined for designing chiller cooling systems, the selection of chillers should take into account numerous specifications. I will start by listing some of the most important ones: the cooling capacity, EER (Energy Efficiency Ratio), refrigerant, the machine's working medium, inlet and outlet temperatures on the evaporator side of the machine, inlet and outlet temperatures on the condenser side of the machine, ambient (external) temperature, noise levels, the types and number of compressors, number of cooling circuits, etc. In order to increase their competitiveness in the market, equipment manufacturers need to develop new and improve their existing products to be offered within their product ranges as multiple options of such products' variants [2]. In addition, defining an optimal chiller variant based on the requirements set for the designing of such systems, both for a single product and for optimal system variants including two chillers or more, has been an increasing challenge faced by designers. "Optimal system" according to the author's refers to a system that will ensure maximum energy efficiency with minimum electricity consumption and minimum noise levels as defined by the industry rules for a particular plant installation site, with

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minimized installation dimensions and weight of the machine, at minimum cost [3].

The approach presented in this paper is based on the authors' years of experience in designing such plants, namely on the Configuration and Change Management (CCM) approach [4] where the required/optimal solution is provided by configuring the product and changing product properties through several loopback steps. The approach is also presented graphically using a flowchart diagram and has been verified against two most common examples of chillers found today: a chiller with an air cooled condenser and a chiller with a water cooled condenser [1].

The approach includes a presentation of all its steps through the product configuration phase and change phases where improvements may be made with respect to the system's efficiency, the noise levels considering the building for which the plant is designed, and the price. Of course, investor's and engineering requirements may be modified and designers may suggest to the investor what may be more appropriate when configuring the system. An evaluation analysis is also provided, after which an optimal solution for the required system may be found.

2. Related work

The research presented in this paper is an extension of the research presented in a paper by authors Osman et al. [3]. It presents the methodology used to develop cooling plant architectures in 4 basic steps. As shown, the methodology presented is of an iterative nature, i.e. it is necessary to complete several steps to obtain the intended cooling plant architecture and is based on equipment normally used in the company, manufactured by TRANE. Accordingly, we used this manufacturer's software (product configurators).

This paper aims to present and explain in greater detail the approach to configuring one of the subsystems within the cooling plant system (chiller) and demonstrate that changes may be made to its system architecture in the process and that they may be evaluated for the purpose of providing a satisfactory solution. To help verify our research, we used the existing TRANE product configurators – Iris © and TOPSS ©. As shown in Chapter 5, the verification of our approach is presented against two examples of the most commonly used water chiller types – a chiller with an air cooled condenser [5] and a chiller with a water cooled condenser [5]. In addition, the results are discussed and these two approach verifications are compared.

3. Motivation

Nowadays the crucial factor for designing companies' success is their ability to understand and handle complex systems and continuously adopt new technologies provided by equipment manufacturers [6]. The knowledge so obtained should certainly be used as a competitive advantage over other similar companies. However, this has been increasingly difficult recently as a result of a radical increase in the complexity of systems (products), which also increases the number of product variants [7]. Product architecture affects many other aspects such as the quality of engineering systems, including technical properties, manufacturing costs and, later, the compliance with the relevant requirements over a product's lifecycle [8]. When selecting equipment, alternative product variants, which are often based on multiple criteria, must be validated many times [9].

Based on their extensive experience in designing cooling plants, the authors made certain discoveries. It was found that, in the decision making process concerning system configuration [10], a lack of engineering knowledge that is always contained in other researchers' experience may present a great problem. The trial and error method is not always the best choice because it requires plenty of time before a satisfactory solution is found. It takes many years of experience to avoid this. This approach aims to provide some, if not all help to inexperienced designers dealing with this topic, in particular with respect to water chiller configuration. We endeavored to show them that a satisfactory solution may be found very quickly by using information already obtained and knowledge of the issues concerned or other similar issues.

4. Description of the proposed approach

As mentioned in Chapter 2, the approach presented is an extension of and an addition to the cooling plant architecture development methodology as described in a paper [3] (by Osman et al.), since phase 1. Provided below is a brief review of the methodology to explain in greater detail the approach proposed in this paper.

The cooling plant architecture development methodology consists of 4 basic steps. As we mentioned, the methodology is iterative, i.e. a loopback enables making changes both to customer requirements and in selection of equipment. It is partly implemented by using equipment manufacturer's software (system configurator), which the authors used in their work. Of course, it may also be implemented using software provided by other manufacturers of such equipment.

The steps of the methodology are as follows:

1. Define customer's (investor's) needs and engineering requirements.
2. Select cooling plant equipment – this includes several sub-steps:
   a) selection of chillers;
   b) selection of cooling towers;
   c) selection of dry coolers – this step is possible, but not always necessary;
   d) selection of circulation pumps on the condenser and evaporator sides of the cooling plant;
   d) pipeline dimensioning; and
   e) selection of armature and measuring and controlling equipment.
3. Evaluation analysis.

The proposed approach elaborates on Step 2a) of the proposed methodology i.e., chiller selection. The aim is to produce an optimal system solution. As mentioned in the introduction to this paper, "optimal system" refers to a system that will provide maximum energy efficiency with minimum electricity consumption, minimum noise levels according to the industry rules depending on the type of building and plant installation site, minimum installation dimensions and machine weight, at minimum cost. We should mention before describing the approach that it is based on settings used by TRANE, a manufacturer the authors have cooperated with throughout their professional careers. Other manufacturers of the same equipment across the world probably use similar or slightly different equipment configuration vocabulary, but the principle is basically the same and may with some modifications be applied to equipment made by other manufacturers, using their product configurators. It is presented in Figure 1.

It is divided into several phases:

1. the configuration phase;
2. the change phase; and
3. the evaluation phase.

The first phase (configuration) is implemented for the purpose of aligning the product with customer's (investor's) requirements as soon as possible. The product configurator [11] allows us to choose a particular range of similar, yet closely related product variants that will satisfy the needs of individual investors. This simplifies the management activities, while reducing the following segments of the product's lifecycle: ordering, sale, designing, manufacturing, delivery and product variant maintenance. The phase includes several sub-steps:

a) Initial input for the chiller – the following machine options are defined in the following order:

- type of chiller – a chiller with an air cooled or water cooled condenser, intended for exterior or interior installation;
- the required cooling capacity of the machine in [kW], based on which the rated tonnage is calculated;
- application of the machine: several options are available:
    - standard ambient mode – the machine may be started and operated at external temperatures ranging from -10 to 46°C;
    - low ambient mode – the machine may be started and operated (cooling) at low external temperatures, below -10°C;
    - high ambient mode – thanks to the machine's control and design, it may be started and operated (cooling) even at high external temperatures of up to 55°C.

b) Pre-configuration – the following machine options are defined in the following order:

- efficiency levels:
    - Standard Efficiency (SE),
    - High Efficiency (HE),
    - Extra Efficiency (XE),
    - High Seasonal Efficiency (HSE).

The first three levels are determined by factor EER, while the last one is determined by factor ESEER (European Seasonal Energy Efficiency Ratio). The High Seasonal Efficiency (HSE) level is also applicable to machines intended to be used for industrial cooling where power consuming equipment is used that requires cooling energy all year or at least during part of the year. The EER range for the first three efficiency levels is defined by the manufacturer and is as such considered to be confidential.

- noise levels (for air cooled chillers) – it should be noted that the range of noise levels is defined by the manufacturer and is as such considered to be confidential. The authors also omitted to mention the relevant design used because this is also confidential information. We should, however, mention that the noise levels will be determined in accordance with the relevant noise level ordinances (a noise ordinance and an ordinance on the noise levels for areas where people stay and reside are in place in Croatia and they are used as the governing regulations). There are 4 noise levels:
    - standard noise (SN),
    - low noise (LN),
    - extra low noise (XLN),
    - low noise with night noise setback – this is used for the areas where the machine is to be installed and requires a very low level of noise during the night (e.g. in facilities such as hospitals).
- Condenser coil options – the condenser flanges feature two basic designs:
    - aluminum – for installation in the continental part of the country and in normal working conditions; and
    - an epoxy resin layer on aluminum, protecting the condenser flanges – it is used in aggressive seaside environments.
- Heat recovery option (optional) – the machine may be designed:
    - without heat recovery;
    - with partial heat recovery; or
    - with full heat recovery.
- Free cooling option (optional) – the machine may be designed:
    - without free cooling;
    - with partial free cooling; or
    - with full free cooling.
- Power supply – different, depending on the market for which the machine is intended (U.S., European, Asian, etc.);
- Factory testing – a test report for the machine operating in normal working conditions specified in the order may be provided; and
- Type of working medium.

c) Hydraulic module selection option – it is possible to select a hydraulic module, including the type of pump control within it. In addition to the pump, the hydraulic module includes the following armature: a water strainer, a safety valve, a balancing valve, freeze protection and an expansion vessel.

- Pump package:
    - On/Off signal,
    - Single pump with standard supply height;
    - Single pump with medium supply height;
    - Single pump with high supply height;
    - Dual pump with standard supply height;
    - Dual pump with medium supply height;
    - Dual pump with high supply height;
- Smart Flow Control – with constant or variable rotational speed adjusted by a frequency converter:
    - not adjustable – with standard rotational speed;

  - speed-adjustable – the rotational speed of the pump is adjusted by making the temperature at the machine's inlet and outlet constant at all times;
  - with constant pressure difference – the rotational speed of the pump is adjusted using a frequency converter, so that the difference in differential pressure at the inlet and outlet is always the same.

d) Evaporator parameters:

- Intended purpose of the evaporator:
  - comfort cooling – temperatures above 4.5°C;
  - process cooling - temperatures below 4.5°C; and
  - ice making – temperatures between 7 and 20°C.
- Number of evaporator passages;
- Working medium temperature at the evaporator outlet [°C];
- Working medium temperature at the evaporator inlet [°C];
- Working medium flow through the evaporator [l/s];
- Working medium in the evaporator;
- Evaporator contamination factor [$m^2 \cdot °C/kW$].

e) Condenser parameters:

- External temperature [°C];
- Number of condenser passages;
- Mounting height of the machine [m].

Options relevant to the chiller with water cooled type of condenser:

- Working medium temperature at the condenser outlet [°C];
- Working medium temperature at the condenser inlet [°C];
- Working medium flow through the condenser [l/s];
- Working medium in the condenser;

f) Heat recovery option (optional):

- Working medium inlet temperature [°C];
- Working medium outlet temperature [°C].

g) Free cooling option (optional) – it is used for machines to be installed in a place where they will have a sufficient number of operating hours if the external temperature is below 0°C:

- Working medium incoming temperature [°C];
- Working medium outgoing temperature [°C].

h) Post-configuration of the machine – the following options are defined in the following order:

- Selection of the language for machine labels and manuals;
- Remote control option – select a protocol type:
  - BACnet interface,
  - ModBus interface,
  - LonTalk interface.
- Machine protection management options – define a type of protection to be used for supply phase changes:
  - Without protection;
  - Protection against supply phase changes;
  - Protection against supply phase changes including grounding.
- Select the exterior installation point of the machine – choose between with and without;
- Electrical panel protection;
- Factory-installed machine insulation – with or without factory-installed neoprene insulation;
- Select a type of hydraulic connections;
- Select a type of switch for deactivating the machine.

The second phase – the change phase – allows a change in parameter selection [12] to obtain better results with respect to the machine's efficiency (based on factors EER and ESEER), lower noise levels, reduced electricity consumption, etc. It is explained in greater detail in Chapter 5 where it is presented against different water chiller examples.

Sometimes it will not be possible to find a satisfactory solution in the change phase by changing system parameters, so it will be necessary to modify both customer requirements and engineering requirements.

The third phase – evaluation of the obtained results – is provided in tabular format by evaluating the relevant water chiller system parameters. An appropriate weight scale of evaluation is defined, with values based on ratings on a scale of 1 - 10. A satisfactory solution is selected according to the aggregate sum of the relevant parameters' ratings. In case there are several satisfactory options, the option having a higher value of the respective parameters will be selected. This phase is explained in greater detail in Chapter 5, where it is presented using two examples of water chillers.

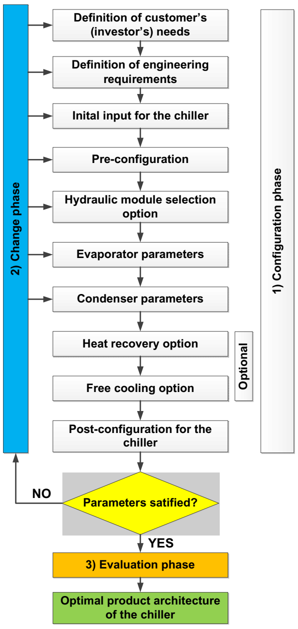


Fig. 1. Presented approach – in flow diagram presentation

5. Case study

As an example for verifying the proposed approach, we selected two most commonly used chiller types with an air cooled condenser and a water cooled condenser. We created the engineering requirements based on the defined customer requirements and preceded to configure these two systems. The whole idea behind the verification is to demonstrate the configuration process on two examples through several iteration steps; including changes to these systems, i.e. to their most significant parameters (see Figures 2 and 3). The verification ends with an evaluation of the respective system architectures for both examples (see Figure 4).

As our examples for system verification we selected equipment manufactured by TRANE, with which the authors have extensive professional experience. However, I reiterate that the approach is applicable to other manufacturers of such equipment subject to some insignificant modifications. We selected the RTAF © [13] type as an example of a chiller with an air cooled condenser and the RTHD © [14] type as an example of a chiller with a water cooled condenser. We used the manufacturer’s catalog to help us carry out the verification as the initial step of configuration under the proposed approach and software (product configurators) manufactured by TRANE TOPSS © and Spectrum © for the system parameter change phase.

According to the proposed approach, the initial step is to create customer requirements and, based on them, the engineering requirements. They are specified below and apply to both water chiller examples. The list of requirements lists the customer’s requirements and preferences resulting from an analysis of needs. To be used as basis for making future decisions and creating engineering requirements based on them, the list needs to be prepared very accurately and completely, although it will be supplemented and corrected during product configuration and the change phase.

The **customer requirements** are as follows**:**

- The machine must be capable of operating all day without interruption and in variable external conditions;
- The machine must have the possibility of exterior installation (mounted on the roof of the building), in which case the machine must be resistant to the elements (water, rain, snow, ice and air) or must have the possibility of interior installation;
- Silent operation must be ensured;
- The circulation pumps on the evaporator and condenser sides (in case of a water cooled chiller) of the machine will be installed separately within the cooling station inside the facility;

The machine must have the highest possible energy class to be able to ensure it’s financing through EU funds.

The **engineering requirements** are as follows:

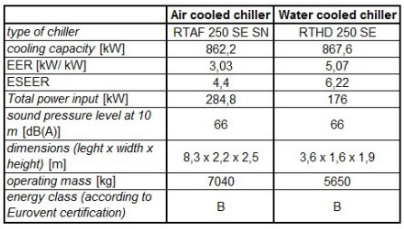
- The machine must be capable of operating in winter (down to -10°C), intermediate and summer conditions;
- The machine must be able to operate at an ambient temperature of -18 °C to 45°C,
- Uninterruptible power supply must be ensured (3x400 V, 50 Hz);
- The working medium temperature on evaporator side is 7/12 °C; the working medium temperature on condenser side is 35/30 °C (only for water cooled chiller);
- The machine must satisfy the needs for cooling energy in an industrial facility surrounded by residential buildings;
- We should aim to select the highest possible energy class according to the Eurovent requirements (according to standard EN 14511) [15], preferably Class A;
- The machine should not contain a hydraulic module with a pump or a water tank;
- The operation must be stable and resistant to shocks and vibrations;
- The chiller must be capable of operating in a “low ambient” mode at down to -18°C;
- The working medium to be used should be a mixture of water and ethylene glycol (the volume concentration in the mixture should be 35%) to ensure operation at an external project temperature for the winter period of down to -18°C;
- Minimum electricity consumption;
- Minimum dimensions of the machine (and therefore minimum mass of the machine);
- The chiller must be thermal insulated;
- The industrial facility’s need for cooling energy is 900 kW.

As shown in the proposed approach, the preferred product variant configuration was defined very quickly, which helped the designer select the appropriate project equipment and thus reduce the time of preparing the project documentation.

When determining a satisfactory variant of the solution, particular parameters of the proposed solution variants were changed through several steps during the change phase, as presented in Figure 2 and 3.

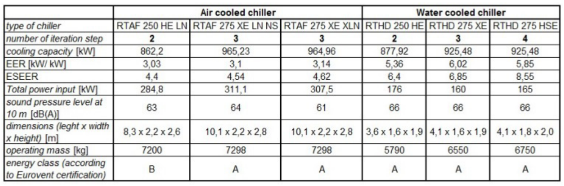
The evaluation consisted of a tabular presentation and rating of the most important parameters for each of the selected concepts for both examples of chillers (see Figure 4.).

A short review of the results obtained and the system architecture selected after the evaluation step is provided in the next Chapter 6.



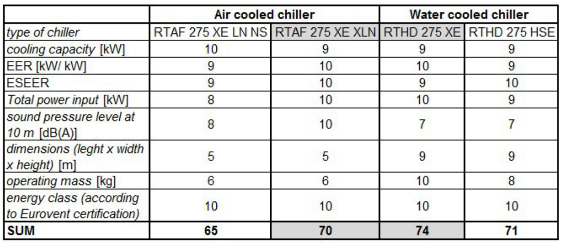
	Air cooled chiller	Water cooled chiller
type of chiller	RTAF 250 SE SN	RTHD 250 SE
cooling capacity [kW]	862,2	867,6
EER [kW/ kW]	3,03	5,07
ESEER	4,4	6,22
Total power input [kW]	284,8	176
sound pressure level at 10 m [dB(A)]	66	66
dimensions (leght x width x height) [m]	8,3 x 2,2 x 2,5	3,6 x 1,6 x 1,9
operating mass [kg]	7040	5650
energy class (according to Eurovent certification)	B	B

Fig. 2. Configuration phase – initial step (step 1)



	Air cooled chiller			Water cooled chiller		
type of chiller	RTAF 250 HE LN	RTAF 275 XE LN NS	RTAF 275 XE XLN	RTHD 250 HE	RTHD 275 XE	RTHD 275 HSE
number of iteration step	**2**	**3**	**3**	**2**	**3**	**4**
cooling capacity [kW]	862,2	965,23	964,96	877,92	925,48	925,48
EER [kW/ kW]	3,03	3,1	3,14	5,36	6,02	5,85
ESEER	4,4	4,54	4,62	6,4	6,85	8,55
Total power input [kW]	284,8	311,1	307,5	176	160	165
sound pressure level at 10 m [dB(A)]	63	64	61	66	66	66
dimensions (leght x width x height) [m]	8,3 x 2,2 x 2,6	10,1 x 2,2 x 2,8	10,1 x 2,2 x 2,8	3,6 x 1,6 x 1,9	4,1 x 1,6 x 1,9	4,1 x 1,8 x 2,0
operating mass [kg]	7200	7298	7298	5790	6550	6750
energy class (according to Eurovent certification)	B	A	A	A	A	A

Fig. 3. Change phase – through several iteration steps (steps 2 – 4)



	Air cooled chiller		Water cooled chiller	
type of chiller	RTAF 275 XE LN NS	RTAF 275 XE XLN	RTHD 275 XE	RTHD 275 HSE
cooling capacity [kW]	10	9	9	9
EER [kW/ kW]	9	10	10	9
ESEER	9	10	9	10
Total power input [kW]	8	10	10	9
sound pressure level at 10 m [dB(A)]	8	10	7	7
dimensions (leght x width x height) [m]	5	5	9	9
operating mass [kg]	6	6	10	8
energy class (according to Eurovent certification)	10	10	10	10
SUM	**65**	**70**	**74**	**71**

Fig. 4. Evaluation phase

6. Discussion of the results obtained

We aimed to provide a discussion of the obtained results. For that purpose, we prepared a comparison table for the two examples, including the main system parameters.

In Table 1 we can see a comparison between the two chiller examples using an air cooled condenser and a water cooled condenser. A difference in EER between these two water chillers is noticeable, which only confirms that chillers using a water cooled condenser are much more efficient, but this also means they use much less electricity. The possibility of conducting large amounts of waste heat on the condenser station makes them much more efficient than those using an air cooled condenser. They are, however, used for larger systems and their cost-effectiveness becomes apparent after several years of use. Water chillers with an air-cooled condenser are capable of operating with very low noise levels as a result of using fans with EC motors. The reduced rotational speed of the fans allows for quite operation of the machine.

Please note, however, that the configuration and changes were only made for one product/machine type. When designing the entire system, as presented in the [3] paper, several such machines should be considered and observed within the evaluation analysis at the end of the methodology to determine which option with which parameters would be the most acceptable with respect to energy efficiency based on the input requirements set.

Table 1. Comparison of the obtained results given by approach verification

Parameters	**Air cooled chiller TRANE type RTAF 275 XE XLN**	**Water cooled chiller TRANE type RTHD 275 XE**
Cooling capacity [kW]	964,96	939,66
EER [kW/kW]	3,14	6,11
ESEER	4,62	6,93
Sound pressure level [dB(A)]	61	65,93
Total power input [kW]	307,5	218
Dimensions (length x width x height) [m]	10,1 x 2,2 x 2,6	4,1 x 1,6 x 1,94
Operating mass [kg]	7298	6550
Energy class (according to Eurovent certification)	A	A

7. Conclusion and directions of potential future research

This paper presents research based on a Configuration and Change Management (CCM) approach [4] to variant designing of chiller products. The approach was primarily developed to help designers (professionals) working in this field (development of thermal engineering systems, specifically in the selection and configuration of chillers) in their decision making processes, so that they could reach a potentially satisfactory solution as quickly and efficiently as possible. A satisfactory solution refers to a solution using less electricity, generating less noise, having smaller dimensions (and consequently a lower mass of the machine), and being competitively priced. If possible, all other requirements set by the investor must be complied with as well. This aims to find the most acceptable chiller variant in the process of product configuration and making changes in product architecture.

The verification provided in this paper is presented using two examples of chillers. We choose two most commonly used water chillers installed in this type of cooling plant – a chiller with an air cooled condenser and a chiller with a water cooled condenser. These examples serve to demonstrate that this approach may very quickly result in an acceptable solution based on the requirements set through a few iterating steps of making changes to each variant's system architecture.

The development of an algorithm that would use the input parameters to autonomously propose an optimal solution for selecting a particular variant of a chiller type could be one of the directions of future research. The algorithm should be expandable, flexible, upgradable and customizable. In addition, it must be practically applicable, i.e. designed for the engineering way of thinking.

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