CHALMERS
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Energy systems for an artificial cross-country skiing tunnel

With focus on snow quality and system boundaries

Master's thesis in Sustainable Energy Systems

SOFIE FREDHEIM

Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
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Sofie Fredheim

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SOFIE FREDHEIM

Supervisor: Mårten Everbrand, Sweco Systems
Examiner: Jan Gustén, ACE Building Services Engineering

Master's Thesis 2019:ACEX30-19-78
Department of Architecture and Civil Engineering
Division of Building Services Engineering
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

The system of an indoor skiing tunnel was first defined with a figure and than simplified in to three points; cooling, gains and losses for the surrounding air and lastly the amount of snow added to the system. Then the snow quality that was defined the best snow quality was snow at around 0.4 g/dm^3. three study visits where done to get a better under standing of the operating and running of tree different tunnels in Gothenburg, Torsby and Gällö. From the study visits it was found that the tunnels were barely ventilated and that air leakage was the biggest contributer to the heating of the tunnels. Then the seasonal climate was defined. And the duration of hours that the different conditions lasted every year in the mollier chart. From this It was found that that the heat loss due to an air leakage of 1 m/s^2 the heat gain to the system is approximately 24000 kWh/year. With this it was found that the energy needed to replace the snow in the different skiing tunnel was in the range between 120-145 MW. The conclusion drawn form this is that the this area need more research on the are of snow quality in indoor skiing tunnel and with conditions will make the snow to last longer. The skiing tunnels are a perfect place because of its controlled conditions to do this.

Keywords: Indoor skiing tunnel, snow quality, air conditions in Mollier.

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From MidSweden I would like thank Barbro, Veronica and Jens for showing me around and welcoming me. Form Torsby skidtunnel i would like to thank Anna L och Oscar for the warm wellcome and ansering my questions. Erik Melin Söderström from Peak inovation for take time of from his perantel leav to have a meeting with me. Jonas Braam fro the Swedish skiing association for been assailable to answer the questions i had on email.

Sofie Fredheim, Gothenburg, October 2019

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1 Introduction

This chapter presents the description of the project and the limitations and delimitation that where used.

1.1 Project description

In this project the student will evaluate the running and operation of cooling and heating systems in a building with an artificial tunnel for cross country skiing with high cooling demand and if the use of access heating in both a sustainable and an economy profitable way Who does the operating personnel handles and operate the system will also be looked in to do they run it by trying to save the day or with a tactical plan with the future in mind. If possible other similar buildings will be evaluated and cooperated.
The cooling possess and the system temperatures will be looked at to see if they are the optimum operation temerature. Recycling of heat and cooling in the building internally and with the district heating system or the geothermal heat pump to recharge or use.

1.2 Limitations and delimitations

The thesis is limited to the boarders of Sweden but some of the literature study was preformed by looking into other countries. The thises is allso limetied to inndoor skiing for cross country skiing så indoor skiing for alpine skiing was not looked at.

2
Theory

In the following sections the theory found in the literature study is presented.

2.1 The System

From the literature study andt the study vistits it was found that the optimum system of and indoor skiing tunnel will look something similar to figure 2.1. The figure is showing how an theoretical optimal designed system for an indoor skiing hall. The system of an indoor skiing hall consist of everything that can be seen in figure 2.1. The arrows in the drawing shows the heat in red, and the blue arows are transportation of air. The System also have losses and gain through the building envelope that will be different whit the different summer and winter conditions.

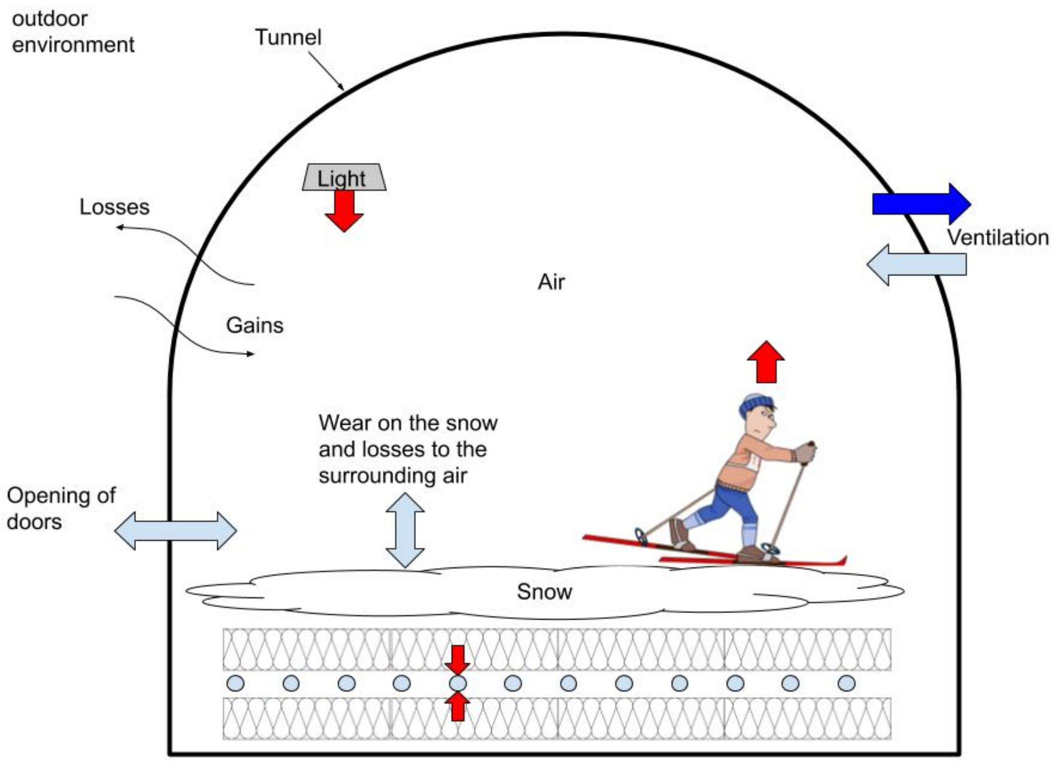

Figure 2.1: A drawing of an indoor skiing hall and the system interactions.

As mentioned he figure 2.1 illustrates what the total system of an indoor skiing tunnel will look like. To make some simplifications of this in the system the heat gain form lighting and from people will be assumed to on value per square meter. The ventilation is neglected because the aoumt of air nnede to the changed whit fresh air is so low because of the amout of people. Also the losses and gains through the building envelope is neglected. The losses and gains that comes from the opening and closing of doors is neglected. This assumtions turns the fugure 2.1 to the figure 2.2.

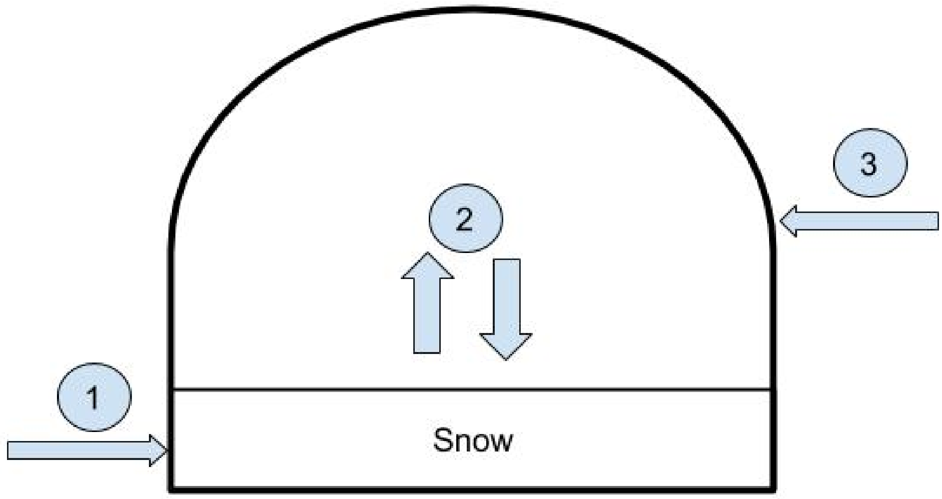

Figure 2.2: The simplifications that are done to the system.

The figure 2.2 Shows what the report will be limited to. Below is a an explemation for the numbering in the figure.

1. The cooling from the cooling masking
2. The gains and losses to the surrounding air.
3. The amount of snow that has to be added to the system.

Futher explemnation of the diffrent points: **Point 1.** Is the cooling added to the system the cooling machine is assumed to provide the the needed cooling demand at all times.

Point 2. Consists for at the internal gains assumed to be one value per square meter. **Point 3.** Is the snow that needs to be added to the system from the snow machine or snow storgage to keep the quality.

2.2 The cooling system of an indoor skiing tunnel

Below are tow figures showing two diffrent ways a system can be designed. In figure 2.3 cooling by ventilation air and figure 2.4 cooling by cooling machines.

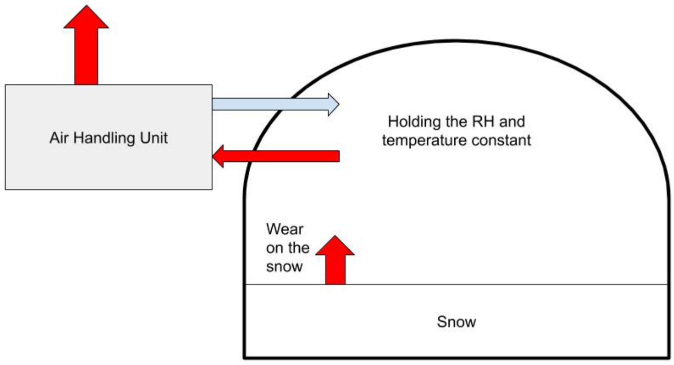

Figure 2.3: The system of an indoor skiing tunnel where cooling is done bye ventilation.

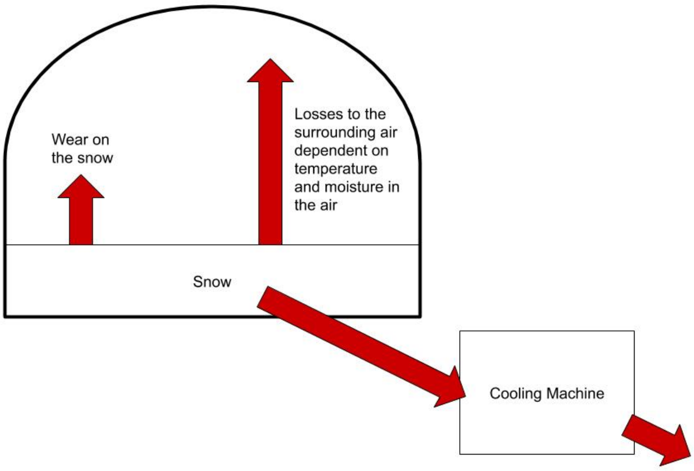

Figure 2.4: The system of an indoor skiing tunnel where cooling is done bye cooling machines.

2.3 Snow quality

With snow quality it is meant the best possible conditions of snow for the best performance of skiing and the lowest losses do to melting. Form the Norwegian department of culture "kulturdepartamentet" it was found that the climate of the area the snow exist in will affect the snow quality. Snow at 40 cm deep with a weight of 0.4 kg/l with a wet bulb temperature of -4 °C. And lastly that snow needs 150h to settle. They also say that the opium is at 0.3 to 0.4 g/dm^3 [2] From the Swedish Ski Association, they have a Scale on snow quality that goes from 1-9 where 1 is dry and 9 is almost rain. They say that the optimum is between 4-5 but they are missing a definition on what that mean. [3] From a company named Technoalpin Nordic AB they said that the optimum snow quality is 380-400 kg/m^3 [4] They all have similar values and the one thing that everyone agrees on is that snow quality is important for the preferences of the snow.

3
Methods

The following sections explains how the master thesis was conducted. First a litterateur study was executed then a study visit to Prioritet Serneke Arena, Torsby Skidtunnel & sportsenter, and MidSweden365. Together with the literature study different persons in the Swedish ski assassination was contacted. From this information the basics of a indoor skiing facility and the basic reason to how the system should be designed to reach the best snow quality was achieved. From the literature study and study visits a system drawing was sketched, see Section 2.1. Other universities in Sweden with Arctic science and research centers focusing on snow was contacted.

3.1 Literature study

The fist a literature study was preformed, where articles on similar buildings and designs where gathered. It did not take long before the realization that there was not a lot of published material on snow, snow quality and indoor skiing tunnels with a design temperature of below 0 degrees indoors. The tooles used to fin rescuers on the subject was Goggle Scholar, Chalmers library and Luleå university library, form Chalmers library and Luleå university library it was searched for bachelor and master thesis on the subject. Another source of information was gatheed by email by finding the right people that is sitting on the information needed. The results from the literature study is presented in the chapter 2 Theory.

3.2 Study visit

Thees are the different ski tunnels that have been visited to gather information about the operation, design principles and handling of the tunnels when it comes to temperature, relative humidity, snow making, and strategies on keeping the snow the best posible quality for cross country skiing. The indoor skiing tunnels where; Skidome in Prioritet Serneke Arena in Gothenbug, MidSweden365 at Gällö outside of Östersund, and Tosby skidtunnel & sportsenter in Torsby.

3.2.1 Torby skidtunnel & spotscenter

Torby skidtunnel & sportscenter was completed in 2006 and is about 1.3 km (1,287 m) it is constructed of concrete tunnel with a radius of 4m that has soil on top of the concrete to insulate. [5]

The system temperature is between 0 to -3 degrees. The tunnel opens late spring and closes in February to remove and replace the snow, this process takes a few months. The snow for the tunnel is created outside with snow making cannons then brought inside in February/March when the tunnel is closed. The tunnel even offers biathlon and has a elevation difference of 12 m.

Figure 3.1: Tunnel openings.

The tunnel is equipped with 8 different air handling units with their own air intake and air outlet and plate heat exchanger that can be seen in figure 3.2

Figure 3.2: Airhandling unit Torsby.

3.2.2 MidSweden365

MidSweden365 is a indoor skiing tunnel placed inside a mountain in an old military base where a small part of the tunnel is outside of the mountain to connect the different side of the tunnel in the mountain, this is on the south side of the tunnel. MidSweden365 is the newest of the tunnels that where visited it opened last year (2018) ringth now they have never changed the snow they have inside the tunnel.[6] The snow making plan is to make the snow outside in a pile with snow machines in January and then move it indoor in February/Mars. The the snow will be transported to the inside where they fist will remove five to seven centimeters of snow and replace it with the new one, this is similar to how it is done in Torsby. Then the snow will rest on one week to be able to settle down before the reopen the tunnel. The have thermostats in the snow always checking the temperature of the snow. They have one air handling unit for the fresh air supply, this is controlled by a couple of CO2 sensors inside the tunnel. If no new air is needed the air in the tunnel is recirculated. [7] Firgure 3.3 shows the inside of the tunnel with cooling batteries hanging in the cealing.

Figure 3.3: The inside of the MidSweden tunnel in side the mountain.

3.2.3 Skidome Prioritet Serneke Arena

The Skidome is different from the other indoor skiing tunnels in a way that is it not really a tunnel more like a skiing hall. It is located in Prioritet Serneke Arena is indoor skiing hall, see figure 3.4, on 10,000 m^2 inside a 43,000 m^2 building consisting of two schools, shops, a football field amongst others. [8]

Figure 3.4: The inside of the Skidome inside Prioritet Serneke Arena.

The snow making principle is make to make snow in a cyclone on the outside then added to the snow inside once a year to change the snow. See figure 3.5

(a) Left side where you can see the snow intake.

(b) Rigth side

Figure 3.5: The cyclone that makes the snow outside the Skidome.

3.3 Calculations

To make the calculations summer, winter and fall/spring was defined using the information from SMHI.[9] Form this it was assumed that all the conditions areas that was above 10 dergees was summer, every one that is between the temperatures 0 and 10 is fall/spring and the conditions areas under 0 degree is considered to be winter. See the blue lines in figure 3.6. The firugre is origanaly from "VVS handboken, tabeller och diagram"[Swedish] see Appendix A, then altered by putting in the blue lines defining the seasons.

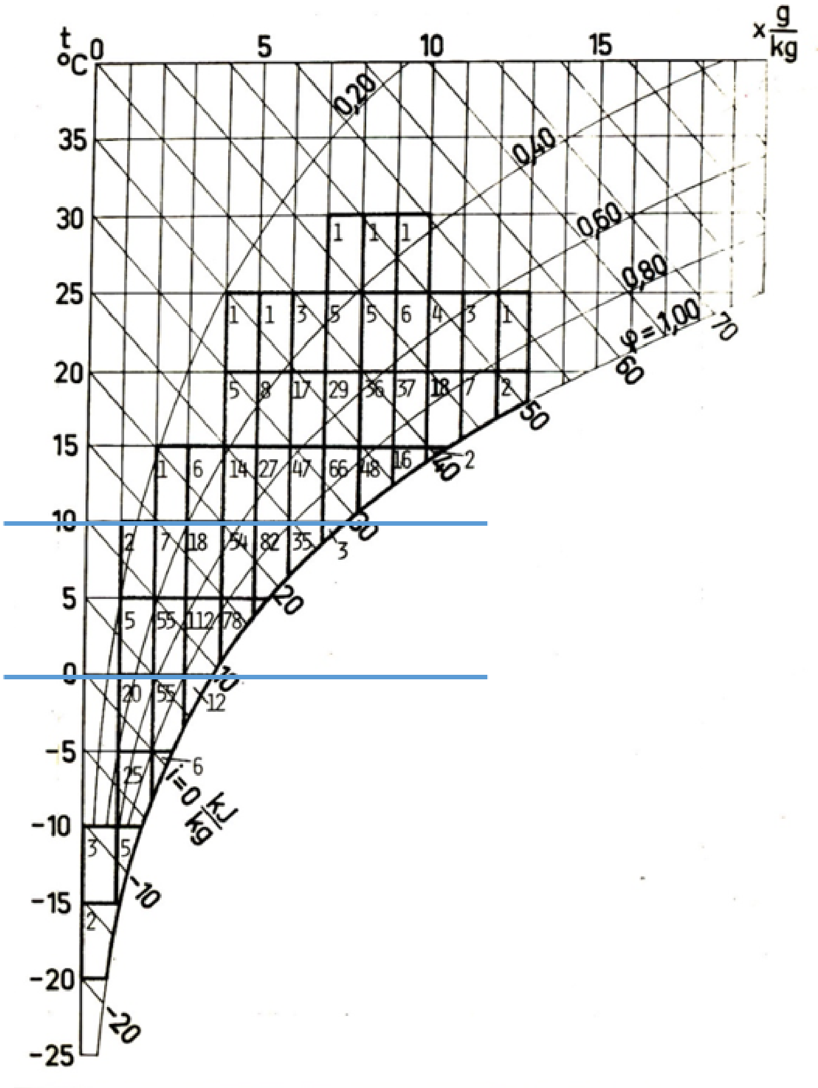

Figure 3.6: Mollier diagram with seasonal definition, above 10 degrees is summer below 0 degrees is winter and between 0 and 10 degrees is fall/spring [9].

After the seasons was defined the duration area boxes with less than 10 hours duration was neglected or merged together.See figure 3.7. All the temperatures below -5 was neglected since this is the lowest temperature the indoor skiing tunnel have an air leakage below this temperature will have an cooling effect and not contribute to heating or melting the snow.

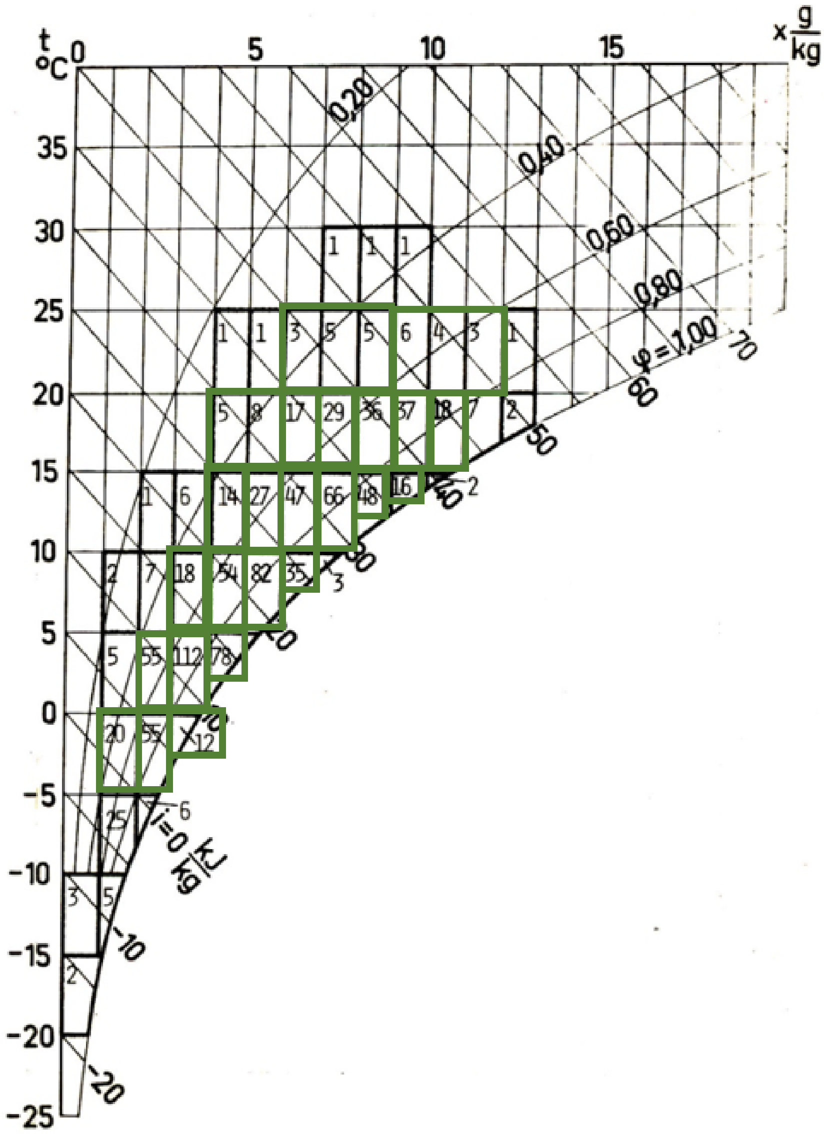

Figure 3.7: The duration area boxes used in the calculation.

The equation used to calculate the energy needed to be removed from the system because of air leakage can be seen below in eqation 3.1. The air leakage will be sett to 4 different volume flows of 1,2,3 and 4 m^3/s, to mark the importance of avoiding air leakage due to opening och doors and leakage of the building shell.

$$Q = \rho * \dot{V} * \Delta h \tag{3.1}$$

Where:
ρ is assumed to be 1.2 for all the temperatures in kg/m^3
$\dot{V}$ is the different volume flows {1,2,3,4} in m^3/s
Δ h is the difference in the entalpy between the air leaking in and the snow in kJ/kg

To do this calculation the quality of snow needed to be defined in the mollier diagram. From the section on Snow Quality 2.3 the condition of what the snow should be is marked in the red area in the figure 3.8.

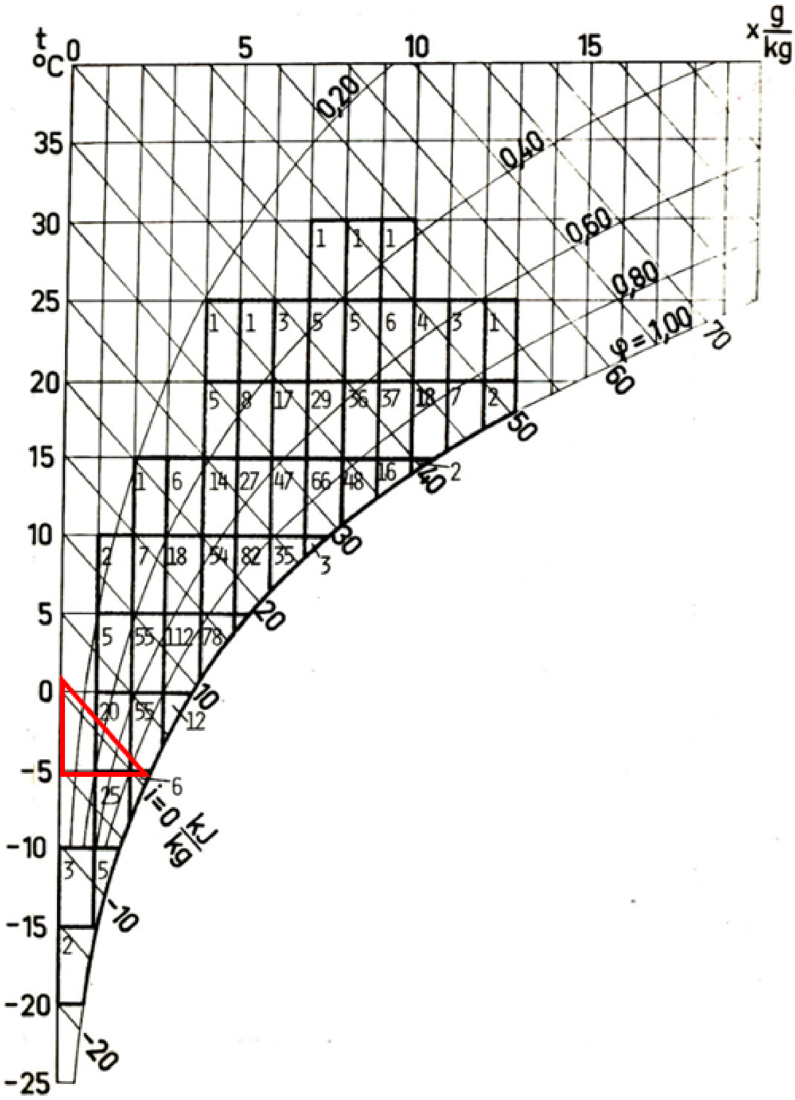

Figure 3.8: Snow quality marked in the red triangle in the Mollier diagram.

4
Results

From the literature study and the site visits it was found that there is not a lot of knowledge about the snow quality among the people working with the skiing tunnels. The knowledge about the cooling system was better. The people working in the tunnels in Torsby was trying to work out how to improve the cooling system and they have not looked into the optimum conditions to keep the snow quality optimum they looked more in to the energy savings and cost savings.

4.1 Results from the calculation

The different areas with different conditions the area is then assumed to be the condition in the middle of the square for the duration that is given i the square. See figure 4.1

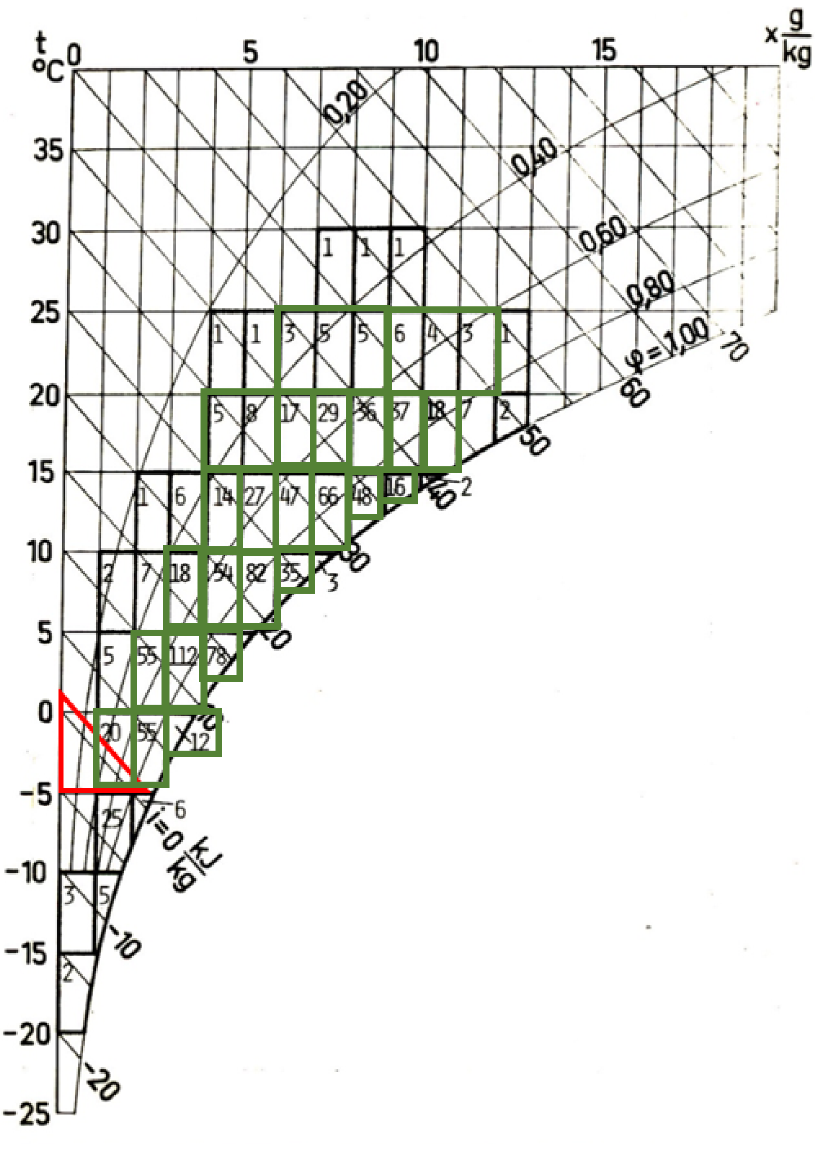

Figure 4.1: Caption

The from the figure 4.1 the tables and the equation 3.1 the results are presented in the tables 4.1-4.7 The summer case i presented in table 4.1-4.2

Table 4.1: Results of heat gain in the system for the different time duration in the summer case.

	Time [h]	Temp [°C]	RH [%]	H [kJ/kg]	H Snow []	rho [kg/m^3]	V [1m^3/s]	Q [kW]	Q [kWh]
	13	22,5	63	49	1,3	1,2	1	57,24	744,12
	13	22,5	45	42	1,3	1,2	1	50,4	655,2
	18	17,5	84	43,5	1,3	1,2	1	52,2	939,6
	37	17,5	75	40,5	1,3	1,2	1	48,6	1798,2
	36	17,5	70	39	1,3	1,2	1	46,8	1684,8
	29	17,5	61	36	1,3	1,2	1	43,2	1252,8
	17	17,5	52	34	1,3	1,2	1	40,8	693,6
	13	17,5	40	30	1,3	1,2	1	36	468
	16	14	97	38	1,3	1,2	1	45,6	729,6
	48	13,5	90	35	1,3	1,2	1	42	2016
	66	12,5	82	31	1,3	1,2	1	37,2	2455,2
	47	12,5	73	28	1,3	1,2	1	33,6	1579,2
	27	12,5	61	26	1,3	1,2	1	31,2	842,4
	14	12,5	52	24	1,3	1,2	1	28,8	403,2
total	394								16261,92

For the summer scenario with different flows will lead to the gain presented in table 4.2.

Table 4.2: The summer case with diffrent flows.

	V m/s	**Q kWh**	**V m/s**	**Q kWh**	**V m/s**	**Q kWh**
	2	1488,24	3	2232,36	4	2976,48
	2	1269,84	3	1904,76	4	2539,68
	2	1823,04	3	2734,56	4	3646,08
	2	3480,96	3	5221,44	4	6961,92
	2	3257,28	3	4885,92	4	6514,56
	2	2415,12	3	3622,68	4	4830,24
	2	1334,16	3	2001,24	4	2668,32
	2	895,44	3	1343,16	4	1790,88
	2	1409,28	3	2113,92	4	2818,56
	2	3882,24	3	5823,36	4	7764,48
	2	4704,48	3	7056,72	4	9408,96
	2	3011,76	3	4517,64	4	6023,52
	2	1600,56	3	2400,84	4	3201,12
	2	762,72	3	1144,08	4	1525,44
Total kWh		31335,12		47002,68		62670,24

The results for the fall/spring case is presented in table 4.3- 4.4

Table 4.3: The resutls for the fall/spring case.

	Time [h]	Temp [°C]	RH [%]	H [kJ/kg]	H Snow []	rho [kg/m^3]	V [1m^3/s]	Q [kW]	Q [kWh]
	35	9	95	25	1,3	1,2	1	28,44	995,4
	82	8	87	22	1,3	1,2	1	24,84	2036,88
	54	7,5	70	18	1,3	1,2	1	20,04	1082,16
	18	7,5	58	16	1,3	1,2	1	17,64	317,52
	78	4	91	15	1,3	1,2	1	16,44	1282,32
	112	2,5	80	11	1,3	1,2	1	11,64	1303,68
	55	2,5	59	9	1,3	1,2	1	9,24	508,2
tot	434								7526,16

The fall/spring case results with different flows is presented in the table 4.4.

Table 4.4: The results for the fall/spring case with different flows.

	V m/s	Q kWh	V m/s	Q kWh	V m/s	Q kWh
	2	1990,8	3	2986,2	4	3981,6
	2	4073,76	3	6110,64	4	8147,52
	2	2164,32	3	3246,48	4	4328,64
	2	635,04	3	952,56	4	1270,08
	2	2564,64	3	3846,96	4	5129,28
	2	2607,36	3	3911,04	4	5214,72
	2	1016,4	3	1524,6	4	2032,8
Total		15052,32		22578,48		30104,64

The winter case results is presented in the tables 4.5-4.6. The winter results have some negative number when the entalpi ended up being less than the entalpi to snow. Thees results is the neglected in the total results for the year presented in the table 4.7 and figure 4.2

Table 4.5: Winter case.

	Time [h]	Temp [°C]	RH [%]	H [kJ/kg]	H Snow []	rho [kg/m^3]	V [m^3/s]	Q [kW]	Q [kWh]
	12	-2,5	90	4,5	1,3	1,2	1	3,84	12
	55	-2,5	80	4	1,3	1,2	1	3,24	55
	20	-2,5	50	1	1,3	1,2	1	-0,36	20
	25	-7,5	70			1,2	1	0	25
Total	87								87

The winter case with different volume flows to the air leakage is presented in the table 4.6

Table 4.6

	V m/s	Q kWh	V m/s	Q kWh	V m/s	Q kWh
	2	92,16	3	138,24	4	184,32
	2	356,4	3	534,6	4	712,8
	2	-14,4	3	-21,6	4	-28,8
Total		448,56		672,84		897,12

The total heat gain from air leakage is presented in the total 4.7 and the figure 4.2

Table 4.7: Total heat gain to the system of one year with the different volume flows.

Velocity [m/s2]	*1*	*2*	*3*	*4*
Total heat added [kWh/year]	23875.08	46836	70254	93672

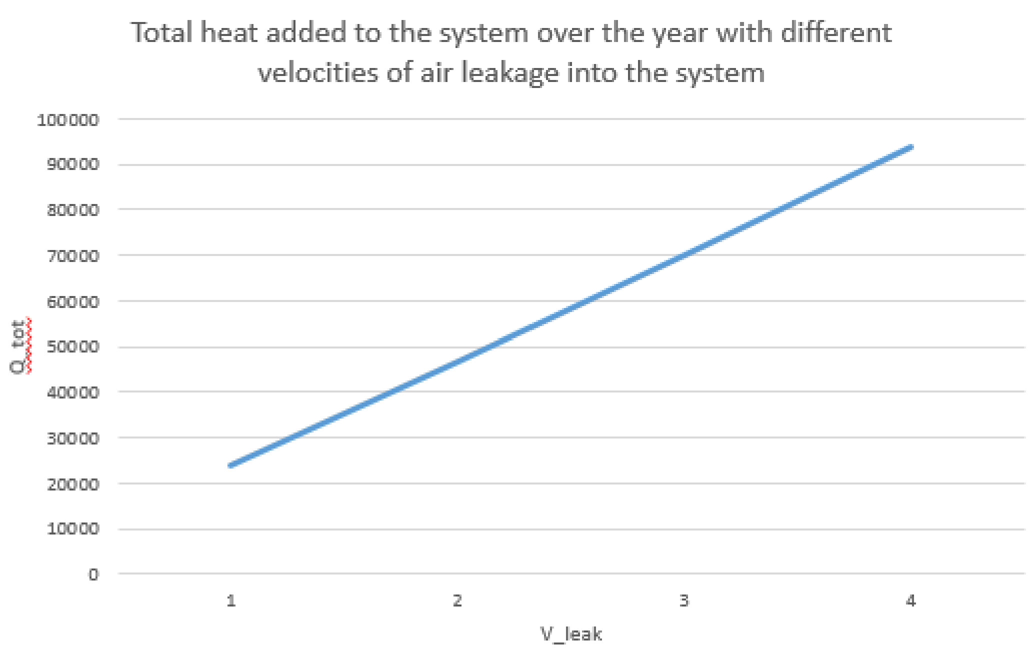

Figure 4.2: Total heat added to the system over the year with different velocities of air leakage into the system.

Because of this gain the snow will have to be replaced. 0.07m is because that is how much a snow preparation machine can remove with its plow. [10] The measurements is presented in table 4.8

Table 4.8: The measurements of the different tunnels

Depth	0,07	m
Width	8	m
Length		
MidSweden	1400	m
Torsby	1287	m
Skidome	1200	m

From the measurements in table 4.8 the volume of snow removed is calculated and presented in table 4.9

Table 4.9: The volume of snow that is removed from the tunnels and will need replacing.

Volume of Snow Removed		
MidSweden	784	m3
Torsby	720,72	m3
Göteborg	672	m3

To the turn this volume into energy a T-Q graph was used, see figure 4.3, the water entering the snow making machines was assumed to be cooled from 10 to -5, the temperature of the snow, from the graph is was be read that this takes Δ Q/m $\approx$ 110 cal/g $\approx$ 461 W/kg to make the water into snow. It is important to note that the results in table 4.10 is only the assumed energy to cool the water and energy need for the snow makers and pumps are excluded.

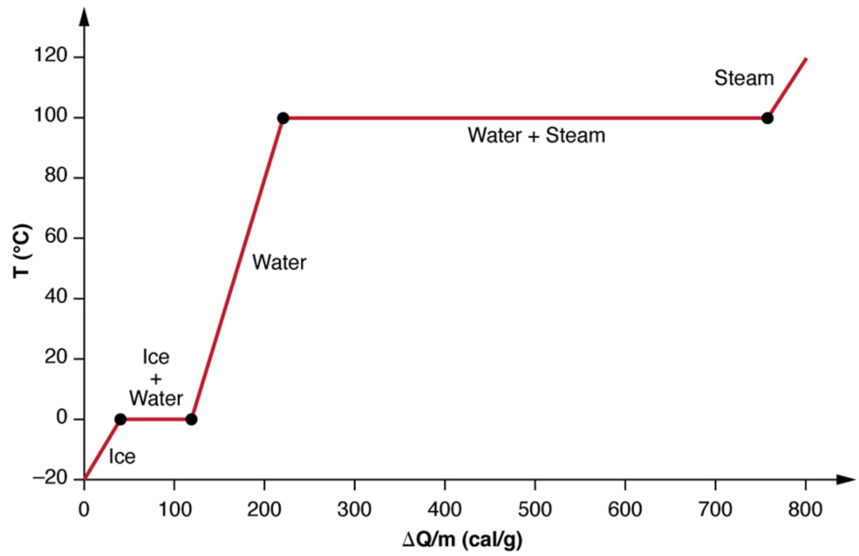

Figure 4.3: T-q graph for water [1]

Results for the energy needed in the different tunnels to cool the water to the temperature of the snow.

Table 4.10

Energy needed to replace removed snow*		
MidSweden	144.6	MW
Torsby	132.9	MW
Skidome	123.9	MW

5 Conclusion

Form the results on the energy needed to replace the snow it can be concluded that the snow quality in the tunnels is a big contributor to energy usage. Because of this and because good snow quality should be one of the main point in having a snow tunnel. Snow quality in a tunnel for indoor skiing should be the biggest priority. The tunnels system should then be designed for to hold conditions that are favorable for the snow. The operation of thees indoor skiing facilities should be designed to keep the optimum snow quality with the lowest energy use.

From this results it is shown that reduce the air leakage into the tunnel will give energy savings. If ventilation is used to control the RH and the temperature in the tunnel then it may not have the same effect on the system as researched in this report.

Since snow quality have not been researched on a lot this should be a research area. There a many facilities for indoor snow skiing so now is a good time to research the different climates of snow and see how the snow behaves under different conditions. The tunnels are a perfect place to research on snow quality because of its controlled conditions. Further research on how to not lose snow in the tunnels and not having to change it out as rapidly or the same amount. The fact that all the tunnels change the snow every year and with more research better strategies can be made and they might end up with a result where the snow does not need to be changed as often as once a year.

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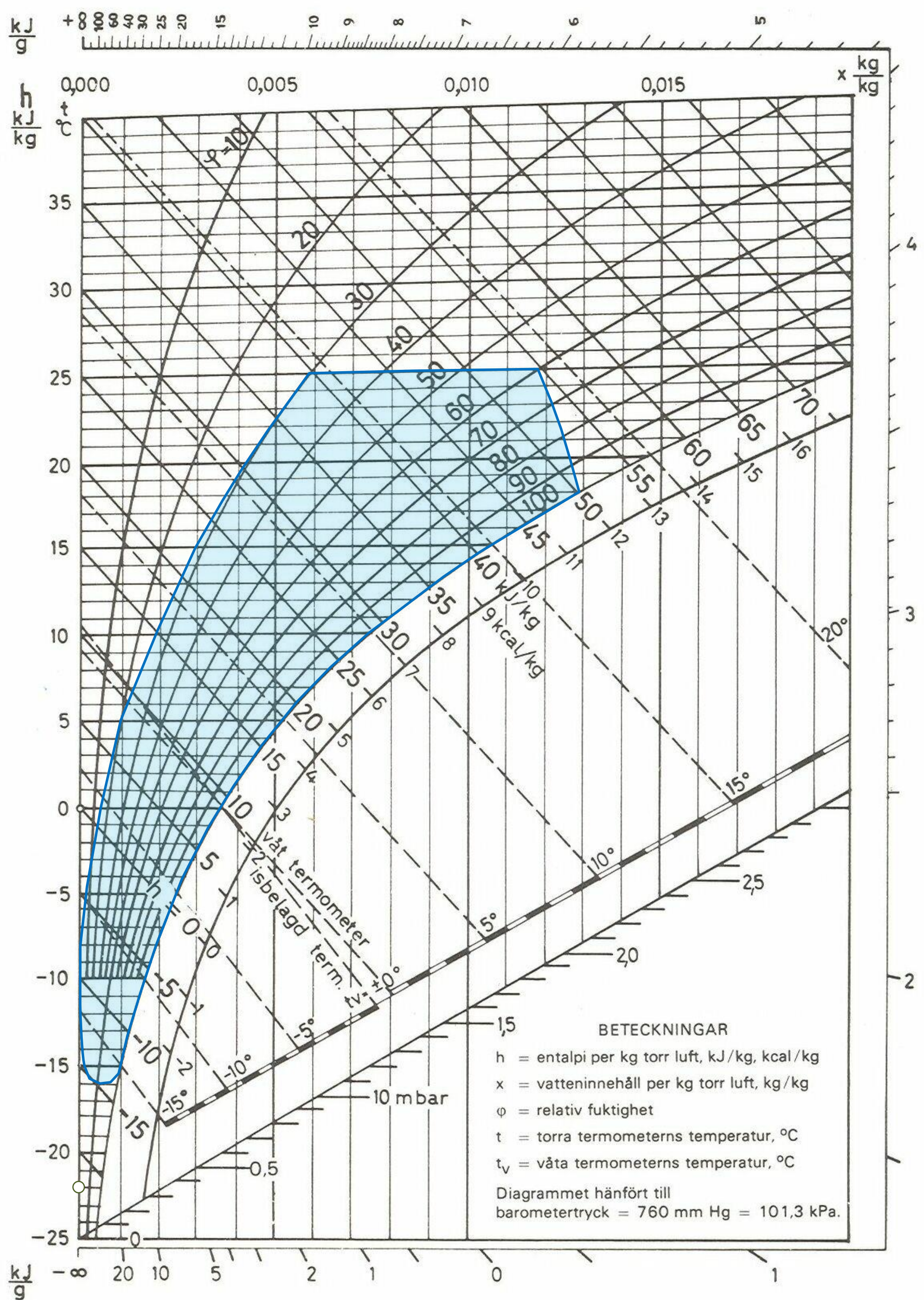
A
Appendix 1



h kJ/kg
t °C
x kg/kg
kJ/g
φ=10
våt termometer
isbelagd term.
10 mbar
BETECKNINGAR
h = entalpi per kg torr luft, kJ/kg, kcal/kg
x = vatteninnehåll per kg torr luft, kg/kg
φ = relativ fuktighet
t = torra termometerns temperatur, °C
tv = våta termometerns temperatur, °C
Diagrammet hänfört till
barometertryck = 760 mm Hg = 101,3 kPa.

B

Appendix 2

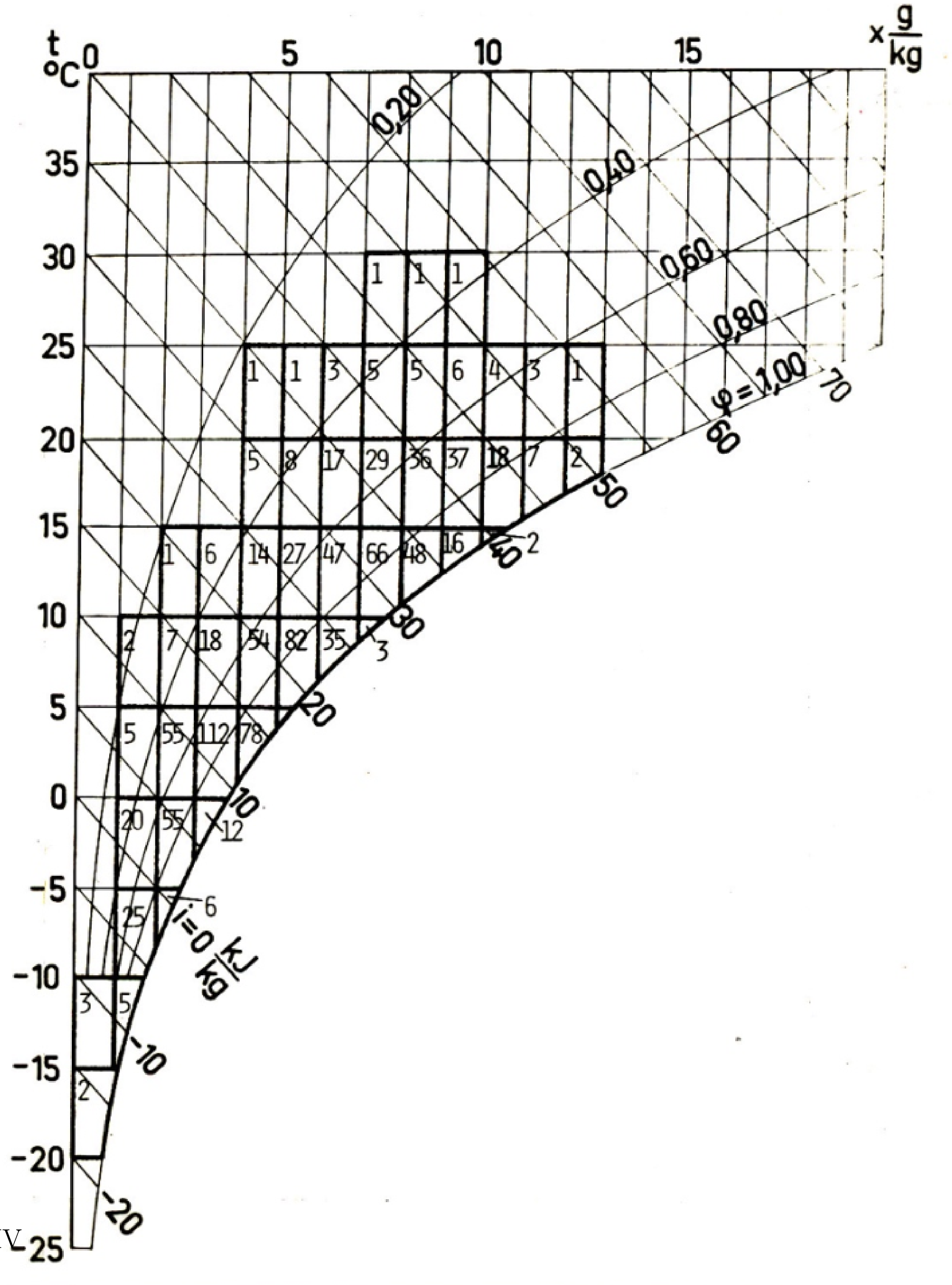


Fig. 10 Göteborg