District-Cooling Technology and Energy Saving

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Abstract

Air conditioning systems are one of the most important systems nowadays, because they increase the human productivity through the control of the air temperature, humidity ratio, contaminants, odors… etc, but it consumes large portion of the world's generated energy. District cooling systems (DC) are considered to be one of the technologies that energy saving could be implemented through it. In this study, practical district heating and cooling systems are defined and investigated. Hydraulic modeling was carried out for the pipe lines distribution systems in order to check the validity of the network distribution under various operating conditions. The studied parameters were the velocity and pressure drop in the system's pipe network. The hydraulic modeling was accomplished by using two different programs. The results were found to be in a good agreement to each other. The results show that the systems need some modifications because there are many pipes have velocity values crossed the upper or lower allowable limits. Here no modifications were carried out as the systems are installed in Arabian countries.

Two economical studies were performed. The first was performed for the district cooling systems when operationally replaced with set of central units for each building individually. The second shows the percentage of saving when DC systems operated electrically verses natural gas. The results show that the installation initial cost of all systems is quite near to each other, but the benefits of saving observed in operating cost. The study verified that it is cheaper to use DC systems, natural gas operated than using DC systems electrically operated, and to use DC systems generally is cheaper than using central systems.

Keywords

District cooling, piping losses, velocity distribution

Introduction

Air conditioning (AC) is the process that simultaneously conditions air then distributes it combined with outdoor air to the conditioned space to control and maintain the space at pre determined limits, /1/. Different types of AC systems are widely used but the latest newly one is District heating and cooling systems (DH&C) which are huge systems used to distribute thermal energy from a central source to residential, commercial, and/or industrial consumers for use in space heating, cooling, water heating, and water cooling. District systems produce electricity, steam, hot or chilled water at central plant and then distribute them through underground wires and pipes to adjacent buildings connected to the system. Thus thermal energy comes from a distribution medium rather than being generated on site at each facility.

Because district energy thermal networks aggregate and link the heating and cooling requirements of dozens or hundreds of buildings, they create a great scale of thermal energy use in community that facilitates fuel flexible solutions at central plant and allow thermal storage applications that would not otherwise be functionally or economically feasible on an individual building basis. These systems have economic and environmental benefits depending on the particular application. Historically, successful DHC systems had the political backing and support of the community.

In addition to fossil fuels, district energy systems can utilize a combination of locally available renewable sources such as municipal solid waste, community wood waste, landfill gas, wastewater facility methane, biomass, geothermal, lake or ocean water, and solar energy. They also improve local economics by increasing energy reliability, stabilizing energy costs, attracting new businesses to the district served by the system, increasing property values and utility, by re-circulating energy dollars in the local economy through capital investment, construction, operation, and maintenance cost.

From sustainability stand point, the essential advantage of a district energy system over a conventional central plant, transmission and distribution system is a far more efficient use of the input power relative to end uses.

Typically one third of the fuel energy input to a conventional fossil fuel power plant is delivered to the end use consumers as electricity. The vast majority of the energy that is generated is discharged in the form of heat to adjacent rivers, lakes, and to atmosphere, resulting in significant thermal pollution. And while this energy is discharged to the environment, consumers purchase more electricity and natural gas to meet their needs that could have been satisfied by recovering and using the wasted thermal energy. By contrast, local district energy systems capture most of the energy generated in electricity production and use it to produce steam and hot chilled water. This process is known as co-generation and is made possible by combined heat and power or “CHP” technologies such as gas fired reciprocating engines, gas turbines, heat exchangers, and absorption chillers. /2/

District heating and cooling systems consist of three primary components. They are the central plant, the distribution net work, and the consumer systems. For district heating systems the central plant may use one of the following types, boilers, refuse incinerators, geothermal sources, solar energy collectors, and Thermal energy developed as a by-product of electrical generation (co-generation).

But for district cooling systems the chilled water can be produced by Absorption refrigeration machines, Electric-driven compression machines, Gas/steam turbine or engine-driven compression equipments, and Combination of mechanically driven systems and thermal energy driven absorption systems.

Nowadays many major cities around the world meet much of their heating requirements through district heating systems. But the leaders globally are the Scandinavian nations of Denmark, Finland, and Sweden; they have been using district energy systems and improving upon cogeneration technologies for more than 85 years now. Since the energy crises of the 1970’s, Denmark has been a world leader in combining district heating technology and investments with government policies to build and strengthen the district heating industry. Nowadays over 60% of homes in Denmark are served by district heating. /2/

During the early 1980s the Russia had over 1000 district power and heating systems in operation serving more than 800 Soviet cities.

In Japan, since 1970’s, and in Korea, since 1980’s, urban planners have carefully integrated efficient co-generation systems with district heating and cooling systems. For example, the Korea District Heating Corporation began operations in 1985 and today provides district energy service to 788 000 households. These households represent over 60% of the country’s population. /2/

Table (1), District systems historical time table. /2/

Ancient Rome	heated water pipe through bath, greenhouse, and palace complexes
1300’s	Hot water systems gain prominence in France and throughout Europe
1835	1st U.S. district steam system built at US Naval Academy in Annapolis, Maryland
1877	First municipal district steam heating system built in Lockport, New York
1882	New York City Steam Company begins serving lower Manhattan
1906	Thomas Edison builds electric generation station in Philadelphia and co-generates steam, creating the district heating system that still serves the city today

1962	Hartford, CT commissions the first downtown combined steam and chilled water district heating and cooling system
1970’s	The first eleven downtown district heating and cooling systems are built in US cities by the local natural gas distribution company
1980’s	Hundreds of colleges and universities build district heating and cooling systems. District energy networks are built in South Korea; Japan and Malaysia
1990’s	Investor-owned electric utilities from non-regulated subsidiaries to build downtown district cooling systems
2000’s	From 1990 to 2006, over 375 000 000 ft^2 of customer space is connected to district energy systems. Huge district cooling systems are built in Middle East to support vast real estate development in the region
Future	Decentralized combined cooling, heating, and power systems supplying and receiving energy from self- generating buildings through interconnected micro-grids

Literature review

In the field of district heating and cooling definition and performance, Yoshiyuki Shimoda, et al, /5/, aim to verify the advantages of district heating and cooling (DHC) systems in terms of energy efficiency. From the measurement data, the parameters that characterize the energy efficiency of a heating/cooling plant are identified for DHC in buildings individually. A simulation model that considers the difference in these parameters is developed. This model examines both the advantages and disadvantages of DHC systems and the effect of each parameter. The results show that the energy efficiency for cooling in DHC systems is superior to that in the case of individual cooling systems because of the “concentration effect” and “grade of operation”.

In the field of renewable energy driven district systems, Leyla Ozgener, et al, /6/, modeled and examined geothermal district heating systems (GDHSs) through the relations between thermodynamic losses and capital costs for the devices comprising the GDHSs. Some possible generalizations are proposed relating thermodynamic losses and capital costs. The model proposed is then applied to a GDHS installed in Turkey using actual data. Finally, the results are discussed in terms of the identification and evaluation of inefficiencies in the system and of possible improvements. The study provides insights into the relations between energetic and exegetic losses and capital costs for GDHSs, in particular, and for energy systems, in general. The results appear to be useful to those involved in the development of analysis and design methodologies that integrate thermodynamics and economics.

The primary energy destructions in the GDHS system are attributable to the thermal line, the heat exchangers, and the pumps. It has been shown how the use of simple thermo economic optimization methods on GDHSs could contribute to determining the correct design of new equipment, especially by ensuring that value of Rex for the equipment approaches an appropriate value of Rex.

In the field of distribution system performance enhancement, Yoshiyuki SHIMODA, et al, /7/, developed an energy simulation program of heat distribution network in a district heating and cooling system. Research on actual condition of heat distribution system of DHC plant was also executed. Using the measurement result, the accuracy of the program is confirmed. By using this program, the relationship between scale of pipeline network and energy consumption of heat distribution system was examined. In the final part, importance of chilled water temperature differences at the building side for energy performance of DHC is clarified quantitatively.

In this study, investigations were achieved on the heat distribution system performance in practical district heating and cooling systems and a simulation program that evaluates the energy consumption of heat distribution system was developed. The measurement results of temperature and static pressure distribution in DH&C systems were used to verify the energy consumption of heating and cooling distribution systems in the modeled DH&C plants.

Software programs

In this study, two software programs were used to study the distribution systems hydraulically for the cases under investigation. The two programs nearly have the same procedure for data entry and results collections, except in very small number of difference points.

The first program is a very powerful pipe flow modeling tool with capabilities to tackle complex pipe networks similar to the present investigated cases. The program has two useful options which are first, the capability of optimizing the pipes sizes, if required, in order to get the most accurate pipes diameters to the specified flow rates. And second, the capability of analyzing a pre-designed system in order to check the degree of accuracy of selection of different equipments used in the system.

It has the ability to deal with pipe networks with total number of pipes up to 1000 pipes, while the largest number of pipes for all selected cases was maximum about 300 pipes. The program is supported with databases for different types of pipe materials, valves types, piping junctions, and pumps types, which makes it so easy to select the required inputs instead of adding them every time.

The second program is also powerful pipe flow modeling tool, it has a very useful option which is the capability of exporting the data to an excel sheet in order to make residual calculations, if required, on the results.

In this study the two programs were used to analyze and examine the selected cases which were already installed.

Distribution Systems Hydraulic and Economic Analysis

Objectives of the study

1- Verification of different cases in the Middle East area that is trending to apply the DHC technology nowadays, by using case studies already installed in Arabian countries.
2- Applying scientific methodology in studying the distribution systems hydraulically in order to locate the points of weakness that may decrease the efficiency of chilled water distribution.

The hydraulic study is performed through studying three main parameters values, which are the maximum and the minimum velocity values through the distribution lines, and the pressure drop occurs through the distribution lines.

A total number of three designs are investigated here. They are differ in the value of load density factor which gives good area of comparison between the cases which are suitable for applying district cooling technology and the cases at which the application of such technology does not make any scene. In this study many scenarios where discussed for each case. Table (2) summarizes the data of these three cases.

Table (2) summary of the case studies data.

Case Study Number	1	2	3
Type of area serviced.	Public	Public	Public
Cooling load (Ton ref.)	19451	29322.5	75000
Area (km^2)	2	1.576	1.5
Distribution system length. (km)	8.5	20	18
Case is found in figure number.	1	4	9
Distribution system figure number	2	5	10
Program input Auto cad figure number	3	6,7,8	11,12

Case study one

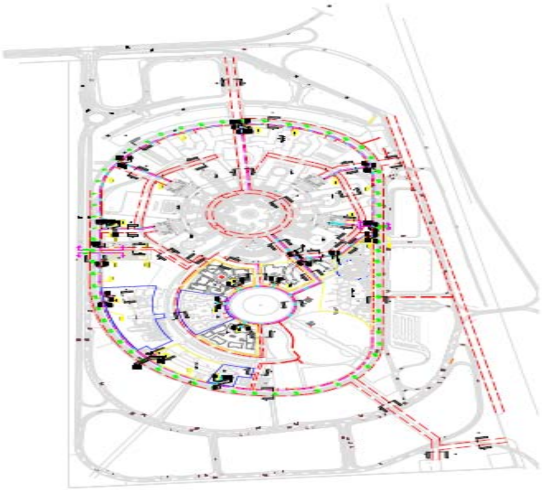

Fig (1), Auto CAD plane for the first case

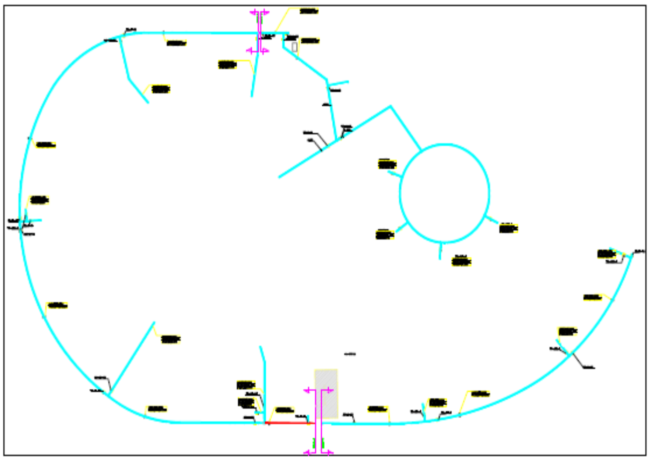

Fig (2),   the pipe line distribution system for first case

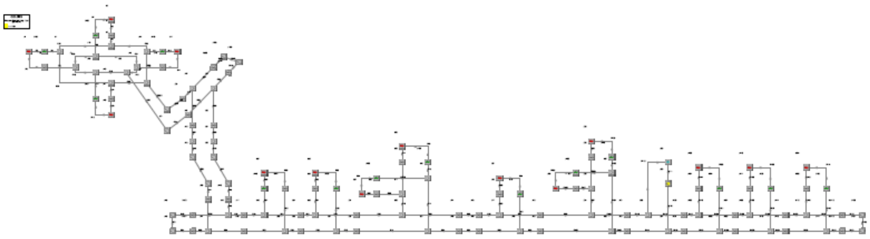

Fig (3), the inlet distribution system to the software program

The hydraulic study of the distribution system

A total number of ten scenarios were carried out in order to study any possible operating condition of the system, but here only important six scenarios will be discussed.

Suggested Scenarios for Case Study (1)

Scenario no.	Total plant flow (gpm)	Description
1	28846	Full load , this is considered as hydraulic test for the whole system
2	19500	Full diversified flow (= 67.7% of undiversified flow) to each Valve Chamber = 19500 gpm.
3	19500	With total diversified flow as above, 100% of undiversified (peak) flow to 50% of most hydraulically disadvantaged Valve Connection , remainder of diversified flow, to remaining Valve connections = 19500 gpm.
4	23942	Full diversified flow (= 83.1 % of undiversified flow) to each Valve Chamber connection = 23942 gpm.

5	23942	With total diversified flow as above, 100% of undiversified (peak) flow to 50% of most hydraulically disadvantaged Valve Connection , remainder of diversified flow, to remaining Valve connections = 23942 gpm.
6	14423	Full diversified flow (= 50 % of undiversified flow) to each Valve Chamber connection = 14423 gpm.

Case Study two:

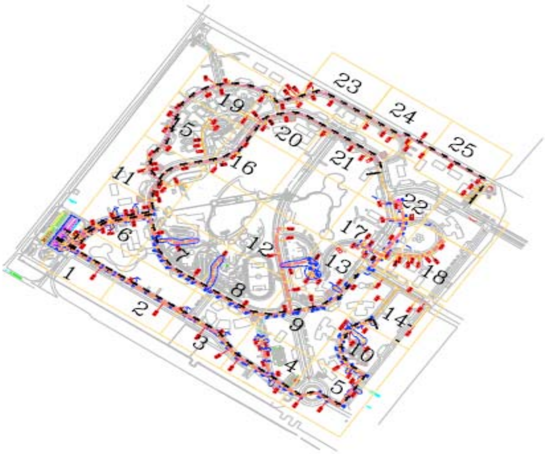

Fig (4), overall view of the village for case two

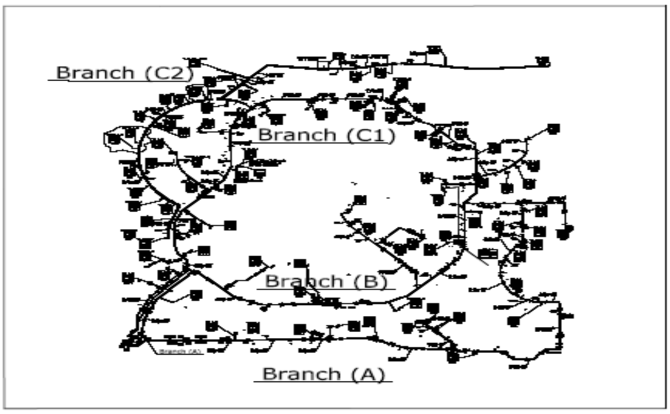

Fig (5), the distribution system for case two

The distribution system is divided into three main branches, A, B and C1+C2. They are also studied separately. Figures (6, 7, and 8) are for the three branches as entered to the program

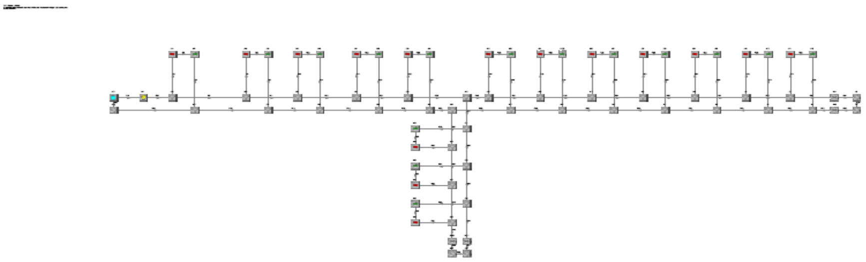

Fig (6), Branch (A) as entered to the software program for case two

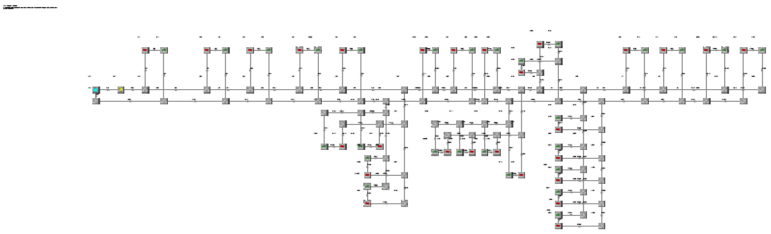

Fig (7), Branch (B), as entered to the software program for case two

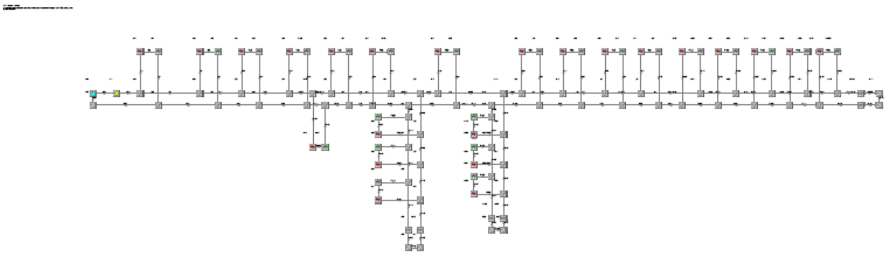

Fig (8), Branch (C1+C2), as entered to the software program for case two

The hydraulic study of the distribution system

Two scenarios were carried out, the first is used as a hydraulic stress test , and the other is near to the operating condition,

Scenarios for Case two

Scenario no.	Total plant flow(gpm)	Description
1	57600	Full load , this is considered as hydraulic test for the whole system
2	46080	Full diversified flow (= 83.1% of undiversified flow) to each Valve Chamber = 46080 gpm.

Case study three

In this case the distribution system is in the form of closed loop starting from the plant which is supplying the system with chilled water through two supply pipes and two return pipes, (i.e. the system is almost separated into two identical systems), figs (11, 12) are the image of the distribution system entered to the software program.

The hydraulic study of the distribution system

One scenario was performed as a hydraulic test to the system.

Scenario for Case three

Scenario no.	Total plant flow(gpm)	Description
1	180000	Full load

Fig (9), Overall view of case three

Fig (10), the distribution system for case three

Fig (11), the first half of the distribution system for case three

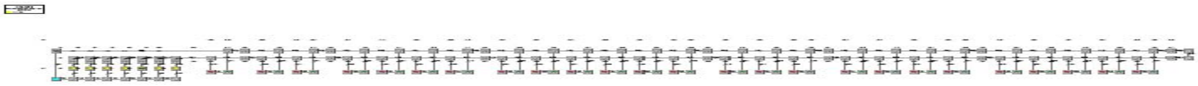

Fig (12), the second half of the distribution system for case three

The economics of the three cases were performed through:

1- Simple comparison between these real systems and imaginary ones replacing them with sets of central units applied to each building separately, depending on the required cooling loads capacity.
2- Comparison between the systems with their current equipments and when these equipments replaced with suggested equipments that may raise the systems total efficiency.

These comparisons were carried out with the variation of three different parameters which are **the systems life time**, Which is given here with three different values, 15, 20, and 25 years. The effect of the systems life time on the economical benefits of it was identified through the results. **The profit rate,** That was given with two different values, 10% and 15%. And finally, **the yearly working hours,** three different values were used, 1800, 3000, and 5400; these values represent wide variation on yearly working hours and their effect on the economical benefits of such type of systems.

The comparison was made between three different models:

1- Central units applied to each building separately, and referred to it here as Central,
2- Applying district technology with traditional chillers which uses electricity and referred to it here as (District Ele).
3- 3-Applying district technology by using non traditional energy resources,(absorption chillers), but for the availability of natural gas in Egypt, natural gas chillers were used in the study and referred to it as District gas.

Results and discussion

For each case study, maximum and minimum flow velocity points are indicated along the network of the distribution system taking in consideration that the flow velocity upper limit is 10 fps under all modeled scenarios, (Velocities above 10 ft/sec are highlighted for reference), and the minimum limit is 3 ft/sec. Pressure drop has been taken with maximum value of 4 ft /100 ft.

Case study one

Figs (13, , and 19) are program outputs for the distribution system with the pipes encounter. Pipes with values of the velocity and pressure drop beyond the specified limits are presented with different color.

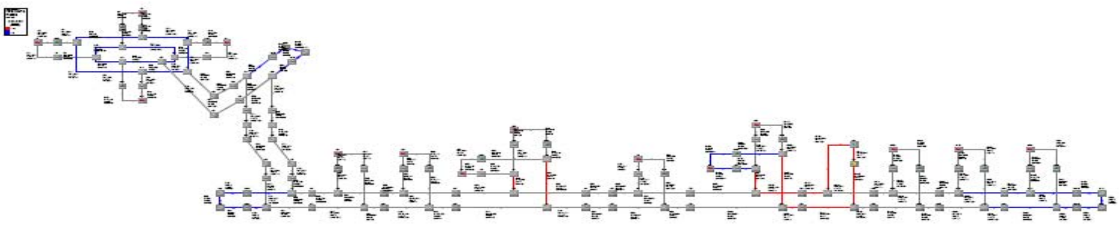

Fig (13), Analysis for velocity distribution for 100 % full load

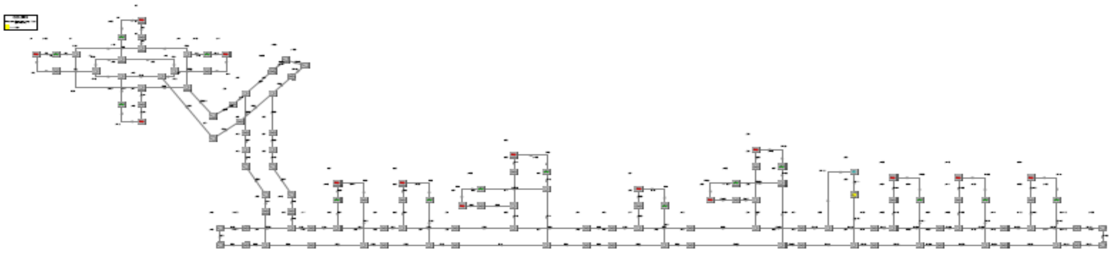

Fig (14), Analysis for pressure drop at 100 % full load

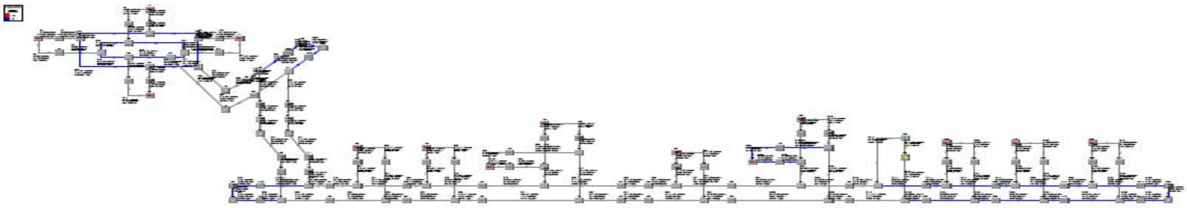

Fig (15), Analysis for velocity distribution for 67.7% of full load

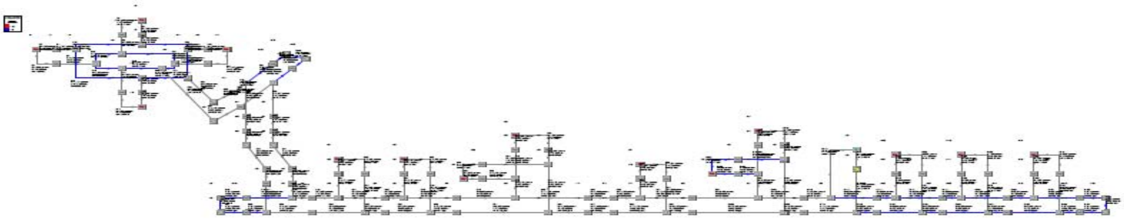

Fig (16), Analysis for velocity distribution for 67.7% of full load worst case

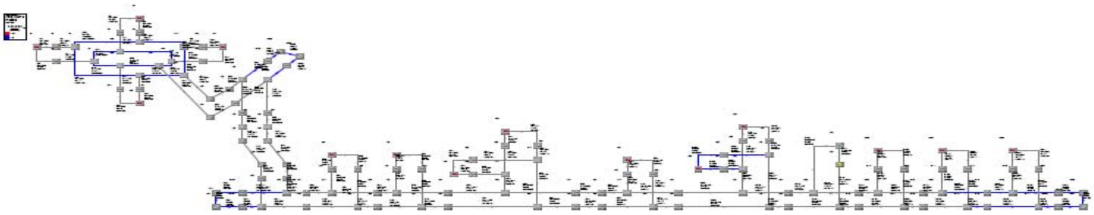

Fig (17), Analysis for velocity distribution for 83.1 % of full load

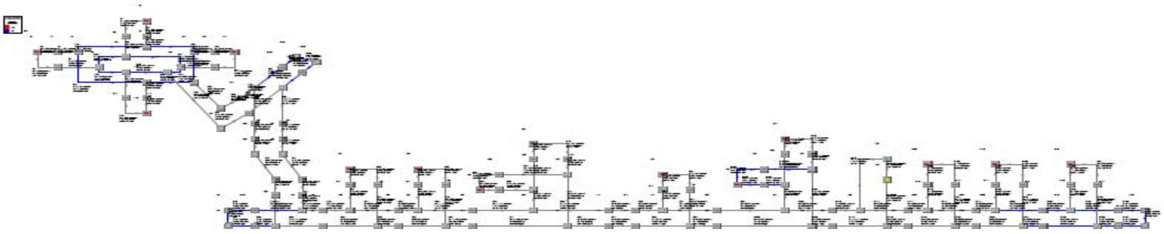

Fig (18), Analysis for velocity distribution for 83.1 % of full load worst case

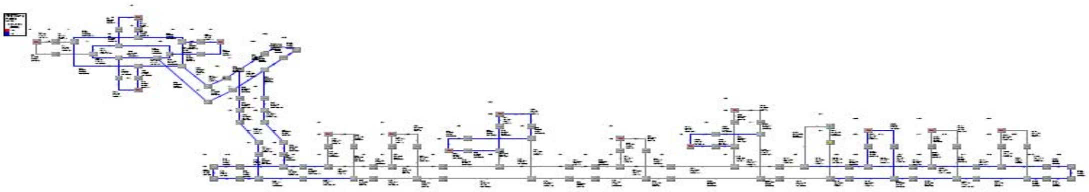

Fig (19) Analysis for velocity distribution for 50% of full load

Generally, the results of the analysis show that there are some comments on the selection of the pipes diameters especially in the ring zone and the short area on the right side of the plant.

No modifications are suggested for these sizes because the system is an already insulted one.

Case study two

Figs (20, , and 25) are the program output results for the distribution system with the pipes encounter problems on the velocity or pressure drop specified with different colors and a label.

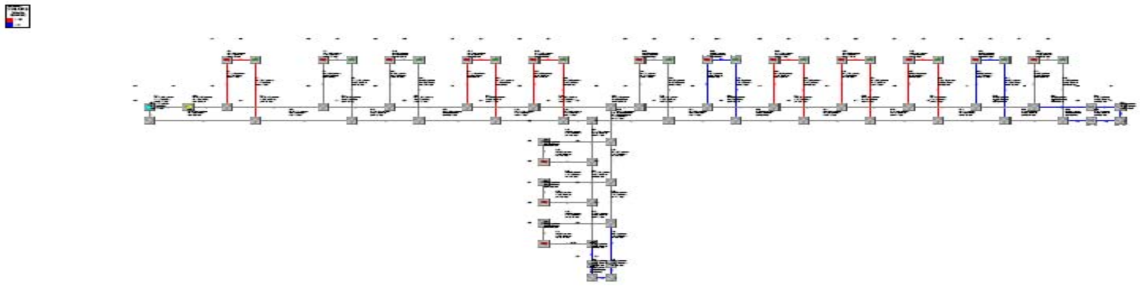

Fig (20), Branch (A) analysis for velocity distribution at full load

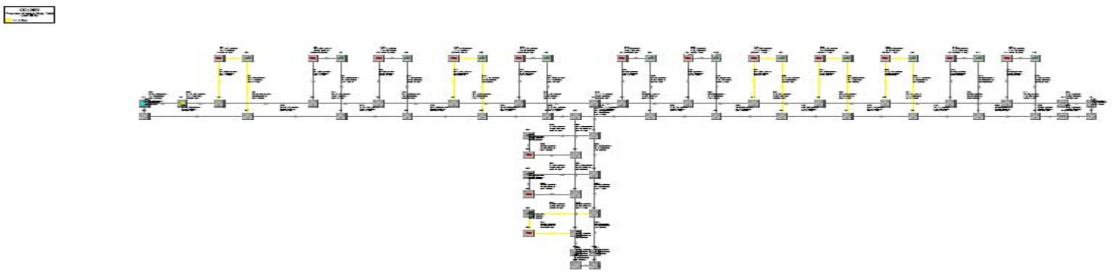

Fig (21), Branch (A) analysis for pressure drop at full load

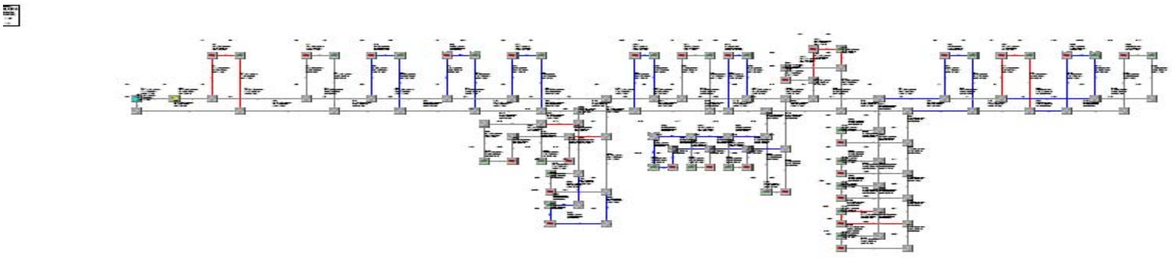

Fig (22), branch (B) analysis for velocity distribution at full load.

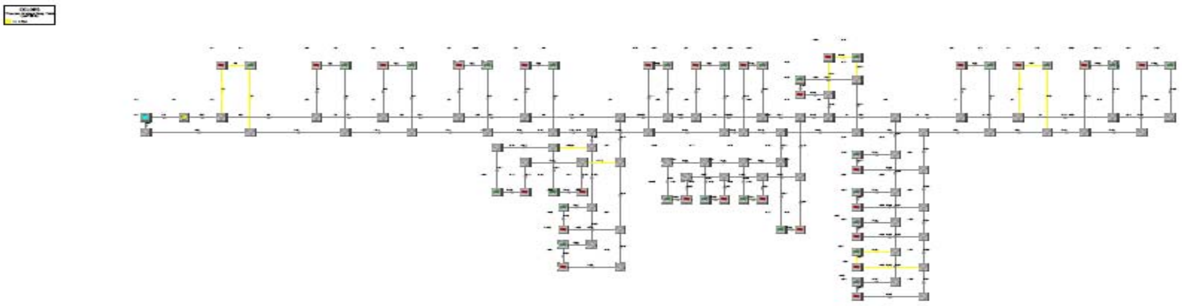

Fig (23), Branch (B) analysis for pressure drop at full load

Fig (24), Branch (C1+C2) analysis for velocity distribution at full load

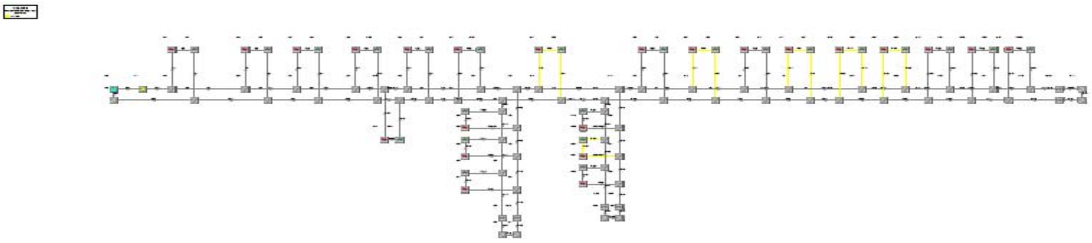

Fig (25), Branch (C1+C2) analysis for pressure drop at full load

Figs (26 ... and 31) show the same case results but when 83% full load applied to the network

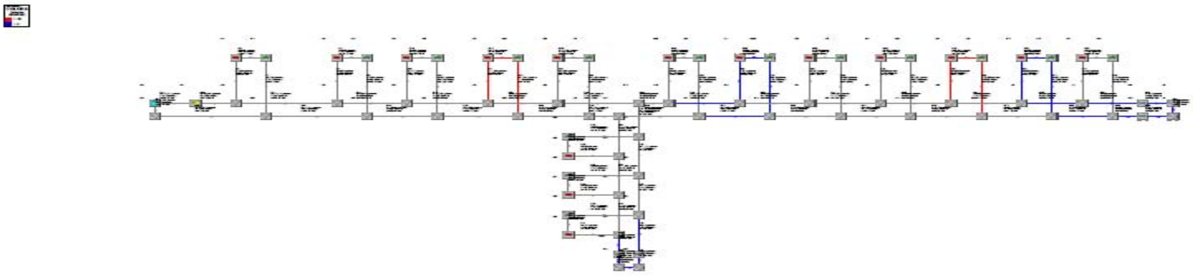

Fig (26), Branch (A) analysis for velocity distribution at 83.1% of full load

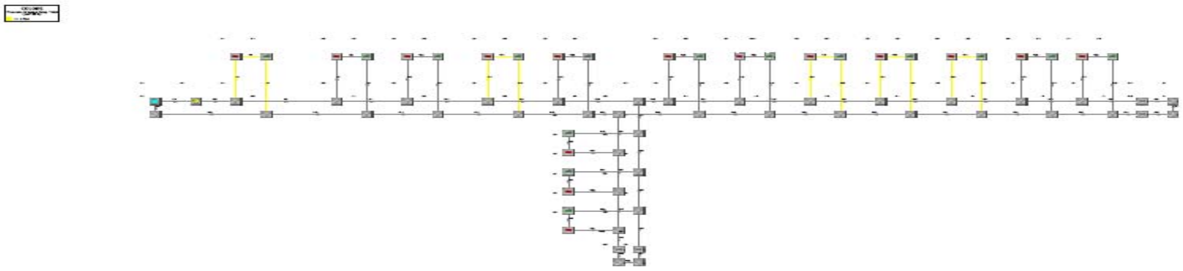

Fig (27), Branch (A) analysis for pressure drop at 83.1% of full load

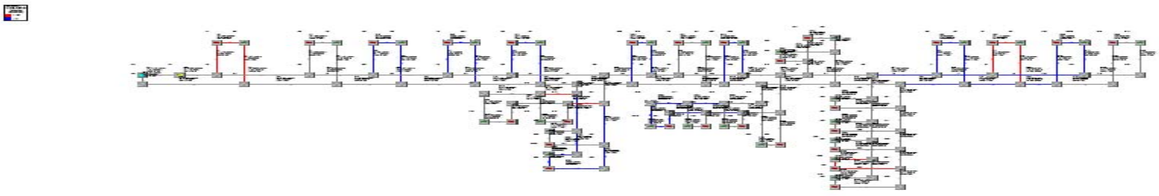

Fig (28), Branch (B) analysis for velocity distribution at 83.1% of full load

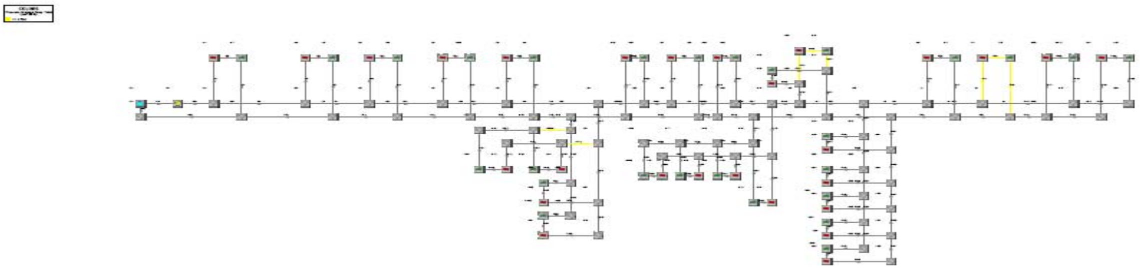

Fig (29), Branch (B) analysis for pressure drop at 83.1% of full load

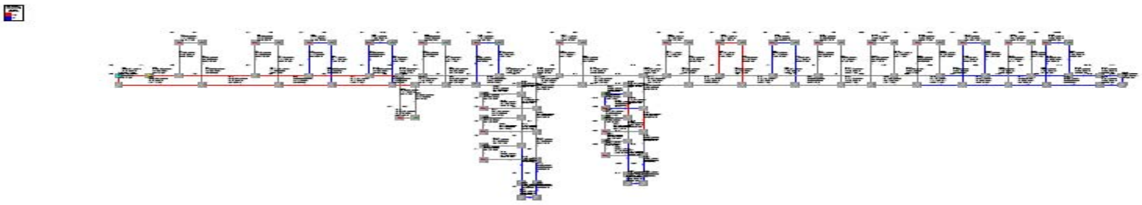

Fig (30), Branch (C1+C2) analysis for velocity distribution, 83.1% of full load

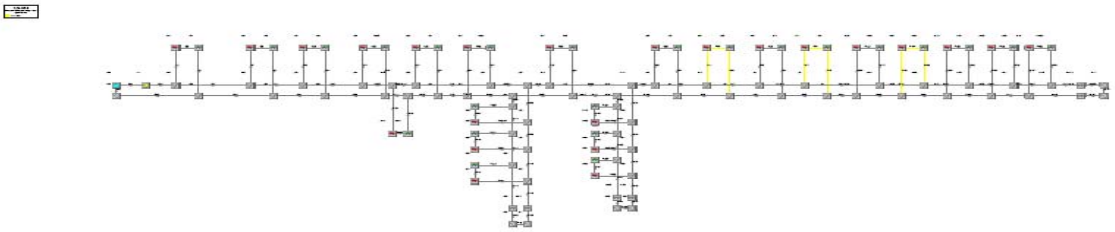

Fig (31), Branch (C1+C2) analysis for pressure drop at 83.1% of full load

Generally the system may be considered as well designed, except on some small number of pipes on the main branches passed the upper and lower limits for velocity and pressure. Problems on side branches are not so important because these branches are so easy to be modified or replaced when problems occurs on them, vice versa problems on the main branches are so difficult to be modified or replaced.

Case study three

Figs (32, , and 35) are the program outputs of the distribution system with the pipes encountered problems on the velocity or pressure drop specified with different color.

Fig (32) Velocity values distribution for the first half of the distribution system at full load

Fig (33), Velocity values distribution for the second half of the distribution system at full load.

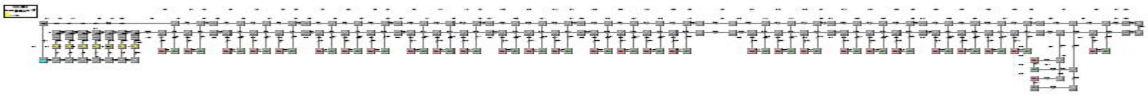

Fig (34) Analysis for pressure drop of the first half of the distribution system at full load

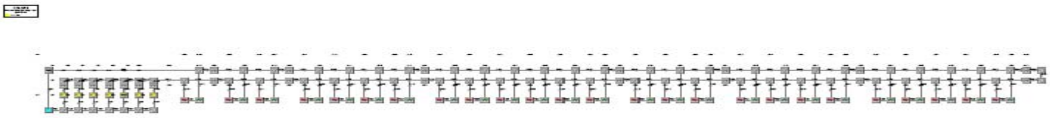

Fig (35) Analysis for pressure drop of the second half of the distribution system at full load

The result for this system show a big problem that is, the main distribution line has a constant diameter value which is not preferable, as in the region near the plant the flow rate is high and hence the velocity is high too, but faraway the flow rate is minimized and hence the velocity value is lower than the allowable limit. Since the designer will try to select a size suitable for these two regions, there must be regions of high velocity and other regions of low velocity.

The following figures present the percentage of saving in energy consumption according to the economical study different parameters.

Case study one

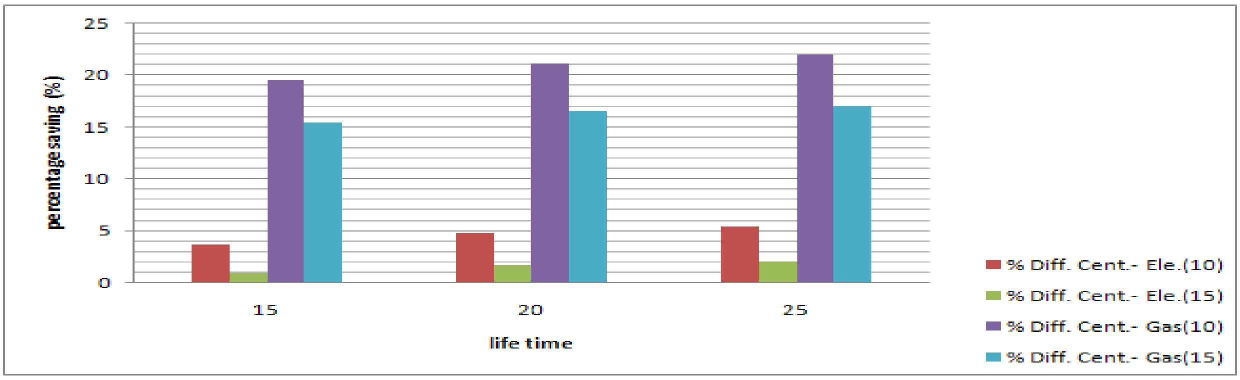

Fig (36), Tonnage price comparisons for different life times, 5400 working hours yearly, 10% ,and 15% profit rate

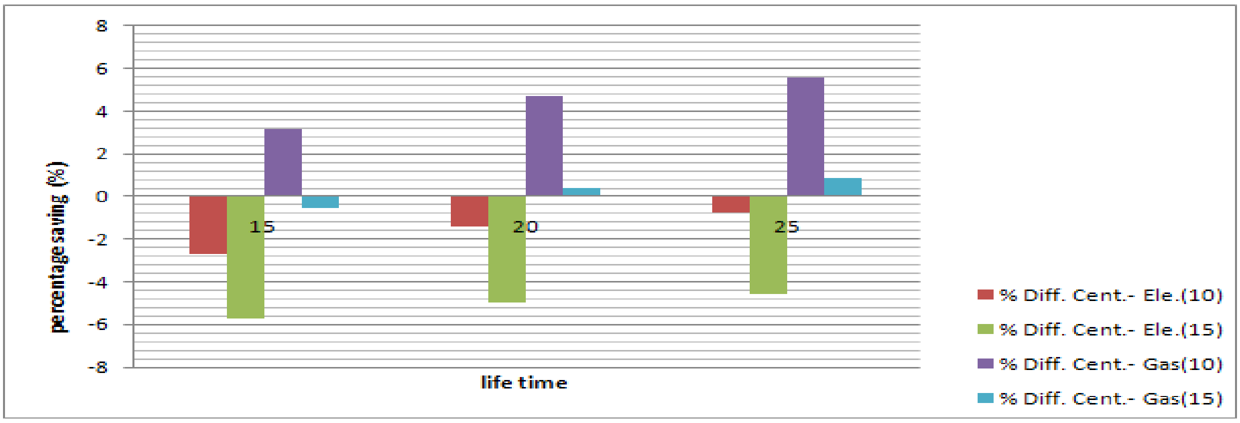

Fig (37), Tonnage price comparisons for different life times, 3000 working hours yearly, 10% ,and 15% profit rate

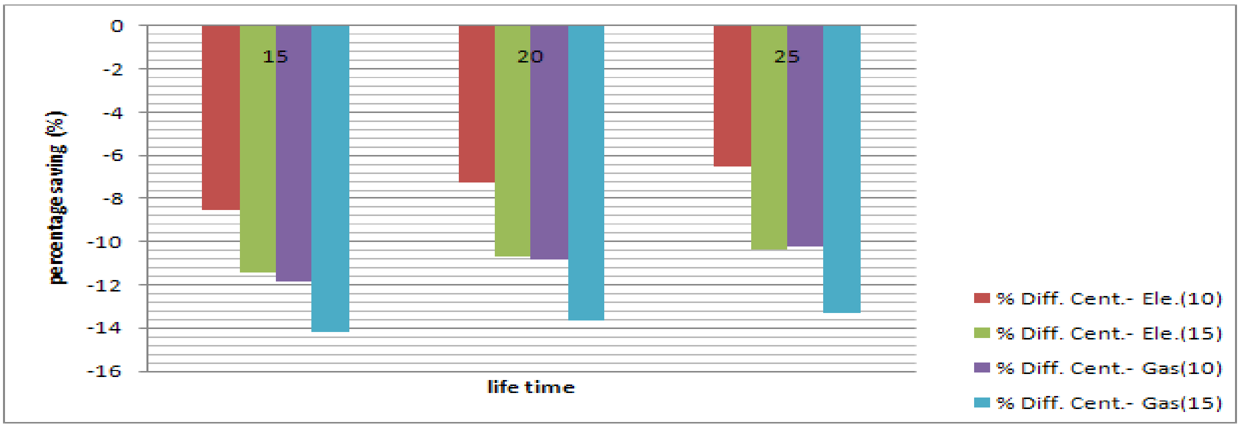

Fig (38), Tonnage price comparisons for different life times, 1800 working hours yearly, 10% ,and 15% profit rate

Case study two

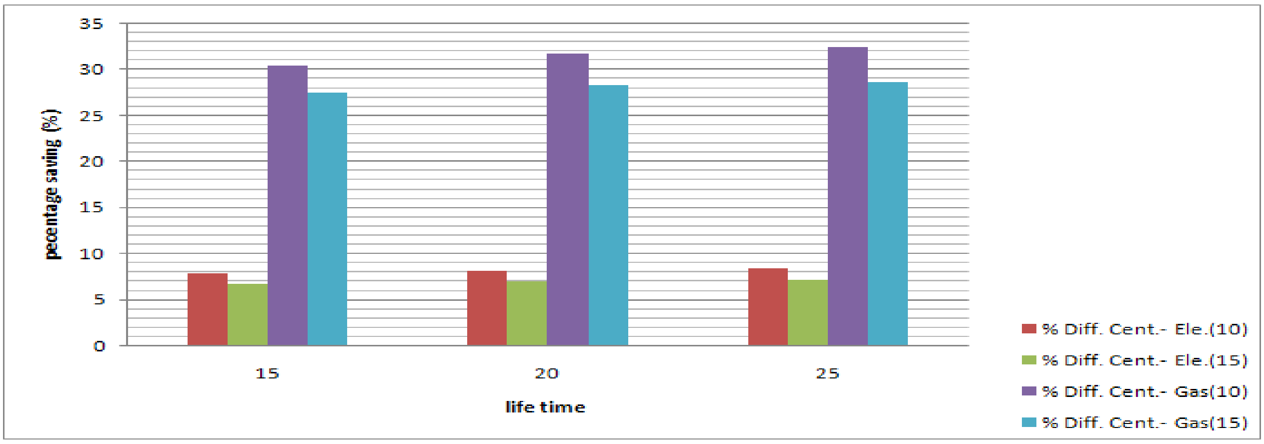

Fig (39), Tonnage price comparisons for different life times, 5400 working hours yearly, 10% ,and 15% profit rate

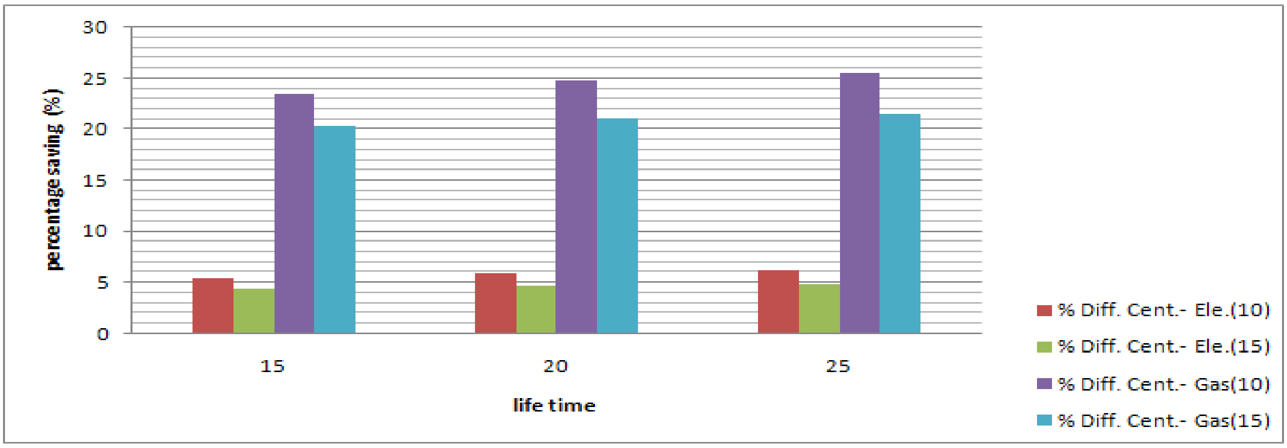

Fig (40), Tonnage price comparisons for different life times, 3000 working hours yearly, 10% ,and 15% profit rate.

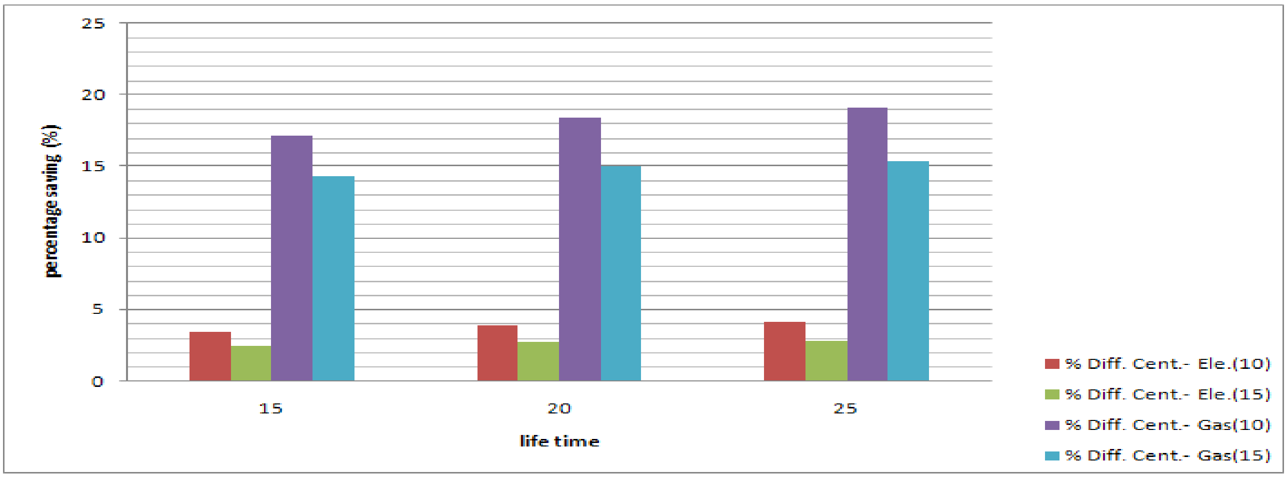

Fig (41), Tonnage price comparisons for different life times, 1800 working hours yearly, 10% ,and 15% profit rate

Case study three

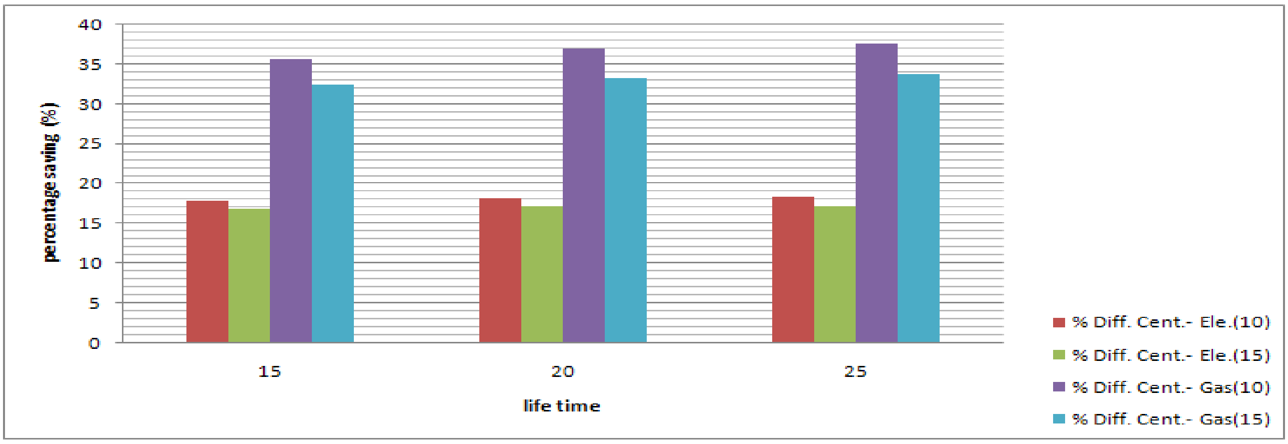

Fig (42), Tonnage price comparisons for different life times, 5400 working hours yearly, direct contact, 10%, and 15% profit rate

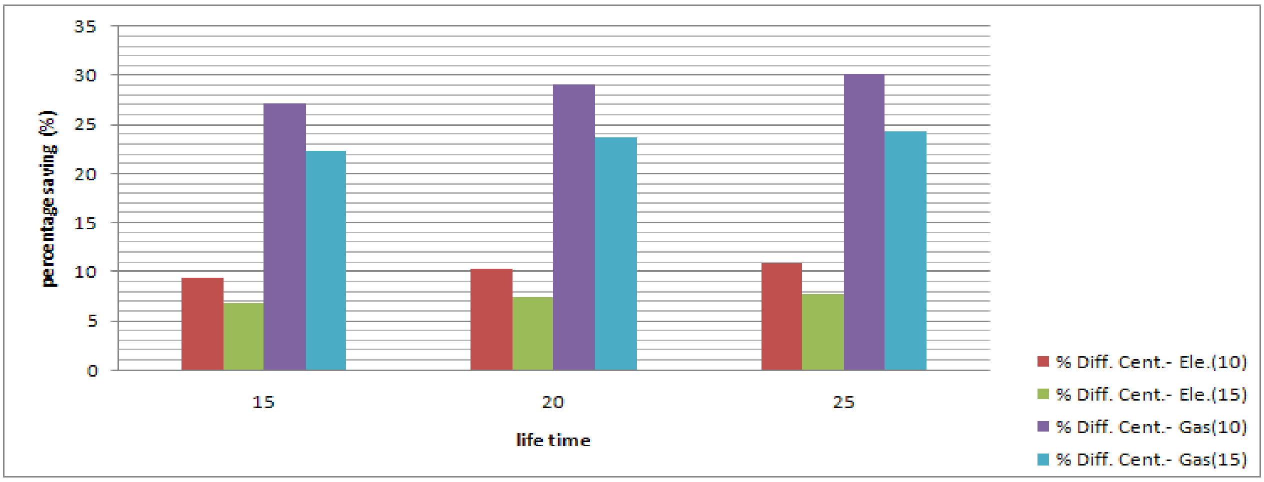

Fig (43), Tonnage price comparisons for different life times, 3000 working hours yearly, direct contact, 10%, and 15% profit rate

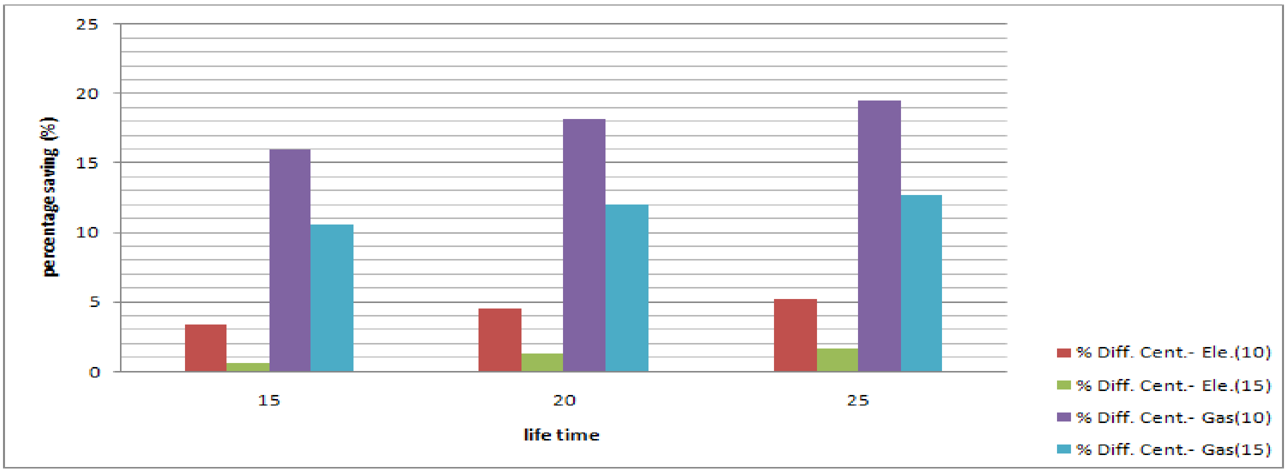

Fig (44), Tonnage price comparisons for different life times, 3000 working hour's yearly, indirect contact, and 10%, and 15% profit rate.

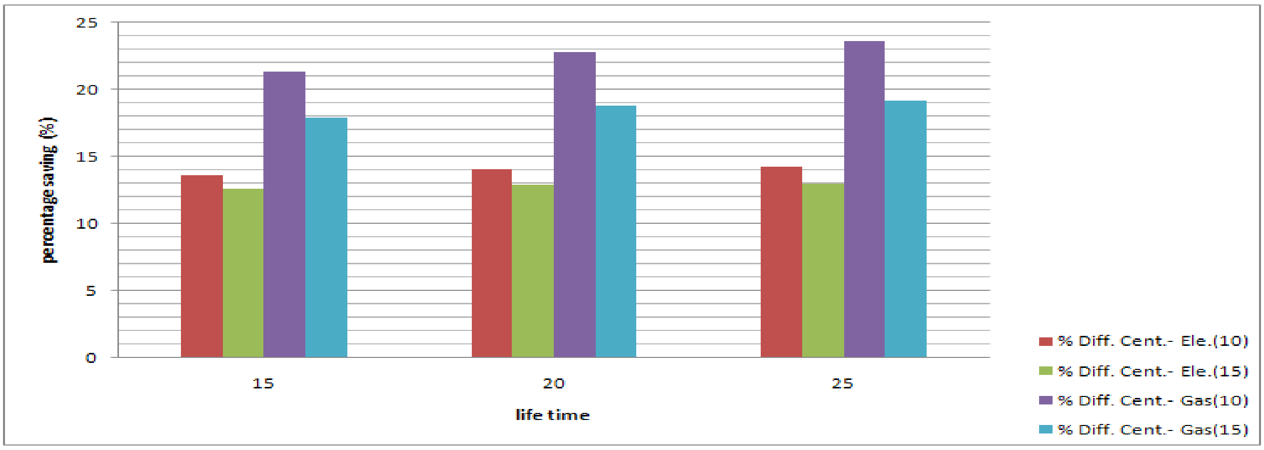

Fig (45), Tonnage price comparisons for different life times, 1800 working hours yearly, direct contact, 10%, and 15% profit rate

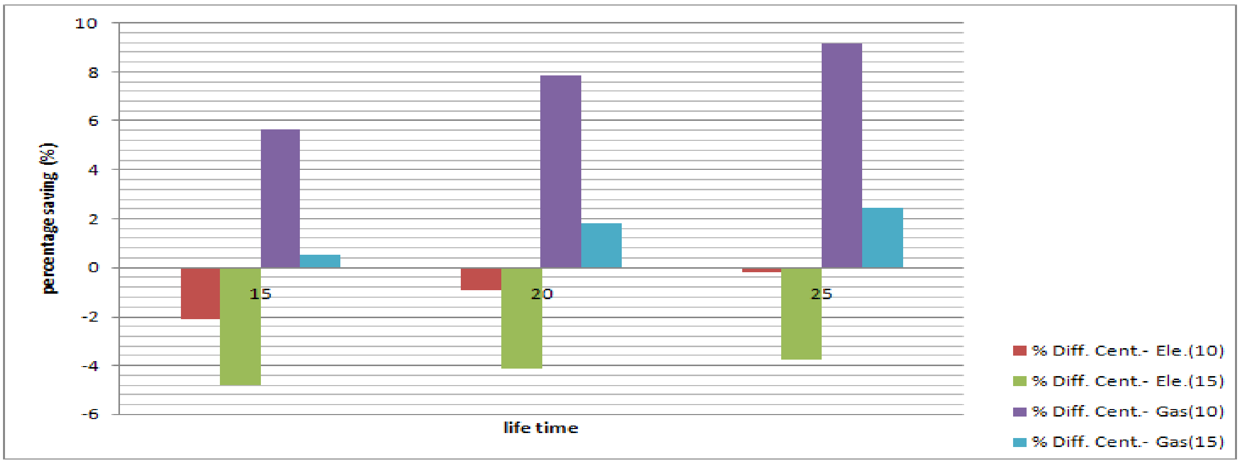

Fig (46), Tonnage price comparisons for different life times, 1800 working hour's yearly, indirect contact, 10%, and 15% profit rate.

From the previous figures it is clear that:

1- As the life time of the project increase, the tonnage price decrease, for the three models,
2- As the yearly working hours increase, the tonnage price decrease, for the three models,
3- As the profit rate increase, the tonnage price increase, for the three models,
4- As the yearly working hours increase, and the profit rate decrease, the economical benefits of using district cooling increase,
5- As the yearly working hours increase, and the profit rate decrease, the economical benefits of using absorption chillers increase

Conclusions

1-As the load density increased the percentage saving on tonnage price becomes significant, this appears from the previous results.

2- For case one the load density factor is small, so the benefits of applying district cooling are not high. In case two the load density is moderate, so the application of district technology is good. For case three the load density factor is high so the application of district technology is very useful as the percentage saving reaches more than 30%.

3- Indirect systems are much expensive on initial cost than direct contact systems but they are more efficient on performance.

4-The use of absorption chillers is better than the use of electric chillers, from two points of view, Energy saving view, since district systems are less energy consumers than central units. From an environmental point of view, they do not use hydrocarbons which are very harmful to environment.

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