Food and Agriculture Organization of the United Nations

Technical and investment guidelines for **milk cooling centres**

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Technical authors

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Preface

Billions of people consume milk and dairy products every day. These are not only a vital source of nutrition for millions of smallholders and their families. Dairying is an essential part of integrated farming systems in developing countries and countries in transition. The share of milk in the livestock GDP of these countries is significant. Thus, milk and dairy are an important subsector in the national economies of many developing countries, providing food, regular incomes for households and sustainable livelihoods for rural farmers and small and microenterprises.

This publication examines and provides guidance on the options for investing in milk collection and cooling for smallholders. As cooling is the most widely used technique for preserving raw milk, the publication focuses on the planning, feasibility, start-up and operation of milk cooling centres (MCCs). The book reviews small-scale milk cooling and preservation technologies employed around the world. It discusses the steps to be followed when establishing a new MCC and selecting appropriate equipment and technology for sustainable operation of the MCC, especially in developing and transitional countries. It also discusses precooling options that minimize the overhead costs of cooling milk. Nine milk cooling options and configurations are discussed in detail. Investors or farmers can select the option best suited to their location, depending on milk availability and access to roads, power, water, etc. Various power supplies and renewable energy options for MCCs are discussed, and the potential for using renewable energy such as solar, wind and geothermal power are reviewed and explored. The last chapter discusses basic economic indicators and financial analysis methods for operating MCCs cost-effectively.

The book aims to serve small and microenterprises, small-scale organizations, non-governmental organizations (NGOs) and government agencies by providing options from which to select suitable milk cooling systems for local areas, taking into consideration milk production and availability, and access to roads, water and an electricity supply. It also aims to serve as a reference and guideline document for the manufacturers of bulk milk coolers for small and microenterprises and for the teaching and educational institutions offering courses in dairying, food sciences and technology.

The book has been prepared by dairy and engineering experts, and an early draft was thoroughly discussed and reviewed in a three-day write-shop on "Techno-Economic Options for Milk Cooling Centres" held at FAO Headquarters in Rome from 16 to 18 December 2014. The objective of the write-shop was to elicit technical contributions from: i) the private sector; ii) the public sector; iii) civil society organizations; iv) NGOs; v) intergovernmental organizations; and vi) other potential partners. Participants provided practically applicable solutions for milk cooling, with an emphasis on energy options for MCCs in developing and transitional countries. Many experts from private-sector manufacturers of milk cooling equipment, refrigeration experts, dairy professionals, faculty members from research, educational and training institutions, and development partners participated and contributed to finalizing the manuscript.

The Nutrition and Food Systems Division (ESN) thanks all those who generously shared their expertise and field experience, time and energy in getting this book completed.

Anna Lartey
Director, Nutrition and Food Systems Division

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The authors wish particularly to acknowledge the contributions made by experts from the private sector and development partners in finalizing the manuscript during a three-day write-shop on "Techno-Economic Options for Milk Cooling Centres" held at FAO Headquarters in Rome from 16 to 18 December 2014. Participants included Mr Jean Claude Lambert, Senior FAO Consultant; Mr Frazer Moffat, lead author; Mr Christian Cesbron, Director, Cesbron Consulting and expert at the International Institute of Refrigeration; Mr Steven Gunst, Business Unit Manager, Packo, Belgium; Mr Tek Bahadur Thapa, Senior Dairy Specialist, College of Applied Food and Dairy Technology, Nepal; Mr Kasturi Lal Arora, Dairy Expert, Maxcare, India; Mr Rajat Bhardwaj, Big Ten BV, Netherlands; Mr Sonnet Malakaran George, dairy industry and losses consultant, FAO; Alessandro Flammini, specialist in greenhouse gas emissions and energy, FAO; and Eva Gálvez Nogales, Agribusiness Economist, FAO.

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Executive summary

In many developing nations, agriculture plays a major role in food security, employment and national income. The small and medium-scale dairy industry provides a means for milk producers to have a regular and sustainable income through the establishment of reliable markets for fresh milk and dairy products. Milk collection schemes provide both a secure market and a means of reducing post-harvest losses by collecting and preserving fresh milk, allowing the manufacture of quality and nutritious dairy products on a sustainable basis. Such schemes also allow the regular flow of cash and income from urban to rural areas.

The small and medium-scale dairy sector produces multiple benefits through which smallholder producers and the private sector can mobilize support for agro-enterprise development. These benefits include: i) poverty reduction though regular family income; ii) off-farm jobs; iii) environmental benefits from cost-effective and sustainable milk cooling options; iv) efficient energy options; and v) improved household food security and nutrition.

Milk collection schemes differ from country to country and no single scheme can be applied universally. Raw milk is a highly perishable product that must be collected and cooled within a few hours to reduce losses due to spoilage and to preserve quality. As milk production is often remote from markets and processing facilities, milk cooling centres (MCCs) provide the means for preserving quality through chilling and hygienic storage prior to onward transportation to processing facilities. In many developing countries, the lack of MCCs is a main limitation to the development of sustainable dairy value chains.

Milk can be cooled in two steps: precooling, followed by refrigerant cooling to 4 °C. Cooling costs at an MCC can be reduced by precooling the fresh warm milk using water from the mains supply or surface, well or groundwater. Precooling reduces the refrigeration load, thereby reducing costs and energy needs. When the temperature difference between the mains/well water and the fresh raw milk is significant, refrigeration costs can be reduced by up to 64 percent.

The final temperature of the precooled milk depends on the temperature difference between the precooling water and the fresh milk. The choice is then on whether the system should use direct expansion refrigeration milk cooling tank, ice bank refrigeration milk cooling tanks or ice builder/plate heat exchange (PHE) refrigeration combined with an insulated, unrefrigerated milk storage tank. The latter two systems build ice over a period of ten-plus hours and are more suited to locations where the electricity supply is reliable, where only a single-phase supply is available and/or where a lower tariff is applied to electricity consumption at night. Nine milk cooling and storage options have been identified, ranging from simple direct expansion to more advanced and complex integrated systems that incorporate energy- and space-saving precooling with ice bank and instant cooling technology. The advantages and limitations of each option are evaluated and presented in this publication. The most appropriate milk cooling technology or system depends on: i) the location; ii) the availability of electricity and water; iii) capacity requirements; and iv) the capital and operating costs. A major finding of this study is the clear benefit of using precooling to reduce overall electricity requirements and the capital equipment and operating costs of the MCC. The nine options identified are:

- *Option 1*: direct expansion refrigerated milk-cooling tank;
- *Option 2*: direct expansion milk cooling tank with precooling using mains or well water;
- *Option 3*: bulk milk cooling tank with precooling using mains or well water followed by instant cooling using ice water from an ice builder unit;
- *Option 4*: integrated ice bank milk cooling tank;
- *Option 5*: integrated ice bank milk cooling tank with precooling using mains or well water;
- *Option 6*: precooling of milk using precooled mains water from an integrated ice bank milk cooling tank;
- *Option 7*: ice bank milk cooling tank with precooling using mains or well water followed by instant cooling using ice water from an integrated ice bank;
- *Option 8*: instant milk cooling using a PHE and an ice bank tank;
- *Option 9*: containerized MCC.

Enterprises planning to establish an MCC should have a basic blueprint of the requirements for where and how to create the facility. Technical guidelines on buildings, services and equipment options and the configurations that provide the maximum benefits at the lowest cost, including energy-saving technologies, should also be considered. An additional benefit of having guidelines available is that it enables the application of standards and best practices. The requirements for establishing an MCC vary from country to country, and a study should be conducted to determine the factors relevant to the specific MCC. Major considerations to be taken into account when planning an MCC are discussed in detail in chapter 9.

After carrying out a rapid assessment and planning an MCC for a specific area, a feasibility study should be conducted. In addition to the factors taken into consideration while planning the MCC, the study should also examine the techno-economic feasibility of the proposed investment for self-financing or to support submission to a bank for a loan. Key indicators to be assessed are the break-even analysis and the internal rate of return. There must be sufficient margin between the purchase and selling prices of the milk to cover overhead costs (fixed and variable) and provide enough profit to repay the loan, plus interest, to the bank within the scheduled period, taking into account any MCC operating overheads that are absorbed by a milk processing plant. The economic viability of the MCC depends on many factors, including capital and operating costs. The volumes of milk collected, capacity utilization, and the purchase and selling prices of fresh and chilled milk – including competition from other buyers and sellers – govern the sustainability of the cooling centre in the long-run.

It is important to keep the initial investment in milk cooling to a minimum. However, the equipment and facilities must be adequate for preserving milk quality and safety. The use of rented buildings and reconditioned, second-hand or locally fabricated (rather than imported) milk cooling and support equipment should be considered. Initially, unit capacity may best be determined on the basis of average collection throughout the year rather than on the maximum available during the peak period of milk production. When the centre is fully operational and found to function well, further investments in a more permanent and larger purpose-built facility can be considered.

MCCs operated by milk processing companies are often treated as a "cost" in the overall milk collection scheme. Given the right conditions, centres that are owned and operated by milk producer groups, cooperatives, associations or the private sector can be profitable, provided that appropriate investments have been made in the buildings and equipment and in energy-saving methods. A high internal rate of return seems to be possible when the MCC or dairy enterprise is managed and governed effectively.

Electrical power is the key requirement for operating a cooling centre, and when the electricity supply is unavailable or unreliable, backup generators are commonly used. Alternative sources of electricity from renewable energy, primarily solar radiation and wind power, may offer a solution, but the high capital costs and limited reliability of such systems currently make their use questionable.

Most refrigeration systems for milk cooling require a continuous supply of single- or three-phase alternating electrical power. Solar photovoltaic (PV) and/or wind power may be options for providing a continuous power supply to a relatively small-scale MCC, but require substantial initial investments, while the necessary energy storage adds substantially to the costs, especially when battery replacement is considered. Alternative power sources for MCCs work best at a relatively small scale for off-grid applications and are most suitable when combined with non-battery power storage technology (e.g. ice banks, chemical storage and direct-driven refrigerators).

For all the options considered, it is recommended that specialists in renewable electrical power generation, energy storage and refrigeration systems be consulted to identify the most suitable solution for a given location and to determine a strategy for exploiting solar PV and wind power in the context of MCCs. Other viable renewable energy options may also be available in specific locations (e.g. geothermal energy sources). The development of renewable energy systems may be more cost-effective and viable when carried out at the community level. When establishing a renewable energy system for an MCC, possible assistance in the form of loans, grants and tax reductions from government and donor organizations should be explored.

Abstract

Dairying is an essential part of integrated farming systems in developing countries and countries in transition, where milk accounts for a significant share of livestock GDP. Milk and dairy are an important subsector in the national economies of many developing countries, providing food, regular incomes for households and sustainable livelihoods for rural farmers and small and microenterprises.

This book examines and provides guidance on the options for investing in milk collection and cooling systems for smallholders. As cooling is the most widely used technique for preserving raw milk, the publication focuses on the planning, feasibility, start-up and operation of milk cooling centres (MCCs). It reviews small-scale milk cooling and preservation technologies employed around the world; discusses the steps to be followed when establishing a new MCC and selecting appropriate equipment and technology for its sustainable operation, especially in developing and transitional countries; and examines precooling options that minimize the overhead costs of cooling milk – nine milk cooling options and configurations are discussed in detail. Investors and farmers can select the option best suited to their location, depending on milk availability and access to roads, power, water, etc. Various power supplies and renewable energy options for MCCs are discussed, and the potential for using renewable energy such as solar, wind and geothermal power is reviewed and explored. The book also discusses basic economic indicators and financial analysis methods for operating MCCs cost-effectively.

This book aims to serve as a reference and guideline document for small and microenterprises, small-scale organizations, non-governmental organizations, government agencies, the manufacturers of bulk milk coolers for small and microenterprises, and teaching and educational institutions offering courses in dairying, food sciences and technology.

Technical authors

Frazer Moffat graduated in agriculture and dairying from the University of Edinburgh and the West of Scotland College of Agriculture in 1966. He joined FAO in 1982 and was posted to India to work on Operation Flood, followed by the FAO/Milk Vita programme in Bangladesh before becoming a member of the FAO team supporting the rebuilding of the Ugandan dairy industry. In 1993, he became general manager of a large-scale intensive dairy farm and fresh milk processing company in Nigeria. Since 1997 he has worked as a consultant in dairying for FAO, other organizations and private-sector consultancy groups in many countries, including the Democratic People's Republic of Korea, Lesotho, Mongolia and Somalia. He has been a lecturer in dairy technology and dairy farm management, and joined the international division of a United Kingdom milk processing and marketing company with postings to East Africa and the Indian subcontinent. He supported the establishment of a dairy school at the University of Rezaieh in the Islamic Republic of Iran, followed by taking up the position of Managing Director for a newly established milk processing and marketing company in Saudi Arabia.

Som Khanal joined the Dairy Science Department of South Dakota State University in 2010. He has ten years of work experience in the field of dairy and food. He worked intensively on developing policies and recommendations for Nepal's dairy sector during his assignment with FAO in Nepal, where he provided technical support and consultation for the government, cooperatives and dairy entrepreneurs in establishing milk cooling centres in different districts of the country. Mr Khanal has more than three years of experience in the private and public sectors, developing and supporting dairy projects including through capacity development. His professional experience in private dairies has added value to his production experience in the dairy sector.

Anthony Bennett joined FAO in 1995. He has worked extensively in Asia and Africa in the design and implementation of dairy industry programmes, mainly for FAO and the International Fund for Agricultural Development (IFAD). Major work areas in which he has been involved include supporting countries in dairy industry strategy, enhancing the inclusiveness of dairy industry programmes and projects, and promoting and enhancing investments to optimize food security, income generation and sustainable dairy enterprise development. Mr Bennett has more than 16 years of international professional experience and is a technical editor and co-author of a number of publications on issues in the dairy industry, ranging from milk safety to dairy institutions. He holds an M.Sc. in agriculture in engineering technology from University College, Dublin and an M.A. from Trinity College Dublin.

Tek Bahadur Thapa graduated in dairy technology in the well-known milk city of Anand, India and holds an M.Sc. in dairy technology from the National Dairy Research Institute, Karnal, India. He worked for a number of years as project manager of the Hetauda Milk Supply Scheme from which the dairy cooperative movement started and expanded. He has served as Chief Executive/General Manager of the Dairy Development Corporation, the largest parastatal dairy industry in Nepal. He has also worked as senior adviser and team leader of food industry, income generation and livelihood projects in Nepal funded by the United States Agency for International Development (USAID). He worked very actively with the dairy farmers and processors who contributed to the formation of the Dairy Entrepreneurs' and Processors' Association of Nepal. From 2000 to 2004, he worked as an FAO consultant at Headquarters in Rome and in a number of countries, including Guyana, Jamaica and The Gambia. Tek most recently served as Senior Dairy Adviser for a number of integrated dairy industry development projects in Afghanistan from May 2006 to January 2014, handling a total project portfolio of US$14 million. These projects were considered very successful by the beneficiary dairy enterprises and the Government of Afghanistan and were one of the success stories of the Agriculture and Consumer Protection Department (AG) Impact series. Mr Thapa was also a founding vice chair of the College of Applied Food and Dairy Technology in Nepal offering graduate and diploma programmes in food and dairy technology and a

Master's programme in human nutrition. He is also the founding chair of the Nepal Dairy Science Association. In addition, he has served as adviser of the Dairy Cooperative Federation of Nepal and the Nepal Dairy Association. He has worked with AGS since January 2015, backstopping missions in Tajikistan and Afghanistan from April before returning to Rome. Mr. Thapa was recently honoured by Ministry of Livestock development and National Dairy Development Board of Nepal, for his outstanding contribution to the dairy industry development of Nepal, during World Milk Day, June 1, 2016. He published a series of newsletter as editor in-chief of the Nepal Dairy Science Association and has a number of books related to SME dairy processing to his credit, which have been published in Nepal.

Sonnet Malakaran George joined FAO in 2013. He has work experience in Asia, Africa and the Near East in the design and implementation of small to medium-scale enterprises for sustainable dairy industry development, including in the South Asian Ksheera Sagaram dairy development project Nature Fresh Milk. In 2014 he backstopped FAO's Eritrea dairy development project. He is one of the main technical contributors to the FAO Information Network on Post-harvest Operations (INPhO) technical hub. Mr Malakaran holds an M.Sc. in food technology, science and nutrition from Katholic University Leuven, Belgium, with an applied research thesis on *Flow ability and spray drying of milk based powders*; and a B.Tech. in dairy science and technology from Kerala Agricultural University, India. Before joining FAO he worked for Almarai and Mead Johnson (United States of America) in the team commissioning the first spray-drier for infant food formula in Saudi Arabia.

Acronyms

Ah	amp hour
BCR	benefit–cost ratio
°C	degree Celsius
CIP	cleaning-in-place
DX	direct expansion
genset	diesel-powered electrical generator
GHG	greenhouse gas
IFAD	International Fund for Agricultural Development
IRR	internal rate of return
ISO	International Organization for Standardization
kW	kilowatt
LAB	lead acid battery
Li-ion	lithium ion
LPG	liquid petroleum gas
LPS	lactoperoxidase
MCC	milk cooling centre
MCP	milk collection point
MPG	milk producer group
MW	megawatt
NPV	net present value
PHE	plate heat exchanger
PV	photovoltaic
SMEs	small and medium enterprises
SVO	standard vegetable oil
W	Watt
Wh	watt hour

Chapter 1
Introduction

Milk,[1] be it from cows, buffaloes, goats, sheep or camels, is a highly nourishing food and has been harvested by humankind for thousands of years. Milk contains numerous nutrients and makes a significant contribution to meeting the human body's needs for calcium, magnesium, selenium, riboflavin, vitamin B_{12} and pantothenic acid (vitamin B_5). Milk is a complex food containing numerous nutrients required for daily human nutrition (FAO, 2013). Milk and dairy products play a key role in healthy human nutrition and development throughout life, especially in childhood. However, raw fresh milk is highly perishable and is an excellent growth media for the microorganisms that cause spoilage. Milk quality deteriorates rapidly without treatment through the application of cooling or/and heating processes (FAO, 2000). Spoiled milk can cause illness for its consumers and economic losses for its producers. Spoilage of milk can also result in the loss of highly valuable and nutritious components of the food supply chain, thereby triggering food insecurity and safety concerns.

Through governments, the private sector and aid organizations, many developed countries have invested heavily in education, training and publicity to promote increased consumption of milk and milk products. Work in this area includes the creation of enabling policy and investment environments to support a strong dairy industry that links milk producers, processors and consumers. Development of the dairy industry can contribute by strengthening dairy production and marketing, increasing rural employment and incomes, and encouraging the start-up of small- and medium-scale food and agro-industries. It also helps reduce post-harvest milk losses, bringing substantial improvements to dairy-based food security.

The objective of this publication is to examine and provide guidance and support on the options for investing in the collection and preservation/cooling of milk to strengthen the dairy value chain and facilitate the development of infrastructure for small and medium enterprises (SMEs). As cooling is the most widely used technique for preserving raw milk (Draaijer, 2002), this publication focuses on the establishment of milk cooling centres (MCCs). Milk is cooled to ensure that nutrition and compositional losses are minimized and hygienic qualities maintained for direct sale of the milk and/or its processing into value-added dairy products (FAO and WHO, 2011) in small- and medium-scale rural processing facilities. The demand for high-quality fresh milk is increasing in line with the growing interest in ensuring safe foods in markets and the use of precise and innovative technologies in the manufacture of dairy products.

The handling of fresh milk from production to cooling and storage in MCCs involves the application of efficient technologies (ranging from the simple to the complex) and requires significant investments. Major investment requirements include: i) buildings/containers; ii) milk handling and cooling equipment; iii) power sources; iv) water supply; and v) waste disposal systems. In addition to these investments, there is also a need for training and capacity building of milk producers and collectors, and for the implementation of good manufacturing practices (FAO and IDF, 2004). Although the establishment of infrastructure for dairy farming and the organization of farmers into milk producers' cooperatives or groups require considerable time and investments, they are sure to result in significant incomes and benefits to milk producers (see Box 1).

[1] Milk is the normal mammary secretion of milking animals obtained from one or more milkings, with no additions to or extractions from the milk, which is consumed as liquid milk or processed into a range of dairy products (FAO and WHO, 2011).

BOX 1

FAO's Afghanistan Integrated Dairy Development Programme

The Integrated Dairy Development Programme in Afghanistan provides a very successful model for dairy industry development for SMEs. Under the programme, from 2005 to 2010, three dairy industry development projects were funded, in Kabul, north and eastern region by the Government of Germany, in Herat Province by the Government of Italy, and in Nangarhar Province by the International Fund for Agricultural Development (IFAD). These projects were implemented in close collaboration with the Government of Afghanistan. Beneficiary farmers were supported in organizing themselves into a three-tier cooperative structure of primary village-level dairy cooperative societies, secondary district-level cooperative dairy unions, and tertiary provincial or regional level dairy cooperative unions. Farmer members are the ultimate owners of the cooperatives' facilities and infrastructure, which were established with technical support from FAO. Farmers received on-the job training on starting, operating and managing activities along the entire dairy value chain and in feed production and marketing. On-the-job training was supported by classroom-based capacity development on business management, business plan development and implementation, and organization and management of dairy feed businesses under cooperative ownership. Five provincial/regional dairy unions were established with total membership of 5 764 families in 56 primary village-level cooperative societies and 17 secondary district-level cooperative dairy unions. The five provincial/regional dairy unions each operate and manage a modern dairy processing plant, with cumulative daily processing capacity of 27 tonnes/day and animal feed processing capacity of 27 600 tonnes/annum.

These are community-based enterprises that are owned and managed by cooperative societies. The programme has made significant contributions to social empowerment and increased participation from women. More than 87 percent of the income from milk sales has gone directly to women, who have been able to prioritize its use to maximize the benefits for their children and all family members. The programme has generated employment at the local level along the entire chain of milk production, collection, transportation, processing and marketing, including the production and marketing of animal feed. About 440 off-farm jobs have been created at the grassroots level. The average annual income of each farmer has increased from US$374 to US$754 through sales of surplus milk production (2005–2013). The approach has contributed to reduced imports and improved food security by injecting locally processed and value-added fresh milk products into the market. By December 2013, US$6.7 million had been transferred from urban to rural areas through the sale of 21 837.9 tonnes of good-quality raw milk from cooperative members to dairy plants.

New skills and capacities have been developed in the operation and management of dairy businesses. The programme has triggered interest in developing and strengthening dairy industry development further among senior government officials and the farmer members of cooperative dairy unions.

Source: FAO, 2014b.

This publication focuses on the technical and economic options for establishing and operating MCCs, which are the primary points or gateways for the flow of milk from farmers to dairy processing plants. MCCs are therefore at the centre of all activities related to regular milk collection and cooling, quality testing and management of the supply cold chain.

The increasing costs of non-renewable fuel and electricity contribute considerably to hikes in the total operating costs of MCCs. To control these costs, it is therefore essential to investigate the potential for using smart and innovative technology and equipment, underlining energy- and space-saving techniques. However, there may be challenges to finding and applying such measures at the local level. Most milk cooling equipment is designed and manufactured for use in conditions where a regular and reliable electricity supply is available. The main alternatives in developing countries are diesel-powered generators and solar panels (in remote geographical locations).

The potential for utilizing renewable stand-alone energy options – primarily solar thermal cells, solar photovoltaic (PV) cells and wind turbines – is being investigated, and research and development are being undertaken in this area. This publication examines renewable energy options in the context of their application to MCCs.

Chapter 2

Production of fresh and clean milk

To a great extent, the hygienic quality of fresh milk is determined by milk handling practices at the milk producer level. Poor-quality of milk at the farm level cannot be corrected further up the dairy value chain. The cooling or processing of milk will not improve its hygienic quality. Implementation of clean milk production at the producer level is therefore essential (FAO, 2014a). Training programmes should be put in place to educate producers on the benefits of clean production. The use of incentive payments for milk producers whose fresh milk is of premium hygienic quality may be considered as a component of efforts to improve milk hygiene as such improvements contribute to reducing milk losses and waste due to spoilage. Better hygiene ensures better-quality milk and milk products. Further information on this subject is available in FAO's *Milk Testing and Payment Systems Resource Book: a practical guide to assist milk producer groups* (FAO, 2009) and the *FAO Dairy Gateway* at: www.fao.org/agriculture/dairy-gateway/dairy-home/en/.

PHOTO 1
Milk transportation from MCC to the Herat Livestock Development Union processing plant at Herat, Afghanistan

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PHOTO 2
Milk collection centre at Mazar, Balkh, Afghanistan

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PHOTO 3
Milk reception at Kabul Dairy Union plant at Guzergah, Kabul Afghanistan

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Chapter 3

Rural milk collection, cooling and preservation

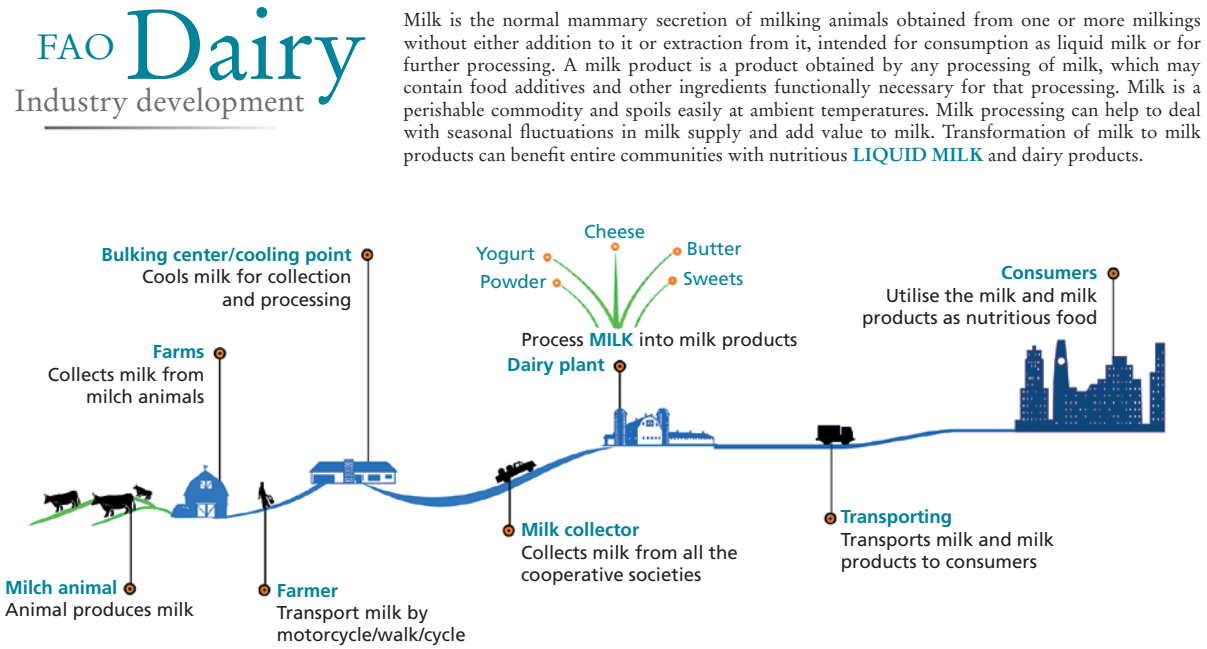
3.1 FRESH MILK DELIVERY

Fresh milk is collected, transported and delivered to MCCs in a number of ways, as shown in Figure 1.

Milk producers may deliver directly from the point of production to collection points. Producers who are distant from collection points may sell their milk to intermediaries or cooperatives, which collect the milk from producers and deliver it to the MCC. In other cases, a milk producer group may establish organized milk collection points (MCPs) where milk is temporarily bulked up in milk cans for delivery to the MCC. Animal-powered transport options, rickshaws/bicycle, boats, motorized transport, river, rail, etc. can all be used for milk delivery to MCCs, depending on their availability and feasibility. The main issue in milk delivery is that all the fresh milk collected must be delivered to the MCC and cooled within three to four hours of milking, otherwise it starts to deteriorate (FAO, 2004).

In situations where fresh milk cannot be delivered within three to four hours, such as when it is collected in the evening, measures must be taken to preserve the milk to minimize microbial growth and prevent spoilage. In the milk collection chain, a major cause of poor quality is the use of unhygienic containers to store and transport the milk. Good hygiene practices at all stages of milk collection are very important. Milk producers and other people involved in the collection chain should be trained to use specially designed milk cans (FAO, 2002) that can be cleaned and sanitized efficiently. The use of proper cans also reduces spillage during transportation. Such cans are made from aluminium alloy or stainless steel, and common sizes range from 10 to 50 litres (such as the standard 40-litre milk can) (FAO, 2009) (Figure 2).

FIGURE 1
FAO rural dairy collection and dairy value chain



Source: INPhO Web site (http://www.fao.org/in-action/inpho/home/en/).

FIGURE 2
Aluminum alloy and stainless steel milk cans of 10, 20 and 40 litres

Source: Sonnet Malakaran George, 2015.

3.2 MILK COLLECTION POINTS

Figure 3 illustrates the approach applied to identify the most appropriate way of developing and establishing an MCC in the field.

In rural areas, access to markets for surplus fresh milk is often very limited. It requires a degree of organization to ensure that milk collection and delivery take place daily and economically. The need to keep transport and cooling time to no more than three to four hours is a major factor to be considered in deciding the location of MCPs and MCCs. The establishment of MCPs and milk producer groups, and the delivery of milk from MCPs to an MCC involve the use of several low-cost inputs. Producers and milk suppliers should agree on a suitable location for the MCP, which can be a simple, low-cost shelter (existing or specially constructed) for milk collection and storage operations. The MCP could be equipped with basic milk testing equipment such as: i) weighing scales; ii) milk cans; and iii) can washing facilities. Milk delivered to the MCC has to be tested organoleptically and with a lactometer to determine its density. Further testing, such as the alcohol test and the clot-on-boiling test, may be performed to determine the stability of the milk proteins (FAO and WHO, 2011). At every MCP and MCC, collection records should be maintained for each producer, including the quality and quantities of milk delivered, for calculating regular payments.

3.3 SMALL-SCALE MILK COOLING AND PRESERVATION TECHNOLOGIES

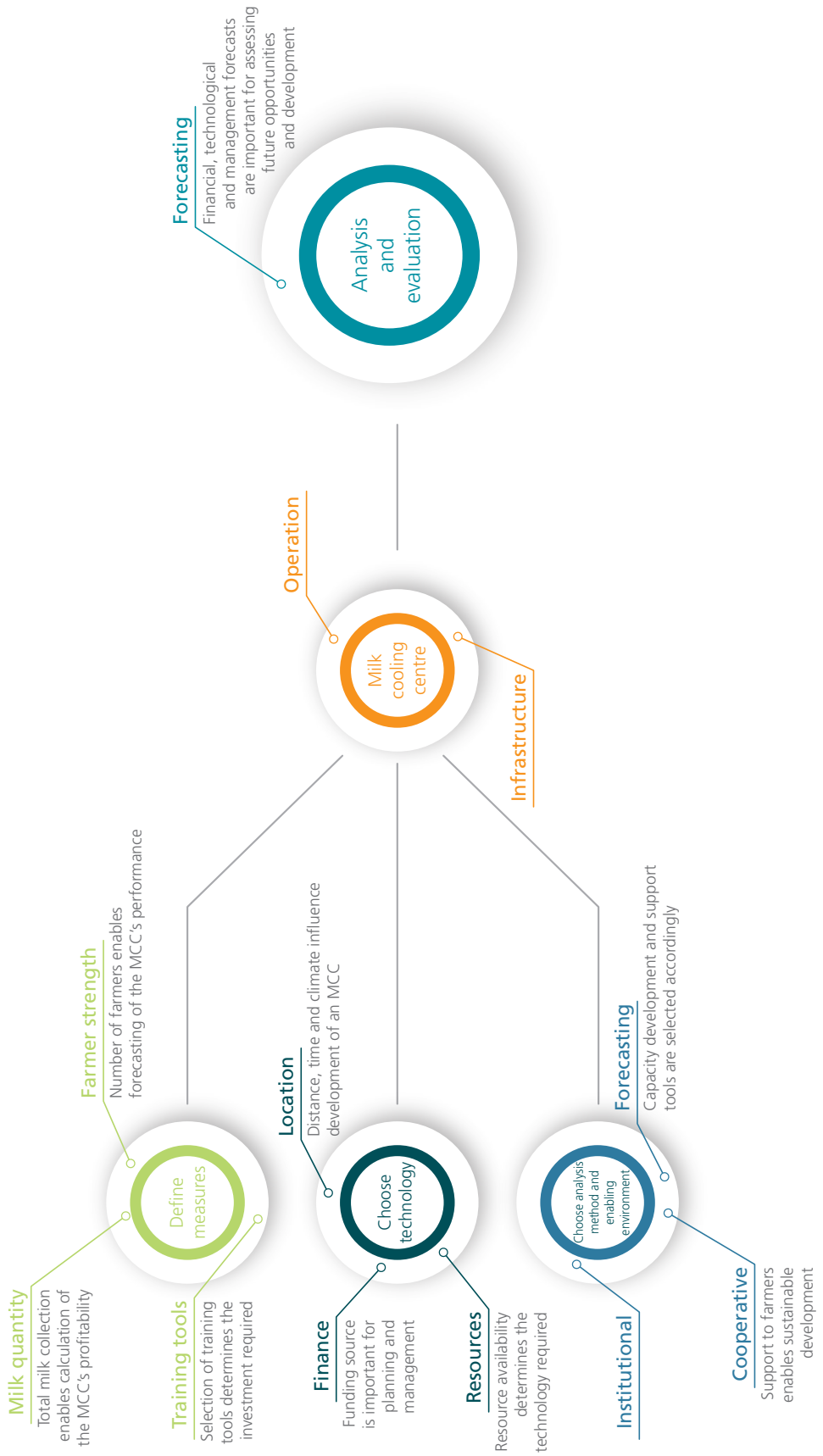
Warm fresh milk should preferably be cooled immediately after milking to preserve quality and prevent spoilage (FAO, 2002). Cooling to 10 °C within two hours of milking and to 4 °C within three to four hours is essential (FAO and WHO, 2011), but more rapid cooling is much preferred (FAO, 2015b). In many temperate and tropical countries, refrigerated cooling systems may not be available at the producer or MCP level. The methods for cooling to 10 °C and below are governed by local circumstances and simple small-scale methods can be employed (FAO, 2015b), as described in the following subsections.

Evaporative cooling using a charcoal cooler

Evaporative cooling is of very limited use other than for small-scale and domestic applications. In this system, the heat from the milk is used to evaporate water contained in a charcoal structure, thus removing heat from the milk and eventually cooling it (Figure 4).

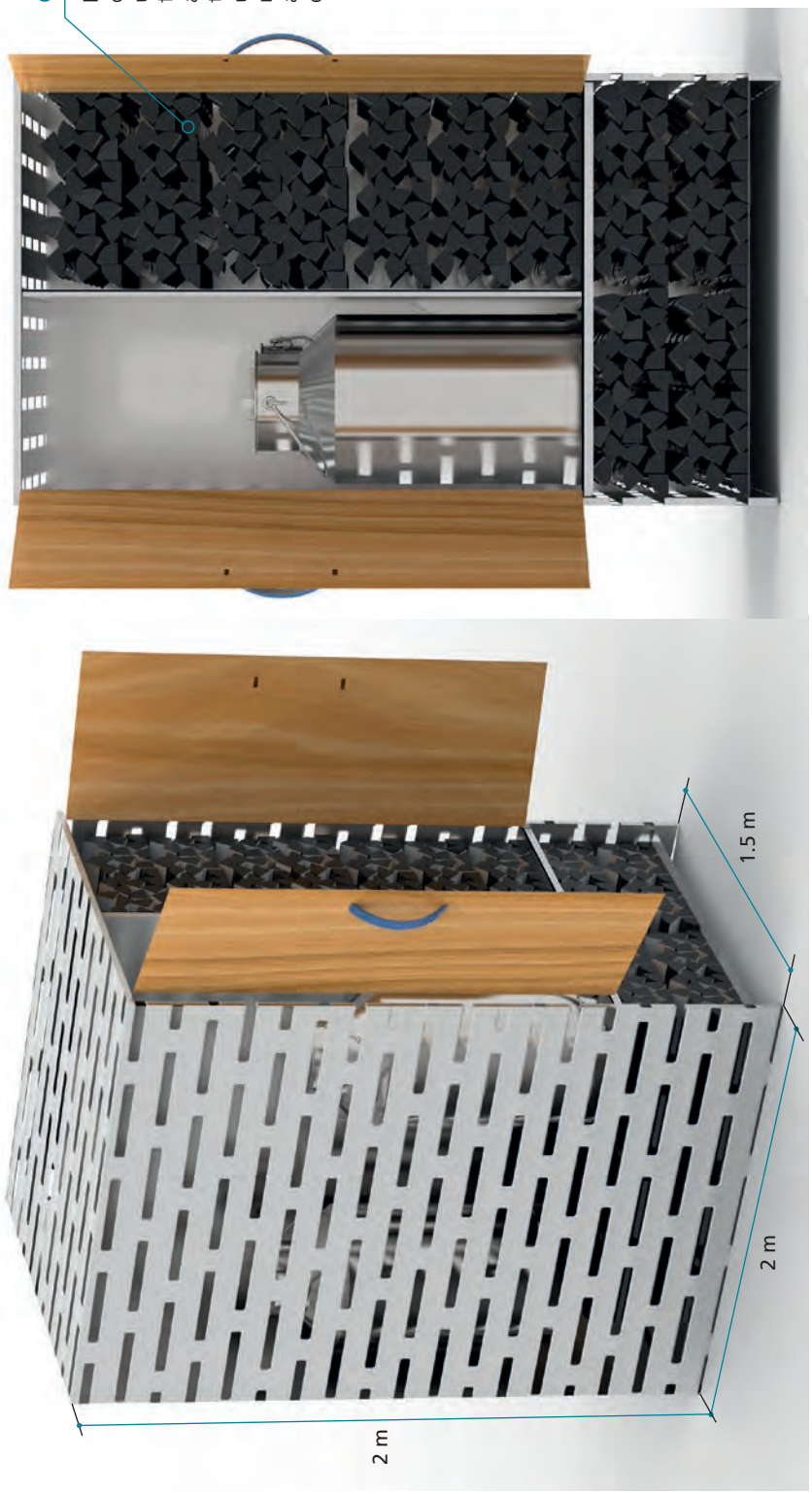
In very small-scale operations, evaporative cooling can reduce the temperature of warm milk, but this system has limitations because it depends on the difference between the wet- and dry-bulb temperatures of the surrounding air. As the relative humidity of the air increases, the performance of an evaporative cooling system will decrease, limit-

FIGURE 3
The pictorial representation of milk cooling centre establishment



Source: Frazer Moffat and Sonnet Malakaran George, 2015.

FIGURE 4
Charcoal cooler with milk cans



Source: Sonnet Malakaran George and Tek .B. Thapa, 2015.

ing its use in moist climates with high humidity (Kitinoja and Kaper, 2002). Evaporative cooling is most effective in climates where the relative humidity is less than 30 percent. If the wet- and dry-bulb temperatures of the air are known, the potential rate and extent of cooling can be predetermined from a psychometrics chart (Engineering Toolbox, no date).

Cooling with natural water systems – mains, well or groundwater

Immersion cooling methods include placing the milk cans in a stream, river, lake or tank (Figure 5). This method is most effective when the water temperature is 10 °C or below. Cooling milk to below 10 °C slows bacterial growth.

Diverting the water source to a cooling tank in which milk cans are placed is another common method. When available, ice can be added to the water tank to facilitate the cooling, but ice should never be added directly to warm fresh milk to cool it. To avoid any heating effect from the surrounding air, cooling tanks should be insulated.

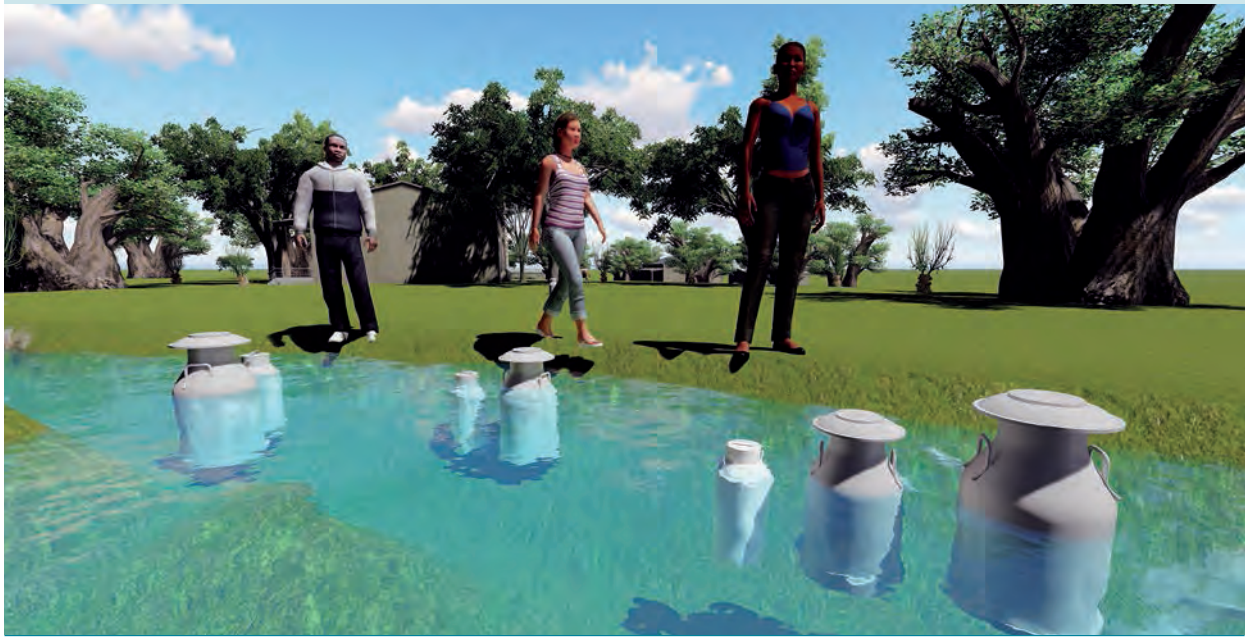
Surface milk coolers (open cooling systems): An open cooling system is based on surface coolers that use pressurized water from the mains or pumped from a natural source. Surface coolers can be constructed from horizontal stainless steel pipes attached to a vertical metal plate; the cooling water is passed through the pipes. Warm milk is fed on to the vertical plate from a small tank mounted at the top of the unit. The milk cools as it passes over the plate and is collected into milk cans (Figure 6). As they are open to the air, surface coolers are subject to contamination from dust and insects, and considerable care has to be exercised to ensure correct cleaning and sanitation.

Refrigerated immersion cooler or cooling rings

Immersion cooling rings also use pressurized water from the mains or pumped from a natural source and can be used to cool milk in cans. In this system, a perforated tubular ring is placed over the neck of the milk can and cold (or iced) water is passed through the ring to run down the exterior of the can and cool its contents.

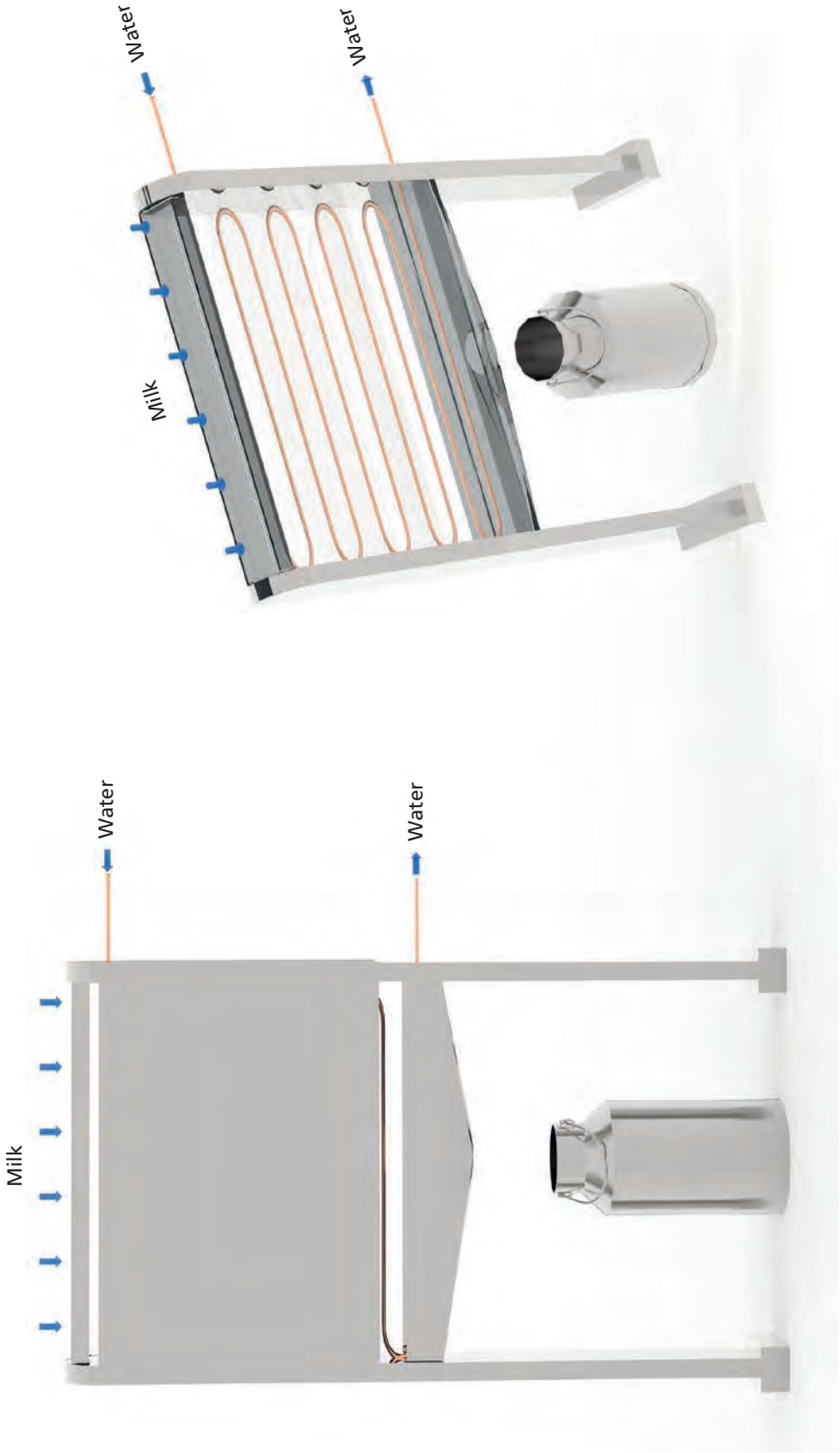
A small-scale refrigeration system can be used for immersion cooling where a single-phase power supply is available. The refrigeration system is attached to a cooling head, which is inserted into a can of warm milk or a specially designed insulated stainless steel container with capacity of 25–125 litres (Figure 7). A refrigerant is passed through the immersion coil to reduce the milk temperature. The system often includes a trolley to allow easy transportation of the milk tank. Such systems may be of use in very small MCCs or privately owned milk cooling stations or milk shops.

FIGURE 5
Cooling using natural water systems



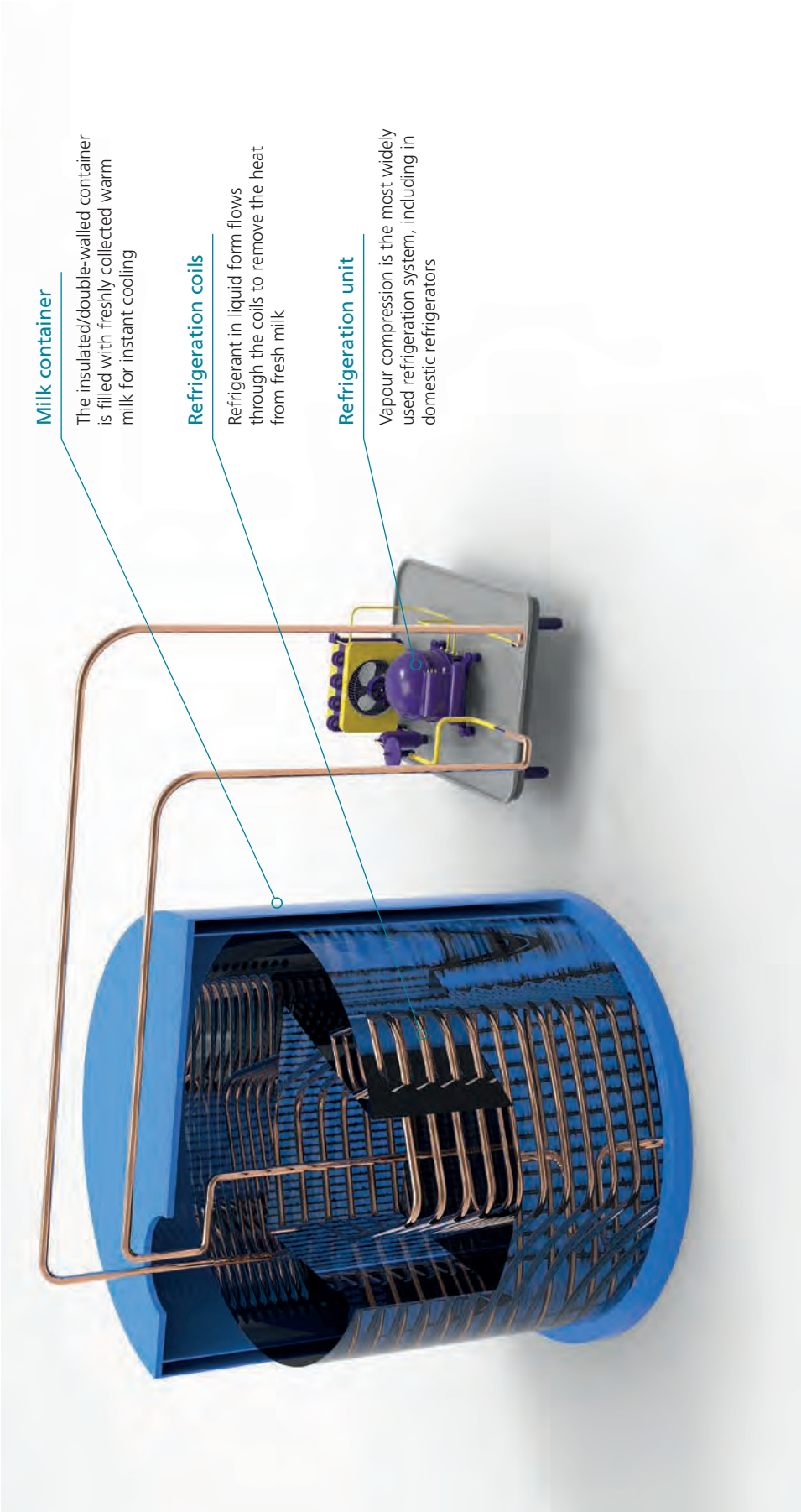
Source: Sonnet Malakaran George, 2015.

FIGURE 6
Surface milk cooler



Source: Sonnet Malakaran George, 2015.

FIGURE 7
Immersion cooler with refrigeration unit and insulated cooling and storage container



Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

There has been much research and commercial interest in reducing losses in the dairy value chain (FAO, 2015b). Current research and development activities include investigating single-can cooling using a range of energy sources such as solar and other renewable systems.

Technologies for small-scale milk cooling using renewable resources include solar energy PV panels for up to 200 litres of milk. Several companies are developing milk cooling facilities powered by PV cells for higher capacities.

3.4 THE LACTOPEROXIDASE SYSTEM OF MILK PRESERVATION

The cooling of raw fresh milk to below 4 °C as soon as possible after milking – and within three to four hours at the most (FAO and WHO, 2011: 210) – is recognized as the best way of preserving quality and avoiding spoilage (FAO, 2015a). As this is not possible in many countries, an alternative means of short-term preservation is available through the use of an approved preservation aid. The lactoperoxidase (LPS) system is a safe milk preservation method that can be used in situations where milk transportation from the producer or MCP takes a long time and where no cooling facility is available or affordable. It is designed to be used by trained people within 30 minutes of milking at the producer's farm or the MCP (FAO, 2005).

LPS is an enzyme that exists naturally in milk and slows the growth of spoiling bacteria. The effect of LPS depends on the temperature, but even at 30 °C, it can prevent souring of the milk for seven to eight hours provided the milk is of reasonably good hygienic quality. LPS can help minimize post-harvest dairy losses and waste. The system cannot improve the bacterial quality of the milk but maintains it at the level that it was when the LPS was applied, helping to enhance and maintain clean milk production at the producer level (FAO, 2006). The LPS system is not an alternative for clean milk production practices, but it delays bacterial growth and helps maintain the milk in as healthy a condition as it was when drawn from the udder (FAO, 2002).

The international authority on food standards, the Codex Alimentarius Commission, has approved the national and international use of the LPS system of milk preservation. Dairy regulation in individual countries may require that the system be adapted (FAO, 2006).

The cost of applying the LPS system is about US$0.01 per litre of milk. In-country pharmaceutical companies can obtain the ingredients and formulate and package the LPS, which reduces costs and improves availability.

Further information on the LPS system of milk preservation, including guidelines on its use, can be found on the FAO Web site,[2] in FAO, 2006 and in the Codex Alimentarius *Guidelines for the preservation of raw milk by use of the lactoperoxidase system* (CAC/GL 13-1991).

[2] http://www.fao.org/ag/againfo/themes/documents/LPS/dairy/mpv/Lactoperoxidase/faqanswer.htm

Chapter 4

Milk cooling centres

4.1 OVERVIEW

In many countries worldwide, MCCs – also referred to as milk collection, milk chilling or milk bulking centres – have been established to the benefit of milk producers and national dairy development. Such centres provide a secure market for raw fresh milk and a regular financial flow from cities to rural areas, encouraging dairy producers to increase their milk production (FAO, 2014a). MCCs have also contributed significantly to food security through the reduction in post-harvest losses of milk (FAO, 2015c).

MCCs are located between the milk producer and the milk processing plant. Before arriving at the MCC, milk may be collected at an MCP where producer groups bulk up milk from many producers for onward transportation to the MCC (FAO, 2002).

MCCs can serve as focal points where milk producers meet and discuss common interests, agricultural extension services and training activities covering all aspects of milk production are provided, and farming inputs are distributed (FAO, 2002). The type and size of MCCs vary from country to country depending on the geography, local climate and socio-economic conditions. Thus, there is a need to carry out a feasibility study before setting up a new MCC to determine whether sufficient milk, land, buildings, water, electricity and labour are available, as illustrated in Figure 3. The requirements for feasibility studies are outlined in chapter 9 and Annex 1. Major factors to be taken into account when setting up a new MCC are discussed in the following section.

4.2 LOCATION AND GENERAL BUILDING REQUIREMENTS FOR MILK COOLING CENTRES

Small to medium-sized MCCs have capacities that range from 500 to 5 000 litres and require significant investment in the milk collection and supply chain.

Before establishing an MCC, an in-depth study should be conducted to determine the milk production potential of all the milk sheds and/or areas around the site of the proposed MCC. The potential quantity of milk likely to be available for collection needs to be estimated, based on accurate forecasting of the likely growth in milk production resulting from MCC activities. The design of the milk collection system should take into account whether there will be one or two milkings/deliveries per day and the frequency of collection. Milk producers' current marketing activities and willingness to sell raw fresh milk to an MCC (FAO, 2002) should be identified and quantified in economic values (FAO, 2009). It is crucial that the milk producers and producer groups that will contribute to the MCC are fully involved in planning and organizing its activities, as their full participation is vital in ensuring effective collection of clean milk (FAO, 2002).

The geographical location of the MCC is very important and should be clearly defined to ensure that warm fresh milk can be transported from the producer to the collector for cooling within two to four hours. Use of the LPS system of milk preservation may allow delivery of fresh milk up to eight hours after milking (FAO, 2006).

A temporary site in rented/leased property may be considered when the milk cooling facility is first established. The economic viability of the facility, its impact on the local community and the response of milk producers to its presence should be evaluated for at least a year before deciding to establish a permanent facility (Kitinoja and Kader, 2002). The degree of competition from other businesses operating collection schemes in the same milk shed, and the percentage shares of available milk collected by existing buyers in both the formal and informal markets should also be evaluated during this initial period.

MCC site selection will be dictated mainly by:

a. proximity to an all-weather road to allow access for delivery/collection trucks – including bulk milk tankers – all year round;

b. access to the national grid electricity supply, which should preferably be a reliable three-phase power supply;
c. access to a supply of potable water from either the mains or a tube well;
d. good drainage so that buildings are not subject to subsidence or encroachment;
e. vicinity to a village to facilitate the employment of MCC personnel and provide increased security.

Figure 8 shows the exterior of an MCC.

The total area required (Figure 13) will depend on the capacity of the milk cooling and storage tank and the support equipment involved, including milk reception tanks, weighing scales, milk/water pumps and piping, heat exchangers and a standby electricity generator. Space should also be available for a basic laboratory, an office and a toilet (Figure 9).

Additional space may be required if the MCC is to serve as a distribution point for milk production inputs such as support materials, equipment and animal feedstuffs. However, this space should be separated from the milk handling areas to avoid cross-contamination and possible odours from the concentrate feed. Facilities for can washing should be considered, to enable appropriate washing of the milk cans and containers in which farmers sell their milk.

MCC buildings must be clean and well ventilated. Expensive buildings are not necessary, as long as the following conditions are met:

a. Walls and roofing provide protection from foreign matter and unwanted substances.
b. There are sufficient windows to allow proper lighting and air movement (Kitinoja and Kader, 2002).
c. All internal walls up to a height of 2 m are smooth-rendered and tiled or painted. Other wall surfaces and ceilings should be painted with high-quality emulsion paint.
d. The building must be well ventilated to provide the refrigeration system with sufficient air to cool the condenser unit (in case of air-cooled milk).
e. Entrance areas, especially at the milk reception point, should be of smooth-rendered concrete and well drained.
f. External walls must be well maintained and painted to provide a clean and hygienic impression of the MCC.
g. A septic tank or other suitable system for toilet and other waste should be established in a separate space.

An elevated, overhead storage tank and environment-friendly disposal system for wash water is required. If milk is precooled with mains or well water, there is need for an acceptable means of disposing of used, warm water. Discharged potable water from precooling can be collected in a separate tank and used to clean milk cans and the MCC. Unused surplus water from the system can be directed to the local community for use as drinking-water or for irrigation, as appropriate.

The dimensions of the building will vary according to the quantity of milk being handled and the cooling capacity. When planning the layout of equipment, 1 m of service space should be provided to allow easy access for cleaning, repair and maintenance.

Guidance on the dimensions and layout for an MCC with one or two milk cooling tanks of 1 000, 3 000 and 5 000 litre capacity is provided in Tables 1–3 and Figures 11 and 12.

A properly functioning MCC requires a purpose-built building (Figure 14) with dedicated areas for a milk reception dock, milk cooling and cleaning-in-place (CIP) facilities, a laboratory (Figure 10), appropriate stores, a generator room, toilets and other facilities. Such a building can be rented or leased until the milk collection scheme has been established and is operating successfully. It is also possible to operate an MCC from a mobile structure – such as a 6–12 m-long shipping container – while the milk collection scheme is being established. Once the mobile MCC is operating with sufficient milk to sustain the scheme, a new purpose-built building can be constructed with the necessary basic facilities. When this building is ready, the milk cooling equipment and facilities can be transferred, installed and commissioned.

4.3 MILK COLLECTION SCHEMES

A milk collection and cooling chain can be established and owned by a private company or individual, the government and/or the member farmers of cooperatives. In the past, MCCs were supported by governments and international development organizations. In some countries, large State-owned parastatal companies or cooperatives used to have a monopoly in overall dairy development and investment activities, including in milk collection, processing and marketing.

Investments in buildings, plant and equipment should be driven by commercial considerations and goals linked to food security and sustainable development. The increased participation of small- and large-scale private, commercial businesses in

FIGURE 8
Milk cooling centre exterior

Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

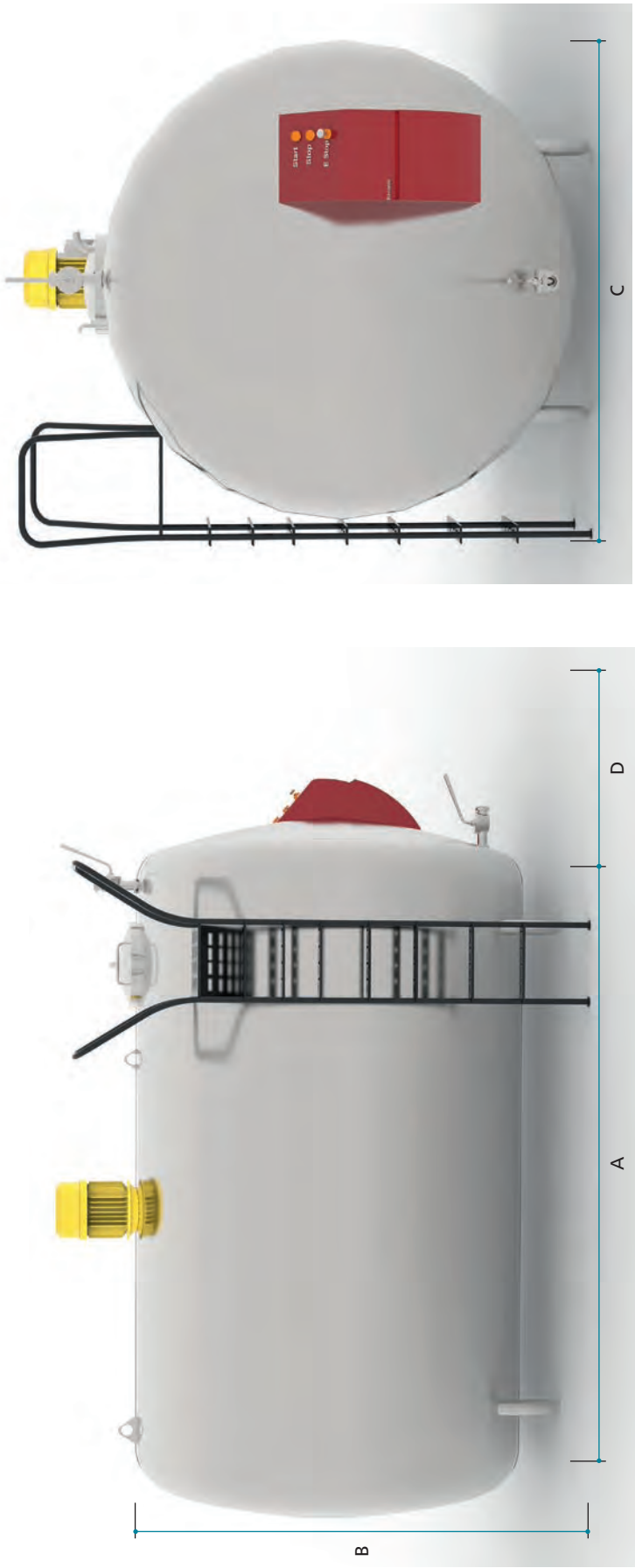
FIGURE 9
Milk cooling centre layout and cross-section

Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

FIGURE 10
Milk cooling centre laboratory layout

Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

FIGURE 11
Milk tank dimensions



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

the dairy sector, together with the privatization of State-owned dairy schemes, has resulted in greater competition throughout the sector, including at the milk collection level. With strong global demand for milk and dairy products, competition for purchasing fresh milk helps to increase the incomes of milk producers. At the buyer level, this competition requires that considerable care be exercised when making decisions on investments in milk collection technologies and processes.

Any decision on fresh milk handling, cooling and storage capacity has to be carefully considered to avoid either over- or underequipping the MCC and to control capital investment, operational and maintenance costs. Milk production at the farm level varies throughout the year, with a peak period of maximum daily production and a lean period when production is at its lowest. These peak and lean periods vary considerably from region to region and country to country.

Seasonal calving affects the supply of milk to an MCC. Similarly, countries that are subject to extremes of weather such as long hot dry spells or sub-zero winter temperatures are especially affected, resulting in periods when milk production virtually ceases. MCCs are forced to operate at minimal capacity during these periods.

In developed countries, the conservation of fodder and the use of concentrate feed during the hot season or in winter make it possible to maintain milk production at a more consistent level throughout the year. In addition, dairy cattle are housed in protective buildings during periods of extreme weather. These provisions are not viable or practical in many developing countries, resulting in high milk output in the peak period and low milk availability during the lean period. These fluctuations in milk availability force MCC operations to alternate between full capacity and underutilization, and some MCCs sometimes have to close completely because no milk is available. In some countries, the peak period is very high but lasts for only a few months. In these cases, for economic reasons, it is often impossible to collect all the milk produced during the peak period, and/or there is no market or insufficient milk processing

TABLE 1
Floor area and height requirements for milk tanks

Capacity (litres)	A Length (m)	B Height (m)	C Width (m)	D Floor area for operator (m^2)
500–1 000	1.2–2.3	0.92–1.6	0.8–1.2	1.0
1 000–2 000	2.3–2.6	1.6–1.8	1.2–1.4	1.0
2 000–3 000	2.6–3.1	1.8–2.0	1.4–1.6	1.0
3 000–4 000	3.1–3.3	2.0–2.3	1.6–1.8	1.0
4 000–5 000	3.3–3.4	2.3–2.4	1.8–1.9	1.0

Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

TABLE 2
Space requirements for milk cooling tanks (including compressors)

Single-chamber tank			Two-chamber tanks		
1 000 litre	3 000 litre	5 000 litre	1 000 litre	3 000 litre	5 000 litre
12.5 m^2 (135 ft^2)	17.5 m^2 (188 ft^2)	27.0 m^2 (290 ft^2)	21.5 m^2 (232 ft^2)	27.5 m^2 (296 ft^2)	35.25 m^2 (380 ft^2)

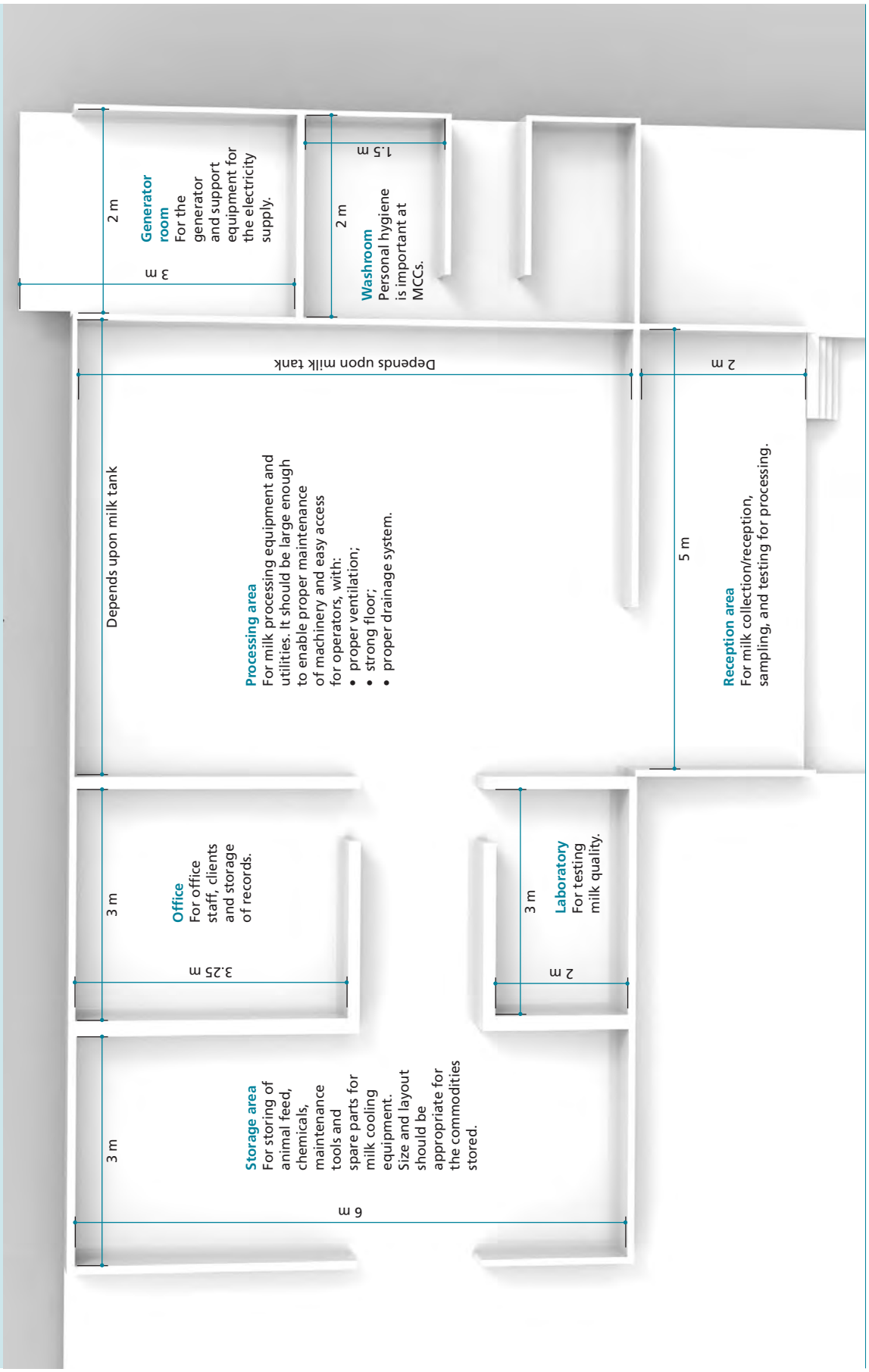
Source: Frazer Moffat, 2015.

TABLE 3
Space requirements for milk collection centres

Milk reception: 12.5 m^2 (135 ft^2)	Store: 18.0 m^2 (194 ft^2)
Laboratory: 6.25 m^2 (68 ft^2)	Generator room: 6–8 m^2 (64–86 ft^2)
Office: 6.25 m^2 (68 ft^2)	Toilet/washroom: 6 m^2 (64ft^2)

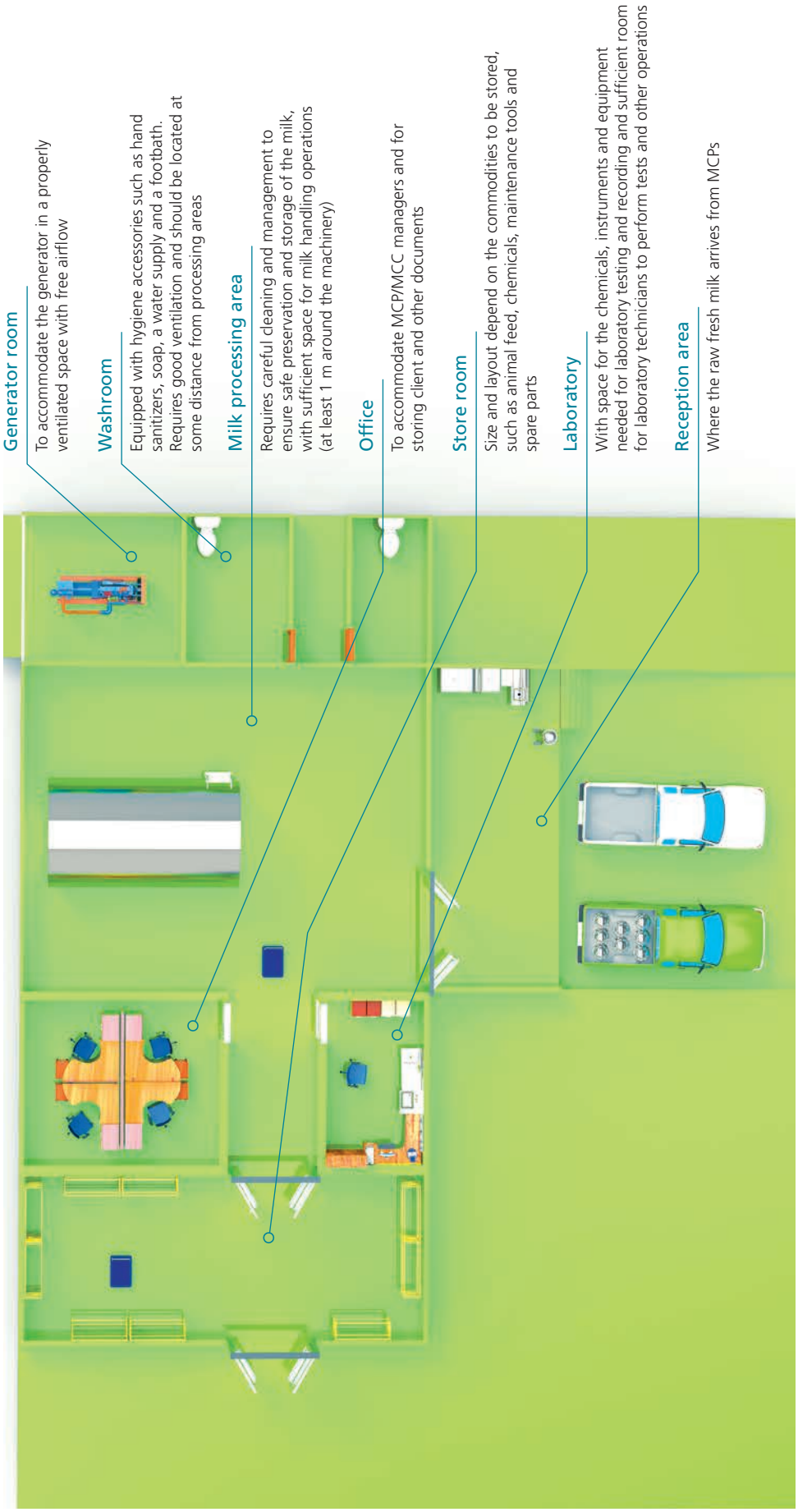
Source: Frazer Moffat, 2015.

FIGURE 12
Section view and floor layout



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

FIGURE 13
Floor layout and description



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

capacity to absorb it. In many countries, surplus milk is used to manufacture long-life, condensed and dried milk products that can be stored and used during the lean period.

There is no fixed percentage capacity utilization that can be applied as a common standard for all milk collection schemes and MCCs. Given the fluctuating intakes of milk over a year, capacity utilization will vary and these varying levels must be estimated prior to setting up a milk collection scheme and MCC. The capacity utilization of an MCC is calculated from its annual operations, from which realistic monthly averages can be defined. MCCs are not necessarily profit centres; all costs may be absorbed into the overall costs of milk collection and reflected in the factory gate price, especially if the MCC is owned and operated by a milk processing plant. For MCCs that are owned d by milk producer groups (cooperatives/associations) and the private sector, part of MCC profits should be used to cover the operational and maintenance costs of the MCC.

Profits generated by an MCC can be used to pay premium prices to the milk producers and to provide them with inputs such as veterinary services, feed, training and capacity building. This additional income will encourage producers to produce higher-quality and larger quantities of milk, helping to sustain operation of the MCC.

Before investing in an MCC, a detailed business and financial analysis should be carried out. In dairy development projects funded by donor agencies, the priority objectives are often to collect as much milk as possible as a way of providing rural employment, boosting rural income and increasing food security. This approach to establishing a milk collection scheme is often successful, although it may not be financially viable in the short term.

FIGURE 14
A rural milk cooling centre

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

Chapter 5

Milk reception, cooling and storage systems

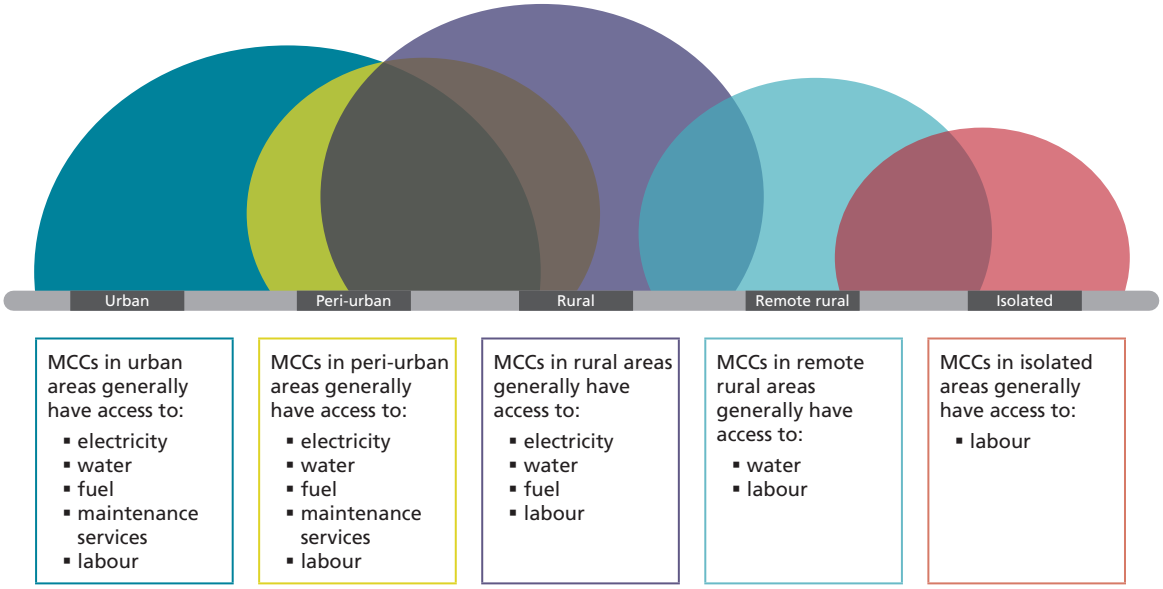
5.1 MILK RECEPTION

The milk reception area (Figure 16) should be designed for receiving fresh warm milk in cans, testing it for compositional and hygienic quality, weighing – and possibly precooling – it, and cooling it instantly by passing it to refrigerated milk cooling and storage tanks. The milk cans are cleaned and sanitized at this last stage.

The range of milk reception (and dispatch) equipment required will vary depending on the design and set-up of the MCC, but is likely to include:

a. simple platform with spring/digital weighing scales;
b. milk dump tank with or without a weighing system;
c. milk filtration and clarification system;
d. milk precooling equipment (optional);
e. milk pump (for loading bulk milk into transportation tankers);
f. tanks and accessories for manual cleaning or cleaning-in-place (CIP);
g. stainless steel milk pipes, valves and fittings;

FIGURE 15
Resource requirements vs milk cooling options



Resources required for milk cooling at an MCC:

- water (mains/well)
- water (mains/well), PHE
- water (mains/well), PHE, water storage for reuse
- water (mains/well), PHE, water storage for reuse, batteries, integrated ice bank tanks
- water (mains/well), PHE, water storage for reuse, batteries, integrated ice bank tanks, chilled water from external source

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

h. unit for manual or powered cleaning of milk cans;
i. tanks for cleaning water, detergents and sterilizing agents;
j. laboratory equipment for testing the milk's butterfat and total solid composition, freedom from adulteration and microbial quality;
k. office equipment.

The actual requirements will depend on the MCC's capacity and the national dairy policy and regulations. The facilities can be adjusted depending on the availability of resources, as long as mandatory quality standards are not compromised.

5.2 MILK COOLING AND STORAGE

Fresh warm milk should be cooled to 4 °C after it arrives at the MCC in the morning and late afternoon/early evening. This cooling requires considerable use of energy, suitable refrigeration equipment and insulated storage tanks designed specifically for milk. There are several ways of satisfying these requirements and these should be examined, bearing in mind the need to minimize operating costs related to cooling.

Cooling systems for MCCs include a refrigerated milk cooling and storage tank or several tanks, stand-alone ice water systems, and various precooling options. All MCCs require a single- or three-phase electricity supply, a potable water supply and a system for reusing or disposing of the water used in precooling.

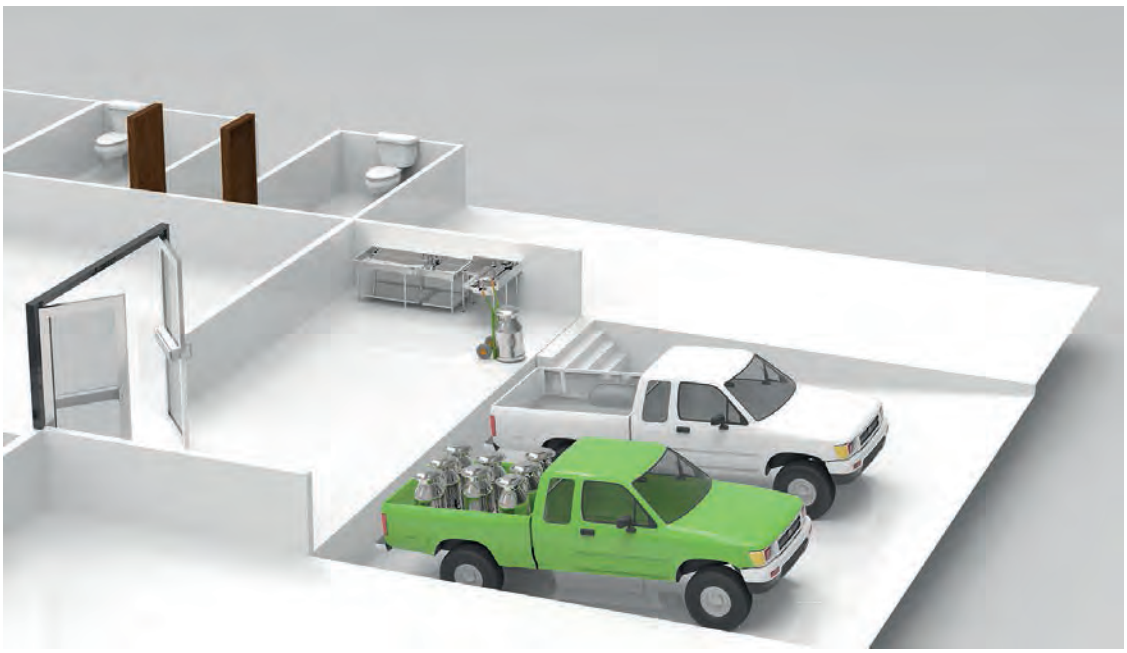
Chilled milk is normally transported from the MCC daily or every two days in insulated bulk milk road tankers, or transferred into hygienic milk cans for delivery to milk processing plants or other points of sale such as shops or catering establishments. When milk is collected every two days, rather than daily, milk collection costs are reduced, while refrigeration cooling costs at the MCC increase slightly.

5.3 REFRIGERATION SYSTEMS

The most commonly used refrigeration system employed in milk cooling equipment for MCCs is vapour compression. Figure 17 illustrates the basic refrigeration cycle.

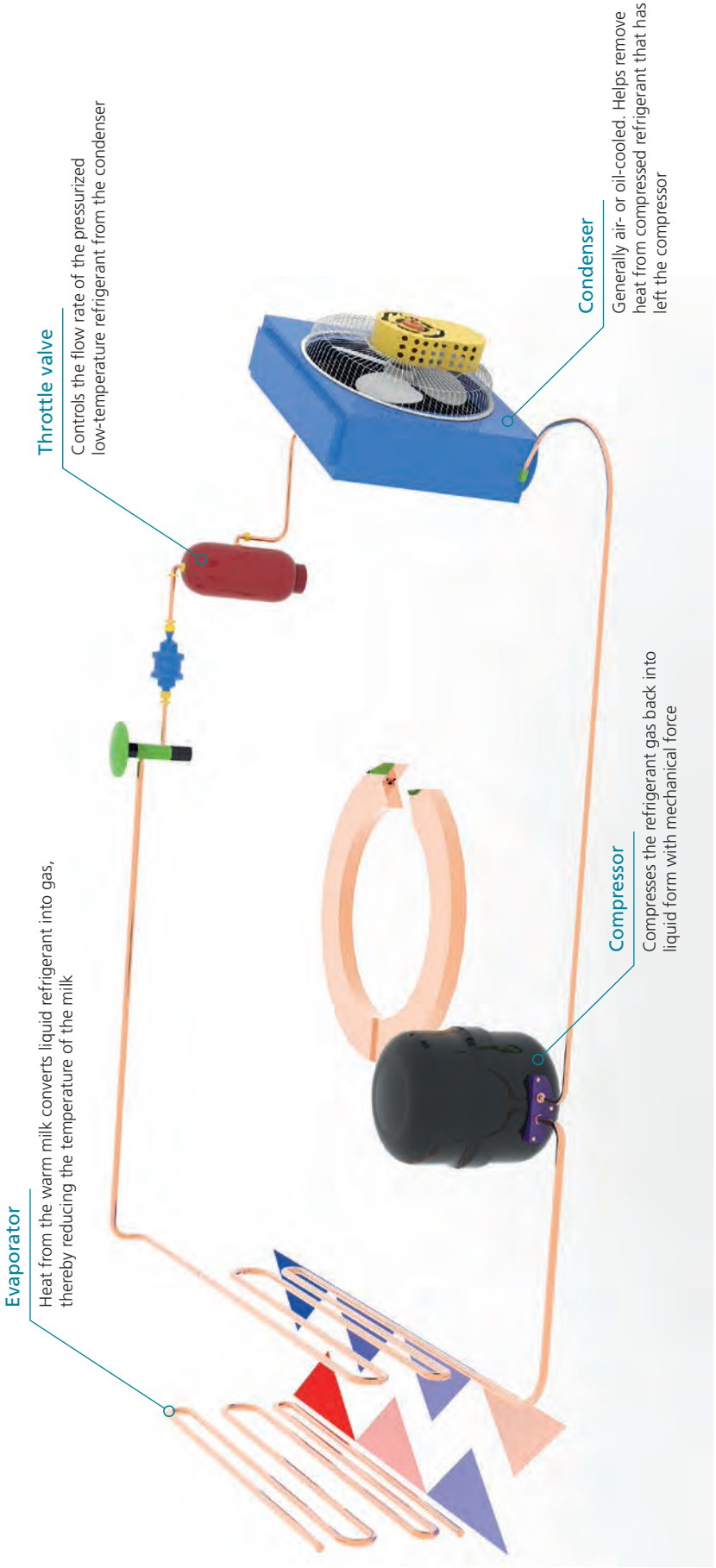
In the refrigeration operating cycle shown in Figure 17, a refrigerant gas (vapour) is drawn into the compressor, which pumps the compressed hot gas into the condenser. In the condenser, the refrigerant gas is cooled to a liquid by removal of the heat. The refrigerant liquid then passes through an expansion valve, enabling it to expand, and the resultant cold liquid-gas mixture passes to the evaporator where heat from water or

FIGURE 16
Milk reception area



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

FIGURE 17
Refrigeration operating cycle



Source: Sonnet Malakaran George, 2015.

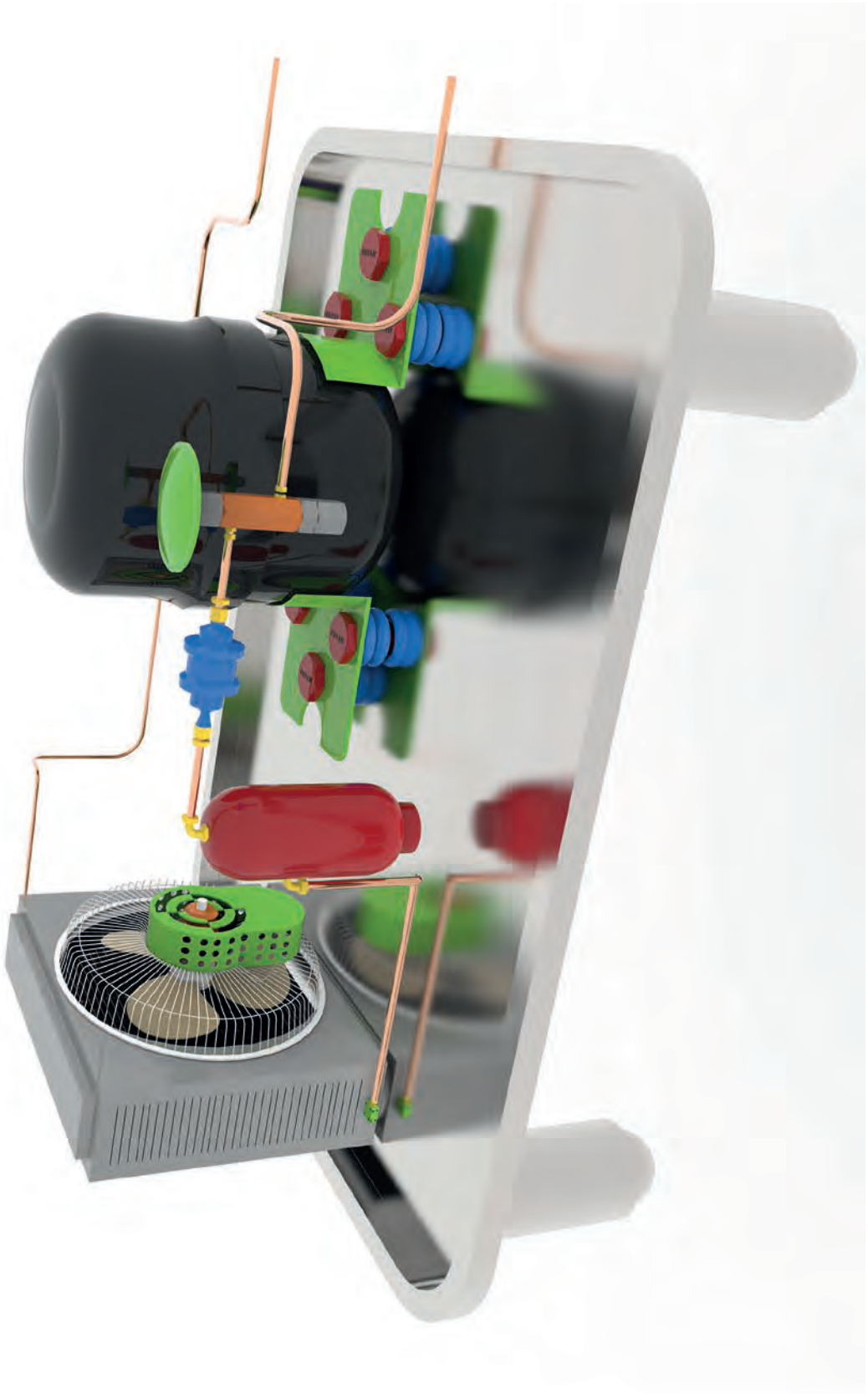
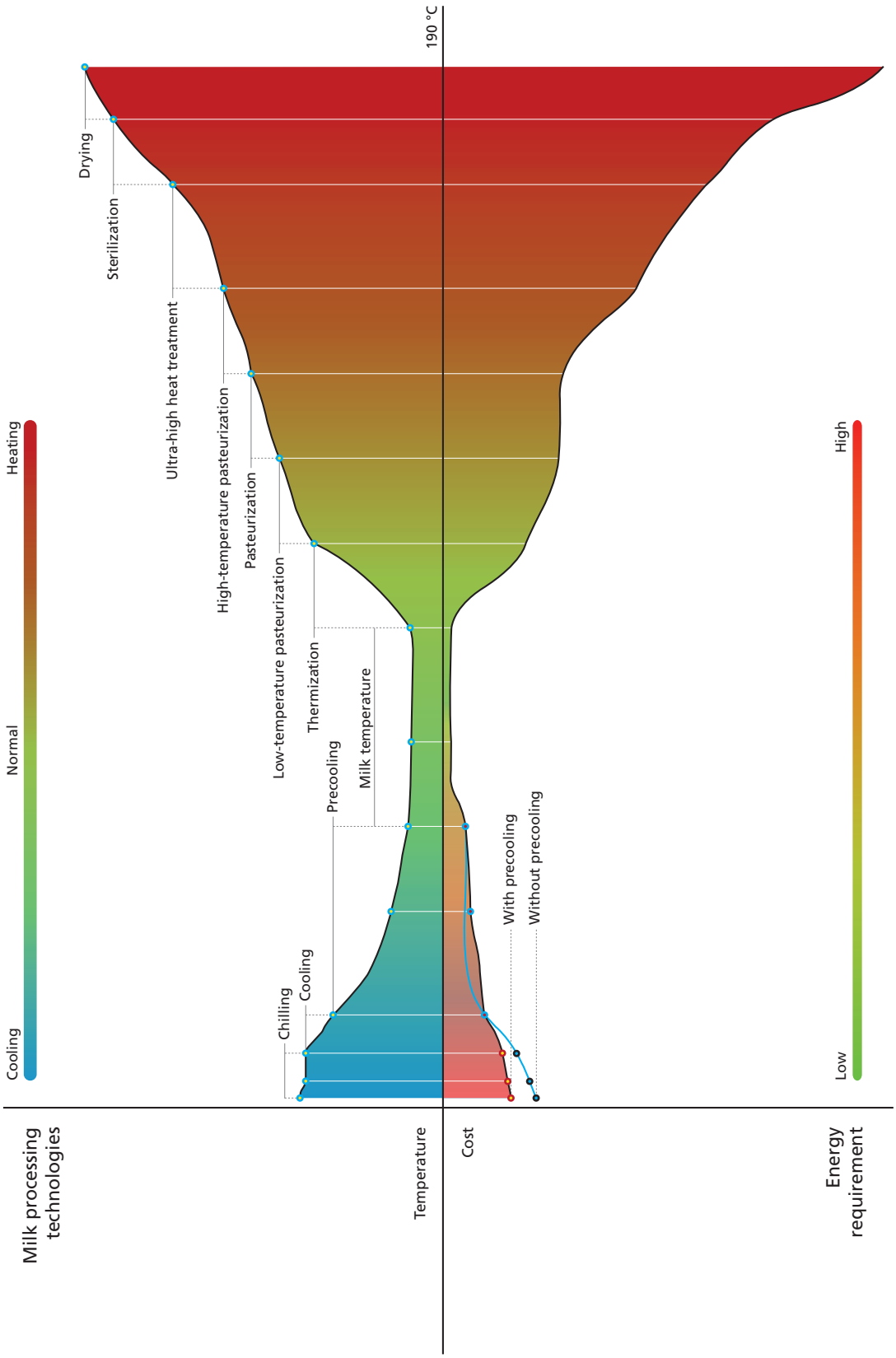


FIGURE 18
Refrigeration unit

Source: Sonnet Malakaran George, 2015.

FIGURE 19
Energy comparison chart



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

warm milk is absorbed by the refrigerant. The reheated refrigerant gas is then drawn back into the compressor to repeat the cycle, removing heat from the water or milk until it is cooled to the pre-set temperature. The refrigerants used can be chlorofluorocarbon or isobutene in compliance with recent international agreements related to atmospheric pollution by the gases that contribute to global warming.

The most common refrigeration compressor is of the reciprocating type, which can be open, semi-hermetically sealed or hermetically sealed. A newer "scroll" compressor is being increasingly used as it is more efficient and uses up to 20 percent less electricity than reciprocating compressors.

Condensers use natural or forced air, water or oil to cool the refrigerant. The most commonly used is the naturally air-cooled condenser. The purpose of the condenser is to condense the refrigerant gas by removing the heat.

Evaporators are commonly made from copper and located close to the source of the heat to be removed.

The compressor and condenser assembly are mounted on the same support frame as the milk tank (Figure 18) or on a separate frame adjacent to the tank. To ensure that the refrigeration system operates efficiently, the room in which it is located must be well ventilated. In very hot countries, the compressor and condenser assembly can be mounted on an external wall of the MCC building. This will improve the efficiency of the refrigeration system, ensure faster cooling of the milk and reduce energy consumption.

Chapter 6

Refrigerated milk cooling tanks

6.1 OVERVIEW

Two types of refrigerated milk cooling tanks are commonly used: the ice bank tank (IBT) and the direct expansion (DX) system. Two types of tank are available for the DX system: one in which the refrigerant gas flows inside copper pipes around the surface of the milk cooling tank allowing heat transfer from milk to the refrigerant; and the other in which the cooling gas flows through a specially designed stainless steel jacket (of dimple plates, pillow plates or DX plates) of which one face serves as the milk holding chamber and the other is covered with insulation material. The term "direct expansion" commonly refers to the second type of cooling tank.

The cooling capacity of the refrigeration unit used in either system is determined by the capacity of the milk tank. Tanks are often designed for the cooling requirements of larger dairy farms with two milking per day, and therefore two coolings – one in the early morning and one in the late afternoon/early evening. (The period between milking and chilling of the milk should not exceed two to four hours). Refrigeration systems are therefore designed with cooling capacities that match the heat load at peak times. However, if the tank is to be filled in only one operation a day for rapid cooling to 4 °C, the refrigeration system will need a much larger cooling capacity. Although ice bank tanks cool milk more quickly than DX tanks, all cooling systems are designed to cool any volume of milk to 10 °C within two hours and 4 °C within four hours.

Milk cooling and storage tanks should be manufactured from food grade-standard stainless steel as specified by international organizations such as the International Organization for Standardization (ISO 304 SS Stainless steel), the American Iron and Steel Institute (AISI 18/10) or equivalent (FAO, 2010). Lower-grade stainless steel is more likely to corrode. All tanks are double- or-triple walled and well insulated with compacted polyurethane foam or expanded polystyrene to keep the milk cool for at least 12 hours with a temperature rise of no more than 1 °C at an ambient room temperature of 30 °C.[3] The refrigeration system can be of the DX type or use an ice bank in the base of the tank. Milk cooling tanks can be of two types: open-top or fully enclosed.

Open-top tanks

The lid of an open tank (Figure 20) can be partially or fully opens to allow access. This allows milk to be poured into the tank and facilitates access for manual cleaning and sanitation. Open tanks range in capacity from 200 to 2 500 litres. Tanks of this type may not require pumps for pouring the milk and can be cleaned manually, making them very suitable for use in rural locations in developing countries and countries in transition.

Fully enclosed tanks

The fully enclosed tank (Figure 21) differs structurally from the open-top tank in that it does not have a wide opening for access. Many enclosed tanks have a standard sized access hole on the top or side. This access hole is generally for occasional observation of the tank by inserting the head through the hole, but it must be large enough to allow an average-sized adult to enter the tank. Milk is pumped into/out of the fully enclosed tank, and a cleaning-in-place (CIP) system is used to clean the tank and processing equipment. A cleaning agent (water, alkali or acid) is circulated through the system with or without dismantling of the equipment being cleaned. The CIP system may be built into the tank or be a separate unit, which will require additional capital investment. The capacity of enclosed tanks ranges from 3 000 to 10 000 litres. Annex 2 provides details on cleaning of MCCs, including with CIP systems.

In both open-top and enclosed tanks, it is essential to provide continuous agitation of the milk during cooling. Milk that is not agitated will

[3] http://www.fao.org/docrep/006/y5013e/y5013e08.htm

not be uniformly cooled – the milk in contact with the tank wall will freeze while that in the centre of the tank remains warm, resulting in degradation of milk quality. Open tanks generally have one or more vertical agitators fitted at the top of the tank. Enclosed tanks may have one or more agitators mounted on their tops or sides.

Tanks can be calibrated to facilitate measurement of the volume of milk. Calibration is usually in volume measurements such as litres or gallons, but some tanks are calibrated in weight – kilograms or pounds.

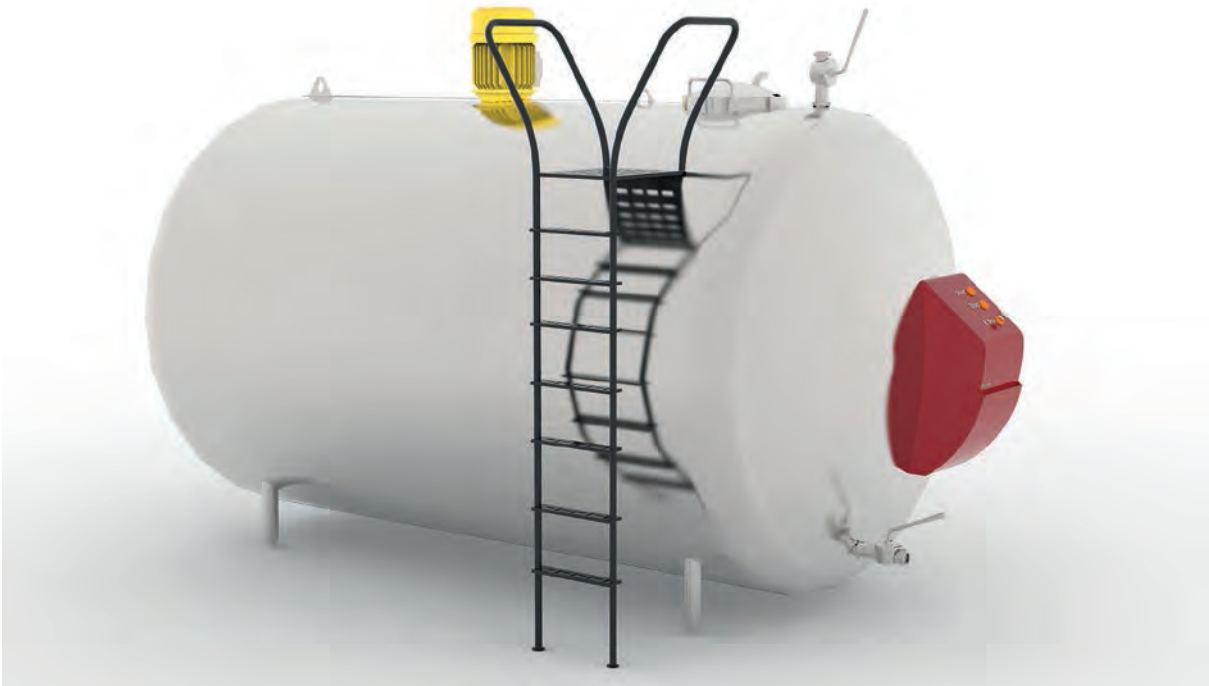
Milk cooling tanks have various accessories depending on the size, type and manufacturer of the tank. Generally, agitators are fitted to facilitate adequate and rapid cooling, and thermostats and thermometers to control and indicate milk temperature. For the cleaning and sanitation of enclosed tanks fitted with integrated automatic CIP systems, special detergents are required. In many countries, these detergents are not available and will have to be imported. In developing countries, it is often advisable to have a non-integrated, manually controlled CIP system.

The precooling of warm fresh milk using mains or well water will considerably reduce the energy requirements of the refrigeration system, thereby reducing the cost of cooling. Precooling using both mains/well and chilled water can be undertaken in one operation. The use of chilled water alone speeds up the cooling process and helps maintain the milk quality.

FIGURE 20
Open-top direct expansion tanks

Source: Sonnet Malakaran George and Frazer Moffat, 2015.

FIGURE 21
Fully enclosed direct expansion tank



Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

One of the major factors contributing to an increase in operating overheads is the rapid rise in energy costs. It is important to choose the correct type of cooling system in relation to energy consumption and this choice will be affected by the source and cost of the energy supply. The design and quality of the equipment will also have a direct impact on energy consumption. There are ISO standards for refrigerated milk cooling tanks (ISO, 2011), and some countries or regions have their own standards.[4] Developing and transitional countries are increasingly fabricating their own milk cooling equipment.

The availability of an electricity supply will decide on the type of milk cooling system to be employed in the proposed MCC. Available power supplies may be single- or three-phase. Where the electricity supply is unreliable or non-existent, diesel electrical power generators or alternative energy sources, such as solar energy, may be used. When using diesel generators, the use of DX milk cooling systems with three-phase refrigeration compressors is the most efficient energy option. Tanks constructed with DX or dimple plates are far more energy-efficient than others. DX systems can cool milk at least 1.5 times more quickly than copper-coiled tanks of comparable size.

6.2 ICE BANK MILK COOLING AND STORAGE TANKS

Ice bank milk cooling and storage tanks (Figures 22 and 23) use an ice bank and chilled water reservoir located at the base of the tank assembly. This reservoir houses the evaporator section of the refrigeration system and, over a period of many hours, allows the build-up of ice on the copper pipes of the evaporator. The ice will be up to 8 cm thick. A device for controlling the thickness of the ice may be fitted to avoid overproduction of ice and the resulting damage to equipment and to control energy use and operating costs. Where there are two milkings per day, ice storage

[4] Such as the European Union's BS EN 13732:2013 Food processing machinery. Bulk milk coolers on farms. Requirements for performance, safety and hygiene: http://shop.bsigroup.com/ProductDetail/?pid=000000000030251686; and the Bureau of Indian Standards (IS), whose FAD 19/T contains standards for milk and milk products equipment: http://www.bis.org.in/qazwsx/td/FAD-19T.pdf. The Australia, New Zealand and the United States of America also have their own national standards for milk cooling tanks.

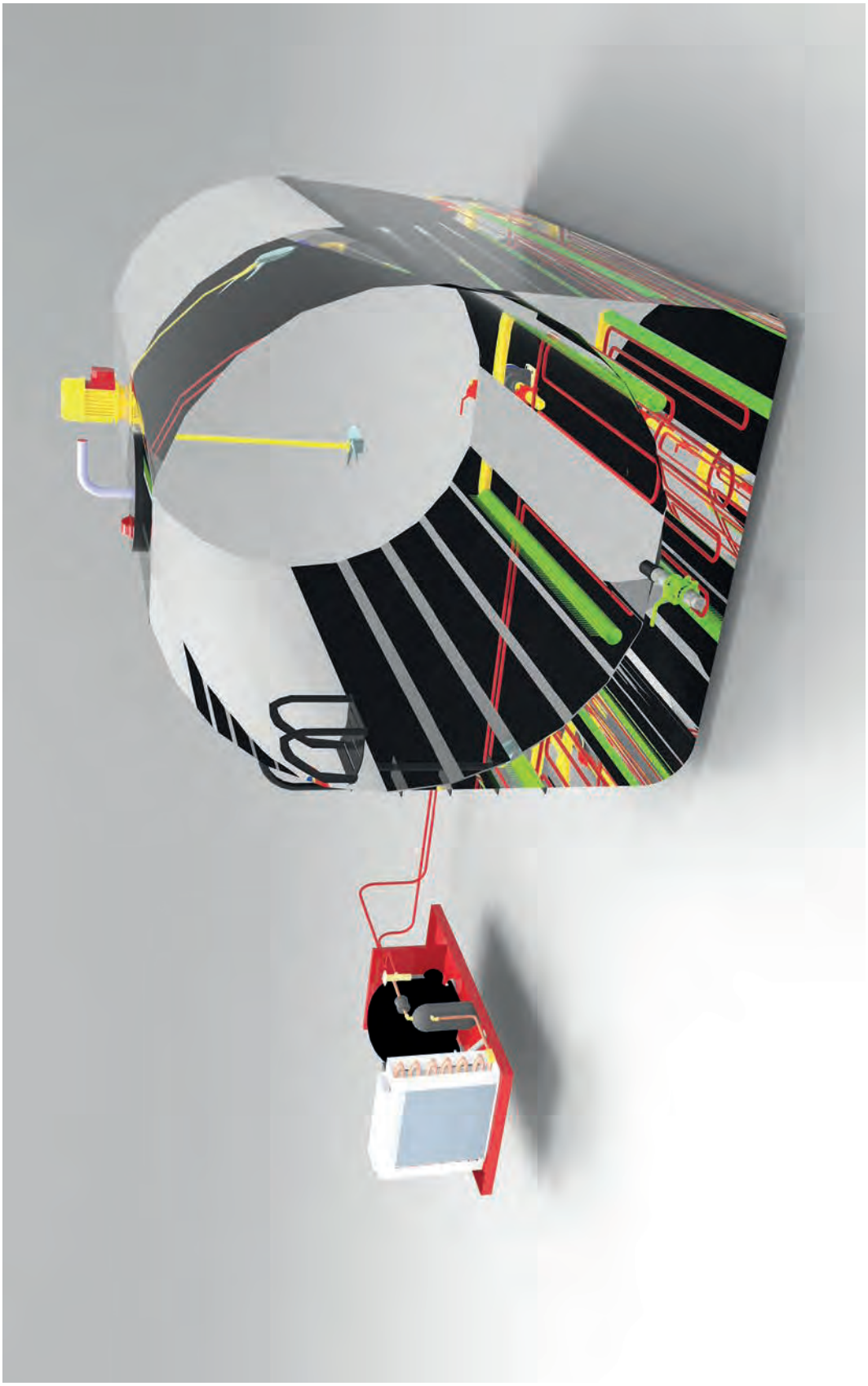


FIGURE 22
Integrated ice bank milk cooling tank

Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

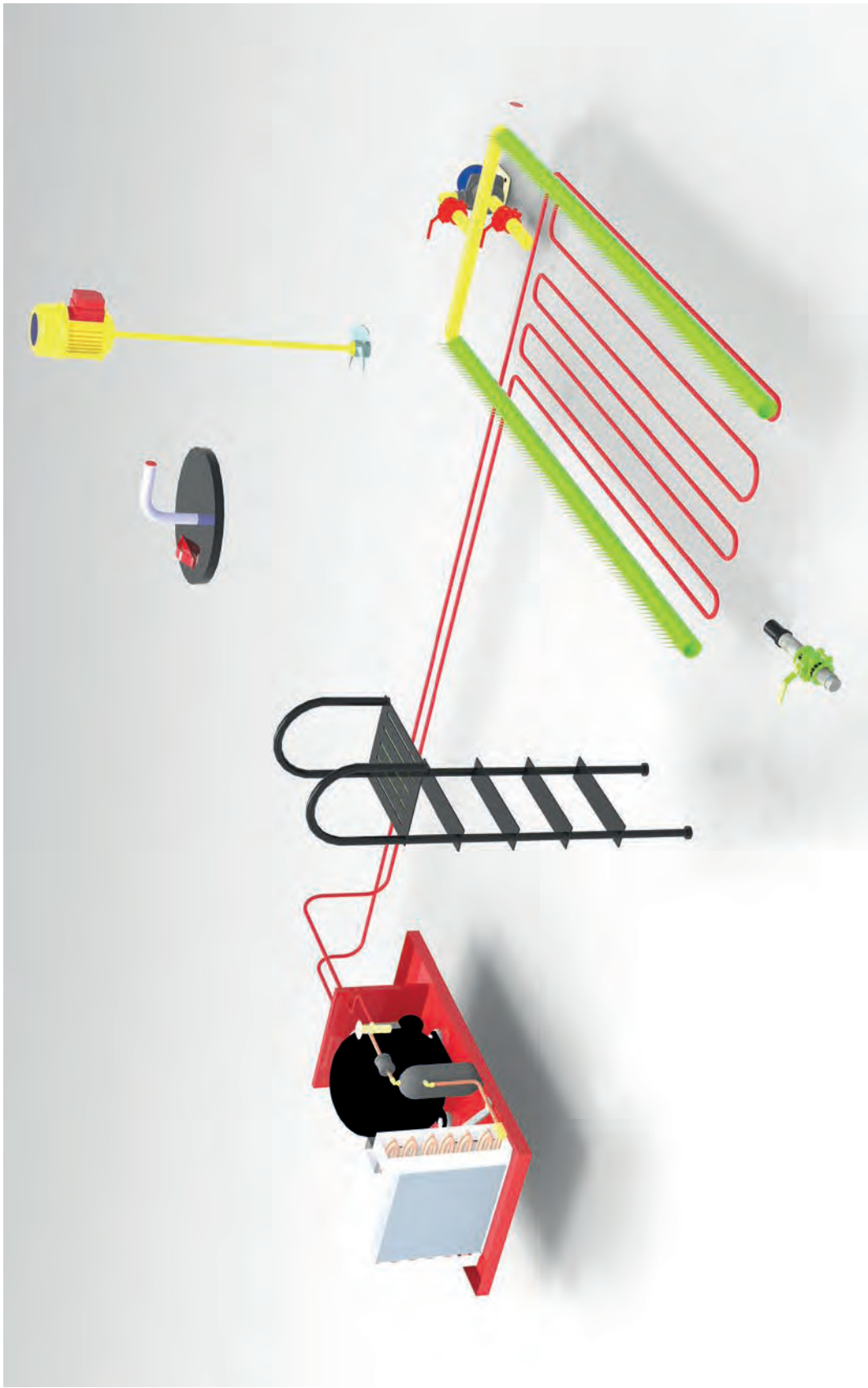


FIGURE 23
Cross-section of an integrated ice bank milk cooling tank

Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

is normally capable of cooling 60–70 percent of the milk in the tank. Ice bank cooling systems are most suited to areas where there is a reliable grid supply of electricity because they need to operate for at least ten hours per day. Solar panels can also be used as a source of electricity for ice generation, but powering an ice bank cooling system using only a diesel generator would be costly.

To enable faster cooling of the warm milk, ice water is pumped to spray heads located on the outer side and the top of the inner tank. Ice bank tanks can cool up to 50 percent faster than DX tanks. Figure 24 illustrates the layout of an enclosed ice bank milk cooling tank.

Many modern tanks are fitted with sophisticated electronic control systems. Such systems are vulnerable to unstable environmental conditions and require the attention of specialist engineers. If available, simpler control systems should be used in developing countries.

Ice builders or banks are designed to generate and store cooling capacity for later use in applications that use chilled water for the cooling process. Ice is generated during off-peak periods, storing sufficient refrigeration capacity (in the form of ice) to meet daily requirements and/or to allow the use of smaller compressor equipment than would be required for instant cooling. Cooling with chilled water in an ice builder normally requires the use of plate heat exchangers (PHEs) or tubular heat exchangers.

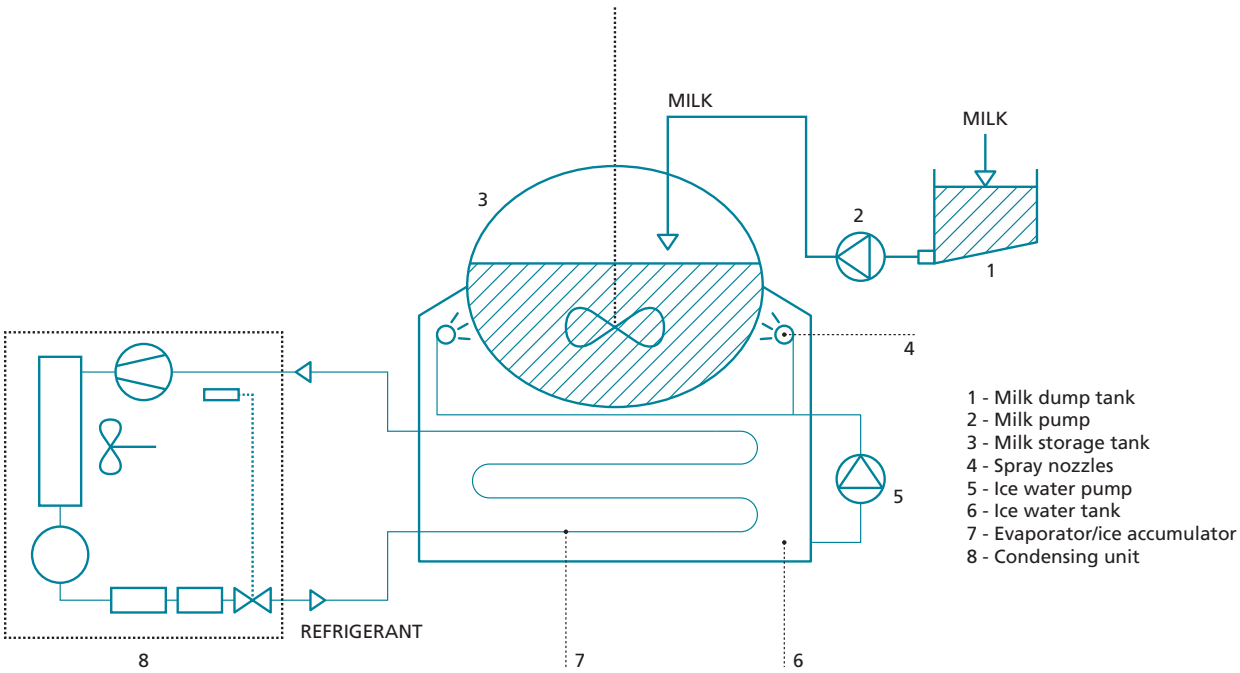
To facilitate instant cooling to 4 °C a PHE can be installed that uses ice water from the reservoir in the tank assembly as the chilling media. Instant cooling will help maintain the milk quality.

The electricity requirements for ice bank milk cooling tanks can be low if a single-phase compressor is used for long periods to build the ice bank. These compressors can operate for 10–16 hours per day when there is a reliable electricity supply. Ice bank cooling also has the advantages of requiring a lower-powered compressor and enabling the use of low-cost overnight electricity, when available, or a single-phase electrical power supply.

6.3 DIRECT EXPANSION MILK COOLING AND STORAGE TANKS

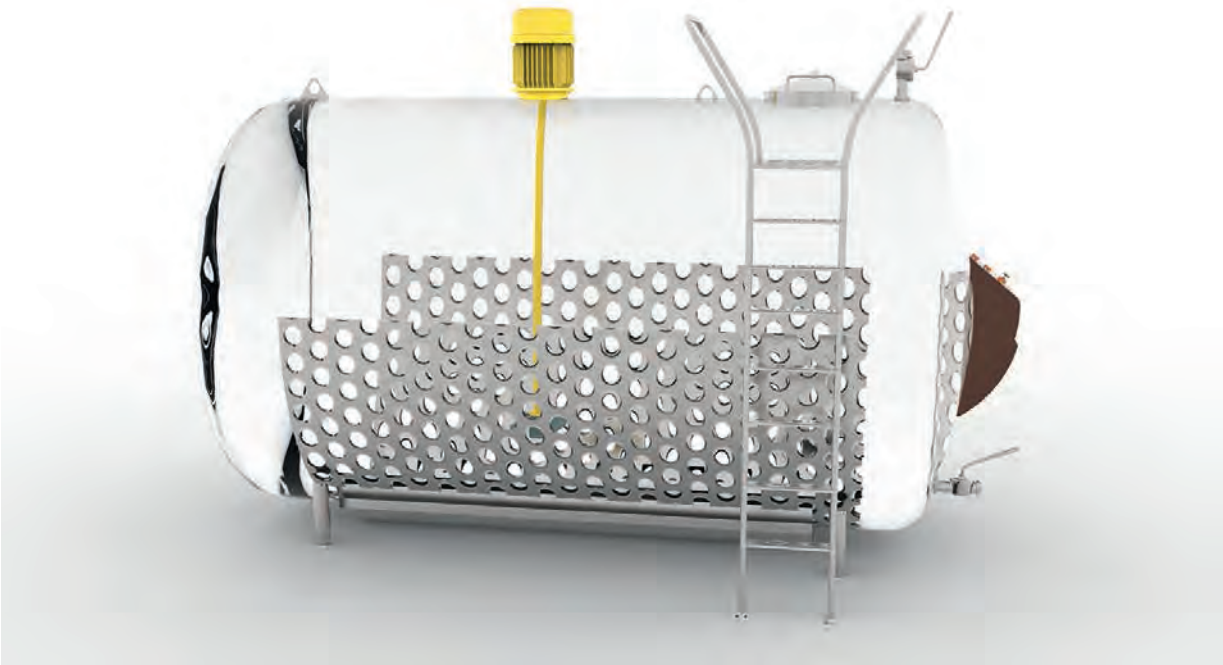
DX milk cooling and storage tanks use refrigeration evaporator pipes or specially designed flat pillow-shaped plates attached to the outer side of the tank containing the milk (Figures 25 and 26). Tanks in this system are much smaller than ice bank cooling tanks as they do not have

FIGURE 24
Integrated ice bank milk cooling tank



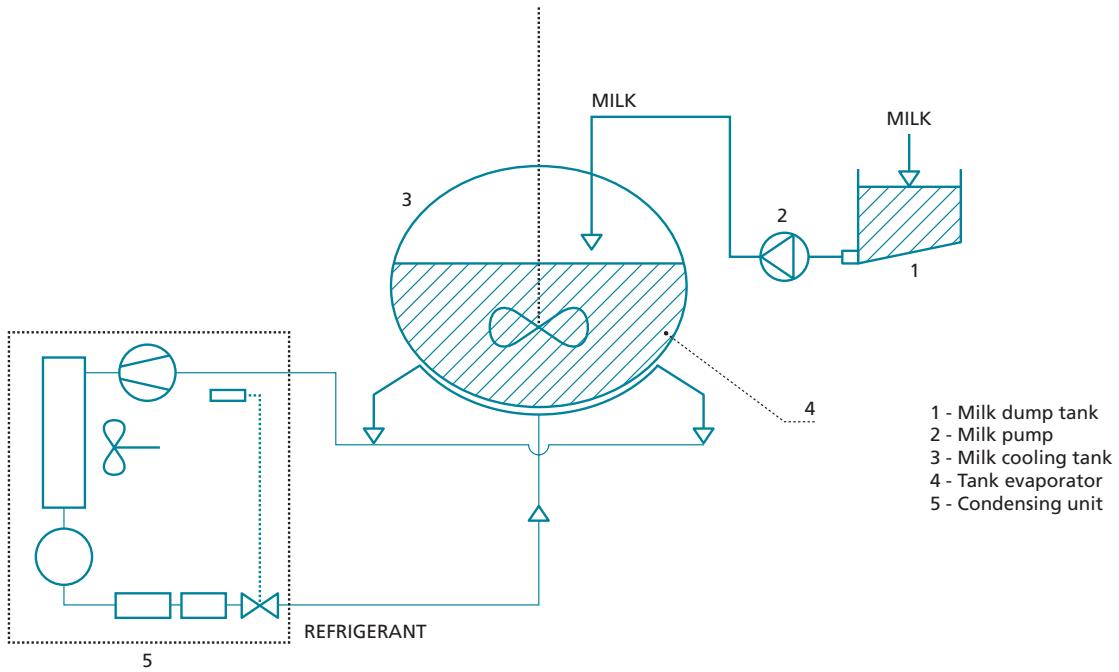
Source: Frazer Moffat, 2015.

FIGURE 25
Cross-section of an enclosed direct expansion milk cooling tank



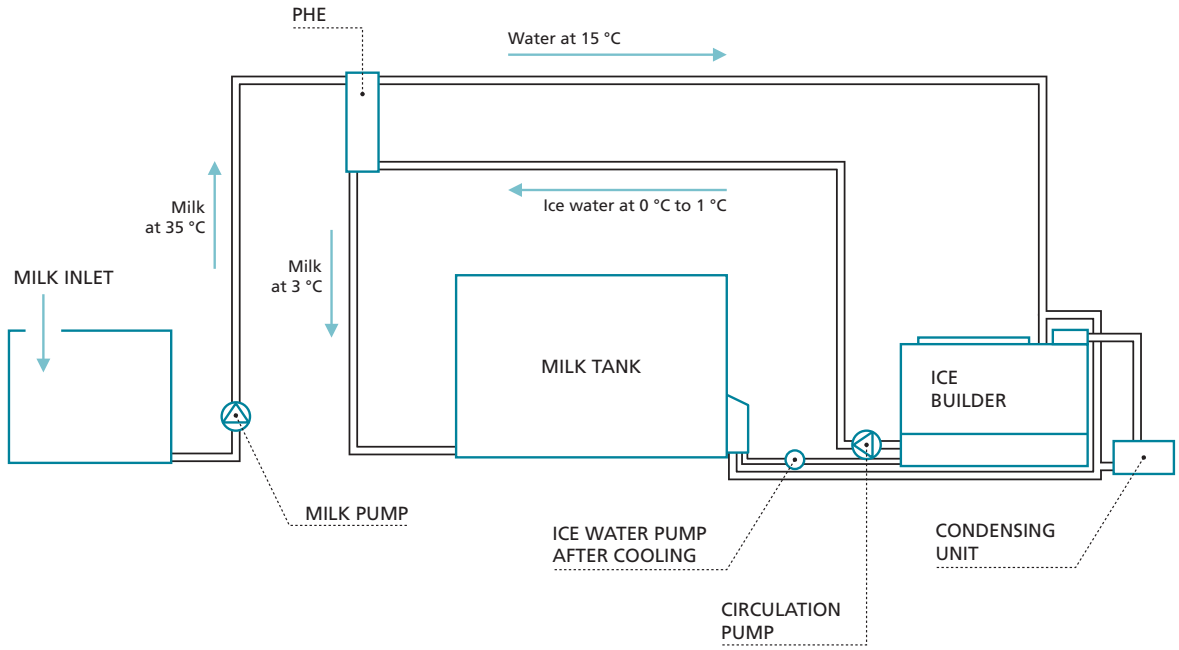
Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

FIGURE 26
Enclosed direct expansion milk cooling system



Source: Frazer Moffat, 2015.

FIGURE 27
Ice builder with instant cooling using a PHE



Source: Frazer Moffat, 2015.

a chilled water reservoir. DX systems can also be up to 50 percent more energy-efficient than ice bank cooling, but require larger compressors. The refrigeration compressor runs constantly during cooling operations, so energy consumption is high over a short period of four to eight hours per day.

6.4 ICE BUILDERS AND INSTANT COOLING

Ice builders (ice accumulators) are basically large reservoirs of water contained in well-insulated tanks in which there are refrigeration evaporator pipes (Figure 28). The refrigeration compressor and condenser assembly is normally built on the same support frame as the water tank. The unit is designed to build ice on the evaporator pipes continuously or at times when electricity tariffs are at their lowest. Single-phase refrigeration compressors are commonly used. The capacity of ice builders used in MCCs ranges from 600 litres of ice water/200 kg of ice to 4 000 litres of ice water/2 000 kg of ice.

The stored chilling capacity can be used in periods of peak demand. With the use of a heat exchanger, fresh warm milk can be instantly cooled to 4 °C. Figure 27 shows the layout of an ice bank cooling system with a PHE.

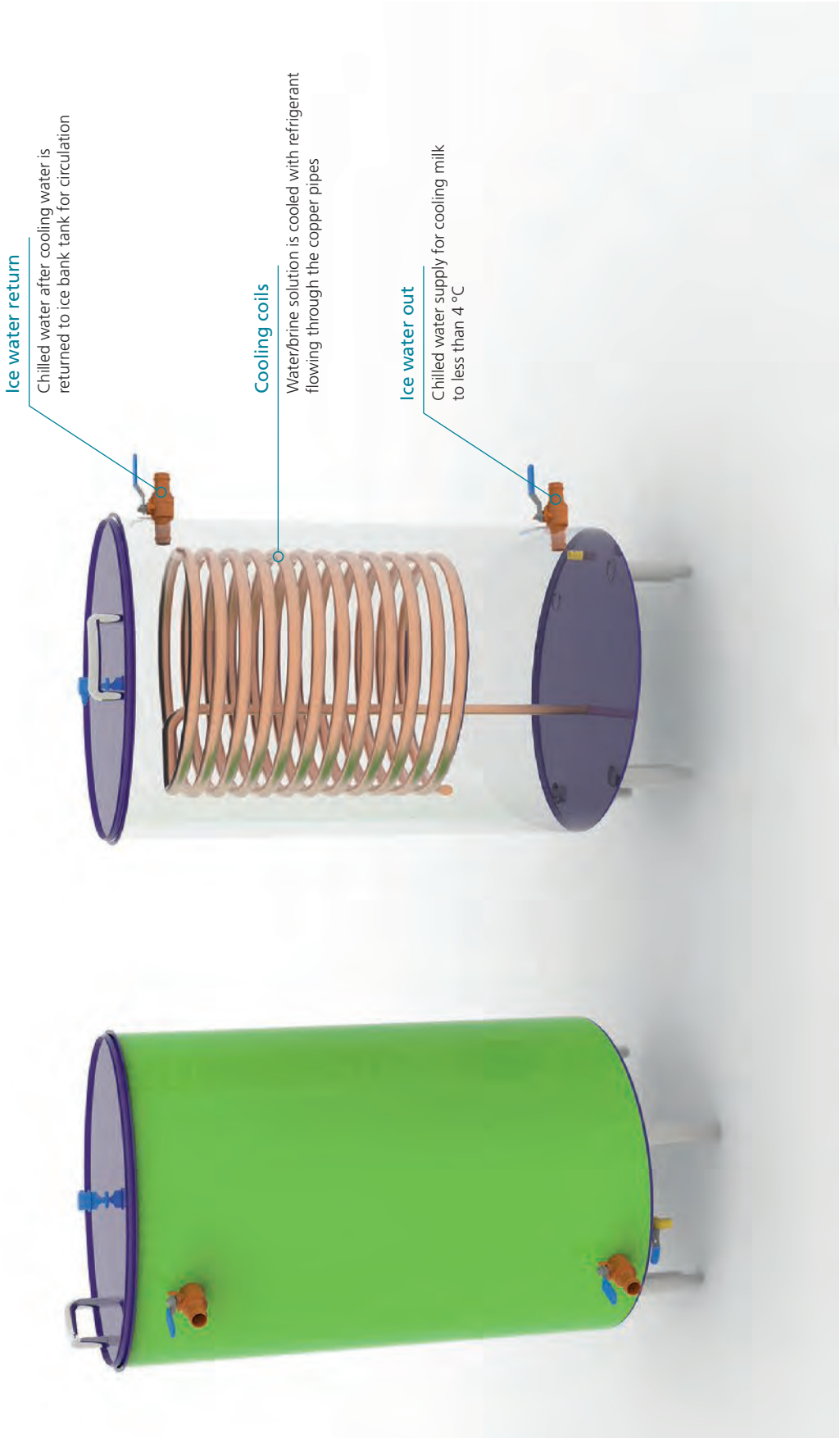
6.5 MILK PRECOOLING EQUIPMENT

Precooling of fresh warm milk at the MCC saves considerably on energy usage. In addition, when precooling uses mains or groundwater (preferably at a temperature that is at least 15 °C lower than that of the milk), it is possible to use a refrigeration unit with lower capacity, thereby reducing the capital costs of establishing an MCC. However, precooling requires additional equipment, including a balance/dump tank, water and milk pumps, a heat exchanger and pipes and fittings.

The most frequently used heat exchangers are of either the plate or tubular type, with the former being the most common and most efficient. In addition, the cooling capacity of a PHE can be increased or decreased, unlike that of a tubular heat exchanger. However tubular heat exchangers are less prone to fouling and have lower maintenance requirements.

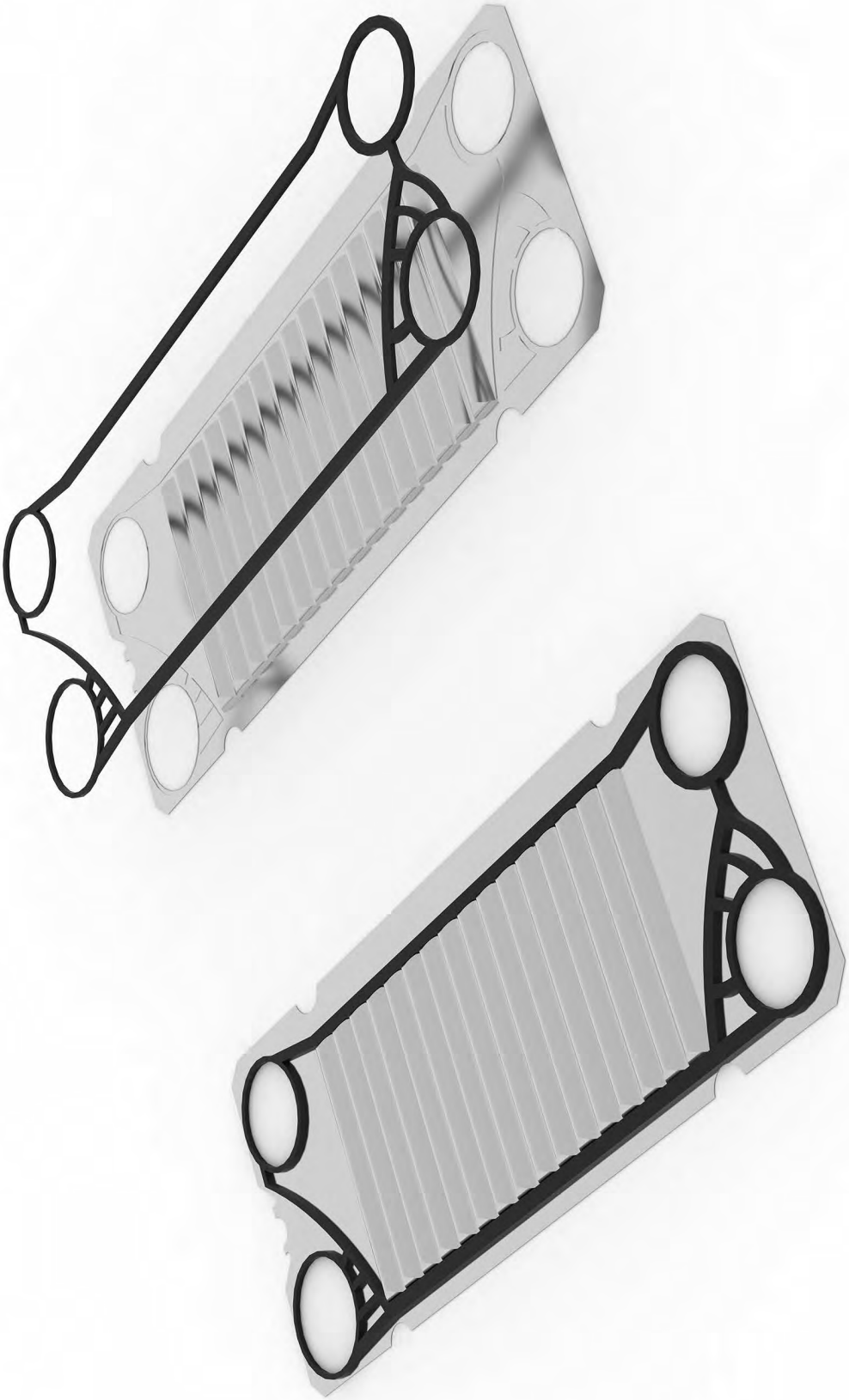
A PHE consists of a series of thin corrugated stainless steel plates clamped together in a support frame (Figure 29). Water flows along one side of each plate while warm milk flows along the other side in the opposite direction (Figure 30). Heat is transferred from the milk to the water through the plates. The ratio of water to milk flow rates ranges

FIGURE 28
Ice bank tank



Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

FIGURE 29
Corrugated plate of plate heat exchanger



Source: Sonnet Malakaran George, 2015.

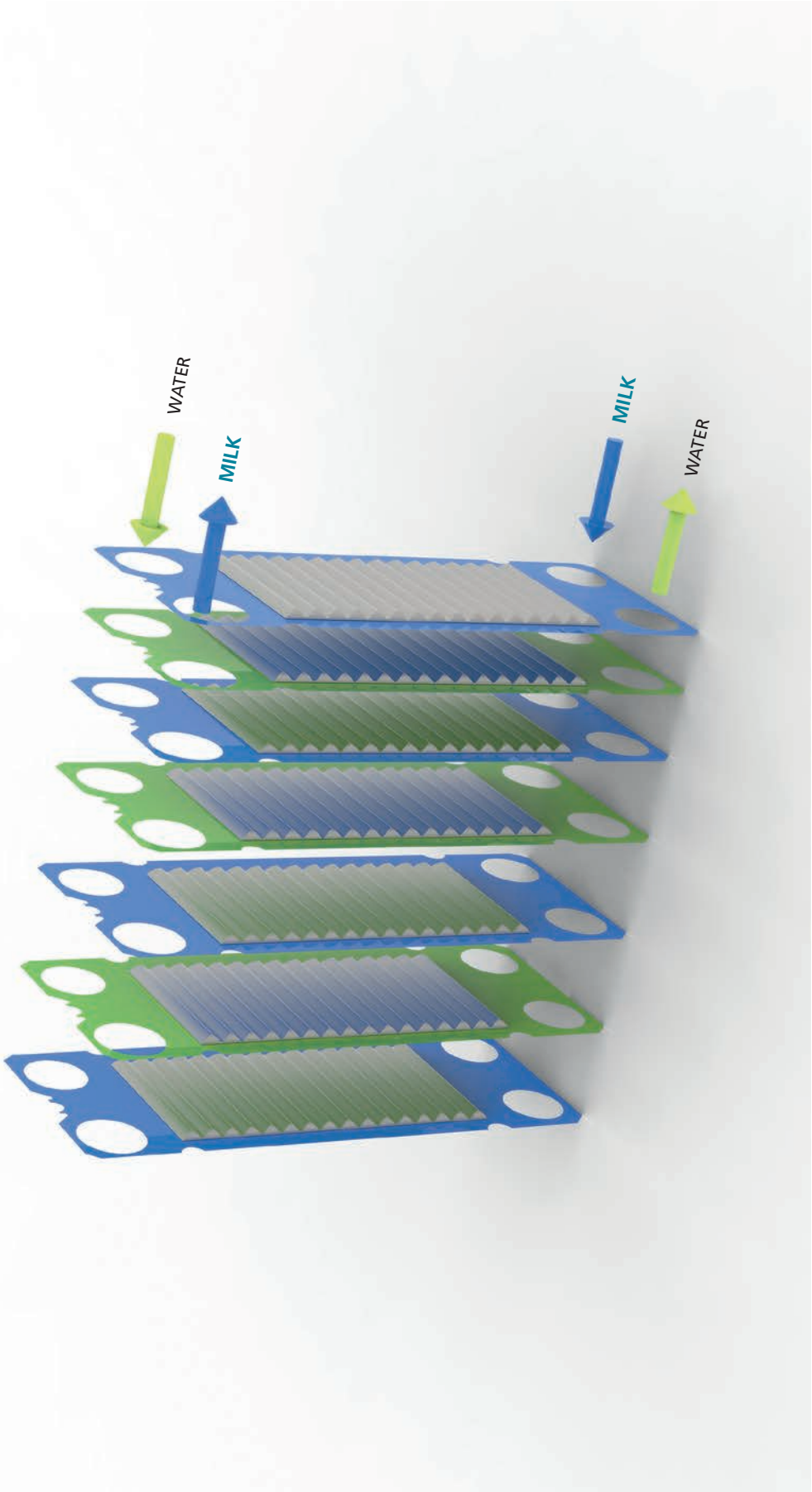


FIGURE 30
Heat exchange pattern in a plate heat exchanger

Source: Sonnet Malakaran George, 2015.

from 1:1 to 3:1 but will depend on the PHE design and the water temperature(s). PHEs may be single- or multi-pass and can be configured to allow precooling with water followed by instant cooling with ice water from an ice bank milk cooler or stand-alone ice builder. The warm milk will be cooled to between 2 °C and 4 °C. Precooling with mains or well water alone can reduce the time and energy required for refrigeration cooling, by up to 32 per cent when the temperature of the cooling water is 20–22 °C and by up to 64 percent when it is less than 12 °C.

PHEs are designed for use with specific products such as milk or fruit juice. The water temperature varies from place to place and often also throughout the year. When purchasing a PHE it is necessary to inform the supplier of the water temperature(s) and the required flow rate of warm milk to obtain a PHE that operates at maximum efficiency. The milk pump and synchronous water pump used must suit the capacity of the PHE.

Water used for precooling can be reused for cleaning purposes in the MCC. If the water is potable, local communities can use it for irrigation.

6.6 HEAT RECOVERY UNITS

Refrigeration systems generate considerable heat, which is removed at the condenser. Some of this heat can be captured to heat water for cleaning the dairy equipment. The refrigerant leaving the compressor (before it reaches the condenser) of a milk cooling system is at 70–80 °C. A heat recovery unit is an insulated water tank through which pipes carry the refrigerant gas to the refrigerant condenser. Heat from the gas is transferred to the water. A heat recovery unit can preheat the water to 45–60 °C, but the actual recovery of heat from the gas will depend on the original temperature of the water as it enters the tank. The higher the original temperature of the water, the lower the degree of heat recovery. In tropical countries, where the original water temperatures are high, the heat recovery rate is much lower than in cooler countries. If a milk precooling system using mains or well water is in place, the refrigeration system will be smaller and produce less heat, so the heat recovery unit will recover less heat.

Heat recovery units may not be economically feasible in small and medium-scale MCCs (capacity of 2 000–5 000 litres).

6.7 ENERGY USE, PRECOOLING AND OPTIONS FOR REFRIGERATED MILK COOLING SYSTEMS

The results of a study comparing DX with ice bank refrigeration systems are outlined in Table 4, which provides information on: i) percentage of investment; ii) refrigeration load, and iii) power consumption.

Table 4 gives an indication of the energy requirements of modern DX and ice bank tanks with or without precooling using mains or well water. Table 5 shows the average reductions in refrigeration cooling requirements that result

TABLE 4
Comparison of direct expansion and ice bank cooling systems

1 000-litre milk cooling tank	Direct expansion	Ice bank
Investment	100%	115%
Refrigeration condenser capacity	3.8 kW	2.0 kW
Average electricity consumption[a]	20 Wh/litre	24 Wh/litre

kW = kilowatts; Wh = watt hours.
[a] Values subject to change depending on the technology used, the phase power of the grid and the timing for milk cooling.
Source: Frazer Moffat, 2015.

TABLE 5
Estimated percentage reductions in refrigeration cooling requirements following precooling

	1 000 litres of fresh milk at 35 °C		
	Precooling to 25 °C	Precooling to 20 °C	Precooling to 15 °C
Temperature of cooling	20–22 °C	15–17 °C	10–12 °C
Potential reduction	32%	48%	64%

Source: Frazer Moffat, 2015.

from precooling, which reduces the electrical energy that refrigeration systems need to cool the milk, as shown in Table 6. Precooling may also reduce the required capacity and capital cost of the refrigeration units(s), but only if there is a reliable and continuous supply of mains or well water at sufficiently low temperatures.

Classification of refrigerated milk cooling tanks

Refrigerated milk cooling tanks are designed and classified for use on dairy farms. There are international, regional and national standards related to the performance of milk cooling tanks. Although designed for use on larger dairy farms – in terms of number of milkings, cooling parameters (generally from 35 °C to 4 °C), ambient operating temperatures and cooling times – these standards also apply to the milk cooling tanks utilized by MCCs. The refrigerated milk cooling tanks at MCCs may be used in one complete filling or several part fillings over one or two days.

Scenario

Example of the selection of a refrigerated milk cooling tank with 1 000-litre capacity based on ISO (5708) and European (EN-13732) standards.

Based on the performance needs of the refrigerated milk cooling tank, model 2BII was selected:

i) 2 – milk quantity per milking (MCC fillings), equivalent to 50 percent of the total tank volume;
ii) B – indicative ambient temperature for cooling milk, 30 °C for B classification;
iii) II – indicative milk cooling time per cycle, three hours for II classification.

When milk is precooled, the manufacturers/suppliers of cooling tanks have to adjust the size of the refrigeration unit to suit the lower temperature of the milk entering the tanks.

There is no set configuration for all MCC cooling systems. The configuration for each MCC should be based on: i) the proposed location of the MCC; ii) the MCC's milk handling capacity; iii) the type of cooling system; iv) the availability of electricity and other energy options; and v) the availability of water resources.

6.8 COOLING OPTIONS AND CONFIGURATIONS

The cooling costs of an MCC can be reduced by precooling warm milk using mains, surface or well/groundwater. Precooling reduces the refrigeration load, thereby reducing costs and environmental impact. The final temperature of the precooled milk depends on the temperature difference between the precooling water and the fresh milk. It is then necessary to decide whether to use a DX refrigeration milk cooling tank, an ice bank refrigeration milk cooling tank or an ice builder/PHE combined with an insulated, unrefrigerated milk storage tank. The latter two systems build ice over a period of ten-plus hours and are more suited where there is a reliable electricity supply, where only a single-phase supply is available, or where a lower tariff is applied for electricity supplied at night.

The choice of refrigerated cooling and storage system will be guided by several factors, some of which are discussed in the earlier sections of this chapter. It is recommended that an energy use audit be carried out on the various cooling systems available prior to decision-making on any capital investment.

Attention should be paid to the technical specifications, including energy consumption, of the cooling equipment available on the market. Energy costs constitute the major cost of MCC operations, so use of an appropriate energy option will help reduce the operating costs and increase the profitability of the MCC.

There are a number of cooling options with different configurations. Basic equipment requirements are outlined in the following paragraphs.

TABLE 6
Electrical power requirements with and without precooling

	1 000 of fresh milk at 35 °C			
	No precooling	Precooling to 25 °C	Precooling to 20 °C	Precooling to 15 °C
Equipment	*kWh/1 000 litres of milk to cool to 4 °C*			
DX tank	20	13.6	10.4	7.2
Ice bank tank	24	16.32	12.48	8.68

Source: Frazer Moffat, 2015.

Option 1 – Direct expansion refrigerated milk cooling tank

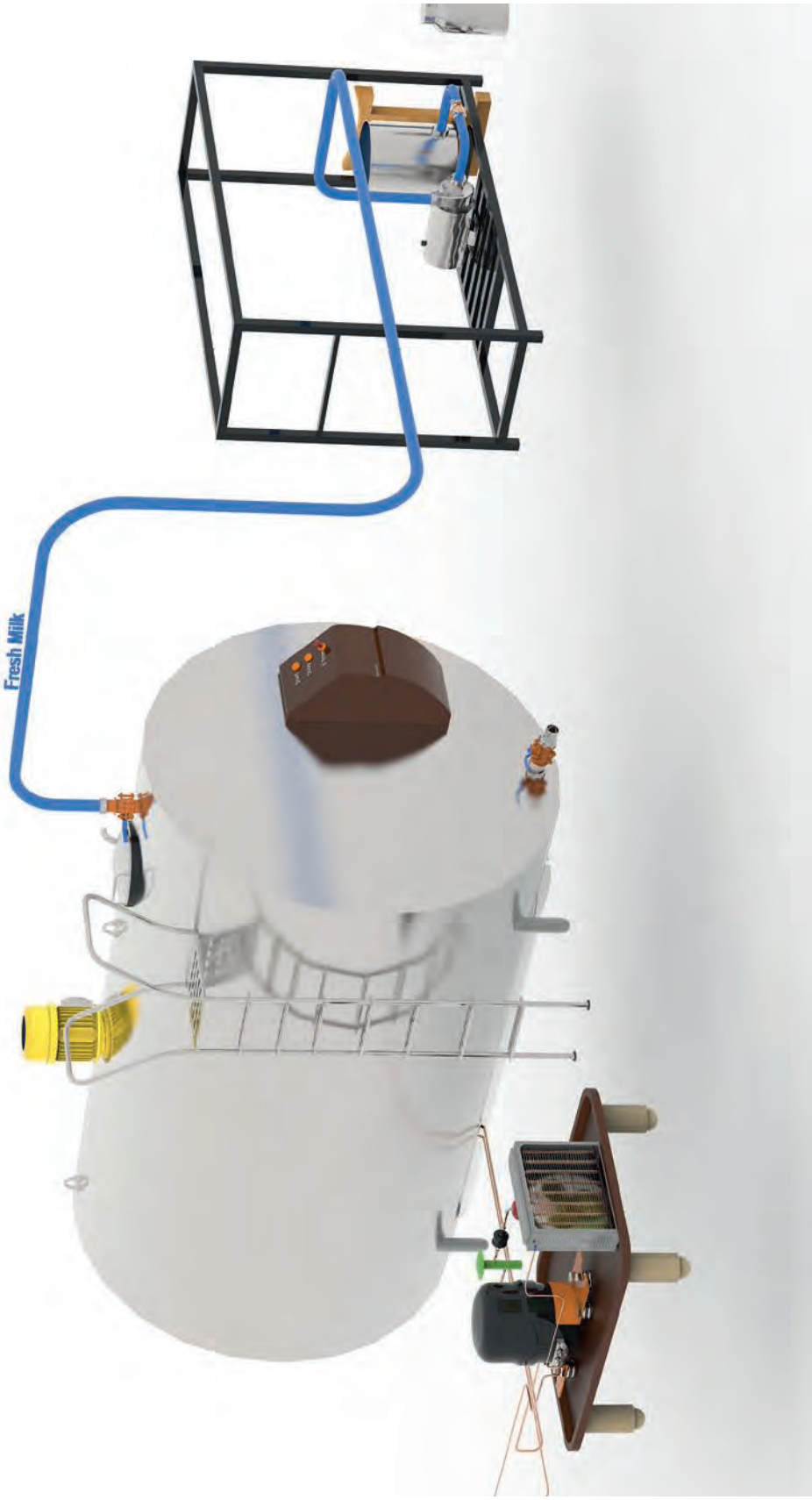


FIGURE 31
Direct expansion refrigerated milk cooling tank

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

Figures 31 and 32 illustrate the DX refrigerated milk cooling tank and system.

Advantages and limitations

Advantages:

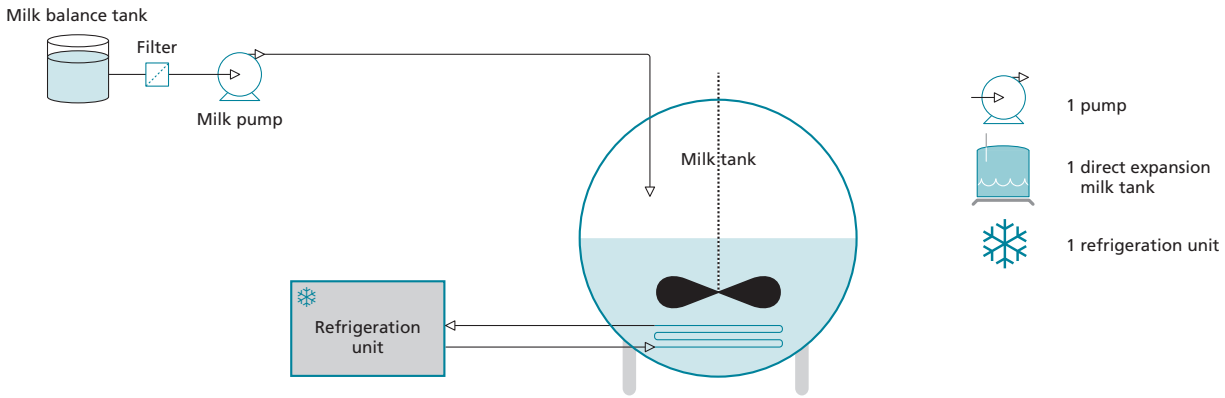
i) The tanks are commercially available; open-top tanks are particularly well suited to rural areas.
ii) Common capacity ranges from 500 to as much as 10 000 litres.
iii) The system can be used with single-phase (for up to 1 000-litre tanks) or three-phase (for all sizes of tank) electricity.

Limitations:

i) The system cools the milk comparatively slowly, taking three to four hours to reduce the milk temperature from 35 to 4 °C when 50-percent full.
ii) It requires high electricity consumption or generator-supplied electricity immediately after filling starts.

Table 7 outlines the basic equipment needed for a DX refrigerated milk cooling system.

FIGURE 32
Option 1



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

TABLE 7
Basic equipment for a direct expansion refrigerated milk cooling system

	Description	No.	Remarks
1	DX refrigerated milk cooling tank	1	Open-top tanks for up to 3 000 litres. Larger tanks are typically of the enclosed type
2	Milk reception weighing scale/calibrated tank	1	Weighing balance (calibrated tank for milk intakes of more than 3 000 litres)
3	Milk reception dump tank with 200-litre capacity	1	Only for DX tanks of 2 000 litres or more. When handling smaller volumes, milk can be poured through a filter directly into an open-top milk cooling tank without a dump tank
4	Milk pump for milk reception and loading of milk into bulk road tankers	1	To suit local conditions
5	Stainless steel hand-operated, non-return valves, pipes, unions and fittings	3	As required
6	Electricity installation, switches and cabling	Main	As required

Source: Frazer Moffat, 2015.

Option 2 – Direct expansion milk cooling tank with precooling using mains or well water

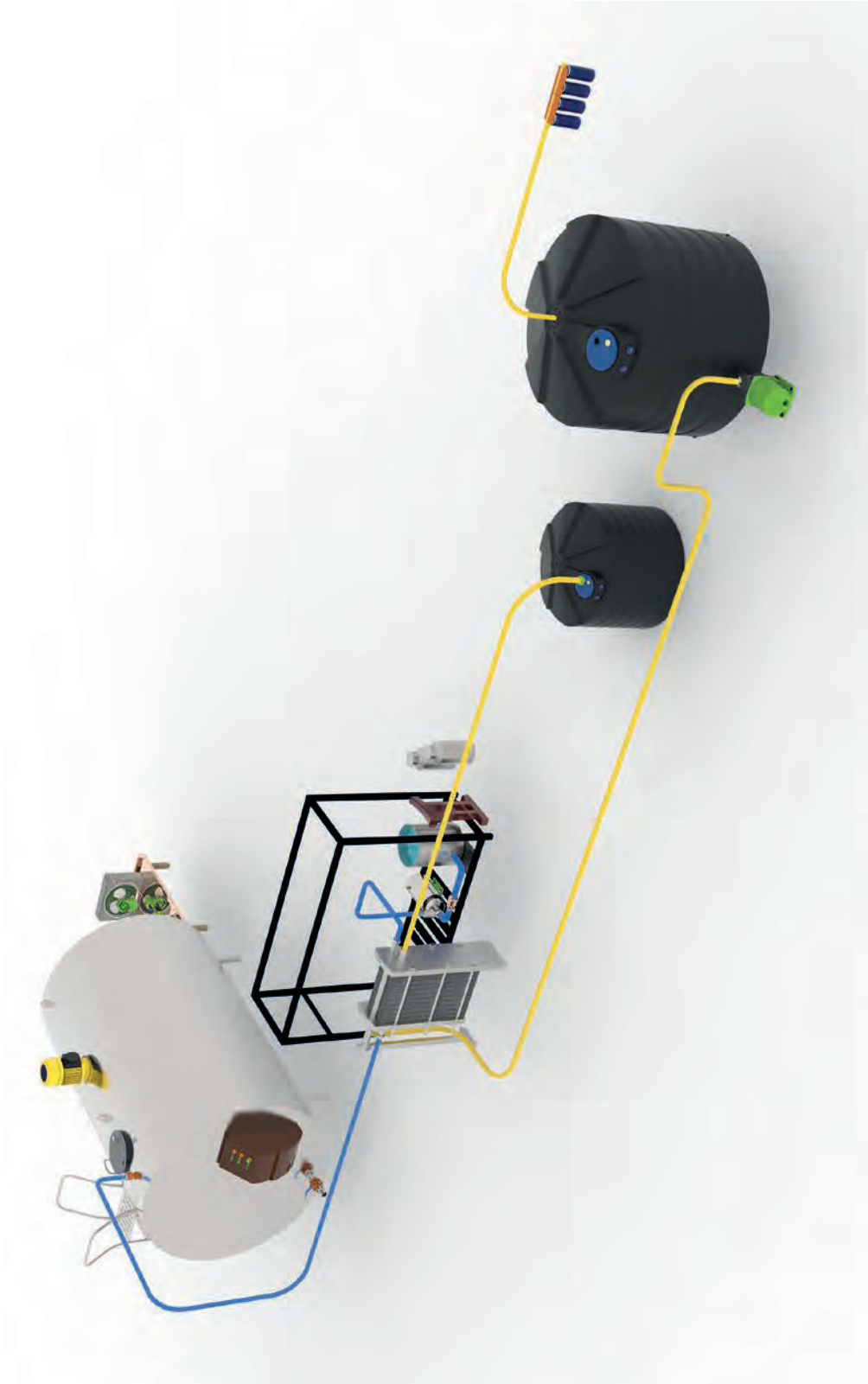


FIGURE 33
Direct expansion milk cooling tank with precooling using mains or well water

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

Figures 33 and 34 illustrate the DX milk cooling tank and system with precooling using mains or well water.

Advantages and limitations

Advantages:

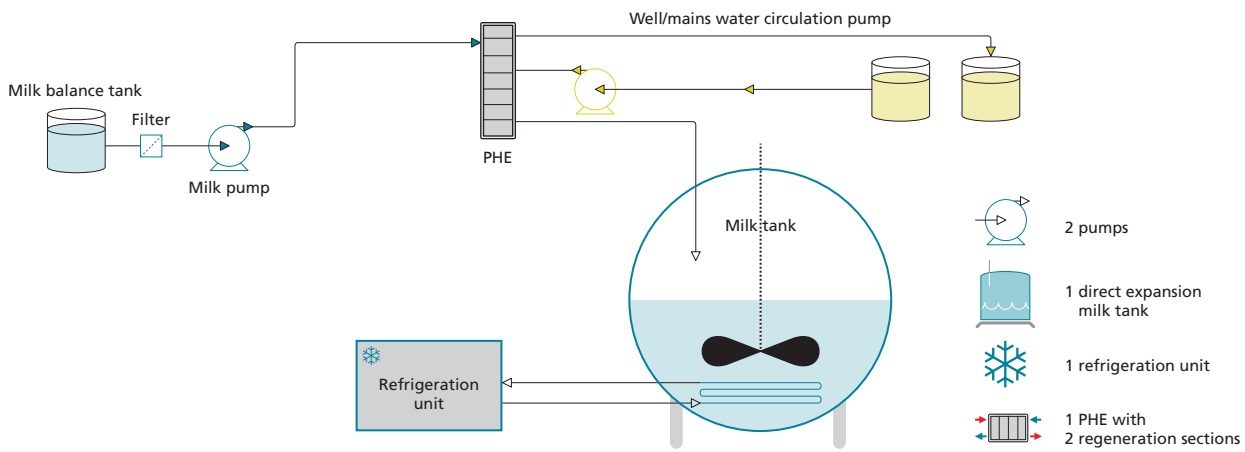
i) The tanks are commercially available; open-top tanks are particularly well suited to rural areas.
ii) Common capacity ranges from 500 to as much as 10 000 litres.
iii) The system can be used with single-phase (for up to 1 000-litre tanks) or three-phase (for all tank sizes) electricity.
iv) Precooling can significantly reduce energy consumption and overall cooling times.

Limitations:

i) Additional investment is required for the PHE and an extra water pump.
ii) Precooling may not be profitable at every location, if the mains, well or groundwater temperature is at 22 °C or more.
iii) A CIP system is needed to clean the PHE, which increases the investment required and the operating costs.

Table 8 outlines the basic equipment needed for a DX milk cooling system with precooling using mains or well water.

FIGURE 34
Option 2



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

TABLE 8
Basic equipment for a direct expansion refrigerated milk cooling system with precooling

Precooling using mains or well water at no more than 15 °C			
	Description	**No.**	**Remarks**
1	DX refrigerated milk cooling tank	1	Open-top tanks for up to 3 000 litres. Larger tanks are typically of the enclosed type
2	Milk reception weighing scale/calibrated tank	1	Weighing balance (calibrated tank for milk intakes of more than 3 000 litres)
3	Milk reception dump tank with 200-litre capacity	1	When handling volumes of less than of 2 000 litres, milk can be poured through a filter directly into an open-top milk cooling tank without a dump tank

TABLE 8
(continued)

Precooling using mains or well water at no more than 15 °C			
	Description	**No.**	**Remarks**
4	Milk filter – coarse filter before the milk pump and in-line filter after	1	In-line filter of a size appropriate to the milk flow rate
5	Milk precooling using mains or well water		The precooling PHE, milk and water pumps should be designed as a single unit and according to the milk intake and pumping flow rates and the temperature of the cooling water
5a	Milk pump for milk reception, precooling and loading of bulk road tankers that are not equipped with their own milk pumps	1	
5b	Pump for mains or well water	1	
5c	Precooling PHE for mains or well water	1	
5d	Stainless steel hand-operated, non-return valves, pipes, unions and fittings	2	As required
6	Water valves, pipes and fittings	1	As required
7	Electricity installation, switches and cabling	Mains	As required

Source: Frazer Moffat, 2015.

Option 3 – Bulk milk cooling tank with precooling using mains or well water followed by instant cooling using ice water from an ice builder unit

FIGURE 35
Bulk milk cooling tank with precooling followed by instant cooling

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

Figures 35 and 36 illustrate the bulk milk cooling system with precooling using mains or well water followed by instant cooling using water from an ice builder unit.

Advantages and limitations

Advantages:

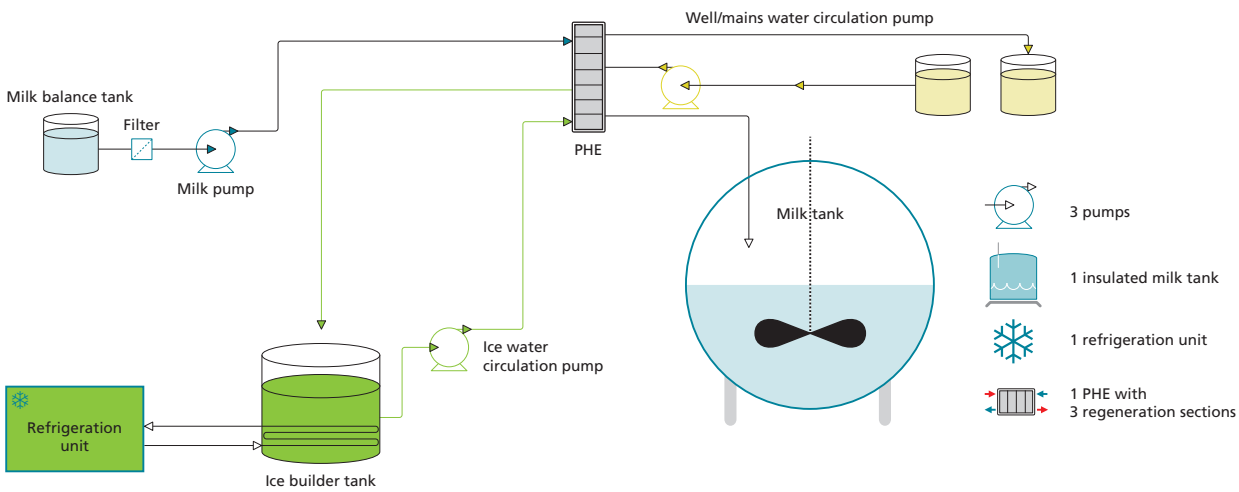
i) Precooling can significantly reduce energy consumption and overall cooling time.
ii) Use of ice water for instant cooling reduces the cooling time and offers rapid and semi-continuous or continuous cooling of milk.
iii) The tank can be used to cool large quantities of milk (3 000–10 000 litres).

Limitations:

i) Although a double-section PHE can be used for both precooling and instant cooling, this type of system needs an extra ice water tank equipped with an independent refrigeration system.
ii) A CIP system is needed to clean the PHE, which increases the investment required and the operating costs.
iii) Precooling may not be profitable in every location, if the mains, well or groundwater temperature is at 22 °C or more.

Table 9 outlines the basic equipment needed for a bulk milk cooling system with precooling using mains or well water followed by instant cooling using ice water from an ice builder unit.

FIGURE 36
Option 3



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

TABLE 9
Basic equipment for a bulk milk cooling system with precooling followed by instant cooling

	Precooling followed by instant cooling to 4 °C		
	Description	**No.**	**Remarks**
1	DX refrigerated milk cooling tank	1	Open-top tanks for up to 3 000 litres. Larger tanks are typically of the enclosed type
2	Milk reception weighing scale/calibrated tank	1	Weighing balance (calibrated tank for milk intakes of more than 3 000 litres)
3	Milk reception dump tank with 200-litre capacity	1	When handling volumes of less than of 2 000 litres, milk can be poured through a filter directly into an open-top milk cooling tank without a dump tank

TABLE 9
(continued)

Precooling followed by instant cooling to 4 °C			
	Description	**No.**	**Remarks**
4	Milk filter – coarse filter before the milk pump and in-line filter after	1	In-line filter of a size appropriate to the milk flow rate
5	Milk precooling using mains or well water		The precooling PHE, milk and water pumps should be designed as a single unit and according to the milk intake and pumping flow rates and the temperature of the cooling water
5a	Milk pump for milk reception, precooling and loading of bulk road tankers that are not equipped with their own milk pumps	1	
5b	Pump for mains or well water	1	
5c	Pump for chilled water	1	
5d	Precooling PHE using mains or well water (double-stage) and chilled water	1	
5e	Stainless steel hand-operated, non-return valves, pipes, unions and fittings	2	As required
6	Water valves, pipes and fittings	4	As required
7	Electricity installation, switches and cabling	Mains	As required
8	Portable CIP system	1	Optional

This system is better suited to milk intakes of more than 2 000 litres per day.
Source: Frazer Moffat, 2015.

Option 4 – Integrated ice bank milk cooling tank

FIGURE 37
Integrated ice bank milk cooling tank

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

Figures 37 and 38 illustrate the integrated ice bank milk cooling tank and system.

Advantages and limitations

Advantages:

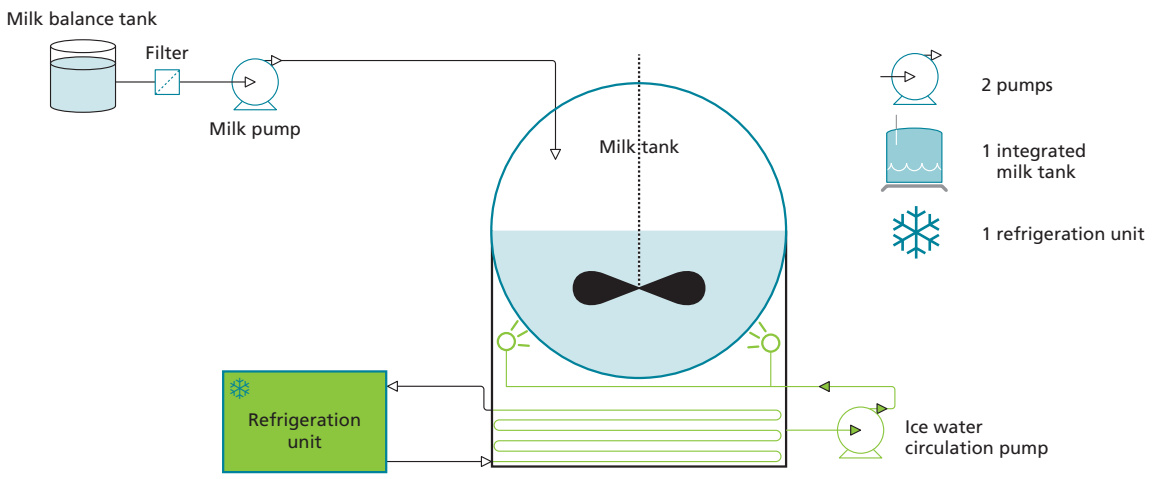
i) Water from the ice bank allows rapid cooling of the milk.
ii) Ice can be generated and stored during periods of low electricity demand, which means that some degree of cooling is possible even if the electricity supply is interrupted or there is a short period of load shedding.
iii) The system requires a compressor of smaller capacity than that required for a DX system (with single-phase electricity), resulting in higher milk cooling capacity.

Limitations:

i) As a large quantity of ice should be formed in advance of the milk cooling, the refrigeration system has to operate for long periods.
ii) The system is normally applied where a reliable grid supply of electricity is available.
iii) It is less energy-efficient than DX systems are.

Table 10 outlines the basic equipment needed for an integrated ice bank milk cooling system.

FIGURE 38
Option 4



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

TABLE 10
Basic equipment for an integrated ice bank milk cooling system

	Description	No.	Remarks
1	Ice bank refrigerated milk cooling tank	1	Open-top tanks for up to 3 000 litres. Larger tanks are typically of the enclosed type
2	Milk reception weighing scale/calibrated tank	1	Weighing balance (calibrated tank for milk intakes of more than 3 000 litres)
3	Milk reception dump tank with 200-litre capacity	1	When handling volumes of less than of 2 000 litres, milk can be poured through a filter directly into an open-top milk cooling tank without a dump tank
4	Milk pump and filter for milk reception and loading of bulk milk road tankers that are not equipped with their own milk pumps	1	Chilled-water pump for internal circulation
5	Stainless steel hand-operated, non-return valves, pipes, unions and fittings	2	As required
6	Electricity installation, switches and cabling	Mains	As required

Source: Frazer Moffat, 2015.

Option 5 – Integrated ice bank milk cooling tank with precooling using mains or well water

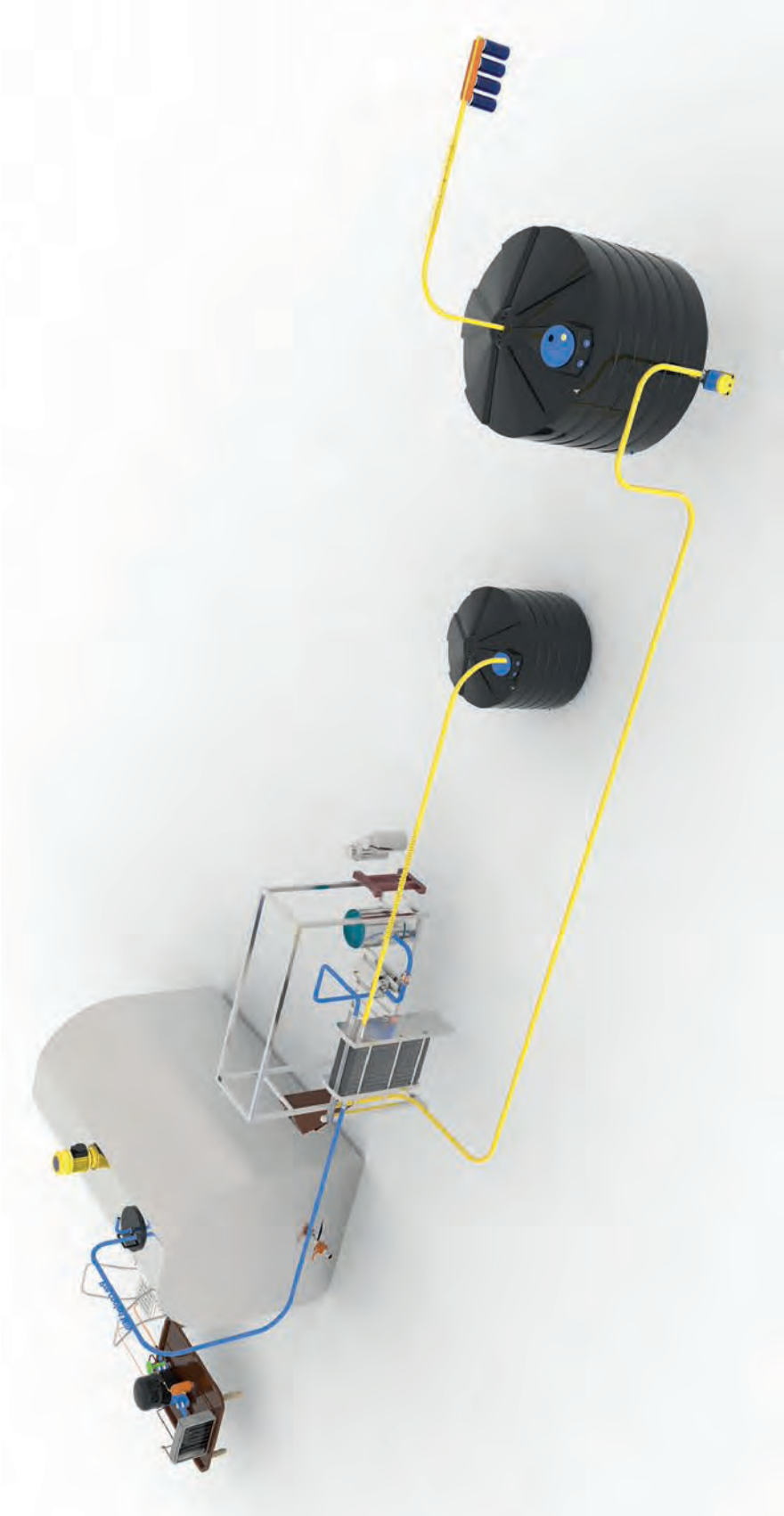


FIGURE 39
Integrated ice bank milk cooling tank with precooling using mains or well water

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

Figures 39 and 40 illustrate the integrated ice bank milk cooling tank system with precooling using mains or well water.

Advantages and limitations

Advantages:

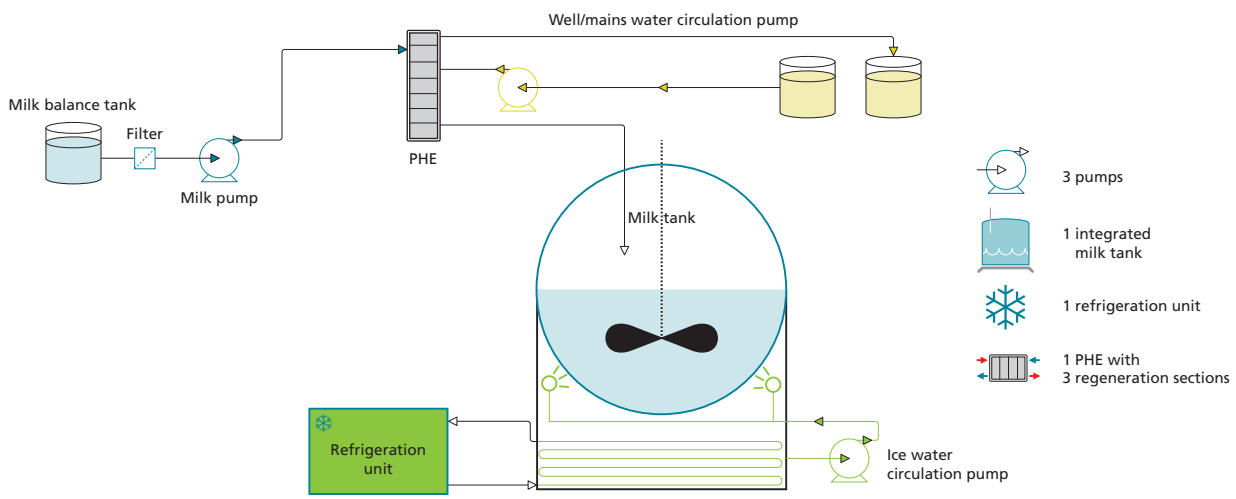
i) Water from the ice bank allows rapid cooling of the milk.
ii) Ice can be generated and stored during periods of low electricity demand, which means that some degree of cooling is possible even if the electricity supply is interrupted or there is a short period of load shedding.
iii) The system requires a compressor of smaller capacity than that required for a DX system with single-phase electricity, resulting in higher milk cooling capacity.
iv) Precooling can significantly reduce energy consumption and overall cooling time.

Limitations:

i) A large quantity of ice should be formed in advance of the milk cooling, the refrigeration system has to operate for long periods.
ii) Additional capital investment is required for the PHE.
iii) The system is normally applied where a reliable grid supply of electricity is available.
iv) The system is less energy-efficient than DX systems are.
v) Precooling may not be profitable in every location, if the mains, well or groundwater is at 22 °C or more.

Table 11 outlines the basic equipment needed for an integrated ice bank milk cooling system with precooling using mains or well water.

FIGURE 40
Option 5



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

TABLE 11
Basic equipment for an integrated ice bank milk cooling system with precooling using mains or well water

Mains or well water ideally not more than 20 °C			
	Description	**No.**	**Remarks**
1	Ice bank refrigerated milk cooling tank	1	Open-top tanks for up to 3 000 litres. Larger tanks are typically of the enclosed type
2	Milk reception weighing scale/calibrated tank	1	Weighing balance (calibrated tank for milk intakes of more than 3 000 litres)
3	Milk reception dump tank with 200-litre capacity	1	When handling volumes of less than of 2 000 litres, milk can be poured through a filter directly into an open-top milk cooling tank without a dump tank

TABLE 11
(continued)

	Mains or well water ideally not more than 20 °C		
	Description	**No.**	**Remarks**
4	Milk filter – coarse filter before the milk pump and in-line filter after	1	In-line filter of a size appropriate to the milk flow rate
5	Milk precooling using mains or well water		The precooling PHE, milk and water pumps should be designed as a single unit and according to the milk intake and pumping flow rates and the temperature of the cooling water
5a	Milk pump for milk reception, precooling and loading of bulk milk road tankers that are not equipped with their own pumps	1	
5b	Pump for mains/well and pump for chilled water	1	
5c	Precooling PHE using mains or well water and chilled water	1	
5d	Stainless steel hand-operated, non-return valves, pipes, unions and fittings	5	As required
6	Water valves, pipes and fittings	2	As required
7	Electricity installation, switches and cabling	Mains	As required

This system is better suited to milk intake volumes of more than 2 000 litres per day.
Source: Frazer Moffat, 2015.

Option 6 – Precooling of milk using precooled mains water from an integrated ice bank milk cooling tank

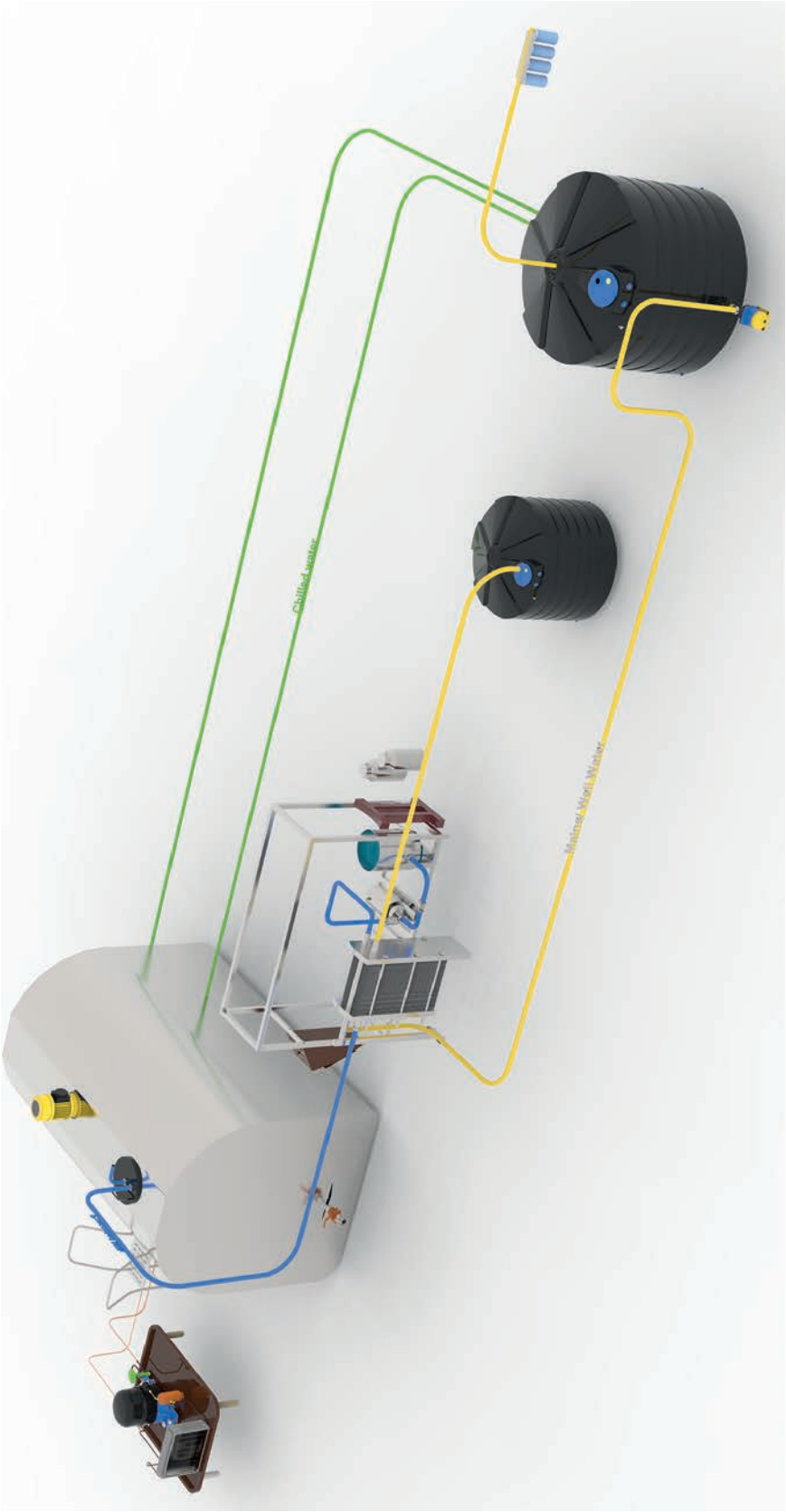


FIGURE 41
Precooling of milk using precooled mains water from an integrated ice bank milk cooling tank

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

Figures 41 and 42 illustrate the precooling of milk using mains water from an integrated ice bank milk cooling tank.

Advantages and limitations

Advantages:

i) Water from the ice bank allows rapid cooling of the milk.
ii) Ice can be generated and stored during periods of low electricity demand, which means that some degree of cooling is possible even if the electricity supply is interrupted or there is a short period of load shedding.
iii) The system requires a compressor of smaller capacity compressor than that required for a DX system (with single-phase electricity), resulting in higher milk cooling capacity.
iv) Precooling can significantly reduce energy consumption and overall cooling time.

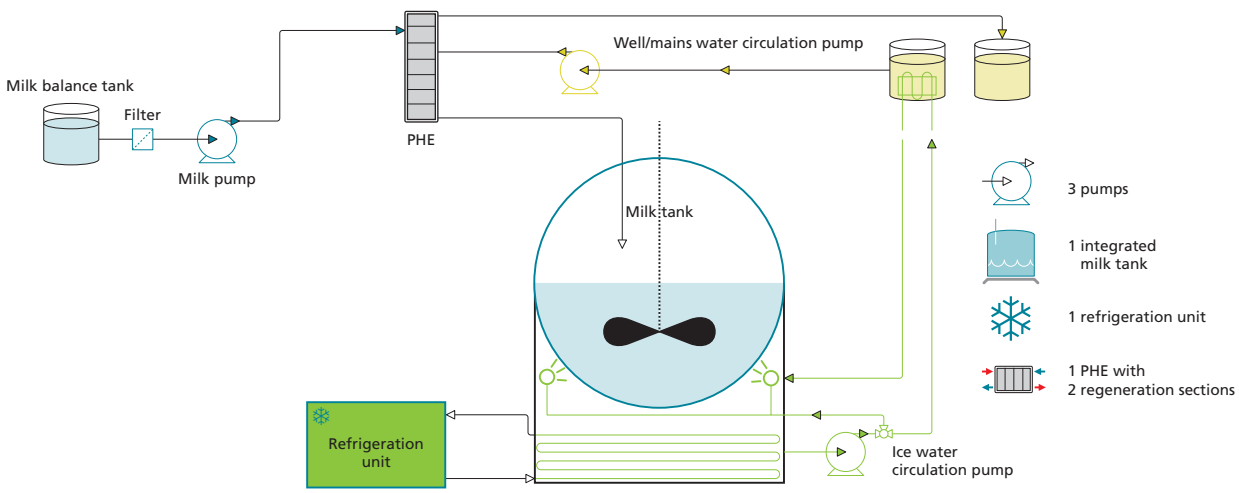
Limitations:

i) As a large quantity of ice should be formed in advance of the milk cooling, the refrigeration system has to operate for long periods.
ii) Additional capital investment is required for the PHE.
iii) The system is normally applied where a reliable grid supply of electricity is available.
iv) The system is less energy-efficient than DX systems are.

The configuration in this system uses the same chilled water to spray on to the integrated milk tank and to cool the milk through a PHE. This system is rarely of practical use for milk cooling facilities of less than 2 000-litre capacity because of its high investment costs. For larger-capacity operations, use of a PHE with recirculation cooling is a better option.

Table 12 outlines the basic equipment needed for precooling of milk using mains water from an integrated ice bank milk cooling system.

FIGURE 42
Option 6



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

TABLE 12
Basic equipment for precooling of milk using mains water from an integrated ice bank milk cooling tank

	Description	No.	Remarks
1	Ice bank refrigerated milk cooling tank	1	Open-top tanks for up to 3 000 litres. Larger tanks are typically of the enclosed type
2	Milk reception weighing scale/calibrated tank	1	Weighing balance (calibrated tank for milk intakes of more than 3 000 litres)
3	Milk reception dump tank with 200-litre capacity	1	When handling volumes of less than of 2 000 litres, milk can be poured through a filter directly into an open-top milk cooling tank without a dump tank
4	Milk pump for milk reception and loading of bulk milk road tankers that are not equipped with their own milk pumps	1	
5	Milk filter – coarse filter before the milk pump and in-line filter after	1	In-line filter of a size appropriate to the milk flow rate
6	PHE	1	The instant cooling PHE, milk and chilled water pumps should be designed as a single unit and according to the milk intake and pumping flow rates
7	Chilled water pump – the integrated chilled water pump	2	
8	Stainless steel hand-operated, non-return valves, pipes, unions and fittings	4	As required
9	Electricity installation switches and cabling	Mains	As required

Source: Frazer Moffat, 2015.

Option 7 – Ice bank milk cooling tank with precooling using mains or well water followed by instant cooling using ice water from an integrated ice bank

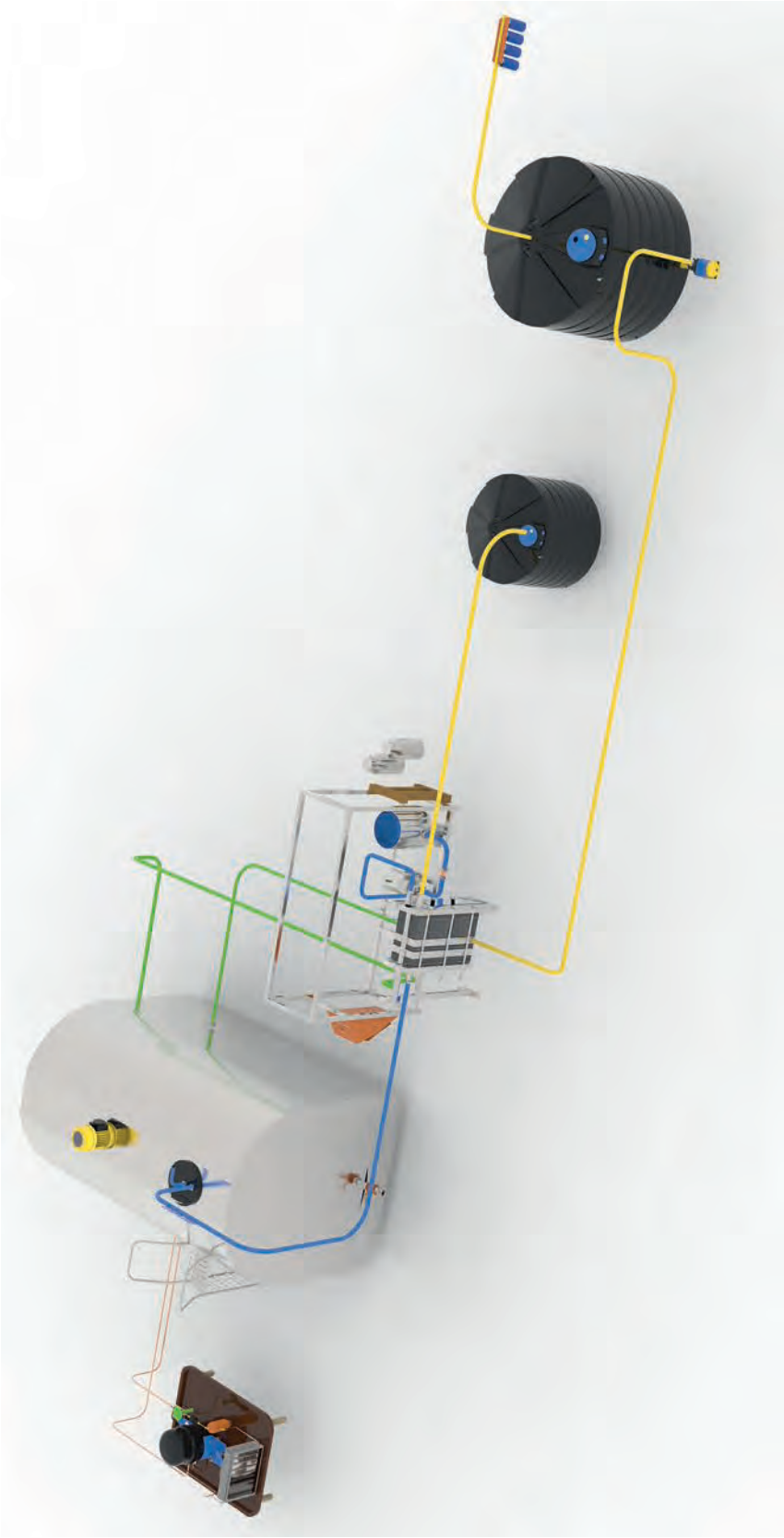


FIGURE 43
Ice bank milk cooling tank with precooling using mains or well water followed by instant cooling using ice water from an integrated ice bank

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

Figures 43 and 44 illustrate the ice bank milk cooling tank and system with precooling using mains or well water followed by instant cooling using ice water from an integrated ice bank.

Advantages and limitations

Advantages:

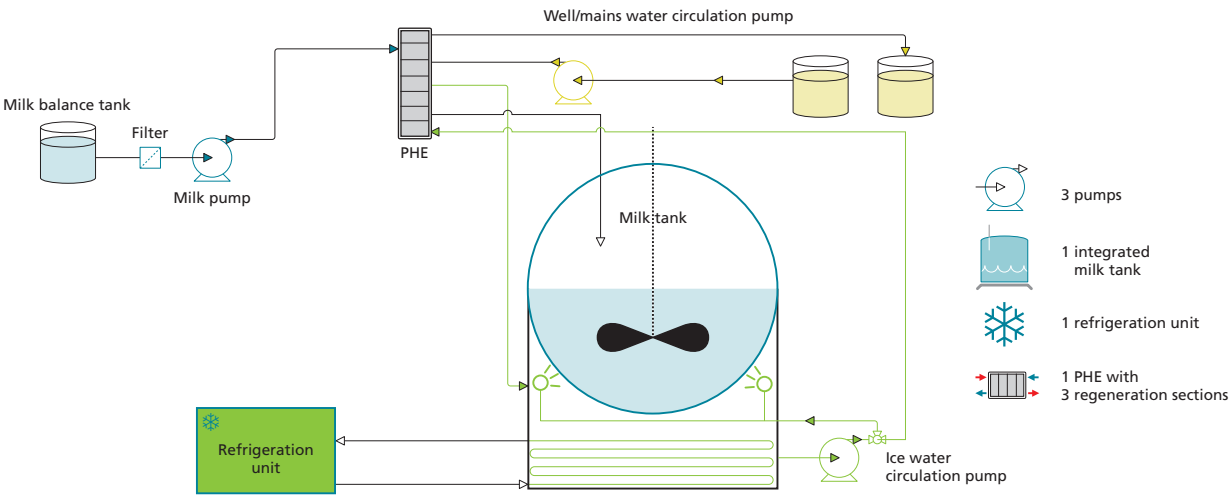
i) Water from the ice bank allows rapid cooling of the milk.
ii) Chilled water allows instant cooling of the milk.
iii) Ice can be generated and stored during periods of low electricity demand, which means that some degree of cooling is possible even if the electricity supply is interrupted or there is a short period of load shedding.
iv) The system requires a compressor of smaller capacity than that required for a DX (with single-phase electricity), resulting in higher milk cooling capacity.
v) Precooling can significantly reduce energy consumption and overall cooling time.

Limitations:

i) As a large quantity of ice should be formed in advance of the milk cooling, the refrigeration system has to operate for long periods.
ii) Additional capital investment is required for the PHE and pumps.
iii) The system is normally applied where a reliable grid supply of electricity is available.
iv) The system is less energy-efficient than DX systems are.
v) Precooling may not be profitable in every location, if mains, well or groundwater is at 22 °C or more.

Table 13 outlines the basic equipment needed for an ice bank milk cooling system with precooling using mains or well water followed by instant cooling using ice water from an integrated ice bank.

FIGURE 44
Option 7



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

TABLE 13
Basic equipment for ice bank milk cooling system with precooling using mains or well water followed by instant cooling using ice water from an integrated ice bank

	Description	No.	Remarks
1	Ice bank refrigerated milk cooling tank	1	Open-top tanks for up to 3 000 litres. Larger tanks are typically of the enclosed type
2	Milk reception weighing scale/calibrated tank	1	Weighing balance (calibrated tank for milk intakes of more than 3 000 litres)
3	Milk reception dump tank with 200-litre capacity	1	When handling volumes of less than of 2 000 litres, milk can be poured through a filter directly into an open-top milk cooling tank without a dump tank
4	Milk pump for milk reception and loading of bulk milk road tankers that are not equipped with their own milk pumps	1	
5	Milk filter – coarse filter before the milk pump and in-line filter after	1	In-line filter of a size appropriate to the milk flow rate
6	Milk precooling using mains or well water plus instant cooling using chilled water		
6a	PHE (double-state) for precooling and instant cooling	1	The instant cooling PHE, milk, precooling and chilled water pumps should be designed as a single unit and according to the milk intake and pumping flow rates and the temperature of the precooling water
6b	Water pump for mains or precooling well water	3	
6c	Chilled water pump, if not integrated into the system	1	
7	Stainless steel hand-operated, non-return valves, pipes, unions and fittings	5	As required
8	Electricity installation, switches and cabling	Mains	As required

Source: Frazer Moffat, 2015.

Option 8 – Instant milk cooling using a plate heat exchanger and an ice bank tank with storage in an insulated, unrefrigerated tank

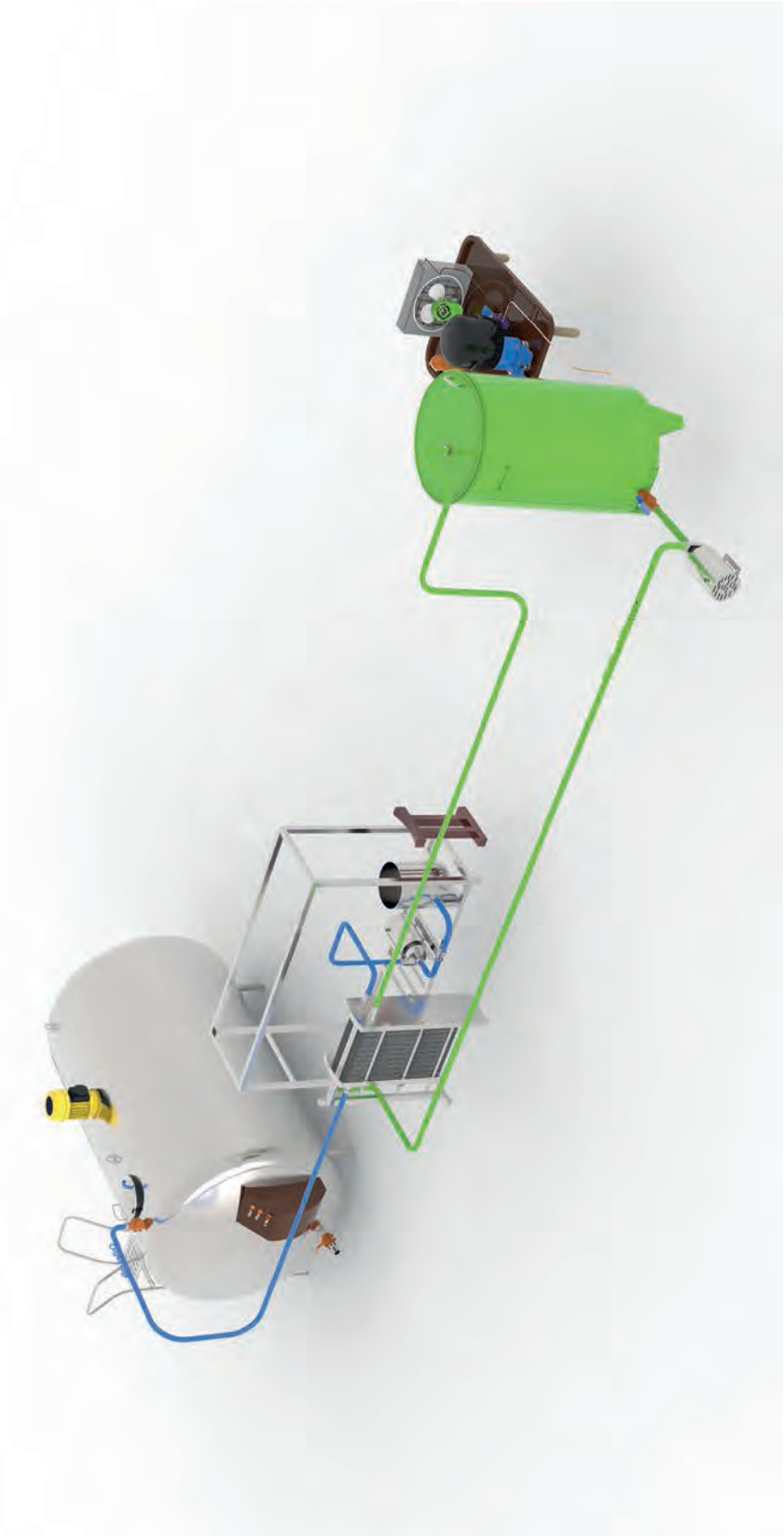


FIGURE 45
Instant milk cooling using a plate heat exchanger and an ice bank tank

Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

Figures 45 and 46 illustrate instant milk cooling using a PHE and an ice bank tank with milk storage in an insulated, unrefrigerated tank.

Advantages and limitations

Advantages:

i) Chilled water allows rapid cooling of the milk, and storage in an insulated tank keeps the temperature virtually unchanged for a significant period (normally of 12 hours).
ii) The system can be used in areas with high ambient temperatures where cooling in a refrigerated tank is slower because of the higher condensing pressure of the refrigeration system.
iii) It is used for continuous cooling of bulk milk in milk processing facilities.
iv) In the peak season, raw milk can be passed through the PHE directly into a road tanker.

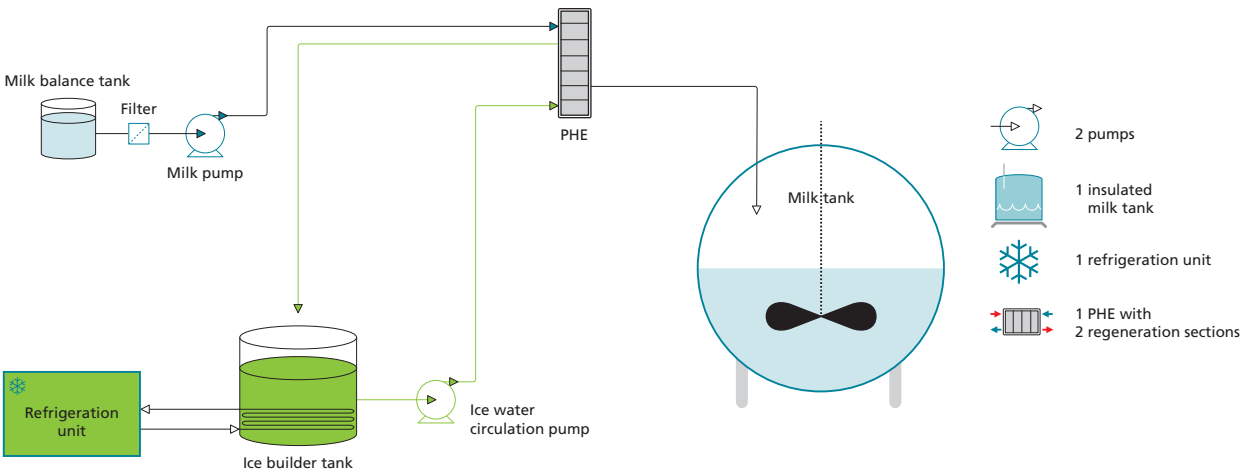
Limitation:

i) The high-capacity refrigeration required for the ice accumulation unit results in higher capital investments and energy requirements.

This system is feasible when handling larger volumes of milk. For quantities of less than 2 000–3 000 litres, the high investments and operating costs of the refrigeration system for the ice bank, the CIP system, the pumping facility etc. affect sustainability.

Table 14 outlines the basic equipment needed for instant cooling using a PHE and chilled water from an ice builder unit, with milk storage in an insulated, unrefrigerated tank.

FIGURE 46
Option 8



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

TABLE 14
Basic equipment for instant cooling using a plate heat exchanger and an ice bank tank

Instant cooling to 4 °C			
	Description	**No.**	**Remarks**
1	Insulated, unrefrigerated milk storage tank	1	Normally of enclosed type
2	Milk reception weighing scale/calibrated tank	1	Weighing balance (calibrated tank for milk intakes of more than 3 000 litres)
3	Milk reception dump tank with 200-litre capacity	1	When handling volumes of less than 2 000 litres, milk can be poured through a filter directly into an open-top cooling tank without a dump tank
4	Milk pump for milk reception and loading of bulk milk road tankers that are not equipped with their own pumps	1	As required
5	Milk filter – coarse filter before the milk pump and in-line filter after	1	In-line filter of a size appropriate to the milk flow rate
6	Instant cooling of milk using chilled water		
6a	Instant cooling PHE (double-section)	1	The instant cooling PHE, milk and chilled water pumps should be designed as a single unit and according to the milk intake and pumping flow rates
6b	Ice builder including refrigeration unit	1	
7	Stainless steel hand-operated, non-return valves, pipes, unions and fittings	4	As required
8	Electricity installation, switches and cabling	Mains	As required

Source: Frazer Moffat, 2015.

Option 9 – Containerized milk cooling centre

FIGURE 47
A containerized milk cooling centre

Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

FIGURE 48
Milk reception area at a containerized milk cooling centre

Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

Figures 47, 48 and 49 illustrate a containerized MCC.

Advantages and limitations

Advantages:

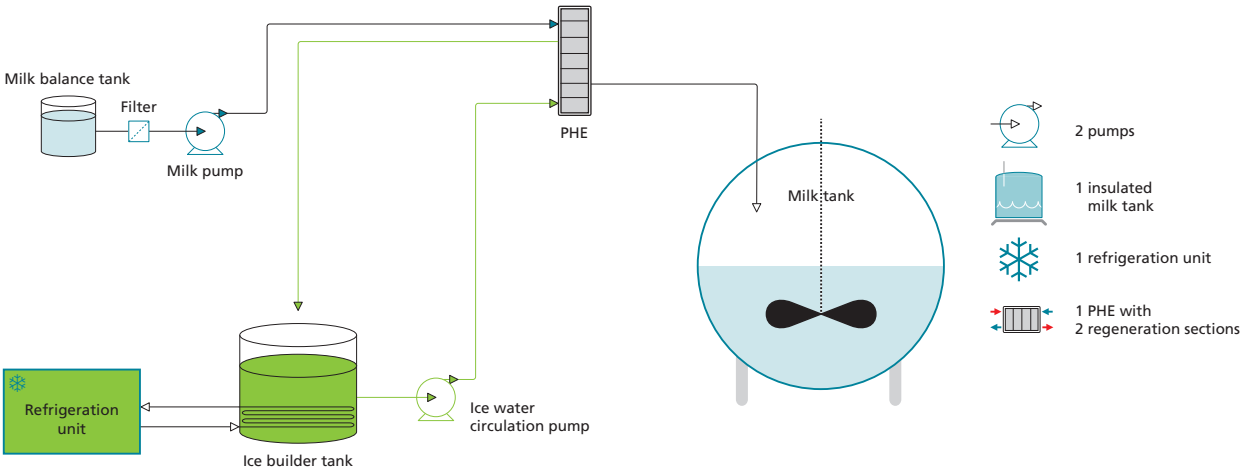
i) Chilled water allows rapid cooling of the milk, and storage in an insulated tank keeps the temperature virtually unchanged for a significant period (normally of 12 hours).
ii) The system can be used in areas with high ambient temperatures where cooling in a refrigerated tank is slower because of the higher condensing pressure of the refrigeration system.
iii) It is used for continuous cooling of bulk milk in milk processing facilities.
iv) In the peak season, raw milk can be passed through the PHE directly into a road tanker.
v) The system allows the mounting of a fully operational plant in a small area.
vi) It is feasible for larger quantities of milk.
vii) It is feasible in remote areas where an appropriate shed or building for the MCC is not available.

Limitation:

i) The high-capacity refrigeration required for the ice accumulation unit results in higher capital investments and energy requirements.

Table 15 outlines the basic equipment needed for a containerized MCC.

FIGURE 49
Option 9



Source: Sonnet Malakaran George, Tek B. Thapa and Frazer Moffat, 2015.

TABLE 15
Basic equipment for a containerized milk cooling centre

	Description	No.	Remarks
1	Insulated, unrefrigerated milk storage tank	1	Normally of enclosed type
2	Milk reception weighing scale/calibrated tank	1	Weighing balance (calibrated tank for milk intakes of more than 3 000 litres)
3	Milk reception dump tank with 200-litre capacity	1	When handling volumes of less than 2 000 litres, milk can be poured through a filter directly into an open-top cooling tank without a dump tank
4	Milk pump for milk reception and loading of bulk milk road tankers that are not equipped with their own pumps	1	As required
5	Milk filter – coarse filter before the milk pump and in-line filter after	1	In-line filter of a size appropriate to the milk flow rate
6	Instant cooling of milk using chilled water		
6a	Instant cooling PHE (double-section)	1	The instant cooling PHE, milk and chilled water pumps should be designed as a single unit and according to the milk intake and pumping flow rates
6b	Ice builder including refrigeration unit	1	
7	Stainless steel hand-operated, non-return valves, pipes, unions and fittings	4	As required
8	Electricity installation, switches and cabling	Mains	As required
9	40-ft (12 m) container	1	New or reconditioned
10	40-ft (12 m) trailer	1	12- or 8-wheeled trailer for greater stability

Source: Sonnet Malakaran, Tek B. Thapa and Frazer Moffat, 2015.

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Chapter 7

Power supply and renewable energy options

7.1 OVERVIEW

With fluctuating and increasing costs of energy derived from fossil fuels, it is important to find ways of decreasing dependency on fossil fuels, not only to control costs today but also to prepare for ever-increasing costs in the future. There is also an urgent need to reduce the greenhouse gas (GHG) emissions that result from the use of fossil fuels. Reducing GHG emissions is not always easy and steps have been taken to reduce energy consumption in the dairy sector by applying energy-efficient measures based on the use of renewable energy sources and emphasizing the need for careful management of energy use. Heat saving and recovery with heat recycling systems are of major interest in energy-saving practices.

Normally the electricity supplied to MCCs comes from a grid. MCCs can use diesel-powered electrical generators to complement power from the national electricity grids, or can be fully powered by generators where no such grid is available. The actual energy requirement for an MCC will depend on the range and type of equipment installed and has to be calculated for each MCC.

In some countries, the tariff charges for electricity are much lower than the true cost of the energy because of subsidies (direct or indirect) provided to consumers for various reasons. The electricity used by agriculture, small-scale agro-industries and cooperatives may also be eligible for reduced tariff charges.

Sources of renewable energy are an increasingly viable option for producing electricity or heat and many are already competitive. Some countries have incentive schemes for renewable energy sources, but such schemes are yet to be introduced in most developing nations. For investors, these schemes increase the profitability of using renewable energy in industrial and domestic applications for investors through direct and/or indirect subsidies (e.g. reduced value-added tax on equipment, tax credits, incentive payments for the electricity produced, and feed-in tariffs for selling power to the national grid). Feed-in tariffs for power sold to the national grid (or private utility companies) can be up to four times the cost of purchasing grid electricity. Such incentives for investing in renewable energy allow the recuperation of capital investments within three to ten years and can provide additional income through the sale of surplus renewable energy after the costs of the system have been recouped. As such schemes are not yet common in many developing nations, and renewable energy systems require large up-front investments, investors usually have to support all the capital costs.

7.2 NON-RENEWABLE ENERGY

Electricity generators

A diesel-powered electrical generator (genset) comprises a diesel compression ignition engine that drives an alternator to produce electrical energy. Gensets are robust systems for providing electricity for agricultural, industrial and domestic applications. When properly operated and maintained they perform very well and are very reliable.

Gensets are the most common source of electricity in countries where the national electricity grid is unreliable and power outages are frequent because of energy shortages (of coal, gas, and water in the case of hydropower). In areas not covered by the national grid, electrical generators are the only sources of electrical power.

Diesel generators can be for prime or backup applications:

i) *Prime/continuous generators*: These units provide a continuous power supply and are for use in off-grid situations. There are no limits on their annual hours of operation, and they can typically supply 100 percent of the power required for MCC operations.

ii) *Standby/backup generators*: These units provide an uninterrupted electrical power supply (at variable loads). No overload is permitted on the alternators in these models, which are rated for peak, continuous use. Usage is normally limited to 500 hours per year.

The choice of genset type will depend on:

i) the availability of national grid power and the reliability of the power supply, including the frequency of outages and the voltage and phase fluctuations;
ii) the type of fuel used/available – gensets usually operate using diesel fuel but can be modified to use biodiesel, straight vegetable oil (SVO), biogas or liquid petroleum gas (LPG).

Deciding which size of genset to acquire is a complex operation that is best done with special computer software and in consultation with a qualified electrical engineer or a genset manufacturer. Many genset manufacturers provide free software to assist in sizing the generator.

When sizing the genset it is important to take the following factors into account:

a) *Minimum and maximum generator loads/capacities:* Most genset manufacturers do not recommend running a genset at less than 30 percent of its rated load. Optimum loading is at least 70 percent.
b) *Climate conditions:* To achieve a given level of performance, the size of the generator needed will increase as the altitude and ambient temperature of its location increase. The relative humidity must also be taken in account, as high humidity has negative effects on performance.
c) *Fuel:* The preference for diesel, SVO, biogas or LPG will affect the genset selected. Generators running on biogas, LPG or SVO often have to be larger than those running on diesel because of derating (resulting from the lower heating value of these fuels).
d) *Phase:* Gensets can be for either single- or three-phase electricity. A three-phase genset can be used for single-phase loads but it is assumed that the single-phase loads will be balanced across three phases. Generators of more than 3.5 kW should be three-phase.
e) *Frequency:* Gensets can be appropriate for either 50 Hz or 60 Hz, depending on the national power grid. (This factor is relevant only if the generator is to be connected to the grid.)
f) *Voltage:* The voltage is normally that for industrial or domestic use (400 or 220 V in most countries).
g) *Exhaust gases:* The use of catalytic converters is advised to reduce nitrous oxide emissions, which harm the atmosphere. Ideally, other impurities in the exhaust gases should also be removed or reduced to safe levels.

To calculate the total power requirement, it is necessary to determine the power requirements of each item of equipment to be installed in the MCC, including start-up loads, lighting and losses. This process involves the following steps:

i) Identify the mains grid electricity supply – voltage, single- or three-phase, frequency.
ii) List all the items of equipment that will need to be powered by the genset.
iii) Note the starting and running wattages of each item.
iv) Calculate the total power requirements in kilowatts or kilovolt amps. In general, 20 percent should be added to the calculated power requirements. This margin helps prevent overloading of the system during the starting up of motors or the switching on of some types of lighting system, or when wear and tear of the equipment increases its power consumption, making it run suboptimally.
v) Specify whether the switch from grid to genset power is to be manual or automatic.
vi) Consult a qualified electrical engineer with genset experience to ensure that all the calculated requirements are correct.

In any facility running on electricity not all the equipment will be in operation at the same time. It is therefore necessary to determine when each item of equipment will be required to operate to calculate the load factor. The size of the genset should match the maximum power requirement.

The power requirement of MCC operations can be calculated for a period of about four hours during milk cooling operations in both the morning and the late afternoon/early evening.

It is possible to procure "off-the-shelf" gensets that provide the power required, but it is much safer to consult genset manufactures/suppliers about the required specifications, factoring in all relevant parameters such as fuel type, altitude of location, ambient temperature and relative humidity. More energy-efficient systems using renewable energy are being developed, for all stages of the dairy chain, from milk collection to processing and storage, but a more rapid transition to renewable energy sources would be desirable.

7.3 RENEWABLE ENERGY

There is increasing awareness of the need to address climate change issues. Food production

and agrifood industries make significant contributions to GHG production and global warming. At the Twentieth Conference of the Parties to the United Nations Framework Convention on Climate Change, in Peru in December 2014, agreement was reached on reducing GHGs to limit the global temperature increase to 2 °C above current levels. The promotion of low-carbon energy sources to replace fossil resources is therefore a high priority.

A number of renewable energy sources can be harnessed to provide heat and electrical power for the dairy industry, these are described in the FAO publication *Utilization of renewable energy sources and energy-saving technologies by small-scale milk plants and collection centres* (FAO, 1992). Of the renewable energy sources available, solar thermal, solar PV, low-enthalpy geothermal and wind power appear to be the most suitable to the power requirements of small-scale cooling systems and MCCs. The nature of renewable sources of wind and solar power make them diffuse, intermittent and unreliable. Therefore, energy availability and demand do not always match, and a battery or other energy buffer has to fill the gap. The current high cost of such energy buffers is an important limitation.

To date, few of the systems available can provide sufficient renewable energy at competitive cost (unit price) for application in small-scale MCCs. Systems using solar or wind energy currently require costly batteries, chemicals and ice banks for energy storage to provide backup energy when solar or wind power is not available.

A range of technologies and processes for the commercial application of renewable energy in milk cooling facilities are being researched and developed. Additional work is needed to enhance the efficiency and effectiveness of these technologies and to reduce their costs.

Solar technologies

The application of solar energy for MCCs is described in FAO's *Solar energy in small-scale milk collection and processing* (FAO, 1983). Two basic options – solar thermal and solar PV – are available for providing a renewable energy supply for small-scale milk cooling operations and MCCs. Both systems harness energy provided by the sun, but solar radiation varies throughout the world and over time (IRENA, 2015).

Data on global irradiation by location is available from a number of sources (e.g. IRENA, 2015), but national meteorological offices, government ministries/departments and agencies specializing in renewable energy can usually provide more precise and reliable data on solar radiation at the local level. To design systems that are suitable for specific locations, most commercial companies providing solar power systems rely on data from national authorities together with the findings of on-site monitoring. Efficiency in capturing solar energy is affected by many factors associated with the specific location, including local weather patterns throughout the year, dust storms, and shade from trees and human-made structures. Determining the right size of solar power system is a complex process and requires the skill and services of experts in solar technologies.

There are examples of solar energy being used in small-scale milk processing enterprises in transitional and developing countries. For example, in Dankunku province of The Gambia, a rural milk processing enterprise located far from the city, where electricity was not available, used solar power to cool pouches of pasteurized milk and pots of yoghurt. The solar power was stored in batteries and subsequently used to operate freezers and refrigerators. The rural dairy enterprise processed an average of 100 litres of milk a day into value-added dairy products.

Solar thermal: Solar thermal systems transform solar radiation into energy for heating, cooling or mechanical applications. In these systems, solar radiation is initially transformed into heat energy. Solar collectors use special surfaces on which sunlight is absorbed and transformed into heat energy, which is then transferred to a medium (e.g. air, water, glycol) flowing through the solar collector. The collector then transfers the heat to a heater, a generator for refrigeration or another machine in which it is converted into mechanical energy. The required temperature of the heat-carrying medium depends on the application served by the solar power system. For example, domestic water heating requires temperatures of 50–70 °C; transformation of heat into mechanical energy in a Rankine cycle heat engine needs temperatures of at least 120 °C; and a turbo-electric generator requires superheated steam at more than 500 °C. Flat plate collectors, parabolic troughs, Fresnel reflectors or evacuated tube systems can be used to harness the solar heat. Evacuated tube collectors are particularly suitable for MCC operations. These systems are easily installed and have low maintenance requirements.

Solar thermal systems are a well-known technology for absorption refrigeration. Solar thermal

refrigeration systems use heat energy from solar radiation to generate power to meet the cooling requirements. The heat energy collected from solar radiation is used to vaporize refrigerant. The cooled refrigerant vapour is then condensed and used to remove heat from warm food through an evaporator. The final cooling temperature required will depend on the combination of absorbent and refrigeration used in the system. A lithium–bromide water mixture can be used as a desorbent in a temperature range of 80–90 °C, while lithium–bromide water, ammonia and hydrogen can be used at temperatures in the range of 120–150 °C. Absorbents for thermal refrigeration system include strontium chloride/ammonia for temperatures of about 90 °C, and calcium chloride/ammonia mixtures for those of about 120 °C. The complexity of the system depends on the volatility of the absorbent, which may be flooded with water, ultimately causing the build up of frost inside the system.

Parabolic troughs can also be used as thermal collectors to harness solar heat energy. A parabolic trough is a concave reflective body that converges solar radiation on to a focal point, thereby concentrating solar radiation into heat energy. The heat energy is then used to drive a heat pump to generate electricity.

Small-scale parabolic troughs using ammonia absorption refrigeration technology to produce ice have been applied in several countries. A successful milk cooling system based on this technology has been developed in Kenya, but has not yet been replicated throughout the region. Equipment for the system can be fabricated locally. Using "free" solar thermal heat, and being close to the equator with long hours of direct sunshine, the system produces 5 kg of ice per square metre of parabolic dish area a day. With a parabolic trough of 11 m^2, up to 50 kg of ice (Photos 4 and 5) can be produced daily, which – after thermal losses – can cool 100 litres of fresh warm milk to 4 °C. However, on days of low sunshine (solar radiation) ice production is likely to be considerably less.

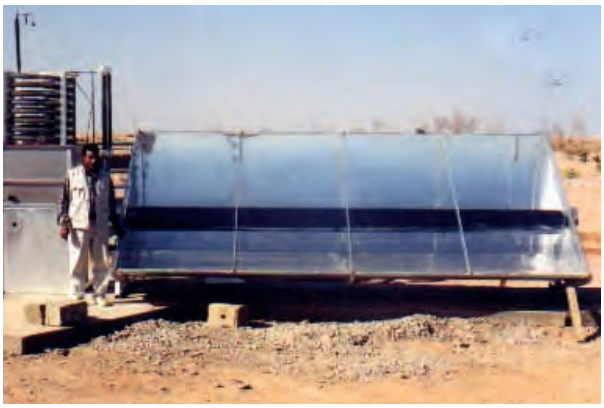
With a refrigeration load of about 4 kW/m^2 and intensive solar thermal insulation between 10.00 and 15.00 hours, only about 1.0 kW/m^2 can be absorbed by the absorbent/refrigerant mixture during generation at 120 °C. In this system, 0.4 kW/m^2 of heat is removed from chilled water every day, equivalent to 80 kW/m^2 annually.

A parabolic trough unit costs about US$7 000 and requires minimal maintenance. The expected working life of the equipment is at least ten years.

Solar photovoltaic: Solar PV energy conversion directly converts sunlight (solar radiation) into electricity. The solar panels are therefore effective only during daylight hours and an energy storage system will have to be utilized to provide an electricity supply at other times. Energy can be stored in electrical batteries, chemicals or ice banks. If the system is connected to a national grid, the surplus electricity generated and not used during the day can be sold to the power company, but only in countries where such schemes are practised.

PV cells, also called solar cells, are made of the semiconductor materials such as silicon that are used in the microelectronics industry. For solar cells, a thin semiconductor wafer is treated to

PHOTO 4
Parabolic trough with ammonia absorption refrigeration unit



© Frazer Moffat, 2015

PHOTO 5
Ice removal for use in cooling milk in cans

© Frazer Moffat, 2015

form an electric field, which is positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. When electrical conductors are attached to the positive and negative sides of the cell, forming an electrical circuit, a flow of electrons is created, based on potential difference, which can be captured in the form of an electric current. This electricity can be used to power an appliance. A PV panel is made from several solar cells that are electrically connected to each other and mounted in a support structure or frame. An assembly of several solar panels is referred to as a solar array. Individual panels are designed to provide between 50 and 1 000 watts of direct current (DC) electricity. The DC power can be converted to single- or three-phase electrical alternating current (AC) using an inverter.

There are three basic types of PV panel.

Monocrystalline panels:[5] Monocrystalline solar panels are made of premium-grade silicon crystals, which contain very few impurities. These panels are therefore far more efficient than other types of solar panel.

Advantages:[6]

i) The average efficiency of monocrystalline solar panels ranges from 15 to 20 percent.
ii) Monocrystalline silicon solar panels make efficient use of space and are economical. As they have higher power outputs, they can be smaller than any other type of solar panel.
iii) They are highly durable. Most producers of monocrystalline solar panels provide guarantees of 20–25 years.

Disadvantages:

i) Monocrystalline solar panels are expensive, and are recommended mainly for small spaces when high power density is required.
ii) Shade affects their efficiency and power production.
iii) Monocrystalline is sensitive to temperature. High temperatures decrease the efficiency of monocrystalline solar panels.

Polycrystalline panels: These are slightly less efficient and expensive than monocrystalline cells. They are easier to manufacture than monocrystalline panels.

Advantages:

i) The manufacturing process for polycrystalline panels is less complicated and more cost-effective than for monocrystalline panels.
ii) The polycrystalline process does not include the Czochralski process, so generates less silicon waste than the monocrystalline process does.

Disadvantages:

i) The higher impurity of the silicon used to make polycrystalline panels reduces the efficiency of their solar energy harvesting. The efficiency ranges from 12 to 17 percent and is generally lower than that of monocrystalline solar panels.
ii) Polycrystalline solar panels need more space (larger surfaces) than monocrystalline panels do.
iii) High temperatures reduce the life span and efficiency of polycrystalline solar panels. Polycrystalline is more sensitive to temperature than monocrystalline.

Thin-film panels:[7] Thin-film solar panel technology is cheaper to produce than either mono- or polycrystalline silicon cells, but thin-film panels have far lower efficiency. Thin-film solar cells are manufactured by joining several layers of thin PV material on to a special structure. The thin film is classified according to the materials used in the substrate, and can be:

i) amorphous silicon;
ii) cadmium telluride;
iii) copper indium gallium selenide;
iv) organic photovoltaic cells.

Depending on the technology, thin-film modules have achieved efficiencies of between 7 and 13 percent; commercial modules typically operate at about 9 percent. The efficiency of future modules is expected to reach about 10–16 percent. The international market for thin-film PV grew by 60 percent a year from 2002 to 2007 (EPIA, 2014).

[5] http://www.solar-facts-and-advice.com/monocrystalline.html
[6] http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/
[7] http://www.energymatters.com.au/panels-modules/thin-film-monocrystalline/

Advantages:
i) Thin-film panels are economical and simple to produce.
ii) High temperatures and shade have less impact on their performance and efficiency.
iii) They can be fully integrated into existing structures and building elements.

Disadvantages:
i) The efficiency of thin-film solar cells is in the range of only 7–13 percent.
ii) Because of this low efficiency, thin-film technology requires a lot of space. Monocrystalline panels harvest three to four times as much energy as thin-film panels.
iii) The low efficiency and need for space increases the cost of thin-film PV equipment, such as support structures and cables.
iv) They are less durable than mono- and polycrystalline solar cells.

In general, the cells used in PV panels for electricity production are of the single-junction type with efficiency of 15 percent. The working lives of PV panels are reported to be 12–25 years. Over this period, efficiency is expected to drop to about 90 percent after 12 years and 80 percent after 25 years. Panel performance is generally rated under standard test conditions: irradiance of 1 000 W/m^2 at a temperature of 25 °C.[8]

Modern solar power systems are usually designed and set up to sell any unused electricity back to the national grid (when available). Selling surplus energy to the national grid avoids the use of batteries, which are a costly and inefficient means of storing electricity. Batteries also have a relatively short life span and their components are potentially harmful to the environment. However, if there is no connection to the national grid it will be necessary to use batteries, chemical storage or thermal storage (such as ice banks) to store surplus energy to enable a stand-alone PV system to operate.

The basic components of a PV power system are:
i) an array of solar panels;
ii) support frames for ground or roof mounting;
iii) an inverter to convert direct current into alternating current, of either single- or three-phase, for use either on- or off-grid;
iv) junction boxes, combiner boxes, cables and connectors;
v) a charge controller;
vi) a meter or software to monitor the PV system;
vii) electrical batteries and solar PV charge controllers or another energy storage option if the system is not connected to the national grid.

The solar PV array generally accounts for about 60–70 percent of total equipment costs if it is connected to the national grid with feed-in capability. When off-grid energy storage for a stand-alone system is required, the overall cost of the solar PV system will rise considerably, depending on the type and quality of energy storage applied. Currently, solar PV panels cost about US$1 per watt of output (for large plants in developed countries).

Electrical batteries to power refrigeration using a thermal ice bank are most suited to the cooling systems of MCCs. In addition, a backup genset may be required.

Batteries: The twenty-first century has witnessed extraordinary growth and improvement in the development of energy sources and power options for MCC operations. Based on studies, rechargeable batteries are the advisable option in locations with an unstable or inconsistent energy supply. Rechargeable batteries are available in different shapes, sizes and voltages, ranging from button cell to megawatt systems according to requirements. Lead acid batteries (LABs) are the recommended option for refrigeration and lighting in MCCs in remote locations, given their massive advantages compared with alternatives. Batteries have a major impact on the economics of MCC operations as they need to be replaced periodically. Batteries can be used as a backup power source, supplying electricity to critical systems in the event of a power outage. Commonly used types of battery for MCC purposes are LABs and lithium ion (Li-ion) batteries.

Lead acid batteries: This is the most economical and affordable energy option for MCCs with larger power requirements, where the weight of the battery is of little concern (Buchmann, 2015).

Advantages: LAB technology is uncomplicated so systems using LAB are durable. The structure of the battery is comparatively simple and inexpensive to manufacture and maintain.

[8] The output of a solar cell, and therefore a solar panel, is affected by its temperature. The power output will be reduced by between 0.25 percent (amorphous cells) and 0.5 percent (most crystalline cells) for each degree Celsius that the temperature rises above 25 °C.

BOX 2

Self-sustaining container with solar energy options for milk cooling

Institut für Luft- und Kältetechnik (ILK) Dresden gGmbH, a German research institute, designed, constructed and conducted trials on a prototype stand-alone milk cooling system. The results indicate that it is possible to cool milk in a containerized, stand-alone, solar PV milk cooling unit, but the capital costs of such a system are high. The system was used to test two types of technology: i) electrical storage; and ii) an ice bank–tank combination.

The prototype PV cooling unit was installed in an ISO-standard 20-ft shipping container (Photo 6); a schematic layout is shown in Figure 50.

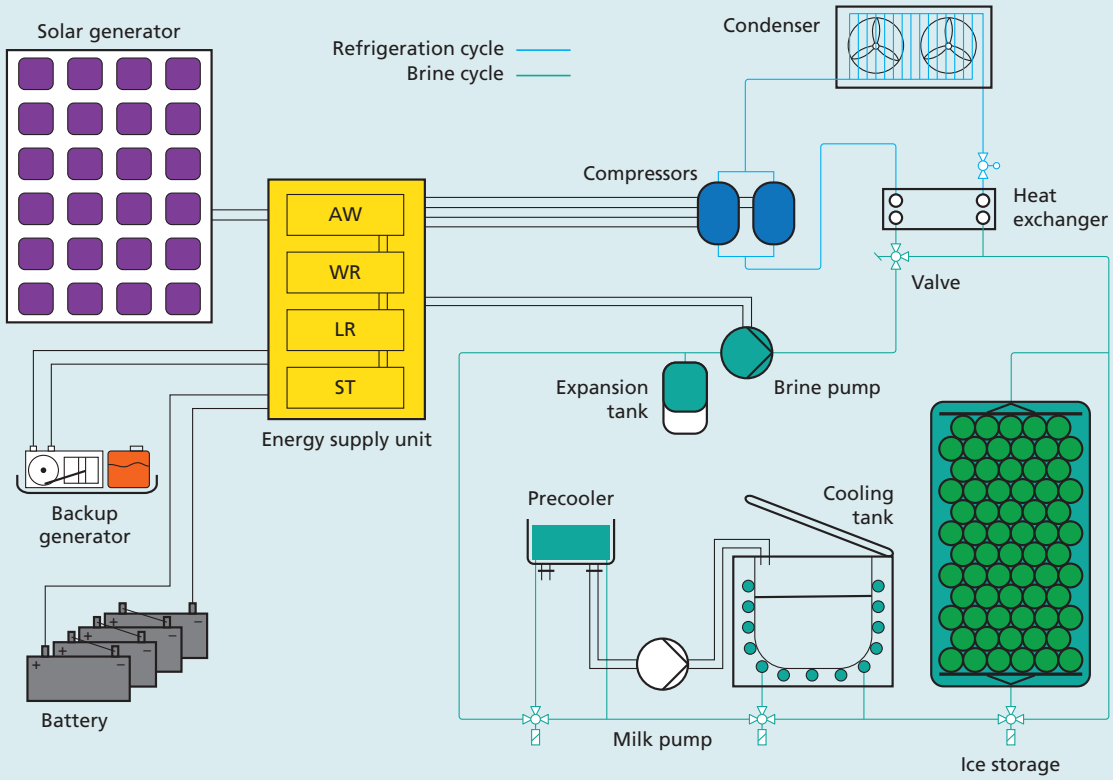
PHOTO 6

Containerized, stand-alone, solar photovoltaic milk cooling unit

© Waschull, 2004

FIGURE 50

Containerized, stand-alone, solar photovoltaic milk cooling unit



Source: Waschull, 2004.

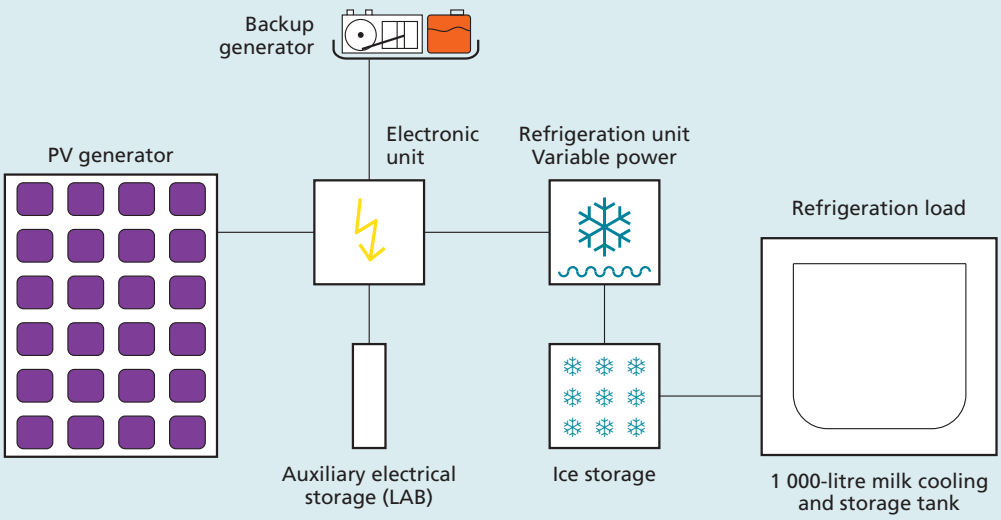
BOX 2 (continued)

Two systems for using solar PV power in milk cooling were examined: one with electrical battery energy storage, and one with ice bank energy storage.

System 1 (Figure 51) consists of:

i) a solar PV electrical power generator;
ii) electrical control units;
iii) LABs for storing two days of electrical energy;
iv) refrigeration unit using constant-power compressor cooling;
v) 1 000-litre bulk milk cooling/storage tank for two days of storage;
vi) a backup generator;
vii) an ISO-standard 20-ft shipping container.

FIGURE 51
Photovoltaic cooling system with electrical energy storage



Source: Waschull, 2004.

These features reduce the energy storage costs for processes with larger power requirements, such as those involved in MCCs.

Disadvantages: Storage of discharged LABs may lead to permanent damage of the cells, and damaged cells have to be discarded. Recycling of lead batteries is costly as they contain lead, which is harmful to the environment. LABs allow a limited number of full discharge cycles.

Lithium ion batteries: Li-ion batteries are another type of secondary/rechargeable battery that are commonly used in MCC operations (Buchmann, 2015).

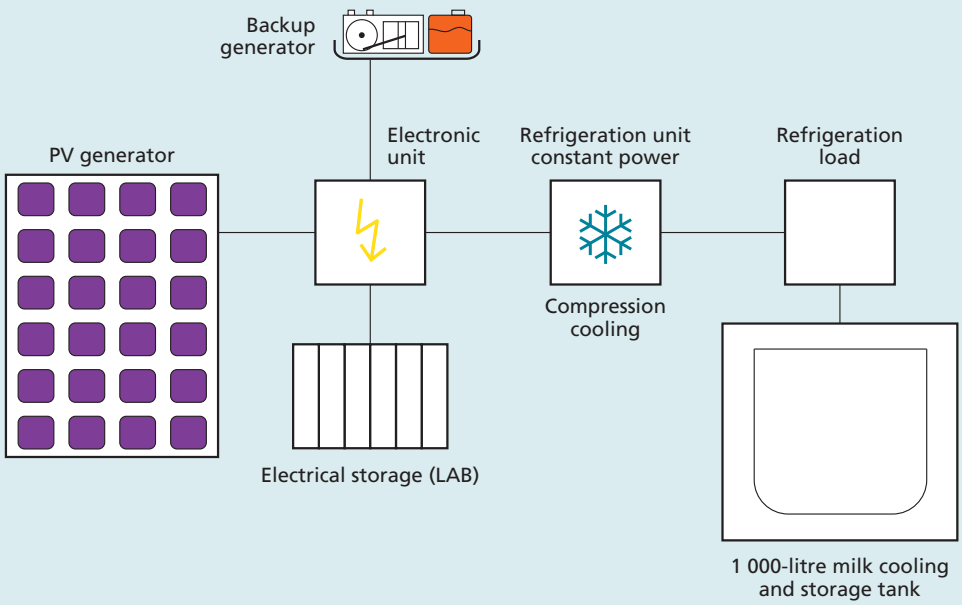
Advantages: Li-ion batteries are used in longer-running operations with fuller discharge of the batteries between charges. The higher energy demanded during these operations is supplied efficiently by Li-ion batteries. Higher power density is a distinct advantage of Li-ion batteries over

BOX 2 (continued)

System 2 (Figure 52) consists of:

i) a solar PV electrical power generator;
ii) electrical control units;
iii) a LAB to store electricity for controls and pumps;
iv) a refrigeration unit using variable speed and two sizes of compressor;
v) an ice bank for cooling/storing two days of milk (cooling 500 litres of milk a day);
vi) a 1 000-litre bulk milk cooling/storage tank for storing two days of milk;
vii) a backup generator;
viii) an ISO-standard 20-ft shipping container.

FIGURE 52
Photovoltaic cooling system with ice bank energy storage



Source: Adapted from Waschull, 2004.

LABs and, unlike other batteries, Li-ion batteries do not require priming. Compared with other technology, apart from LABs, the maintenance cost of Li-ion batteries is very low and their durability very high.

Disadvantages: Li-ion batteries are highly susceptible to self-discharge, which results in quick ageing. To prevent self-discharge, proper protection and atmosphere control is a high priority, but is very costly. Compared with LABs, Li-ion batteries are very costly, and great care is needed to prevent the system from short-circuiting. It is also recommended that Li-ion batteries be kept charged.

The cost of providing a more conventional means of cooling using a refrigerated DX 500-litre milk cooling tank with a backup genset is estimated at US$8 500 (including delivery and installation), but operating costs (fuel supply) should be added to this cost, making the total system costlier.

BOX 2 (continued)

The trials were successful as the location provided sufficient solar radiation. Other locations with lower solar radiation levels will result in poorer performance. The high capital cost, together with the need for specialized maintenance over time, may be impediments to further development of this off-grid solution. The costs involved in developing the prototypes are indicated in Table 16.

TABLE 16
Photovoltaic generator sizes, storage and system costs for cooling 500 litres of milk per day

	Cooling system with LAB energy storage	Cooling system with ice bank energy storage
PV generator size	3.5 kW	5.5 kW
Energy storage	33.6 kW_{el}	45 kW_{th}
PV system and other equipment costs	US$13 700	US$31 570
Battery cost	US$10 000	US$2 600
Total system costs	US$23 700	US$33 170
Battery replacement after 4–5 years[a]	US$10 000	US$2 600
Total costs	US$33 700	US$36 770

[a] Depends on discharge rate and temperature of environment.
el = energy stored in electrical form; th = energy stored in thermal form.
Source: Frazer Moffat, 2015.

Technological solutions that utilize a combination of PV and ice bank technology are being researched and developed. For example, researchers have been working on substitute energy resources for ice bank tanks, taking into account the costs and benefits for small- and medium-scale MCC units in terms of environmental and social well-being (European Commission, 1999; KTH, 2009). Clean and efficient energy technology allows the growth and development of off-grid systems that can meet the requirements of developing SMEs (Donnelly, 2012). Ice bank tanks and thermal storage batteries are emerging technologies for the dairy sector, especially for milk cooling.

Containerized MCCs (Figure 53) are a feasible solution for remote locations where national grids are less reliable. A containerized MCC is a fully operational MCC mounted on wheels for mobility, enabling the MCC to operate in a wide range of locations. A containerized MCC equipped with an ice bank can cool and store milk for two days before it is transported to a processing plant. Combining this option with the use of solar energy provides a system with a fully independent energy source for its operations. Custom-made and easily upgraded, containerized MCCs are suitable for a wide range of geographical locations, irrespective of the availability of energy sources. They provide an innovative tool in situations where conditions allow organized milk collection. This option is suitable for testing the potential sustainability of a fixed MCC in a specific location. Containerized MCCs can be replaced with a permanent structure after a dependable and reliable milk supply has been established.

Wind power

Overview and constraints: Electrical power generators driven by wind turbines can be used to capture wind energy. In this system, the inherent kinetic energy in moving wind spins two, three or four propeller blades, which are connected to a rotor hub. The rotor spins a central shaft through a gear box that mechanically increases the rotational speed of the shaft, which in turn drives a generator to produce electricity. The electricity can then be stored in batteries for later use or be sent to the power grid. The rotors are usually made from simple plastics or fibreglass and carbon fibre-reinforced plastics. Bases for medium and large wind turbines are made from

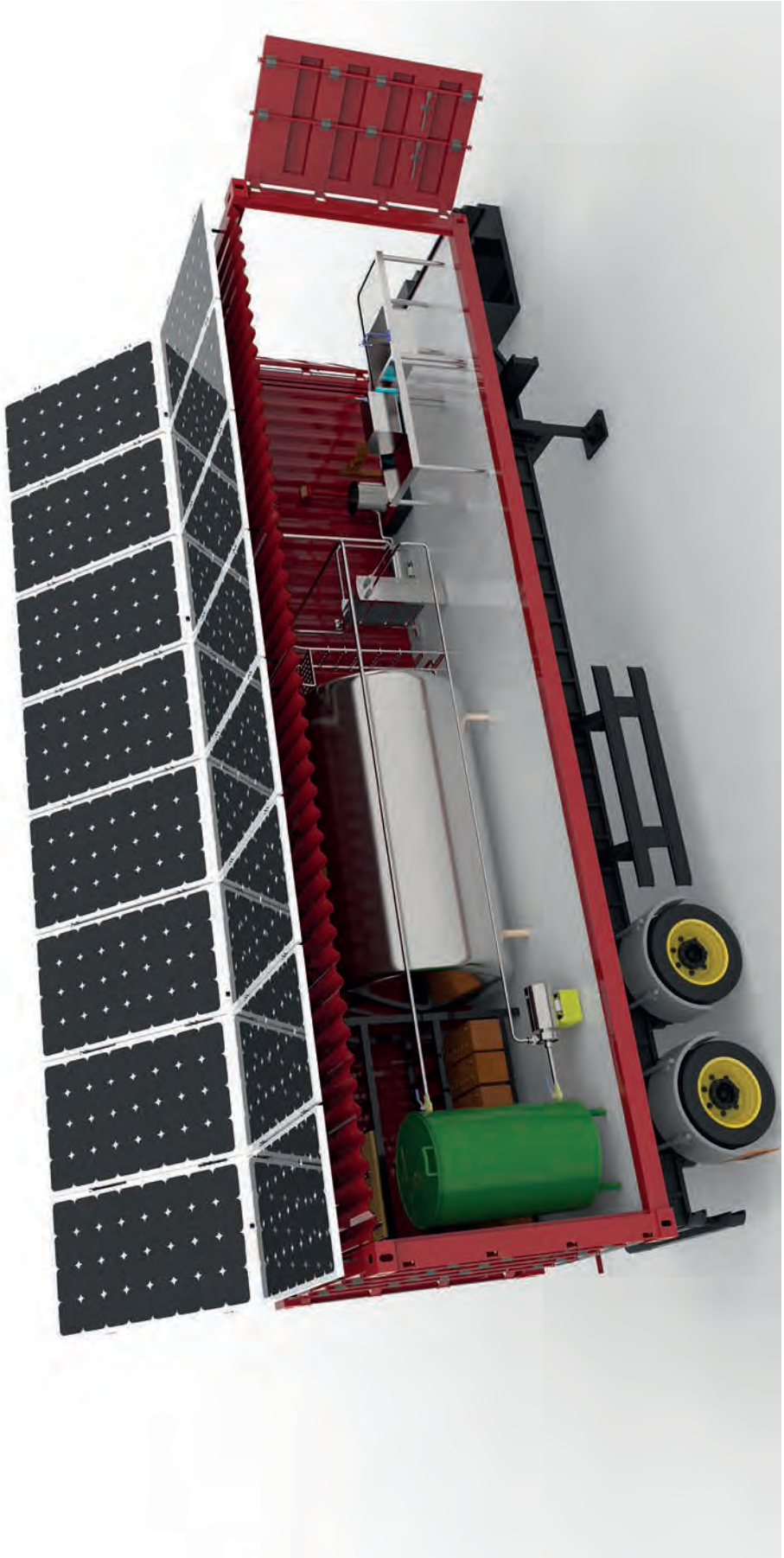


FIGURE 53
Containerized milk cooling centre using solar panels

Source: Sonnet Malakaran George and Tek B. Thapa, 2015.

steel-reinforced concrete to withstand the energy that the moving blades generate in high winds. Generators, motors and electricity converting/delivering systems are built into a sheath behind the propellers and the base.

Modern wind turbines can generate up to 3 MW, and have rotor diameters that vary from 3 m to more than 80 m. DC or single- or three-phase AC power is produced. Although two-bladed rotors were used in the past, most commercially available rotors today are three-bladed. The hub height generally varies from 10 m to 1.25 times the rotor diameter, and most manufacturers offer wind turbines with two or three different rotor diameters for low, medium and high wind conditions. The actual output compared with the installed capacity of a wind turbine generator is dictated by the wind speed. Manufactures provide data on power generation outputs for different wind speeds. While simple in concept, the engineering aspects of wind power are complex and involve many disciplines.

As with solar energy, wind power is intermittent and varies over space and time. The local topography, such as buildings, trees and hills, can also negatively affect the potential power production of a wind turbine. Information and data on wind occurrence and speeds at all periods of the day and throughout the year can be obtained from national meteorological offices or government ministries/departments and/or agencies specialized in renewable energy. It is important to have winds of relatively constant speed and intensity to make the production of wind energy viable.

Information obtained from national agencies can be used as guidance, but it is recommended that on-site monitoring of wind speeds be conducted for 12 months before designing a wind power electrical generation system. If historical data are available, it is possible to calculate annual electrical power output reasonably accurately. The daily energy output will be fully dependent on wind speed, which varies constantly. As the power output is therefore also not constant, a stand-alone system will require that the power be channelled through electrical battery storage to ensure a regular supply of electrical power.

As with electricity generated from solar sources, the times of highest wind power production and demand may not match, including when the power is required for cooling milk. If connected to a national grid, surplus electricity can be sold to the grid (sometimes benefiting from high feed-in tariffs) and electricity can be bought from the grid when required. For stand-alone systems, energy storage facilities and a backup genset are required.

Turbines provide about 20 years of service, with maintenance checks every few years. Batteries typically have a life expectancy of four to ten years, so will require replacement during the service life of the turbine.

Use of wind turbine power in milk cooling and MCCs: Dairy farms in European and other developed countries are already using wind turbine power, but these systems are usually connected to the national grid and supported by government incentive schemes. Additional income can be derived from selling excess electricity to the national grid. In developing countries, there are no known cases of wind-powered systems – either grid-connected or stand-alone – being used in commercial milk cooling or MCC operations.

Stand-alone wind-powered systems for milk cooling must be sized specifically for each location. The actual energy generated from wind turbine generators averages about 20 per cent of the potential capacity primarily because wind power is variable and sometimes not available.

Typical small-scale turbines range from 1 to 5 kW and cost US$3 000–15 000. Medium-scale turbines range from 6 to 50 kW and cost US$16 000–100 000. All turbines provide single- and three-phase AC power, which needs to be stored in an energy storage system in off-grid conditions (battery or ice bank energy storage). To cover periods of low wind speed or no wind, a backup genset is also required for off-grid installations.

As described in section 7.2, the power requirements of MCC operations can be calculated for periods of about four hours during milk cooling operations in both the morning and the late afternoon/early evening. A stand-alone system with a 5-kW wind turbine producing 12 800 kilowatt hours (kWh) a year at an average wind speed of 5 m/second, or an average of 35 kWh per day, would be sufficient to cool up to 1 000 litres of milk a day using an ice bank or a DX milk cooling tank. The indicative costs of such a system are shown in Table 17.

The initial capital costs of establishing a stand-alone wind turbine system to provide electrical power are high, but they are repaid in savings on energy costs over time. Batteries will need to be replaced every five to seven years. Use of conventional power supplies from a national grid, a backup genset and a DX milk cooling tank of 1 000 litres would cost about US$10 000, but fuel

costs for the life of the plant should also be taken into account.

Table 17 provides only indicative costs. More accurate data on costs can be obtained from experts in wind power systems, electrical energy storage and refrigeration, who should also be involved in designing a system for the specific location when the wind availability and speed are known.

Viability of using solar PV and wind turbine power for MCC applications: Electricity produced from stand-alone (with no connection to the national grid) solar PV and wind turbine systems costs more to the final user than does national grid power, when available. However, renewable energy systems are already a viable alternative for off-grid applications and their costs are steadily decreasing – the cost of electricity from an on-grid solar PV system is expected to fall to as low as US$0.5/W in the near future (CleanTechnica, 2014). As cooling applications require a continuous supply of energy, the need for energy storage adds to the costs, especially when battery replacement is considered.

For large milk cooling systems with three-phase motors ranging from 8 kW for a 2 000-litre milk cooling tank to 20 kW for a 5 000-litre tank, the electrical power input would require costly solar arrays or wind turbines and energy storage units, electrical or other, which would have to be paid for up-front.

Solar PV and wind turbine systems connected to the national grid have the major advantage of being able to use the national grid when the sun and wind do not provide sufficient power, allowing significant savings on energy storage equipment. However, all renewable energy applications become more attractive to MCC investors when incentive schemes are in place (e.g. tax incentives, feed-in tariffs for power sold to the national grid) or when establishing an MCC in an off-grid, remote location.

The choice of system is always very context-specific. For example, the use of both solar PV and

TABLE 17
Costs of a 1 000-litre milk cooling system operated with wind power

	Ice-bank with 2 kW single-phase electricity	DX with x 4 kW single-phase electricity
Wind turbine	5 kW/single-phase AC	5 kW/single-phase AC
Energy storage – LABs	2 500 Ah	1 400 Ah
	***Cost** (US$)*	***Costs** (US$)*
5kW/single-phase AC wind turbine, off-grid controller, off-grid inverter, DC/AC inverter, 12-m monopole tower, cabling and installation	16 120	16 120
LABs (ice bank with 16 x 200 Ah/12 v; DX with 12 x 200 Ah/12 v) plus 20% for safety factor and system efficiency	4 800	3 600
Total	**20 920**	**19 720**
Backup genset	3 600	4 500
Ice bank milk cooling tank	6 600	
DX milk cooling tank		5 500
Total cost wind turbine/ice bank with backup generator, excluding battery replacement	31 120	–
Total cost wind turbine/DX with backup generator, excluding battery replacement	–	29 720
Battery replacement every 4–5 years[a]	35 920	33 320
With national grid electrical power supply and no wind turbine system	–	–
Total cost with backup generator	**10 200**	**10 000**

[a] Cost and life of battery for conditions in tropical developing countries (realistic picture). The life of the battery will depend on the charging and discharging ratio.
Source: Frazer Moffat, 2015.

wind turbine systems at dairy farm milk collection points has been studied in the Azores (Rodrigues *et al.,* 2011). The study concludes that such systems "will not be economically viable, even with generous feed-in tariff".

The use of renewables for different purposes, including MCCs, compared with traditional energy sources, must be evaluated case by case. More specific research is needed on the integration of renewables (solar thermal and PV) into MCCs and similar cooling applications to develop more cost-effective solutions.

Geothermal energy

Geothermal power is a renewable energy resource that uses heat from deep underground. The element responsible for this heat energy is the radioactive substance in the earth's core. The heat gradient depends on the distance from the surface of the earth to the earth's core, which is estimated to be at a temperature of 5 000 °C. The flow of heat energy from the earth's core is equivalent to 2 000 times the output of the world's largest hydroelectric power plants and is expected to continue for billions of years (FAO, 2015d). However, geothermal energy is site-specific and viable only where the geothermal source is near the MCC.

Solar thermal and geothermal are two different sources of heat energy from the sun and the earth respectively. The basic principle of thermal refrigeration works for both of these energy sources, as the initial form of energy is the same.

Thermal refrigeration can be classified into two types:

I) lithium bromide/water, in which water is the refrigerant and lithium bromide the absorbent;
II) ammonia/water, in which ammonia is the refrigerant and water the absorbent.

In MCCs, type II is used, as the low boiling point of ammonia helps to achieve temperatures below zero. Milk has to be cooled to below 4 °C to prevent quality deterioration. Type II is therefore used for MCC operations in stand-alone systems with combination ice bank tanks.

Geothermal energy is accessible only in specific locations, but where it exists it provides a virtually infinite energy source at almost no cost. Exploitation of geothermal energy is limited mainly because of the up-front costs of exploration, with the risk that initial investments (although not very high) do not achieve results.

Chapter 8
Economic indicators

Economic indicators are the cumulative statistical information and data on current and future investment possibilities. They enable analysis of the economic performance of existing operations and forecasting for new projects. The elements investigated include the internal rate of return, the net present value, the benefit–cost ratio and trial profit and loss statements. Investors, small-scale entrepreneurs and governments analyse these elements to determine the economic benefits of and potential returns on investments. For an MCC, economic indicators related to the enabling environment provide an estimate of future returns on investments. Economic indicators for MCCs provide the parameters of profits and losses resulting from MCC operations under standard/recommended conditions. The important economic indicators considered for MCCs relate to:

1. quantity and price of milk;
2. number of producers;
3. numbers of competitors and buyers;
4. transport, services and utilities;
5. manufacturing and trade inventories;
6. storage and maintenance;
7. outstanding commercial and industrial loans and the prime rate;
8. labour and unemployment rates;
9. consumer and producer credit outstanding to personal income.

8.1 PLANNING AND FEASIBILITY STUDIES FOR A NEW MILK COOLING CENTRE

After carrying out a rapid assessment and planning an MCC for a specific area, a feasibility study should be conducted. In addition to the factors taken into consideration while planning the MCC, this study should examine the techno-economic feasibility of the investment for self-financing or to support submission to bank for a loan. Key indicators to be assessed are the break-even analysis and the internal rate of return. There must be sufficient margin between the purchase and selling prices of the milk to cover overhead costs (fixed and variable) and provide enough profit to repay the loan, plus interest, to the bank within the scheduled period, taking into account any MCC operating overheads that are absorbed by a milk processing plant.

The fixed costs are interest on the capital, and depreciation of the plant equipment and building. Investment costs include land, building construction (or rental), milk cooling equipment and accessories, and utilities and service equipment. This chapter discusses basic economic indicators and financial analysis methods for guiding the cost-effective operation of an MCC. It describes the basic financial analysis methods and parameters that are used to project the financial sustainability of an MCC.

8.2 BASIC FINANCIAL ANALYSIS METHODS

Ratios

Different financial ratios are used to estimate/forecast an establishment's liquidity and financial status. Based on the establishment's activities, bills, productivity and efficiency, the liquidity of the establishment can be identified in real time (Carter, Macdonald and Cheng, 1997).

Three ratios can inform decisions on establishing a new MCC: the current and quick ratios, the debt ratio and the profit analysis.

Current and quick ratios: These are used to estimate the establishment's short-term capability/capacity to handle its financial liabilities and responsibilities.

Current ratio: Current liabilities are the financial values owed by the business, payable within one year. Current assets are financial assets acquired for conversion into cash in the ordinary course of business; they should not be valued at a figure greater than their net realizable value:

$$= \frac{\text{Current assets}}{\text{Current liabilities}^{9}}$$

Equation 1: Current ratio

Quick ratio: This ratio measures the establishment's ability to meet its short-term obligations with its most liquid assets:

$$= \frac{\text{Current assets}}{\text{Current liabilities}^{10}}$$

Equation 2: Quick ratio

Debt ratio: This ratio is used to estimate the establishment's long-term liquidity. It shows the establishment's leverage (debt) in total capitalization:

$$= \frac{\text{Total debts}}{\text{Net worth}^{11}}$$

Equation 3: Debt ratio I

$$= \frac{\text{Long-term debt}}{\text{Total capitalization}^{12}}$$

Equation 4: Debt ratio II

Profit analysis: Break-even analysis is the financial method used to estimate the number of units (volume) or the quantity of sales required to acquire neither profit nor losses. The break-even is the point in financial values where the costs of production and the sales volume are equal.

Break-even is calculated using sales and cost data:

$$= \frac{\text{Fixed costs}}{\text{Price unit} - \text{variable cost unit}}$$

Equation 5: Break-even point

[9] Should be greater than one.
[10] Stock minus (subtracted).
[11] Net worth = Current liability + Short-term debt + Long-term debt.
[12] Total capitalization = Long-term debt + Net worth.

The indicative value of any investment in establishing and operating an MCC can be analysed from the following indicators:

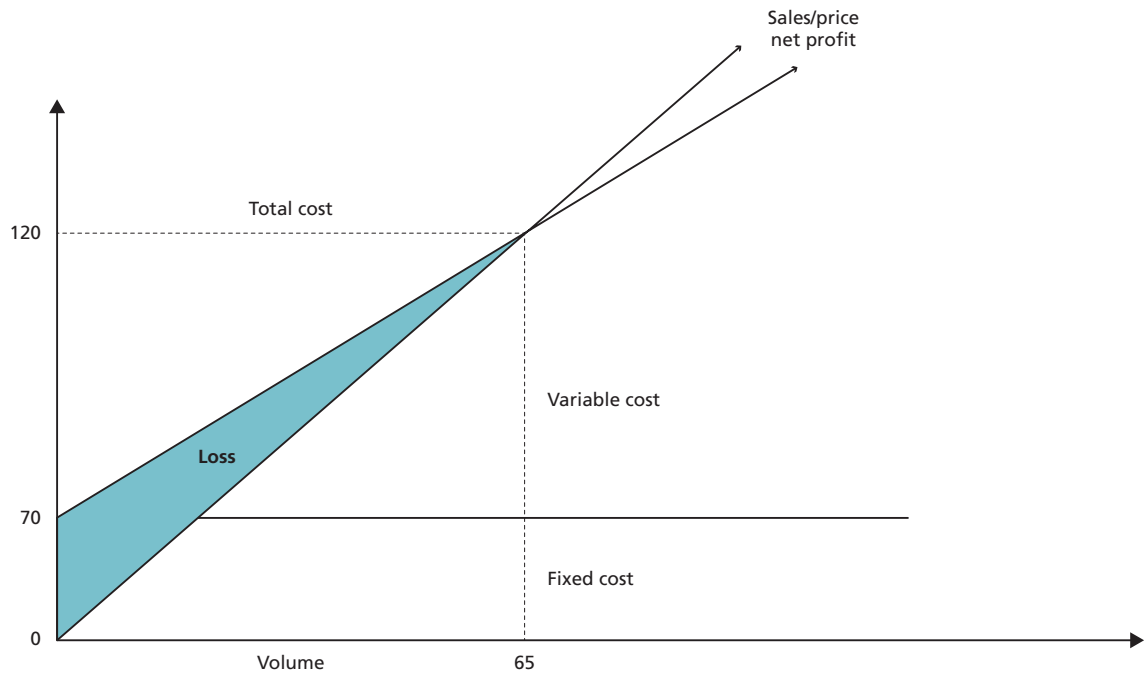
i) *Net present value:* In finance, the net present value (NPV) is defined as the sum of the present values of the individual cash flows. NPV is a standard method for using the time value of money to appraise long-term projects, because it measures the excess or shortfall in cash flows in terms of their present value. If there is a choice between two mutually exclusive alternatives, the one yielding the higher NPV should be selected.
ii) *Internal rate of return:* The internal rate of return (IRR) is used in capital budgeting to measure and compare the profitability of investments. It is also called the discounted cash flow rate of return or simply the rate of return. In the context of savings and loans, the IRR is also called the effective interest rate. The term "internal" refers to the fact that calculation of the IRR does not incorporate environmental factors (e.g. the interest rate or inflation).
iii) *Benefit–cost ratio:* The benefit–cost ratio (BCR) takes into account the amount of monetary gain realized by performing a project versus the amount it costs to execute the project. The higher the BCR the better the investment. As a general rule of thumb, if the benefit is higher than the cost, the project is a good investment.

Table 18 shows an example of the IRR, NPV and BCR for an MCC with capacity of 3 000 litres a day.

8.3 FACTORS AFFECTING THE OPERATING OVERHEADS AND PROFITABILITY OF A MILK COOLING CENTRE

Milk collection points (MCPs) and MCCs are the primary cost centres in the dairy processing industry where the primary raw material – fresh milk – is tested, collected, cooled and stored before it is transported in bulk to a dairy processing plant. There is need to minimize operating overheads at all stages of milk collection, cooling, transportation, processing, storage and marketing. It is therefore important to make judicious decisions when planning an MCC, based on careful analysis and selection of milk availability, location, sizes and capacities of cooling and ancillary equipment, laboratory facilities, and mode of transporting the

FIGURE 54
Break-even point



Source: Carter, Macdonald and Cheng, 1997.

milk from the MCP to the MCC and to the dairy plants. Proper care needs to be taken to avoid procuring over- or undersized equipment such as milk cooling tanks, backup generators or the use of a milk analyser. If milk cooling tanks are too large and their potential capacity is not utilized, the fixed costs will remain the same but the operating overheads will increase, ultimately resulting in reduced profit margin or even losses. To maximize the profit margin and minimize the losses in MCC operations, the following should be considered:

- *Locations of the MCPs and the MCC:* The locations of and distances between the MCPs, the MCC and the processing plant are very important when planning the mode of transport for bulk milk. Milk should be cooled to less than 4 °C within three to four hours of milking. In difficult rural terrain, milk may have to be carried from the MCP to the MCC on foot or using a bicycle or tricycle rickshaw, or a pick-up truck if the milk quantity is sufficient. The mode of transport from the MCC to the plant is also determined by the volume of milk. For volumes of more than 1 000 litres, it is better to use a road milk tanker, which will reduce per-litre transport costs and handling losses.
- *Reliability of the power supply:* Energy costs are the major recurring factor that affects the cost of milk cooling. In most cases, a reliable source of grid power results in lower energy costs compared with the use of diesel generators.
- *Volume of milk collected and utilization of handling capacity:* These are important factors that affect the profitability and sustainability of an MCC. When more than 50 percent of the capacity of the milk cooling tanks is utilized, or more than half of the tank is filled every day, the per-unit overhead costs will be less, resulting in an increased profit margin and enabling the MCC to operate sustainably.
- *Availability of trained staff:* The MCC should be staffed with trained personnel who understand the dynamics and consequences of all MCC operations. Staff should have sufficient knowledge of milk testing procedures, record keeping, and operation and general maintenance of the MCC, particularly the genset. MCC operators should have basic knowledge of refrigeration

and general servicing of the equipment installed in the MCC. Without trained staff, the MCC is likely to incur losses because of improper and untimely functioning of the milk cooling tank or the generator.

- *Raw milk price versus cooling overheads:* In an MCC, milk is collected and cooled, but no value is added despite the costs incurred; cooled raw milk is therefore more expensive than uncooled raw milk. MCCs are often owned by a dairy processing plant, which absorbs the cooling costs so that the MCC does not incur losses. The owners of MCCs that are independent cost centres, must work hard to reach break-even and move towards profitability.

8.4 SAMPLE FINANCIAL ANALYSIS OF A MILK COOLING CENTRE IN BANGLADESH

Table 18 provides the economic analysis of an MCC with 3 000-litre capacity, outlining the various cost components such as variable and fixed costs, and how capacity utilization affects profitability and the return on investment. As the utilization of the installed cooling capacity progressively increases from 50 to 80 percent, the net profit increases significantly.

When considering the establishment of an MCC it is essential to prepare a budget and a trial profit and loss statement. This statement starts with the gross income, from which all costs are deducted to provide the net profit or loss. The profit and loss statement is important because it provides guidance on the expected sales, operating costs and profits of the proposed MCC. An example of a trial profit and loss statement is shown in Table 19.

TABLE 18
Sample financial analysis of a milk cooling centre in Bangladesh

		3 000 litre/day capacity					
i) Investment in the bulk milk cooler				US$			
No	**Item**						
1	DX bulk milk cooler and genset	26 400					
2	Laboratory equipment	1 500					
3	Total cost	27 900					
ii) Income and expenditure				US$			
A		**1**	**2**	**3**	**4**	**5**	**6**
No	**Item**	**Cost**					
1	Installed capacity (litres/day)	3 000	3 000	3 000	3 000	3 000	3 000
2	Capacity utilization (percentage)	50	60	70	70	80	80
3	Cost of milk (US$/litre)	0.4125	0.4125	0.4125	0.4125	0.4125	0.4125
4	Payment for chilling milk (US$/litre)	0.45	0.45	0.45	0.45	0.45	0.45
B	**Expenditure**						
1	Power and fuel consumption (US$/litre)	0.004	0.004	0.004	0.004	0.004	0.004
2	Repairs and maintenance (2% equipment cost) (US$)	558	558	558	558	558	558
3	Labour (US$/month)	375	375	375	375	375	375
4	Chemicals, stationary, water (US$/month)	40	40	40	40	40	40
5	Rental of building (US$/month)	87.5	87.5	87.5	87.5	87.5	87.5
C	**Others**						
	Depreciation (%)	10					
iii) Cash flow statement				US$			
A	**Income**	**1**	**2**	**3**	**4**	**5**	**6**
1	Payment for chilling milk	246 375	295 650	344 925	344 925	394 200	394 200
	Total income	**246 375**	**295 650**	**344 925**	**344 925**	**394 200**	**394 200**
B	**Expenditure**						
1	Capital	27 900					
2	Recurring						
3	Milk purchases	225 843.75	271 012.5	316 181.25	316 181.25	361 350	361 350
4	Power and fuel consumption	2 190	2 628	3 066	3 066	3 504	3 504
5	Repairs and maintenance	558	558	558	558	558	558
6	Labour	4 500	4 500	4 500	4 500	4 500	4 500
7	Chemicals, stationary, water	480	480	480	480	480	480
8	Rental of building	1 050	1 050	1 050	1 050	1 050	1 050
9	Milk losses (0.5%)	1 231.875	1 478.25	1 724.625	1 724.625	1 971	1 971
10	**Total expenditure**	**263 753.63**	**281 707.00**	**327 560.00**	**327 560.00**	**373 413.00**	**373 413.00**
C	**Benefits**	**-17 379**	**13 943**	**17 365**	**17 365**	**20 787**	**20 787**
	Depreciation (10 %)	2 790	2 790	2 790	2 790	2 790	2 790
D	**Net benefits**	**-20 169**	**11 153**	**14 575**	**14 575**	**17 997**	**17 997**
iv) Financial analysis		1	2	3	4	5	6
1	NPV	25 541	49 540	45 818	38 116	29 258	15 650
2	IRR	62%					
	NPV of benefits and costs		1 228 209	1 192 110	1 045 325.67	857 199.52	640 854.44
3	BCR	01:00	1.03				

Data collected in 2012.
Source: Frazer Moffat, 2015.

TABLE 19
Sample trial profit and loss statement for a milk cooling centre in Bangladesh

Item	Jan	Feb	Mar	Apr	May	Jun	Jul
Installed capacity (litres)	31 000	28 000	31 000	30 000	31 000	30 000	31 000
Capacity utilization (%)	50	50	40	35	40	45	60
Milk purchased (litres)	15 500	14 000	12 400	10 500	12 400	13 500	18 600
Income							
Local sales chilled milk (5%)	387.500	350.000	316.200	273.000	322.400	378.000	465.000
Milk to processing (95%)	7 215.3	6 517.0	6 007.8	5 286.8	6 007.8	6 412.5	8 658.3
Others	0	0	0	0	0	0	0
Total income	**7 602.8**	**6 867.0**	**6 324.0**	**5 559.8**	**6 330.2**	**6 790.5**	**9 123.3**
Milk costs							
Milk purchased	6 975.0	6 300.0	5 704.0	4 935.0	5 704.0	6 075.0	8 184.0
Others	0	0	0	0	0	0	0
Total milk costs	**6 975.0**	**6 300.0**	**5 704.0**	**4 935.0**	**5 704.0**	**6 075.0**	**8 184.0**
Operating costs							
Plant operations (1% income)	76.028	68.670	63.240	55.598	63.302	67.905	91.233
Utilities	20.150	18.200	16.120	13.650	16.120	17.550	24.180
Labour	275	275	275	275	275	275	275
Repairs/maintenance	5.3208	5.3208	5.3208	5.3208	5.3208	5.3208	5.3208
Rental of building	75	75	75	75	75	75	75
Depreciation	106.42	106.42	106.42	106.42	106.42	106.42	106.42
Milk losses (1% purchase cost)	69.75	63.00	57.04	49.35	57.04	60.75	81.84
Total operating costs	627.67	611.61	598.14	580.34	598.20	607.95	658.99
Total costs	7 602.67	6 911.61	6 302.14	5 515.34	6 302.20	6 682.95	8 842.99
Gross profit/(losses)	0.085	(44.610)	21.863	44.415	28.001	107.560	280.310
Tax/others	0	0	0	0	0	0	0
Net Profits/(loss)	0. 085	(44.610)	21.863	44.415	28.001	107.560	280.310
Milk purchase (US$/litre)	0.45	0.45	0.46	0.47	0.46	0.45	0.44
Local sales chill milk (US$/litre)	0.50	0.50	0.51	0.52	0.52	0.56	0.50
Milk to processor (US$/litre)	0.49	0.49	0.51	0.53	0.51	0.50	0.49
Utilities (US$/litre)	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013
Labour (US$/month)	275	275	275	275	275	275	275
Rental of building (US$/month)	75	75	75	75	75	75	75
Capital investments, coolers etc. (US$)	12 770	12 770	12 770	12 770	12 770	12 770	12 770
Depreciation over 10 years (US$/month)	106.42	106.42	106.42	106.42	106.42	106.42	106.42

Data collected in 2012/2013.
Source: Frazer Moffat, 2015.

Item	Aug	Sep	Oct	Nov	Dec	Year
Installed capacity (litres)	31 000	30 000	31 000	30 000	31 000	365 000
Capacity utilization (%)	75	90	85	65	55	74
Milk purchased (litres)	23 250	27 000	26 350	19 500	17 050	210 050
Income						
Local sales chilled milk (5%)	558.000	634.500	619.230	477.750	434.775	5 216.000
Milk to processing (95%)	10 602.0	11 799.0	11 765.0	9 262.5	8 422.70	97 957.0
Others	0	0	0	0	0	0
Total income	11 160.0	12 434.0	12 385.0	9 740.3	8 857.48	103 173.0
Milk costs						
Milk purchased	9 997.5	11 070.0	11 067.0	8 385.0	7 502.0	91 899.0
Others	0	0	0	0	0	0
Total milk costs	9 997.5	11 070.0	11 067.0	8 385.0	7 502.0	91 899.0
Operating costs						
Plant operations (1% income)	111.600	124.340	123.850	97.403	88.575	
Utilities	30.225	35.100	34.255	25.350	22.165	
Labour	275	275	275	275	275	
Repairs/maintenance	5.3208	5.3208	5.3208	5.3208	5.3208	
Rental of building	75	75	75	75	75	
Depreciation	106.42	106.42	106.42	106.42	106.42	
Milk losses (1% purchase cost)	99.98	110.70	110.70	83.85	75.02	
Total operating costs	703.55	731.88	730.55	668.34	647.50	7 764.72
Total costs	10 701.05	11 801.88	11 797.55	9 053.34	8 149.50	99 663.22
Gross profit/(losses)	458.960	631.630	586.990	686.910	707.978	3 510.000
Tax/others	0	0	0	0	0	0
Net Profits/(loss)	458.960	631.630	586.990	686.910	707.978	3 510.00
Milk purchase (US$/litre)	0.43	0.41	0.42	0.43	0.44	
Local sales chill milk (US$/litre)	0.48	0.47	0.47	0.49	0.51	
Milk to processor (US$/litre)	0.48	0.46	0.47	0.50	0.52	
Utilities (US$/litre)	0.0013	0.0013	0.0013	0.0013	0.0013	
Labour (US$/month)	275	275	275	275	275	
Rental of building (US$/month)	75	75	75	75	75	
Capital investments, coolers etc. (US$)	12 770	12 770	12 770	12 770	12 770	
Depreciation over 10 years (US$/month)	106.42	106.42	106.42	106.42	106.42	

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Chapter 9
Recommendations

9.1 PLANNING

Enterprises planning to establish an MCC should have a basic blueprint of the requirements for where and how to create the facility. Technical guidelines on buildings, service and equipment options and the configurations that provide maximum benefits at the lowest cost, including which energy-saving technologies to deploy, should also be considered. An additional benefit of referring to guidelines is that it enables the application of standards to ensure that best practices are employed.

The requirements for establishing an MCC vary from country to country. Major considerations to be taken into account when planning an MCC include the following:

- Identify the present and projected market demand for fresh milk, both locally and nationally.
- Identify the number of milk producers, the cattle/buffalo populations, milk production levels, potential volumes of collectable milk, and projected increases in these volumes for at least five years resulting from establishment of the MCC.
- Identify the government and/or private-sector agricultural extension services available to milk producers, including veterinary services.
- Assess the trend in farmgate milk prices, including the effects of any government (and/or local authority) policy on milk pricing. Identify suitable options for payment schemes and record keeping.
- Outline the likely business and financial benefits for local milk producers and communities of establishing an MCC. Provide an indication of the likely volumes and values of milk losses that will be prevented (see chapters 4 and 8).
- Identify national (and/or regional) dairy regulations that are relevant to milk collection schemes, MCCs and the transportation of milk to processing plants/companies.
- Identify the standards for fresh milk quality and handling that milk processing plants/companies impose.
- Contact milk producers, milk producer groups, milk cooperatives/associations and private-sector milk collectors to identify their likely support and use of an MCC.
- In consultation with milk producers, identify services and inputs in addition to milk collection that an MCC could provide, such as supplying feed concentrates.
- Identify the locations of MCPs and the MCC.
- Detail the main features of the proposed milk collection scheme, including producer numbers, collectable milk potential, establishment of MCPs, and the distances and timing of deliveries of fresh milk from the producer and MCPs to the MCC. The time between milking and cooling should not exceed three or four hours.
- For any proposed MCC location, identify the proximity of all-weather roads, ease of access for bulk milk road transportation, and time scale for bulk milk deliveries to milk processing plants.
- Assess the availability of a national grid electricity supply and identify whether it is a single- or three-phase supply. Check whether the national grid power supplier is obliged to provide power supply lines and a transformer, if necessary, or if the MCC will have to bear these costs.
- Identify the availability and volumes of a potable water supply and/or a tube well or similar groundwater source. Identify national and/or local regulations related to groundwater extraction and use.
- Identify means of disposing of sanitary and cooling water in compliance with national and/or local regulations and laws.
- Identify the means of communicating with the MCC – land phone, cell/mobile phone or radio.

- Identify building and land requirements related to rented premises and to the construction of a purpose-built MCC. Consider the requirements for both start-up and future expansion.
- For rented buildings, outline the structural requirements, including for the electricity supply and internal wiring, water supply, storage piping and wastewater disposal. Outline aspects related to security, including fencing and night lighting. Outline accessibility requirements for bulk milk transportation.
- For purpose-built MCCs, provide an outline of the dimensions and structural requirements, including for electricity and internal wiring, water supply, storage and distribution piping, and wastewater disposal. Outline aspects related to security, including fencing and night lighting. Outline accessibility requirements for bulk milk transportation.
- Provide details of the options for milk reception, cooling and handling equipment, including for precooling and heat recovery from refrigeration systems. For the precooling options, provide details on the necessary volumes and temperature of the cooling water.

9.2 ASSESSING FEASIBILITY

After carrying out a rapid assessment and planning an MCC for a specific area, a feasibility study should be conducted. In addition to the factors taken into consideration while planning the MCC, this study should also examine the techno-economic feasibility of the proposed investment for self-financing or to support submission to a bank for a loan. Key indicators to be assessed are the break-even analysis and internal rate of return. There must be sufficient margin between the purchase and selling prices of the milk to cover overhead costs (fixed and variable) and provide enough profit to repay the loan, plus interest, to the bank within the scheduled period, taking into account any MCC operating overheads that are absorbed by a milk processing plant.

The fixed costs to be considered are the interest on the capital and the depreciation of equipment and buildings. Investment costs include land, construction (or rental) of the MCC, milk cooling equipment and accessories, and utilities and service equipment. Chapter 8 discusses basic economic indicators and financial analysis methods for assessing the cost-effectiveness of MCC operations.

When calculating the costs, it is advisable not to give the MCC too large a capacity. It may be better to base calculations of capacity on the average potential volume of collectable milk over the year than on the volume in peak production periods. Capacity can be increased once the milk collection scheme and the MCC are operating satisfactorily and sustainably.

9.3 MILK COOLING OPTIONS

Milk can be cooled in two steps: precooling, followed by refrigerated cooling. Cooling costs at the MCC can be reduced by precooling the warm milk using water from the mains supply or surface, well or groundwater. Precooling can reduce the refrigeration load, thereby reducing costs and environmental impact. The final temperature of the precooled milk depends on the difference in temperature between the precooling water and the fresh milk. The choice is then on whether the system should use a DX refrigerated cooling tank, an ice bank refrigerated cooling tank, or ice builder/PHE refrigeration combined with an insulated, unrefrigerated milk storage tank. The latter two systems build ice over a period of ten-plus hours and are more suited to locations where the electricity supply is reliable, where only a single-phase supply is available and/or where a lower tariff is applied to electricity consumption at night. Nine milk cooling and storage options have been identified (see chapter 6), ranging from simple DX to more advanced and complex integrated systems that incorporate energy- and space-saving precooling with ice bank and instant cooling technology. The nine options are:

- Option 1: DX refrigerated milk cooling tank;
- Option 2: DX milk cooling tank with precooling using mains or well water;
- Option 3: bulk milk cooling tank with precooling using mains or well water followed by instant cooling using ice water from an ice builder unit;
- Option 4: integrated ice bank milk cooling tank;
- Option 5: integrated ice bank milk cooling tank with precooling using mains or well water;
- Option 6: precooling of milk using precooled mains water from an integrated ice bank milk cooling tank;
- Option 7: ice bank milk cooling tank with precooling using mains or well water followed by instant cooling using ice water from an integrated ice bank;
- Option 8: instant milk cooling using a PHE and an ice bank tank;
- Option 9: containerized MCC.

DX refrigeration systems have lower total energy requirements than ice bank systems, unless off-peak, low-cost power tariffs are offered, or only single-phase power is available. The MCC should be located where there is a reliable three-phase electricity supply. The distance and time for delivering milk to the MCC will vary depending on the distances from MCPs. As many cooling options as possible should be explored in consultation with experienced refrigeration/dairy engineers, and it is important to ensure that when dealing with equipment manufacturers and suppliers the correct details on electricity usage and tank insulation levels are obtained and that they are suitable for the range of ambient conditions and temperature at the MCC site.

Rented buildings or a containerized MCC can be used for the start-up. A containerized MCC is a feasible option for remote locations and for establishing a new MCC. Off-peak electricity tariffs and tariff discounts should be used where available. An energy audit should be conducted on all equipment before procurement.

Applying precooling in conditions where the difference in temperature between mains/well water and raw milk is significant can generate savings in refrigeration costs of up to 64 percent. Wherever possible, milk precooling technology should be used to reduce electrical energy requirements. Heat recovered from the refrigeration system can be used to heat water for cleaning floors, milk cans, etc.

To facilitate in-country manufacture of highly efficient milk cooling tanks and refrigeration systems, technical assistance and training should be provided to all in-country manufacturers of milk cooling equipment, along with design specifications and material requirements.

9.4 RENEWABLE AND NON-RENEWABLE ENERGY OPTIONS

The electricity supply for MCCs normally comes from the national grid. Diesel-powered electrical generators can provide backup power or, when no grid power is available, MCCs can be entirely powered by generators. The actual energy requirement for an MCC will depend on the range and type of equipment installed and will have to be calculated for each case.

Sources of renewable energy are an increasingly viable option for producing electricity or heat, and many are already competitive. Several renewable energy sources can be harnessed to provide heat and electrical power to the dairy industry. Solar thermal, solar PV, geothermal and wind power appear to be the most suitable sources for small-scale cooling systems and MCCs. However, the renewable sources of wind and solar power are diffuse, intermittent and unreliable so energy availability will not always match demand, and a battery or other energy buffer will have to be used. Power supply requirements for MCCs using various non-renewable and renewable energy sources are discussed in chapter 7.

Alternative power sources for MCCs work better in relatively small-scale off-grid applications, particularly when combined with non-battery power storage technology (e.g. ice banks, chemical storage, direct-driven refrigerators). Chapter 7 describes a prototype solar PV cooling system and the requirements for a wind-powered cooling system with single-phase motors of < 4 kW. For larger milk cooling systems with three-phase motors ranging from 10 kW for a 2 000-litre milk cooling tank to 20 kW for a 5 000-litre tank, the electrical input would require very large solar arrays or wind turbines and energy storage units, incurring high up-front investment costs, which would need to be carefully considered.

When considering any of the options described, it is recommended that specialists in renewable electrical power generation, energy storage and refrigeration systems be consulted to identify the most suitable solution for a given location and to determine the best strategy for exploiting solar PV and wind power in MCCs. There may also be other viable renewable energy options for the specific location being considered (e.g. geothermal).

The development of renewable energy may be more cost-effective and viable if carried out at the community level. Possible assistance in the form of reduced taxation or loans and grants from government and donor organizations should be explored when establishing a renewable energy system for MCCs.

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Annex 1

Study requirements when considering the establishment of a milk cooling centre

INTRODUCTION

Milk cooling centres (MCCs) can be broadly defined as rurally located, agro-industrial units designed for the collection, cooling and storage of fresh raw milk in hygienic and controlled conditions that restrict the growth of spoilage organisms and slow the chemical reactions that result in milk spoilage and losses. MCCs contribute significantly to food security by reducing milk losses and are an essential part of the milk collection system and supply chain between the milk producer and the consumer and/or milk processing plant.

Any country planning to establish MCCs will need a basic blueprint of the requirements for where and how to create such facilities. Technical guidelines on buildings, service and equipment options and the configurations that will provide maximum benefits at the lowest cost, including which energy-saving technologies to deploy, should also be considered. It is highly recommended that such information is readily available to all the people and companies planning to establish an MCC. An additional benefit of referring to guidelines is that it enables the application of standards to ensure that best practices are employed in establishing MCCs. MCC managers and operators require suitable technical and management training, and milk producers need to be educated on the benefits of the milk marketing opportunities and technical support services that can be provided by an MCC.

With ever-growing urban populations, it is essential that food safety and quality be improved and maintained. Increasingly, milk processing companies and retailers are driving the demand for milk standards, and for many companies (including MCCs) in the supply chain it is mandatory to be certified as adhering to standards in milk quality and the use of a milk safety management system.

ESTABLISHING A MILK COOLING CENTRE

There are many reasons for establishing an MCC, including the need to improve marketing opportunities and incomes for milk producers; reducing post-harvest milk losses; improving the quality of fresh milk; satisfying market demand, including from milk processing companies, for increased volumes of fresh milk; and providing investment opportunities for private-sector entrepreneurs. Irrespective of the driver for establishing an MCC, all MCCs should be treated as businesses, and detailed technical and financial studies and analyses are required prior to embarking on any investment.

SCOPE OF STUDY

The scope of the required techno-financial study will vary from country to country, and the factors to be taken into account must be related to the needs and expectations of all stakeholders – milk producers, milk cooperatives and associations, milk collectors/buyers, transporters, and end users of fresh raw milk, including milk processing companies, retailers and consumers. The need to reduce post-harvest losses and contribute to national food security will also have to be taken into account, together with an assessment of the likely impact of any sustainable increases in rural employment and income, government policies and objectives related to overall agricultural development, and the support available to the dairy sector. In most cases the MCC will have to generate profits.

Elements to be covered by a study include the following:

- Within the milk shed to be served by the MCC, identify the number of milk producers, the cattle/buffalo populations, milk production levels, potential volumes of collectable milk, and projected increases in these volumes for at least five years resulting from establishment of the MCC.

- Identify, nationally and within the milk shed, the history of milk collection and the current or planned collection schemes operated by government, milk producer groups, milk cooperatives/associations or the private sector.
- Identify the government and/or private-sector agricultural extension services available to milk producers, including veterinary services.
- Assess past and present trends in farmgate milk prices, including the effects of any government (and/or local authority) policy on milk pricing. Identify payment schemes.
- Outline the likely business and financial benefits for local milk producers and communities of establishing an MCC. Provide an indication of the volumes and values of milk losses that will be prevented.
- Identify national (and/or regional) dairy regulations that are relevant to milk collection schemes, MCCs and the transportation of milk to processing plants/companies.
- Identify the standards for fresh milk quality and handling that milk processing plants/companies impose.
- Identify the present and projected market demand for fresh milk, both locally and nationally.
- Contact milk producers, milk producer groups, milk cooperatives/associations and private-sector milk collectors to identify their likely support and use of an MCC.
- In consultation with milk producers, identify services and inputs in addition to milk collection that an MCC could provide.
- Identify the locations for a milk collection scheme and the MCC.
- Detail the main features of the proposed milk collection scheme(s), including producer numbers, collectable milk potential, establishment of milk collection points, and the distances and timing of deliveries of fresh milk from the producer and milk collection points to the MCC.
- Identify the proximity to local communities where MCC staff can be housed.
- For any proposed MCC location, identify the proximity of all-weather roads, ease of access for bulk milk road transportation, and time scale for bulk milk deliveries to milk processing plants.
- Assess the availability of a national grid electricity supply and identify whether it is a single- or three-phase supply. Check whether the national grid power supplier is obliged to provide power supply lines and a transformer, if necessary, or if the MCC will have to bear these costs.
- Identify the availability and volumes of a potable water supply and/or a tube well or similar groundwater source. Identify national and/or local regulations related to groundwater extraction and use.
- Identify how to dispose of sanitary and cooling water in ways that minimize environmental pollution and comply with national and/or local regulations and laws.
- Identify the means of communicating with the MCC – land phone, cell/mobile phone or radio.
- Identify building and land requirements related to rented premises and to the construction of a purpose-built MCC.
- For rented buildings, outline the structural requirements, including for the electricity supply and internal wiring, water supply, storage piping and wastewater disposal. Outline aspects related to security, including fencing and night lighting. Outline accessibility requirements for bulk milk transportation.
- For purpose-built MCCs, provide an outline of the dimensions and structural requirements, including for electricity and internal wiring, water supply, storage and distribution piping, and wastewater disposal. Outline aspects related to security, including fencing and night lighting. Outline accessibility requirements for bulk milk transportation.
- Provide details of the options for milk reception, cooling and handling equipment, including for precooling and heat recovery from refrigeration systems. For the precooling options, provide details on the necessary volumes and temperature of the cooling water.
- Milk cooling options include:
  - DX refrigerated milk cooling tank(s);
  - DX milk cooling tank(s) with precooling using mains or well water;
  - DX milk cooling tank(s) with precooling using mains or well water followed by instant cooling using chilled water from an ice builder unit;
  - ice bank milk cooling tank(s);

- ice bank milk cooling tank(s) with precooling using mains or well water;
- ice bank milk cooling tank(s) with precooling using chilled water from an integrated ice bank tank;
- ice bank milk cooling tank(s) with precooling using mains or well water followed by instant cooling using chilled water from the integrated ice bank tank;
- instant cooling using a PHE with chilled water from an ice bank tank and milk storage in an insulated, unrefrigerated tank;
- precooling using a PHE and mains or well water followed by instant cooling using chilled water from an ice bank tank with milk storage in an insulated, unrefrigerated tank.

▪ Outline the quality control requirements at milk collection points and MCCs. Provide details of the quality control equipment and materials required, including automatic milk analysers.
▪ Outline the office support equipment required, including security safes for valuables.
▪ Provide details of the electrical requirements for all items of equipment, including their start-up loads and maximum and minimum loads. Indicate the rating for a prime or standby diesel-powered electrical generator, including switching gear.
▪ Identify the requirements for road transportation (motorcycle/pick-up truck) to the MCC.
▪ Identify the requirements for MCC staffing and training in MCC management and operations.
▪ Provide a programme and timescale for the planning, design and establishment of an MCC.
▪ Provide detailed estimates of all capital, pre-operational and start-up costs.
▪ Provide a financial analysis of the investment, covering return on capital, a sensitivity analysis related to interest on bank loans, the internal rate of return and a trial profit and loss statement covering five years.

In addition to these elements, the study may be required to identify sources and/or provide advice on:

▪ preparation of a business plan;
▪ sources of funding, including government support to agricultural/rural development;
▪ organizations/authorities with expertise in determining the potential of milk sheds;
▪ statutory dairy regulations, milk processing company standards and related subjects;
▪ milk marketing and pricing
▪ architects/building contractors for designing and constructing the MCC building;
▪ milk handling, cooling and service equipment, including manufacturers and suppliers and the potential for develop in-country facilities for manufacturing equipment;
▪ training of MCC staff and identification of establishments/institutions with the necessary knowledge and skills to undertake training activities.

REPORTING

Provide a detailed report on the activities covered in the study, including all reference material and communications with people, government ministries/departments, organizations and companies. Provide a blueprint for developing a milk collection scheme and establishing an MCC, including a detailed business plan.

Provide a PowerPoint presentation of no more than 30 frames covering all aspects of the survey and its recommendations.

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Annex 2

Cleaning and sanitation of milk cooling centres

At many rural and small-scale MCCs, the equipment and systems that come into direct or indirect contact with the milk are often not cleaned and sanitized appropriately. MCCS are established and operated to prevent milk from spoiling, but dairy processing creates large volumes of liquid effluents that contain milk fat, lactose and protein, which are highly polluting. Lack of proper cleaning and sanitation may cause increased spoilage and contamination of the source of milk. Investment in the cleaning and maintenance of MCCs is therefore essential, and the costs of cleaning and maintenance should also be considered carefully when calculating the MCC's overall operating costs. The following are the equipment and materials required for cleaning and maintaining hygiene in MCCs:

1. *Portable cleaning-in-place unit:* The unit consists of a small CIP tank (50 litres) equipped with a spray device (bulb or sprinkle) and connected to a centrifugal pump. Cleaning solution of an appropriate concentration is poured into the tank and passed through the milk intake pipes, any PHEs installed and the milk cooling tank. The cleaning solution is then returned to the CIP tank via the milk downloading pump and pipes to complete the CIP circulation that is essential during tank cleaning. It should be noted that CIP units are not appropriate for cleaning the equipment used in milk processing. When cleaning the milk cooling tank and pipes, the CIP unit should be used to:
   a) rinse the cooling tank with cold water, which is then drained – minimum five minutes;
   b) clean the tank with a 1-percent solution of caustic soda (NaOH) at 65–70 °C – minimum 25 minutes;
   c) drain the used solution into a separate tank;
   d) rinse the cooling tank with hot water at 60 °C, which is then drained – 15 minutes;
   e) rinse with cold water, and drain – ten minutes;
   f) clean with 1 percent nitric acid between steps b and c once a week to keep the equipment (especially pipes and PHEs) free of scale – minimum 25 minutes.
2. *High-pressure water jet cleaner:* The floor of the milk cooling room and the sides, drains, corners and exterior surfaces of milk cooling and storage tanks are easily contaminated by milk spills. This spilled milk soon becomes a source of bacteria that contaminate the clean milk. To prevent the accumulation of old milk, thorough cleaning and spraying of water through a high-pressure pump is required.

PHOTO 7
CIP cleaning unit

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Technical and investment guidelines for
milk cooling centres

Dairying is an essential part of integrated farming systems in developing countries and countries in transition, where milk accounts for a significant share of livestock GDP. Milk and dairy are an important subsector in the national economies of many developing countries, providing food, regular incomes for households and sustainable livelihoods for rural farmers and small and microenterprises.

This book examines and provides guidance on the options for investing in milk collection and cooling systems for smallholders. As cooling is the most widely used technique for preserving raw milk, the publication focuses on the planning, feasibility, start-up and operation of milk cooling centres (MCCs). It reviews small-scale milk cooling and preservation technologies employed around the world; discusses the steps to be followed when establishing a new MCC and selecting appropriate equipment and technology for its sustainable operation, especially in developing and transitional countries; and examines precooling options that minimize the overhead costs of cooling milk – nine milk cooling options and configurations are discussed in detail. Investors and farmers can select the option best suited to their location, depending on milk availability and access to roads, power, water, etc. Various power supplies and renewable energy options for MCCs are discussed, and the potential for using renewable energy such as solar, wind and geothermal power is reviewed and explored. The book also discusses basic economic indicators and financial analysis methods for operating MCCs cost-effectively.

This book aims to serve as a reference and guideline document for small and microenterprises, small-scale organizations, non-governmental organizations, government agencies, the manufacturers of bulk milk coolers for small and microenterprises, and teaching and educational institutions offering courses in dairying, food sciences and technology.

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