TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

School of Engineering

Department of Materials and Environmental Technology

DISTRICT COOLING POTENTIAL IN PANAMA CITY, PANAMA. A CASE STUDY

KAUGJAHUTUSE POTENTSIAAL PANAMA LINNAS, PANAMA. UURIMISTÖÖ

MASTER THESIS

Student: Rafael Antonio Osorio Aguilar

Student code: 165568KAYM

Supervisor: Igor Krupenski, Ph.D (TTÜ)

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AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

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Author: Rafael Antonio Osorio Aguilar ....

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Thesis is in accordance with terms and requirements

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Supervisor: Igor Krupenski ....

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Accepted for defence

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Chairman of theses defence commission: ....

/name and signature/

Department of Materials and Environmental Technology

THESIS TASK

Student: Rafael Antonio Osorio Aguilar, 165568KAYM

Study programme: KAYM09/09, Materials and Processes for Sustainable Energetics

Main speciality: Processes for sustainable energetics

Supervisor: Dr. Igor Krupenski, Lecturer at Tallinn University of Technology, +372 5800 3989

Thesis topic:

(in English) District Cooling Potential in Panama City, Panama. A Case Study.

(in Estonian) Kaugjahutuse Potentsiaal Panama Linnas, Panama. Uurimistöö.

Thesis main objectives:

1. Provide a theoretical background reference of the cooling needs and actual cooling capacity in Panama as a geographical region.
2. Set up an experimental simulation, based on a local delimited area, to analyse the potential of setting a District Cooling system, including area to be cooled, pipe laying diagrams and overall economic analysis of costs of production and management.
3. Determine, using this experimental simulation, if implementation of a District Cooling system could provide economic and environmental benefits in comparison to be "Business as Usual" model.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Review of available literary references related to District Cooling	15.01.2018
2.	Design of the experimental setup and data collection	19.02.2018
3.	Results collection, data analysis and final calculations	26.03.2018

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Student: Rafael Antonio Osorio Aguilar .... "......."...................201….a

/signature/

Supervisor: Igor Krupenski .... "......."....................201….a

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PREFACE

The following research project and its development were inspired by a series of lectures on Energy Saving and Conversion techniques, where the topic on District Energy Systems was introduced.

Although there is no referential background research on this area on the geographical region studied in this project, acknowledgement should be given to those pioneer projects in District Cooling that are quietly, yet inspiringly been developed in countries in South America and the Caribbean. These projects are valuable examples on how District Cooling technology can be implemented and are opening the path for future projects on DC implementation that could be set in the region.

We would like to show our gratitude to the staff of the Ciudad del Saber complex in their availability and resourcefulness in every step of the development of this research study. Personally, I would like to thank my family for their help during data collection and their role in contacting certain public and private authorities in search for data for the development of this project. As well, I would like to provide my gratitude to all those involved and who in any extent have provided their assistance to the improvement of the thesis report and have provided their support during all the steps on this project.

Finally, but by no means less importantly, I would like to thank my supervisor and professor, Dr. Igor Krupenski, who has provided support, advice and recommendations during the complete process of this research report.

The aim of this research project is to provide an extensive background on District Cooling in areas in hot and humid climates, mostly located in the tropics and subtropics regions. As well, we aimed to provide an overall study on the possible implementation of a District Cooling system in a controlled, segregated and limited area in the western boundaries of Panama City, capital city of Panama. Among the components of the study, are the possible economic and environmental factors that could face a system of this kind in this area and provide a certain and definite outcome of the possible results of the implementation of this system. As a result, we found that a District Cooling implementation could provide large financial benefits in the short term for the clients located in this area and environmentally, we encountered large savings in CO_2 emissions in a scenario where District Cooling was implemented. In summary, the study shows that District Cooling, even in a small scale can be a highly profitable endeavour if implemented correctly.

Keywords: District cooling, Panama, absorption chiller, tropical climates, implementation

List of abbreviations and symbols

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

BAU: Business as Usual

CDD: Cooling Degree Day

CDH: Cooling Degree Hour

CHP: Combined Heat and Power

CO_2: Carbon Dioxide

COP: Coefficient of Performance

DC: District Cooling

DES: District Energy System

EUI: Energy Use Intensity

GIS: Global Information System

HVAC: Heating, Ventilation and Air Conditioning

IEA: International Energy Agency

Kg: Kilogram

LCOC: Localized Cost of Cooling

NGO: Non-Governmental Organization

NPV: Net Present Value

PR: Property Ratio

PRF: Primary Resource Factor

TES: Thermal Energy Storage

USA: United States of America

USD: United States Dollar

W: Watt

Wh: Watt-hour

η: Efficiency

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INTRODUCTION

In today's world, integration seems to be a growing phenomenon seen in several places in society. Energy wise, there is a clear aim to integrate energy systems looking for increases in efficiency, production and overall improvement of the system, locating great importance in the concept that smaller pieces together can achieve greater goals than individually. This urge for integration can be readily seen in the field of District Energy Systems (DES). DES, which are not a new technology, have been around for approximately a century in European cities and more recently in North American ones. It is the production of centralized energy, usually in the form of thermal energy for heating to be readily used in a grid, which can encompass a whole city or region. With a connection to the grid, users in buildings, offices, private or public, can enjoy of the production of thermal energy without dealing with maintenance, production or installation costs. In that sense, economy of scale can be applied to large sectors of energy consumers, increasing efficiency and decreasing CO_2 emissions, proving to be a win-win solution for an ever-growing energy sector.

However, DES are not solely found in heating needs, but as well for cooling. Cooling needs are even greater, in comparison to heating needs, in countries that are located in the tropical and subtropical regions, in several cases reaching around 25-40% of the total energy consumption only dedicated to cooling needs. Here is where DES technologies as District Cooling are slowly, yet vigorously showing to be of great importance in the search for better, more efficient and economically viable solutions for energy consumers. Following this trend and interested in the possible economical and environmental impact that District Cooling could have, we focused our interest in measuring the impact of the implementation of District Cooling in a country located in the tropical region, specifically in the Latin American region where the country of Panama was selected. Current research in District Cooling in the tropics and subtropics has been greatly localized in the Asian continent, with several research clusters dedicated to studies in China, Singapore, Malaysia and Middle East countries. However, the Latin American region has seen little to no research on District Cooling, possibly due to economical and technological restraints. Due to this scarcity in referential information, research in any extent is a valuable base on which later researchers can grow their studies on.

Interested in providing certain base for the topic on District Cooling in Panama, and concurrently looking for certain support for specialized research for future researchers, we intended to construct a theoretical background on the cooling needs and capabilities for cooling energy production that are present in the country. We then proceeded to analyse the use of several technologies within District Cooling, probing the capacity of free cooling, cooling by cogeneration and cooling by mechanical means as possible ways to implement District Cooling in this region. After each of these options was assessed, we decanted for the most beneficial one and focused in testing its economical feasibility in an enclosed, test area intended to recreate how District Cooling could be used and implemented in other commercial sectors of the city, all within the area known as Ciudad del Saber (City of Knowledge) in the western side of Panama City, Panama. Several tools were used for the analysis section, mainly Global Information Systems were needed to assess the distances and lengths for pipe layover, as well as to assess the buildings and locations that would be the first customers for this implementation. Financial analysis was mainly processed using Microsoft Excel, and most of the information was obtained via internet from governmental databases.

Our main objectives with this modelling project were to assess and obtain a rough approximate of: length, scope and possible constraints that District Cooling implementation could face in a scale model. We looked, as well, once the scope was assessed, on the economical and financial impact of the physical installation of a system of this kind in the area. A comprehensive analysis on installation, operation and maintenance cost was applied to obtain a globalized total cost of the implementation. Consequently, we compared this model application with a “Business-as-Usual” scenario where the usual system of individual cooling for each building is used. Finally, we assessed the environmental impact of this implementation by looking into the amount of CO_2 emissions that could be saved if the District Cooling scenario could be implemented.

Our last task included the analysis of the results obtained, as well as the constrains found along our research analysis. Importance was given to the fact that most of the data used had to be obtained from source from other countries or even from regions in other continents, as the study of District Cooling in the Latin American region is scarce to the say the least. As well, we located the topics where future research should be focused to.

1. THEORETICAL FRAMEWORK

Aiming to provide an appropriate base for the analysis and development of the topic of District Cooling in the tropics and subtropics, it is crucial to set up a framework to succinctly explain the concept, types and technologies that are found in the complex topic of District Cooling implementation. In the following sections, a brief discussion is offered to expose the history, technologies and mechanics that have allowed the implementation of this technology in different areas throughout the world. As well, as part of the theoretical framework, a brief exposition of the successful advances of District Cooling technology that we can find in the tropical and subtropical regions of the world will be showcased. Having in mind what have successfully worked in the past and how fundamental problems have been resolved, we will embark into the fundamental research questions that we aim to provide explanation and analysis in this research project.

1.1 Technologies based on District Energy Systems(DES)

When District Cooling, and its variant, District Heating are mentioned, it is important to assess that these are a subset of a larger concept known as District Energy Systems (DES) [1]. These systems are based in the idea that heating or cooling energy demands could be produced in a central energy generation plant that would provide cooling or heating capacities to a large group of buildings instead of having a localized individual heating or cooling mechanism for each and every building in the system [1]. This centralized arrangement provides a more efficient use of the energy resources, showing economic and technical savings to the users involved. Although, a robust implementation of these technologies is a relatively new scenario in some countries, the implementation of District Energy Systems has been around in Europe and North America since the early to mid-20th century [2]. The first reviews and technical assessments are recorded around the 1930s, having the United States, several European countries and Russia as the pioneers in the implementation of District Energy Systems in their major cities and urban settlements [3].

It is important to note that in the District Energy Systems, there are mainly two types of technologies that has been progressively developed throughout the years [4]. District Heating is the distribution of heating capacity from a central heating production plant through a pipeline network to the final users. District heating has been implemented successfully along the 20th century throughout several cities and capitals around northern Europe [3]. On the other hand, District Cooling, the distribution of cooling capacity from a central cooling plant, although implemented successfully in several cities, has yet not enjoyed the same vigorous implementation as the more popular District Heating [2]. District Cooling can be found since the mid-20th century in several cities in Europe, e.g., in France, Finland, Sweden, Denmark among others. It is only until the late 90s to the early 2000s and 2010s that the District Cooling technology has been implemented to other regions around the world [3]. Examples of these implementations are in the Middle East in the United Arab Emirates [5], China in Beijing [6], Singapore [7], Malaysia [8] and a very recent case in Latin American, in Medellin, Colombia [9]. It is most possible that the main reason for the late implementation of District Cooling technologies in tropical and subtropical regions is due to the recent adoption of better and more environmentally sustainable energy policies by countries in these regions. With goals of reducing drastically CO_2 emissions and greatly improve energy production and consumption efficiency, this type of technologies, as District Cooling, shows as a great tool to implement and study in these novel experimental environments [4]. Thanks to these improvements, these environmental goals may be at reach in the near future.

Although the scenario looks promising, it is of vital importance to assess the problems and technical hindrances that adapting district energy systems, as District Cooling, may arise. Considerations should be aimed to create policies and frameworks for both public and private sectors to be able to base future investments in this sector.

1.2 Summary of technologies behind district cooling

These are several methods available to run district cooling in a system. As well, there are various methods available to store the cooling resources for later use, especially when there is excess of cold generation thanks to energy availability for this purpose [10]. In the following section, these technologies are summarized for better understanding.

1.2.1 Free cooling

As the name implies, the process of free cooling uses "free" resources, that is, natural cooling resources available to provide cold water for the process of district cooling. These free resources are usually found nearby the area needing cooling resources. Among these resources are waterbodies as lakes, rivers, seawater and in some cases ground water [11]. To gather these natural cooling resources, energy is only used for pumping the cold water to the cooling facilities, which minimize at a great extent the energy needed to exploit these resources. However, it is very important to mention that the natural cooling sources need to be at nearby distances to be gathered without major investment in pipelines [2]. As well, the temperatures of the source water need to be low enough to be usable in the system, which in some cases, especially in tropical and subtropical regions, can prove to be not low enough to be exploited for district cooling.

1.2.2 Absorption chillers

The second technology widely used is the application of absorption chillers in the system. Absorption chillers can use heat from combustion of natural gas or other fossil fuels to run the compression chillers in their systems [2]. The largest improvement in this technology is the use of waste heat that can be obtained from energy production processes in powerplants. The use of this "waste heat" greatly increases the efficiency of the cooling process, allowing the utilization of what could be heat release as waste to the environment for the production of cooling capacities in this model [3]. These powerplants can be thermal energy plants, waste-to-energy energy plants or natural gas plants, which can be run in a more environmentally sustainable manner with the implementation of District Cooling in their operational framework. This technology can be readily applied to systems in the tropical or subtropical regions where there are already energy plants with excess heat that can be harnessed, however in some cases these energy plants may be on areas far away of the urban centres or have a complex ownership scheme, that could bring hindrances in case a public or private district cooling system would be implemented [12].

1.2.3 Mechanical/electrical chillers

The third technology widely used for district cooling is the application of electrical chillers to produce cooling capacities to run the system. For processes where there are no or not enough free cooling resources and waste heat to run absorption coolers is not enough, there is the most traditional option of running a mechanical, run by electricity, compression chillers [3]. These mechanisms work in a similar way as the ones found in refrigerating systems or air conditioning systems, where compression is provided by motors using electricity. As a method that is not dependant of geography or waste heat source, this is the most applicable method in District Cooling systems. As well, can be used to supplement other methods in case the cooling loads needed are large enough [1].

1.2.4 Thermal Energy Storage (TES)

As with electricity production and consumption, where exist peak and low demand periods, cooling needs are as well ruled by peak and low demands based in the period of the day and day of the week, as well as season of the year. As most of the systems are based in commercial and industrial areas, there is the inherent situation where most systems will find themselves in period where the cooling capacities can be funnelled to be stored for future used where peak demands are found. By storing cooling resources, the systems can benefit of production cost reductions as well as increase in efficiency in the system overall [13]. For Thermal Energy Storage, the usual method for storing cooling energy is using insulated water tanks, where cooled water is stored to be used in peak demand periods, usually at 4 °C, where the density of water is maximum [14]. Another method is the use of ice storage tanks, where ice is stored for future use. This method requires less space and can be used in cooling plants where there are space limitations [14]. The use of any of these systems should be carefully studied, as there should be a real and concrete evidence of economic savings using TES to offset costs in peak demand periods. Characteristics as limited space, implementation process, storage material and overall cost operation should be studied before assessing the utilisation of TES along the introduction of District Cooling in a system [15].

1.3 District cooling in tropical and subtropical climates

1.3.1 Current situation of district cooling in hot & humid climates

District Cooling implementation has been plentifully researched mostly in the northern region of the Northern Hemisphere, with several examples found in cities in countries such as France, Italy, Spain, Sweden, Finland, Germany, Denmark, Netherlands, and others in Europe [4]. As well, examples can be taken from cities in Canada and the United States [4]. Among the factors heavily researched in these systems are mainly on the resources used to provide cooling resources to their cities, whether using natural cooling resources, electrical chillers or using waste heat to power absorption chillers. As well, factors as savings in CO_2 emission, total energy costs savings and overall reduction in cooling related costs are as well studied and accounted for [16]. However, the situation for District Cooling implementation in hot and humid climates, as the ones found in the Tropical and Sub-tropical regions of the world is quite different. The amount and diversity of examples is quite scarce, with most experiences in District Cooling been found South East Asia (Malaysia, Singapore) and regions in China [17]. Entire regions in Latin America, Africa, Middle East, Oceania and Asia have not been even researched for implementations of District Cooling, leaving a great void of possible energy and operational costs savings in cities in these regions.

1.3.2 Advantages of district cooling in hot and humid climates

One of the main advantages of implementing District Cooling and Heating in a city's system is to obtain sensible savings in energy costs and in cooling production by pooling resources among the possibly users to achieve better efficiency and cost reduction throughout the grid. In the case of District Cooling, the amount of savings obtained for each system depends greatly on the needs for Cooling among the users. These needs are directly related to the ambient temperatures that the region would find during the year, for which cooling is needed [2].

For countries and regions in temperate zones, these ambient temperatures are usually found in the summer months, were temperatures rise to the point where cooling is needed to maintain a comfortable temperature in the office, residential and commercial buildings in the city. Although other large benefits are obtained from District Cooling (reduced operational and building costs per building unit, increase in space availability and overall efficiency in the system), the large reduction in operational and energy costs are the most looked upon [4].

For countries and regions in the tropics and sub tropics, the benefits that could be obtained from District Cooling could be easily multiplied in the sense that in these regions, ambient temperature is, for most of the year, higher than that required for a comfortable ambience [18]. For countries in these regions, the mean temperature is around 18°C [19], and depending on the specific climate, prolonged dry seasons are the usual, with temperatures ranging well above the mark of 20°C to 30°C [19], causing a spike in the need for cooling residential, office and commercial spaces for several months, or even in a year around scheme.

1.3.3 Drawbacks found from previous experiences in district cooling

Although research experiences in hot and humid climates with District Cooling are scarce, it is possible to enlist the drawbacks found for these systems.

Lack of natural free cooling sources. One of the main advantages of countries in northern regions is the availability of natural heat sinks, where free cooling resources can be found, e.g. lakes, seawater, rivers [4]. And is not only the availability of these resources, but that temperatures found in these sources are adequate to introduce district cooling in these locations [4]. For hot and humid climates, these free cooling sources are not easily found [20]. There might be availability of waterfront resources as lakes, rivers and sea/ocean water, however to reach water with adequate temperature (ranging from 4° to 8° C), is not possible to use surface water, and to get to depths were water at these temperatures can be found, a large and extensive collection network is needed, providing economic difficulties for this option [20].

Lack of waste heat/cogeneration opportunities. Another main advantage of District Cooling, is the opportunity of generate cooling capabilities from waste heat obtained from a diverse set of sources, from energy production in powerplants from several sources (waste to energy plants, natural gas combustion, among others) and channelling this waste heat resource into what is known as absorption chiller system, where waste heat is used to produce cooling resources, only relying on electricity to pump the working fluid in the system. In this sense, cooling production could only need electricity, and could completely disassociate from CO_2 generating combustion processes from fossil fuels. In tropical and sub-tropical regions, there is a lack of waste heat reconfiguration [21]. Usually, there is not a clear policy to use and reuse this waste heat for cogeneration. Although possibly sources are found in the system, there is no real research or planning behind to usufruct from it. Overall, could be seen as a lack of technology rather than lack of resources [21].

Lack of proper research or initial exploitation guidelines. It can be stated that District Cooling, although it is not a new technology, it can be defined as new for implementation in tropical and sub-tropical regions. This novelty brings the lack of proper research from where business-related ventures can relay themselves to launch district cooling projects. In Europe, there is present and active involvement of the local government, and intergovernmental entities as the European Union, who are investing in the proper research and initial guidelines towards District Cooling implementation. Cases as the RESCUE Project [22], EuroHEAT and Power [23], Heat Roadmap Europe [24], to name a few that are currently creating and updating guides and guidelines on how District Cooling should be looked upon and initiated in the region, following clear and detailed steps to assess mainly the economic and financial aspects of District Cooling.

1.3.4 Major district cooling systems located in hot and humid climates

Although it is a fairly new technology entering in the regions of the tropics and subtropics, District cooling has already found several niches around these regions where it has been successfully installed and it currently serving private and public clients. Some of their experiences are:

Marina Bay in Singapore, located in the south-central portion of the city state of Singapore, we can find the Marina Bay District Cooling project, which accounts as the largest underground district cooling system in the world as 2018 [25]. A planned 5 cooling plants with a total capacity of 900 MW of cooling power are proposed for this project, with 2 cooling plants already operational, with a total of 330 MW of cooling power [25]. The system works as a joint venture between a private company(Veolia) and the Singapore's Energy Authority. The total area to cover is around 8 million m^2 and all the production, plants and piping are planned to run underground, saving space [24]. However, the project has seen few drawbacks, presently in the efficiency of the compression electric chiller used, which at the moment has not reached the planned efficiency, mainly due to problems with the Thermal Storage Systems used [26] [27]. It is important to mention that most of the works of pipeline installation and tunnelling has been provided without cost to the joint venture company by the Singapore government, allowing some budget flexibility for the project. As for CO_2 emission savings, the authority reports that there is a saving of around 23,000 tons per year at current demand [28].

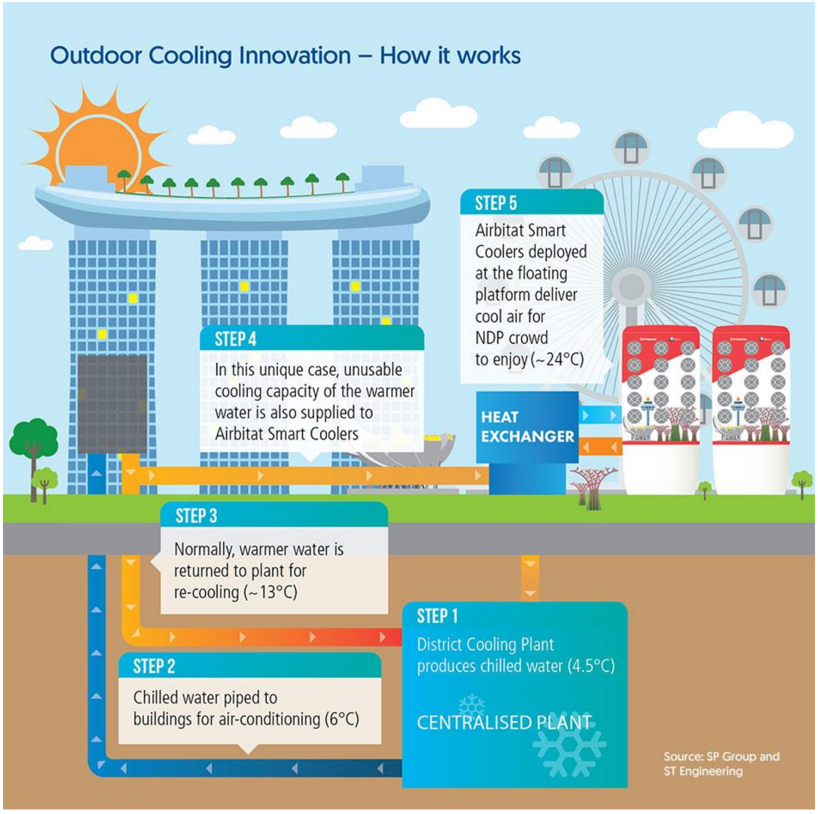


Figure 1.1 Marina Bay, Singapore District Cooling system. Source: SP Group and ST Engineering

Kai Tak District Cooling System in Hong Kong, is located in the area that contained the old Hong Kong airport, in what is known as the first totally public District Cooling system in the tropics and subtropics. The system is planned to provide cooling power to a new development area in Hong Kong, of around 1,7 million m^2 of ground floor area with a total of two cooling plants with a total capacity of around 284 MW of cooling power [25]. It is calculated that it will save approximately 59,500 tonnes of CO_2 per year [29]. It is estimated as well to save around 20-25% in total electricity consumption, however there are drawbacks in the project. In this project, most of the tunnelling and pipeline excavation needs to be assessed by the public government, instead of a joint venture, increasing costs [30]. Additionally, the implementation of new tariffs for this service can bring risks related to estimated and planned demand versus the actual demand the service might experience [30]. Finally, the ownership of the equipment near private lands is as well a topic that is still speculative and needing revision from public and private parts as well [30].

Cyberjaya District Cooling System in Malaysia, is located south of Kuala Lumpur, Malaysia's capital city, and although a much smaller capacity system compared to the previous two, is still a very important example of District Cooling system in the region. With around of 50 MW of cooling power and providing cooling energy to around 48 multi storey buildings, it is the largest project of its kind in Malaysia. It is estimated to reduce energy consumption by 65% and save 1,160 tonnes of CO_2 emissions per year [31]. Being a smaller project, and privately funded, it allows for better development, and it has proved to be successful as new expansions are planned in the future for this system [32].

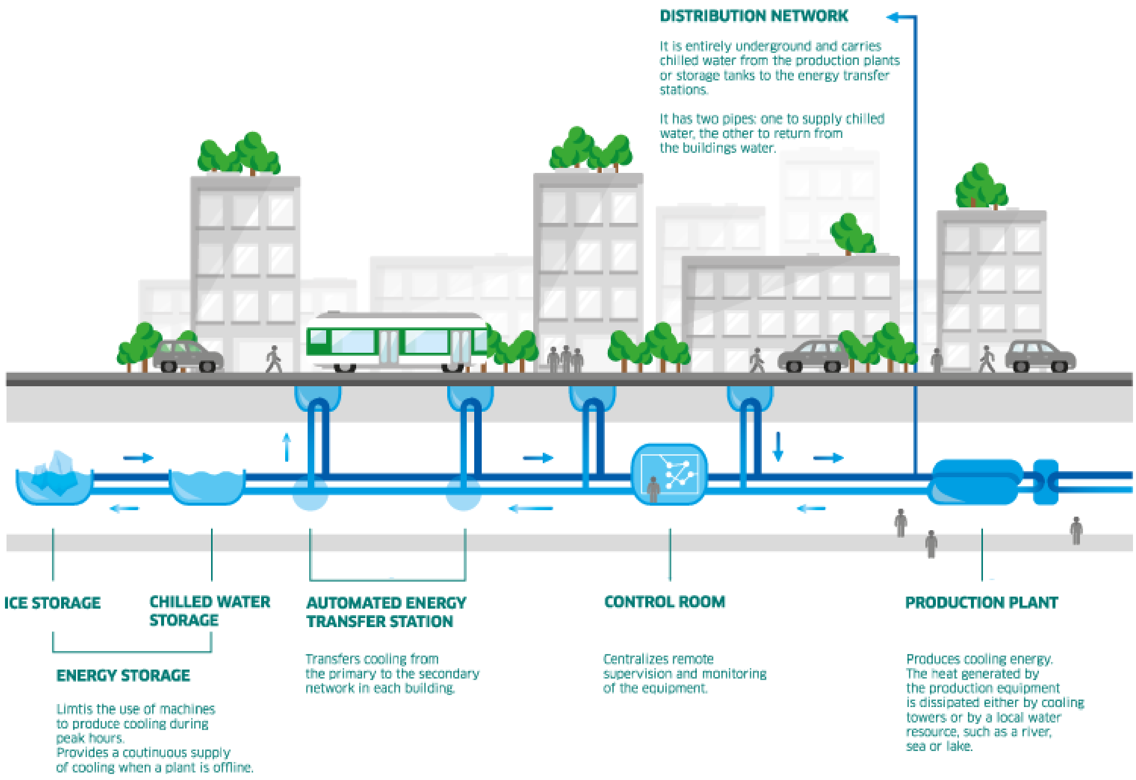


Figure 1.2 ENGIE group scheme for the District Cooling system used for Cyberjaya City in Malaysia. Source: ENGIE group.

Medellin District Cooling System in Colombia, is the first District Cooling system located in Latin America, is rather an experimental setting to provide District Cooling to nearby municipal buildings of the local government of Medellin. With approximately 13 MW of cooling power, is calculated to provide enough cooling energy for 5 multi-storey buildings [33]. It uses both absorption and electric chillers and aims to reduce around 30% the CO_2 emissions and provide 30% of electric consumption savings [33]. The funding is provided mainly by the Swiss Government and International entities. As an experimental setup, it aims to provide research information for other projects to be implemented in similar settings in the Latin American region [33].

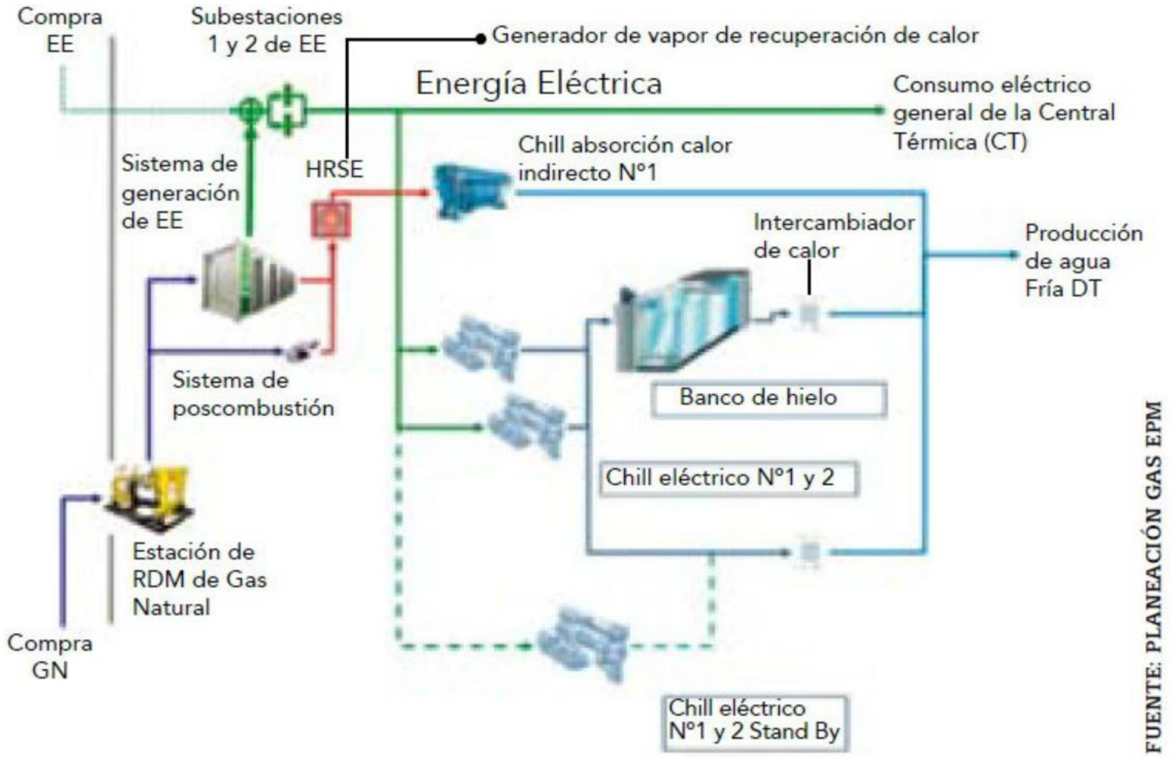


Figure 1.3 EPM group scheme for the District Cooling system used in Medellin.
Source: Group Empresas Publicas de Medellin (Public Companies from Mdellein)

Aside from these 4 projects, there are other several projects located mainly in Bahrein and United Arab Emirates [25], however these are not publicly researched and finding reliable information on costs, expected and actual expenditures among other information is difficult, therefore will not be furtherly discussed here.

1.4 District cooling in Panama City, Panama: A case study

To fully assess the potential of District Cooling in Panama, there are several aspects to take into account to correctly analyse its feasibility. Aside from the climate found in this region, analysis should have in mind the amount of energy that is used to fulfil refrigeration and cooling needs throughout the country, as well as forecasts for the near future for cooling needs and how the country is planning to face these increases in energy needs. As every country worldwide, Panama is working towards improvements in energy efficiency and CO2 emissions, therefore technologies as District Cooling could be regarded as useful tools towards these goals [34].

1.4.1 Climate classification

Panama is a country located in Central America, between 7° and 10° N in the northern hemisphere. Panama enjoys a tropical savannah climate, under the Köppen climate classification, with a high relative humidity and high temperatures year around [19]. In the capital, and largest city, Panama City, temperature ranges during the day are usually minimal, with an average minimum of 24°C in the morning and an average maximum of 29°C in the afternoon [19].

1.4.2 Energy expenditure for cooling purposes

Panama has published an Energy Plan for the period 2015-2050 [34], where current energy consumption statistics where displayed. As well a "Business-As-Usual(BAU) Scenario" and an "Alternative Scenario" were described, where the BAU scenario describes how the energy scenario will evolve following the current trend in energy spending, meanwhile the Alternative one describes how energy consumption could be improve by using renewable energy resources, energy efficiency measures and overall better planning towards a future scenario where the public, commercial, industrial and residential sectors could enjoy savings.

In the residential sector, which accounts for 34% of the total energy consumption in the country, official statistics show that for the most recent sample taken in 2016, 11% of Panamanian houses where equipped with Air Conditioning systems [34]. For 2050, the Panamanian authorities forecast a 5-fold increase with 55% of the Panamanian residences equipped with Air Conditioning. These numbers translate to a total of 12,7% of the energy used in the residential sector is destined to cooling purposes in 2016, while it is expected to increase to 32,2% for 2050 [34].

In the commercial sector, which accounts for 48% of the total energy consumption in the country by 2016, we can observe a total investment in cooling purposes of 42% of its total [34]. For 2050, the forecasts indicate that this sector will account for 62% of the economy, due mainly to Panama's largest economic sector in services. For cooling purposes, by 2050 the cooling needs would account for almost half of its consumption at 49% [34].

In the public sector, which accounts for 12% of the total energy consumption in the country by 2016, it is observed that cooling needs account for a similar level as the commercial sector, around 42% of its total consumption [34]. However, the authorities only accounts for an increase of 2.5% annual in its cooling expenditures as the government looks to decrease the amount of energy consumed by increase efficiency and renewal of cooling technologies used in public offices as part of the energetic plans [34]. With this view, the public sector for 2050 will account for 7% of the total energy expenditure, and its cooling needs located at around 27% of its total consumption [34].

In the industrial sector, which accounts for 6% of the total energy consumption, the cooling needs are around 15% of its total expenditure [34]. As the economy of the country relies on services, there is no projected large increase in the industrial sector, which it is forecasted to be around 3% of the country energy consumption by 2050 [34]. As for its cooling needs, for 2050 there will be a slight increase to 18% for its cooling purposes [34].

As a summary, charts are presented to graphically show the changes forecasted between 2016 and the 2050 scenarios, in Figures 1.4, 1.5 and 1.6 below.

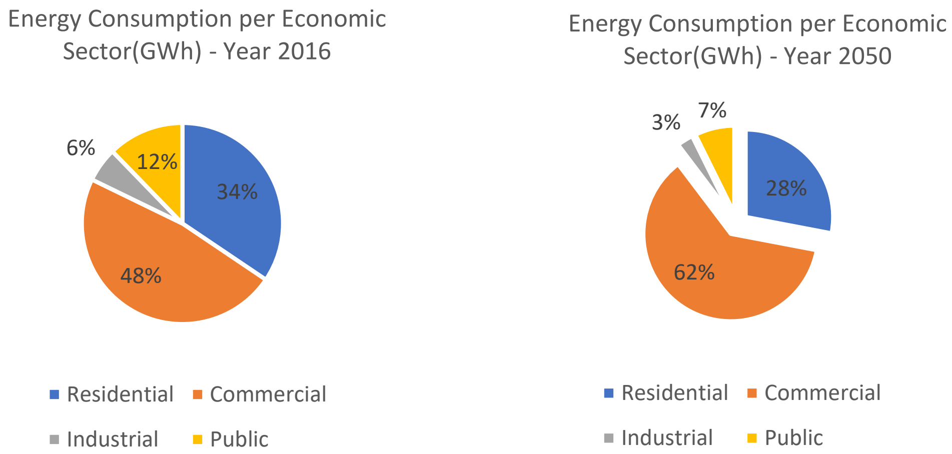
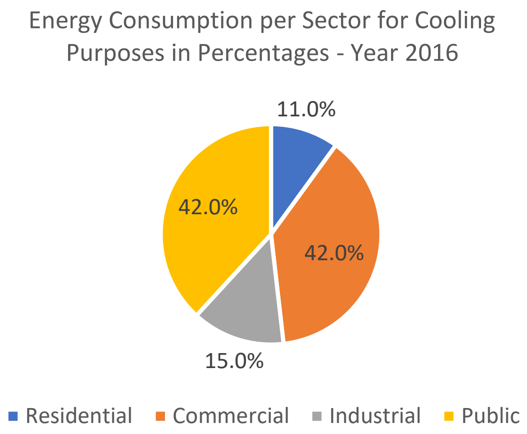


Figure 1.4 Energy Consumption in GWh in Years 2016 and 2050

Figure 1.5 Energy Consumption for Cooling Purposes in % per Sector for Years 2016 and 2050.



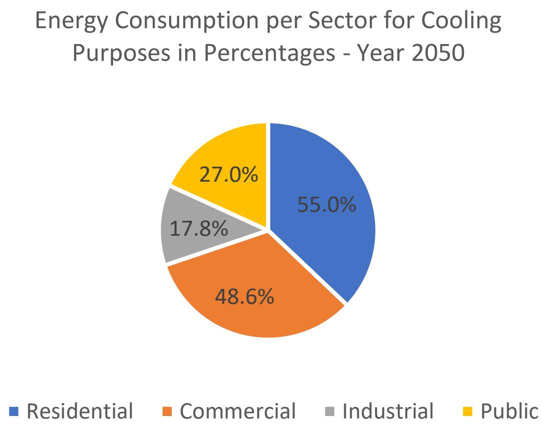


Figure 1.6 Energy Consumption for Cooling Purposes in % as part of the total for Years 2016 and 2050.

1.4.3 Availability of free cooling resources in Panama

Based on the previous statistical analysis for the current (year 2016) and future scenarios (year 2050), it clearly shows a tendency for a robust increase in cooling needs in the urban area of Panama's capital city. It is only logical to assess the availability of free cooling resources (lakes, rivers, seawater) to be used as primary resource for district cooling. In the case of Panama City, as seen in Figure 1.7, its primary water resource is located in its waterfront in Panama Bay. No nearby large lakes or rivers are located which could support free cooling technologies as seen from satellite views.

Assessing bathymetry and hydrology studies, we can observe that temperatures at the surface from Panama Bay are in average 29,2 °C and at a depth of 24 metres, temperatures are slightly lower at 25,3 °C [35], which shows that are by no means near the temperatures needed to sustain free cooling using District Cooling technology [3].

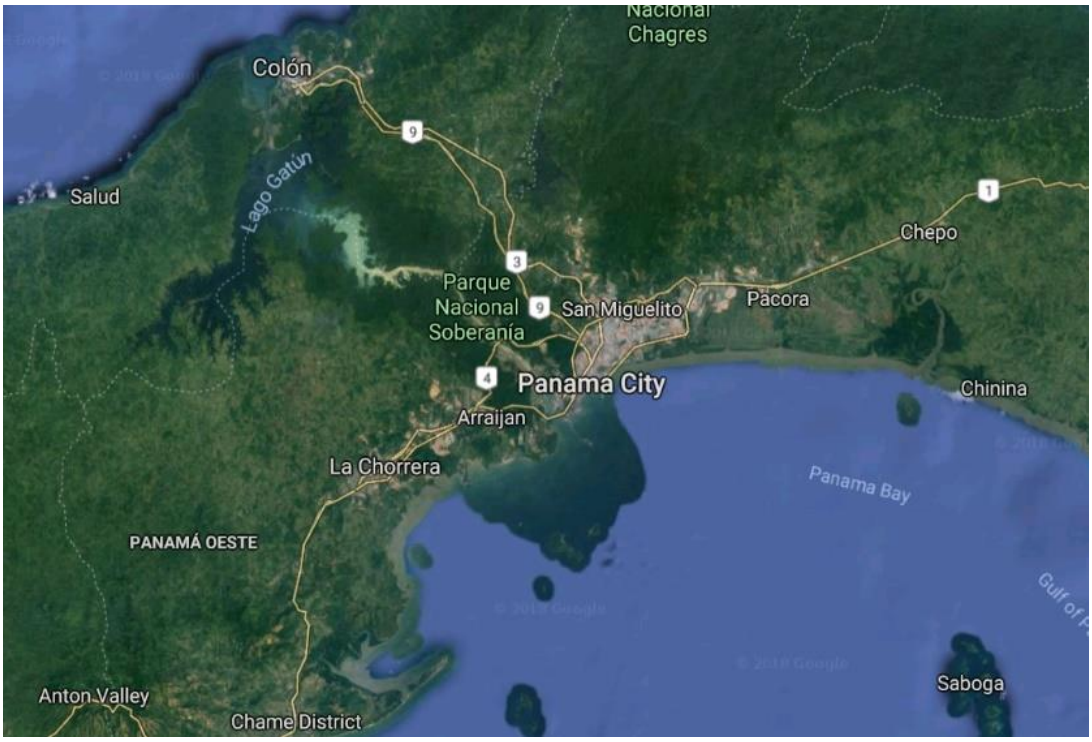


Figure 1.7 Satellite shot of Panama City, showing nearby water resources. From Google Earth, 2018.

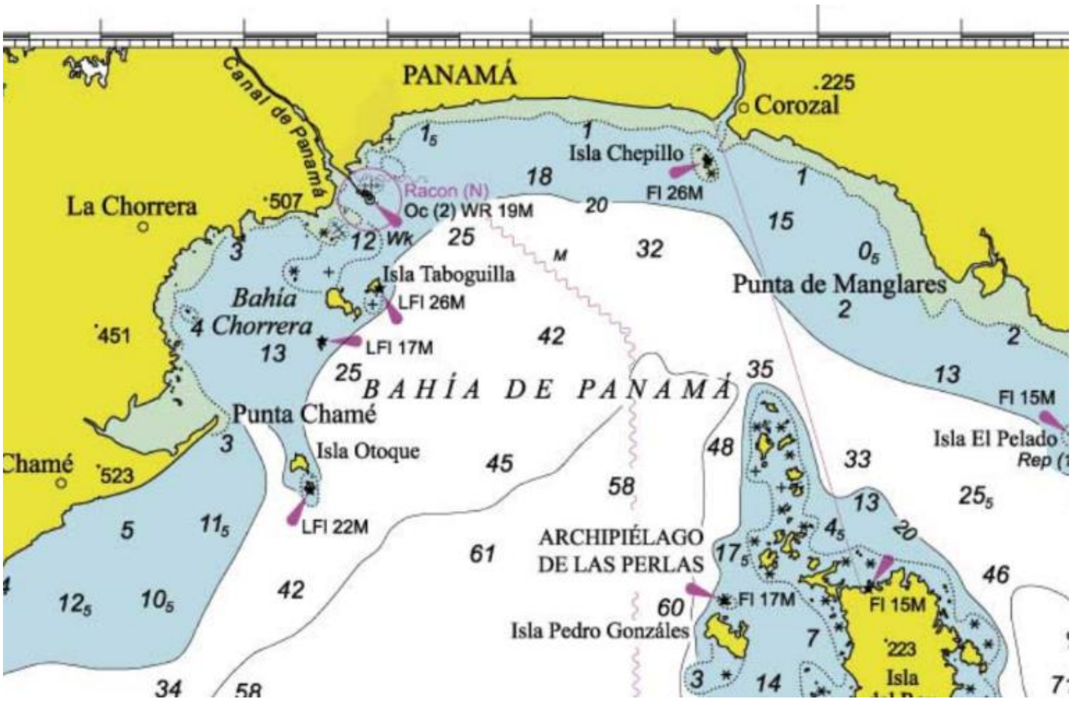


Figure 1.8 Bathymetry map of Panama Bay, showing depth in metres at different locations [37].

Even by depth, observed in Figure 1.8, we can see that waters near Panama City are rather shallow, not even reaching depths larger than 65 metres even at distances of several kilometres from the city, therefore not deep enough to probably sustain temperature cool enough to provide free cooling from this natural resource [36]. As a result, free cooling can be momentarily discarded.

2. IMPLEMENTATION FEASIBILITY ANALYSIS

Although the presented theoretical background clearly shows a distinctive and promising scenario for District Cooling implementation in Panama City based on previous experiences in other cities in tropical and subtropical regions, it also presents a clear lack of natural resources available to work as source for free cooling. As noted in studies and research in other tropical and sub-tropical regions, this is a common situation in these regions, for which the aim in these cases are centred in looking for waste heat sources, as energy powerplants, to be used as source for absorption chillers or the use of electric compression chillers if no waste heat is available [21]. Having this aim into account, and plunging into the analytical section of this study, we will proceed to introduce the methods that will be used to assess the potential of District Cooling implementation in Panama City, Panama.

2.1 Location to be analysed

As the principal and capital city of the country, Panama City retains the largest metropolitan area in the country, with 275 km^2 and an urban population of 880,000 providing a relatively dense population area to work with [38]. As the city area is rather dissimilar with certain urban areas dating from the 1500's up to newly developed areas, it would be difficult to determine District Cooling potential as its implementation would vary greatly due to proximity to waste energy sources, city planning, population density and overall grid characteristics found. Due to this situation, it was decided that a delimited area in the city will be considered for this analysis to simplify the process and provide a scenario where District Cooling could be adapted.

For this purpose, the area known as Ciudad del Saber or City of Knowledge, in the Western section of Panama City, as shown in Figure 2.1, was selected, having in mind that certain characteristics are vital for this type of analysis such as a well delimited area, high density of commercial/office buildings, availability of a well-planned grid layout. This area, part of the Ancon district, used to function as a United States Army base in what used to be the Panama Canal Zone, a zone controlled by the United States which surrounded the total length of the Panama Canal, which was transferred to Panamanian administration by 1999 [39]. The Ciudad del Saber is a 120-hectares complex where more than the 200 buildings that were used by the United States Army were repurposed to be used as central offices for several Non-Governmental Organizations, international scientific organizations, certain government offices, United Nations headquarters in the country and overall promotion of academic, research and humanistic purposes [39].

Figure 2.1 Feasibility study location, City of Knowledge, NW of Panama City, besides the Panama Canal. Image obtained from Google Earth.

2.2 Methods

Already selected a delimited area to analyse for implementation and feasibility for District Cooling system, a series of questions will be taken to properly analyse the proper feasibility and economic cost of implementing a District Cooling system in this area. These questions are the following:

1) As the study aims towards the use of waste heat from nearby energy powerplants, the first research question is to properly analyse how much waste energy could be gathered from nearby powerplants, Natural Gas processing plants and any other type of powerplants that could provide waste energy for the working of an absorption chiller system.

2) Using the Master Plan for Ciudad del Saber, calculate the amount of cooling energy demand using real data and find the actual total energy needs for this area.

3) Based on the data obtained from research question 2, calculate the dimensions for pipes and distribution networks to be installed in the area for the District Cooling system. Among the data that would be obtained is the total length of the pipeline network, pressure needs as well as the actual pipe diameters that would be needed to meet the area's cooling

demands. With this information, an estimated actual cost in US Dollars will be obtained of the total cost of the system based in equipment investment costs as well as operation and maintenance costs.

4) With the cost analysis from research question 3, we aim to provide a comparison between investing in this system versus using the reference scenario of decentralized, individual electric chiller systems per building. As well, we plan to assess the total potential CO_2 emission savings that District Cooling implementation could bring.

In the following sections, we will provide the methodology, formulae, assumption and calculations needed to provide answers to these research questions.

2.2.1 Waste heat availability calculation for absorption type chillers

To analyse the potential of using waste heat from energy production plants, a throughout depiction of the location and type of energy plants in Panama City was needed. Based on the latest report from the Panamanian Authority for Electrical Transmission [40] we were able to find the types and location for energy plant in the periphery of the Ciudad del Saber compound.

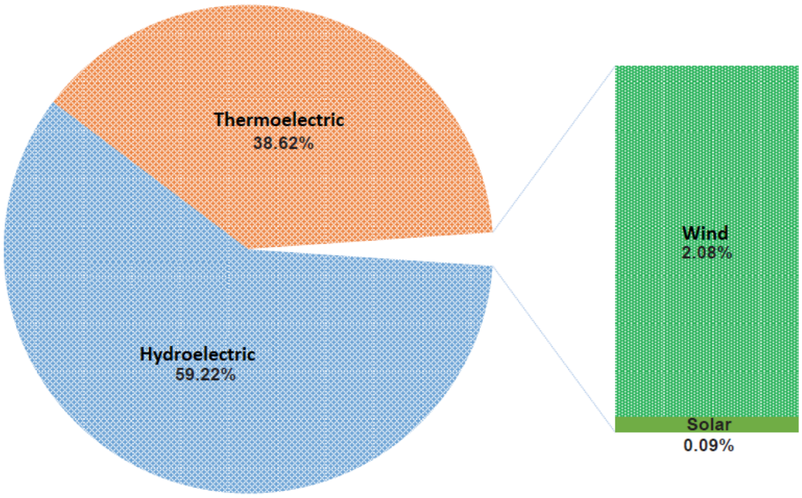


Figure 2.2 Current energy production in the country by type. [40]

Based on the information found in the Energy Generation Report for the country showed in Figure 2.2, almost 60% of the energy production was centred in Hydro power, and most of these energy plants are located several hundred kilometres from Panama City, mostly in the Western province of Chiriquí and Bocas del Toro, near the border with Costa Rica, and in the Atlantic coast in Colon province [40].

Looking into the thermoelectric plants located in the country, which accounts for almost 39% of the energy production, all these plants are located several hundred kilometres from Panama City, mainly in the Atlantic coast in the Colon Province, and the nearest one to the analysed are is located 50 kilometres from it [40], which render the distance far from the maximum allowable for profitable use of waste energy [3].

Although the scenario does not appear particularly promising for using absorption chillers for District Cooling implementation in this area, there is one private energy plant located at merely 5 kilometres from the Ciudad del Saber compound. This energy plant is in the largest public landfill servicing Panama City, known as Cerro Patacon landfill. The energy powerplant uses biogas channelled from waste treatment in the landfill compound as well as solid residues that would be burned [41]. The plant has an installed capacity of 8,1 MW from three 2,7 MW generators. These generators are J620 Jenbacher engines, with reference specifications as detailed in [42]. In order to assess the available waste energy from this powerplant, the following formulae were used to calculate waste heat potential, based on D.F. Dominković et al. [21]:

$$\mathbf{WH = (\eta_{total} - \eta_{electrical}) \cdot Fuel} \tag{2.1}$$

$$\mathbf{C_{supply} = WH \cdot 0{,}7} \tag{2.2}$$

where

WH refers to theoretical yearly waste heat potential in kWh

$\boldsymbol{\eta_{total}}$ refers to total potential efficiency from the powerplant in kWh_{output}/kWh_{fuel}

$\boldsymbol{\eta_{electrical}}$ refers to real electrical efficiency of the powerplant in kWh_{e}/kWh_{fuel}

Fuel refers to yearly consumed fuel energy for the powerplant in kWh

$\boldsymbol{C_{supply}}$ refers to the cold potential obtainable from the powerplant in kWh

0,7 value was selected as the COP value of the single phase LiBr-water absorption chillers from [43]

2.2.2 Calculating cooling demand

Using the grid layout provided by the Ciudad del Saber organization [44], which is a fundamental part of a Master Plan for the use of the area, a classification of the buildings that could benefit from District Cooling will be assemble. As the Ciudad del Saber compound is a special area within the city, where strict building and environmental codes must be followed, it can be reasonably assumed that the plot areas and overall cooling demand will remain stable for the near future [45]. To calculate the actual cooling demand for each building, plot ratios, which are the ratios between the maximum allowable area that can be built on to the land area that the building occupies. Following D.F. Dominković et al. provided calculations, formula 2.3, which describe total area to be cooled is presented [21]:

$$A_{cool} = PR \cdot A_{land} \qquad (2.3)$$

where

A_{cool} refers to total area to be cooled in m^2

PR refers to Plot Ratio

A_{land} refers to land plot area in m^2

Once that the area to be cooled is obtained, it can be used to calculate the cooling demand for the building by using formula 2.4 which simply multiply the area needing cooling by the Energy Use Intensity(EUI) for the type of building (commercial or industrial). The EUI metric is valuable as its measures the building's energy use based on the floor area as well as usage of the building [46]. This EUI value was readily available from official references in the country [47]. Formula 2.4 is described as following:

$$C_{demand} = PR \cdot A_{land} \cdot EUI \qquad (2.4)$$

where

C_{demand} refers to yearly cooling demand per m^2

PR refers to Plot Ratio

A_{land} refers to land plot area in m^2

EUI refers to Energy Use Intensity in $kWh/(m^2 * year)$

This calculation is applied to every building that would be considered to take advantage of District Cooling in the Ciudad del Saber compound. Principally, it would be applied to large office and commercial buildings, as well to public and non-governmental organization buildings. Residential buildings, will not be considered for this calculation to simplify the calculation.

2.2.3 Calculating peak cooling load

Having at hand a complete and detailed classification of the buildings located in the Ciudad del Saber complex [44], we can use the actual floor area for each building to calculate the peak cooling load for each building analysed in the complex.

It is important to mention that, unfortunately, there is no statistical data related to actual cooling loads and specific demand for different sectors in Panama. For this research work, we have considered the similarities between Panama and Singapore in climate classification, as shown in Table 2.1, taken from ASHRAE Climatic Design Conditions for 2017 [48] and we have taken Singapore as a model to take certain data for our modelling purposes. Contrary to the case of Panama, Singapore has an extensive research and database related to building needs and technical data.

Table 2.1 Climate data comparison between Singapore and Panama. Data from ASHRAE, 2017 [48].

Location	Hottest Month	Air Temperature in °C			Annual Cooling Degree Hours(CDH) and Days(CDD) at different temperatures (°C)			
		0.4% Percentile	1% Percentile	2% Percentile	CDD 10 °C	CDD 18,3 °C	CDH 23,3 °C	CDH 26,7 °C
Panama	April	34,1	33,2	33,0	6337	3295	31549	11451
Singapore	May	33,2	32,9	32,2	6614	3572	37915	12698

To compare both location, two main data classifications were considered. As we are speaking about peak cooling loads for our calculations, we have used maximum air temperature in degrees Celsius, as these are of critical importance in peak cooling demand calculations. As well, we have considered the Cooling Degree hours and days for comparison. This measurement allows us to quantify in a succinct way the energy demand in a location, by taking a base temperature and noting the amount of degrees that the outside temperature was above this base temperature [4]. Proportionally, the peak cooling loads will increase as a location presents larger cooling degree days/hours temperatures [4].

Having thusly demonstrated the similarities in climates and cooling settings for both locations, we are able to extrapolate Singapore's peak cooling demand data for our analysis. Table 2.2 shows the data obtained from Singapore's Building and Construction Authority recollected during energy audits in the year 2015 [49]. It is important to mention that the Singaporean authorities mention a series of caveats in the setting of this data. Primarily, that these are not designed peak cooling demands, as most of the buildings are not planned to be running on full design peak load [49]. As well, that there is a large relation between seasons/time of the year and the measured data. Although the data is heavily influenced by factors related to the year it was taken, it is safe to assume it for calculations [49].

Table 2.2 Measured cooling loads for the year 2015 audit. Taken from [49].

Type of Building	Measured in W/m2	
	Range	Average
Office Buildings	54-100	74
Hotels	40-98	61
Commercial Buildings	93-195	130

Taking into account the measured cooling load for Singapore, we have determined that a value of 75 W/m^2 would be acceptable to be applied on our calculations, as it encompass the average value for office buildings, which are the type of the large majority of the buildings found in the study area.

Allowing for better planification about costs and phase implementation of District Cooling in the Ciudad del Saber compound, it was decided that the study area to be separated in subareas for better analysis and pipeline network simplification. A total of 4 subareas were designated as shows in Figure 2.3. For these areas, only areas 1, 2 and 3 will be fully analysed as those where most of the commercial, public and private office buildings are located. Area 4 is mainly residential area and implementation of District Cooling would be greatly dependent of the public acceptance and adequate economical and financial planning of the communal service for this area. As well, there is future planning for the use of this area to be changed from residential to commercial/office spaces therefore rendering any plans here tentative and dependent of the outcome of future zone planning in the area.
For these reasons, we considered would be beyond the scope of this research project.

2.2.4 System design: Pipe network cost calculation

As our aim is to analyse the impact of District Cooling in the overall area of Ciudad del Saber, we have planned to introduce the District Cooling system to all the 3 areas that are under analysis. For this analysis, assuming we aim to obtain a final amount in US dollars on how much would it cost to implement a system at this scale, we primarily need to obtain the cost of the pipe network that would be distributing the cooling energy to the buildings in our study areas. For this approach, we will use the following formulae to obtain the pipe diameters needed based on the peak cooling demands calculated in section 2.2.3. The cooling demand that can be transferred via pipelines can be obtained from the following, based on [50]:

$$\mathbf{\Phi} = \mathbf{Cp} * \boldsymbol{\rho} * \mathbf{V'} * \boldsymbol{\Delta T} \qquad \textbf{(2.5)}$$

Where

Φ refers to the cooling load calculated in 2.2.3 in W.

Cp refers to specific heat capacity of water, from literature [50], 4200 J/Kg K

ρ refers to density of water, from literature [50], 1000 kg/m^3

V' refers to volume flow rate in m^3/s

ΔT refers to the temperature difference, between the supply and return temperatures.

From literature [51], the ΔT normally used is of about 8°C.

Figure 2.3 Area division of the Ciudad del Saber complex for better DC implementation

To calculate the volume flow rate, it is useful to use the following formula [50]:

$$V' = \frac{V}{t} = \frac{Area*length}{t} = \frac{\pi\left(\frac{d}{2}\right)^2 l}{t} = \pi(\frac{d}{2})^2 v \quad \textbf{(2.6)}$$

Where

v refers to the flow velocity, taken from literature [51], 2 m/s.

d refers to the diameter of the pipes under consideration

If we substitute formula 2.6 into formula 2.5 we will get formula 2.7 for which is simplified to find the diameter of the pipelines in consideration, dependent on the cooling load in W for each area, in formula 2.8.

$$\phi = Cp * \rho * \pi * \left(\frac{d}{2}\right)^2 * v \quad \textbf{(2.7)}$$

$$d = 2\sqrt{\frac{\phi}{Cp* \rho* \Delta T*\pi*v}} \quad \textbf{(2.8)}$$

2.2.5 System design: Pressure drop and Pumping power calculations

Once we have obtained the piping diameter requirements for each area, we can proceed to find the pressure drop and consequently, pumping power that would be needed for the implementation of district cooling for the analysed areas.

As basic mechanics, for this system to be able to circulate cool water throughout the system, there should be a pressure difference or pressure drop to run the system. To find the pressure drop necessary, we would need to apply the following formula from [51]:

$$\Delta p = \frac{\lambda*L}{2d} * \rho * v^2 \quad \textbf{(2.9)}$$

Where

Δp refers to the pressure drop in Pascals.

λ refers to the friction factor obtained from literature [52]

L refers to the pipe diameter in meters

v refers to the flow velocity, taken from literature [51], 2 m/s

ρ refers to density of water, from literature, 1000 kg/m^3

With the pressure drop value calculated, we can input this value to obtain the total pump power needed to maintain the system running. To calculate the total pressure in the system, to then calculate the power needed, we can use formulas 2.10 and 2.11 as follows, from [52]:

$$\Delta P_{pump} = \Delta P_s + \Delta P_r + \Delta P_{min} \quad \textbf{(2.10)}$$

Where

ΔP_{pump} refers to the total pressure needed in Pascals

ΔP_s and ΔP_r are the pressure for supply and return, in Pascals, from formula 2.9, and are the same value for both quantities.

ΔP_{min} refers to the minimum pressure needed to reach the further location from the plant. This value can be obtained from literature [23] to be 50 kPa.

Once we have the pressure needed, we can obtain the total electricity power needed using formula 2.11, as follows [52]:

$$P_{el} = (\Delta P_{pump}/\eta_{pump}) * V' \quad \textbf{(2.11)}$$

Where

P_{el} refers to the electricity power needed for pumping in Watts

ΔP_{pump} refers to the total pressure needed in Pascals

η_{pump} refers to the pump conversion efficiency, from literature [53], estimated on 79%

V' refers to volume flow rate in m^3/s, from formula 2.6.

We will use an extrapolation method to assess the cost of the circulating pumps. To obtain the costs for systemwide pumps based on their capacity, we used literature references from [54], where different pumps are listed compared to their size capacity and investment price in US dollars. As for the cost related to the operation and maintenance, we will assign a fixed cost of 3% of the cost of the pump, as data obtained from literature from the International Energy Agency [55].

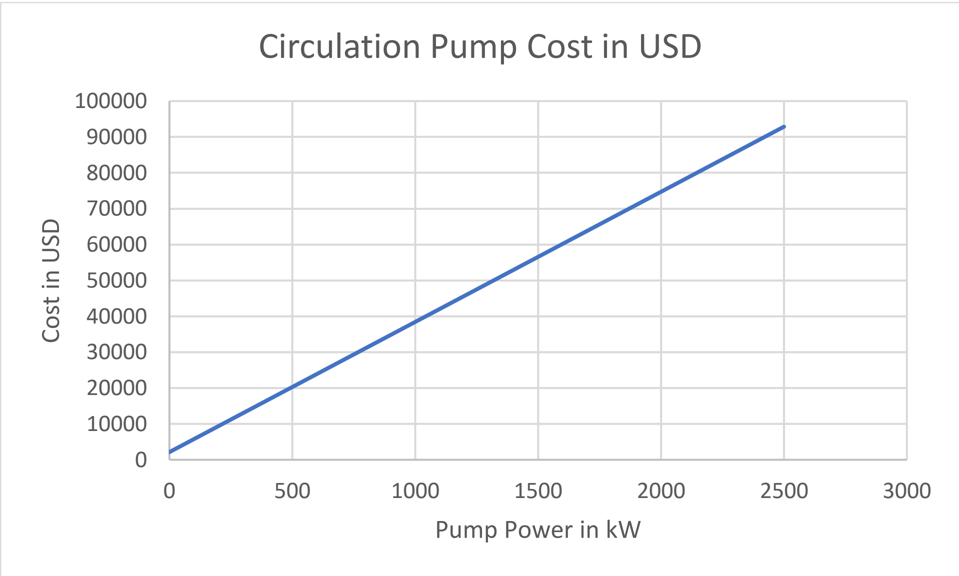


Figure 2.4 Extrapolation for Circulation Pump cost in USD, based from International Energy Agency[55]

Finally, and as a caveat, the thermal losses to the pipes can be as well calculated. However, from cited literature, it is usually found that the thermal losses to the surroundings for district cooling systems is about or less than 2% [56], which for simplification of the calculations carried out in this research study, will be omitted.

2.2.6 System design: Pipeline network installation cost

Going forward without inclusive calculation of all the costs related to the implementation of a District cooling system, we must continue with the estimated costs of the pipes, which are directly related to the diameter size used in each area.

As mentioned before, there is little to none information for pipelines or installation costs on regards to the Panamanian scenario. Fortunately, we can extrapolate these costs, from the pioneer project of District Heating for public buildings of the city of Medellin. From this experience, we can take reference values for pipe estimated costs based on their estimated costs as well as installation costs found in that scenario. On figure 2.5, we can observe a graph taking into account the diameter of a set of two pipes, as there is always a supply and return pipe in the network, and their cost per meter in USD at the conversion rate from Colombian Pesos to US dollars at March, 2018 [57]. For maintenance and operation costs, a value of 0.5% of the investment cost was considered, based on the IEA handbook for District Cooling [55].

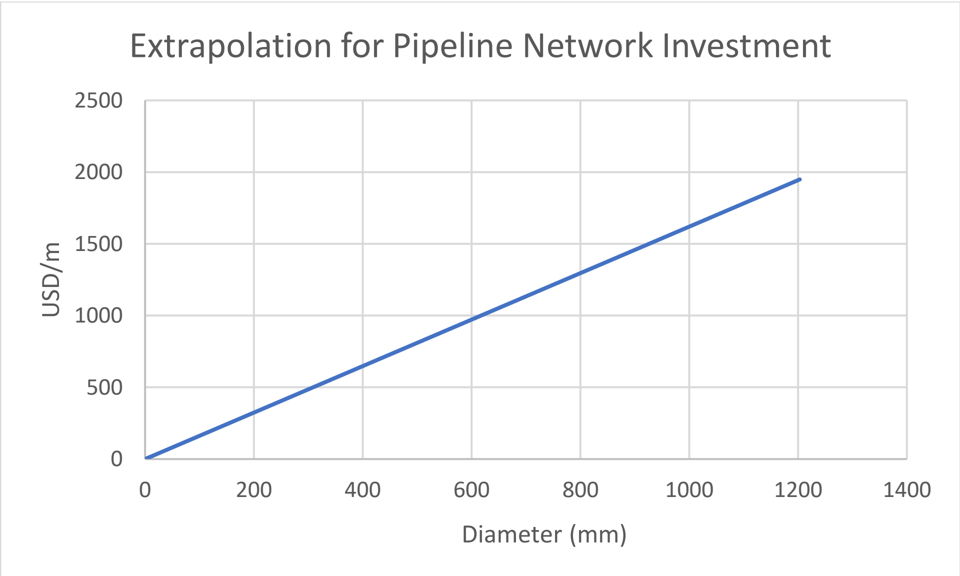


Figure 2.5 Extrapolation of Pipeline cost based on the Medellin, Colombia scenario.

2.2.7 System design: Chiller types, installation and maintenance costs

For the selection of the chiller type to be implemented in the system, we have looked upon the ASHRAE handbook for HVAC purposes [58], and listed in this handbook, are the installation and maintenance costs for several types of chillers, including absorption and electrical(compression) chillers along with COP values and typical size ranges. In table 2.3, we can observe the absorption type chillers listed for sampling purposes [58].

Table 2.3 Characteristics and sample costs for different types of absorption chillers. From ASHRAE [58]

Summary Table of Chiller Characteristics				
Type	Efficiency in COP	Size Range in kW	Equipment costs in USD/kW	Maintenance Costs in USD/year
Direct-Fired Absorption Chiller	0,85 – 1,20	350 - 11430	114 – 569	$4800 - $5500
Hot water Absorption Chiller	0,55 – 0,70	210 - 11430	128 – 284	$4800 - $5500
Steam Absorption Chiller	0,60 – 0,75	210 - 11430	128 – 227	$4800 - $5500

Added to this value, we should mention the cost of the energy and water consumption that the selected chiller technology will need as input. Based on ASHRAE 2016 [58], for an absorption chiller, the electric demand is about 0,15 kW_e per every $kW_{chiller}$ as well, for the water consumption, it is located on 5,5 m^3 per $kW_{chiller}$. At the moment of the writing of this research paper, the energy cost in Panama for industrial clients is based in 122,93 USD/MWh, based on [59]. And for water consumption, the price for a cubic metre of water for industrial use is 1,63 USD/m^3, based from [60].

The combination of all the calculations previously mentioned would allow us to have a grasp of the total initial investment that the implementation of District Cooling in the Ciudad del Saber complex could arise. It is important to mention that in this calculation we have left out several cost calculations that, although of importance, are beyond the scope of this research project. Characteristics as type of piping, insulation, installation modes, property ownership of the properties where the system will be installed requires of extremely complex calculations and input from several private and public parties involved. As well, such type of complexities arises from the selection of the type of chiller technology to use, ownership, and most importantly, demand studies related to the estimated demand that such type of installation could arise in the possible customers in the area.

Overall, we have satiated with the most basic and, in our opinion, vital aspects that encompass most of the installation, operation, maintenance and investment costs that this system could bring.

2.2.7 Economic feasibility from the district cooling implementation

Once we have obtained a global amount of investment and operation & maintenance costs related to the project, we are able to investigate the economic and financial perspective, which is the one that finally would be most importance to arise public and private support for this project. To achieve this, the most straightforward method to investigate the present and future value of the implementation would be to calculate the Net Present Value(NPV) to understand how the financial cashflow of the project would behave during a certain period of time in the future. The NPV shows us the expenses and possible profits that the system would produce, in a value that is adjusted to the present value, accounting for discount rates to the future [51]. For our calculation, the NPV can be obtained from the following formula:

$$NPV = C_0 + \Sigma \frac{C_n}{(1+i)^n} \tag{2.12}$$

Where

C_0 is the value of the total investment or capital in year 0

C_n is the expenditures (operation and maintenance costs) for year n

i is the discount rate, assumed to be 5%, from most recent data, in [61]

n is the year for which the calculations are taken from

With this value, we can obtain a cost for the project for a period of 20 years in the future, and in this case, as well analyse the minimum cost that the district cooling service would have to the customers on the system. This cost, known as well as Levelized Cost of Cooling, is the ratio between the total costs of the system, that would be the NPV value calculated on formula 2.12, divided by the Cooling energy output that the system would have in the same time, 20 years in this model scenario. This value is the so called, “break even” value that the service would have to be paid at the end of the system projected lifetime of 20 years [62]. This relationship can be represented in formula 2.13.

$$Levelized\ Cost\ of\ Cooling\ (LCOC) = \frac{Total\ Cost\ of\ the\ System}{Total\ Cooling\ Energy\ Output} \tag{2.13}$$

With this value, as well we can assess and compare the differences between what could the tentative customers would pay in a District Cooling system versus the reference, individual, non-centralized cooling scenario in the present.

2.2.8 Environmental efficiency assessment

The final step in our analysis is the assessment of the environmental impact that the use of this type of District Cooling system would have if implemented as we have calculated. Although a throughout analysis of the environmental efficiency in the system would be a quite complex task, we would focus primarily and solely in the impact in CO_2 emissions. To assess this, we need to know the primary fuel that would be used to produce cool loads to the system. The primary fuel refers to the resource that is extracted and used directly for energy production, as fossil fuels, or renewable energy resources as wind, solar energy, or wood. Each type of fuel is assigned a factor value, as shown in table 2.4 [63]. This value is a ratio between how non-renewable a fuel resource is versus the amount of fuel is delivered to the system, and this translate to the easy measurement of the sustainability and renewability of the resources used in an energy system [63].

Table 2.4 Table of Primary Resource Factor values for different fuels. [63]

Fuel	Primary Resource Factor
Oil	1,10
Renewable sources	0,05
Waste as fuel	0,00
Free Cooling	0,00
Natural Gas	1,10

As we can observe, the use of oil, fossil fuels and even natural gas produces a PRF value above of 1, meanwhile the use of waste and free cooling produce a value of zero, indicating a sustainability infinitely larger than the use of fossil fuels [63]. PRF values are as well assigned to different types of chillers in district cooling systems. In table 2.5 are noted the different PRF values for different technologies of district cooling.

Table 2.5 Typical PRF values for different chiller technologies. [63]

Cooling system	PRF
Free Cooling	0,07
Absorption	1,3 * PRF value for waste heat fuel
Heat Pump	0,8
Electric compressor chiller	1,0-2,0

Ideally, every energy system would have a specific PRF CO_2 emission factor that can be use to calculate in a conservative manner the amount of CO_2 emissions that are released by the energy system, however, this value is not yet resolved for the Panamanian energy market. However, we can use conversion rates noted for specific cooling systems in order to assess the amount of CO_2 emission each cooling system produces. In table 2.6, we can observe the rates of CO2 emissions based on different cooling systems.

Table 2.6 Usual CO_2 emissions for different cooling systems. [63]

Cooling System	CO_2 emission [g/kWh]	Waste Heat Type	CO_2 Emissions [g/kWh]
District Cooling (Free Cooling)	25	Oil	360
District Cooling (Absorption)	1,3 * type of waste heat used	Waste Incineration	20
District Cooling (Heat Pump)	270	Biomass	30
Non-centralized building specific compressor	340 - 680	CHP gas	10

To show the amount of CO_2 emission of each system we can use formula 2.14, to arrive to the amount in grams of CO_2 produced in each scenario [63].

2 CO_2 emissions in grams = Total Energy used for Cooling * CO_2 emission factor (2.14)

At the final step of this method, we can readily compare both amounts and determine how district cooling system can improve the overall CO_2 emission production in the system.

In the following section, we will provide the results arisen from the methodology we have proposed to follow to assess the implementation of District Cooling in the Ciudad del Saber complex.

2.3 Results

Running the methodology proposed above using the data obtained from different sources, including Global Information System(GIS) software and the master plan for Ciudad del Saber compound, the following results were obtained for each task.

2.3.1 Waste heat availability

Having in mind that the only readily available source for waste heat in the zone was through the Waste-to-Energy plant located in the nearby landfill of Cerro Patacon, the total waste heat available was calculated using reference values for this powerplant, and the results presented in table 2.7.

Table 2.7 Results for cold energy supply for Cerro Patacon PowerPlant

Waste heat available for Waste-to-Energy Powerplant, Cerro Patacon, Panama City						
Powerplant Capacity (MW)	η_{total} (kWh_{output}/kWh_{fuel})	$\eta_{electrical}$ (kWh_e/kWh_{fuel})	**Fuel** $_{yearly}$ **(MWh)**	WH_{yearly} **(MWh)**	COP_{absorp}	**C** $_{supply\ year}$ **(MWh)**
8.1	0,842	0,437	162 371	65 760	0,7	46 032

2.3.2 Cooling demand for Ciudad del Saber

For the calculation of the cooling demand, the masterplan for the Ciudad del Saber compound was used. In this document, there is record of more than 100 buildings already built in the area, with total area used per building as well as intended use [44]. As the records show already the maximum floor area, there was no need to use the plot area ratio for this calculation, as all buildings in Ciudad del Saber are permanent, and new structures are seldomly built/projected to be built. The Energy Use Intensity(EUI) value, for these calculations was taken from the official guide for sustainable building, obtained from the Energy Secretary of the Panamanian Government [47]. In table 2.8, the total values for the cooling demand are shown. For a complete list of the values analysed, building codes, building activity use and location within the Ciudad del Saber compound, please refer to Appendix 1 and [44].

Table 2.8 Cooling demand per type

Cooling Demand Summary per Type			
	Area (m^2)	EUI value used (kWh/(m^2 ∗ year)	C_{demand} (MWh/year)
Office Use	171 075	202	34 557
Commercial Use	11 287	172	1 941
Total Area Analysed	182 362		36 499

2.3.3 Grid layout cost calculation

Following the methodology for cooling load calculation in section 2.2.2, we present in table 2.9 the calculated peak cooling load for each subarea analysed. In the Appendix, the detailed peak load for each building is presented.

Table 2.9 Calculated peak cooling load per area and totals for Ciudad del Saber complex

	Total area in m^2	Calculated peak cooling demand in kW
Area 1	75 072	5 630
Area 2	54 506	4 088
Area 3	52 784	3 959
Total	**182 362**	**13 677**

Assuming that these values correspond to the peak cooling demand, we can now select a chiller type and calculate the investment, operation and maintenance costs for this equipment. Considering the information found above, we can determine these values as follows:

Table 2.10 Equipment and operation/maintenance costs for the absorption chiller selected.

Chiller Type	Power(kW)	COP	Equipment cost(USD)	Operation and Maintenance(USD)
Absorption	13 677	0,60	2,817,462	5,150

Once we have determined the peak cooling demand for each subarea, we can use formula 2.8 to determine the pipe diameter needed for each area based on their peak cooling demand, as shown in Table 2.11. For the calculation of unitary cost for pipeline, we used a pipeline type as the one used in the Medellin District Cooling system in Colombia, where plastic cross-linked polyethylene (PEX) was used for pipe material. As well, for this step, we can observe a grid location of the pipeline network over the map of the Ciudad del Saber complex, on figure 2.6.

Table 2.11 Data regarding pipeline network cost

Pipe	Length (m)	Diameter (mm)	Unitary Cost (USD/m)	Total Cost in USD	Operation and Maintenance in USD
Area 1	1690	327	600	**$1,014,000.00**	**$5,070**
Area 2	1620	278	500	**$810,000.00**	**$4,050**
Area 3	2590	274	500	**$1,295,000.00**	**$6,475**
Transmission Pipe	7430	509	850	**$6,315,500.00**	**$31,577.50**
			Total Cost for Pipeline Network	**$9,434,500.00**	**$47,172.50**

Our next calculation in focused in the cost related to the electricity needed to provide the pressure and pumping needed to run the system. Using formula 2.10 and 2.11, we can obtain the total cost for pumping needs for the system, as shown in table 2.12.

Table 2.12 Pumping Power in kW per area

Pipes	ΔPump (Pascals)	V'(m^3/s)	P_{el}(kW)	Pump Cost(USD)	Operation and Maintenance(USD)
Area 1	352 099	0.17	75	$2,797.35	$83.92
Area 2	389 856	0.12	60	$2,248.81	$67.46
Area 3	602 141	0.12	90	$3,363.61	$100.91
Trans	902 164	0.41	465	$17,411.04	$522.33
			Total	**$25,820.81**	**$774.62**

2.3.4 Overall Implementation Costs for District Cooling system

Based in the analysis and calculations obtained in section 2.3.3, we can provide a succinct economic analysis of the overall initial costs and annual maintenance and operation costs that the implementation of the District Cooling system could arise in the scenario that was implemented as exposed in this research. For this analysis, we will separate the costs that would be initial, as investment costs, and the operational or recurrent costs that will be incurred during the implementation and operation phase annually.

Table 2.13 Total investment and operational cost for the DC-Absorption Scenario

Type of Cost	Investment (USD)	Operation & Maintenance (USD)
Pipeline Network	**$9,434,500.00**	**$47,172.50**
Pumping System	**$25,820.81**	**$774.62**
Electricy Cost	**-**	**$858,173.17**
Water Consumption	**-**	**$312,840**
Absorption Chiller	**$2,817,462**	**$5,150**
Total	**$12,277,782.81**	**$1,224,110.29**

Figure 2.6 Map depiction of the pipeline network as implemented by subarea. Map from [44]

2.3.5 Economic analysis: Benefits from District Cooling Implementation

To analyse the idea of implementing a District Cooling system, as an experimental setting in Ciudad del Saber complex, we should, as well, investigate the economic and financial aspects. A first step towards this is to describe the cooling load profiles that the sectors and areas studied have. From above, we can obtain the annual cooling loads in MWh per area as seen in table 2.14.

Table 2.14 Annual cooling loads and peak loads divided per studied area in Ciudad del Saber complex

Area	Annual Cooling Load in MWh	Peak Load in MW
1	15 165	5,63
2	11 010	4,88
3	10 662	3,96
Total	**36 837**	**13,68**

We must mention that these values account for annual cooling loads in areas where the large portion of the buildings are destined for office use. Less than 10% of the floor area is used for commercial or educational (e.g. schools) purposes. As office areas, a time setting use of approximately 8AM to 5PM for around 6 days a week is taken into consideration for most of the office buildings in the area. As for the cooling load, it is assumed that is a constant use throughout the year, partially explained by the constant number of Cooling Degree Days during the course of the year, as seen for example for reference year 2017, shown in figure 2.7.

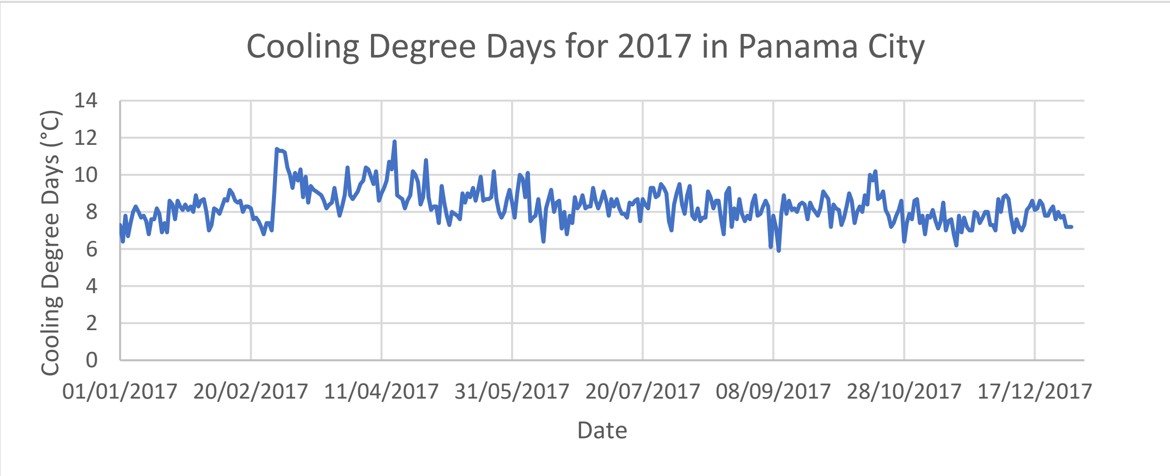


Figure 2.7 Cooling Degree Days for 2017

In order to assess the economic impact of this project, we apply a simple calculation of Net Present Value with a normal discount rate of 5% and having the initial investment as a expenditure for year

0, as well as the operation and maintenance costs as negative cash flow per year. At the end of a 20 year period, we have NPV of $28,308,391.60 for this project.

As well, we looked into the localized cost of cooling for this amount, having in mind the amount previously mentioned as the total costs that the project will incur during a 20 year period, and having the total cooling energy that will be produced by the end of this period. We have summarized this calculation results in table 2.15

Table 2.15 NPV and LCOC for District Cooling implementation

NPV in USD	Annual Cooling Demand in MWh	LCOC in USD/MWh	District Cooling Price [USD]
$28,308,391.60	**36,837**	**$38.42**	**$1,415,277.54**

To be able to compare the implementation of District Cooling versus the Business as Usual(BAU) scenario, we need to find the investment and yearly expenditures of the reference scenario. Comparing both values, we can assess how both technologies (centralized versus de-centralized) are related to the economical aspect of its implementation. For the cost calculation of the BAU scenario we will take the cooling demand as a communal amount and use the values in the ASHRAE Handbook for Heating, Ventilation and Air Conditioning [48] to obtain an electric chiller global investment value and account the operation and maintenance costs per building unit in the areas studied. Under these conditions, we obtained a global investment in de-centralized electric chiller technology of **$8,361,999 USD**. As for the operation and maintenance costs, we obtained a global amount of **$643,500 USD** for the BAU scenario. Our next step would be to find the Net Present Cost (similar to the NPV) for each scenario, taking into account the following:

- In the BAU scenario, the initial investment would be the global investment for de-centralized chiller system. As for cashflows, we will account the operation and maintenance costs as negative cashflow values for each year until the end of the period.

- In the District Cooling scenario, the initial invest is a positive value as we are assuming as a saving the amount that would be invested in the decentralized chiller system, and assuming as negative cashflow since year 0, district cooling purchase that would be the cooling demand in MWh by the LCOC shown in Figure 2.21.

- For both scenarios, a discount rate of 5% is assumed.

Considering the assumption aforementioned, we calculated the Net Present Cost for both operations and determined in which scenario the client receive a better economic outlook at the end of the 20-year period, as shown in Table 2.16.

Table 2.16 Life-cycle costs for both BAU and DC scenarios.

Business as Usual Scenario	**Year**			
	0	1	2…	20
Equipment Investment [USD]	**$8,361,999.00**	---	---	---
Operation & Maintenance [USD]	---	**$643,500.00**	**$643,500.00**	**$643,500.00**
Discount rate = 5%	**Net Present Cost = $15,601,363.20**			
District Cooling Scenario	Year			
	0	1	2…	20
Investment Savings [USD]	**($8,361,999.00)**	---	---	---
Operation & Maintenance Savings [USD]	**---**	**($643,500.00)**	**($643,500.00)**	**($643,500.00)**
Purchase of District Cooling at LCOC price [USD]	**$1,415,277.54**	**$1,415,277.54**	**$1,415,277.54**	**$1,415,277.54**
Discount rate = 5%	**Net Present Cost = $2,544,126.27**			

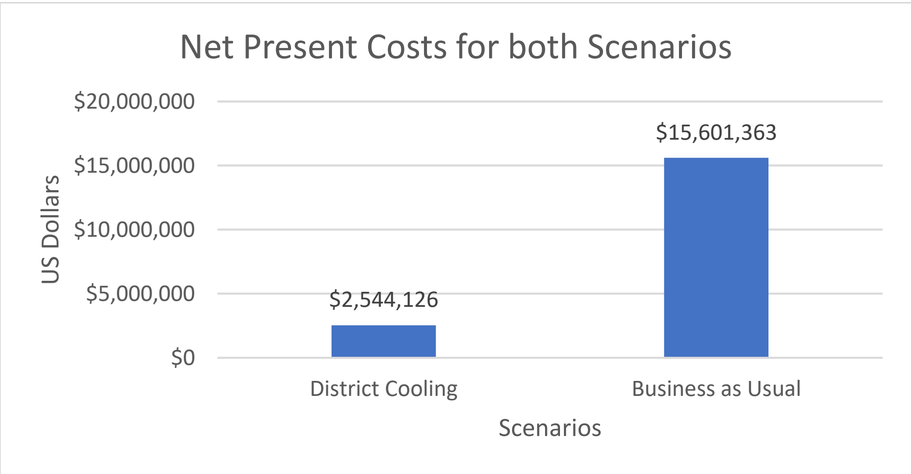


Figure 2.8 Graphical representation of the difference in costs for both scenarios.

As a final note, we can observe that the overall savings that the final customer will gain with the implementation of District Cooling could arise to **$13,057,237 USD** based in our calculations.

As a final caveat for this calculation, we should mention that based on other well studied and developed District Cooling systems, not all consumers will be connecting to the District Cooling network, at least not in the beginning of the implementation. Therefore, although this analysis provide a round amount, it is important to note that it is expected a difference with this model on the initial years of implementation due to that some clients would be preferring to remain with their usual cooling system, would be questioning about the technology and how reliable it could be and overall internal decisions that could render the adaptation process to be slower than expected.

As well, there must exist a concurrent economic and marketing model that should be developing before, meanwhile and after the implementation is done. Existing DC systems has provided enough evidence that a clear, reliable, understandable and manageable pricing model can improve and incentivise the adaptation of DC systems, however it is a process that takes several years up to decades to be successful.

2.3.6 Environmental assessment: Benefits from DC Implementation

Our final metric to assess in this final research question relies on the environmental impact that the implementation of a District Cooling system could provide. Considering that we are implementing an absorption chiller system with the usage of waste heat from a waste-to-energy powerplant, we can use formula 2.14 to obtain the total amount of CO_2 that this system would produce. The total amounts for each scenario are shown in table 2.17 below.

Table 2.17 Total estimated CO_2 emissions for each analysed scenario

CO_2 emission estimated for Business as usual Scenario	CO_2 emission estimated for District Cooling Scenario
25,049 tonnes of CO_2	958 tonnes of CO_2

The difference between District Cooling and Business as usual scenario is a total of 24,091 tonnes of CO_2 emissions that could be saved from the environment with the implementation of this technology in the Ciudad del Saber complex.

3. RESULTS' DISCUSSION AND SUGGESTIONS FOR FURTHER WORK

In this section, we aim to discuss the impact of the results obtained in the previous chapter and expand on the idea on the possible hindrances, difficulties and overall technicalities that introducing and implementing District Cooling, whether in a small portion or a larger section of Panama City could arise.

3.1 District Cooling Incentivisation Ideas

Based on the results obtained, there is a clear opportunity for savings, both economic and in environmental impact, from implementing District Cooling. However, knowing that these results are already known in other cities with similar climates as Panama City, how can we manage to incentivize the introduction of this technology in this region? From our point of view, there are several fronts we can investigate:

- Introduce and publicize the idea and the technology to public offices that can provide public and governmental support to make the idea of District Cooling popular, not only with the general population, both as well, and perhaps, more importantly, to the local businesses and international organization set up in Panama, to understand the benefits that this technology can bring.

- On a similar point, introduce the idea of District Energy Systems into the energy planning framework that the public authorities have set up for future planning. As we can see in Panama's energy framework from 2020-2050, there is not a single mention of District Cooling in it. More than seeing this as a lack of interest, we should use it as an opportunity to introduce the idea and make the public decisionmakers be aware of it.

- There is a latent and clear need of updated and specific studies to properly categorize and quantitively describe the energy situation in the Panamanian scenario. As we can observe from this research project, there is a clear absence of data for several values, most importantly in the area of energy consumption and energy needs for the future. Without this data, even using models that are similar to outs, we would never be able to correctly describe our actual situation, and therefore, impossible to describe proper solutions for these problems.

3.2 Overall benefits from District Cooling

From the results obtain in our analysis, we can enlist the following broad benefits from introducing District Cooling systems in Panama City, in the current conditions, based on the model applied in the Ciudad del Saber complex:

- We found a total yearly CO_2 emission savings in the vicinity of 24 thousand tonnes of CO_2 in the District Cooling Scenario, assuming the use of Absorption cooling. A different range could be obtained if free cooling or mechanical cooling is applied depending on the technology. As a measure of comparison, for 2016, the estimated total CO_2 emissions for Panama was calculated on 11,6 million tons [34]. On this model, we obtained a reduction of 0,2% of the total emissions for the whole country, which represents an important amount taking into account the overall minimal size of the sample area analysed. District Cooling applied to a larger area, with a larger amount of consumers could signify a reduction that could greatly impact and reduce the total CO_2 emissions for the country.

- We found that for a 10 year period analysis of the contrast between a District Cooling scenario versus a Business as Usual scenario, a total saving of around 13 million USD could be obtain with the implementation of District Cooling in this sample area. We need to strongly emphasize that this calculated amount is highly variable, operation and material costs were obtained from sources from other countries/regions, and may not include other hindrances related to construction, energy availability and overall operability of the system. However, assuming all these caveats, a reduction in costs of over 10 million USD is an important quantity to have in mind and could easily demonstrate that the implementation of a District Cooling system is economically sound and further professional and detailed financial feasibility studies should be carried out.

- Although not expressed in a hard figure, improvement in cooling conditions are obviously a clear benefit from the implementation of a District Cooling system. As most of the consumers of cooling energy in the area are public institutions, non-governmental organization, schools and educational organization/universities, a net improvement could be forecasted for these institutions, with lower costs in cooling related needs, and availability of resources for other needs/investments.

In summary, economic, environmental and overall practicability improvements can be foreseen in the implementation of a District Cooling system in this area. As well, the Ciudad del Saber complex installation could function as a showcase of these improvements to be offered to the cities in Panama or nearby countries in the region. Examples can be seen in Singapore or China, where the introduction of District Cooling in a city in those countries improve the chances for the implementation of this technology to be shared and expanded to other cities, than to the overall awareness of perceived benefits for the general public.

3.3 Constraints found during the research

As already mentioned before throughout our methodology and results analysis, our main constraint during our research was the scarcity of proper referential material from where to based our cost calculation and overall modelling for District Cooling in the Latin American region. The only current examples from where we can gather information and references are from public projects, one located in Medellin, Colombia and the other in Dominican Republic. As both projects are funded by public government and in no way associated with proper research institutions, there is a clear absence of proper documentation and follow-up behind the implementation of these two projects in their area.

As there is a reduced amount of information on the Latin American regions, most of our reference are obtained from countries as Singapore or China, were there is a better research documentation of the processes followed on their work area, although are far from appropriate in some scenarios. We should also mention the lack of information or even acknowledge of the concept of District Energy systems in regions of the tropics and subtropics. District Cooling technologies are completely unheard of in some countries and Panama is no exception to this. Even in nearby Colombia, with a current project in a important city, is lacking of proper documentation on DES technologies in other cities of importance, as their capital city. In general, there is a clear absence of scientific awareness in the research bodies in these countries towards the use and benefits of DES in their regions and this is possibly the main reason of the low level of implementation of this kind of technologies in this area of the world.

3.4 Ideas for further work

Having in mind the hindrances that we found during our research study, it is clear that several steps and aims should be taken to improve the awareness and consequent implementation of District Cooling technologies in these regions:

- Awareness programs should be funded from countries where these initiatives are already mature and proven to be passed and analysed in these regions where great savings in energy production and environmental impact could be achieved. Proper research studies should be funded to provide a proper background on several areas related to energy production to assess how DES technologies can be implemented.

- Theoretical and practical databases should be produced and reproduced for data related to climate, environmental resources, hydrology and overall meteorology resources. These databases are of great utility for scientific research on how climate and local weather can affect the actual energy consumption in cooling needs in cities and consumers in these regions.

- Proper research documentation should be applied to current projects in District Cooling in the region and this data be freely available for other research groups to use for refining their modelling and simulation for better and more reliable feasibility studies on District Cooling implementation scenarios in the region.

- Although modelling and simulation are proper and important tools in research methodology, research on physical and real installation of District Cooling systems on model buildings could be a way to improve and prove our current methodologies on how operation, installation and maintenance costs are calculated. Further work should also focus on integration of empirically obtained data and compare this data with data obtained from other regions, to assess how near or far are our simulation based on data obtained from other countries.

4. CONCLUSIONS

With this research work, we aimed to tackle the scarcity of information related to District Cooling in the Panamanian scenario, constructing a sound base and theoretical background analysing data to assess how District Cooling should be implemented in this geographic area. We consequently obtained that free cooling is not a reliable resource, however cooling capacities along with absorption and mechanical coolers are a viable option which could be readily applied on different scales.

We found that the economical and environmental benefits are outstanding, having in mind the relative small area that was assessed in this study. If these results are scalable, we could see economic savings of millions and reduction in CO_2 emissions that could reduce greatly the overall total CO_2 emissions of the country, just by implementing a system that is, as well, economically sound.

We strive to assess these results with methodological reserve, as most of the data used for calculation and comparison were obtained from resources and databases from other regions in the world, as there is a large scarcity of proper academically sound and reliable data for District Cooling systems in this region of the world. Although there is a large need for data, there is as well a large source for further investigation of the implementation of DC systems in the region and should be fair to assume that attention from researchers should be focused in improving our knowledge on how DES technologies could be implemented in this area of the world and how can our societies could benefit, economically, environmentally and in efficiency with its use.

In conclusion, we believe that District Cooling promises to be a potential source of great improvement in energy management in the area and we can only encourage other researchers to focus in the developing world, as much work is needed.

SUMMARY

District Cooling implementation was analysed in the geographical area encompassing the Central American country of Panama. With the introduction of this technology, we aimed to see important reduction in operational and maintenance costs versus the Business-as-Usual scenario of building centered cooling solutions (localized chillers for each building/building section) that is currently used in the country. As well, we aimed to look for environmental impact of this implementation by a reduction in the CO_2 emissions in a certain extension.

To analyse the case of DC implementation, a theoretical background was assessed, where different technologies related to DC where discussed, among them free cooling, absorption chillers and mechanical/electrical chillers. As well, current examples of DC in the tropical and subtropical regions were presented, with their current achievement in CO_2 emission reduction and overall commentary on their relative success. The advantages of DC in these types of climates were discussed and presented systematically.

Entering into the dissection of the area to be analysed in this study, important information on climate classification, energy expenditure and resource availability were presented for the Panama case study. Among our results for this area, we obtained that the free cooling option is not feasible due to high temperatures year around for surface water, although commentaries for further studies were mentioned as water below the surface may provide free cooling capacities at achievable depths.

As the area to be assessed encompassed the capital city of the country, a location within the city was selected to be analysed for the modelling and simulation section of the study. Methodology, area selection metrics and overall system design (including formulae and calculations) were provided in order to assess the cooling demand, peak cooling load, pipe network necessary and the usage of an absorption chiller to provide cooling needs to the selected area under scrutiny. A nearby waste-to-energy powerplant was selected as the source of waste heat that the absorption chiller would use to provide the cooling needs for the model at hand. Economic feasibility and overall environmental efficiency (in CO_2 emission reductions) calculations were introduced in order to assess these metrics on the model.

Our results presented that enough waste heat was available from the nearby powerplant to provide the heat necessary to run the absorption chiller. Cooling demand and overall grid layout cost calculation were obtained, and the economic and environmental analysis were processed with this data.

As a result, a 13 million USD saving was found in the DC scenario versus the BAU scenario for a 10 year period, and a yearly reduction in 24 ktons of CO_2 were obtained in the DC scenario versus the BAU scenario.

Our evaluation on the results are that the implementation of DC in this area represented an important saving in operational and maintenance costs for the consumers of cooling energy and a yearly reduction in 24 ktons of CO_2 represents a reduction of 0,2% in the overall total emissions for the country, which taking into account the small area for our test, represents an important reduction in emissions, which could translate, using a larger scale implementation to a much larger and important reduction in the country's emissions. Overall, the DC implementation in this area has shown to be promising in our more conservative calculations and should be taken as a positive turn towards better and more detailed studies on DC implementation in the country.

Among the problems we found during our study are the scarcity of scientifically sound references for DC implementation in tropical and subtropical regions, which lead to the need to use data and empirical references from studies from regions in Asia and Middle East which could or could not be applicable to our model and economic simulations. Our best recommendation is to assess this lack of data and fund studies that could fill the blanks needed for researchers to fine-tune the modelling of DC systems in tropical and subtropical countries, in search for better simulations and more reliable data for input in current models.

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APPENDICES

Data on builing type, area and identification number categorized for Area in Ciudad del Saber.

Area 1		
Building #	Area (m2)	Type
220	764	Office
221	5102	Office
222	3528	Office
223	3610	Office
224	3000	Office
225	3550	Office
227	3000	Office
228	3000	Office
229	1337	Office
230	2985	Office
231	3001	Office
232	3499	Office
233	2957	Office
234	2981	Office
235	2998	Office
237	3000	Office
238	5102	Office
239	3000	Office
240	5102	Office
243	324	Office
244	363	Office
245	342	Office
300	8780	Office
341	308	Office
342	308	Office
347	308	Office
348	308	Office
200A	1321	Office
247	780	Office
248A	1194	Office
Total	75852	

Area 2		
Building #	Area (m2)	Type
108	1027	School
109	1064	Office
110	864	Office
111	864	Office
112	467	Office
113	467	Office
114	467	Office
115	357	Office
116	467	Office
117	357	Office
118	357	Office
119	357	Office
120	357	Office
121	357	Office
122	357	Office
123	357	Office
124	467	Office
125	467	Office
126	2116	Office
127	9590	Hotel
128	3511	Office
129	3486	Office
130	3157	Office
131	357	Office
132	357	Office
133	357	Office
134	357	Office
135	357	Office
136	357	Office
137	357	Office
138	357	Office
139	357	Office
140	357	Office
141	357	Office
142	357	Office
143	357	Office
144	357	Office
145	357	Office

Area 3		
Building #	Area (m2)	Type
100	3730	Office
101	2711	Office
102	2711	Office
103	2362	Office
104	13185	Office
105	2748	Office
106	2766	Office
107	2366	Office
200	124	Office
201	1877	Office
202	704	Office
203	2561	Office
215	3710	Office
216	1239	Office
217	5414	Office
218	866	Office
219	3710	Office
TOTAL	52784	

146	357	Office
147	357	Office
148	357	Office
149	357	Office
150	357	Office
151	357	Office
152	357	Office
153	357	Office
154	357	Office
161	620	Office
162	602	Office
163	311	Office
164	604	Office
165	604	Office
166	431	Office
167	431	Office
168	431	Office
169	431	Office
170	431	Office
171	431	Office
172	431	Office
173	442	Office
174	431	Office
175	431	Office
176	431	Office
177	431	Office
178	604	Office
179	431	Office
180	604	Office
181	588	Office
182	958	Office
183	1795	Sport Hall
184	1697	Ccenter
TOTAL	54506	