PRELIMINARY DESIGN OF A SNOW STORAGE COOLING SYSTEM FOR A POULTRY HOUSE PLACED IN QUEBEC

by

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ABSTRACT

While conventional renewable energies such as hydro, solar, wind or geothermal are constantly being developed and implemented, there has been far too little research into the use of snow for cooling purposes. A Snow Storage System (SSS) consists of a deposit where snow is stored and insulated during the winter as well as a cooling station that uses the cold of the snow to condition a building during the summer. This technology can only be applied to countries with both snow and hot seasons, but there is a big potential in some regions - for example, in certain parts of Canada - for the use of this system.

Current SSS utilisation mainly consists of big facilities like the Sundsvall Hospital in Sweden, the Sapporo airport in Japan or the Oslo's airport in Norway, all of which are analyzed in this project. Nevertheless, the chief objective of the project is to study the implementation of this technology in a smaller facility, specifically a broiler house situated in Quebec. This broiler house only has a ventilation system to refrigerate the building, and some days in summer the ventilation is insufficient to meet the necessary quality and health standards. Moreover, this problem will likely worsen as temperatures in Canada are projected to increase in future years during the warmer seasons.

MATLAB software has been used to program and simulate the model of a melting snow pile while applying the load needed to cool the broiler house. As a preliminary design, the model only takes into account the volume of snow melted due to rain (V_{rain}), due to ground contact (V_{ground}) and due to convection with air (V_{air}), this last factor representing 80% of the total. For the periods of refrigeration, the model uses the volume melted due to the cooling system (V_{cool})

to calculate the total, this last representing 90% of the total. The size of the SSS allows for the air conditioning of two different flocks during the summer.

The model gives satisfactory results and serves as a tool that can size the SSS and adapt its dimensions to fit the cooling load needed for the building. Even though this tool was used to size a SSS for a broiler house placed in Quebec, it could also be used effectively for other facilities.

Keywords: renewable energies, snow storage system, broiler house, MATLAB

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RESUME

Alors que les énergies renouvelables classiques telles que l'hydroélectricité, le solaire, l'éolien ou la géothermie sont continuellement développées et mises en œuvre, les recherches sur l'utilisation de la neige à des fins de refroidissement sont encore trop peu nombreuses. Un système de stockage de la neige (SSS) consiste en un dépôt dans lequel la neige est stockée et isolée en hiver et une station de refroidissement qui utilise le froid de la neige pour rafraîchir un bâtiment en été. Cette technologie ne peut être appliquée que dans les pays connaissant à la fois de la neige et des saisons chaudes, et le potentiel d'utilisation de ce système dans certaines régions du Canada est considérable.

La majorité des SSS actuels sont de grandes installations telles que l'hôpital Sundsvall en Suède, l'aéroport de Sapporo au Japon ou l'aéroport d'Oslo en Norvège, et sont analysées dans le cadre de ce projet. Néanmoins, la portée du projet est d'étudier la mise en œuvre de cette technologie dans une installation plus petite, plus précisément un poulailler situé au Québec. Le poulailler étudié ne dispose que d'un système de ventilation pour réfrigérer le bâtiment et, certains jours en été, la ventilation n'est pas suffisante pour respecter les normes de qualité et de salubrité. De plus, les températures au Canada vont augmenter les années suivantes, entraînant des saisons plus chaudes.

Le logiciel MATLAB a été utilisé pour programmer et simuler le modèle d'un tas de neige en fusion tout en appliquant la charge nécessaire pour refroidir le poulailler. A titre de conception préliminaire, le modèle ne prend en compte que le volume de neige fondue due à la pluie (V_{rain}), au contact avec le sol (V_{ground}) et à la convection avec air (V_{air}), cette dernière représentant 80% du total. Sur les périodes de réfrigération, le modèle utilise le volume fondu dû au système de refroidissement (V_{cool}) pour calculer le total, ce dernier représentant 90% du total. La taille du SSS permet de conditionner l'air de deux troupeaux en été.

Le modèle donne des résultats satisfaisants et sert d'outil pour dimensionner le SSS et adapter les dimensions à la charge de refroidissement nécessaire au bâtiment. Même si cet outil a été utilisé pour dimensionner un SSS pour un poulailler situé au Québec, il peut également être utilisé pour d'autres installations.

Mots-clés: énergies renouvelables, système de stockage de neige, poulailler, MATLAB

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LIST OF ABREVIATIONS

CO_2	Carbon dioxide
COP	Coefficient of performance
CPU	Central processing unit
CSS	Conventional snow storage system
CWEC	Canadian weather year for energy calculation
HSS	High-density snow storage system
LHP	Latent heat production
P&ID	Piping and instrumentation diagram
RH	Relative humidity
ROI	Return of investment
SDF	Snow disposal facility
SHP	Sensible heat production
SSS	Snow storage system
TDS	Total dissolved solids
THP	Total heat production
TS	Total solids
WSS	Watertight snow storage system

LIST OF SYMBOLS

Δ	Variation
α	Albedo
δ	Incremental
λ_g	Coefficient of thermal conductivity for the ground [W/(m·K)]
λ_i	Coefficient of thermal conductivity for the insulation layer [W/(m·K)]
σ	Stephan Boltzmann constant
κ	Von Karman constant
ρ_a	Air density
ρ_a	Snow density
ρ_w	Water density
A	Area [m^2]
A_g	Area directly in contact with the ground [m^2]
A_{surf}	Area [m^2]
a	Slant height of a frustum of a pyramid [m]
CC	Cold content [kW]
c_p	Specific heat [kJ/K]
B_1	Lower base of a frustum of a pyramid [m^2]
B_2	Upper base of a frustum of a pyramid [m^2]
E_i	Long wave radiation [kW]
e_i	Thickness of the insulation layer [m]
$\mathrm{e_h}$	Vapor pressure on level 0 [Pa]
$\mathrm{e_0}$	Vapor pressure on level h [Pa]
G	Conductive heat from the ground [kW]
h	Height of a frustum of a pyramid [m]
H	Sensible heat [kW]
k	Day degree constant [m / (°C·day)]
L	Latent heat [kW]
L_s	Latent heat of fusion for the snow [kJ/kg]

LT	Light code
l_v	Heat of vaporization [kJ/K]
l	depth [m]
M	Energy available for melt [kW]
M_c	Body mass of the chicken [kg]
$\dot{m}_0$	Vapor flux [kg/s]
p	Ambient air pressure [Pa]
P	Precipitation [m]
P_1	Lower perimeter of a frustum of a pyramid [m]
P_2	Upper perimeter of a frustum of a pyramid [m]
Q	Snow melt rate [m^3/day]
Q_g	Thermal flow from the ground [W]
Q_{surf}	Thermal flow from the surface [W]
Q_{sup}	Thermal flow from heater [W]
Q_{equip}	Thermal flow from equipment inside the building [W]
R	Net radiation [kW]
r	Heat from the rain [kW]
RH	Relative humidity
S	Surface [m^2]
S_g	Short wave radiation [kW]
T_a	Air temperature [K]
T_c	Temperature of the frozen layer [K]
T_{db}	Dry bulb temperature [K]
T_e	Exhaust air temperature [K]
T_g	Ground temperature [K]
T_h	Temperature on level h [K]
T_i	Inside air temperature [K]
T_i	Outside air temperature [K]
T_{rain}	Rain temperature [K]
T_s	Snow temperature [K]

T_0	Temperature on level 0 [K]
t	Time
U	Internal energy [kJ]
U_b	building heat transfer coefficient [W/K]
u_h	Wind velocity on level h [m/s]
u_0	Wind velocity on level 0 [m/s]
V	Volume [m^3]
V_{ground}	Volume melted due to ground [m^3]
V_{surf}	Volume melted due to air convection [m^3]
V_{rain}	Volume melted due to rain [m^3]
V_{cool}	Volume melted due to SSS [m^3]
z_0	Level 0 [m]
z_f	Freezing depth [m]
z_h	Level h [m]
w	Liquid water content

INTRODUCTION

The effects of global warming are pushing our society towards a transition between fossil fuels and renewable energies. While some other renewable energies have been widely developed, there is so far little research regarding snow storage systems for cooling purposes, and it seems to be a perfect technology for northern countries. In Canada, on winter, snow is removed from roads, streets and other public places and piled up in specific spots. The snowpack is usually left behind until the changing season will slowly melt it away. The primary objective of this research is to design, simulate and analyze a snow storage system for cooling a poultry house placed in Quebec, Canada.

Ice and snow storage for preserving food is an old technique that was very common in Europe and North America until cooling machines were introduced at the beginning of the 20th century. In Japan, Yukimoros are traditional houses or rooms used to store vegetables in snow, and Himuros are the same but using ice instead of snow. In the last century, most of these techniques became obsolete, but in the last few decades the interest in snow storage systems has increased. Universities from Sweden, Japan, Canada, China and USA have developed researches concerning this question and there are actual ongoing projects performing this technology. In the last century, more than 100 seasonal snow or ice storage projects were built in Japan and other 50-100 projects in China (Skogsberg 2005). In Sundsvall, Sweden, there is a Hospital that meets the 70% of its cooling demand using a SSS (Skogsberg 2005), in Sapporo, Japan, the Chitoise airport uses a SSS to fulfill the 30% of its cooling demand (Nordell 2015), and Oslo’s airport also uses this technology.

In 1995 the International Energy Agency evaluated the performance data of 50 seasonal cold storage systems in Canada, Germany, Netherlands and Sweden. The studies demonstrated that most of this projects have a payback period of five years or less, and the vast majority of Snow Storage system have a higher COP than chillers.

Ferme Du Grand Orme Inc is a privately held company in Sainte-Melanie, Québec and is a Single Location business in the food industry sector. The main building consists in two floors of 200’ x 60’ x 8’4’’ (LxWxH) where thousands of chickens run free. The inner conditions of the poultry farm may vary as long as chickens grow, the ideal inside temperature depends on the bird’s life cycle. Whereas at the beginning of the life cycle the chicks need higher temperatures to keep them warm and healthy, at the end of it they release big amounts of energy and a fresher conditions are needed to guarantee the quality standards. Most part of the year the building needs to be heated up in order to meet the mentioned requirements, but there is a period of time on summer where the poultry house has to be cooled. Currently the building has no cooling system and, on summer season, a fan system is the only method available to remove all the energy released by chickens. This means that the inner temperature and humidity will be the same as the outside conditions, and at some point they might not be the ideal ones.

On winter, big amounts of snow must be removed from the paths to enable the access to the farm and allow further operations. The fact as well that a cooling system is needed in summer makes the SSS a very appealing option. This report embraces the design, sizing, simulation and analysis of a Snow Storage System for the building described above as well as the economic and environmental impact.

CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

On a relentless global warming renewable energies are essential to face climate change. All the research and improvement in that field is increasing the possibilities of those technologies to compete with traditional carbon fuels. Make renewable energies cheaper or more efficient than carbon fuels is the biggest challenge for engineers in order to make this alternative a viable option. This chapter resumes all the information and research available to date about the Snow Storage System technology and other concerning topics.

1.2 Snow properties

Snow is commonly defined as forms of ice crystals that precipitates from the atmosphere. It can adopt different shapes depending on weather conditions and the location of the snowfall (Figure 1.1). Snow play a major role in regulating ecosystems due to several reasons, and one of them is it can be used as an energy bank. Snow stores and releases energy, it stores latent heat of fusion, sublimation and crystal bonding forces. The latent heat of fusion is large, approximately 333 kJ/kg and it makes the snow a great way to store cold energy. The porous structure of the snowpack allows change to both liquid and vapor forms at temperatures that they are normally encountered in the winter (Pomeroy et al 2001).

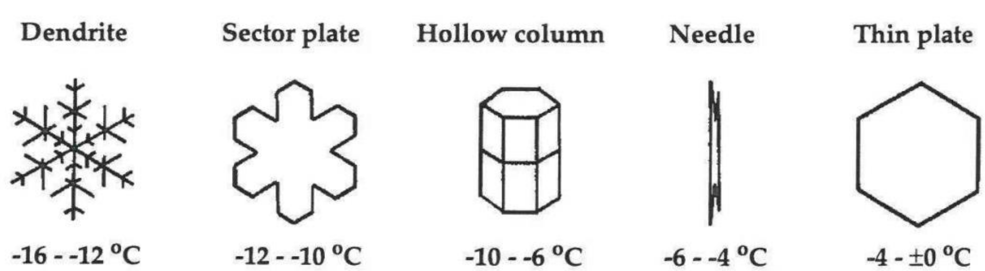


Figure 1. 1 Basic snow crystals

Snow density depends on many factors and once the snow is piled the density of the snowpack will vary along the following days. The values can vary from 50-70 kg/m^3 for the new snow (dry snow immediately after falling in calm) to 400-600 kg/m^3 for the wind packed snow. As long as it melts, the snowpack increases its inner humidity (wet snow) and reaches the last values commented. Those values can even be highly increased by mechanical compaction or water spraying techniques.

Apart from humidity and temperature, the density varies depending on the height of the snowpack. Tabler et al. (1990b) report that the mean density of deep snow drifts ρ_s kg/m^3 increases with depth d_s (cm) as shown in equation (1).

$$\rho_s = 522 - \frac{20470}{d_s}(1 - e^{-\frac{d_s}{67.3}}) \tag{1}$$

1.3 Overview of Snow Storage System technology

As mentioned before, SSS technologies are not very as popular as other renewable energies and there is so far little research in this field. Energy storage technologies tend to be a very valuable part of an energy system. Storing energy in the form of heat, electricity, potential energy or other types can always be challenging and it can mark the difference between a high performing system and an inefficient one. When it comes to the storage of cold, different techniques have been used along the years.

Himuros and Yukimoros are examples of old cold storing techniques used in Japan. They consist in an insulated house where vegetables are placed in shelves and the ice or snow are stored in boxes and placed on specific spots in the room. While Yukimoros use snow to cool the room, Himuros are powered by ice. The food/snow ratio varies depending on the climate and thermal insulation of the building. The main variables to be controlled are the temperature and relative humidity, and certain tools such as shutters or curtains can be used in order to set the adequate conditions. The precision obtained for those variables is not highly accurate but it works for the main purpose. In China facilities similar to Himuros and Yukimoros were used. The systems consisted in collecting ice blocks from the lake during the winter and storing them on a shed, this old technique has been used since 1,000 B.C (Sundin 1998). Those ice blocks were covered with sawdust or other insulation materials and used in summer for cooling purposes. In most cases ice houses were placed next to buildings and small apertures were used to let the air flow from the outside and through the ice room cool the building.

Nowadays techniques such as ice ponds or pits are used as well to store snow. It consists mainly of a pond sealed with rubber or plastic to enhance the insulation capacity and to prevent the leakage and mass loss through the ground. At the top of the pile other insulations materials are placed to cover and protect the snow from radiation or other heat losses. Another application for these facilities is the purification of the water since impurities are pressed out of the ice as it freezes. In Greenport, USA, seawater was cleaned from 30,000 ppm to about 5 ppm i.e. well below the authority regulations for potable water (Skogsberg 2005).

Other techniques like Iceboxes can be a good option for high cold demands. They are un-insulated boxes inside insulated shelters, where several layers of ice are frozen during the winter by spraying water. Systems powered by this technic can reach COP values of 95 and sizes of 250 MWh (Skogsberg 2005).

Cities and villages from northern countries who expect several snowfalls during the winter collect all the snow from the streets and pile it up on snow deposits or other specific spots in the city. Cipcigan and Michel (2012) carried a study of the potential utilization of those spots for seasonal cooling in Ottawa. The city of Ottawa has 11 snow disposal facilities (SDFs), the places where all the snow removing machines go to unload the snow, and all of them combined have a capacity of over 3 million m^3. The study shows that the estimated cooling capacity of city could potentially 130,000 MWh of cooling energy. Nevertheless, one of the disadvantages of the technology would be that the SDFs are placed outside the city and the transportation of the heat could entail several losses and the facility cannot be built near residential neighborhoods due to the big amounts of noise and lightning it involves. Although this technology could be interesting for cold countries, the low electricity cost in Canada makes this option less appealing as the project would have larger ROI. However, as a result of that study the potential for snow cooling was included as one of the criteria for future SDF sites.

An important aspect to mention regarding the Ottawa study is the contamination of the snow. The snow stored in SDF sites is highly contaminated since it comes from the streets of the city. Not only the pollution from cars and vehicles contaminates the snow but all the de-icing materials used for traction control on the roads. The main de-icing materials used in Ottawa are a mixture of salt and sand, and the vast majority of it will be picked up by snowplows and deposited on the pile. Among the snowpack different contaminants can be found and they are mainly divided in total solids (TS), total dissolved solids (TDS) and salinity. Those components drastically affect the performance of the system and the cost of it as several filters have to be placed, maintenance operations are needed regularly and lot of anticorrosion materials are essential. In the study Cipcigan and Michel refer to a particular Ottawa's SDF were samples of snow were taken and brought to a laboratory to be analyzed during the winter of 2008/2009. Samples of snow coming from major arterial roads presented almost twice the values of both dissolved TS and TDS than the ones coming from secondary residential roads. The snow used for this project will come from the surroundings of a poultry house outside Montreal where there are barely no vehicles and any de-icing materials are used on the way. Though similar units will be needed to treat the snowmelt, the factors mentioned will completely change the sizing of the filtration, piping and pumping system.

1.4 Current facilities

There are different ways to use the snow stored to cool a building, but the most common used is to transfer the heat through the snowmelt. The Sundsvall Hospital in Sweden proves to have a successful snow storage cooling system. The plant, which has been in use since 2000 is the first of its kind in the world and still operates with great efficiency today.

Figure 1.2 shows the outline of the Sundsvall Hospital cooling system. The snow is collected during the winter with snow trucks and piled in a pond near the hospital, where at the end of the season will be covered with sawdust for heat insulation. Artificial snow is also generated with snow guns and distributed all over the snowpack, representing the 30% of all the snow stored. The pond size is 160 x 64 x 2 m (LxWxD) and has a capacity for 60,000 m^3 of snow, about 40,000 tons. The asphalt surface has a slight slope of 1% that allows all the snowmelt to be accumulated in one side of the pond, where the outlet pipes extracts the snowmelt at 2°C. The water coming out of the pond has levels of TS and TDS dissolved that can damage the pump system and harm the piping due to the corrosion, this is why a set of filters are placed at the outlet pipe. The snowmelt is pumped to a heat exchanger where the heat will be removed from the liquid and used by a secondary system to distribute the cooling throughout the building. The overheated snowmelt returns and is injected to the snowpack through the inlet pipes. The few degrees gained through the heat exchanging will allow the melting of the stored snow and feed the snowmelt flow through the closed loop. There is also a valve to remove the extra water from the loop and regulate the quantity and meet the power needed. The porosity of the insulation layer plays a major role in keeping fresher conditions in the snowpack by allowing the release of the moisture and regulating inner humidity.

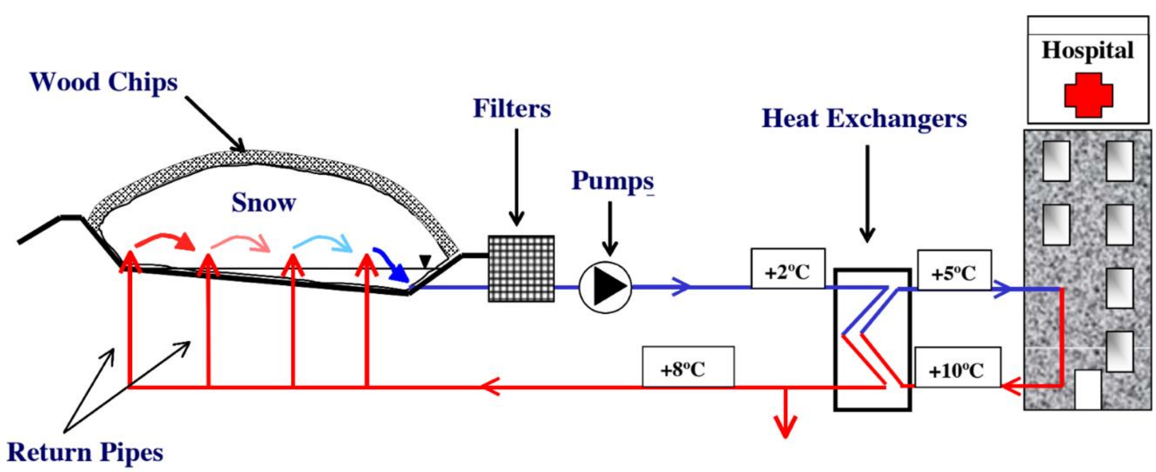


Figure 1. 2 Snow Storage System outline from Sundsvall Hospital

Scandinavian countries are pioneers on using snow storing technologies. The last large project carried in Norway was in Oslo's airport, in Gardermoen. The airport was built in 1998 with a capacity of 17 million passengers a year and a cooling demand of 8 MW, but the constantly increasing number of passengers year by year leaded to build a new terminal between years 2013 and 2017. The expansion raised the capacity to 21 million passengers and the cooling demand incremented to 19 MW. Oslo's airport faces several snowfalls during the winter and uses snowplows to keep the tracks clean, that is why a snow storage system was a great solution to meet the new cooling demand. The system was designed to reduce the summer cooling load by up to 5 MW, in 2016 the watertight SSS was built and in 2017 the system already saved 375 MWh. It is expected further improvements over the next years.

In Sapporo, Japan, the Chitoise airport uses a SSS to fulfill the 30% of its cooling demand reducing 2100 tons of CO_2 per year (Nordell 2015) and several residential areas use this technology, mostly in Finland, China and USA. In Japan further applications such as mobile systems (as shown in Figure 1.3) are studied for public places (Hamada et al. 2010)

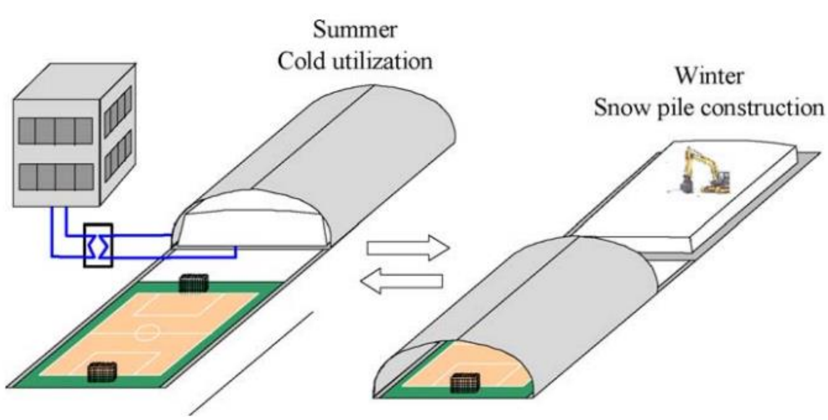


Figure 1. 3 Concept of a mobile SSS

The International Energy Agency, 1995, evaluated the performance of different snow storage projects in Canada, Germany, Netherlands and Sweden, demonstrating that the costeffectiveness of most of this projects have a payback period of five years or less. Nevertheless, recent studies claim that depending on the region payback periods for these projects can be around three years (Kumar et al. 2016).

1.5 Different SSS technologies

There are different ways to store the snow, mainly classified as indoors, on the ground, in open ponds/pits and underground. All these techniques require some sort of insulation layer except for the snow stored indoors, where the same shelter acts as a heat insulator. Snow density can adopt values from 50 kg/m^3 to 850 kg/m^3 depending on several factors, and in SSS the higher the density the more efficient the system will be.

A conventional snow storage system (CSS) is a SSS where the snow is collected into a shallow coarse grain sand base pit and the water melted is extracted through pipes to a heat exchanger. These are the least efficient SSS due to the low density of the snow stored and the lack of insulation materials used to keep the cold. The estimated payback to deliver 7 MW of mean cooling energy with 90,000 m^3 of snow is about 10 years (Skogsberg 2005).

A watertight snow storage system (WSS) is the same idea as a CSS but the snow is stored in a pit insulated with asphalt or plastic liner to prevent the leakage through the ground. The waterproof bottom not only prevents the water loss but also avoids contamination from the ground. The ground surface of the pit is covered with polystyrene foam for better insulation. The density of the snow in a WSS is around 650 kg/m^3, higher than in a CSS. This is due to the operating machines all over the pit on the storing season. All studies conclude that this system performs much higher energy efficiency than a conventional chiller cooling systems. The first large-scale WSS was the Sundsvall Hospital in Sweden (Skogsberg 2005). The most used insulator for the snow pile is a layer of wood chips, the prove to be an excellent option due to its porosity, allowing evaporation so the extra moisture is released to the environment keeping the snowpack fresher (Skogsberg and Lundberg 2005). As an alternative to wood chips sometimes bark and cork are used as insulators performing similar results. These materials present a low economy impact and environmental benefits. The estimated payback for a WSS delivering 6000 MWh of cooling energy with 120,000 m^3 is around 3 years (Kumar et al. 2016).

A high-density snow storage system (HSS) is a SSS that uses snow with a density around 750-800 kg/m^3. Hamada et al. (2010) developed the idea of collecting and mechanically compacting the snow in order to reduce the space needed for the storage and increase the energy efficiency. The HSS system is similar to the WSS but the snowpack can be placed insulated in a room instead of covering the snowpack with wood chips, and usually incorporates an insulated deposit to keep cold water to cover demand peaks. The snow could be even more compressed with a water-spraying system, reaching ice density values of 920 kg/m^3.

1.6 Broiler house Industry in Canada

Chicken products represent an important part of the food industry and also the Canadian economy, and it is going to grow on the following years. Animal productions contributes to air pollutant emissions such as ammonia, hydrogen sulfide, organic compounds and other greenhouse gasses (Huang and Guo, 2019).

In 2018, Canada Produced poultry and egg products worth $4.6 billion, contributing 7.3% of cash receipts to farming operations (AAEC, 2018). Table 1.1 shows the poultry industry in Canada and how the provinces contribute to it. After Ontario, Quebec is the second province with most chicken producers in Canada, representing the 26% of the total.

	BC	AB	SK	MB	ON	QC	NB	ND	PE	NL	CANADA
Chicken producers	316	253	64	121	1,244	740	38	87	8	6	2,877
Broiler stock hatcheries	10	4	2	4	7	5	2	3	0	1	38
Total chicken slaughter plants	35	5	3	6	18	10	2	1	0	1	81
Turkey producers	67	48	11	55	165	147	18	20	0	0	531
Turkey hatcheries	1	2	0	1	4	3	0	0	0	0	11
Total turkey slaughter plants	24	3	2	4	7	4	0	1	0	0	45
Egg producers	138	164	69	154	404	157	16	24	7	6	1,143

Table 1. 1 Provincial poultry facts

The size of the industry is big enough to research and develop a system to enhance the energy performance of a standard Canadian broiler house. While lots of Canadian broiler houses have no cooling system, some of them use conventional chillers to condition the building. The Canadian weather pushes the broiler house owners to invest more in isolating technics rather than conditioning technologies. Nevertheless, as explained in section 3.1, on summer seasons the hot weather can cause unhealthy inner conditions.

CHAPTER 2

MATLAB SIMULATION FOR THE MELTING OF THE SNOW PILE

There are different models to approximate and simulate the melting rate of the snow pile. Scientist have developed several differential equations to predict the behavior of snow depending on the environment conditions. Hydrologist use all this models to study variations in humidity, density, volume, snowmelt rate and other variables. However, all engineering projects regarding SSS use linear approximations to ease simulations and result analysis. Each facility requires a particular model to suit the specifications and boundary conditions, therefore the first need is to develop the model suitable for this project.

2.1 Geometry

The quantity of snow needed and the way of removing and packing it will determine the geometry of the snowpack. Usually the snow is stored in a shapeless pile, and some of the projects studied such as Sundsvall Hospital or Chitoise airport approximate this pile to a frustum of a cone or a semi sphere. In this case the pile proportions will be similar to the building's proportions, which means with a rectangular basis instead of a square. The geometry of the pile will be a frustum of a rectangular pyramid (Figure 2.1).

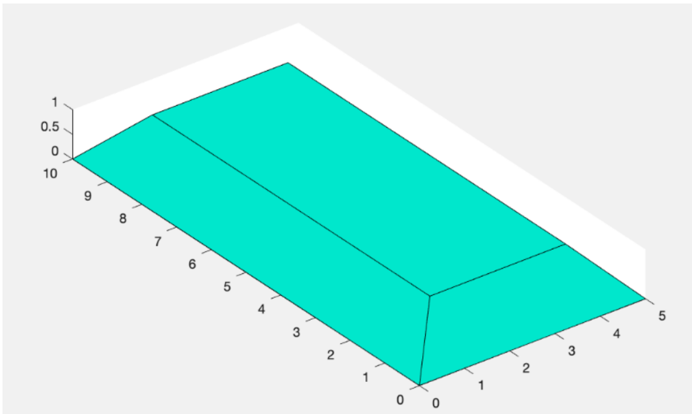


Figure 2. 1 Snowpack geometry

In order to increase the capacity of the facility, the deposit will consist in a pond, so there will be snow stored below the ground level and also a pile of snow above this level. As further discussed in Chapter 3, the bottom snowpack is better preserved than the one piled up over the surface. This is the main reason why the depth of the deposit should be as big as possible, on the first simulations the value will take twice the height of the pile.

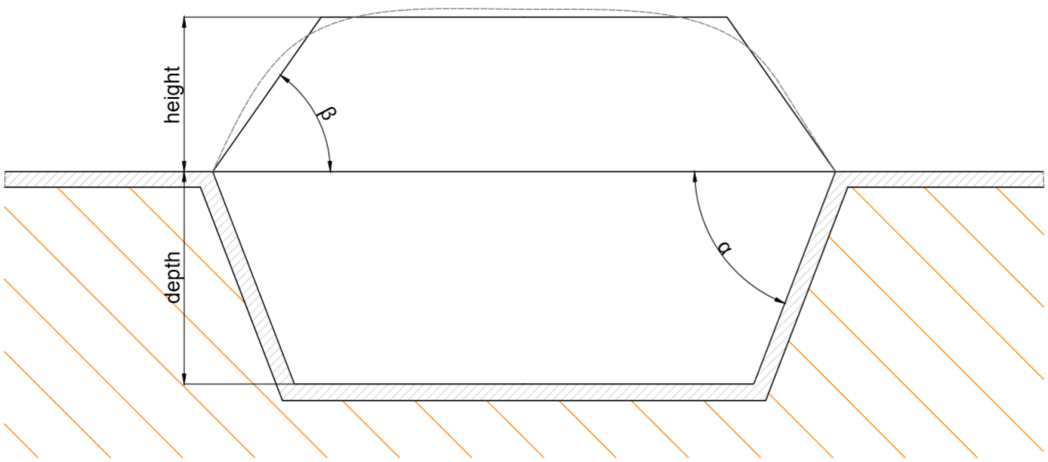


Figure 2. 2 Section of the deposit filled with snow

The geometry of the pond will be as well a frustum of a pyramid. A slight slope on the pond's wall will help the snowmelt flow towards the bottom. Figure 2.2 shows both shapes conforming the total snowpack, and different parameters for each shape has been taken. Equations (1) and (2) will be used to calculate the volume and the area of the snowpack.

$$V = \frac{h}{3} \cdot (B_1 + B_2 + \sqrt{B_1 \cdot B_2}) \quad (1)$$

$$S = B_1 + B_2 + \frac{1}{2} \cdot (P_1 + P_2) \cdot a \quad (2)$$

2.2 Thermal equations

The energy budget approach is the theoretical method to calculate all the energy available for snow melt, all the factors involved are shown on equation (3). This balance provides an overview of the heat transfer on the snow pile, where *M* is the energy available for melt, *R* is the net radiation, *H* and *L* are sensible and latent heat, *G* is conductive heat from the ground, *r* is the heat from the rain and *ΔU* is the variation of the internal energy.

$$M = R + H + L + G + r + \Delta U \tag{3}$$

Equations (4 to 9) describe all the terms for a horizontal snow cover. Eva Sundin (1998) carried a study for different shaped snow piles, and these equations have to be adapted to the geometry of the snow pile as well as the variation of its volume. In this study conductive heat losses from the ground were took empirically. Energy losses due to radiation, latent and sensible heat require more elaborate geometrical considerations, see Sundin et al. (1999)

$$R = (1 - \alpha)S_g + E_i - \sigma T^4 \tag{4}$$

$$H = \frac{\kappa^2 c_p \rho_a (u_h - u_0)(T_h - T_0)}{[ln(z_h/z_0)]^2} \tag{5}$$

$$L = l_v \dot{m} = \frac{0.622\kappa^2 \rho_a l_v (u_h - u_0)(e_h - e_0)}{p[ln(z_h/z_0)]^2} \tag{6}$$

$$r = \rho_w c_{pw} (T_h - T_0) P \tag{7}$$

$$U = CC + \rho_w l_h w z_f \tag{8}$$

$$CC = \rho_s c_{pi} z_f T_C \tag{9}$$

As described at the beginning of this chapter, linear models are used to approximate the equations of snow. One of the most used approaches is de Degree Day method, shown in equation (10), taking into account the air temperature as the index for melt (Pomeroy et al. 2001). This method was used by Eva Sundin (1998) on the Snow Deposit Melt study and for Skogsberg (2005) on the SSS for Sundsvall Hospital in has proved to give satisfactory results.

$$Q = kA(T_a - T_s) \tag{10}$$

The degree day approach simplifies the energy balance, where Q is the snow melt rate (m^3 day^{-1}), k is the day coefficient (m °C^{-1} day^{-1}), A is the surface area of the snow pile facing the air (m^2), T_a is the air temperature and T_s is the snow temperature (°C). Aside from being a reliable model, the degree day approach is widely used since the main variable to iterate is the day temperature, easy to obtain from any weather station. The day degree coefficient k is not a constant, depends on the location and varies along the year, it is usually measured empirically.

$$A = f(V) \tag{11}$$

$$-\frac{\rho_s}{\rho_w} \cdot \frac{\delta V}{\delta t} = Q \tag{12}$$

For a better approach to model the snowmelt, the modified method uses equations (11) and (12) to take into account the volume variation of the snow pile. The area A facing the air depends on the total volume V and the shape of the pile, and each geometry has a relation between those two variable, as long as the pile shrinks the melting rate Q will change accordingly. Although the density of snow ρ_s and water ρ_w depend on several variables, most of the studies using the modified degree day method assume those values as constants.

2.3 Snowmelt model

As described in section 2.1 the geometry of the deposit will consist in two frustums of pyramids, one above the ground level and the other one below it. The snow pile has to be insulated to keep the cold as long as possible, and one of the most efficient ways to do it is by covering the surface with bark, wood chips or sawdust. The ground must be thermally insulated as well and must have waterproof properties to prevent the snowmelt from filtering through the soil. All the insulation features are further discussed in section 2.6.

Lintzen and Knutsson (2018) bring a recent study to improve the modified degree day method. This model uses the degree day linear equation to calculate the heat transfer through the surface due to the convection with air, but it adds as well the thermal flow through the ground and the snow melted due to rain. All this energy need to be expressed in m^3 of snow melted in order to work with the geometry equations and evaluate the overall size variation of the pile.

2.3.1 Ground melt

Equations (13 to 15) are used to calculate the losses through the ground. Q_g is the thermal flow from the ground (W) and it can be calculated with equation (13) where λ_g is the coefficient of thermal conductivity for the ground (W m^{-1} K^{-1}), A_g is the snow area directly in contact with the ground (m^2), T_s is the snow temperature (K) and T_g is the ground temperature at a certain depth l (m).

$$Q_g = \frac{\lambda_g A_g (T_g - T_s)}{l} \tag{13}$$

$$\dot{v}_g = \frac{Q_g}{Ls \cdot \rho_s} \tag{14}$$

$$V_{ground} = \dot{v}_g \cdot t \tag{15}$$

Equation (14) will be used to calculate de rate of melted snow v_g (m^3 s^{-1}), where L_s is the latent heat of fusion for the snow (kJ kg^{-1}) and ρ_s is the density of snow (kg m^{-3}). Finally, equation (15) will be used to calculate the total volume melted V_{ground} due to the ground (m^3).

2.3.2 Surface melt

The surface melt caused for the convection with the air is the most important term as further discussed in chapter 3. Equation (16) is the core of all this model, it gives similar results as the degree day equation.

Q_{surf} is the thermal flow on the surface (W) and it can be calculated with equation (16) where λ_i is the coefficient of thermal conductivity for the insulation layer (W m^{-1} K^{-1}) and e (m) is the thickness of that layer. A_g is the snow area facing directly the air (m^2), T_s is the snow temperature (K) and T_g is the ground temperature. As in the previous section, equations (17) and (18) will be used to calculate the snow volume flow and total rate (m^3).

$$Q_{surf} = A_{surf} \cdot \frac{\lambda_i}{e_i} \cdot (T_a - T_s) \tag{16}$$

$$\dot{v}_{surf} = \frac{Q_{surf}}{L_s \cdot \rho_s} \tag{17}$$

$$V_{surf} = \dot{v}_{surf} \cdot t \tag{18}$$

2.3.3 Rain melt

The last term of the model is the snow melted due to rain. The convection and heat exchange with the rain drops will melt an important volume of snow. It is necessary to analyze this total amount of volume melted to decide if it is worth protecting the snow pile from the rain.

Equation (19) calculates the volume of snow V_{rain} melted due to rain (m^3). P is the precipitation (m), A is the area of the pile exposed to rain (m^2), ρ_w is the density of the water (kg m^{-1}), c_w is the heat capacity of water (J kg^{-1} K^{-1}), T_{rain} and T_s are the temperatures of the rain and the pile surface (K), L_s is the latent heat of fusion for the snow (kJ kg^{-1}) and ρ_s is the density of snow (kg m^{-3}).

$$V_{rain} = \frac{PA\rho_w c_w (T_{rain} - T_s)}{L_s \rho_s} \tag{19}$$

2.3.4 Total volume melted

The total volume melted will be calculated with equation (20), it is the sum of the volume melted due to the losses through the ground, the one melted due to surface convection with air and the volume melted for the rain. The sum of those three components give more approximate results than the ones given for the degree day method.

$$V_{TOT} = V_{ground} + V_{surf} + V_{rain} \tag{20}$$

2.5 Simulation of the snowmelt

Once the model has been chosen, it's time to evaluate the equations with different values. The software used to run the model is MATLAB, it will iterate all the equations described above and plot the results. Before running the code, certain parameters of the snow pile have to be set. Using the geometry described in section 2.1, the first simulation will use the following values:

GEOMETRY FEATURES		PHYSICAL PROPERTIES	
Short side of the base	a = 5m	Density of water	ρ_w = 1000 kg / m^3
Long side of the base	b = 10m	Density of snow	ρ_s = 750 kg / m^3
Depth	d = 2m	Latent heat of fusion of water	L_s = 334 kJ / kg
Height	h = 1m	Heat capacity of water	c_w = 4.185 kJ / (kg·K)
Beta angle	β = 45°C	Ground thermal conductivity	λ_g = 1 W / (K·m)
Alpha angle	α = 60°C	Sawdust thermal conductivity	λ_i = 0.1 W / (K·m)
Thickness insulation layer	e = 0.1m		

Table 2. 1 Variables used on the first simulation

Although the density of the snow will vary along the year, it is considered to be a constant. As described on chapter 1, the snow will be compacted before covering it with the insulation layer, that means that the density values will raise from the common 590 ~ 640 kg / m^3 to 710 ~ 780 kg / m^3. Regarding the temperatures, the snow temperature has been considered as well to be constant at 0°C, the water freezing point. The weather data has been collected from the Canada's official website, using the 2018 daily temperatures from Montreal. Those temperatures seem to be not entirely accurate since the location of the poultry farm is not exactly Montreal, and temperatures in 10 or 20 years from now are not going to be the same. This is further discussed in chapter 3. The rain temperature has been considered to be the same as the air temperature.

The initial volume of the snow pile is 104.8 m^3, far much less than the 60.000 m^3 of the SSS in Sundsvall Hospital in Sweden. The different weather conditions and this huge difference in the size of the SSS is what leads this project to test and rethink the model used by Skogsberg (2005). Figure 2.3 shows the results of this first simulation, were two slightly different ways to iterate the model have been used. The orange line shows the model taking into account the variation of the volume for the snow pile, while on the other hand, the blue line shows the model run on a static geometry.

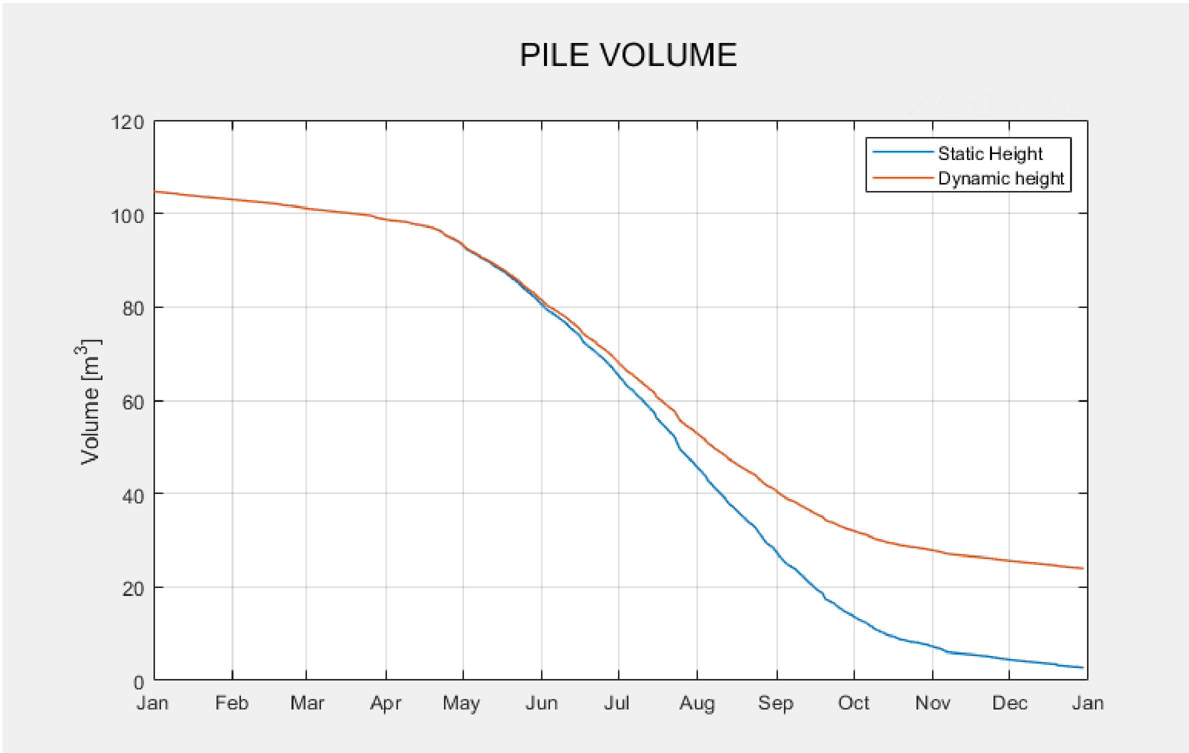


Figure 2. 3 Simulation of the snow melt

In some projects were the total snow volume melted along the year is less than the 10% of the initial volume, the blue model could be a good approach and that highly eases the code and the simulations. In this project, the target is to use all the snow stored, so the most accurate model is the orange one, were the variation of the geometry is taken into account. To evaluate this variation, the following methodology has been used:

1. At the beginning of the code, the total volume of the pile is calculated with the geometry parameters previously set.
2. The equations of the model are used to calculate the total amount of snow melted in one day. This value is subtracted from the initial volume and the result will be used in the next iteration.

3. The proportions of the initial geometry remain constant (*a*, *b*, *alpha*, *beta* and *e*), and the only parameters modified are the height of the pile and after the melt of the top volume, the depth of the pile.

Figure 2.4 displays the snow melt performances during one year. The top chart shows the daily snow melted depending on its origin (due to ground, due to rain or surface melt). It clearly demonstrates that the main cause for the melt is the surface convection with air, representing around 85% of the total melt. The ground temperature is set as a constant, performing the same melting values along the year. Rain does have a significant impact on the melting rate, but Montreal and in general Quebec is not a rainy location. The bottom chart in the figure shows the variation of the height of the pile during the year. Obviously the months were the melting rate is higher are on summer, from June to September.

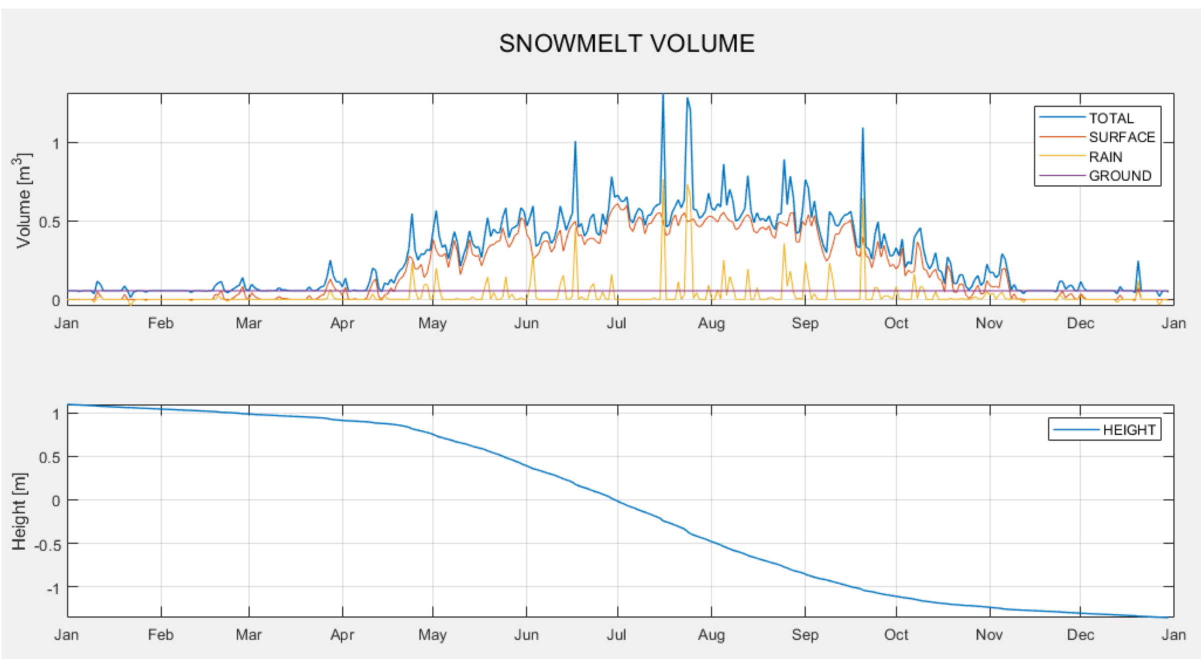


Figure 2. 4 Snow melt performances

Ten simulations have been done in order to analyze which variables influence the most the melting rate (Table 2.2). Two good indicator for the performance of the melt are the initial volume of snow and the amount of snow left at the beginning of September. The depth has been set to 2 m deep because higher values would mean complex construction procedures and higher costs.

On an ideal situation, the snow pile geometry would be 2 meters deep and two meters high, and the length and width of the pond would reach its higher values (8m x 18m). That would mean an initial volume of 424.3 m^3 of snow (around 318,225 tons of snow), exploring the limits the location and the budget can offer. The thickness of the insulation layer on this simulation only affects to the snow left on September, at first the value chosen was 0.1m, but depending on other factors this could change to meet the specifications of the system.

GEOMETRY FEATURES	S1	S2	S3	S4	S5	S6
Short side of the base *a* (m)	5	6	8	8	8	8
Long side of the base *b* (m)	10	12	18	18	18	18
Depth *d* (m)	2	2	2	2	2	2
Height *h* (m)	1	1	1	1	1	2
Beta angle β (°)	45	45	45	45	45	45
Alpha angle α (°)	60	60	60	60	60	60
Thickness insulation layer *e* (m)	0.1	0.1	0.1	0.15	0.2	0.1
INITIAL VOLUME (m^3)	104.8	160.9	350.3	350.3	350.3	424.3
VOLUME IN SEPTEMBER (m^3)	40	67.5	163.4	204.4	226.4	221.2

Table 2. 2 Simulations of the model varying the main parameters

2.6 Insulation material

Thermal insulation is the key for preserving the snow pile along the year. The equations of the model already take into account an insulation layer, where thermal conductivity and thickness have been defined.

The traditional material for insulating snow or ice is saw dust, although other materials such as different plastic materials, encapsulated hay, rice shell or other wood chips can work as well. When referring to wood chips, wood powder, saw dust, bark or cutter shavings are included. The most important feature of the insulation layer is its porosity and the ability to release moisture through its pores. Skogsberg and Lundberg (2005) carried an experiment to study the physic properties and the performance of wood chips as an insulation material.

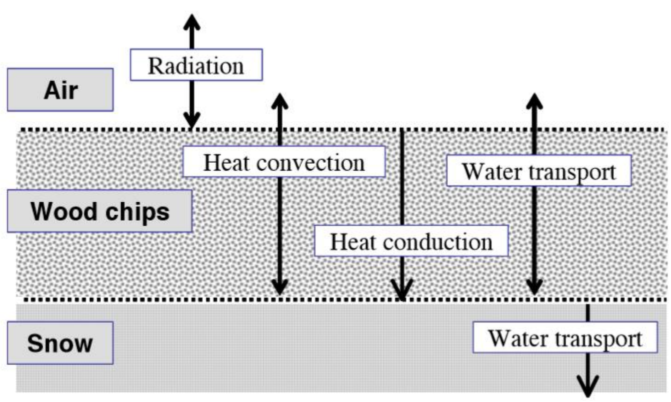


Figure 2. 5 Heat and mass transfer through a layer of wood chips on snow

Figure 2.5 show the principle of heat and mass transfer through the wood chip layer, and while most of the snowmelt goes downwards a small portion of it is transferred upwards due to evaporation and capillary forces. Certain amount of energy is needed to evaporate water, and this breathing effect of the pile is what will cool the snowpack and the wood chips. The latent heat of vaporization is considerably greater than latent heat of fusion, about 7.5 times bigger, and with only a few portion of water evaporated the snow melting rate will decrease significantly.

Covering the pile with wood chips not only protects the pile from rain and from convection with air but also decreases losses due to radiation. Albedo's values for snow (or solar radiation reflectivity) can reach values around 0.8 and decreases as long as the snow gets old and dirty, and wood chips can have albedo values around 0.1.

Skogsberg (2005) found that the thermal conductivity of cutter shavings varies linearly from 0.1-0.3 W m^{-1} K^{-1} when moisture ratio varied from 11-380% with dry density 70-100 kg m^{-3}. For simulations, values around 0.15 W m^{-1} K^{-1} have been taken into account, and Figure 2.6 shows simulations of the snow melt model with different thickness of insulation layer (wood chips). As commented before, without insulating the pile there will be no snow left by the end of April, and only using a 50 mm layer there will be not enough snow for the cooling periods on summer. The size of the pile for this simulation is 8x18 m with a depth of 2 m and a height of 2 m.

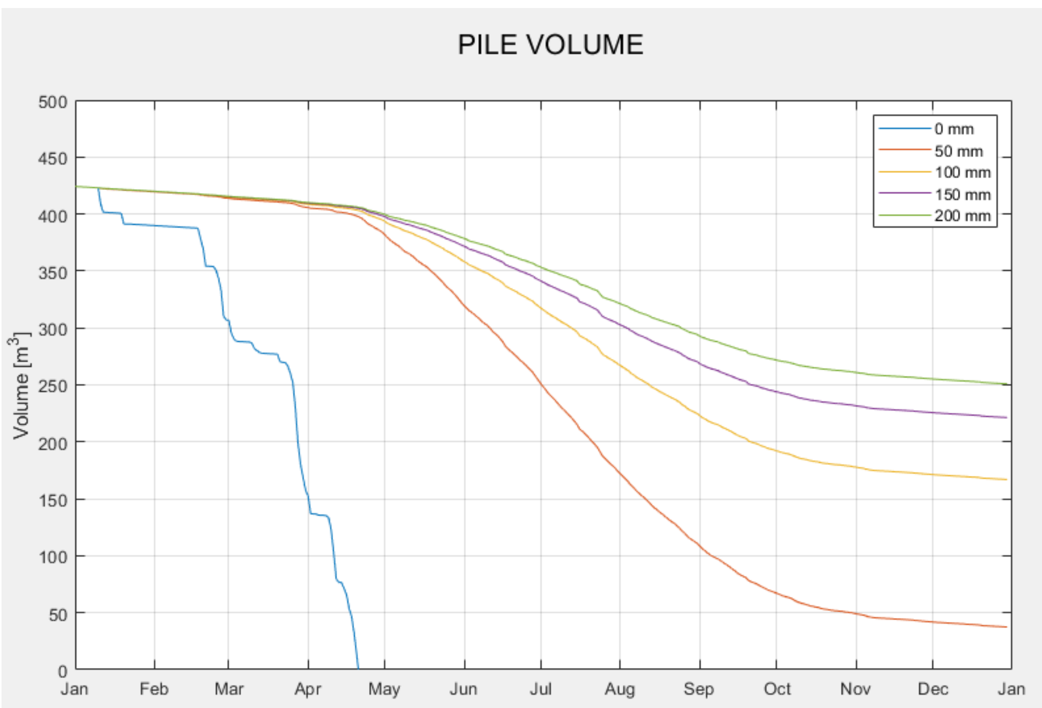


Figure 2. 6 Performance of snowmelt depending on the insulation layer thickness

CHAPTER 3

VALIDATION OF THE SNOWMELT MODEL AND RESULTS

3.1 Conditions

The next step of the project is to introduce the snow melted due to the refrigeration system into the model. In order to accomplish the goal, it is necessary to model the conditions inside the poultry house. Once the conditions are modelled and the exact cooling demand is calculated the sizing of the facility will be done. The amount of energy needed to acclimatize the building will depend on the weather and the total heat released by the birds. The dynamics of the inside air flow and its heat exchange will not be discussed in this project.

3.1.1 Building conditions: Temperature

The poultry house consists of a two floor building with dimensions of 76m x 18m x 2.5m (LxWxH) each floor. Each of this floors contains about 19,000 to 21,000 chickens, and even there are some slight differences in terms of energy performance between those two stages they will be treated as equal for simulations, selecting the worst case scenario. The second floor faces a bigger A-shaped roof surface, this extra area exposed to radiation and convection eases the heat exchange with the outside.

Weather in Montreal and surroundings tend to be hot and sunny during the summer. Although the data used for the first simulations comes from the official Canada website, it would not be appropriate to use 2018 temperatures for sizing the facility. Belcher et al. (2012) show patterns to approximate future temperatures taking into account the effects of the climate change. Global warming will affect to building performances all over the world on the next decades, it is a matter that will affect engineering projects that depend on the weather. On the following years, the global warming not only will increase the melting rate but will consolidate the need of a cooling system to reduce the overheating inside the poultry house.

One of the best ways to see where the peak of cooling demand would be is by overlapping the outside temperature with the inside temperature. Figure 3.1 shows the average temperature in the location during 2018 in blue and the ideal temperature inside de building in orange. The simulation below takes seven cycles about 38 days each, and between each cycle there is about 10 to 14 days where the poultry house remains empty. The owner preheats the building a few days before the new flock will come in order to set the proper conditions in time. At the beginning of each cycle the ideal inside temperature would be about 31ºC, and it will progressively decrease until 21ºC (Ross broiler handbook, 2018). As shown in Figure 3.1, at the end of the fourth and fifth cycle the outside temperature during the day clearly surpasses the ideal inner conditions. Obviously this period of time coincides with summer season, more precisely on July and August. This time the ventilation will not be enough to keep the temperature below the threshold.

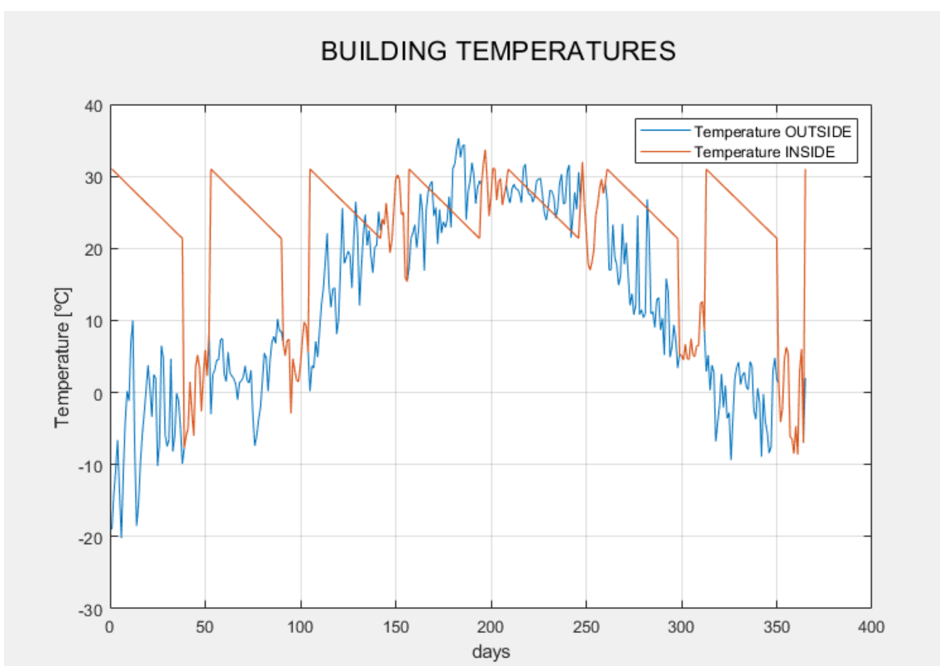


Figure 3. 1 Temperatures inside and outside the building

3.1.1.1 The wind chill effect

The broiler house has no cooling system, so that means that ventilation is used to freshen up the interior. By smooth air circulation, the chicken will feel a cooling effect and will eat and perform thinking the air temperature is lower than it actually is. As the air flows around the bird it removes the heat released by his body and it produces a cooling effect. The curve varies depending on the age of the bird, the smaller ones are less feathered and have more space between them, therefore have bigger heat losses. The wind-chill effect is very difficult to predict because it depends in too many random factors (Czarick and Lacy, 1996). Figure 3.2 shows some of these studies, all of them concluding that the results from the laboratory are far from the actual ones in a broiler house. In a wind tunnel the chicken is exposed to a constant air flow, while in broiler houses the turbulences inside the building and the big amount of chickens reduce the cooling effect. Broiler houses with ventilation systems rely on this effect, although it is very difficult to calculate the exact wind chill factor and therefore the thermal comfort of the chickens.

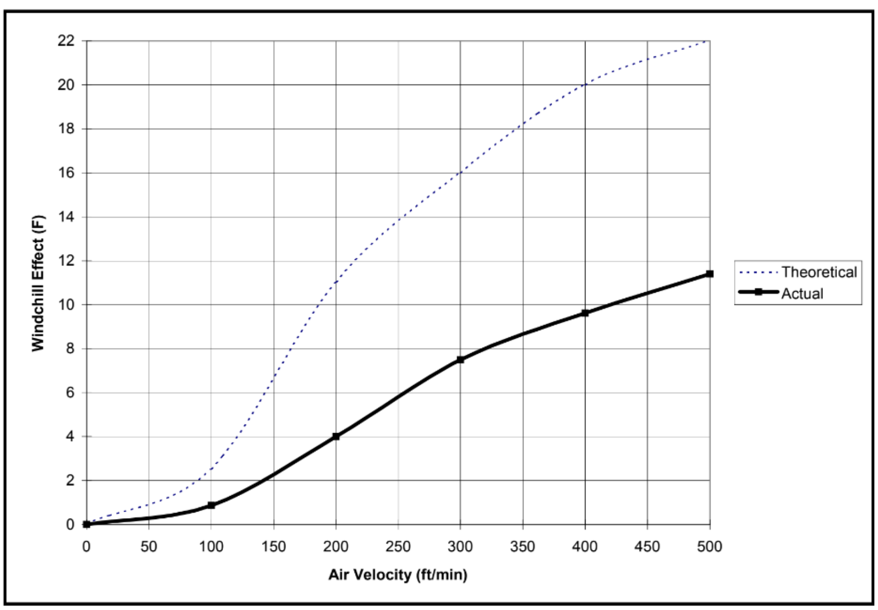


Figure 3. 2 Wind-chill effect for mature birds

3.1.1.2 Future weather conditions and climate change

As commented on section 3.1.1, using current weather data to simulate the model would not be appropriate as the climate change is warming the globe year by year. Belcher et al. (2005) developed a model called "morphing", a method to generate future weather data combining present-day observed weather data with results from climate models. Robert and Kummert (2012) show a study were the morphing method is applied to design net-zero buildings using the weather of Montreal, since most of the buildings lose their net-zero target in few years.

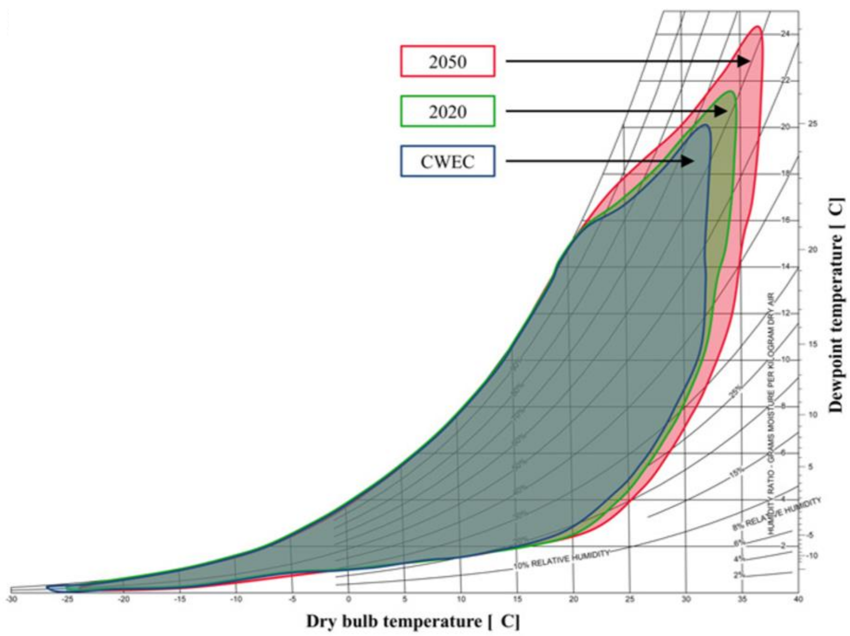


Figure 3. 3 Psychometric chart for Montreal

Even though the facility does not pretend to be a net-zero building, the performance of the system depends on weather conditions. Figure 3.3 shows hourly data points on a psychometric, and the area of the 2050 weather clearly expands towards higher values of temperature and absolute humidity. Data from 2050 has been used for the simulations of the model, the snow melt rate will increase but the need of a cooling system will augment as well.

3.1.2 Building conditions: Humidity

Relative humidity is a very important variable to monitor in order to keep comfort conditions inside the building. As further shown in section 3.1.3, the chickens release a lot of sensible heat in form of humidity and at the end of a cycle it can reach values of 150 kW per stage. The Ross broiler handbook (2018) sets the ideal temperature depending on the relative humidity as shown in table 3.1, where the temperature RH should remain at 60-70% up to three days and a RH of 50% thereafter.

Age (days)	Dry Bulb Temperature ºC			
	40 RH%	50 RH%	60 RH%	70 RH%
Day-old	36.0	33.2	30.8	29.2
3	33.7	31.2	28.9	27.3
6	32.5	29.9	27.7	26.0
9	31.3	28.6	26.7	25.0
12	30.2	27.8	25.7	24.0
15	29.0	26.8	24.8	23.0
18	27.7	25.5	23.6	21.9
21	26.9	24.7	22.7	21.3
24	25.7	23.5	21.7	20.2
27	24.8	22.7	20.7	19.3

Table 3. 1 Ideal inside temperature depending on relative humidity

As the chick grows, the ideal RH falls. If high RH levels (above 70%) are measured 7 days onwards it can cause wet litter and its associated problems. Low humidity equals less bacteria and less disease growth, and controlling levels of humidity and temperature are the key to a healthier flock. Other health benefits of conditioning a poultry house are that birds don’t overheat in summer months, the mortality drops and birds perform better as eating consistently.

Litter quality is also affected by humidity, and lower levels means less damage to building structure, less ammonia production, cleaner floor and therefore better feet health of chickens. Dry floors equal less bacteria on the feet and less chance of bacteria entering to chicken's blood through their feet wounds.

The inner humidity is controlled only by ventilation and several sensors are placed inside the building. When those sensors detect humidity levels above the ideal ones the CPU calculates the ventilation needed and sends the order to the fans. The fans are only activated when the inner humidity is above the threshold, if it is below the ideal humidity the system will remain still. The CPU will keep calculating and sending signals until the target is reached, and this process can take from few minutes to hours. This system depends entirely on the weather, which means the best case scenario is to reach the humidity levels outside the building, and sometimes those levels can be above the target, missing the ideal conditions.

The relative humidity along a typical month in July is plotted on Figure 3.4 (CWEC data). The average humidity is 76% and it goes from values around 40-50% in the afternoon to 100% around midnight. Heat waves can come on summer like in days 24-25-26 where the average level was 90%, that values can be dangerous for the chicken's health.

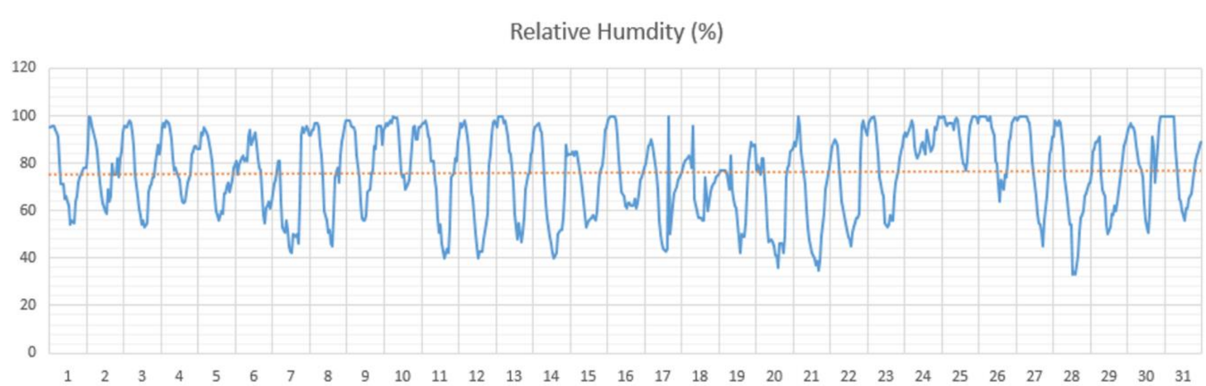


Figure 3. 4 Relative humidity in during July

3.1.3 Heat production model inside the building

To model the inside energy production several data has been collected. The owner of the poultry house monitors on a daily basis variables such as the outside temperature, the inside temperature, the levels of CO_2 inside the building, the relative humidity, the total number of birds, the total weight of the birds, the quantity of heat used by the heaters to warm up the building and the amount of electricity used. All this data facilitates the approximation the energy performance inside the building. The conditions inside the building depends on variables such as the air temperature, the amount of radiation received, the total heat released by the chickens, the heat released by the lightning or other machines, the performance of the ventilation, etc. As there is no intention in modifying the structure or disposition of the poultry house, the main objective of the SSS is to counteract the energy released inside the building by imposing the quality standard. Each floor has four big, three small and three mid-size fans, making a total of twenty all over the building. On summer, these twenty fans working at its maximum speed not only involve large electricity bills but they cannot meet the ideal inside temperature by only circulating hot air from outside.

$$THP = M_c^{b_1} \cdot e^{(b_0 + b_2 \cdot LT + b_3 \cdot T_{db} + b_4 \cdot T_{db}^2)} \tag{21}$$

$$SHP = \rho V c_p (T_e - T_o) + U_b (T_i - T_o) - Q_{sup} - Q_{equip} \tag{22}$$

$$LHP\% = b_0 + b_1 \cdot T_{db} + b_2 \cdot T_{db}^2 + b_3 \cdot RH \tag{23}$$

To approximate the heat release inside the building the model described by Xin et al. (2001) has been used. Equations (21-23) are used to calculate the total heat production, the sensible heat production and the latent heat production by the birds. The most important term to evaluate will be the LHP as the system will remove all this heat by condensation. In equation (23) b_0, b_1, b_2 and b_3 are coefficients determined by least squares, T_{db} is the dry bulb temperature at the bird level (°C) and *RH* is the relative humidity (%). The value calculated is a percentage of the total THP, where in equation (21) *M* is de body mass of the chicken in kg, *LT* is the light code, 0 for 100%-time light, 1 for 100%-time darkness and between 0 and 1 for partial light/darkness during the hour.

During the year, several flocks of chickens pass through the poultry house. Each cycle consists of about 19.000 to 21.000 chicks that will grow during the next 38-40 days. At the beginning of the cycle, a lot of heat is needed as the young animals need warmth. As long as they grow, they start releasing more and more energy until the end of the cycle where all that amount of energy combined with the external conditions can be a big issue for their health. A few simulation of the model described by the previous equations have been done with all the actual values of the poultry house. The results are shown in Figure 3.5, where the THP, LHP and SHP have been plotted for a cycle (about 900 hours). The quality standards require different light setups along the cycle, that is the reason for the dented shape of the graph.

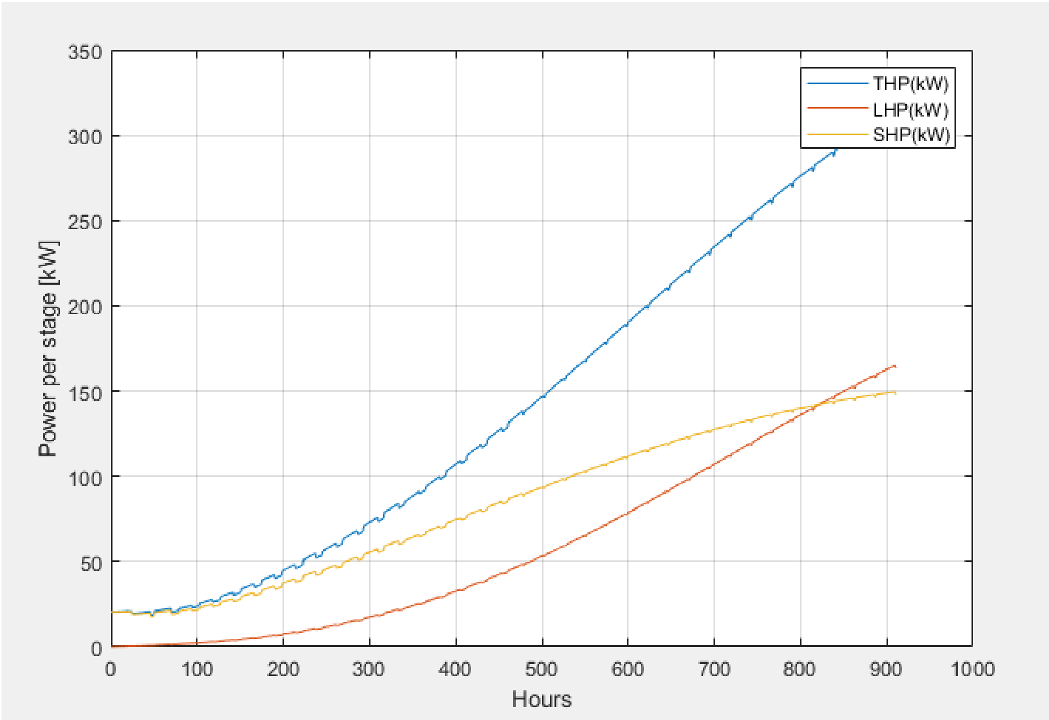


Figure 3. 5 Heat released by the birds per stage

3.2 Cooling system performance

In order to plot the melting rate taking into account the volume melted due to the cooling system, the model expressed in section 2.3.4 has been modified, as shown in equation (24). The term V_{cool} refers to the amount of snow used for refrigeration.

$$V_{TOT} = V_{ground} + V_{surf} + V_{rain} + V_{cool} \tag{24}$$

To calculate this value, the threshold has been set on keeping the LHP below 100kW. As shown in Figure 3.5, the LHP crosses this limit around hour 680 and keeps increasing until the end of the cycle. That means around 9 to 10 days of refrigeration 8 hours a day. The first day of refrigeration small quantities of latent heat have to be removed, but each day higher amounts of energy will have to be removed. This progressive growth can be assimilated as a linear increase from 0 to 60 kW in 10 days. Figure 3.6 shows the simulation of the model described above during a year. The cycles of refrigeration will be on the months of July and August, and after that considerable amounts of snow will remain still in the pond.

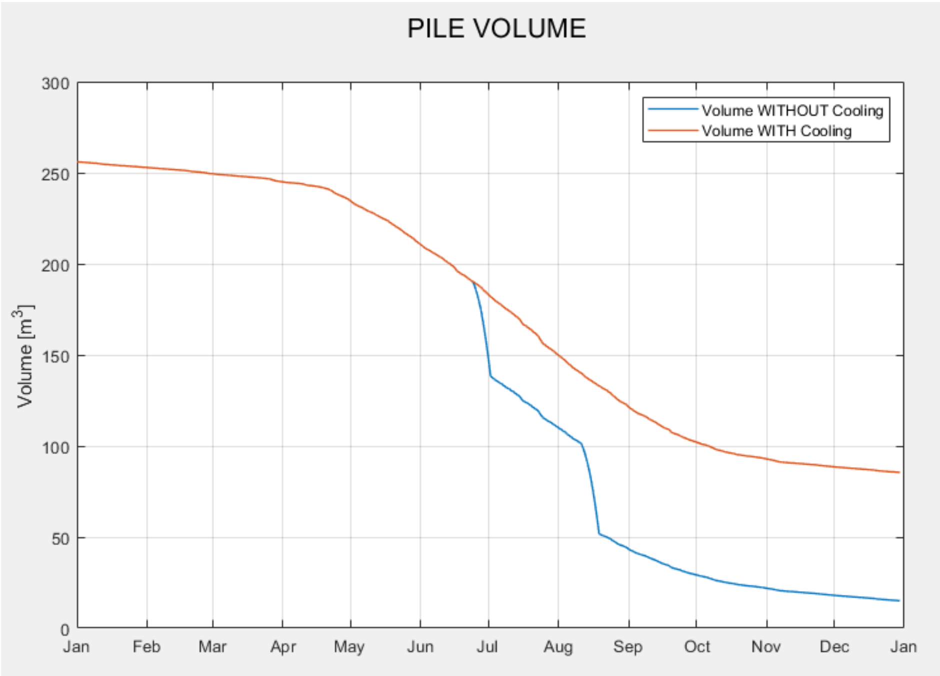


Figure 3. 6 Melting rate using the refrigeration system

Oversize the facility is the best option in order to face future possible problems such as other heat losses, low efficiency, losses on the pumping system, bad insulation or unpredictable changing weather among others. As a preliminary design, only the main variables influencing the energy performance and heat transfer have been taken into account to meet the scope of this project.

Figure 3.7 shows the melt performances of the snow deposit when the SSS is operating. On the two peaks the volume melted due to the refrigeration system represents about 90% of the total snow melted. It seems that there is no need to refrigerate other cycles, so the system would be operating twice a year. After the second peak the snow left should be removed in order to proceed with maintenance and cleaning operations to set the SSS for the next season. The insulating material can be removed and stored so it can be used next year.

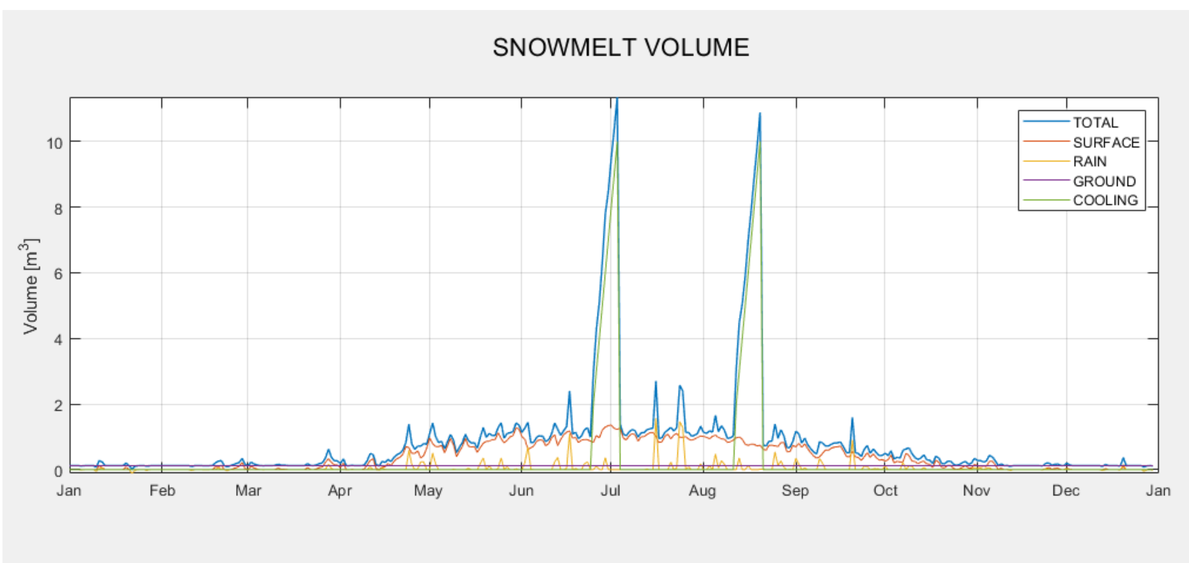


Figure 3. 7 Snow melt performances using the SSS

3.3 The cooling system

The snow deposit must be connected to the building through a piping system. The system must be able to regulate the flow, regulate the cooling power, filter the impurities and monitor the main variables such as temperature and pressure in order to prevent damages and ease the maintenance operations. Figure 3.8 shows a draft of the piping and instrumentation diagram of the facility and the main constructive parts. The installation has two different hydraulic circuits: the primary circuit and the secondary circuit, both connected through the heat exchanger.

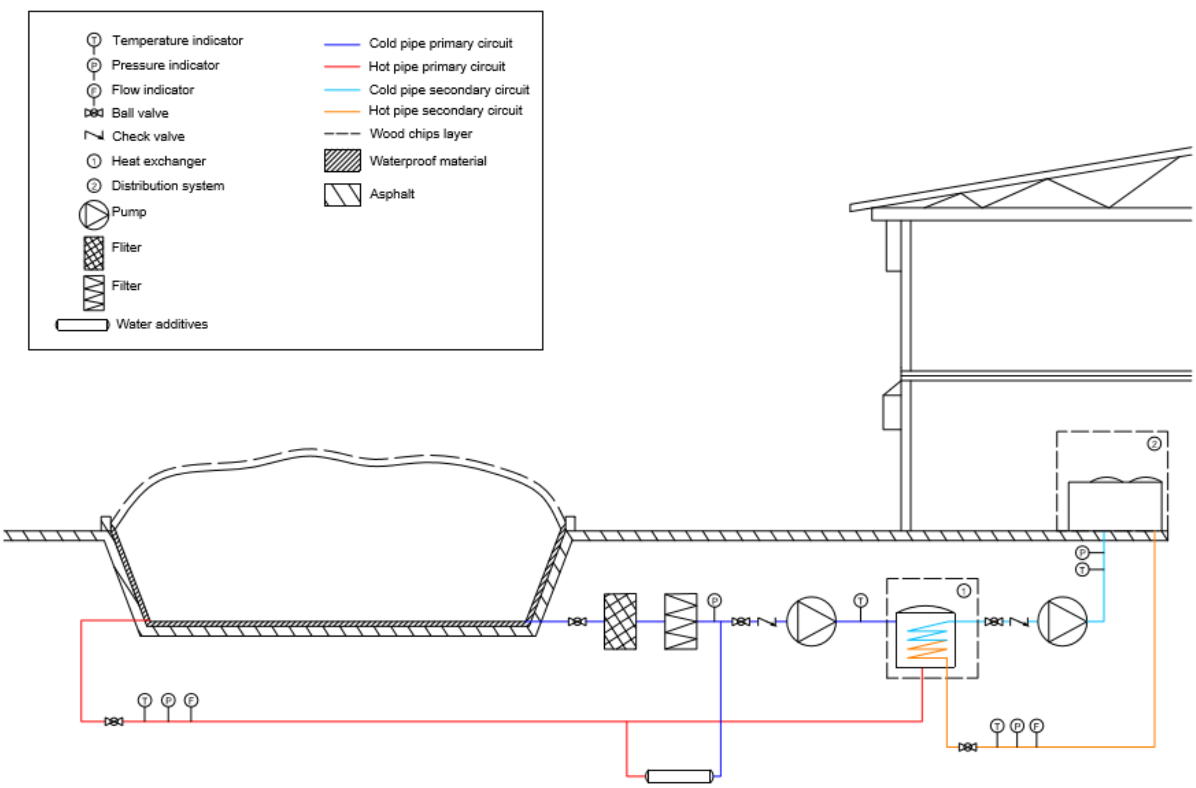


Figure 3. 8 Piping and Instrumentation Diagram

The first one is the circuit pumping the snowmelt from the deposit to the heat exchanger and returning the heated water to the pit. After the outlet valve, a first filter is needed for the sand, rocks or other solid that can damage the pump. The second filter is necessary to remove the impurities dissolved in the water such as salt, de-icing products or other particles. The water is stored in an insulated deposit that will act as a heat exchanger. A constant flow will keep the water inside the deposit at the same temperature.

Some additives must be applied to water in order to prevent corrosion of the pipes or the formation of bacteria such as legionella. It is a closed loop and on summer time, the days where the system is not performing, the water stuck in the pipes can reach ambient temperatures and there are big chances of formation of legionella, this is why chemicals and maintenance procedures are needed. A check valve is placed before the pump to prevent the damage of the instrumentation due to reflux and pressure, temperature and flow indicators are placed along the line.

The second circuit only disposes of a pump, indicators and valves. The cooling liquid flows through the heat exchanger absorbing the heat from the primary loop and returning to the distribution system. This project only analyzes the amount of energy and cooling power needed for the poultry house, and further studies would be necessary to analyze the inner cooling flow and design the energy distribution.

3.4 Economic study

The economic impact of this project can be observed from two different points of view. The first one would be assuming that the system is only replacing the excess of ventilation and economize the electricity consumed by the fans. The second point of view would be assuming that the broiler house needs a conditioning system to improve poultry welfare, in that case the SSS will be compared with a standard chiller system.

3.4.1 Ventilation

The building has 11 fans per stage and the total power of the ventilation system is 26.6 kW. Nevertheless, the fans are not always working at the nominal power, it depends on many factors such as the weather conditions, the size of the flock and most especially the day of the cycle. It is not easy to calculate the exact amount of electricity consumed by the fans since it is not reflected on the electric bills and the consumption of the fans depends on their performance.

Table 3.2 shows the performance of the fans by the percentage of its nominal power during a whole cycle. The data was provided by the owner of the broiler house, coming from the CPU. The rates go from 0% to 100% on the last weeks of the cycle, which means there is a period of time where ventilation could not enough to keep the ideal conditions. The total electricity consumption in a flock is 10,811 kWh. This value is obtained by multiplying the average percentage of ventilation per day by the nominal fan power.

Day	Temperature	Ventilation Min (%)	Ventilation Max (%)
0	31.0	0.0	4.8
3	29.5	0.0	4.8
7	29.0	1.5	4.8
14	26.5	3.0	25.0
21	25.5	5.0	50.0
28	23.0	6.5	90.0
35	13.0	6.0	90.0
42	13.0	8.0	100.0
56	26.5	9.0	100.0
57	20.0	9.0	100.0

Table 3. 2 Ventilation performance

With the SSS working the ventilation form day 42 to day 57 can be lowered down, however, even if the conditions inside are already correct a minimum amount of ventilation is needed to remove the CO_2 released by the chickens. As studied in section 3.1.3 the last 10 days the values of LHP increases more than 50%.

Quebec has the lowest energy rates in all North America. The current price of electricity for an installation like this in Quebec can oscillate from 7.62 to 9.9 cents/kWh depending on the conditions of the facility (Hydro Québec, 2019). Table 3.3 shows how the electricity bill would vary if the last two weeks the ventilation rate would be set at 50%. The SSS will save $230 per flock, that means $460 per year. However, the other electricity consumption due to pumps and other systems have to be taken into account. Only around $460 saving per year is too little margin to operate and invest in a cooling system.

	Energy consumed (kWh)	Price Electricity paid ($)
Without SSS	10,811	947.04
With SSS	8,184	716.95

Table 3. 3 Electricity consumed by fans per flock

3.4.2 Piping, pumps and excavation

As commented previously in Figure 3.7, the cooling days the SSS can melt around 10 m^3 of snow (0.75 m^3 of water). The model assumes that the cooling system will work 10 hours a day, which means a flow of 750 l/h. The pump can be working continuously at 750 l/h, intermittent 5 hours at 1500 l/h, only 3 periods of 3 hours at 2500 l/h, and so on. A further study should be taken in order to analyze the hydraulic system, the load losses and choose the exact pump, but a standard centrifugal pump with these features can cost around 200 – 500 $ and have a nominal power of 0.75 – 1.2 kW.

As commented before, a whole new study should be taken to specify the hydraulic performance, the construction procedures and the detailed cost of the whole system. However, some numbers have to be shown .The price of the piping installation can vary depending on the material, the length of the line, the diameter of the pipe and the excavation works needed for the facility. The fact that the liquid running through the pipes is going to be water at low temperature with some impurities with risk of freezing makes stainless steel an appealing option. Nevertheless, other cheaper options such as PVC or copper should be studied. The lines have to be insulated in order to reduce the heat losses, and polyurethane foam is the best choice for that purpose.

The average price offered for Quebecois companies to proceed with an excavation like the desposit studied (the standard prize for a pool with this size) can vary between 3,000 - 10,000$. The price depends on the exact dimentions of the deposit, the type of soil and the accessability of the site. Other procedures such as covering the deposit with concrete and insulation material can cost around 750 – 1100$.

Item	Min prices (CAD$)	Max prices (CAD$)	Average (CAD$)
Centrifugal pumps 12 Hp (x2)	300	1,000	650
Excavation work	3,000	10,000	6,500
Concrete plus insulation material	750	1,100	925
Indicators (thermometers, preassure, flow) (x10)	65	135	100
Piping and insulation foam	600	2000	1300
Valves (ball & check) (x7)	40	125	82.5
Water additives system	150	350	250
Water deposit	200	300	250
Wood chips	580	730	655
TOTAL	5,685	15,740	10,712.5

Table 3. 4 Preliminary economic approach

As the price of each item can vary in a wide range, different companies and providers have been compared. Table 3.4 shows an approximation of the maximum and minimum values found in the market. The overall price of the installation can cost around 10.712,5 C$ and that would mean a payback of around 20 years for the broiler house studied. This value is way too high to make this investment appealing. The fact that the ventilation system doesn't consume much electricity and the price of the electricity in Quebec is quite cheap doesn't leave much room for operations. Nevertheless, if the investment is seen as a necessity rather than an upgrade, the SSS offers way better prices and efficiency than conventional cooling systems. The current weather conditions and the increasing temperatures along the next years claims for the need of a cooling system in order to keep the welfare of the chickens.

3.5 The SSS in the USA

A further study could be done to implement this technology in the American poultry market. With similar conditions to Canada, some of the states in the USA have snowfalls on winter and harder temperatures on summer. Figure 3.9 shows the snow regions in USA.

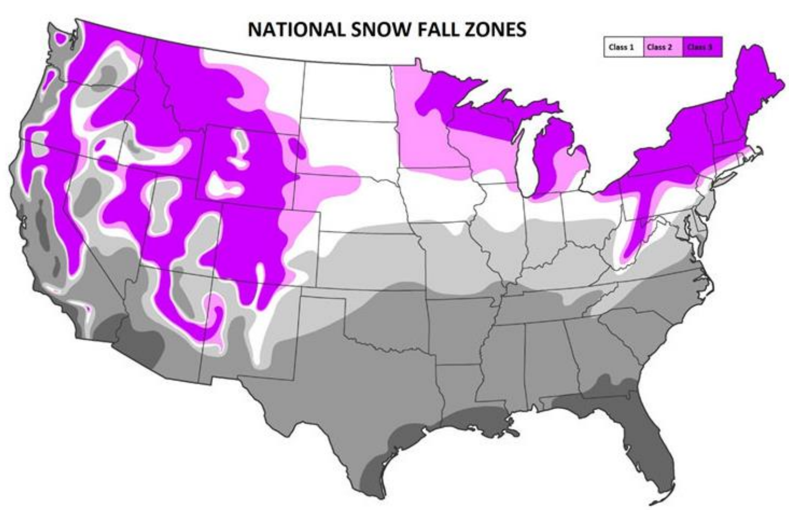
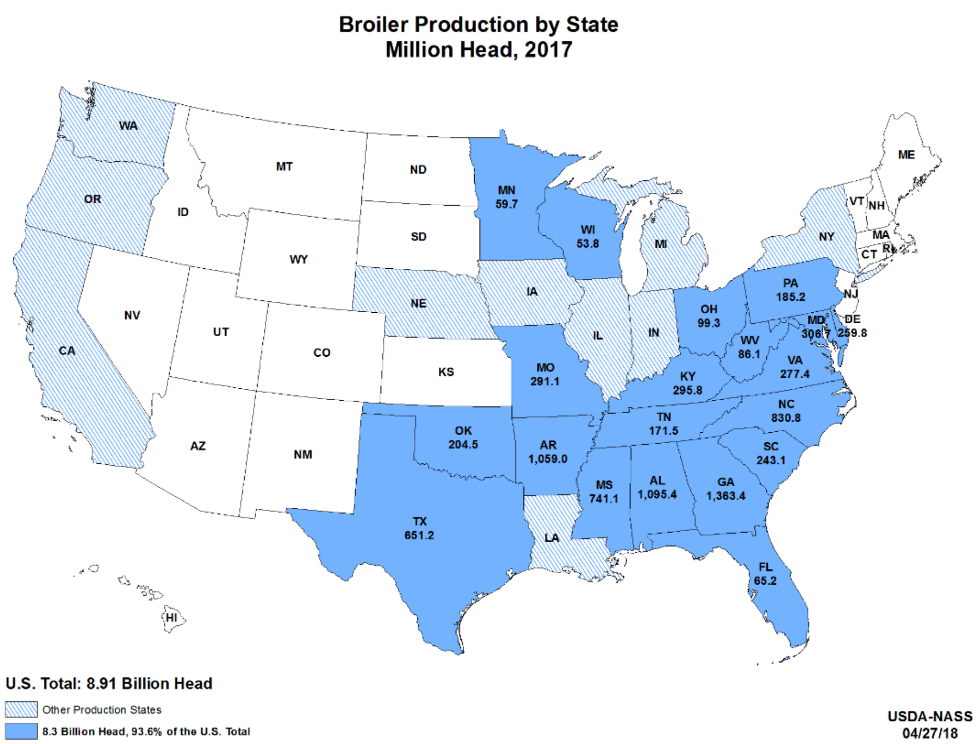


Figure 3.10 show the broiler production in USA by states (USDA-NASS, 2017). Overlapping the last two maps some interesting regions are appreciated. States like Minnesota, Pennsylvania, Wyoming or even West Virginia are regions that have snowfalls during the winter and a high broiler production among the USA. The electricity there is more expensive than in Canada, with values (in USD) around 12,3 cents/kWh in Wyoming, 14,38 cents/kWh in Pennsylvania or 14,09 cents/kWh in Minnesota.

Only by looking at these values it can be concluded that those states have a great potential for this technology. Lots of broiler houses are equipped with some sort of air conditioning system, and the replacement of these systems for SSS or implementing brand new SSS can be an interesting option.



CONCLUSION

Using seasonal snow for cooling purposes clearly has been proved to have more benefits than conventional cooling systems. Large SSS projects have been developed in countries like Sweden, Norway, Japan and China and the COP of the installations are 10 times higher than standard cooling facilities (Skogsberg, 2005). Nevertheless, the lack of research and popularity on this matter makes this technology go unnoticed among the other renewable energies. While Canada is a country with a great potential regarding snow storage technologies (Cipcigan et Michel, 2012) not a single significant SSS has been yet developed, and this project has proven the feasibility of a facility like this for southern Quebec conditions.

For sizing an installation, a MATLAB code has been developed to simulate the melting of a snow pile depending on the weather factors and the cooling load of a building (Annex I and Annex II). This project has validated and adapted this code to a broiler house placed in Quebec but it can be used to size a SSS for any other facility. For future projects, this code can provide the energy performance, the size needs and can be a great tool for designing a SSS installation.

After running a few simulations, it was demonstrated that one of the most important variables for the preservation of the snow pile is the thickness of the insulation layer. Values around 0.1 and 0.2 m have been proven to be enough, and for the sizing of the SSS the value has been set to 0.15 m. The density of snow has been set to 750 kg/m^3 since the snow will be mechanically compacted. The size of the facility has been set to 6x16x2x2 (WxLxDxH), with an initial volume of 256.12 m^3, consuming around 50 m^3 per flock and leaving 51 m^3 of snow at the end of the cooling season (September). That means that only the 39% of the snow stored will be used for cooling purposes while the 61% left will melt due to weather conditions. The cooling load needed has been calibrated adjusting the following variables: The LHP released by the chickens, the air temperature and the fan velocity, and 1,200 kWh of LHP are removed cooling period. The 50 m^3 snow of per flock can offer 1,500 kWh, a factor of 1.25 has been used for future contingencies.

It is shown that weather values will evolve on the following years towards a warmer climate. Over the next 30 years snow will not disappear from Canada but the summers will be warmer and in general the average temperature will increase. This scenario encourages in investing on this technology.

As for the economic impact, further studies have to be carried in order to determine the exact cost of the installation. Between a conventional cooling system and a SSS, this last one proves to be a better choice. Higher performance and efficient values and lower electricity consumption makes this technology the best option. The cooling system will provide better conditions and ameliorate chicken's welfare. However, it practically doesn't economize the ventilation system and the payback period is unappealing. As the temperature will grow on the following years, a cooling system will be more and more necessary. The investment will only be feasible when the owner of the facility decides that a cooling system is needed and choses the SSS over other systems.

To conclude, this project aims to research and study other renewable energies that are not yet developed, as the climate change will strike the energy market and renewable energies will play a very important role. Low carbon buildings and proper energy performances will be the key for sustainable societies.

ANNEX I

Matlab Code for the snowmelt

```
 %%%%%%%%%%%%%%%%%%%%%%%%%%%% SNOW MELT %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% This code simulates the snowmelt and volume variation of the SSS

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

close all;
clear all;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%    PROPERTIES     %%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


a = 6; % Short side [m]
b = 16; % Long side [m]
alpha_degrees = 60; % Slope angle below surface
beta_degrees = 45; % Slope angle above surface
d = 2; % Pit depth
h = 2; % Pile height
beta = beta_degrees * pi / 180;
alpha = alpha_degrees * pi / 180;

Dw = 1000;          % Density of water[kg m-3]
Ds = 750;           % Desnity of snow [kg m-3]
Ls = 334000;        % Latent heat onf fusion [J kg-1]
cw = 4185;          % Heat capacity [J kg-1 K-1]
lambda_i = 0.1;     % Sawdust thermal conductivity [W m-1 K-1]
lambda_g = 1;       % Ground thermal conductivity [W m-1 K-1]
thickness = 0.1;    % Insulation layer thickness

Prop = [a b alpha beta d h Dw Ds Ls cw lambda_i lambda_g thickness];
Prop0 = Prop;

aa = Prop(1);
bb = Prop(2);
dd = Prop(5);
hh = Prop(6);

filename1 = fullfile('Weather_Montreal_2018.xlsx');
Table_weather = xlsread(filename1); % Open Excel file
filename2 = fullfile('Birds_Data.xlsx');
Table_birds = xlsread(filename2); % Open Excel file
```

```
Geo = Geometry(Prop);
Vi = [Geo(1) + Geo(2)]  % Inital volume of snow
Vi0 = [Geo(1) + Geo(2)];  % Inital volume of snow

mass = Vi*Ds;
Vf = [0 0 0 0 0 0]';

Tair = Table_weather(:,6); % Diurnal air mean Temperature avobe freezing
point [°C]
Tmax = Table_weather(:,4);
P = Table_weather(:,7);    % Total Rain [mm]
s = size(Tair);

P(isnan(P)) = 0;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%    MAIN LOOP     %%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

birds_cycle(Table_weather);

% LOOP VARYING H WITH COOLING


for i = 1:s(1)

    Temp = Tair(i);
    Rain = P(i);
    day = i;

    [V_melt,V_melt0,V_surf,V_rain,V_ground,V_cool] =
Melted_Volume(Temp,Rain,Prop,day);

    Vf2(:,i) = [V_melt V_melt0 V_surf V_rain V_ground V_cool]';         %
New Volume of the pile

    Vnew2(i) = Vi - Vf2(1,i);

    Vi = Vnew2(1,i);

    h_new = height(Vnew2(i),Prop);      % New Height of the pile

    storeh(i) = h_new;

    Prop(6) = h_new;

end

% LOOP VARYING H WITHOUT COOLING
```

```
for i = 1:s(1)

    Temp = Tair(i);
    Rain = P(i);
    day = i;

    [V_melt,V_melt0,V_surf,V_rain,V_ground,V_cool] =
Melted_Volume(Temp,Rain,Prop0,day);

    Vf0(:,i) = [V_melt V_melt0 V_surf V_rain V_ground V_cool]';         %
New Volume of the pile

    Vnew0(i) = Vi0 - Vf0(2,i);

    Vi0 = Vnew0(1,i);

    h_new0 = height(Vnew0(i),Prop);  % New Height of the pile

    storeh0(i) = h_new0;

    Prop0(6) = h_new0;

end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%% PLOT FEATURES %%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%% PLOT FIGURE 1 %%%%%%%%%%%%%%%%%


f1 = figure('Name','1');
f1.WindowState = 'maximized';
subplot(2,1,1);
p1 = plot(storeh);
axis tight
grid on
legend('HEIGHT')
datetick('x','mmm')
ylabel('Height [m]');
p1(1).LineWidth = 1;

title({' ';'\fontsize{16} \rm SNOWMELT VOLUME'; ' '})

% PLOT SNOWMELT VARYING H

subplot(2,1,2)
p2 = plot(Vf2');
axis tight
grid on
```

```
legend('TOTAL', 'SURFACE', 'RAIN', 'GROUND', 'COOLING')
datetick('x','mmm')
ylabel('Volume [m^3]');
p2(1).LineWidth = 1;

%%%%%%%%%%%%%%%%% PLOT FIGURE 2 %%%%%%%%%%%%%%%%%


% PLOT SNOW PILE WITH COOLING

f2 = figure('Name','2');
f2.WindowState = 'Maximized';
grid on;
s = size(Vnew2);
i = 1;

while i < s(2)
    count = Vnew2(i);
    if count < 0
        break
    end
    i = i + 1;
end

if i == s(2)
    p3=plot(1:1:i,Vnew2);
    p3(1).LineWidth = 1;
else
    zero = i + 1;
    Vnew2TOP = Vnew2;
    Vnew0LOW = Vnew2;
    Vnew2TOP(zero:s(2)) = NaN;
    Vnew0LOW(1:i) = NaN;
    p3 = plot(Vnew2TOP);
    hold on
    col = get(p3,'Color');
    p4 = plot(Vnew0LOW,'--','Color',col,'HandleVisibility','off');
    p3(1).LineWidth = 1;
    p4(1).LineWidth = 1;
end

hold on;

% PLOT SNOW PILE WITHOUT COOLING


while i < s(2)
    count = Vnew0(i);
    if count < 0
        break
    end
    i = i + 1;
end
```

```
if i == s(2)
    p5=plot(1:1:i,Vnew0);
    p5(1).LineWidth = 1;
else
    zero = i + 1;
    Vnew0TOP = Vnew0;
    Vnew0LOW = Vnew0;
    Vnew0TOP(zero:s(2)) = NaN;
    Vnew0LOW(1:i) = NaN;
    p5 = plot(Vnew0TOP,'.');
    hold on
    col = get(p5,'Color');
    p6 = plot(Vnew0LOW,'--','Color',col,'HandleVisibility','off');
    p5(1).LineWidth = 1;
    p6(1).LineWidth = 1;
end


legend('Volume WITHOUT Cooling', 'Volume WITH Cooling');
title({' ';'\fontsize{16} \rm PILE VOLUME'; ' '});
datetick('x','mmm');
ylabel('Volume [m^3]');
f2 = gcf;
grid on;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%   FUNCTIONS   %%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% FUNCTION TO CALCULATE MELTED VOLUME

function [V_melt, V_melt0, V_surf, V_rain, V_ground, V_cool] =
Melted_Volume(Temp,Rain,Prop,day)

    a = Prop(1);
    b = Prop(2);
    alpha = Prop(3);
    beta = Prop(4);
    d = Prop(5);
    h = Prop(6);
    Dw = Prop(7);
    Ds = Prop(8);
    Ls = Prop(9);
    cw = Prop(10);
    lambda_i = Prop(11);
    lambda_g = Prop(12);
    thickness = Prop(13);

    % SURFACE MELT
```

```
    %    Insulated with wood chips

    if h > 0
      A = (a - 2*h/tan(beta)) * (b - 2*h/tan(beta)) + (h/sin(beta))*((2*a
+ 2*b) + 2*(a - 2*h/tan(beta)) + 2*(b - 2*h/tan(beta)))/2;
    else
      A = (a - 2*abs(h)/tan(alpha)) * (b - 2*abs(h)/tan(alpha));
    end

    % Ag = (d/3) * ( (a*b) +  (a - 2*d/tan(alpha)) * (b - 2*d/tan(alpha))
+ sqrt((a*b)*(a - 2*d/tan(alpha)) * (b - 2*d/tan(alpha))));
    Ag = (a - 2*d/tan(alpha)) * (b - 2*d/tan(alpha)) +
(d/sin(alpha))*((2*a + 2*b) + 2*(a - 2*d/tan(alpha)) + 2*(b -
2*d/tan(alpha)))/2;

    if Temp <= 0
        Q_surf = 0;
    else
        Q_surf = A * (lambda_i / thickness) * (Temp); % Thermal flow [W]
    end

    v_surf = Q_surf / (Ls * Ds);  % [m3 s-1]
    V_surf = v_surf * (3600 * 24); % [m3 day-1]


    % RAIN MELT

    V_rain = ((Rain/1000) * A * Dw * cw * (Temp)) / (Ls * Ds); % P[m],
T[K], cs [J kg-1 K-1]

    % GROUND MELT

    Q_ground = lambda_g * Ag * (2); % Thermal flow [W]
    v_ground = Q_ground / (Ls * Ds);    % [m3 s-1]
    V_ground = v_ground * (3600 * 24); % [m3 day-1]

    % SNOWMELT FOR COOLING

    if day == 177 | day == 225
        V_cool = 0.01 * 200;
    elseif day == 178 | day == 226
        V_cool = 0.015 * 200;
    elseif day == 179 | day == 227
        V_cool = 0.020 * 200;
    elseif day == 180 | day == 228
        V_cool = 0.025 * 200;
    elseif day == 181 | day == 229
        V_cool = 0.030 * 200;
    elseif day == 182 | day == 230
        V_cool = 0.035 * 200;
    elseif day == 183 | day == 231
        V_cool = 0.040 * 200;
    elseif day == 184 | day == 232
```

```
        V_cool = 0.045 * 200;
    %elseif day == 185 | day == 233
        %V_cool = 0.050 * 200;
    else
        V_cool = 0;
    end


    % TOTAL SNOWMELT

    V_melt = V_surf + V_rain + V_ground + V_cool;
    V_melt0 = V_surf + V_rain + V_ground;

end

% FUNCTION TO CALCULATE DIMENSIONS OF THE PILE

function Geo = Geometry(Prop)

    a = Prop(1);
    b = Prop(2);
    alpha = Prop(3);
    beta = Prop(4);
    d = Prop(5);
    h = Prop(6);

    % VOLUME

    Vol_surf = (h/3) * ( (a*b) +  (a - 2*h/tan(beta)) * (b -
2*h/tan(beta)) + sqrt((a*b)*(a - 2*h/tan(beta)) * (b - 2*h/tan(beta))));
    Vol_below = (d/3) * ( (a*b) +  (a - 2*d/tan(alpha)) * (b -
2*d/tan(alpha)) + sqrt((a*b)*(a - 2*d/tan(alpha)) * (b -
2*d/tan(alpha))));
    Vol_tot = Vol_below + Vol_surf;

    % AREA

    a_surf = (a - 2*h/tan(beta)) * (b - 2*h/tan(beta)) +
(h/sin(beta))*(2*a + 2*b + 2*(a - 2*h/tan(beta)) + 2*(b -
2*h/tan(beta)))/2;
    a_below = (a - 2*d/tan(alpha)) * (b - 2*d/tan(alpha)) +
(d/sin(alpha))*((2*a + 2*b) + 2*(a - 2*d/tan(alpha)) + 2*(b -
2*d/tan(alpha)))/2;

    Geo = [Vol_surf Vol_below Vol_tot a_surf a_below];
end

% FUNCTION TO CALCULATE THE HEIGHT OF THE PILE FOR A GIVEN VOLUME

function h_new = height(V,Prop)

    a = Prop(1);
```

```
    b = Prop(2);
    alpha = Prop(3);
    beta = Prop(4);
    d = Prop(5);


    Vol_below = (d/3) * ( (a*b) +  (a - 2*d/tan(alpha)) * (b -
2*d/tan(alpha)) + sqrt((a*b)*(a - 2*d/tan(alpha)) * (b -
2*d/tan(alpha))));

    if V > Vol_below

        Vol_matrix = [0];

        h_max = tan(beta) * a / 2;
        h_max = h_max * 50;

        for i = 1:h_max

            h = i/100;
            Vol = (h/3) * ( (a*b) +  (a - 2*h/tan(beta)) * (b -
2*h/tan(beta)) + sqrt((a*b)*(a - 2*h/tan(beta)) * (b - 2*h/tan(beta))));
            Vol_matrix(i) = Vol;

        end

        [r,m,b] = regression(1:h_max,Vol_matrix);
        h_new = (V - Vol_below) / (m*100);

    else

        Vol_matrix = [0];

        d_max = tan(alpha) * a / 2;
        d_max = d_max * 50;

        for i = 1:d_max

            d = i/100;
            Vol = (d/3) * ( (a*b) +  (a - 2*d/tan(alpha)) * (b -
2*d/tan(alpha)) + sqrt((a*b)*(a - 2*d/tan(alpha)) * (b -
2*d/tan(alpha))));
            Vol = Vol_below - Vol;
            Vol_matrix(i) = Vol;

        end

        [r,m,b] = regression(1:d_max,Vol_matrix);
        h_new = -(V-Vol_below)/(m*100);

    end
```

```
end


function birds_cycle(Table_weather)

    Temp_in = [31];
    day = 1;
    for k = 1:7

        end_day = day + 37;

        for i = day:end_day
            j = i + 1;
            Temp_in(j) = Temp_in(i) - 0.26;
        end

        day = end_day + 1;
        rest = day + 14;

        for r = day:rest
            Temp_in(r) = Table_weather(r,4);
        end

        Temp_in(rest) = 31;

        day = rest;
    end

end
```

ANNEX II

Matlab Code for chicken heat production

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%% BIRDS DATA %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% This code plots heat and power release of the birds

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


close all;
clear all;

filename1 = fullfile('Birds_Data.xlsx');
filename2 = fullfile('Weather_Montreal_2018');
T1 = xlsread(filename1); % Open Excel file
T2 = xlsread(filename2); % Open Excel file

f1 = figure;
p1 = plot(T1(:,1),T1(:,3));
hold on
p2 = plot(T1(:,1),T1(:,4));
hold on
p3 = plot(T1(:,1),T1(:,5));
grid on

legend('THP(kW)','LHP(kW)','SHP(kW)')
ylabel('Power per stage [kW]')
%datetick('x','dd')
xlabel('Hours')

Temp_in = [31];
day = 1;

for k = 1:7

    end_day = day + 37;
    for i = day:end_day
        j = i + 1;
        Temp_in(j) = Temp_in(i) - 0.26;
    end

    day = end_day + 1;
    rest = day + 14;

    for r = day:rest
        Temp_in(r) = T2(r,4);
```

```
    end

    Temp_in(rest) = 31;

    day = rest;
end


f2 = figure;

plot(T2(:,4))
hold on

p4 = plot(Temp_in);
grid on

ylabel('Temperature [°C]');
xlabel('days');
p4(1).LineWidth = 0.8;
legend('Temperature OUTSIDE', 'Temperature INSIDE');
title({' ';'\fontsize{16} \rm BUILDING TEMPERATURES'; ' '});

THP = T1(:,3);
SHP = T1(:,4);
LHP = T1(:,5);
```

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