Demand-Response Management of a District Cooling Plant of a Mixed Use City Development

Segu Madar Mohamed Rifai

Master of Science Thesis
KTH - Royal Institute of Technology
School of Industrial Engineering and Management
Department of Energy Technology
SE-100 44 STOCKHOLM
Thesis Registration No.: EGI- 2012-011MSC

Title: Demand-Response Management of a District Cooling Plant of a Mixed Use City Development.

SEGU MADAR MOHAMED RIFAI
Student Number: 731222 A-315

<table>
<thead>
<tr>
<th>Approved Date: 05/06/2012</th>
<th>Examiner</th>
<th>Supervisor at KTH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prof. Björn Palm</td>
<td>Dr. Samer Sawalha</td>
</tr>
</tbody>
</table>

|                           | Local Supervisor          | Dr. Hari Gunasingam         |
|                           |                           |                             |

|                           | Commissioner             | Contact person              |
|                           |                           |                             |
Abstract

Demand for cooling has been increasing around the world for the last couple of decades due to various reasons, and it will continue to increase in the future particularly in developing countries. Traditionally, cooling demand is met by decentralised electrically driven appliances which affect energy, economy and environment as well. District Cooling Plant (DCP) is an innovative alternative means of providing comfort cooling. DCP is becoming an essential infrastructure in modern city development owning to many benefits compared to decentralized cooling technology.

Demand Response Management (DRM) is largely applied for Demand Side management of electrical grid. Demand of electrical energy is closely connected with the demand of alternative form of energy such as heating, cooling and mechanical energy. Therefore, application of DR concept should be applied beyond the electrical grid; in particular, it could be applied to any interconnected district energy systems. District Cooling Plant is one of a potential candidate and Demand Response management solutions can be applied to DCP for sustainable operation. The study of demand response and its applicability has not been attempted previously for district cooling systems. To our knowledge, this is the first attempt to evaluate its applicability and economical feasibility.

This thesis focused on some of the DR objectives which have the potential to implement for DCP of a mixed-use city. General published data on mixed use city developments and a specific city in Dubai was taken as a case study to show the usefulness on DRM objectives.

This study primarily addressed the issues related to load management. The findings are: DRM creates greater flexibility in demand management without compromising service levels. Also it reduces the operation cost and impact to environment. However implementation is a big challenge. Therefore implementation strategies are also proposed as a part of recommendation which includes a generic model for demand response management.

Moreover, a review is provided on key enabling technologies that are needed for effective demand response management. Finally this thesis concludes with recommendations for prospective applications and potential future works.

Key Words: Mixed-Use City, District Cooling Plant, Demand Response Management.
Acknowledgement

All praise is to Almighty God on whom ultimately we depend for sustenance and guidance. First of all I would like to express my sincere gratitude to my supervisor, Dr. Hari Gunasingam for his guidance, and time consuming proof reading of manuscript. Also his excellent research attitudes always inspire and encourage me and without him it would have been a dream. I am very much grateful to Dr. Samer Sawalha from KTH, for his kind support and assistance to make this study a success.

I sincere gratitude goes to staffs of the Department of Mechanical Engineering, Open University of Sri Lanka for their utmost support and dedication in making this thesis a success. Especially I would like to thank Mr. Ruchira Abeweera, coordinator, DSEE program, Sri Lanka, for his tireless help and consistent support extended to me for making this work a success. I am also indebted to my colleagues at DSEE program for their support, motivation, encouragement and peer review of my report. I regret my inability to thank many individuals who assisted this effort through contribution of data, studies or articles.

Finally, I thank my parents, wife, Aazmy and my children Ayesha, Adhnan and Hashim for their care, love and emotional support during my hard times and their patience during my hectic work schedule.

Mohamed Rifai, February 2012.
# Table of Contents

Abstract ................................................................................................................................. ii

Acknowledgement .................................................................................................................. iii

Table of Contents ................................................................................................................... iv

Figures .................................................................................................................................... vii

Tables ...................................................................................................................................... viii

Abbreviations .......................................................................................................................... ix

1. Introduction ......................................................................................................................... 1
   1.1 Cooling Demand in Mixed-use city development ......................................................... 2
   1.2 Demand Management Problems ................................................................................... 3
   1.3 Research Objectives ....................................................................................................... 4
   1.4 Methods .......................................................................................................................... 8
      1.4.1 Literature survey ...................................................................................................... 8
      1.4.2 Case Study ............................................................................................................... 9
   1.5 Layout of the Thesis ....................................................................................................... 10

2. District Cooling Plant ........................................................................................................... 12
   2.1 District Cooling Plants (DCP) and Future City Developments .................................... 12
      2.1.1 Introduction to District Cooling Plant .................................................................... 15
      2.1.2 Benefits and Challenges ....................................................................................... 16
   2.2 District Cooling Technology and its Components ......................................................... 18
      2.2.1 The Cooling Technology ....................................................................................... 18
      2.2.2 The Central Plants .................................................................................................. 20
      2.2.3 The Distribution Networks .................................................................................... 21
      2.2.4 The Consumers' Systems ...................................................................................... 22
      2.2.5 Thermal Energy Storage (TES) system .................................................................. 22
      2.2.6 Operation and Control ........................................................................................... 23
3. DRM-Electrical Analogy to DCP ................................................................. 24
   3.1 Demand-Side Management ................................................................. 24
      3.1.1 Demand-Side Management Concept ............................................. 24
   3.2 Demand Response .............................................................................. 26
      3.2.1 Why is Demand Response Important? ........................................... 26
      3.2.2 Types of Demand Response .......................................................... 27
      3.2.3 The Benefits of Demand Response ............................................... 29
   3.3 Demand Side Management of DCP ...................................................... 29
      3.3.1 Electrical Analogy of District Cooling Model ................................. 29
      3.3.2 Traditional Load Management and its problems of DCPs ............... 30
      3.3.3 The Demand Side Management in DCP ....................................... 31
      3.3.4 DRM for load management of DCP .............................................. 31
      3.3.5 Challenges .................................................................................. 33

4. Case Study ............................................................................................... 35
   4.1 Introduction ......................................................................................... 35
   4.2 Mixed Use City in Dubai ................................................................. 36
   4.3 District Cooling Plant ......................................................................... 37
      4.3.1 Central Plant ............................................................................... 37
      4.3.2 Distribution Network ...................................................................... 38
      4.3.3 Customer Installations ................................................................. 38
      4.3.4 Operational challenges of the Central Plant ................................ 40
      4.3.5 Commercial users ....................................................................... 43
      4.3.6 Needs and Opportunities of Demand Response ............................ 46

5. Demand Response Implementation Strategies ........................................ 49
   5.1 Determination of Energy Use Behavior ............................................... 49
      5.1.1 Energy Consumption Behaviour .................................................. 49
      5.1.2 Approaches to Determine Energy Use Behaviour .......................... 49
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2</td>
<td>Setting Baselines</td>
<td>50</td>
</tr>
<tr>
<td>5.3</td>
<td>Linking DCP and Customers through DRM</td>
<td>50</td>
</tr>
<tr>
<td>5.3.1</td>
<td>Demand Response Model Structure</td>
<td>50</td>
</tr>
<tr>
<td>5.3.2</td>
<td>Demand Management</td>
<td>52</td>
</tr>
<tr>
<td>5.3.3</td>
<td>The Demand Management in the Commercial Sector</td>
<td>53</td>
</tr>
<tr>
<td>5.3.4</td>
<td>Voluntary non-fiscal methods</td>
<td>54</td>
</tr>
<tr>
<td>5.4</td>
<td>Utility Operation</td>
<td>54</td>
</tr>
<tr>
<td>5.4.1</td>
<td>Load shifting for Peak Load Management</td>
<td>54</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Economic Control</td>
<td>55</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Integration of Efficiency with DRM</td>
<td>55</td>
</tr>
<tr>
<td>6.</td>
<td>Enabling Technologies</td>
<td>56</td>
</tr>
<tr>
<td>6.1</td>
<td>Overview of enabling technologies</td>
<td>56</td>
</tr>
<tr>
<td>6.2</td>
<td>Information and Communication Requirements</td>
<td>56</td>
</tr>
<tr>
<td>6.2.1</td>
<td>Information system requirements</td>
<td>57</td>
</tr>
<tr>
<td>6.2.2</td>
<td>Communication Systems Requirements</td>
<td>57</td>
</tr>
<tr>
<td>6.3</td>
<td>Advanced Metering</td>
<td>60</td>
</tr>
<tr>
<td>6.4</td>
<td>Direct Load Control Systems</td>
<td>61</td>
</tr>
<tr>
<td>6.5</td>
<td>Energy Efficiency Technologies</td>
<td>61</td>
</tr>
<tr>
<td>7.</td>
<td>Discussion and Conclusion</td>
<td>63</td>
</tr>
<tr>
<td>7.1</td>
<td>Discussion</td>
<td>63</td>
</tr>
<tr>
<td>7.1.1</td>
<td>Demand Response in the DCP Sector and its applicability</td>
<td>63</td>
</tr>
<tr>
<td>7.1.2</td>
<td>Case study</td>
<td>64</td>
</tr>
<tr>
<td>7.2</td>
<td>Recommendations</td>
<td>64</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Limitations of the DR model</td>
<td>66</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Potential Future Work</td>
<td>67</td>
</tr>
<tr>
<td>Bibliography</td>
<td></td>
<td>68</td>
</tr>
</tbody>
</table>
Figures

Figure 1-1: Growth of District Cooling in Helsinki (Riipinen, 2011) .........................................................2
Figure 1-2: Schematic Diagram of a typical DCP with chilled water as energy carrier (Chow, 2004).........3
Figure 1-3: Daily cooling-load profiles for three day-types in a summer month (Chow, 2004) ...............6
Figure 1-4: Average daily combined cooling-load profiles of all the building types for 12 months. .......7
Figure 2-1: Layout of DCP/DHP in a mixed-use city (IDEA, 2005) .................................................................15
Figure 2-2: Simple vapour compression cycle (Source: Bruned, 2009) ..........................................................19
Figure 2-3: Absorption Cooling system (Source: http://www.cenerg.ensmp.fr) ...........................................19
Figure 2-4: Free Cooling using sea water (Source: http://www.cenerg.ensmp.fr) ........................................20
Figure 2-5: Single-effect and double-effect chillers (Sakraida, 2009) .........................................................21
Figure 3-1: Six load shape objectives for load management program (Hong, 2009) ...............................24
Figure 3-2: Classification of price based and incentive based Demand Response Programs ..................28
Figure 3-3: Cooling-load profiles for three day-types during a summer month (Chow, 2004) ..............32
Figure 4-1: Variation of temperature, humidity and solar radiation (Radhi, 2010) ...............................35
Figure 4-2: Cooling Degree Days at 10 and 18 °C base temperatures for UAE climate (Radhi, 2010) ....36
Figure 4-3: Cooling demand distribution across the city ..........................................................40
Figure 4-4: System peak demand for year 2009 and 2010 (source: www.dewa.gov.ae) .........................41
Figure 5-1: Conceptual Demand Response Model for a DCP .................................................................51
Figure 5-2: Generic Physical Model for Central DRM (Siemens, 2010) .......................................................51
Figure 6-1: Demand response communication infrastructure (Siemens, 2010) ...........................................57
Figure 6-2: Proposed Demand response communication infrastructure for DFC .................................59
Figure 6-3: Demand response communication infrastructure (Siemens, 2010) .........................................60
Tables

Table 2-1: COP of cooling technologies (Potter, 2004) ................................................................. 18
Table 3-1: Direct and Indirect Benefits of Demand Response (Gyamfi, 2010). .............................. 29
Table 3-2: DRM challenges ............................................................................................................. 34
Table 4-1: Climate conditions ........................................................................................................ 37
Table 4-2: Main technical design parameters .................................................................................. 38
Table 4-3: Design parameters of Heat exchangers at ETS ............................................................... 39
Table 4-4: Name of the buildings served by the plant in DFC (Source: As-built drawings) ............. 39
Table 4-5: Total cooling demand of the building types in DFC (Source: As-built drawings) .......... 40
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHU</td>
<td>Air Handling Unit</td>
</tr>
<tr>
<td>ASHRAE</td>
<td>American Society of Heating, Refrigeration and Air Conditioning Engineers</td>
</tr>
<tr>
<td>BMS</td>
<td>Building Management System</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined Heat and Power</td>
</tr>
<tr>
<td>COP</td>
<td>Coefficient of Performance</td>
</tr>
<tr>
<td>CPP</td>
<td>Critical Peak Pricing</td>
</tr>
<tr>
<td>DCP</td>
<td>District Cooling Plant</td>
</tr>
<tr>
<td>DCV</td>
<td>Demand Controlled Ventilation</td>
</tr>
<tr>
<td>DES</td>
<td>District Energy System</td>
</tr>
<tr>
<td>DHC</td>
<td>District Heating and Cooling</td>
</tr>
<tr>
<td>DLC</td>
<td>Direct Load Control</td>
</tr>
<tr>
<td>DRM</td>
<td>Demand Response Management</td>
</tr>
<tr>
<td>DSM</td>
<td>Demand Side management</td>
</tr>
<tr>
<td>EDRP</td>
<td>Emergency Demand Response Programs</td>
</tr>
<tr>
<td>ETS</td>
<td>Heat Transfer System</td>
</tr>
<tr>
<td>IAQ</td>
<td>Indoor Air Quality</td>
</tr>
<tr>
<td>kW</td>
<td>Kilo Watts</td>
</tr>
<tr>
<td>kW_{el}</td>
<td>Kilo Watts Electrical</td>
</tr>
<tr>
<td>kW_{th}</td>
<td>Kilo Watts Thermal</td>
</tr>
<tr>
<td>LC</td>
<td>Load Curtailment</td>
</tr>
<tr>
<td>MW</td>
<td>Mega Watts</td>
</tr>
<tr>
<td>MW_{th}</td>
<td>Mega Watts Thermal</td>
</tr>
<tr>
<td>PCM</td>
<td>Phase Changing Materials</td>
</tr>
<tr>
<td>RTP</td>
<td>Real-Time Price</td>
</tr>
<tr>
<td>SOP</td>
<td>Standard Operating Procedures</td>
</tr>
<tr>
<td>SSM</td>
<td>Supply Side Management</td>
</tr>
<tr>
<td>TES</td>
<td>Thermal Storage System</td>
</tr>
<tr>
<td>TOU</td>
<td>Time of Use</td>
</tr>
</tbody>
</table>
1. Introduction

It is generally accepted that cities are a platform for the development of civilizations in the history of human beings. A city is a combination of people and various socio-economic systems which function together in order to meet the needs of the human beings. The major socio-economic systems can be divided as people, energy, environment and economics and the relationship of these systems are inherently very complex. Energy is vital for survival of people and economy but at the same time its usage has great impact on environment too. Rapid economic and social developments and advancement of technology in the last few decades improved the life style and living conditions, and changed the habit of people, consequently, increased the demand of energy services in residential, commercial and industrial sectors of the cities (Lindmark, 2005). This problem has been deepening with rapid growth of cities around the world.

More than 50% of the world population lives in urban environment. Urbanization is one of the primary causes for many problems such as depletion of natural resources and environmental degradation (NAP, 2010). The main drivers of future city development are population density and sustainability (Energy, Environment and Economy). In many mega cities around the world, mixed-use development is becoming increasingly essential for the creation of an attractive and sustainable environment that promotes economic vitality, social equity and environmental quality (Cheah, 2011).

Therefore, future cities will have smart energy systems (intelligent and integrated energy systems) with the following characteristics.

- Coexistence of multiple networks such as electricity, DHC and Gas networks.
- Complete management of all district energy systems under one entity
- Virtual grouping of buildings to plan and control the energy consumption
- Advanced communication infrastructure for smart energy management
- Energy demand and supply with central demand control application
- Distributed demand control application (district controller) and home automation gateway

As mentioned above, technology development and innovation have improved the living condition of people. Providing thermal comfort is one such example where technological development and innovation have made it a common feature any urban environment. Demand for cooling has been increasing around the world for last couple of decades due to the various reasons, and it is continuing to increase in the future particularly in developing countries.

Figure 1-1 shows the growth of cooling energy in Helsinki, most northern capital in the world. Climatic condition of Helsinki demands heat energy throughout the year for space heating. Despite short summer, cooling energy demand increases due to diversified applications. If this is the case for a city with short summer period, we can imagine what would be the scenario for city in warm and hot climatic region.
For instance, in Dubai 60% of peak electrical power is contributed by cooling demand during summer months (DEWA, 2010). Refrigerant technologies including air conditioning presently account for 15% worldwide electrical energy use (IIR, 2010). Most refrigerants that are used for cooling are predominantly depleting Ozone layer and/or Green House Gases (GHG) and contribute to the climate change when released to atmosphere.

1.1 Cooling Demand in Mixed-use city development

Traditionally, the cooling demand has been met by decentralised, electrically driven appliances. Ever increasing cooling requirements, especially during summer, increase peak demand of electricity and push electrical systems to their limits thus increasing the risk of outages. If the traditional, decentralised approach to cooling continues to grow, it will require massive expansion on electrical energy system. Such an attempt would impact the environment and accelerate climate change consequently affect the both economy and built environment of urban development.

District Cooling (DC) is an innovative alternative approach to provide the comfort cooling. DC reduces the impact on the environment and to the electricity supply infrastructure and provides opportunities for the energy business, its customers and society (Potter, 2004).

A DC system is a district thermal energy network that produce and circulate chilled water through insulated pipes to serve commercial, residential, institutional, and industrial energy needs such as space conditioning and industrial processes (IDEA, 1985). DC is becoming an essential infrastructure in modern city development owing to many benefits compare to its counterpart. Figure 1-2 shows the schematic diagram of a district cooling system. The supply side consists of chilled water production, bulk transmission and distribution. The demand side results from consumption to support the economic and non-economic activities. Water is used to extracted the heat from customer installations and its is rejected to atmosphere.
1.2 Demand Management Problems

The supply side and the demand side always should ideally be in balance. Production and distribution infrastructures of a DCP have been planned, built and operated to meet the anticipated customer demand. For this reason, peak demand, which is the maximum demand for cooling over a specified period of time, has been the focus of the industry for many years. For any energy system, the period of peak load is shorter than base load but capital and operation cost of peak load is much higher than the base load case.

Peak load problems occur basically when production and distribution capacity are insufficient to meet the demand during peak load hours. This is a common problem for any energy system including DC. This results in an imbalance in supply and demand. Traditionally, the peak load problems are addressed through supply side, for instance, by expanding the system capacity. The drawback of traditional load management is larger investment, greater energy losses, high distribution costs etc. Consequences will be greater in the event of system failure.

Furthermore, the negative impact of peak load is increase of peak electricity demand (Lindmark, 2005). Reduction of electrical energy consumption is an important operational strategy of DCP. Use of renewable energy or free energy ensures reduction of electrical energy consumption. Most of renewable energy sources can be used directly for producing cooling. However, problems associated with renewable energy sources is a hindrance to reliability of a DCP.

Traditionally, customer demand of almost all the energy systems are met by utilities by taking action on utility side of the meters and this is called as Supply Side Management (SSM). SSM can be defined as “Activities conducted on the utility's side of the customer’s meter. Activities designed to supply electric power to customers, rather than meeting load though energy efficiency measures or on-site generation on the customer side of the meter” (NCSEA, 2011). Supply-side management (SSM) ensures the generation, transmission and distribution of energy are conducted efficiently. The term is used mainly with reference to electricity but it can also be applied to actions concerning the supply of other energy resources such as fossil fuels and renewable energy sources (SSM_UNIDO, 2011). This definition is applicable to any energy system including district cooling system. DCP uses SSM principles for demand management.

Supply side management options require increase in capacity hence increase of capital and operational expenditures and also, tends to have adverse environmental consequences. Peak load capacities have to be reserved to mitigate the problems of energy security. Peak load reserves are critical for thermal dominated
energy systems where rise in consumption is high or quick. Thermal dominated energy systems are the ones where major proportion of peak load constitutes thermal loads. Associated capital and operational cost are high owing to the nature and ability of these reserves to match the fluctuations during peak-load condition.

Conversely, Demand Side Management (DSM) deals with the customer side of the utility meters and defined as “Activities, programs, or initiatives undertaken by an electric power supplier or its customers to shift the timing of electricity use from peak to nonpeak demand periods. DSM includes, but is not limited to, peak load management, electric system equipment and operating controls, direct load control, and interruptible load” (NCSEA, 2011). Demand side management programs aims to change customer load shapes and reduce the total cost of energy for program participants (IndEco, 2003). Traditionally DSM is applied to the electrical energy nevertheless the principle is applied any energy system.

The practical effectiveness of some demand-side measures often depend on the cumulative actions of individuals and it makes DSM uncertain in some cases. However DSM brings more benefits to energy systems than SSM. Significant cost benefits together with reduction in emissions are the two areas which SSM have failed to capitalize on.

Since electrical grid and DCP have many common aspects as far as operation concern principle of DSM can be applied to load management of DCP too. Opportunities for reducing energy demand are numerous in district cooling industry and investment requirement is low compare to its counterpart. District cooling technology is more beneficial to Middle Eastern region where 60-70% of electrical peak demand accounts for cooling loads (David Hayes, 2010 & Daniels, 2011). It could help to reduce the peak load thus environmental emissions. District Cooling was introduced in this region latter part of last century. However the growth is not as expected.

If we consider UAE as an example, DCP contributes only 10% of total cooling demand. There are numerous reasons affect its growth. Poor planning is one of the primary reasons. Most DCPs are developed by real-estate developers. The boom in the real-estate sector during 2000-2007 created a huge demand. The developers considered only speedy return of capital invested by delivering the real estate assets as quick as possible. Most of the developers preferred installing stand alone system as DCP need at least 18 months to complete the construction. Few developed DCP using all electrically driven chillers but without thermal storage facilities. Availability of water is another reason; water is neither free nor cheap as in the other region. The real-estate crash, increase of fuel cost together with all the other factors explained above increased the cost of operation hence tariff rate. Customers no longer willing to pay more as they think it is expensive compare to stand alone units.

## 1.3 Research Objectives

The objectives of this paper are to:
1. Investigate the applicability of demand response program in the district cooling plant of a mixed use city by investigating behaviors that are prevalent during the peak hours and behavior modification likely to be adopted.

2. Provide recommendations and implementation frameworks based on DRM principles for managing customer demand in mixed-use city development.

The expected outcomes of this thesis are:

1. Demand Response model of a DCP for managing demand especially peak demand and
2. Verification of the model using actual building load profiles for different building types that would comprise a mixed development as well as a specific case of a mixed development.

Application of DRM concept is far advanced in electrical energy systems which undoubtedly, is most preferred form of energy in the modern world. DRM system is considered to be a critical infrastructure component to control, operate and monitor an electrical grid especially Smart Grid.

Demand response is defined as “changes in electricity usage by the end-users from their normal consumption pattern in response to changes in price of electricity over time, incentive payment designed to induce lower electricity use at times of high wholesale market price or when system reliability is jeopardized” (USDOE 2006). DRM is used to counter the challenges related to conventional peak load management. The benefit of DRM includes cost reduction, improved environmental sustainability, increased supply reliability and market efficiency, customer service improvements and market power mitigations (Gyamfi, 2010). Demand of electrical energy is closely connected with the demand of alternative forms of energy such as heating, cooling and mechanical energy. Therefore, application of DR concept must reach far beyond the electrical grid and include all interconnected district energy systems (Siemens 2010).

During design phase of a DCP, precise estimation of the cooling demand of all consumers is not feasible. Demand is determined by prospective population, climatic factors, types and distribution of the buildings, surveys and consultations. Always there is a mismatch between predicted and actual load profile. Consequently this mismatch is clearly visible during operational phase of the plant.

The demand management especially peak demand management of a mixed use city is more complex as the user behavior is quite different from user to user. For instance, residential user behavior is different from retail stores in a mall or commercial offices due to difference in use and occupancy of the facilities. Figure 1-3 shows the normalized cooling load profiles, of major five types of buildings in the Hong Kong city during summer months (Chow, 2004). The building types include commercial offices, residential, retail shops, hotels and mass transit railway (MRT) stations. The actual profiles determined by the total area of the each sector. From the figures we can observe that;

- Weekday profiles are different from weekend profiles even Saturday and Sunday profiles also different from each other.
- Peak load of each building type appears at different time periods implies multiple peaks in a day.
- The load profile between each building type is significantly different.

Figure 1-3: Daily cooling-load profiles for three day-types in a summer month (Chow, 2004).

Moreover, cooling demand is strongly dependent on the seasonal variation of climatic conditions (temperature, solar irradiation and humidity) (Söderman, 2007). The combined effect of human behavior and climate conditions make demand to change significantly from moment to moment. In most of the cases, utilities have no control over customer assets that lead to inefficient consumption or wastage of energy.

Climatic factor, in many cases, would not change shape of the weekly load profile significantly but systematically raise or lower the magnitude of profiles. Load profile of a city in Cairo, shown in Figure 1-4, consolidates this observation. The building types include residential, commercial offices, retail mall, hospitality services, leisure and entertainment and schools. According to the DCP designers, seven load profiles of different buildings were used to generate cooling load profiles of the DCP.

Here, shape of the profile is similar for all the seasons. From the graph, we can observe that cooling demand is at maximum during summer months. The peak demand ratio between extreme months is almost double. If SSM is being adopted for load management then we need a cooling plant with minimum capacity of 10,000 TR and the plant at its maximum efficiency during few hours of a year compare to annual operating hours.

Conversely, if DSM strategy, for instance thermal energy storage, is being applied for load management then the load shape can be modified by filling the valley and plant capacity can also be reduced.
considerably. However optimum size of the storage capacity is the question we need to answer. If the storage is optimized to meet summer peak then the capacity will be underutilized during the rest of the year especially during winter. This results in increase in capital investment and reduction in operational cost.

TES will help to change the load profile but the peak demand remains same. However, application of DRM principles with or without TES would result in desired load profile. The peak can be clipped and valley can be filled by changing the behavior of the customers.

DRM solutions will bring benefits to utilities, customers and the environment. For utilities, it can reduce peak demand, cost of operation and helps to integrate customer devices to maintain and manage the active records. Reduction in peak demand eliminates the need of building new generation capacities which usually incur higher capital and operational costs (Freeman, 2005). Moreover, peak demand reduction improves system security and enables operators to work with flexible resources to meet contingencies. These benefits results in reduction of cost of operation.

![Average daily combined cooling-load profiles of all the building types for 12 months](image)

Figure 1-4: Average daily combined cooling-load profiles of all the building types for 12 months (CFC_DCP, 2010)

As customer relation is paramount for achieving demand response objective it make possible integration and management of customer loads and information related to energy use. On the other hand, for customers, it can reduce energy usage hence the cost, increase awareness of energy information and helps to conserve the energy. For environment, it can improve efficient use of resources like water and reduce CO2 emission to the atmosphere. DRM can function as a tool for achieving a more sustainable operation of DCP.
1.4 Methods

Literature survey and case study are the methods used to achieve the thesis objectives. They were completed in two steps. In first step, literature survey of periodicals, conference proceedings, and research reports were completed. In second step, a case study was conducted. The goal of the case study was to assess the DR potential in managing demands especially peak demand in a mixed use development. The results of the literature survey and case study are described below.

1.4.1 Literature survey

Selected literatures have been reviewed to identify information, methods and ideas that are relevant to this thesis. The selected literature cover the following areas: mixed-use city development and their cooling demand, district cooling technologies, demand management of district energy systems, demand response management and information and communication requirements.

According to the literature survey, cooling demand has been increasing for last couple decades and contributes to 15% of worldwide electrical energy use (IIR, 2010). Demand increments have been met by traditional decentralized cooling technologies which use electricity as driving energy. Consequently, increase of cooling demand creates many peak load related problems electrical systems thus increasing the risk of outages. This approach would require massive expansion of the electrical energy system hence would increase pressure on both economy of utility operation and environment. Therefore, decentralized cooling is not sustainable in long run.

DCP is an innovative and alternative method for meeting cooling demand (Potter, 2004). DCP eliminates negative impacts of vapour compression system driven by electricity on individual buildings. However operation especially demand management of a DCP is subjected to many challenges due to the many problems such as system reliability, energy efficiency, long response time etc. results in supply-demand imbalance.

Demand side management is very popular technology used in electrical grid primarily for meeting the demand without changing supply conditions. DSM is not so popular concept in DCP operation though it has the potential to deliver many benefits to utility and customers as well. However energy storage, an important DSM objective, is being used for load management. Unlike electrical energy thermal energy can be stored at relatively low cost. Numerous studies have been carried out on thermal energy storage. Thermal storage systems primarily shift electrical demand to off-peak periods hence avoiding peak demand charges. It increases the possibilities of utilizing renewable energy sources and waste heat for cooling generation (He, 2004). Benefits of thermal energy storage solely go to utility operators but not to consumers.

Only few studies have been carried out on application of DSM concepts for District Heating system operation. As operation of DH systems is similar to DC systems in many ways and most of DH plants have been operated together with DC plants. Therefore findings from these studies are applicable to DC
system as well. Demand management is a control problem where operational optimization (maintaining intended comfort level at minimum cost) is the ultimate objective. Optimal control requires load control of the installation and flow of information across boundary (Meulen, 1988). Wernstedt, (2005 & 2007) did few studies on demand management of DH system using multi-agent system. But these studies aimed at distributed control of district energy systems.

Sitting on top of all these studies, the work presented in this Thesis is the first to provide a study of Demand Response Management as applied to DCP.

DR is a subset of DSM and adopted by electrical network operators for peak load management. As DR has its roots in the electrical grid, a comparative study has been done to develop a demand response analogy to DCP as it resembles an electric grid (can be considered as a micro-grid) in many aspects. DR principles can be applied for DCP operation especially for peak load management. Applicability of DRM for DCP operation is discussed in chapter 3.

1.4.2 Case Study

Developing theoretical concepts and models will not benefit anyone unless we find real-life application. Operation of a DCP plant in Dubai is subject to many challenges: the scarcity of water and electricity are two of them. Water and electricity are critical elements for efficient operation of the plant. Load control strategies need to be reviewed to reduce water and electricity consumption. Therefore, data from mixed-use city in Dubai was used to assess DR potential for peak cooling demand reduction using concepts and model developed in this research work.

Case study was divided into two phase; research and analysis. Research work includes finding out of what has been done before about the case site on DCP, and interview of stakeholders. However, city management of the selected city had decided to explore the possibility of applying DRM techniques for load management harnessing available information on energy usage and its impact on the city operation were used as fundamental information for the case study. The collected literatures include energy audit reports, previous case studies on energy performance of buildings and equipments, energy and cost data and drawings. Considering business issues, no survey, interview or any other direct interaction with their tenants were not allowed to collect the information. This made limited the exploration of full potential of DRM in a mixed use city development.

We initially focused towards the need and opportunities of DRM for DCP operation. Study showed that there was a strong need for DRM with many opportunities and benefits. During the analysis phase, the information collected in the first phase put together and analysed to understand the applicability of DRM in the DCP operation. The detail of the case study has been presented in Section 4 onwards.
1.5 **Layout of the Thesis**

This thesis is divided into seven separate yet inter related chapters to present the research finding in more précised and organised manner. Chapter 1 to 3 is dedicated to elaborate findings from literature survey and chapter 4 and 7 discusses the case study and its outcome.

Chapter one describes the background of the thesis, research objectives and methods to achieve the objectives. The background study covers the challenges and issues associated with the operation of energy systems in general, and the DCP in particular. The focus of this thesis is to identify the requirement for DR Management for a DCP in mixed use city.

Chapter two and three present the findings of the literature search. Chapter Two illustrates the principle of a DCP. This chapter concerns mostly on role of DCP in a mixed use city development. Enabling technology, operation and load control are the major subtopics of this chapter. Each subtopic is explained in detail.

Chapter three is a comparative study of Demand Response Management in electrical networks and DCP. Demand Response has wide spread application in electrical grid system and it spans up to national level. Still, as energy systems, electrical and DCP have similarities in managing demand across various customers. This section elaborates the similarity between energy systems as far as DRM concern.

Chapter four discusses the case of a typical mixed use city development and the potential for implementing DRM for demand management. The case study includes Energy Use Behavior (Cooling Load) and its variation in the Mixed Use City and DR initiatives that can be deployed to DCP of a mixed-use city. Applicability of DR methods is limited to residential and commercial sectors only.

Chapter five discuss the potential general strategies which could be adopted to implement DRM concepts in a mixed use city development. The strategies should include both demand and supply side operations. Changing use behaviour is the primary strategy for demand side management especially peak load management where as supply side should consider economic control and distribution system operations and optimization. A generic DR model has been proposed as a part of implementation strategy. Also this section discusses possible DR objectives which can be adopted for changing user behaviour.

Chapter six outlines the information and communication requirements needed to automate DRM. ICT infrastructures are vital for success of DR for any energy network. Communication infrastructure and enabling technologies are paramount for successful implementation of DRM in a district energy system particularly DCP. Despite integration of customer installations and control are challenging tasks, the technology development making them possible in near future.

Chapter seven summarises the research undertaken and highlights the main issues addressed and includes subjects for future studies. The Demand Response concept can be extended to DCP operation. Implementation strategies should be done in three phases. The first phase involves gathering information related to consumption profiles. This would be possible with the help of Smart BTU meters but reliable
communication should be ensured. Information gathered during first phase can be analysed to demand response models in phase two including the supply-side operation and management strategy. In the third phase customer systems and supply systems should be integrated to yield desirable results.
2. **District Cooling Plant**

This chapter describes the functional and operational aspects of DCPs in mixed use city development. DC technology is advantageous in hot and humid climatic regions (Chow, 2004). DCPs are located in places like dense urban settlements, universities, hospitals, military bases and airports. DCPs always serve cluster of buildings with different use and occupancy with common or separate owners. DCPs are more preferred method for cooling buildings in above said environments owing to the fact that they are a secure and reliable energy supply. As a district energy system, DCP is a candidate to participate in DRM programs.

### 2.1 District Cooling Plants (DCP) and Future City Developments

Energy sustainability is the top most priority of the global energy agenda. Integration of available technologies, best practices and energy policies will pave the way to sustainability that may help to decrease the environmental impact of energy sector, while providing an adequate standard of energy services (Massimilian, 2010). At present, larger cities worldwide account for 75% of energy demand and generate 70% of GHG emissions (Chow, 2004). Energy system created catastrophes in the environment in the foam of Climate change, environmental pollution and resource depletion. Most importantly these are the issues need to addressed under global sustainability context.

Development of sustainable energy system is the main drive of national energy policy of many countries now. Many metropolitan areas set strategic goals to develop city into a sustainable city without affecting the quality of life style. In many mega cities around the world, mixed-use development is becoming increasingly essential for the creation of an attractive and sustainable environment that promotes economic vitality, social equity and environmental quality (Cheah, 2011). These challenges created a paradigm shift in district energy system of cities (Massimilian, 2010).

The key challenges that the future district energy systems (including district cooling plants) have to overcome are:

1. **Sustainable Energy Systems**

   Cities are developing all over the world but developments are unsustainable. Increasing in demand for district energy services is followed by these developments. Having realised consequences of unsustainable development, regional and national governments enacted policies to encourage sustainable developments. Use of district energy services causes climate change through emission of CO₂ and depletion of natural resources. Climate changes is emerging as key issue in energy production, distribution and consumption of all the energy system and district energy systems are not
exceptions to this trend. Climate change is a main driver of national energy policy so the government wants the energy systems to be sustainable.

There are several barriers exist in developing and operating sustainable energy systems. They are technical, institutional and economic in nature. Nothing is sustainable if poverty, hunger and economic insecurity prevail in the city. Sustainability requires healthy, educated population with good sense of optimism (Schaffer, 2010). Future district energy system developers have to overcome these socio-economic barriers for sustainable operation.

2. Efficiency improvements from production to final end use

Energy efficiency is another area which plays key role in achieving sustainability. District energy systems are striving for energy efficiency improvements. Energy efficiency improvements will help to reduce capital and operational expenditure, and fuel use hence CO₂ emission.

However, energy efficiency is not only purely related to equipment technology in concern but also many other factors such as human behaviour. Therefore efficiency improvement should be approached from many directions and the improvement should be continuous one. In reality, continuous efficiency improvement in district energy systems is difficult task due to the involvement of many interconnected systems at different zone of a city. Moreover, continuous monitoring of efficiency is important keep the performance above required levels but lack of information and communication networks make this task even difficult.

3. Flexibility, stability and security of energy supply

Future DES should be flexible to adopt different form of energy sources which make the operation more economical and competitive in the market. An electrically driven system should be capable to extract energy from waste heat stream and utilize it for its operation by integrating its operation with some other energy system.

4. Interaction between supply and end-use

At present supply is adjusted to meet the demand and to maintain the balance. Future energy systems are expected to operate with a high proportion of distributed and intermittent supply sources. For the energy system it will be difficult and costly to ensure short-term security of supply if demand is unable to react to fluctuations on the supply side. Since most consumers connected to DES billed on fixed tariff rate they don’t get any incentive to alter their consumption pattern. This calls for more interaction between the supply and demand sides, which in turn would allow better matching of demand to intermittent supply (Larsen, 2005).
5. **System control and communication**

System control and communication infrastructure at all level are driving rapid and ongoing development in the energy sector. The challenges related to system control and communication requires attention in the following areas (Larsen, 2005).

Operational aspects: control system has to play a major role in meeting the expectations of security of supply robustness and vulnerability. On demand side controlling of intelligent loads need sophisticated and intelligent control systems.

Communication infrastructure: Timely, accurate and secure communication infrastructure is essential to the smooth running of the markets and tighter couple of different energy systems.

Renewable energy mix: use of different energy sources especially large amounts of renewable energy (RE) to produce energy services is a challenge for control systems because of the temporal variation of many RE sources. Therefore control system will be much more complex for the future DES.

6. **Lack of integrated and closely coupled supply technologies**

The future DES would be operated using multiple supply technologies rather than single supply technologies as now. Central and distributed energy production and energy storage will be some of the key characteristic of those systems. These characteristic necessitate the integration and close coupling of supply technologies.

In this context, the energy system of future cities is going to be integrated and intelligent district energy systems. District Energy system is the centralization of utility services to serve several load points within a city. The District Heating and Cooling (DHC) systems are some of the most common form of District Energy systems found around the world. As the district energy systems are socio-technical in nature technical, economical and social factors will have significant influence in developing district energy system. District energy systems function as combined heat and power (CHP) plants. In this mode they generate heat, cool and electricity for customers while utilizing available fuels efficiently as shown in figure 2-1.
Cooling energy demand increases due to industrialization and enhanced standard of living. Energy policies, which driven by economical and environmental factors, demand decrease in use of fossil fuel and increased use of renewable energy. Increase energy demand and limited cheap energy supply makes supply of cooling energy more expensive. Ever increasing cost of energy and environmental impacts associated with energy systems are making the District Cooling Plants an inevitable infrastructure for new city developments and growing in popularity.

District cooling refers to coolant circulation through an underground distribution network between a central cooling plant and a district comprising multiple buildings. Primary components of a DCP are the central plant, the heat rejection system, the distribution network and the consumer substation (Chow, 2004). DCP plant commonly can be found in regions with tropical, temperate and arid climate conditions. Most common applications of district cooling in these regions are space conditioning and fewer industrial applications.

Chilled water is produced in a remotely located central plant using various cooling technologies determined by the fuel sources. Vapour compression and absorption are the two popular technologies typically used for producing chilled water. Vapour compression systems use electrical energy whereas absorption systems use heat energy from various sources as driving force to produce cooling. Absorption cooling is going to play a major role in developing sustainable energy systems where heat from various sources (Fossil fuel, Solar, Biomass and waste) can be utilized (Lindmark, 2005).

The chilled water produced in the central plant delivered to various customers through a closed loop distribution network, some time called as primary circuit. The Energy Transfer System (ETS) is individual buildings transfer the energy from primary to secondary circuit that circulates the chilled water with in the
building system. Thermal storage is an energy management strategy where cooling energy is stored to shave the peak of system demand and electrical demand. Chilled water, ice and PCM are the three technologies commonly used for thermal storage.

2.1.2 Benefits and Challenges

DCP provides many benefits to the system operators, consumers as well as to the environment (IDEA, 2005). Some of the benefits are:

1. Comfort and convenience for customer
   
   Increase the thermal comfort of the building by enabling better control of space temperature and humidity. Higher system reliability can be achieved compare to the stand alone operation. These two factors reduce the risk of operational liability of building owners. Eliminate the need of chillers on roof top makes the building noise free and save the space too.

2. Improve energy efficiency

   Total capacity of the chiller plant is smaller than the small individual chiller plant due to diversity of the loads. Large scale make possible of increase of efficiency in many areas that is not possible with small scale counterpart.

3. Fuel Flexibility

   Use of renewable energy and enhanced fuel flexibility, increase the efficiency of district cooling system and reduces the operating cost. More over fuel can be switched according to the availability and competitive at times.

4. Enhance environmental protection

   Smaller overall plant capacity together with improved efficiency reduces the refrigerant leak, GHG emission and use of natural resources like water. DCP plants employ more stringent emission control techniques than commercial buildings hence provide benefits to environment. District cooling is instrumental in phasing out of refrigerant like CFC and HCFC which deplete zone layers.

5. Reduce life cycle cost

   District cooling equipments are industrial type equipment which has higher life time and efficiency compare to equipment produced for commercial applications. Larger size enables to reduce the capital and operational costs.

6. Reduce electrical power demand

   Cooling load contribute significantly to the peak load of regional power system. DCP is helps to reduce peak demand of electricity grid. From the perspective of the electricity grid operator, with district cooling potentially serving dozens of buildings in a congested urban setting, there is potential
to shift many megawatts of peak electric demand from the power grid to absorption chillers, thermal storage or more efficient district cooling facilities (IDEA, 2005). From the capacity point of view, total capacity requirement of a DCP is always smaller than total capacity of individual equipments installed on single buildings. This result in reduction of total installed capacity of the electrical load associated with the HVAC operation hence reduction in peak demand of electricity grid.

However, there are many challenges and/or barriers which DCP systems have to overcome for their sustainable operation. The challenges and barriers can be grouped under three major areas as technical barriers, environment barriers and social and economical barriers.

1. **Technical Barriers**

DCP are conventionally designed and operated to meet the maximum peak demand. For any energy system, the period of peak load is shorter than base load but the cost of operation for peak load is much higher than the latter case. Larger investment, greater energy losses, high distribution costs are some of the drawbacks of this conventional method. Consequences will be greater in the event of system failure. For example, failure of DCP during mid day of summer season in the Middle Eastern countries some time may lead to disasters.

Sustainable operation of a DCP demands supply of integrated closely coupled renewable energy systems with intelligent control and communication systems. Unlike electrical grid networks, DCP has many gaps in these areas and the gaps have been explained in Section 2.1.

2. **Environment Barriers**

Scarcity of resources and emission to environment are some of the key environmental barriers which have to be overcome by DCPs. Clean water is vital for a DCP to be economically viable but in many parts of the world where demand for cooling energy is very high, water is a major concern, either scarce or inaccessible. In many cities of Saudi Arabia, water is a scarce resource whereas for cities like Dubai, water needs to be treated before using it.

Electrical energy requirements of DCPs are a key driver behind the significant increases in electrical peak load of a region, consequently, increases the air emissions. Solar powered – absorption chillers together with electrical chillers are the solution to reduce the peak demand but this option is subjected to availability of land resources. Recourse scarcity and environmental emissions are couple of key factors act as environmental barriers.

3. **Economic barriers**

Economic viability is the first barrier that developers have to overcome. There is no single business model available to model economic viability. One successful proven business model in one country could fail in another country due to policies and market challenges. Existing cooling system in operation of a customer is another barrier. Technical creativity, innovative energy efficient design and
engineering are the keys to overcome these barriers. When the cost of cooling reduces customers will adopt district cooling as the preferred method for cooling their facilities (Feature, 2007). Moreover, electricity and water infrastructures of the city need to be improved by local government agencies to meet to ensure need of DCPs. Budget pressures of local municipalities will slow down the development of DCPs.

2.2 District Cooling Technology and its Components

Cooling technology is the primary factor determines the operation and control of a DCP. There are several technologies are commercially available to suit various requirements of the operators. Vapour compression and absorption are the two widely accepted technologies both have its pros and cons.

The central plants, distribution network and consumers’ systems are primary components of a DCP. The central plant is the heart of the system where district cooling water is produced for distribution. The distribution network is used to circulate chilled water from central plant to consumer's system and back to central plant. Consumer's system which forms demand side of the system consists of heat exchangers and secondary distribution system. The details of different components and its functions explained below.

2.2.1 The Cooling Technology

Production of cold and extraction of heat are two sides of a coin. A cooling effect is produced when heat is extracted from a body by means of a thermal gradient. Though there are many technologies available for district cooling to suit market factors and customer demand, the selection of technology is mostly governed by development of sustainable energy market. Each technology has its own saving potentials which are tabulated in Table 2-1 in terms of Coefficient of Performance (COP) of whole system.

\[ COP = \frac{\text{Cooling Energy Received}}{\text{Electric Energy in}} \]

Equation 1

Table 2-1: COP of cooling technologies (Potter, 2004)
Cooling technology can be classified as vapour compression, absorption and free cooling. The source of energy for the vapour compression is typically electric power whereas heat is the source of energy for other two technologies.

1. **Vapour Compression**

   Vapour compression is the most commonly used technology for producing cooling in the world. Electrical energy is the primary energy source used in vapour compression cooling system. Mechanical work is applied to compress the refrigerant vapour which results in increase of temperature and pressure.

   Compressor, a condenser, an expansion valve and an evaporator, as illustrated in Figure 2-2, are the major components of vapour compression system.

   ![Simple vapour compression cycle](https://example.com/image1)

   **Figure 2-2**: Simple vapour compression cycle (Source: Bruned, 2009)

2. **Absorption Cooling Technique**

   The absorption technique is used to produce district cooling using thermal energy that is generally a waste in energy generation. Absorption cooling uses heat as primary driving energy not electrical energy as in the former case. Source of heat can be from waste heat from industrial processes, solar energy and bio energy. This system is simple with less moving parts. Figure 2-3 illustrate absorption cooling system.

   ![Absorption Cooling system](https://example.com/image2)

   **Figure 2-3**: Absorption Cooling system (Source: http://www.cenerg.ensmp.fr).

   The principle behind this technique is creating pressure differential using generator that resembles the function of compressor in vapour compression system. Other functions of absorption system are similar to vapour compression cycle.
3. Free Cooling

Free cooling refers to the extraction of energy required for cooling from natural sources. The free sources can be found in oceans, lakes or rivers, aquifers. The cool is transferred to distribution network via heat exchangers. Free cooling chillers are always used with other cooling technologies due to seasonal variation of source temperature.

![Free Cooling using sea water](http://www.cenerg.ensmp.fr)

**Figure 2-4:** Free Cooling using sea water (Source: http://www.cenerg.ensmp.fr).

### 2.2.2 The Central Plants

The central plant includes cooling equipment, power generation system, thermal storage and heat rejection system. The function of central plants is to produce cooling by extracting head from consumer loads. Different technologies have been used to produce cooling. Vapour compression and absorption are the technologies widely used. Free cooling is an emerging concept with considerable potential. The technical background of these technologies briefly explained below.

#### 2.2.2.1 The Cooling Equipment

The main component of cooling plant is chiller. Chillers can be classified based on the energy source and cooling technology used for driving the chillers. Most common type of used for district cooling applications are chillers are electric driven vapour compression chillers, heat driven absorption chillers and free cooling chillers.

1. **Electric Chillers**

   Electric chillers are vapour compression chillers and further can be divided as reciprocating, screw and centrifugal chillers. The sizes of reciprocating and screw chillers are widely used for capacities up to 400 kW. Therefore, these chillers are not suitable for DCP applications. Centrifugal chillers are available in sizes, most commonly, from 200 to 2000 kW. They have highest full-load efficiency among all chillers. These factors enable them to be a suitable candidate for DC applications.

2. **Absorption Chillers**

   Absorption chillers can be categorized as single-effect and double-effect chillers. Single-effect chillers have COP in the range of 0.6 to 0.75 and double-effect chillers have in the range of 1 to 1.35. It is obvious that double effects chillers are more efficient than its counterpart however single-effect chillers are beneficial where heat stream temperature is not high to drive a double-effect chiller. Capacity of the single-effect...
absorption chillers range from 100 to 1350 tons and double-effect chillers typically available in the range of 100 to 1500 ton (Sakraida, 2009). Capital costs of absorption chillers are higher than electric-driven chillers but operation and maintenance cost is relatively lower. Absorption chillers are the ideal options for CHP plants where electricity and cooling is generated. Advantages of absorption chillers include:

- Simple and few moving parts
- Low operation and maintenance cost due to use of cheap waste heat
- Reduced electricity consumption
- Reduced emissions and fuel saving
- Lower noise and vibration

Figure 2-5: Single-effect and double-effect chillers (Sakraida, 2009).

3. Free-Cooling chillers

Free cooling involves utilizing natural cold sources such as water from lakes, seas or ambient air to produce district cooling. When the temperature of the cold source is below set point of chilled water supply temperature, the water or air is used to cool the water circulating in the district cooling network by means of heat exchangers. Snow collected in winter can also be used for free cooling.

4. Combined System or partial free cooling

Combine system involves integrated production of cooling using electric, absorption and free cooling techniques with systematic operation schedule. Disadvantage of free cooling is its availability with seasons which makes it unreliable and demands use of other technologies. Advantage of combined system is increased efficiency in traditional cooling system.

2.2.3 The Distribution Networks

The distribution network is closed network of insulated pipes that circulates chilled water from central plant to customer substations and back to the central plant. The distribution network is similar to the DH
system with two separate pipes for supply and return. The pipe network has two sections, trunk and branch and the buildings are connected through branch pipes from trunk lines. The supply temperature is normally between 5-7 °C and sometime an ice mixture at 0 °C also used. The chilled water supplied to the customer extract the heat load of customer from air stream. This causes a rise in temperature of the chilled water and return pipe carries warm water at temperate 12-17 °C. The return water is chilled again when send through the central plant.

This is the most expensive part of any DCP. The low temperature difference makes district cooling distribution expensive, so district cooling networks is feasible in areas with high cooling demand densities, such as mixed-use city and commercial areas.

### 2.2.4 The Consumers’ Systems

The consumer system primarily consists of substations (customer intake stations), secondary cooling circuits and air handling units (AHU) and metering and control panels. Substations are heat exchangers and used for extract heat from hot stream (usually air) to cold stream (usually chilled water). Hot stream carries heat energy from conditioned space and/or process cooling applications. There is wide range of consumers connected to district cooling. Type consumers can be grouped under three major classes namely domestic, commercial and industrial.

Domestic consumers utilize the cooling for maintaining thermal comfort in their dwellings. Commercial consumers utilize cooling to provide thermal comfort to in-house staffs and visitors. Thermal comfort is vital for business operation as it affects productivity and customer satisfaction. Industrial consumers need cooling for both industrial processes and comfort cooling. Industrial processes generate heat that should be removed promptly for optimal performance. District cooling is an ideal option for industries to meet process cooling demand as it eliminates need for separate cooling system within the facility.

Metering and control systems are usually linked to a central control station through communication networks.

### 2.2.5 Thermal Energy Storage (TES) system

The fundamental difference between electrical network and district cooling network is the capability of energy storage. Electrical energy cannot be stored in its original form but thermal energy can be stored in the form of sensible or latent heat. Major storage mediums are chilled water, ice and PCM. TEC can be effectively used for peak shaving that is one of a DSM load shape objective. TES also brings flexibility and reliability in the supply of cooling energy.

Advantages of a well-designed and correctly operated cool thermal storage are:

- Installed capacity of the plant can be reduced (both chiller and cooling tower)
- Make it possible to utilize low cost off-peak electricity to drive cooling production
- Better energy performance than a conventional system without TES
- Increased efficiency due to operating near to the design points
- Flexible operation as storage makes it easy to operate variable flow systems by acting as a buffer between the consumption and production
- Higher reliability as they do not totally depend on instantaneous cooling production. In cases of short shutdown of a chiller it is possible to serve critical areas for a period of time from storage (IEA_DHC, 2002).

TES increase the use of renewable energy sources and absorption cooling for producing cooling at higher capacity. In arid climate reasons cooling has been used to beat the summer heat without realizing the fact that potential of solar energy to produce cooling. TES can be charged by Solar driven absorption systems and the energy can be used for cooling throughout 24 hours of a day.

### 2.2.6 Operation and Control

Operation of DCP is affected by many factors and some of them are listed below.

1. Infrastructures in place (Central Plant, Building type and Distribution Networks)
2. User Behaviours Demand Profile
3. Supply Options
4. Economical factors
5. Environmental Factors

User behaviour is the most important factor among all of the above because environmental sustainability is primarily about changing user behaviours (Ross, 2008). Rest of the factors, most of the time, remains unchanged. User behaviours play a major role in determining operational strategies.

Operation strategies of a DCP include energy efficient operation, CO₂ reduction and water conservation. COP of electrically driven direct chilled water production is in the range of 5.0-5.5 kWth / kWel compare to the commercial buildings' average COP benchmark of 1.5-3 kWth / kWel (DCSS, 2011). The ability to operate the District Cooling System at a higher energy efficiency level depends on loading chillers at or close to their design capacity at their most energy efficient loading level. The higher energy efficiency in chilled water production has led to an annual reduction in equivalent CO₂ emissions.
3. DRM-Electrical Analogy to DCP

This chapter mainly reviews the background of DRM in electrical network. The review includes its principle of operation, needs, implementation options and benefits to customers and utilities. Demand for energy has been steadily increasing from year to year due to development of economy and technology. The old strategy in meeting the demand was building new power plants and expanding transmission and distribution capacity. This is called Supply Side Management (SSM). However this strategy failed to capitalize due to constrains such as energy security, economy and environmental problems. Soon it was realized that change of energy use behavior in the demand side could solve the problems of load management and now it is called as Demand Side management (DSM) (Hong, 2009).

Section 3.1 discusses the application of DR in electrical grid. The aim of this section is to introduce concept and implementing strategies of DR in managing loads especially peak loads. Applicability of DR to DCP is analyzed in details in the proceeding section with great attention to peak load management.

3.1 Demand-Side Management

3.1.1 Demand-Side Management Concept

Six load shape objectives are classified for DSM programs as illustrated in Figure 3-1 which further can be classified as basic level (peak clipping, valley filling and load shifting) and advanced level (strategic conservation, strategic load growth and flexible load shape) (Hong, 2009).

Figure 3-1: Six load shape objectives for load management program (Hong, 2009).
1. **Peak clipping**

Peak clipping is one of the traditional load management, used to reduce the system peak loads during specific period of time. Direct load control is the strategy generally used to achieve peak clipping. Aim of the peak clipping is to reduce system operation cost and dependency on critical fuels of economic dispatch (Hong, 2009). Figure 3-1 (a) shows the resultant curve after peak clipping.

2. **Valley Filling**

Valley filling is the improvement of system load factors by developing loads during off-peak periods. This may be particularly desirable where the long-run incremental cost is less than the average price of electricity (Hong, 2009). Electrical based energy storage is a common method used by utilities to accomplish this load shape objective. Figure 3-1 (b) shows the resultant curve after valley filling.

3. **Load Shifting**

Load shifting can be regarded as combination of peak clipping and valley filling. This objective reduces the loads during periods of peak demand while at the same time builds the load in off-peak periods. Popular applications include thermal energy storage and pumped hydro. Change of load shape through load shifting objective is shown in Figure 3-1 (c). Load shifting will not necessarily increase sales of electricity.

4. **Strategic Conservation**

Strategic Conservation is a relatively recent and advanced load management concept. It decreases overall demand by improving efficiency of energy use. It is a utility driven program aimed to reduce the load along the load curve. This results in change of load shape as shown in Figure 3-1 (d). The resultant load curve tells us that the demand including peak demand reduces during the operating cycle. The benefits include reduced cost of operation and postponing of construction of new plants.

5. **Strategic Load Growth**

Strategic Load Growth is another advanced load management option used to increase load level by electrification during certain time period or certain customer types. Under this option customers are encouraged by utilities to adopt electro-technologies either to replace inefficient fossil fuel equipments or to improve productivity and quality of life. Load growth increases the overall sales and reduces cost of energy services by distribution of fixed cost over a larger customer base thus benefiting the customers and utility (Hong, 2009). This objective changes the load shape as shown in Figure 3-1(e).

6. **Flexible Load Shape**

Flexible Load Shape is the last of the advanced forms of load management options. This concept is related to reliability of energy supply with the possibility of variable controlling customers’ equipments as in load interruptible/curtailment programs (Hong, 2009). This objective changes the load shape as shown in Figure 3-1(f).
3.2 Demand Response

Demand Response (DR) is a subset of demand side management (DSM). The objective of DRM is load management on demand side by using economical and technical measures to reshape the load profile into desired one (Hong, 2009). This mechanism has arisen in recent times to describe a set of pricing structures, programs, and related technologies and services that provide options for customers to change their electricity demand in response to signals from the electric utility industry (He, 2004).

3.2.1 Why is Demand Response Important?

Challenges and uncertainties of an electrical power system make the DR a valuable asset for utilities. When we look at the power system, we can observe three fundamental characteristic and they can be classified as challenges.

1. Electricity cannot be stored economically, so supply and demand must be maintained in balance in real-time.
2. Operating condition of grid changes significantly from day-to-day, hour-to-hour, and even within moments. Load flow also changes quite rapidly and unexpectedly, and resulting mismatches in supply and demand can threaten the integrity of the grid over very large areas within seconds.
3. Investment is highly capital-intensive, and generation and transmission system investments have long payback periods and multi-decade economic lifetimes.

These challenges of electric power systems constantly require that power grids be planned and managed in advance to ensure that the system can operate reliably in real time despite the many uncertainties. Some of the uncertainties are future demands, fuel sources, asset availability and grid conditions (USDOE, 2006). According to California Energy Commission, to build peaking power plant to meet peak load costs US $ 600/kW whereas implementation of demand response measures costs only US $ 100/kW. This alone is a good indicator why demand response is more popular for smart grid applications.

The demand response may consist of any combination of the following four intertwined actions either by manual actions or by some automated system (Roscoe, 2004 and Chuang, 2008);

- Energy reduction during peak load periods (Peak Clipping)
- Filling of valleys of off-peak demand to improve load factor (Valley Filling and Smoothing)
- Shifting of load from peak to off-peak between time of day or season (Load Shifting) through embedded and domestic storage schemes
- Inducing demand variations or desired load shapes determined in operational timeframes (Flexible load growth)

These actions are applicable to all the energy systems including district cooling however scalability is differs from systems to systems. Load shifting using large central storage schemes are very popular technology in district heating and cooling system. But in electrical system, this option is limited to
domestic schemes. Applicability of these actions towards district cooling plants is discussed in proceeding sections.

### 3.2.2 Types of Demand Response

Industrial users consume thousand of kW and they generally identified as large scale consumers. On the other hand commercial and residential sectors can be identified as medium and small scale consumers as far as grid capacity concerns. Hence, the types of demand response programs also vary from sector to sector. However, Type of Demand Response can be broadly classified as load responsive and price responsive both provide economical benefits to the customers.

#### 3.2.2.1 Load Responsive Programs

Sometime these programs are called as incentive based DR programs. There are several load responsive programs operative in the electricity market across the globe. There are several variations between the economic models of these programs. However these programs can be grouped under four major categories as explained below.

1. **Direct Load Control (DLC)**
   DLC allows the utility to control the customer loads remotely subject to a mutually agreed contract. Under this agreement, utilities shed customer loads by switching the equipments on and/or off directly. In return, the utility provide incentive payments to the customers. These equipment include air conditioners, lighting system and water heaters. This program targets the small commercial residential consumers usually with less than 100 kW of demand (Hong, 2009).

2. **Load Curtailment (LC)**
   These programs are designed to provide rate discount or bill credit to the customers for agreeing to reduce load to pre-specified level during system contingencies. The utility must inform the customers before the curtailments events take place. Customers those who are not in compliance with the agreement usually are penalized in the form of very high tariff rates. This program traditionally has been offered to largest industrial and commercial customers (DOE, 2005).

3. **Emergency Load Responsive (ELR)**
   In these programs, customers are paid incentives for measured load reduction during emergency conditions. The incentive rates are very high for these programs and levy no penalties for non compliance of the enrolled customers. These two factors make the programs very attractive particularly among industrial customers (DOE, 2005).

4. **Capacity Market Programs (CMP)**
   In capacity market programs, customers commit to provide pre-specified load reductions when contingencies arise and subjected to penalties when they do not respond. Customers typically receive notice of events a day ahead. Incentive payments usually consist of upfront reservation payments,
determined by capacity market prices, and additional energy payments for reductions during events (DOE, 2005).

### 3.2.2.2 Price Responsive Programs

1. **Time-of-use (TOU)**
   This is the basic type of price based DR programs. The unit price of energy varies with different time blocks. Generally, peak rate is higher than off-peak rate and it reflects average cost of energy generation and distribution during those time periods. TOU rates are in use for many years and found widespread use among large industrial and commercial customers.

2. **Real-time pricing (RTP)**
   Real-time pricing is a tariff option in which energy prices fluctuates hourly according to the changes in the wholesale price of energy. The rates are usually communicated to the customers a day or hour ahead basis. This program is recognized as the most direct and efficient approach to achieve DR objectives in electricity markets.

3. **Critical Peak Pricing (CPP)**
   CPP rate is a pre-specified high rate designed to use during critical peak period. CPP rates typically combined with either TOU or normal flat rate. CPP is called during system contingencies or higher wholesale market prices for limited number of hours or days during a year. The rate is 3-10 higher than the normal usage rate.

### 3.2.2.3 Voluntary Non-fiscal Methods

Demand profiles can be changed by purely voluntary DR methods. Although it is difficult to quantify its affects on load management cannot be ruled out completely. In the modern world, individuals as well as organizations are willing to alter their behaviour for the sake of environmental and/or economical interests. Promoting voluntary DR will bring benefits to utilities and customers as well. However information has to be disseminated for success of this method (Roscoe, 2004). Figure 3-2 summarizes the demand response programs described above.

![Figure 3-2: Classification of price based and incentive based Demand Response Programs.](image-url)
3.2.3 The Benefits of Demand Response

The benefits of demand response of electricity market include improved economic efficiency, improved security of supply, reduced price volatility and the incentive for the exercise of market power, reduced investment in peak generation. These benefits create variety of benefits and can be categorized under two main groups: benefits that accrue directly to customers and benefits on electricity market operation (Gyamfi, 2010). Direct and indirect benefits of DR programs are tabulated in Table 3-1 which was identified by Gyamfi.

Table 3-1: Direct and Indirect Benefits of Demand Response (Gyamfi, 2010).

<table>
<thead>
<tr>
<th>Direct Benefits</th>
<th>Indirect Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial benefits – customer bill savings and incentive payments earned through adjustment of demand in response to changes in supply cost or other incentives.</td>
<td>Market performance – reduces the ability of generators to excise market power.</td>
</tr>
<tr>
<td>Market-wide financial benefits - lower wholesale price that results from demand response due to avert of costly power generation that result in lower electricity rate for all customers.</td>
<td>Improved choice - customers have more options for managing their electricity cost</td>
</tr>
<tr>
<td>Reliability benefits – DR lowers in the likelihood and the consequence of forced outages that results in reduced financial costs and inconvenience to customers.</td>
<td>Reduce Emission – ability of supply mix and the way it is deployed, demand response may result in reduced environmental emissions.</td>
</tr>
</tbody>
</table>

As such, Demand-Response management solutions can be applied to DCP for sustainable operation. Large DR potential has been identified in district cooling systems but hardly researches been carried out to ascertain know how and the economical feasibility.

3.3 Demand Side Management of DCP

3.3.1 Electrical Analogy of District Cooling Model

Operation and control of a district cooling model can be explained using electrical power system analogy. This is vital as we are trying to do a relative analysis of electrical demand side management concept with DCP. The primary components in the power system are generating plants, transmission and distribution network. These components are controlled by sophisticated control system to keep the system service levels within limit. Voltage and frequency ideally should be kept constant however small variation is allowed. On the other hand, current flow is allowed to vary according to variation in load.
Central plants of DCP can be compared with power generation plants. At both plants energy is produced using various energy sources; power plants use chiefly chemical and mechanical energy as primary source of energy whereas district cooling plant consume electrical and thermal as driving energy sources. Distribution networks of DCP can be compared with transmission and distribution networks. Similarly, customer side of both the networks is similar in nature. Both have consumer substations and functions of them are analogues to each other.

Water pressure differential and temperature differences can be compared with voltage and frequency in electrical system and water flow rate with electric current. The notable difference here is there is no strict requirement to keep the differential pressure and temperature difference at constant but allowed to vary at higher magnitude. This gives more flexibility to district cooling operators in controlling the plant.

### 3.3.2 Traditional Load Management and its problems of DCPs

The ultimate objective of the load management is to maintain the indoor climate at optimum comfort level at minimal total cost (Meulen, 1988). This means that function of DCP is not merely producing cooling but thermal comfort of the connected building or group of buildings at maximum efficiency. To achieve this objective, optimization must be considered for design and operation of a DCP. Load management is not only a part of operational optimization of the plant but also the key for optimization of whole system. Load management connects all the sub systems connected to the network. Factors affecting heat load can be classified into three groups (Wernstedt, 2005):

1. Human factors (user behavior): The consumption of chilled water is mainly dependent on behaviors of the consumers.
2. Weather conditions: Major proportion of heat load in a building can be attributed to outdoor weather conditions such as temperature, humidity, solar radiation, wind direction and velocity.
3. Distribution losses: Approximately 5% of the total heat load is attributed to distribution losses.

The cooling load of any DCP is subject to large variations due to the fluctuating demands of customers. A DCP must be capable of withstanding fluctuating energy demands. Meeting the demand is subjected to the characteristic as listed below;

- Delay in load control due to time delay in production and distribution (Slow Process). Time required to detect change of thermal load is high compare electrical system.
- Substations are locally optimal. Traditionally building control system is locally optimized without focusing on other buildings. For instance, when ambient temperature goes high all the buildings will try to optimize the operation separately and results in inefficient energy resource allocation.
- Lack of information on demand results in waste of resources (Wernstedt, 2005).

These characteristics cause fluctuations in the demand and always create a gap between supply and demand. This gap must be bridged by load management efforts. Several courses can be taken to balance the system;
1. Adjusting production to the demand (utilization of spare capacity);
2. Utilizing buffer storage capacity
3. Demand side management (adjusting demand to production);

Traditional load control of DCP focused on first and second causes of action explained above and it involves optimization of production plants and distribution system. Utilization of spare capacity causes relatively high energy costs. Energy storage is taking place centrally next to the production plant. The storage capacity of the network is also utilized for load management. Its utilization is limited by economic yield of the storage system which is a function of number of loading and unloading cycle during a season.

A little attention has been paid to control the load from demand (customer) side which determine heat load of DCP. However, economical and environmental factors have changed focus of load control from supply side to demand side management. Economical factors include high investment on production plant and distribution system and ever increasing cost of energy. Environmental factors include increased emission and resource scarcity for instance water and land in densely populated cities.

### 3.3.3 The Demand Side Management in DCP

The objective of electric DSM is to reduce peak load and change the load profile by adopting six load shaping concepts explained in section 3.1.1. DSM is the standard technique for load control in electric grid. There is very little information and knowledge available on application of DSM techniques to DHC (Wernstedt, 2007). Nevertheless, some studies have been carried out on application of DSM techniques on DHP. As operation and control of DH and DC are similar in nature, research findings related to DH is assumed to be applicable to DC as well. However, DSM consideration for DCP applications is at its inception stage.

### 3.3.4 DRM for load management of DCP

In warm climate the annual Electric Peak demand occurs during summer and air conditioning and refrigeration are the major contributors. Several actions have been taken by electrical utilities to control the cooling demand through DSM techniques especially DRM techniques. This strategy work well when the HVAC equipments installed on individual buildings. Application of DRM to buildings connected to a DCP definitely creates problems to operation and control and results in reliability and security issues. However DRM through DCP is more beneficial to both DC operator and electrical utility.

As far as electric grid concerns, DR is about;

- Reducing peak load by Peak Clipping
- Improving load factor through Valley Filing and Smoothing
- Shifting loads from peak to off-peak through storage schemes
- Inducing demand variations to achieve Flexible load growth
Direct load control (DCL) and time of use (TOU) methods can be used for reducing peak demand. Thermally heavy buildings can be used for improving load factors. Here thermal mass of the building can be used to store the energy which can be released during peak hours. If we consider a DCP operation thermal energy storage is widely used for peak load management. This technique enable shifting of loads from peak to off-peak however it will not reduce the magnitude of peak load. This scheme works well when time of use pricing scheme is applicable to DCP operation.

Total cooling load intensity for 5 hypothetical building types in Hong Kong during a summer month is shown in Figure 3-3. These profiles are generated based on the studies done by Chow et al. in 2004 for optimizing DCP operation with thermal storage in Hong Kong. The building types considered in the profile are Retail shops, Office, Hotel, Residential and Mass rail transport stations (MRT). During weekdays the peak load appears from 5-8 PM in the evening and after mid-night it is very low. During Saturday the peak load appears during midday and it gradually reduces as offices are closed for business. During Sunday the profile almost same as weekday one but magnitude is smaller than latter one.

Weekly profile shows the cooling load variation during a week. From the figure we can observe that the peak load and troughs appear alternately and create a valley. Traditional load control methods demand a plant capacity is greater than or equal to maximum peak demand. However, clipping the peak and load shifting can be achieved through DR objectives. DLC can be used to clip the peak and storage mechanisms for shifting the load from off-peak to peak hours. Theoretically load control can be achieved by applying DRM techniques. Application of DRM for load control will results in reduced installed capacity and reduction of operating cost. Cost reduction could be achieved by make use of electricity for charging storages during off-peak hours and discharging during peak hours.

Figure 3-3: Cooling-load profiles for three day-types during a summer month (Chow, 2004).
DRM works well for new plants as capital investment required for its implementation would be readily available and it would be less than the actual amount required without DRM. However, for an operating plant it is a challenging task as additional capital investment will increase the time of return. Nevertheless, potential saving in operational cost and environmental cost would offset the investment required.

### 3.3.5 Challenges

Demand response is a promising technology for district cooling operation. However there are many challenges limiting its practical implementation in a mixed use environment.

1. **Technology challenges**

   DRM needs a secure and reliable information and communication infrastructure for its operation. The choice of technology comes first. The technology should be customer oriented and future proof to handle future advancement in technology. Information security is another concerned area as energy systems is increasingly becoming vulnerable to information threats. To overcome this challenge the control operation has to be distributed over the city. Integration of energy meters to utility operation is a main focus of demand response. Advanced meter management is needed for developing strategies and decision making.

   Attention needs to be paid to energy system integration and management for executing demand response algorithms. Large numbers of intelligence sensors and meters should be integrated and the large amounts of data should be managed without any room for error. It is also required to link customer installations to utility backend, billing and business operation. This raises a big technological challenge which needs to be overcome.

2. **Economic and business challenges**

   Socio-economic and business challenges need to be addressed before implementing DRM. It is really tough to answer what would be the cost and benefits to the market players. It is impossible to estimate potential savings. Unlike electrical grid, district cooling business is dealt with relatively small market revenue schemes and, hence, return on investment may be longer..

3. **Regulation challenges**

   Interoperability ensures successful operation and control of energy system. This is possible or sustained through seamless integration of system devices. In reality, this is not the case; devices are built with different application interfaces. Resolving this issue is not an easy task unless all the vendors agree to integrate their system on a common interface. Lack of industrial standards or regulations make implementation difficult. There is a great need to develop standards and they have to be established especially for communication protocols.

Summary of the challenges are tabulated in table 3-2.
Table 3-2: DRM challenges

<table>
<thead>
<tr>
<th></th>
<th>Communication Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Challenges</td>
<td>Information Security</td>
</tr>
<tr>
<td></td>
<td>Distributed control</td>
</tr>
<tr>
<td></td>
<td>Advanced Metering Infrastructure</td>
</tr>
<tr>
<td></td>
<td>System integration and management</td>
</tr>
<tr>
<td>Economic Challenges</td>
<td>Social and Economic Issues</td>
</tr>
<tr>
<td></td>
<td>Market Barriers</td>
</tr>
<tr>
<td>Regulation Challenges</td>
<td>Interoperability</td>
</tr>
<tr>
<td></td>
<td>Lack of Standards and Regulations</td>
</tr>
</tbody>
</table>
4. Case Study

4.1 Introduction

Dubai is the second largest emirates in United Arab Emirates (UAE). Dubai is an ultra modern city and growing very rapidly. Dubai is firmly established as hub for business, finance and commercial services in the region. During the early 2000s, the city of Dubai witnessed a rapid rate of growth in its built environment which was driven by real-estate demand. This unprecedented growth transformed the city completely. Geographical location together with rapid economic development increased the demand for cooling. 70% of the peak electricity out of 9 GW is used for meeting the cooling demand (DC_UAE, 2010).

Figure 4-1 and 4-2 are good examples to indicate the necessity of cooling in UAE. The monthly average ambient air temperature is varies approximately from 20 to 40 °C. Ambient air temperature reaches as high as 50 °C during summer months. Also humidity is high during summer months. As the climate pattern is almost same throughout UAE, these figures are applicable to Dubai too.

![Figure 4-1: Variation of temperature, humidity and solar radiation (Radhi, 2010).](image)

The no of cooling degree days is the most important parameter which determines the operational strategy of the business. From the figure 4-2, we can conclude that cooling is required throughout the year. Load factor of the plant would be smaller during winter months that have a direct impact on operational costs.
Figure 4-2: Cooling Degree Days at 10 and 18 °C base temperatures for UAE climate (Radhi, 2010).

District Cooling was introduced in Dubai in 1999 and envisaged as the technology for mitigating environmental problems and cutting ever increasing peak demand. After one decade of business, the growth of the technology is not as expected. DC contributes only 10% of total cooling requirements in Dubai as at 2010 (DC_UAE, 2010). There are several factor affect its growth. Higher capital investment and long pay back are few of them. Despite its advantages, in terms of energy efficiency and environmental performance, the industry has started facing many challenges in the recent past. After the real-estate crash, banks are increasingly reluctant to extend long-term project financing and contractors experiencing skill shortages and uncertain construction costs. Water is an essential resource for DCP operation but it is scarce in this region. Recent legislation on water conservation requires operators and potential developers to review their strategies. These are the some of the significant challenges the sector faces.

Considering all the issues which going to challenge the business operation of the city management has decided to find solutions through a scientific study. The aim of this work is to;

- Identify issues which affect plant operation
- Recommendations for eliminating or reducing their impacts.
- Implementation strategies for business continuity

Going forward, this report presents results of this study.

### 4.2 Mixed Use City in Dubai

The specific case study that has been used is a mixed-used city development comprising the following elements

- Shopping - Festival Centre
- Dining - largest F&B offering in Dubai
- Entertainment & Leisure
- Residential Community - Villas, apartments & duplexes
- Schools -
- Hospitality -
- Commercial Offices
- Automotive
- Infrastructure

### 4.3 District Cooling Plant

The DCP serves all the buildings within the development. The planned total capacity of the plant is 80,000 tonnes which include a chilled water generation plant, distribution network (approximately 20 km of piping), energy transfer stations and metering and monitoring systems. The construction was planned to be completed in two phases; in the first phase 35,000 TR capacity was put into operation and rest will be added as development progresses. Another 45,000 TR will be added to existing capacity at the end of second phase. However the main headers of the distribution networks have been installed to meet total planned capacity of the plant.

Climatic information of the plant location is tabulated in table 4-2. From the table we can find out that number of cooling degree days is relatively high thus amount of cooling required in one year.

Table 4-1: Climate conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average annual temperature</td>
<td>29.7</td>
<td>°C</td>
</tr>
<tr>
<td>Average annual solar radiation</td>
<td>21.6</td>
<td>MJ/m²/day</td>
</tr>
<tr>
<td>No of cooling degree days</td>
<td>2300</td>
<td>°C Days</td>
</tr>
</tbody>
</table>

#### 4.3.1 Central Plant

The central plant consists of chillers, cooling towers and water storage facility. Electrically driven vapour compression is the technology employed for production of chilled water. Figure 4-3 illustrates the schematic of the central plant. There are 7 centrifugal water cooled chillers with 5000 TR capacity in operation currently producing cooling round the year. Plant operation type is “all-chiller” that is only chillers are utilized to meet entire cooling demand. Each chiller is duplex series counter flow type and design power consumption is approximately 0.8 kW/TR. Variable flow control is used for plant load management.

Moreover, this plant has 7 cooling towers each of them associated with each chiller unit. Makeup water is obtained from municipal supply networks. Water consumption is approximately 12.3 l/TR. Each cooling tower is provided with a chemical treatment facility for maintaining water quality as it affects the performance of cooling tower.
Cooling load is usually very low during night due to low temperature and usage. However, chillers need to be operated even during low load periods (part load operation) which makes the plant to operate at reduced efficiency level. Average annual load factor is not available to access the degree of plant utilization.

Hourly cooling load profile also not available to study the loading patterns without this information it is hard to take any informed decision on business operation.

### 4.3.1.1 Operating parameters of the plant

The main technical parameter of the plant is tabulated in table 4-3. Total installed capacity of the plant is 123 MW and subscribed cooling capacity is 160 MW. Subscribed capacity includes existing buildings and some new buildings some of them are under construction and others going to be built.

Table 4-2: Main technical design parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total subscribed cooling capacity</td>
<td>160</td>
<td>MWth</td>
</tr>
<tr>
<td>Dimensioning outdoor temperature (DOT)</td>
<td>45</td>
<td>°C</td>
</tr>
<tr>
<td>Installed cooling capacity</td>
<td>123</td>
<td>MWth</td>
</tr>
<tr>
<td>Annual Cooling Demand</td>
<td>246</td>
<td>GWh</td>
</tr>
<tr>
<td>Equivalent annual full load hours</td>
<td>2000</td>
<td>Hours</td>
</tr>
<tr>
<td>Temperature at customer substation</td>
<td>4.5-5.5</td>
<td>°C</td>
</tr>
<tr>
<td>Return temperature from customer sub-station at DOT</td>
<td>13.5</td>
<td>°C</td>
</tr>
<tr>
<td>Return temperature from customer sub-station at minimum load</td>
<td>8.5</td>
<td>°C</td>
</tr>
</tbody>
</table>

### 4.3.2 Distribution Network

Distribution network consists of approximately 20km pipe network and associated facilities. It circulates chilled water from central plant to buildings through closed loop network. It is a meshed type network running along the service corridors provided by the side of the roads. The size of the pipes varies according to the amount of cooling load it carries. Chilled water supply and return pumps are used to maintain the required pressure drop in the network. Diameter of trunk lines are 900 mm and branches are varies with subscribed load requirements.

### 4.3.3 Customer Installations

Customer installations primarily consist of Energy Transfer Stations (ETS) and chilled water pumps, secondary chilled water distribution network, metering and monitoring systems. ETSs are heat exchangers
used to extract heat generated from customer environment. Basic parameters of a heat exchanger are tabulated below.

Table 4-3: Design parameters of Heat exchangers at ETS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Primary Side (Cold Stream)</th>
<th>Secondary Side (Hot Stream)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>Water</td>
<td>Water</td>
</tr>
<tr>
<td>Inlet temperature (°C)</td>
<td>4.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Outlet temperature (°C)</td>
<td>14.5</td>
<td>13.5</td>
</tr>
<tr>
<td>Pressure Drop (kPa)</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Capacity</td>
<td>Varies for building</td>
<td></td>
</tr>
</tbody>
</table>

4.3.3.1 Developments served by the plant

The chilled water produced at the plant is circulated to many buildings within the festival city. The buildings can be broadly classified as residential and commercial developments. Each development consists of many building with different use and occupancy. The complete list of the buildings served by the plant is given in Table 4-4.

Table 4-4: Name of the buildings served by the plant in DFC (Source: As-built drawings)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sub Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>Apartments</td>
</tr>
<tr>
<td></td>
<td>Residencies</td>
</tr>
<tr>
<td>Commercial</td>
<td>Commercial Offices</td>
</tr>
<tr>
<td></td>
<td>Festival Centre</td>
</tr>
<tr>
<td></td>
<td>Hospitality</td>
</tr>
<tr>
<td></td>
<td>International School</td>
</tr>
<tr>
<td></td>
<td>Leisure and entertainment</td>
</tr>
<tr>
<td></td>
<td>Associated facilities</td>
</tr>
</tbody>
</table>

4.3.3.2 Customer Profile

The total connected cooling capacity on the DCP is 200 MW and maximum demand about 123 MW (35,000 TR/hr). 8 customer categories are connected on the district cooling through 32 delivery stations and the distribution is as shown in table 4-5.
Table 4-5: Total cooling demand of the building types in DFC (Source: As-built drawings)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sub Category</th>
<th>Total Cooling Demand (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>Residential</td>
<td>38,300.00</td>
</tr>
<tr>
<td>Commercial</td>
<td>Commercial Offices</td>
<td>12,000.00</td>
</tr>
<tr>
<td></td>
<td>Retail</td>
<td>52,000.00</td>
</tr>
<tr>
<td></td>
<td>Hospitality</td>
<td>25,700.00</td>
</tr>
<tr>
<td></td>
<td>International School</td>
<td>7,800.00</td>
</tr>
<tr>
<td></td>
<td>Leisure and entertainment</td>
<td>18,400.00</td>
</tr>
<tr>
<td></td>
<td>Automotive</td>
<td>5,200.00</td>
</tr>
<tr>
<td></td>
<td>Associated Facilities</td>
<td>2,200.00</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>161,600</strong></td>
</tr>
</tbody>
</table>

From the figure 6-1, residential and retail customers share nearly major proportion of cooling demand and the value stands at approximately 55% of the total demand. This followed by hospitality customers and leisure and entertainment customers. Associated facilities are consuming least amount of cooling energy.

![Customer Distribution By Category](image)

Figure 4-3: Cooling demand distribution across the city.

### 4.3.4 Operational challenges of the Central Plant

Capacity utilization: The plant capacity designed to meet maximum demand during summer. Examination of load profiles during summer shows that the peak is several times higher than the average load and
duration of the peak is very short compare to daily operating hours. This indicates that the capacity is underutilized most of the time. This leads to energy inefficient operation and increased operational costs.

4.3.4.1 Water and electrical energy consumption

Despite DCPs are 40% energy efficient than conventional systems they consume huge amount of fresh water from desalination plants in Dubai. As desalination is energy intensive process the savings achieved by DCP is consumed by desalination plants.

Electrical energy contributes more than 50% of the operating cost of DCP and the plant designed and operated without a TES system. The current tariff system for DCP constitutes a flat rate for energy usage and demand charges. Despite its advantage to customers current tariff structure creates several problems to sole electrical utility operator DEWA. The figure 4-4 shows the electrical system peak demand for the year 2009 and 2010. Demand is very high during summer month; 60% of peak demand is due to cooling load during summer period (DEWA, 2012).

![System Peak Demand (MW) 2009 and 2010](source: [www.dewa.gov.ae](http://www.dewa.gov.ae))

Despite the fact that DCP contributes to peak demand reduction it indirectly increase peak demand by consuming more water from electrically driven desalination plants. Dubai Electricity and Water Authority (DEWA) enacted legislations to reduce fresh water and peak hour electricity consumption of DCPs. DEWA expects to accompany the changes through pricing and incentive mechanisms. Variable price for electricity tariff to reduce peak-load electrical energy consumption and incentives for implementing TES are the proposed two mechanisms.

The processes are underway to limit the fresh water usage of DCP through following mechanisms

1. Variable tariff (Time of use) for peak and off-peak energy usage.
2. Incentives for the customers who use TES
3. Water from other sources such as treated water

Variable tariff and unavailability of TES would severely affect plant operation.
4.3.4.2 Thermal energy storage

The plant has no thermal energy storage for shifting load to off-peak hours. TES technology is a matured and accepted as a proven technology to improve energy efficiency by many in the DCP operation (IEA_DHC, 2002). TES is beneficial for plants with low night time cool load and low night tariff rate is in effect.

Advantages of a well-designed and correctly operated cool thermal storage are elaborated in chapter 2. TES makes an impact on economy and operation of a plant. With the introduction of variable tariff rates, DEWA is planning to provide incentives to DCPs with TES. Absence of TES and cost of electricity both together will reduce the profit margin of business.

4.3.4.3 Low Efficiency

The plant suffers severe efficiency problems. Some identified root causes of the problems are part load operation, higher summer temperature fouling of HEX in ETS and.

Most of the time chillers are operating at varying load conditions or part load conditions which results in reduction of overall efficiency of the plant. During part load operation is the primary pumps consume their full electric power. Variable speed drives are omitted as due to higher capital cost required for medium voltage drives. Part-load operation affects the profitability of the plant.

Day time ambient temperature during summer reaches as high as 50 °C. Higher ambient temperature reduces the efficiency of the cooling production. This is true for both air cooled and water cooled systems. But the demand is at its peak when the temperature rises to its maximum limit. Even at 100% loading the efficiency cannot be achieved as specified.

4.3.4.4 Sustainability

Sustainability is becoming a part of business strategy in all the sectors and real-estate too not exempted from the trend. The operation of the city is not economically and environmentally sustainable as it lacks in many sustainable aspects. The technology and operation practices adopted for DCP operation is not sustainable because; electricity is used as sole energy source for business operation and water from desalination plant. Both these activities cause depletion of energy resources and increased emission of GHGs. Moreover electricity is a high exergy energy source but for production of cooling low exergy energy sources are sufficient. Waste heat and solar heating are some of low exergy energy sources available in abundance in Dubai.

Alternately solar driven absorption cooling could have been used for meeting part of cooling load but the opportunity has been missed in the wake of faster return of investment. Sufficient quantity of treated wastewater is available at relative lower cost. However, the plant is designed for freshwater switching of water source is impossible at this stage.
4.3.4.5 **User behavior**

User behavior is an important factor determining the amount of energy consumed. It is considered that unit consumption of chilled water in residential sector in DFC is relatively high compared to other developments in Dubai. Primary reasons for over usage are lack of awareness and prevailing flat rate tariff structure. Tariff structure encourages the customers to over consume chilled water. On the other hand, customers are paying for chilled water even for winter months and most of them complain about the transparency in tariff structure in practice.

4.3.4.6 **Operation and control**

No central or proprietary building control systems are available to monitor and control the consumption. The control is left to customer mercy. The only control available at buildings is thermostat. Re-adjusting thermostat setpoint is not happening and left at very low setpoint in apartments even in winter months.

4.3.4.7 **Energy efficiency**

Cooling coil fouling is the factor affecting energy efficiency. Unavailability of control and monitoring system and ineffective maintenance aggravate the problem. Wastage in the form of leak is left undetected.

4.3.5 **Commercial users**

Issues related to commercial customers are explained in the following sub-sections. The issues are presented according to the problem areas.

4.3.5.1 **Flat rate tariff**

Tariff rate for commercial users is flat fees based on consumption. The charges include annual capacity charges and energy charges. BTU meters are installed at ETS and connected to DCP. The billing is based on monthly basis. 0.5 AED is charged for 1 ton of thermal energy consumption.

4.3.5.2 **Operation and control**

Observation and data collection of operation of end user systems revealed the following operation and control related issues.

Most of the buildings are equipped with Building Management System (BMS) for monitoring and controlling heat exchangers, chilled water pumps, AHU and various other devices connected to HVAC system. Standard Operating Practices (SOP) are defined in the control system for optimizing operation. Optimization can be achieved by controlling process parameters such as temperature, flow rate, speed setpoints by adjusting them according to the real-time requirements. BMS is capable of monitor tenants’ energy consumption in real-time.

Measurement of electrical power consumption of AHUs in selected buildings indicates that most AHUs operate for 24 hours at same level of output irrespective of status of occupancy. Though Standard Operating Practices (SOP) is in place no schedule for night mode operation has been implemented and
controls are bypassed to operate manually. Controlling of cooling system has been done manually in response to complaints and some predetermined levels.

4.3.5.3 Lack of energy efficient measures

Energy efficiency measures practiced by the commercial customers are not sufficient. Issues associated with energy efficiency measures include;

1. Cooling coil fouling
2. Excess fresh air intake
3. Missing Free cooling opportunities
4. Un-optimized operation (Night time operation, Manual control of FCU etc.)

Impact of these issues discussed in detail below.

Cooling coil fouling

Cooling coils of AHUs and Heat Exchangers are prone to fouling. Fouling of heat transfer surfaces reduces the thermal performance of heat exchangers in HVAC systems. A separate study on performance of heat exchangers and cooling coils installed at festival centre showed that effectiveness of the cooling coil were 60% (EEI, 2011) compare to clean condition.

A heat exchanger fouled on its hot side or cold side requires more flow of chilled water to maintain a regulated supply air temperature at a given airflow rate. The primary impact of such fouling are:

- Loss of thermal comfort
- Increase in chilled water flow rate
- Increase in speed of fans to maintain higher CFM

The fouling of exchangers in AHUs results in a significant cost impact in terms of energy efficiency and maintenance costs. The obvious reasons are:

- Increased pump power for higher water flow requirement.
- Increased fan power for increased airflow rate.
- Spend on maintenance (cleaning) of the coils and exchangers

The actual energy costs depend on several factors and they are specific to each system installation and operation aspects. In normal automatic regulation of air-handling unit (AHU), supply air temperature and airflow rate compensate the fouling and thus unavoidably masks the ongoing loss of performance and efficiency. This makes the fouling to escape undetected by building operation and/or maintenance staff until it worsens to the condition in which occupied spaces can no longer be kept comfortable. At that point, the penalties of fouling may have accrued undetected for months (Goliath, 2010).

Another problem of cooling coil fouling is low Delta-T (Difference of inlet and outlet temperature) syndrome which affects District cooling plant (DCP) operation. This is common problem for a DCP serving large complex buildings similar to one in DFC. Simultaneous fouling cooling coils or heat
exchangers and HVAC system in several buildings will lead to a reduction in Delta-T. If the delta-T in this system is low, at least two problems result: increased pump energy usage and an increase in chiller energy usage due to part load operation.

**Excess fresh air intake**

Ventilation is a fundamental requirement for any building to maintain required Indoor Air Quality (IAQ). IAQ is affects health and productivity of a conditioned space. IAQ requirements are always met by introducing appropriate amount of fresh air into the building. Measurement of CO₂ level is one way to ensure IAQ in many buildings. Control of fresh air intake based on CO₂ level is one of a strategy for achieving energy efficiency in buildings and this technique is called as Demand Controlled Ventilation (DCV).

Measurement of CO₂ level in 3 major buildings namely Festival Centre, Festival Tower and Marza Plaza indicated that the level was falls 400 – 550 ppm. But according to ASHRAE standard 62.1: 2007, at 23 °C and 65% RH, CO₂ level below 1000 ppm is considered as comfortable. From this measurement it can be deduced that excess amount of fresh air has been coming into the building. Though the system is equipped with required sensors and equipments to regulate fresh air flow no attempt had been made to implement DCV based ventilation control.

**Missing free cooling opportunities**

Ambient air night time temperature reaches as low as 15 °C during winter months. This is a free cooling opportunity available to use if for cooling requirements during winter months. From figure 4-1 it is obvious that cooling is required even in winter months. This free cooling can be used for meeting part of cooling load. However, as explained above outdoor air intake is fixed in all the buildings.

**Un-optimized operation**

Operation of many buildings is not optimized. The operation sequences miss many SOP which are common in most of the buildings for energy efficient operation. For instance, operation of AHUs is not scheduled according to the occupancy demand. They operate all over the day in many buildings. These AHUs can be switched off during night times. FCU are operating without any remote monitoring and control is done by manually. Un-optimized operation makes the systems to operate at very low loads; especially pumps operate continuously at low flow rates.

**4.3.5.4 Building Monitoring and Controls**

BMS is installed in all the commercial buildings by different vendors. The purpose of BMS is to monitor and control of building operation. Many building service elements are monitored by BMS including HVAC and electrical systems. The functions of BMS includes

1. Efficient building operation through interoperability of various systems
2. Energy management
3. Monitoring and control of thermal comfort and IAQ
4. Predictive maintenance of critical equipments

From this need assessment, we can observe that customer behavior predominantly play a role in the cooling load demand of the city. Other operational gaps in all the system components and processes also have impacts on the cooling load. However these gaps are mostly due to behavior of the people. Modification of human behavior will definitely change the load profile. When we analyze the system using System Thinking Approaches, we can identify three subsystems within this energy system: People, Process and Profit.

4.3.6 Needs and Opportunities of Demand Response

An assessment of all the problems indicated in the above sections indicates that the district cooling energy system needs a paradigm shift from the present operation strategies. The main drivers are;

1. Market Factors

Economy is the great concern in energy business. Energy is essential for business but it affects economy of all the business as it is a cost for doing business. The perceived cost of energy and water will have their impacts on profit of the business. DR enables reduction of cost of operation by changing the customer behaviors.

If the cost is one side of the coin the budget is other side. Limited budget available for business operation is a constrain for increasing energy system capacity when it requires and it is unusually need longer period and prior resource scheduling as well. On the contrary, implementation of DRM can be realized at relative smaller investment within very short period. Inherent capability of DRM makes possible scheduling and reserving of resources days ahead.

Cutting the corners of costs should not affect the energy services levels delivered to the customers and it should be a win-win solution. It is obvious that customers satisfy when they get benefited from its use at the same time supplier wants their investment back with reasonable margin. Therefore the benefits of the cost reduction should be transferred to customers too. This would be possible only when the customers active involving in the cost reduction measures. DR enables mutual sharing of benefits.

2. Legislative and Regulatory Factors

While the market drivers and its operating conditions provide a foundation for DRM, there are also government policies and regulations which enable the setting up of pillars on the foundation. In Dubai electric and water utilities is regulated under a common authority (DEWA). Legislatures have mandated improvements of energy and water consumption for buildings and DCP. Demand-side initiatives and other energy efficiency activities have to be implemented to comply with the requirements. The present of legislative or regulatory actions is not directly supporting DRM; however they are crucial for DRM.

3. Sustainability Factors
DFC envisions their business operation to be sustainable. Sustainability is possible when the business evolves toward reduced greenhouse gas emissions and low-carbon growth. This is impossible if there is very close interaction among the stakeholders; in this case supply and demand side of DCP. There is a need for technology and market solutions to achieve corporate sustainability goals. DR is part of a more flexible system, allowing both supply and demand to interact frequently and in a carbon-constrained system. This flexibility can shift generation away from greenhouse-gas-emitting sources and therefore reduce carbon emissions in a meaningful way and strengthen the sustainability (Smith, 2011).

4. Command and control Factors

The controllability and operability of remote assets is very poor. There is a strong need for control, operate and monitor remote/customer assets. For this purpose the city management system is looking for a new breed of system. The DRM is not only a legacy load management systems but an operational system used to control distributed resources in an energy system. From an enterprise management perspective DRM system can be considered as an information management system carrying various types of information across the network. DRM can support communication of most of the information critical for the assets management.

City wide fibre optic communication infrastructure and Central Command & Control Centre (CCC) at CMS is an additional opportunity to realize DRM.

5. User behaviour

There is a strong need for implementing DRM measures at DFC due to

- Change of user behavior.
- Actively implement load management measures,
- Integration of market based instruments along with the policy/regulatory interventions for promoting energy efficiency and environmental performance of business operation

From the above need assessment it is obvious that Demand Response provides an opportunity to DCP operator to reduce water and electricity consumption according to their business and legal needs. On the other hand it provides an opportunity to customers to reduce their bills through a commitment to reduce load in response to system requirements. Implementation of DRM will benefit to people, business and environment. Additionally, it would enable use of absorption system with electrical chillers to optimize the operation. Load reductions during peak demand conditions also will help electrical and water utilities to cut down their peak-load. This would reduce emissions and environmental impact associated with operation.

However based on the findings during investigation, the following actions have been proposed as prerequisites for implementation demand response.
Residential Buildings

- Installation of BTU meters
- Educate and encourage customers towards behavioral changes
- Integration to CMS through home automation gateway
- Introduce Time Differential Tariff for Residential Consumers

Commercial Buildings

- Implementation of energy efficiency building codes
- Rectification of BMS system issues and optimization of operation
- Educate and encourage customers towards behavioral changes
- Integration of building to CMS
- Introduce Time Differential Tariff for Residential Consumers

District Cooling Plant

- Rectification of instrumentation and control issues.
- DCP operation should be integrated to central control centre. This will increase the operational flexibility while improving efficiency of the operation.
- Optimization of DCP operation this includes both central plant and distribution operation. Culture should be changer to see whole system rather than separate systems in order to optimize the system. Optimum control determines the flow across the system components and balances it accordingly. This is one of a best practice to create a culture in energy saving.
- Real-time information should be used to perform maintenance. The current maintenance practices should be changed from reactive to proactive.

Common to all Buildings

- Create awareness; disseminate information and capacity building among all the stakeholders.
- Optimization of customer installation: customer installations should be optimized by eliminating all the problems identified. This includes technical as well as behavioral changes.
- Integration and optimization of complete system
- Implementation of DRM: implementation strategies are explained in the following chapter. These are specific recommendations essential for DRM.
5. Demand Response Implementation Strategies

This chapter outlines strategies needed for DRM operations in mixed-use environment. This section will examine ability and will of the customers to reduce their energy consumption. The main focuses on demand management and utility operation. Demand management focuses on customer side activities where as utility operation focuses on potential technologies available for demand reduction. This chapter targets mainly residential and commercial sector as industrial facilities seldom operated in mixed-use development.

This chapter describes some of the DR implementation strategies required to initiate deployment of DRM. The key strategies are:

1. Determination of Energy Use Behavior (Cooling Load) and its variation in the City
2. Collection and Management of information required for DRM (setting baselines for buildings)
3. Linking DCP and Customers through DRM

5.1 Determination of Energy Use Behavior

This strategy is related to determination of energy use behavior (Cooling Load) and its variation in the Mixed Use City. It is concerned with how cooling energy is commonly used across the various consumer classes in the city and providing information to influence the customers to reduce the load.

5.1.1 Energy Consumption Behaviour

In a mixed use city development, different buildings have different loading profiles, for example office buildings and shopping mall in the city can have very different load profile. The office buildings have relatively high loads during the office hours and no load during night and holidays; the daily peak load occurs during afternoon of every weekdays and its magnitude is almost equal throughout the week. The shopping mall has longer daily operating hours and the cooling-load pattern is relatively the same for all days; the peak occurs during Friday (weekend) afternoon. Unlike commercial buildings, residential buildings peak loads occur at midnight, when the majority of the occupants are at home. However, unlike those in the non-domestic buildings, the residential demand is virtually zero during the winter period.

5.1.2 Approaches to Determine Energy Use Behaviour

Energy use behaviour can be determined by collecting load profile data from the DCP operator. The objective of the data collection was to develop a picture of representative chilled water usage behaviour during peak times. This energy usage behaviour is affected by the activities being carried out. The second objective of the survey was to determine the demand modification to two factors; price and environmental impacts. The third objective was to relate those modifications to behaviour changes.

However there is no historical data is available at the DCP operator to develop a thermal load model of the city. First strategy involves installation of advanced BTU meters and integration to communication
infrastructure for acquisition and deployment of demand data. This data can be used to benchmark the consumption levels. Integration of BTU meter to CMS will enable advanced metering communications (2-way connectivity) between energy consumers and the utility.

5.2 Setting Baselines

This strategy is related to collect and manage massive amounts of consumption and performance data utilizing the connectivity established under strategy 1. The major tasks involving in this strategy are installation of systems to manage information across network, utilization of this information for demand response and customer empowerment.

Baselines are necessary to set the reduction targets hence incentives for reduction. Consumption pattern of buildings are not widely understood. Implementation of first strategy will enable to baselines of building consumption. A specific building tends to have consistent and predictable consumption patterns, but often vary by season. For instance, Festival Centre always sees large increases in summer months due to ramping up of temperature.

5.3 Linking DCP and Customers through DRM

The final strategy is related to linking the utility to its customers by tight integration of command, control and communication infrastructure with the Central Plant, transmission and distribution and customer portals and information systems. During this stage the Demand Response Management Solution (DRMS) comes into DCP operation as the critical infrastructure component. The preceding section describes the DR model proposed for a typical mixed used city development.

5.3.1 Demand Response Model Structure

The conceptual demand response model is shown is figure 5-1. The basic idea of this model is balancing supply and demand. The model is divided in to two parts: supply and demand side. The demand side primarily consists of baseline load profiles and climatic data. Baseline demand profile further splits into several components determined by the load types namely domestic, commercial and industrial. These profiles were considered to have consistent shape throughout a week but modified by climatic effects. In another word annual baseline load profile is determined by combined effect of weekly baseline load profile and climatic effects.

Supply side primarily consists of distribution network, thermal storage, central plant and critical resources required to run the system reliably. Resources include energy sources, water and financial resources. Energy sources can be electricity, fossil fuel, solar or waste heat from a CHP plant. Modern DCPs do not relay on only one energy sources rather multiple sources due to various factors. The entire system must work in tandem to meet the demand. Failure of any of these components will results in loss of supply thus system imbalance.
Demand response comes into play when a system imbalance is forecasted. Demand response technology helps consumers change their demand. Depending on system condition, the demand response request will be forward the demand response controller. The controller acts according to the predefined set of instructions. Planning the demand response is the major task of demand response application. Planning involves calculating of preferred energy availability for the period to come. This is achieved by forecasting schedules for energy production and energy demand. The resource planning schedule also important for calculation. Based on these inputs, a schedule is derived that specifies the periods of shortage of the energy. Demand Response logic invokes the necessary schedules to balance the system. Figure 5-2 shows a generic physical model of the demand response application.

Energy production forecast schedule is generated considering the possible constrains. Energy and other resources are the two major constrains considered in this model. Constrains are identified by resource
planning schedule by getting the inputs of energy market forecast and availability of energy assets. Energy market forecast provides pricing information of energy commodity. Energy assets include all the infrastructures essential for providing energy services.

Energy demand forecast can be generated from historical data and climatic information as shown in figure 5-1. Any imbalance sensed in the system will trigger Central Demand Response application to work out a most appropriate DR schedule. This will be communicated to customers and utility operators to take necessary actions. The most probable DR objectives are discussed in the proceeding section.

5.3.2 Demand Management

The DRM solution should be a complete one to cover all the customer classes and cases. The customer classes can further be categorized as residential, commercial and industrial. Each customer class has different load profile and user behavior so different approaches are required to reduce the demand. Industrial customers seldom connected to DCP in a mixed use development. Therefore, strategies needed for industrial customers will not be discussed here.

Behavior of inhabitants in responding to demand response requests is largely not understood in the mixed developed environment. This section sought to answer some of the critical questions related to DRM of a DCP.

1. What are the factors that motivate customers to participate in demand response?
2. What are the DR programs mostly suitable for DCP operation?
3. What are the expected load shape changes?

5.3.2.1 The Demand Management in the Residential Sector

Motivating and educating customers themselves are the first step towards success of DR programs. Studies show that many factors motivate customers to participate in DR programs. Economical (pricing), environmental and security factors are the three of them largely dominate customer participation in national level DR programs in electrical systems. Price and environment factors are the motivating factors at local and national level. Security is more popular and influential factor at national level but for mixed use developments its influential is limited.

DR can be achieved through fiscal and non-fiscal methods. In fiscal method, two basic strategies can be used to control the demand: direct load control (DLC) and time of use (TOU) programs. The case studies of residential electrical energy use behavior in different countries have demonstrated that most of the residential customers non responsive to price changes (Gyamfi, 2010).

5.3.2.2 Direct Load Control

Direct load control technologies have been available in various configurations. In electrical system, DLC programs have been very popular as it reduces residential peak demand. Basic DLC programs offer households recurring monthly bill credit in exchange for the utility controlling some large energy consuming equipments (Gyamfi, 2010). Similar principals can be adapted to DCP as well. Furthermore,
communication and metering requirements for DLC are simple and inexpensive. However controlling individual equipments are not feasible with this method as residential equipments are smaller in capacity. Alternately, a central controller that can be a part of home automation gateway may be used to control all the equipments collectively.

But recent development like remote control thermostat enables control of conditioned spaces directly. All the residential units has home automation gateway with a communication link to city management system. This can be used to control and monitor residential loads.

Expected load shape changes

1. Peak clipping and load shifting are the expected load shapes.
2. DLC is possible when the consumers are willing to participate in this type of programs. DLC would enable controlling of loads during peak hours and results in reduction of peak load.

5.3.2.3 Time of Use Pricing

DCP operator uses flat tariff rates that may not be an appropriate method. In the electrical network TOU is used to influence customers to shift their electricity usage from peak to off-peak hours. Unlike electrical network, cooling loads cannot be shifted to peak to off-peak in residential buildings. Small scale energy storage devices also are not available in the market. Instead, TOU may motivate customers to reduce the consumption and wastages, and also improve the energy efficiency of the cooling equipments.

The outcome would be peak clipping strategic conservation not peak shifting as in the case of electrical load profile.

5.3.3 The Demand Management in the Commercial Sector

All the commercial buildings are almost unique as far as HVAC concerns. Major components of the system are HEX, chilled water pumps and air distribution devices. The building control system can seamlessly be integrated to CMS. Most of the commercial buildings have been already integrated to CMS. Direct Load Control (DLC) and Time of use pricing can be also be used as in residential buildings.

5.3.3.1 Direct Load Control

DLC can be achieved by integrating BMS to CMS. The SOPs can be overridden by CMS whenever required. One of a possible load control methodology for commercial building is flow control to heat exchangers. Two way communication links available from CMS to building and DCP in the city can be made use for control purposes. DLC should be applied to the buildings such a manner not to affect service level requirements of the customers. When applying, all the buildings should be treated similarly such a manner to optimize the resource allocation. Additionally it enables implementation of Load Curtailment if the customers are willing to do so. Participation should be compulsory. The incentives can be fixed payment or a billing credit during four summer months.
5.3.3.2 **Time of use**

DCP operator uses flat tariff rates that may not be an appropriate method. Current flat rate tariff is a hindrance to behavioral change. In the electrical network TOU is used to influence customers to shift their electricity usage from peak to off-peak hours. In commercial buildings, cooling loads cannot be shifted from peak to off-peak using TES. Large scale energy storage devices also are available in the market. Instead, TOU may motivate customers to reduce the consumption and wastages, and also improve the energy efficiency of the cooling equipments. The outcome would be peak clipping, strategic conservation and peak shifting.

5.3.4 **Voluntary non-fiscal methods**

Voluntary methods could be a strategy to achieve DRM objectives in a mixed use environment. There are factors that could influence occupants to change their behaviors to achieve demand response. Such two factors would be supply security and environmental impact. Therefore developers can promote voluntary methods among occupants as they are generally bounded to some compliance such as environment protection and social equity. This method may work well among domestic customers and environmental factors would be the most ideal for these methods.

5.4 **Utility Operation**

Implementation of DRM will require some changes in operation strategy of DCP. Utility operation includes the peak load management through load shifting, economic control, fuel switching, distribution system operation and optimization and integration of efficiency with DRM.

5.4.1 **Load shifting for Peak Load Management**

Peak load management is critical for security and reliability of a district cooling plant. Thermal Energy Storage (TES) is well suited for permanent load shifting hence has been used for peak load management. Load shifting using TES helps to reduce installed capacity therefore capital cost. Traditionally, TES has been considered as a part of central plant (supply) component. However, when implementing DR concepts this should be considered as a load component as in the case of electrical system.

With proper planning and the right control equipment in place, TES can be used to achieve substantial operation cost savings, especially in summer when electricity rates are very high. Utility operator should establish a comfortable charging schedule for chiller operation and sticking to it year round. Load shifting provides economic advantages to utility even if there is no demand response program.

Conventional DCPs employing electric chillers operate at partial operating conditions most of the time. This is a highly energy inefficient operation. In contrast, TES system chillers can be operated at its full load for longer period of time without considering system load conditions. Furthermore, as charging is taking place during at nights, when the ambient temperature is low, heat rejection is much improved.
Moreover, TES system provides operational flexibility by acting as a buffer for varying load conditions. Also it enables to shut down part of the plant during normal working hours for maintenance and service.

5.4.2 Economic Control

Objective of the economic control is cutting down the operating cost of the plant. Economic control is an important aspect of system operation. Reduction of electrical consumption, use of renewable energy, reduction of water consumption and environmental emissions are the factors affect this aspect. DRM is the key for economic control of DCP.

5.4.2.1 Reduction of electrical energy consumption

The specific consumption is the measure of electrical energy consumption which is equal to electrical energy required to produce 1 kWh of cooling. The specific annual consumption ratio should be brought down by setting benchmarks based on baseline values. The specific electrical consumption ratio should consider the consumption of chiller units, auxiliaries as well as the pumps. Reduction can be achieved in many ways DRM is one mechanism and improvement of energy efficiency is another one.

5.4.2.2 Fuel Switching

Operational strategies should be modified to switch the fuel from costly electricity to cheap and free fuels. For developments in the Middle East, solar energy and low temperature air are the two opportunities available with economical feasibility.

The DCP standard operation practices should be modified to utilize free cooling available in the air. Consequently DCP can alter its operation and alert the customers too. Solar driven absorption chillers are another technology available for consideration. Future development should consider all these possibilities while making business decisions.

5.4.3 Integration of Efficiency with DRM

The DCPs have the ability to operate at higher efficiency levels. Higher efficiency leads to reduction of energy and resources consumption thus reduction of CO₂ emission. In most of the system, the efficiency is limited to production facility; however, there are huge potentials for efficiency improvement in distribution and end-user installations. DRM can be used to coordinate efficiency of the system.
6. Enabling Technologies

6.1 Overview of enabling technologies

Some of the Demand response programs (TOU and CPP) have been existed for decades. However implementation has been restricted to large commercial and industrial customers due to lack of enabling technologies required to facilitate demand response. DR is becoming an asset in any energy system. The ability to control, operate and monitor this asset needs state of art technologies. First part of this technology involves making linkage between utility systems to its customers (Communication). Second part of the technology involves utilizing the connectivity established to collect and manage massive amount of performance and consumption data (Information Management).

In this context, communication infrastructure and information management system are paramount for collecting and processing information required for effective DRM. Moreover, these are necessary to promote demand response or to remove barriers to demand response participation. Advanced Metering Infrastructure (AMI) and Smart meters are appeared as enabling technologies for effective use of demand response strategies. Two-way communications, intelligent networks, and multifunctional technologies will allow for demand response programs that are both more extensive and more efficient.

Demand response programs built on AMI will not only promote increased participation by commercial and industrial customers, but will foster the integration of residential customers into demand response programs. AMI includes smart meters, modules and interface units, Local Area Networks (LAN) and Wide Area Networks (WAN), communication technologies, network management platforms, and integration frameworks (Siemens, 2010).

This chapter examines information and communication requirements and other enabling technologies to automate DRM. The technologies presented here developed based the requirements of future smart cities. According to some predictions, future smart cities would have a single central control system to monitor and control all the energy systems in operation.

6.2 Information and Communication Requirements

Information and communication technologies are prominent components in any demand response program. Demand response will not be possible if communication and infrastructure is in place. Communication and information infrastructure are paramount for executing the tasks. The primary functions of the technologies are to form a communication linkage between control centre and other facilities, to carry data and information over the link established and to control set of devices and equipment at the facilities that participate in demand response activities.
6.2.1 Information system requirements

Good Information management and exchange are the fundamentals for balancing the energy system thus success of DRM (AMI-ENT 2009). Information required to balancing energy system includes: Load profiles of all customer classes, Weather Data and Resources planning data. DR information management system includes the following activities.

- Data acquisition and processing which include customer energy consumption data; weather data; energy price signals; and energy demand-response event information.
- Maintenance of active records of customer devices and manage them on behalf of the utility.
- Integration with customer interfacing systems.
- Providing customers with valuable, decision-making information.

6.2.2 Communication Systems Requirements

Fast and dependable communication infrastructure is paramount for secure and reliable operation of any energy system. DR communication infrastructure is illustrated in Figure 6-1 is developed by Siemens for integration of energy and water system of a city. This model was developed for extended DRM application of electrical network. This covers all energy sources including distributed storage devices. Electric car has identified as possible electrical distributed energy storages where as chilled water plants for thermal energy storages.

![Communication Infrastructure Diagram](image-url)

Figure 6-1: Demand response communication infrastructure (Siemens, 2010)

This infrastructure is called energy automation infrastructure. Real-time monitoring control applications can be used here for collecting dynamic information of energy flow. In a conventional cities distribution of energy system is very vast and huge amount of information to be handled. It is difficult for data model in the control centre to handle and maintain communication of all the devices. Moreover, communication...
between devices and control centre should be unified otherwise sophisticated control technologies should be used to manage the communication among the participants. The communication infrastructure should be capable to function on various technologies. The communication technologies that can be used for DRM includes; Energy automation technology, “Last mile” communication technology and In-building/in-home technology.

The solution for this problem is distributing control functions across the network. This controller is called as district controller and can be arranged to deal with particular customer classes. Also it enables using of different communication technologies especially Last-Mile communication technologies. Last-Mile technology is a telecommunication technology which carries data on telecommunication backbone along a relatively short distance.

Information and communication infrastructure is in place but not properly integrated. Information infrastructure includes a state-of-art Central Control Centre at CMS with required hardware and software. iViva.works™ is the Rapid Application Development (RAD) platform and information management system for infrastructures and facilities in the city. The functions of RAD include Enterprise Application Integration (EAI), Business Process Management and Portal Services in real-time. Single organization always uses several applications for their day to day operation especially for automation the business operation. These applications typically cannot communicate to each other and sometime referred as information silos where identical information stored in multiple locations. This is a barrier for unified communication, interoperability and automation, and result in inefficiencies.

Enterprise application integration (EAI) is used for seamless integration of traditional applications across a large networks such as real estates. This integration solution enabled operation of multiple buildings from CMS without affecting their BMS systems. Benefits include interoperability, data integration and stability.
Figure 6-2: Proposed Demand response communication infrastructure for DFC.

The current communication infrastructure functions on a reliable city wide fibre optic network which is the backbone of the network. DFC operates high performance TCP/IP based data network for providing communication across the city. Communication infrastructure provides centralized monitoring and control of multiple buildings and city wide infrastructures such as street lighting, call centre and traffic management. Figure 6-3 elaborates proposed information and communication infrastructures with necessary modifications. The present metering system can communicate to BMS but is not smart enough to communicate in duplex mode (2 way communications) thus need additional capabilities built in. The schematic diagram in figure 6-4 illustrates the information and communication structure required for implementation of DRM in DFC.

Zone controllers are the only additional components missed out at present system. However, the system has the capability to implement the DRM. Zone controllers enable distributed demand management applications by bridging the central demand response application to individual systems. This controller can be installed within an existing building or ETS in the zone and the controller is to be connected to existing network.

This present ICT infrastructure can support the basic requirements essential for DRM. Last-mile technologies are rarely required for DRM in DFC as all the customers are connected to network. Development of smart mobile phone technologies together with cloud computing further enhances the application of last-mile technologies among the communities living in an urban environment. These technologies can be used to send out billing and pricing signals to the customer in real-time. At the same time the customers also respond to these signals.
6.3 Advanced Metering

Advanced metering technology plays a critical role in making DRM a success. Advanced metering technology is defined as a metering system that records customer consumption with other parameters at set time interval and provides for daily or more frequent transmittal of measurements over a communication network to a central collection point (DR&AMI, 2008).

The present energy (BTU) metering in DFC uses traditional practices. The metering is done primarily for bulk consumers’ billing purposes and the bills have been generated once every month by taking the reading manually or remotely. Traditional metering is subjected to many problems; accuracy and reliability are two of them. Accurate and reliable BTU meters and comprehensive metering program are essential for managing today’s district energy systems. The functional requirements of advanced meters for DRM application enable:
1. Accurate flow and energy measurement in real-time (Provide consumption data to create load profiles of individual customers)
2. Continuous monitoring of customer installation performance
3. Improved central plant control
4. Real-time commissioning and balancing data

For the success of DRM, flow and energy should be measured accurately and reliably. Consumption data is required to set the baseline for DRM. Baseline is the estimated BTU consumption that would have been consumed by a load in the absence of a Demand Response Event. Incentives are determined based on reduction against energy baseline values. In addition to that advanced meters should help to monitor performance of customer systems. Furthermore advance meters improve control of the central plant by sensing the changes in the load rather than change in system temperature which makes the load control usually a slow process. It should enable faster data transfer from customer to utility over the communication infrastructure. Also advanced meters can be used to record commissioning and balancing data. Therefore advance meters ensure proactive load management efficiently and reliably.

There are BTU meters emerging in the markets with higher accuracy, reliability and the capability to transfer the data to utilities or control centers over wire or wireless. These meters have capability to communicate with utility back end using TCP/IP or mobile technologies.

6.4 Direct Load Control Systems

Traditionally, direct load control technologies have been available for various loads in residential sector for many years. Direct load control technologies have been used to reduce peak demand by controlling load elements directly. In electrical utility networks, these systems were used for control of electric domestic hot water (DHW) heaters. Similar technology can be extended to control HVAC equipments in a commercial facility. The controlling can be achieved by either directly controlling equipment in different facilities or integrated control of multiple facilities.

There are several new technologies available which enable direct control of HVAC system components in commercial and industrial sectors. One such kind of technology is programmable, direct load control thermostats. These systems, which have been deployed both in the residential and commercial sectors, increase the thermostat setpoint during the cooling for connected systems in response to a DR event (Epstein, 2005).

6.5 Energy Efficiency Technologies

Energy efficiency refers to using less energy to provide the same or improved level of service to the energy consumer in an economically efficient way. In contrast, demand response entails customers changing their normal consumption patterns in response to changes in the price of energy over time or to incentive
Energy efficiency reduces the load permanently even during peak-load periods. Any changes in energy efficiency will reflect in the demand response programs.

Unlike the electrical system energy efficiency in thermal energy systems are subjected to rapid changes. Energy in thermal energy system is transferred from one fluid to another across the metal surfaces in heat exchangers. Fouling of these surfaces may lead to reduction in effectiveness of energy transfer. This is a prominent problem in DH and DC networks. Low Delta-T syndrome is one of a problem caused by fouling. Low delta-T results in increased energy consumption.

Degradation of heat exchanger performance can be measured by comparing the specific heat transfer coefficient at clean condition with the real time one to give the heat Exchanger Efficiency Index (EEI), which is a relative measurement of degradation in exchanger performance. For the fouled coil conditions the EEI will be a low against a coil which is clean. By calculating EEI on regular basis, we can easily determine the effectiveness of coil cleaning maintenance as and when done on heat exchangers. EEI changes rapidly and usually undetected in automated control systems as the system compensate the changes in heat exchangers by increasing flow rates.

Therefore continuous monitoring of EEI is required for energy efficient operation of district cooling system. But manual measurement, monitoring and periodic maintenance is not helpful to get rid of this problems. The calculation should be done in real-time and maintenance should be predictive one rather than preventive one. Automated calculation method uses real-time data available at CCC to calculate the EEI according to the user defined frequency. A software tool will execute the calculation sequences. All the steps and necessary calculations required for automated calculation will be done after validating the field data.

This method enables real-time continuous monitoring and triggering of an advance notice for maintenance when the EEI goes below expected level (KPI). Accordingly a maintenance order can be generated by the system to the respective managers. This is called predictive maintenance. Maintenance efficiency can be analyzed based on the EEI of cooling coil after cleaning.

Performance evaluation and maintenance effectiveness can be analyzed in Real-Time following coil cleaning activities. Maintenance efficiency can be analyzed based on the EEI of cooling coil after cleaning. Real-time calculation increases the ability to diagnose the cause of fouling and to treat the cause in order to slowdown or reverse the degradation of heat exchangers (EEI, 2011). This energy efficiency technology must be coordinated with DRM otherwise the saving from DRM will diminish in no time.
7. Discussion and Conclusion

7.1 Discussion

Traditional methods of demand management will no longer be feasible due to pressures on energy supply system at global level. In case of energy or infrastructure resource constrains, operating the energy system reliably (balancing supply and demand) is difficult or in some cases not possible at all. This research seeks to develop solutions for alternative load management for DCP using demand response management techniques. This thesis has presented the finding of theoretical study and implementation methodology associated with the DRM concept suitable for district cooling system. Demand response is expected to play an important role in the future district energy systems. The objectives are repeated here as:

1. Investigate the applicability of demand response program in the district cooling plant of a mixed use city by investigating behaviors that are prevalent during the peak hours and behavior modification likely to be adopted.
2. Provide recommendations and implementation frameworks based on DRM principles for managing customer demand in mixed-use city development.

The highlights of the work are described as follow:

7.1.1 Demand Response in the DCP Sector and its applicability

Literature review was aimed to find relevant previous research work in line with the objectives. Fortunately or unfortunately no works has been carried out at previous instances. However there were handful of studies have been done on DSM of district heating operation. District heating and cooling operations are similar in nature except temperature level of working fluids. District heating and cooling operations frequently are carried out in a same plant. The available information is insufficient for a complete study of DR aspects of district cooling operation. DR has its deep root in electrical grid operation. Its application spans to national level and efforts are underway to extend its application across countries.

A comparative study has been done to identify the applicability of DRM in district cooling operation. The achievement of the objectives shows that the DR technical concept is going to influence future district cooling energy system as it is very much successful in the electrical system.

The literature review revealed that DCP has great potential to become a candidate for DRM. Moreover, the interesting finding was that DR in DCP is an un-tapped and promising component of demand management. It will be the future technology for achieving sustainability. At the enterprise point of view, sustainability has to be built on three major pillars or 3P. The Profit, Planet and People are those three pillars representing economic, environment and the social dimensions of a business environment respectively. DRM reduces the cost of operation with the active participation of customers which lead to environmental protection.
However, its realization still remains a great challenge. Lack of information and poor understanding of customer behavior are some of the barriers that limit the extension of demand response programs to the DCP with the operation.

7.1.2 Case study

The applicability and usefulness of DRM were demonstrated using a case study. The outcomes of the study are summarized in the following sub-sections. Investigation of customer behavior was the first step towards understanding the applicability of DRM. A review of district cooling operation was carried out to understand the problem in operation and control and to identify the potential contribution of demand response in resolving the problems.

7.2 Recommendations

1. It was strongly recommended to adopt DRM for demand management. Considering the practical difficulties the implementation is not immediately possible but possible. The strategies proposed for implementation can be implemented in three steps.

2. In step one, the production, distribution and end user systems should be optimized and sustained for longer period. This is very critical and important for the rest of the strategies. In other word we can call it as optimizing the system locally. This would help to gather information required for DRM. All the customer installations should be provided with advanced metering technologies for collecting load data. This might provide an opportunity to test demand response management manually.

3. In step two, the all the communication and information requirement should be completed and a link from CMS to all the customers and DCP should be established. The link established can be used to collect and manage the massive amount of information generated in the energy system.

4. In step three, DRM can be implemented using the model proposed in this report. The proposed generic demand response model is a generic one not mathematic. A mathematic model has to be developed for final implementation and that is not covered here considering its complexity of such development.

Different types of load shaping objectives recommended for implementation. For residential buildings DCL and TOU prices were proposed and both were aimed for peak clipping. In the case of commercial buildings LC also can be used in addition to DCL and TOU. All these load shaping objectives will lead to clipping the peak and DLC can be used for filling the valleys in some buildings such as large retail malls. TES can be used for shifting the loads from peak to off-peak and to maintain constant load factor. This measure is associated with utility operation but in DRM it should be considered as large industrial load and measures should be taken to redefine utility operation strategies.
Many organizations within the city are operating with environmental awareness and Corporate Social Responsibilities (CSR) portfolios. They may find value in participating in demand response as it adds value to their CSR activities. Also there are many individuals living within the city who might show interest in protecting environment through participating in these programs. These opportunities may help to implement voluntary non-fiscal method of demand response programs.

Role of enabling technologies are inevitable for successful implementation of DRM. Enabling technologies are required for carrying out following tasks. First task is to form a communication linkage between control centre and other facilities. Second task is to carry data information over the link established. Third is to control set of devices and equipment at the facilities that participate in demand response activities. Communication and information infrastructure are paramount for executing the tasks. The available information and communication infrastructure need few modifications to cater the requirements. In addition, some enabling-technologies are required for control of facilities to remotely control the devices. Smart thermostat is becoming a most widely recognized technology for DLC in residential sector.

Energy efficiency is a prominent component in reducing the amount of energy to be supplied. Energy efficiency of DCP should be coordinated with DRM events to get the maximum benefit out of it.

These recommendations are intended to guide management in the selection of the desired outcome. The management should agree to all the recommendation to make this research work a success. The agreed recommendations should be entered into an action plan including estimated budget and desired results to be achieved. The evaluation of recommendation will be carried out based on the action plan. Technical and economical feasibility of the recommendations has to be done before implementing any recommendation. Performance data can be gathered time to time to evaluate the achievement of desired results. However evaluation is not going to be easy. Implementation of recommendation involves many areas with different technical aspects. At the end of the implementation all the system need to be integrated to achieve objectives. This may create problems in qualitative and quantitative data collection and analysis.

New environmental and energy policies demand efficient use of natural resources especially energy and water in urban environments. The primary aim of these policies is to reverse the damages done to the environment and to preserve natural resources. However, policies require technologies for their practical implementation.

This thesis is focused on a new breed of technology associated with sustainable element of an urban energy infrastructure. This research work is a preliminary investigation of the possibility of extending of the DRM concept from electrical grid to another energy network; in this case district cooling network. This work covers various aspects of DRM from design, application and implementation in practice.
From this study, it is obvious that Demand Response provides an opportunity to DCP operator to reduce water and electricity consumption according to their business and legal needs. Load reductions during peak demand conditions will help electrical and water utilities to cut down their peak-load. This would reduce emissions and environmental impact associated with operation.

On the other hand it provides an opportunity to customers to reduce their bills through a commitment to reduce load in response to system requirements.

Implementation of DRM will benefit to people, business and environment. Additionally, it would enable use of absorption system with electrical chillers to optimize the operation. As a whole, overall load reduction of a DCP enables the utility operators to participate in DR programs designed by electrical utilities. Consequently, this would bring many financial benefits to the operator.

The implementation of demand response for non-electrical grids will simplify implementation of DRM in electrical grids. Electrical grid operators can deal with other non-electrical utilities (single entity) directly rather than targeting huge numbers of customers and their equipment within industrial, commercial, and residential sectors. On the other hand, it will create a common view of economical resources utilization and energy pricing. Integrated DRM approach will have the capacity to create truly smart energy systems in long run.

We can conclude that the research objectives are contributed to advance the knowledge of DRM in district energy networks and its implementation is highly achievable one.

### 7.2.1 Limitations of the DR model

In order to perform an analysis on prevalent user behavior and its impact on DCP operation, both demand and supply profiles are required. DRM objectives are concerned with the measures taken on the demand side to keep the supply conditions within its limits. Neither real-time nor statistical demand data is available to analyze the applicability. The DRM model is generic to accommodate demands from all sources. However when the more accurate and detailed the demand profiles available, better control strategy and DRM model can be developed. Moreover, if demand and supply parameters relevant to this model are specified, the more accurate mathematical model that can be realized.

Another limitation is direct load control of residential loads. DLC allows utility to control customer loads directly by installing a remotely controllable smart thermostats in customer facility. This thermostat cycles the cooling supply off and on, or disconnects it for brief periods of time, during high-demand periods or a supply emergency. In exchange for customers’ participation, they will receive credits on their bill based on the amount of load reduced. However the problem arises when measuring amount of load reduced. This is only possible when shutting off the load completely for certain amount of time period. This approach would severely affect thermal comfort. User behavior during this period of occupancy can have a significant impact on this method.
This becomes even difficult when the occupants are elders or sick and higher standards of comfort and service levels demanded by householders. Very precise DRM program is inevitable to get rid of this problem. Another problem is, it is practically impossible to set same set point for all the customers. Cooling loads are particularly sensitive to seasonal changes. The climatic inputs are required to simulate the performance of dwellings. Present model is not capable to address these issues.

### 7.2.2 Potential Future Work

There are few limitations have been identified in this study. Future works on the following area might address these limitations.

Sufficient data is not available to generate load profiles hence user behaviors and performance of the DCP. A study is needed to establish load profiles; this can be done either by simulation or by measurements. This is a prerequisite for implementation of DRM.

A mathematical model can developed using the physical model developed in this research work. The mathematical model can be used to simulate the DRM operation in practice via real-time monitoring encompassing demands, supplies and environmental variables. Mathematically these variables can be represented by state-space matrix.

DRM strategies vary for different supply technologies. All the energy generation operations are subjected to environment and energy security constrains and these are increasing. DCP developers are increasingly focusing on absorption cooling technologies operating on renewable energy technologies and low carbon emission technologies and these technologies has huge potential in the near future. The model should be redesigned particularly for penetration of renewable and low carbon energy sources required for absorption cooling.
Bibliography


Natalia Moreno Bruned, 2005. Optimization of a district Energy system in Zaragoza (Spain), Master’s Thesis in Energy Systems, Department of technology and built environment, University of Gavley.


Samuel Gyamfi, Demand response assessment and modeling of peak electricity demand in the residential sector: information and communication requirements, PhD thesis, Department of Mechanical Engineering, University of Canterbury, 2010.


(Statement given at COP-16 and CMP-6, United Nations Framework Convention on Climate Change, November 29 - December 10, 2010)


Jeff Daniels, 2011. Cool Idea, an article published on Business Excellence


