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Performance Comparison between Water-Cooled and Air-Cooled Chillers with Natural Gas and Electric Resistance Powered Boilers for Use in a Libyan Hospital

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ABSTRACT

Libya is a large country in northern Africa and the majority of its land area is desert with high temperatures during the summer and cold temperatures during the winter. Therefore, HVAC systems are a very important aspect in building design and management. This research is a comparison of the performance of two HVAC systems in Libya, which are water-cooled and packaged air-cooled chillers for large buildings. This study utilized the simulation software eQUEST, which is based on DOE-2. Chiller systems are designed for a large hospital where the water-cooled (cooling towers) and packaged (dry condensers) are the heat rejection options. The boilers used for these systems utilize natural gas and electrical resistance as the source of heat for both chiller designs and their performance were compared. The performance was determined based on the energy consumption, and the energy efficiency ratio. Results showed that a water-cooled system, which needs water to operate, spends less electrical energy than a packaged air-cooled system, which does not need water to operate, to reject heat for the hospital building. Results also showed that the using natural gas for the boiler was far cheaper than electrical resistance. The study showed that using a water-cooled chiller with a natural gas powered boiler is the most efficient option for Libyan hospitals.

Keywords: Air cooled chiller, Water cooled chiller, HVAC Libya, Energy Efficiency Ratio.

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مقارنة الأداء بين المبردات المبردة بالماء والمبردة بالهواء مع غلايات تعمل بالغاز الطبيعي والمقاومة الكهربائية للاستخدام في مستشفى ليبي

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ملخـــــــص البحـــــــث

ليبيا دولة كبيرة تقع في شمال أفريقيا وأغلب مساحة أراضيها صحراوية مع ارتفاع درجات الحرارة خلال فصل الصيف ودرجات الحرارة الباردة خلال فصل الشتاء. لذلك، تعد أنظمة التدفئة والتهوية وتكييف الهواء (HVAC) جانبًا مهمًا جدًا في تصميم المباني وإدارتها. هذا البحث عبارة عن مقارنة لأداء نظامي التدفئة والتهوية وتكييف الهواء (HVAC) في ليبيا، وهما مبردات المياه المبردة ومبردات الهواء المعبأة للمباني الكبيرة. استخدمت هذه الدراسة برنامج المحاكاة (eQUEST) المبني على (DOE-2). تم تصميم أنظمة التبريد لمستشفى كبير حيث يكون تبريد المياه (أبراج التبريد) والمعبأة (المكثفات الجافة) هي خيارات طرد الحرارة. الغلايات في هذه الأنظمة تستخدم الغاز الطبيعي والمقاومة الكهربائية كمصدر للحرارة لكل من تصميمات المبردات حتى يتم مقارنة ادائها. وتم تحديد الأداء بناءً على استهلاك الطاقة، ونسبة كفاءة الطاقة،. وأظهرت النتائج أن نظام تبريد المياه، الذي يحتاج إلى الماء لتشغيله، يستهلك طاقة كهربائية أقل من نظام تبريد الهواء المعبأ، الذي لا يحتاج إلى ماء لتشغيله، لطرد الحرارة اللازمة لمبنى المستشفى. وخلصت الدراسة إلى أن استخدام مبرد بالماء مع غلاية تعمل بالغاز الطبيعي هو الخيار الأكثر كفاءة للمستشفيات الليبية.

الكلمات الدالة: مبرد الهواء المبرد، مبرد الماء المبرد، HVAC ليبيا، نسبة كفاءة الطاقة.

1. Introduction

A chiller system has three loops: the refrigerant loop, a building cooling load loop typically via chilled water, and a heat rejection loop. The building cooling loop goes between the air handler’s cooling coils in the building and the evaporator section of the chiller. This loop takes the building thermal load from the air handler’s cooling coils to the refrigerant loop, and then the refrigerant loop takes this load to the heat reject loop to reject the thermal load outside. This heat rejection from the condenser is either water-cooled or air-cooled [1], [2]. Figure (1) shows a building cooling load loop and a water- cooled heat rejection loop.

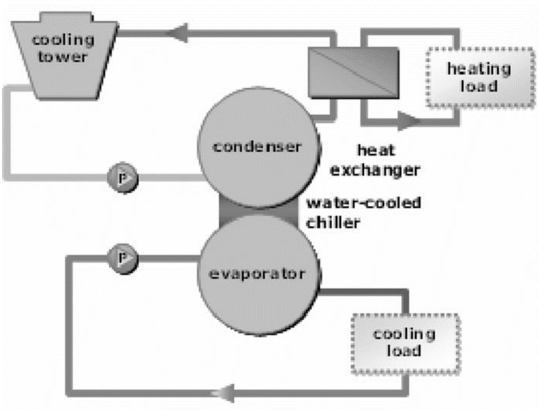

Figure 1. Building Cooling Load and Heat Rejection [3]

Water-cooled is also called a wet, open cooling tower. It is an important part of the chiller unit’s efficiency because heat is rejected to the lower wet bulb temperature of the outside air, instead of the usually much higher dry or sensible air temperature. The simple working principle of cooling towers is to make the air from the atmosphere contact the sprayed water to reject the heat mainly through partial evaporation of the water. Sprayed water is recirculated but makeup water is needed to replace that which is evaporated. Figure (2) shows this loop of the cooling tower.

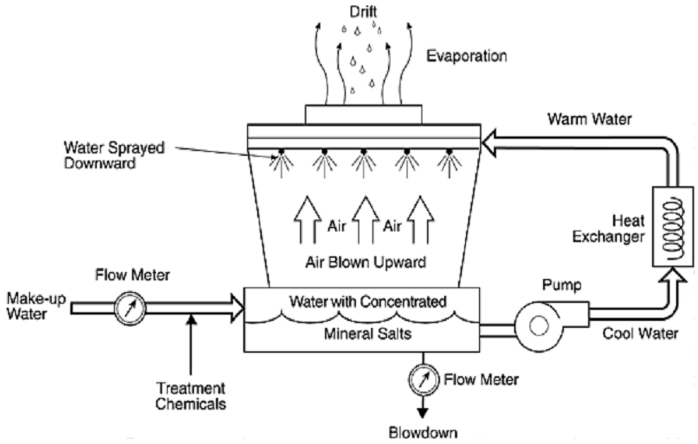

Figure 2. Cooling tower [4]

In air-cooled, heat is rejected from the compressed refrigerant liquid to the outdoor airstream via extended surfaces. The performance of the packaged air-cooled therefore depends on the dry bulb temperature of the outdoor air. Air-cooled systems do not include a condenser-side water loop, so there is no water consumption for evaporation. Packaged Air-Cooled units are always mechanical draft [5] as shown in figure (3).

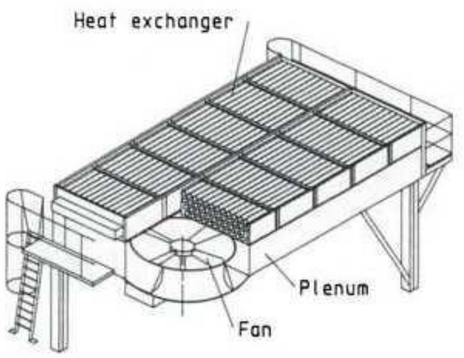

Figure 3. Packaged Air-Cooled [5]

There are many studies that study the use of chillers as a HVAC option and their effect on the energy consumption of the building. Wang et al. presented a study that used a strategic approach on energy saving analysis of the HVAC system and chiller sizing optimization for a library building. eQUEST software was used for the building's simulation and was applied to verify and predict the long-term energy consumption of HVAC systems [6]. Another study by Boghosian et al. examined the behavior and energy consumption in a hybrid chiller plant that includes a combination of two air-cooled screw vapor compression and three single effect absorption chillers. The pattern of energy consumption was analyzed in a mechanical room that has been studied for five months and is used in a hospital located in Tehran, and its energy consumption has been compared with the optimized model [7]. A study presented by Yik et al. compared using air-cooled and water-cooled conventional and oil-free chillers in hospitals in Hong Kong. The study recorded cooling demands of two existing hospitals, the life-cycle energy consumption and cost of the two system options. The results show that water-cooled air-conditioning systems with conventional chillers and cooling towers are still more energy efficient than air-cooled systems with oil-free chillers [8]. Since very few studies in Libya have covered the performance of chillers in the Libyan climate, especially comparing water and air-cooled chillers and finding the most optimum, the topic was chosen for this study. The current study is a performance comparison of air-cooled and water-cooled chillers. The simulation has been conducted on a generic hospital design located in Tripoli, Libya. The building is modeled with one of the most useful simulation tools, eQUEST, which is a simulation software used to calculate the monthly and annual gas and electricity consumption of buildings. eQUEST includes a large database of HVAC systems, operating schedules, and utility' types [9]. Another study has been conducted to compare both systems when they use a natural gas boiler and a electrical resistance boiler. The energy consumption, energy efficiency ratio, water consumption and total energy costs are used to compare all four cases with one another. This study will local companies select the most efficient chiller options for hospital, which are very important infrastructure and have high-energy consumption. This will help reduce costs and improve environmental footprint of the building.

2. eQUEST Software

The software used in this study is eQUEST, which is a software used to estimate energy's consumption of the building. This software is a widely-accepted simulation tool for energy analysis [10–13], and it can predict the hourly, daily, monthly, and annual building energy consumption for a typical year. The eQUEST software includes the updated version of DOE-2 as the simulation core, a building creation wizard, an energy efficiency measure (EEM) wizard, and graphical reporting. Therefore, the eQUEST package is [10]:

$$\text{eQUEST} = \text{enhanced DOE} - 2 + \text{Wizards} + \text{Graphic}$$

eQUEST comes in two main parts, Wizards and the Detailed Interface.

3. Methodology

In this study, a generic hospital building was modeled and is assumed to be located in Tripoli, Libya since suitable detailed weather data are only available for Tripoli. The weather file used can be found on the EnergyPlus website [14]. The weather file required conversion from EnergyPlus (epw) format to eQUEST/DOE-2 (bin) format. The weather file is then inputted in eQUEST via the first step in the Schematic Design Wizard (SD). Schematic Design Wizard (SD) is the Wizard option that was used in this study because the buildings are general in design. The hospital building used is a building type that could utilize a chiller with either a wet cooling tower or dry condenser DX units. In hospital, the indoor space needs heating even in the summer months to remove the moisture from the air. The system used was dual-duct, with reheat, which is known to provide excellent thermal comfort but at the cost of high energy use. Equation (1) was used to calculate the energy efficiency ratio (EER) of the cooling systems of each building [15].

$$EER = \frac{Cooling\ output\ \left(\frac{BTU}{hr}\right)}{Supply\ Fan\ (W) + Compressor\ (W) + Condenser\ fan\ (W)} \quad (1)$$

Equation (2) explains how to find makeup water for a water-cooled condenser.

$$Makeup\ Water = Evaporation\ loss + Drift\ Loss + Blowdown \quad (2)$$

In this research project, the total makeup water requirements were estimated to be three percent of the condenser loop's water flow rate, a common but conservatively high design percentage. The monthly cooling loads for the buildings and for how many hours each month are obtained from eQUEST software. These loads were used with the above design estimation to predict the monthly water consumption of the cooling towers. Since hospitals are buildings that are in operation continuously, this means the energy consumption for heating, cooling, and ventilation are high, which is why they (the hospitals) were chosen. This model has five floors above ground and one floor below ground. The height between floors is 15ft and between a floor and a ceiling is 10ft, so there is a generous 5ft ceiling plenum for equipment. The next eQUEST interface window that appears is for the Building Envelope Construction. In this step, the materials of the roof, the above ground walls, and the floors are chosen. There is a Layer-By-Layer option if the user cannot find a suitable predefined assembly in the software. The standard common envelope assembly often used in Libya cannot be found, therefore the Layer-By-Layer option was utilized for this study. The wall construction above the ground consists of 12in.-thick hollow masonry blocks, and on both sides, cement plaster with sand-aggregate 1 in. thick, as shown in Figure (4). The total thermal resistance (R) value is only 1.68h·ft^2·°F/Btu. The roof construction is 6in.-thick lightweight (LW) concrete, 40lbm/ft^3, 6in.-thick hollow blocks, and both sides have cement plaster with sand-aggregate, 1in. thick, as shown in Figure (5). Here the total value of R= 6.8h·ft^2·°F/Btu. The below-grade walls are just 12in concrete without insulation. Both these resistance values were calculated and obtained directly from the eQUEST software.

The next step in the data entry is about doors and windows. Table (1) has the details about the materials and number of the doors and windows for every side of the building. Table (2) shows the activity areas and the percentage of each area within the building. Also, this table presents design maximum occupancy, design ventilation rate, lighting loads, and equipment ("plug") loads.

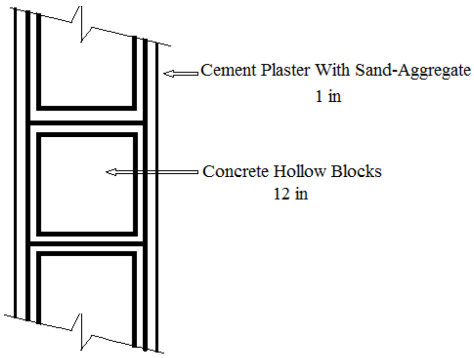

Figure 4. Above-Grade Walls

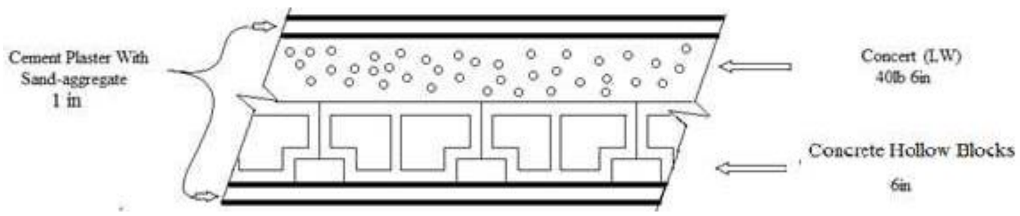

Figure 5. Flat Roof

Table 1. Doors and Windows used in the hospital model

Type	Material	Dimension		Frame Type	N	S	E	W
		Ht	Wd m(ft)					
Doors	Single clear Glass 1/4 in.	2m (7ft)	1.8m (6ft)	Alum w/o Brk 3in	1	1	1	1
Windows	Double Glass clear tint 1/2 in. Air (2004)	1.6m (5.2ft)	1m (3ft)	Alum w/o Brk, Fixed 3in	40	0	0	0
	Double Glass clear tint 1/4 in. Air (2203)	1.6m (5.2ft)	1m (3ft)	Alum w/o Brk, Fixed 3in	0	40	40	40
	Every window in every side has a 2ft exterior window shade.							

Table 2 Occupancy, Ventilation, Lighting, and Plug Loads ued in the hospital model

Area Type	Percent Area (%)	Design Max Occupy Per Person		Design Ventilation Per Person		Lighting		Plug Lds	
		m^2	**ft^2**	**m^3/h**	**CFM**	**W/m^2**	**W/ ft^2**	**W/m^2**	**W/ft^2**
Medical and Clinical Care	60	13.9	150	14.7	25	0.13	1.4	0.14	1.5
Laboratory, Medical	15	13.9	150	11.8	20	0.14	1.5	0.19	2
Corridor	10	13.9	150	4.4	7.5	0.06	0.6	0.02	0.2
Laundry	5	13.9	150	14.7	25	0.08	0.9	0.28	3
Mechanical and Electrical Room	5	41.8	450	13.2	22.5	0.07	0.7	0.02	0.2
Restrooms	5	4.9	52.5	29.4	50	0.06	0.6	0.02	0.2

Because this building is big, chilled water coils are selected for the building, and a boiler with hot water coils is used for space heating. For the air distribution, dual-duct air handlers were selected for supply and "ducted" was used for the return air path instead of plenum-return, since they do not allow the returned air to mix with the outside air and therefore avoids contamination. In the cooling season, the supply air design temperature is 55°F and the design indoor temperature is 75°F. The supply air design temperature is 95°F, and design indoor temperature is 75°F in the heating season. Figure (6) shows the HVAC system that was selected which is a Chilled Water System. In the same figure, the condenser type is Water-Cooled which is a wet cooling tower system. The other option for a condenser system is Packaged Air-Cooled, which has a dry condenser; and this system will be selected after finishing the base case to compare the energy and water consumption. When the water-cooled system is selected, the next interface window which appears, shown in Figure (7), consists of the water cooled system specifications. After this point, the next data entry steps are about the heating system. Appendix A shows the specifications of the heating system, which is a natural gas fired boiler with a hot water loop. Another heat source that was evaluated in this research project was an electric resistance boiler. The point here was to see how much electricity was saved when the system instead used natural gas for the boiler.

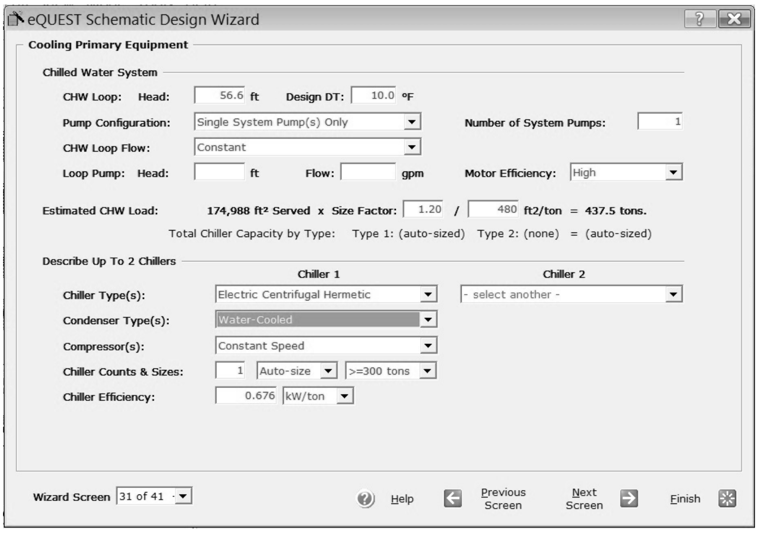

Figure 6 Chilled Water System (from eQUEST Output)

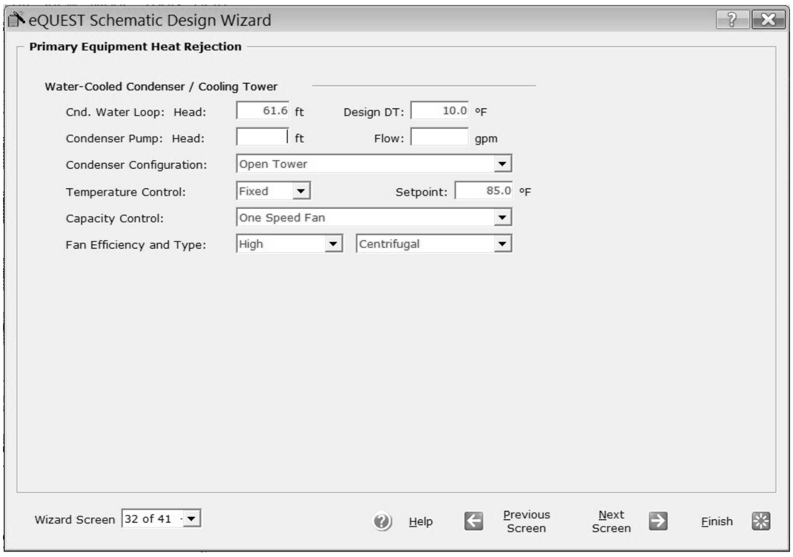

Figure 7 Water Cooled (from eQUEST Output)

4. Results and discussion

4.1 Energy consumption

The eQUEST simulations calculated the amount of the electricity that the HVAC systems used monthly and annually for two cooling-system's heat rejection options. Case 1 was when the condenser is Water-Cooled via evaporative cooling towers. Case 2 was when the Packaged Air-Cooled or dry condenser was selected as the heat rejection system. Case 1 is when the water-cooled system was used. Figures (8) and (9) show the electric and natural gas consumption respectively when the system using the water-cooled Chiller and natural gas boiler during the year. For case 2 when Packaged Air-Cooled is used, Figures (10) and (11) show the electricity consumption and natural gas consumption respectively.

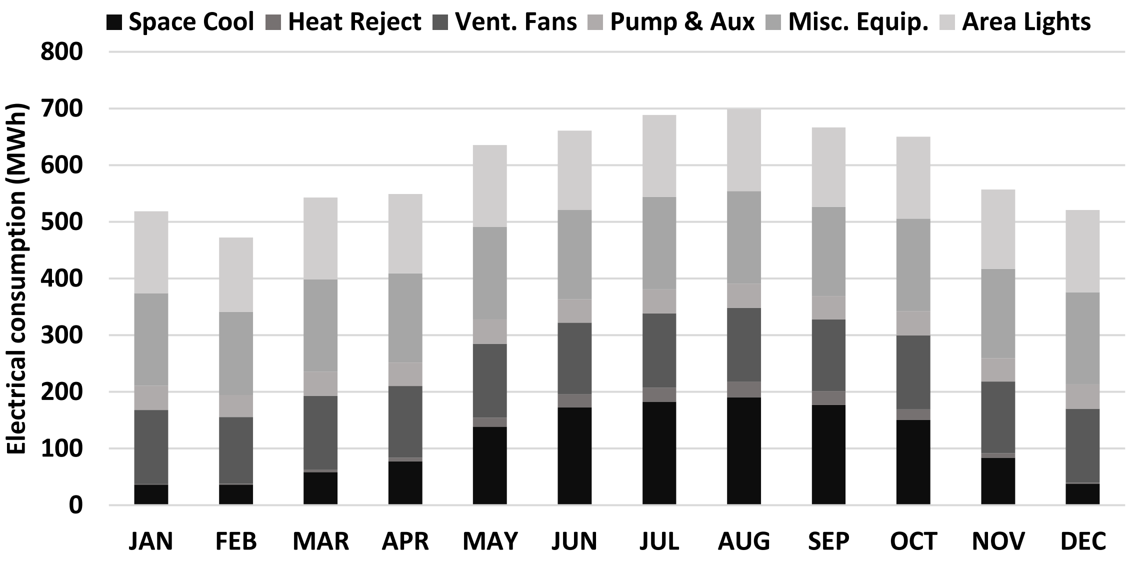

Figure 8 Electric consumption when the system uses water-cooled Chiller and natural gas boiler **during the** year

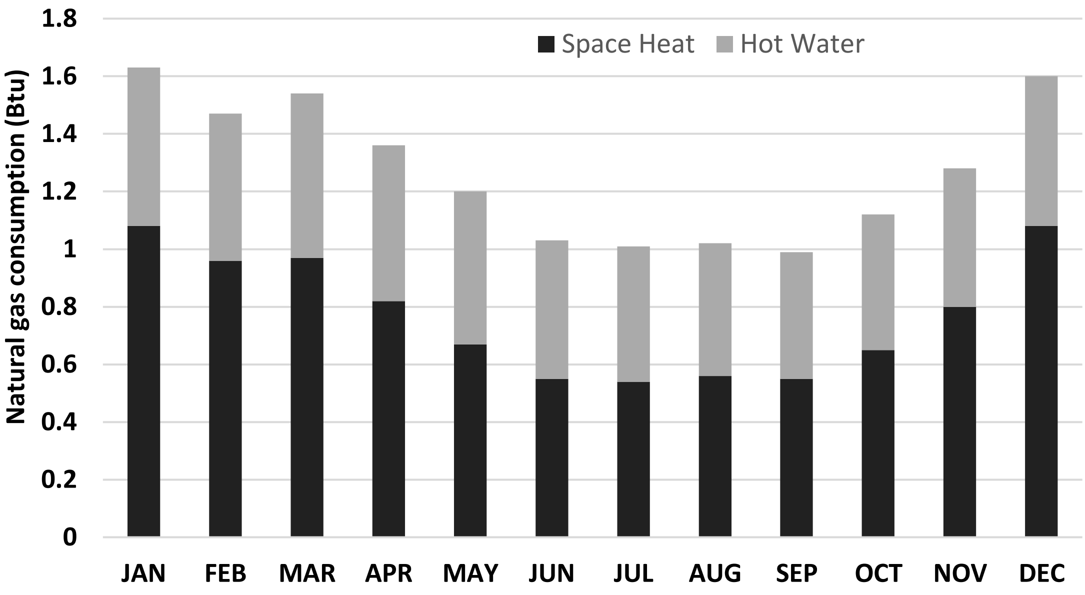

Figure 9 Natural gas consumption when the system uses water-cooled Chiller and natural gas

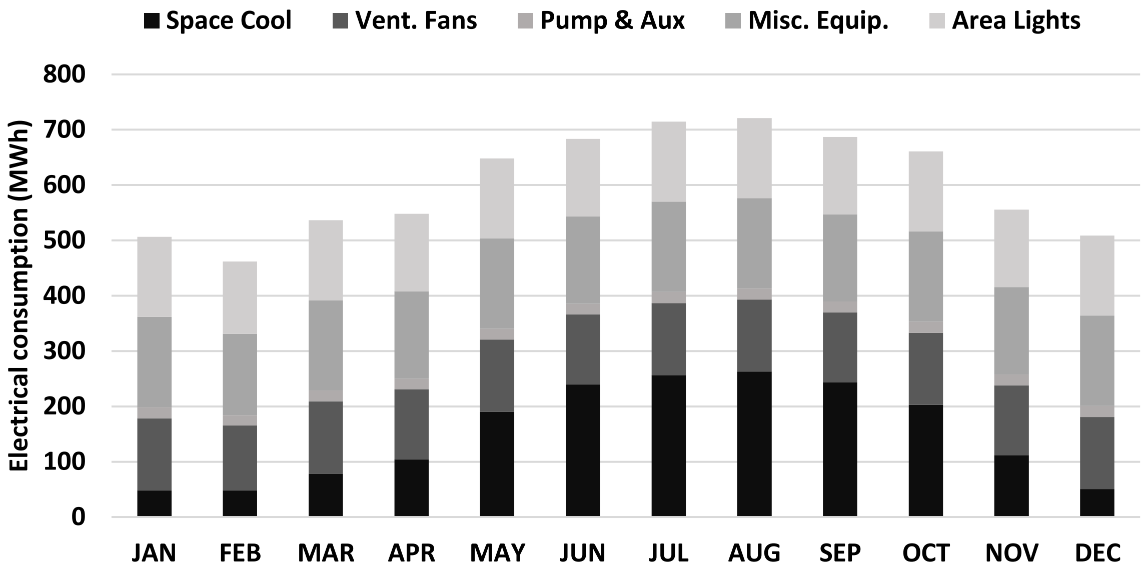

Figure 10 Electric consumption when the system uses Packaged Air-Cooled Chiller and natural gas boiler during the year

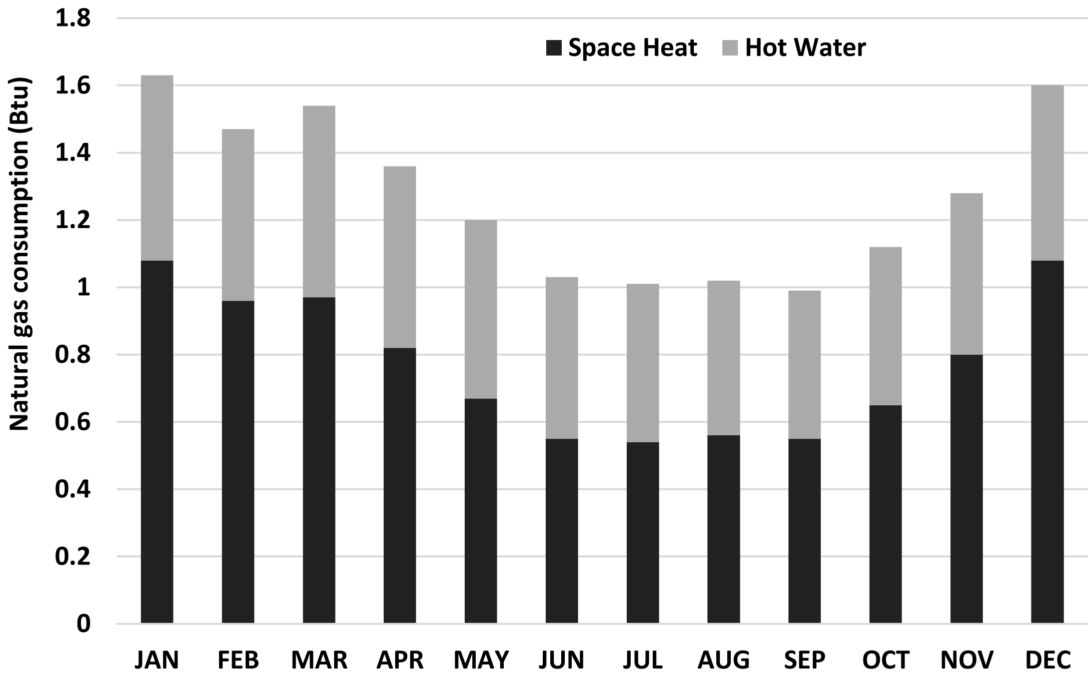

Figure 11 Natural gas consumption when the system uses Packaged Air-Cooled Chiller and **natural gas boiler** during the year

For case 1, the electrical energy required annually for space cooling is less than in the case 2 by 70MWh, but the difference is not that big compared with a total amount of the electricity energy. As shown in table (5) and table (6) the space cooling uses more energy than in case 1. The heat rejection and pumps' consumption in case one is more than that in case two because of the cooling tower's fan and chiller's condenser loop's loop pumps. Using an electrical resistance boiler instead of natural gas boiler greatly raises the consumption of electricity. Tables (3) and (4) show the differences in the electricity consumption in both cases under consideration when a resistance boiler is used, e l ectricity consumption increased in case 1 by 46% and case 2 by 47% this is because the boiler itself plays similar role in both cases and therefore, will have similar consumption for both cases.

Table 3 Electric consumption when the system uses water-cooled Chiller and electrical resistance boiler during the year

Electric consumption (kWh)													
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**Total**
Space Cool	37	36	58	78	138	172	183	191	177	150	84	38	1342
Heat Reject	1	1	4	6	16	23	25	27	25	19	8	1	156
Space Heat	239	213	212	179	145	118	117	122	119	141	174	238	2017
Hot Water	118	110	122	116	114	104	101	98	94	100	102	112	1291
Vent. Fans	130	118	130	126	130	126	130	130	126	130	126	130	1532
Pump & Aux	43	39	43	42	43	42	43	43	42	43	42	43	508
Misc. Equip.	163	147	163	158	163	158	163	163	158	163	158	163	1920
Area Lights	145	131	145	140	145	140	145	145	140	145	140	145	1706
Total	876	795	877	845	894	883	907	919	881	891	834	870	10472

Table 4 electric consumption when the system uses Packaged Air-Cooled Chiller and electrical resistance boiler during the year

Electric consumption (kWh)													
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**Total**
Space Cool	48	48	78	105	190	240	256	263	244	202	112	50	1836
Space Heat	239	213	212	179	145	118	117	122	119	141	174	238	2017
Hot Water	118	110	122	116	114	104	101	98	94	100	102	112	1291
Vent. Fans	130	118	130	126	130	126	130	130	126	130	126	130	1532
Pump & Aux	20	18	20	19	20	19	20	20	19	20	19	20	234
Misc. Equip.	163	147	163	158	163	158	163	163	158	163	158	163	1920
Area Lights	145	131	145	140	145	140	145	145	140	145	140	145	1706
Total	863	785	870	843	907	905	932	941	900	901	831	858	10536

4.2 Resulting EER

The energy efficiency ratios (EER) of the water-cooled and packaged air-cooled options calculated by Equation (3) and are shown in Figure (12). The EER of the water-cooled systems were significantly higher as expected due to the lower heat rejection temperatures.

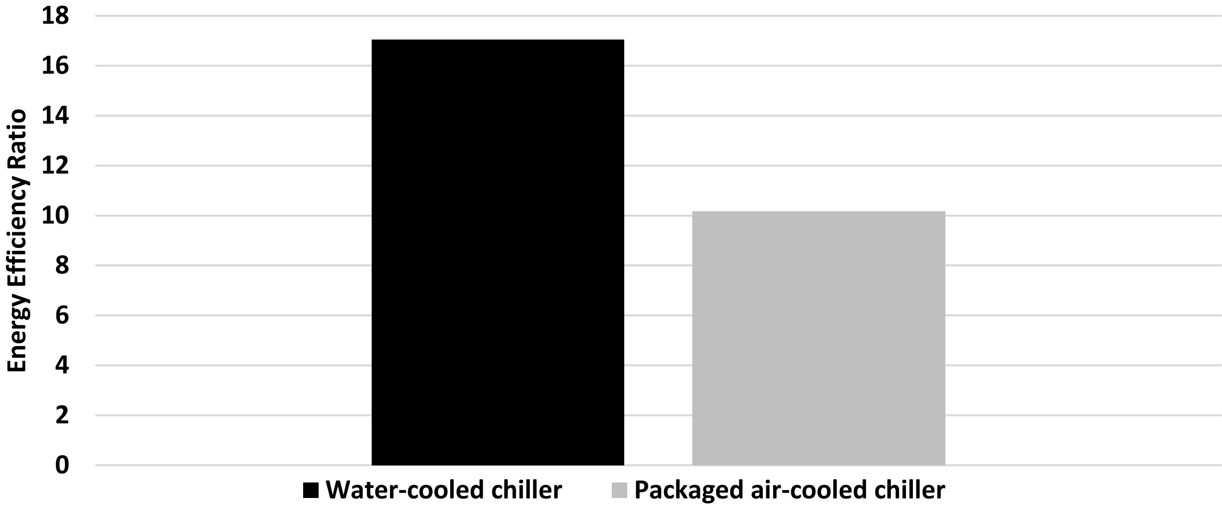

Figure 12. EER of Water-Cooled and Packaged Air-Cooled

5. Conclusion

In Libya, weather is seasonal and affected by a few factors like the location of Libya at low latitudes on desert, Libyan's landform and the Mediterranean Sea. Buildings in Libya need better HVAC systems to make indoor spaces more comfortable and productive. These large HVAC systems need electricity, water and natural gas to operate. For this study, two chiller systems were taken into consideration for a hospital located in Tripoli, which are air and water cooled chillers. Both chillers were compared to one another in terms of energy consumption, resulting EER, water consumption and cost. Furthermore, the effect of using an electric resistance and natural gas boiler for each chiller was investigated. The study was conducted using simulation tool called eQUEST. The results have shown that overall, a water-cooled chiller system, which needs water to operate, spends less electrical energy than a packaged air-cooled system, which doesn't need water to operate.

6. Recommendations

The Meteorology Department of Libya needs to install more weather stations. Personnel need to be trained to operate and maintain the stations. Weather files for Libyan cites can then be created so these files can be used not only for HVAC design and analysis, but also for oil companies, renewable energy projects and weather forecasting. The building construction codes need to be updated if future research shows that, for example, adding insulation to roofs, walls, and foundations saves energy as well as makes the buildings more comfortable. Creating a retail natural gas piping network is needed to let the gas reach buildings. This would decrease the need for even more new electrical generating stations in Libya, and improve the overall efficiencies and economics.

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APPENDIX A

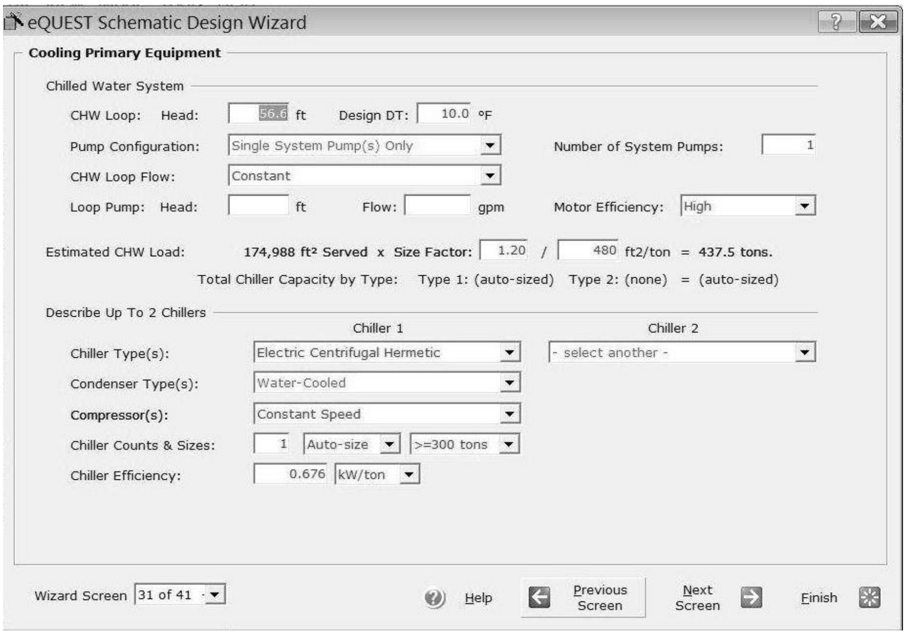

Figure A.1 Water-Cooled (Hospital eQUEST Input)

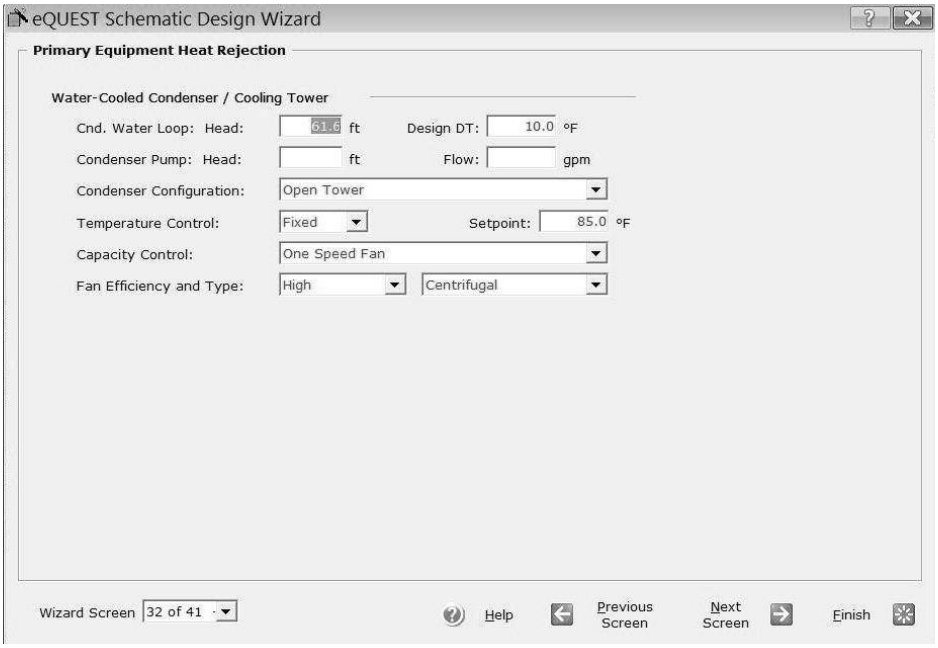

Figure A.2 Cooling Tower Specification (Hospital eQUEST Input)

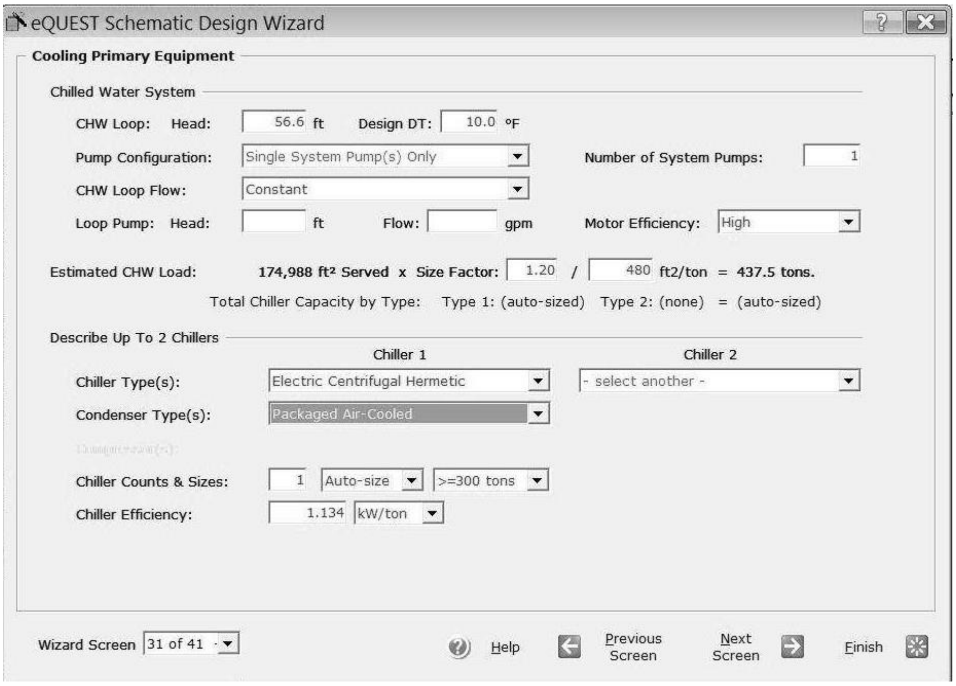

Figure A.3 Packaged Air-Cooled (Hospital eQUEST Input)

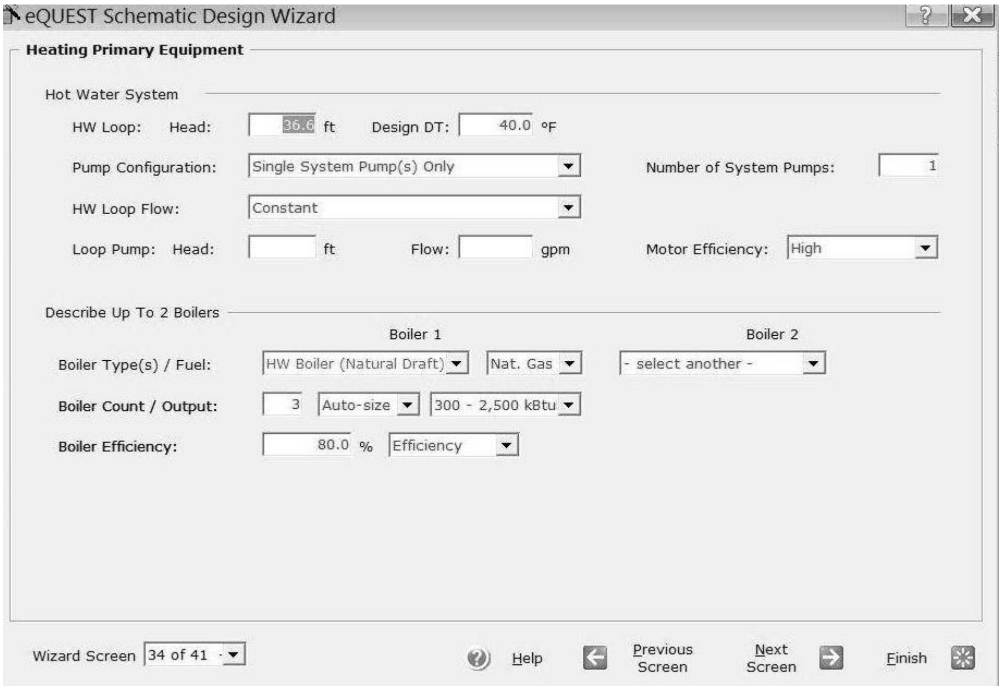

Figure A.4 Natural Gas Boiler (Hospital eQUEST Input)

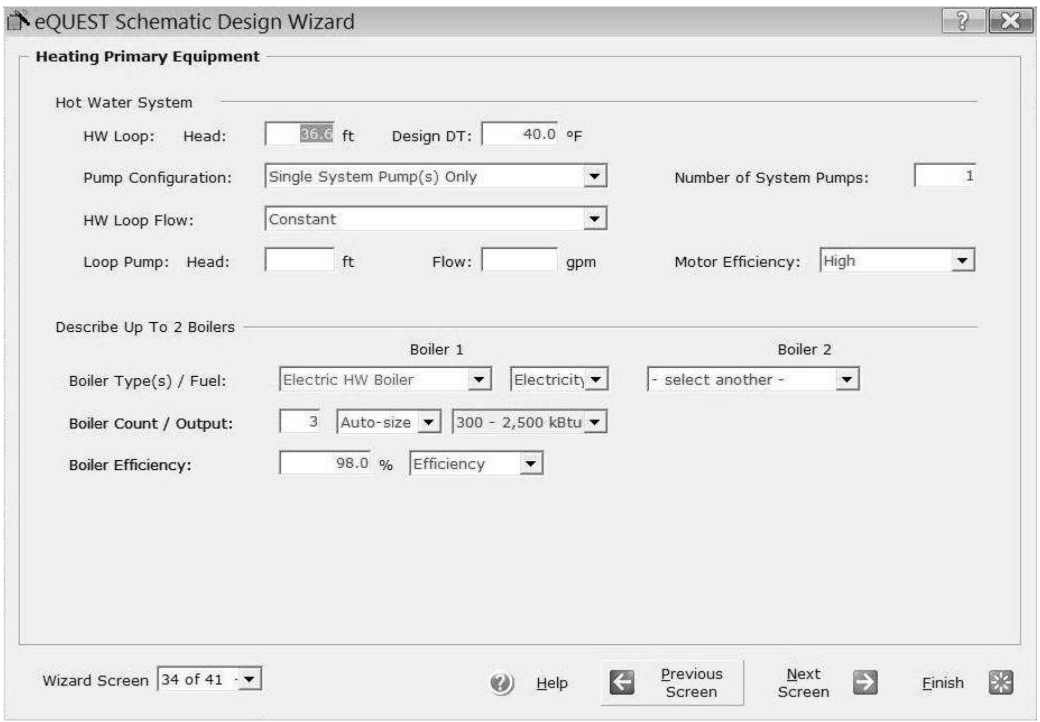

Figure A.5 Electric Boiler (Hospital eQUEST Input)