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Atmospheric Water Generator
Spring Quarter Report 2008

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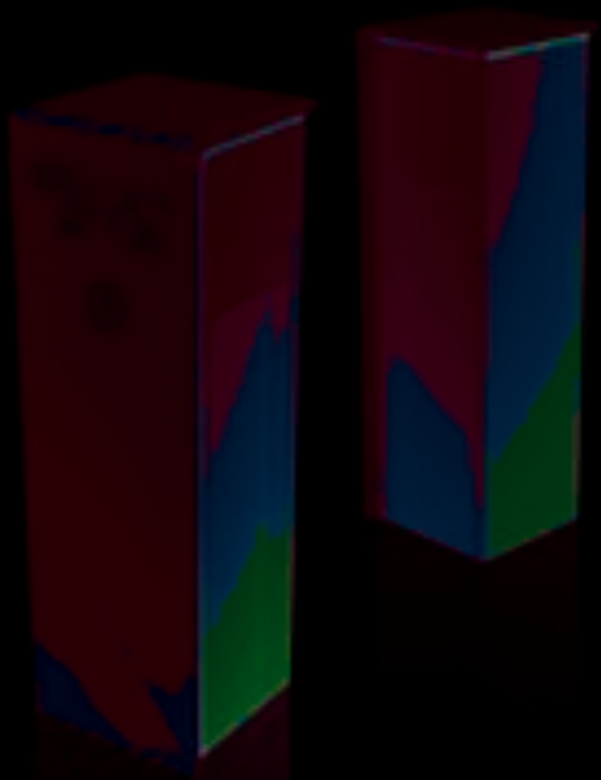

Mímir

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1 FRONT MATTER

1.1 Executive Summary

Water is the most precious resource known to mankind. Its importance to the survival of life on the planet can hardly be overemphasized. However, lack of access to pure drinking water is one of the key issues facing the world today. Conventional means of water generation have proved inadequate to fulfill the growing global drinking water needs. The traditional sources such as rivers, lakes and ground water have proved to be highly unreliable sources of drinking water. Therefore, there is a need to develop a novel, innovative technology that is more reliable and is able to produce pure, safe drinking water at all locations even under adverse environmental conditions.

With this vision in mind, the Design Team set on the task to design a new generation Atmospheric Water Generator to harness nature's most abundant resource: Air. Three main project objectives were identified (See Figure 1). Since the most critical objective of the project was reliable water production, the team decided to focus primarily on the technical aspects of water generation for most part of the project.

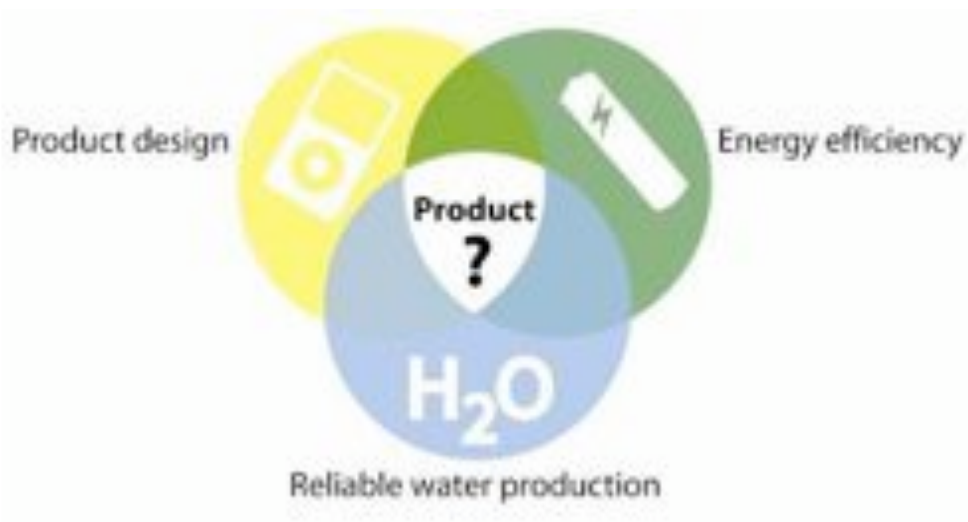

Figure 1: Three main project objectives

During the design process in the autumn quarter, the team pursued an extensive benchmarking exercise to explore various processes and technologies prevalent in the water processing industry. The team looked at refrigerators, dehumidifiers and various water purification processes in great detail. It also studied processes involved in the treatment of other liquids such as petrochemicals and alcohol. Through this exercise, the team learned the limitations of the technology (known as ‘vapor compression cycle’) presently employed in the atmospheric water generation and dehumidification industry. It was found out that vapor compression cycle is highly inefficient and energy consuming in dry conditions.

The team believed that successful generation of water in highly arid zones (with relative humidity as low as 20 %) would require the development of a radically new technology. Therefore, all its efforts from the very beginning were geared towards the search of a new, better technology that would give a marked improvement in performance over all the current designs. Based on the encouraging results of the initial fall quarter prototypes, the team pursued and developed the technology of desiccants for most of the winter quarter.

Desiccants are chemical substances that have a natural tendency to absorb atmospheric moisture. The key advantage of desiccant technology over vapor compression cycle is that it is more efficient at low humidity conditions and is energy efficient. Based on extensive prototyping and testing done in the winter quarter, the team demonstrated the practical feasibility of the liquid desiccant technology. The liquid desiccant system used desiccants in aqueous form and worked as an independent system without the need of any other system (like vapor compression cycle) for water absorption.

During the last quarter, the team employed the liquid desiccant technology in the final product, Mímir. The design was further improved and optimized in many ways (See Figure 2). The absorption chamber, for example, was customized for the application by a series of calculations and simulations to optimize the airflow. A heat exchanger was also added to improve the energy efficiency of the product. To fulfill the aims to provide a complete drinking experience to the consumer the team also implemented a unique interface to the product (See Figure 3).

Mimir produces 10-20 liters of pure, cheap, fresh drinking water under a wide range of atmospheric conditions. It has been tested to produce 10.2 liters of water at 41% relative humidity and 22°C. It consumes 1.2kW of power and the energy cost per liter of water consumed can be as low as 45 cents at 40% RH. This is not only much cheaper than bottled water but is also environmental friendly, as Mimir does not produce any waste products. The acrylic based exteriors, new look and the unique interface of Mimir provides a complete drinking experience to the user.

Mimir has been a break through in the technology and design front, but further testing and optimization is needed before the product could be introduced on the market. Many new aspects of optimization have been realized in the process of Mimir’s development and with this knowledge the team has no doubt that the product has a great potential of fulfilling most of the drinking water needs of the world in near future.

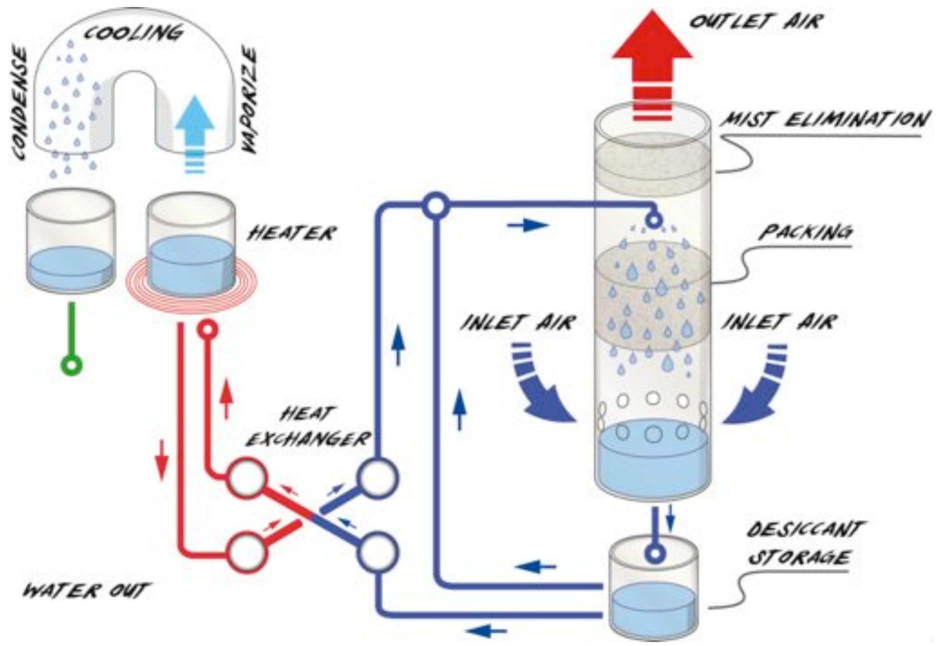

Figure 2: Overview of the final liquid desiccant technology

Figure 3: The final product - Mímir

1.2 Table of Contents

1 FRONT MATTER **1**

1.1 EXECUTIVE SUMMARY 1
1.2 TABLE OF CONTENTS 4
1.3 LIST OF FIGURES 8
1.4 LIST OF TABLES 13
1.5 GLOSSARY 14

2 CONTEXT **18**

2.1 NEED STATEMENT 18
2.2 PROBLEM STATEMENT 19
2.3 DESIGN TEAM 19
2.3.1 Student Design Team *20*
2.3.2 Coaches *22*
2.3.3 Liaison *24*
2.3.4 Teaching Team *24*

3 DESIGN REQUIREMENTS **26**

3.1 INTRODUCTION 26
3.2 FUNCTIONAL REQUIREMENTS 26
3.2.1 Functional Constraints *28*
3.2.2 Functional Opportunities *29*
3.2.3 Functional Assumptions *29*
3.3 PHYSICAL REQUIREMENTS 30
3.3.1 Physical Constraints *30*
3.3.2 Physical Opportunities *31*
3.3.3 Physical Assumptions *32*

4 DESIGN DEVELOPMENT **33**

4.1 DESIGN STRATEGY 33
4.2 BRAINSTORMING 35
4.3 BENCHMARKING 39
4.3.1 Amount of Water in Air *39*
4.3.2 Technology Research *40*
4.3.3 Existing Products *45*
4.3.4 Benchmarking Exercises *46*
4.3.5 Lesson learned from Benchmarking *49*
4.4 CRITICAL FUNCTION PROTOTYPES 50
4.4.1 Prototype 1: Comparing different desiccants *51*
4.5.2 Prototype 2: Water extraction from desiccants using RO process *55*
4.5.3 Prototype 3: Water Extraction using Peltier element *59*
4.5.4 Prototype 4: Better Heat transfer *62*
4.5 DARK HORSE PROTOTYPE – MICROWAVE HEATING 65
4.5.1 Questions addressed *65*
4.5.2 Concept – The key idea *66*
4.5.3 Prototype details *66*
4.5.4 Results *68*
4.5.5 Lessons learned *68*
4.6 OTHER EXPLORATORY PROTOTYPES 69
4.6.1 Exploratory Prototype I: Pre-cooled Vapor Compression Cycle *69*
Questions addressed *69*
Concept – The key idea *69*

Lessons Learned 70
4.6.2 Exploratory Prototype II: Desiccant Wheel - VCC 71
Questions Addressed 71
Concept – The key Idea 72
Lessons Learned 74
4.7 FUNCTIONAL SYSTEM PROTOTYPE : LIQUID DESICCANT CYCLE (LDC) 75
4.7.1 Questions Addressed 75
4.7.2 Concept - The Key Idea 75
4.7.3 Results 77
4.7.4 Lessons Learned 78
4.8 FINAL PROTOTYPE - MIMIR 78
4.8.1 The Mímir process 79
4.8.2 The absorption cycle 83
4.8.3 The extraction cycle 86
4.8.4 LiCl cycle 88
4.8.5 Extraction of water 92
4.8.6 Chamber 92
4.8.7 Fan 96
4.8.8 Nozzle 97
4.8.9 Heater 98
4.8.10 Heat Exchanger 99
4.8.11 Condenser 101
4.8.12 Filter 102
Mist Eliminator 103
Distillation 105
Active Carbon Filters 105
UV-light 106
4.8.13 Display 107
4.8.14 Choice of material 107
4.8.15 Control System 108
Design Issues 108
System Overview 110
Sensors 110
Relays 112

5 DESIGN SPECIFICATIONS 112

5.1 OVERVIEW 112
5.2 FRAME AND EXTERIOR PARTS 113
5.2.1 Frame 113
5.2.2 Wheels 114
5.2.3 Front Panel 114
5.2.4 Side Panels 115
5.3 ABSORPTION CHAMBER 115
5.3.1 Plastic chamber 115
5.3.2 Mist eliminator 116
5.3.3 Nozzle 116
5.3.4 Tower packings 116
5.3.5 Radial fan 117
5.4 HEATER 117
5.4.1 Heat chamber 117
5.4.2 Immersion heater and heat exchanger 118
5.4.3 Sensors and meters 119
5.5 CONDENSER SYSTEM 119
5.5.1 Condenser 119

5.5.2 Water tank ... *120*
5.6 Dispenser system ... 120
5.7 Control system ... 121
5.7.1 LabJack ... *121*
5.7.2 LabVIEW ... 124
5.7.3 Sensors ... 130
5.7.4 Relays ... *132*
5.7.5 Dispenser Control System ... 133
5.8 Power supplies used ... 135
5.9 Requirements vs. Specifications ... 135
5.10 Energy consumption ... 137

6 FUTURE DEVELOPMENT ... 139

6.1 Heat exchanger ... 139
6.2 Heater ... 139
6.3 Condenser ... 140
6.4 Demister ... 140
6.5 Air filter ... 140
6.6 Water filter ... 140
6.7 Refilling of desiccant solution ... 140
6.8 Tilt and transport system ... 140
6.9 Better Control System ... 141
6.10 Additional features ... 141
6.11 Extensive Testing ... 141

7 PROJECT MANAGEMENT ... 142

7.1 Overview ... 142
7.2 Communication ... 142
7.3 Deliverables and Milestones ... 142
7.2 Project Budget ... 145
7.2.1 Stanford Team Budget ... *145*
7.2.2 Global Team Budget ... *147*

8 REFERENCES AND RESOURCES ... 150

8.1 Literature ... 150
8.2 Articles ... 150
8.3 Websites ... 150
8.1 Words used in the literary search ... 151

9 APPENDICES ... 152

Appendix 2: Geographical Climatic Distribution ... 154
Appendix 3: Related Technologies ... 156
Appendix 4: Patent list ... 171
Appendix 5: Benchmarking Exercises ... 172
Appendix 6 : Critical Function Prototype ... 181
Appendix 8: Exploratory Prototype I - Pre-cooled VCC ... 194
Appendix 9: Exploratory Prototype I - Desiccant Wheel & VCC ... 201
Appendix 10: Functional System Prototype - Liquid Desiccant Cycle ... 217
Appendix 11: Dimensioning and Evaluating the Desiccant Wheel ... 235
Appendix 12: Heat exchanger ... 238
Appendix 13: Water extraction ... 239
Appendix 14: Frame ... 241
Appendix 15: Front panel ... 242
Appendix 16: Side panels ... 243

APPENDIX 17: PLASTIC CHAMBER 244
APPENDIX 18: TOWER PACKINGS..246
APPENDIX 19: RADIAL FAN 247
APPENDIX 20: PUMPS 248
APPENDIX 21 HEAT EXCHANGER 250
APPENDIX 22: ACTIVE CARBON FILTER 251
APPENDIX 23: HEAT CHAMBER 253
APPENDIX 24: TEMPERATURE AND PRESSURE SENSOR...254
APPENDIX 25: GANTT CHART FOR THE FALL AND WINTER QUARTERS...............................256
APPENDIX 26: DETAILED GANTT CHART FOR THE WINTER QUARTER 257
APPENDIX 27: GANTT CHART FOR THE SPRING QUARTER 258
APPENDIX 28: CAD DRAWING OF THE ASSEMBLY...245

1.3 List of Figures

Figure 1: Three main project objectives 1
Figure 2: Overview of the final liquid desiccant technology 3
Figure 3: The final product - Mímir 3
Figure 4: Where there is a lack of clean water, polluted water is used instead 18
Figure 5: The different universities: SU, LTU, KTH and LTH 19
Figure 6: A flowchart showcasing the team's design development strategy 34
Figure 7: An early brainstorming activity on Functional Benchmarking 35
Figure 8: A brainstorming exercise on Product Usability 36
Figure 9: A brainstorming exercise on different technologies that can be used for various required processes 37
Figure 10: A brainstorming exercise on intra team communication performed by the global team 38
Figure 11: Three major project focus areas 39
Figure 12: Amount of water vapor in air and its dependence on temperature and relative humidity 40
Figure 13: (a) A Schematic of the Vapor Compression Cycle Showing the Four Components ..42
Figure 14: A peltier element 43
Figure 15: Different desiccants – a) clay desiccant, b) lithium chloride desiccant (salt), c) calcium chloride desiccant (salt) and d) calcium chloride desiccant (salt) 44
Figure 16: Two different AWGs, from Immerse Global and Aquosus 46
Figure 17: Condensing experiment and dissembly of Kenmore dehumidifier 47
Figure 18: Dissembled hair drier 48
Figure 19: Disassembled refrigerator 48
Figure 20: The dissembling of the existing product 49
Figure 21: Experiment with different desiccants 52
Figure 22: Tested desiccants 53
Figure 23: Results from desiccant experiment 54
Figure 24: A schematic for the reverse osmosis process 56
Figure 25: The RO system 57
Figure 26: RO experiment setup 57
Figure 27: TDS graph 58
Figure 28: The peltier experiment 60
Figure 29: Blowing bubbles in the oil 63
Figure 30: Air being blown into the oil through mouth 63
Figure 31: Air being blown into the oil through an air pump 64
Figure 32: The fluid test using snow to keep the oil cold 64
Figure 33: Microwave Prototype: The Idea 66
Figure 34: The Dark Horse Prototype for the moving air case. The fan was used to push the air in and the RH meters in the two ducts measured the RH segregation. 67
Figure 35: Holes drilled to the back wall for air flow and duct tapes used to close other holes inside the microwave 67
Figure 36: An extra fan used to circulate air through the magnetron and inside oven walls68
Figure 37: Mockup of the pre-cooled VCC prototype 70
Figure 38: The final Pre-cooled VCC prototype. The ducts were added to divert the airflow through the Heat exchanger (HEX) 70
Figure 39: A commercial desiccant wheel 72
Figure 40: Schematic of the desiccant wheel operation 72
Figure 41: Schematic of the final desiccant wheel-VCC idea that the team pursued 73
Figure 42: The Desiccant Wheel-VCC prototype 74

Figure 43: Functional System Prototype idea : Liquid desiccant cycle..76
Figure 44: The final LDC prototype...77
Figure 45: Schematic for the liquid desiccant cycle. To the left are the Condenser and the heater. To the right is the absorption chamber. 79
Figure 46: The parts visible from the right side of Mímir. 81
Figure 47: the parts visible from the left side of Mímir..82
Figure 48: Air enters the absorption chamber trough the air filter (right side view) 83
Figure 49: Air enters the absorption chamber trough the air filter (back side view).................84
Figure 50: The mist eliminator 85
Figure 51: The storage tank and chamber pump circulating the solution. 85
Figure 52: The heat system 86
Figure 53: The condensing system 87
Figure 54: The dispenser system 88
Figure 55: Graph showing LiCl solution concentration with corresponding RH level and temperature. Source: M. Conde Engineering 2004 89
Figure 56: Graph showing the boiling point of different LiCl solution concentrations. Source: M. Conde Engineering 2004...91
Figure 57: Cross-flow chamber design with two chambers 93
Figure 58: Graph of simulation with less suiting geometry. Air inlet located at down to the left and outlet at the top. 94
Figure 59: An earlier counter flow design 94
Figure 60: Air flow simulation in a counter-flow packed bed absorber with less suiting geometry of the previous figure. Air inlet is located down to the right and outlet in the top. Green color shows the wanted flow rate. 95
Figure 61: Graph of simulation with more suiting geometry. Air inlets located on both sides at the lower part and outlet at the top. 95
Figure 62: Picture showing the final design of the chamber with radial fan, nozzle and tower packings. 96
Figure 63: Two early designed nozzles for a cross-flow chamber..97
Figure 64: A swirl nozzle characterized by small droplet size...98
Figure 65: The whirl nozzle that was finally used in the prototype, characterized by medium droplet size. 98
Figure 66: First prototype tube-in-tube heat exchanger. Inlet and outlet can be seen in the foreground. 100
Figure 67: The plate heat exchanger used in the prototype. 101
Figure 68: Exploded view of a plate heat exchanger used in the prototype 101
Figure 69: Schematic of the Condenser system...102
Figure 70: The filter system 103
Figure 71: CAD-model of early designed zig-zag baffles for a horizontal air flow. The baffles should, according to simulations, prevent particles down to 7 µm from leaving the chamber. 104
Figure 72: Wire mesh demister from Begg-Cousland. 105
Figure 73: UV light spectrum showing UV-A, UV-B and UV-C 106
Figure 74: TFT display 107
Figure 75: Display concepts...107
Figure 76: Batch process vs. Continuous Process. The batch process requires the use of two extra tanks and valves. This complicates the fabrication and control process. 109
Figure 77: Control System Block diagram 110
Figure 78: Flowchart showing how pressure sensor readings are used to control the pumps supplying liquid into (PumpIN) and out of (PumpOUT) the heater. 111
Figure 79: Extruded aluminum profile 114

FIGURE 80: FRONT PANEL 114
FIGURE 81: SIDE PANEL....115
FIGURE 82: PLASTIC CHAMBER 116
FIGURE 83: TOWER PACKINGS....116
FIGURE 84: RADIAL FAN 117
FIGURE 85: HEAT CHAMBER....118
FIGURE 86: IMMERSION HEATER 118
FIGURE 87: HEAT EXCHANGER 118
FIGURE 88: FLOW METER 119
FIGURE 89: THE CONDENSER SYSTEM....120
FIGURE 90: LED TAP 120
FIGURE 91: SLIDING MECHANISM....121
FIGURE 92: AN ACTUAL PICTURE OF THE LABJACK WIRING AS IT LOOKS IN THE MACHINE 122
FIGURE 93: LABJACK WIRING DIAGRAM 123
FIGURE 94: OUTPUT SCREEN OF LABVIEW SHOWING THE TEMPERATURE AND PRESSURE SENSOR READINGS AND THE ELECTRICAL DEVICES' STATES 124
FIGURE 95: THE COMPLETE BLOCK DIAGRAM OF THE .VI PROGRAM IN LABVIEW....125
FIGURE 96: LABVIEW RUNNING ON THE MANUAL MODE. THE HEATER IS CURRENTLY SWITCHED ON. AUTOMATED MODE CAN BE SET BY CHANGING THE CONTROL FROM 0 TO 1 126
FIGURE 97: BLOCK DIAGRAM FOR THE MANUAL MODE AS IMPLEMENTED IN LABVIEW. THIS BLOCK DIAGRAM IS ACTIVATED WHEN THE CONTROL SWITCH IS SET TO 0. 127
FIGURE 98: AUTOMATED MODE DISPLAY. THE TEMPERATURE AND PRESSURE READINGS CAN BE READ DIRECTLY ON THE DISPLAY. 128
FIGURE 99: A FLOWCHART SHOWING THE LOGIC THAT HAS BEEN IMPLEMENTED IN LABVIEW 129
FIGURE 100: THE UNIVERSAL EI-1034 TEMPERATURE SENSOR....130
FIGURE 101: THE PRESSURE SENSOR IN OPERATION 132
FIGURE 102: (A) COSMO DC/AC SS RELAY, (B) ECE DC/AC SS RELAY AND (C) KYOTO DC/DC SS RELAY 133
FIGURE 103: SCHEMATIC OF THE DISPENSER CONTROL SYSTEM. THE VALVE HAS NOT BEEN CONNECTED TO THE HOT WATER SWITCH (RED) AS THE HOT WATER FUNCTION WAS NOT IMPLEMENTED 133
FIGURE 104: THE DISPENSER SYSTEM. THE LED BUTTONS ARE ON THE TOP PANEL OF THE USER CONTROL.134
FIGURE 105: THREE MOST CRITICAL REQUIREMENTS OF THE SYSTEM, NAMELY WATER PRODUCTION, ENERGY EFFICIENCY AND COST OF THE WATER PRODUCED, HAVE BEEN MET 137
FIGURE 106: YEARLY AVERAGE TEMPERATURE DISTRIBUTION AROUND THE WORLD....154
FIGURE 107: YEARLY AVERAGE RELATIVE HUMIDITY DISTRIBUTION AROUND THE WORLD....154
FIGURE 108: YEARLY AVERAGE SOIL MOISTURE DISTRIBUTION AROUND THE WORLD 155
FIGURE 109: BASIC REFRIGERATOR 156
FIGURE 110: ENERGY FLOW OF THE VAPOR COMPRESSION CYCLE 157
FIGURE 111: BASIC PARTS OF PELTIER DEVICE....157
FIGURE 112: PICTURE OF PELTIER DEVICE....158
FIGURE 113: BASIC PRINCIPLE OF CONDENSERS....159
FIGURE 114: DIFFERENT KINDS OFF DRY BALLS....160
FIGURE 115: DRY SILICA GEL....160
FIGURE 116: HYDRATED SUPER ABSORBENT....161
FIGURE 117: DRY LITHIUM CHLORIDE 162
FIGURE 118: MICROWAVE OWN 163
FIGURE 119: BASIC PRINCIPLE OF A CONDENSER 163
FIGURE 120: BASIC PRINCIPLE OF RO SYSTEMS 164
FIGURE 121: COMPRESSOR 165
FIGURE 122: SOLAR CELL....165
FIGURE 123: ULTRA SOUND HUMIDIFIER HONEYWELL EH-5200E 166

FIGURE 124: IONIC WHISPER SILENT AIR PURIFIER/IONIZER 166
FIGURE 125: SNOW CANNON 167
FIGURE 126: CATALYTIC CONVERTER ON A SAAB 9-5 167
FIGURE 127: FUEL CELL 168
FIGURE 128: DIMROTH CONDENSER 168
FIGURE 129: MICRO COOLING COPPER FLANGES 169
FIGURE 130: SCHEMATIC FIGURE OF WATER CYCLE 169
FIGURE 131: AIR CONDITIONER 170
FIGURE 132: AMOUNT OF COOLING NEEDED FOR CONDENSATION TO TAKE PLACE AT DIFFERENT RH VALUES 173
FIGURE 133: THE SETUP 174
FIGURE 134: THE RECEPTACLE 174
FIGURE 135: THE MIST DEVELOPED ON THE COLD SURFACE 175
FIGURE 136: WATER DROPLETS DRIPPING DOWN 176
FIGURE 137: THE FIRST WATER DROPLET STILL CLINGING TO THE TIP 176
FIGURE 138: THE SET UP 181
FIGURE 139: THE $CaCl_2$ PLACED INSIDE THE "PIPE" FIGURE 140: THE LICL PLACED INSIDE "PIPE" 182
FIGURE 141: PELTIER SYSTEM MOUNTED ON THE "PIPE" 182
FIGURE 142: ANTEC P180 183
FIGURE 143:THE RO CFP 184
FIGURE 144: WIRING DIAGRAM FOR THE PELTIER CFP EXPERIMENT 185
FIGURE 145: BASIC EQUIPMENT USED IN THE EXPERIMENTS 187
FIGURE 146: ICE ON COPPER SHEET, EXPERIMENT 1 187
FIGURE 147: DURING, AND AFTER EXPERIMENT 4 187
FIGURE 148: AFTER EXPERIMENT 4 187
FIGURE 149: EXPERIMENT 5, MOISTURE ON SCRATCHED COPPER SHEE 188
FIGURE 150: RESULT FROM EXPERIMENT 6, POURED THE WATER TOGETHER 188
FIGURE 151: EXPERIMENT 7, TILTED PELTIER, 45° 188
FIGURE 152: THE CARDBOARD TUBE WITH THE RH METER 190
FIGURE 153: THE THIRD TUBE WITH FAN ATTACHED TO BLOW IN AIR 191
FIGURE 154: HOLES DRILLED TO THE BACK WALL FOR AIR FLOW. DUCT TAPES WERE USED TO CLOSE OTHER HOLES INSIDE THE MICROWAVE (SIDE WALLS AND FLOOR) 192
FIGURE 155: FAN ADDED AT THE BACK WALL OF THE OVEN 193
FIGURE 156: MICROWAVE PROTOTYPE WITH STRAIGHT, LAMINAR AIR FLOW 193
FIGURE 157: CROSS FLOW HEAT EXCHANGER USED IN THE PROTOTYPE 195
FIGURE 158: HONEYWELL DEHUMIDIFIER AFTER BEING TAKEN APART, EVACUATED AND REPOSITIONED 196
FIGURE 159: 3D CAD PICTURE OF PRECOOLING SETUP 196
FIGURE 160: THE LOOP SHAPED DUCT 197
FIGURE 161: THE DUCT ATTACHED TO THE EVAPORATOR AND THE HEAT EXCHANGER 197
FIGURE 162: COMPLETE CAD SETUP 198
FIGURE 163: EXPLODED VIEW OF THE PRE-COOLED VCC. THE NUMBERS DENOTE THE LOCATIONS OF THE TEMPERATURE AND HUMIDITY PROBES. 198
FIGURE 164: DESIGN ITERATION 1: ONE OF THE EARLIER MECHANISMS CONSIDERED TO COUPLE DESICCANT WHEELS WITH VCC 201
FIGURE 165: DESIGN ITERATION 2, IDEA: THE MOISTURE LEFT IN THE AIR STREAM AFTER CONDENSATION AT THE EVAPORATOR WAS RETRIEVED USING DESICCANT WHEEL 202
FIGURE 166: DESIGN ITERATION 2, DESIGN: THE CIRCUITOUS AIR DUCT DESIGNED TO IMPLEMENT THE ABOVE IDEA IN PRACTICE 203
FIGURE 167: SCHEMATIC OF THE FINAL DESICCANT WHEEL-VCC IDEA THAT THE TEAM PURSUED 204
FIGURE 168: DESICCANT WHEEL USED IN THE PROTOTYPE 204

FIGURE 169: FRAME FOR THE WHEEL. THE RUBBER PARTITIONS ARE USED TO ENSURE THAT THERE IS NO MIXING BETWEEN PROCESS AIR AND REGENERATIVE AIR....205
FIGURE 170: DESICCANT WHEEL INSIDE THE WHEEL FRAME....205
FIGURE 171: PROTOTYPE 1: THE OBJECTIVE WAS TO TEST THE DESICCANT WHEEL EFFICIENCY....206
FIGURE 172: THE ELECTRIC HEATERS CONNECTED INSIDE THE AIR CHAMBER OF SUB PROTOTYPE 1....206
FIGURE 173: THE THERMOCOUPLE PROBES USED TO MEASURE AIR TEMPERATURE OUTSIDE THE DESICCANT WHEEL....207
FIGURE 174: THE CONTRAPTION USED TO CRUDELY CONTROL THE AIR FLOW THROUGH THE WHEEL....207
FIGURE 175: THE SEARS DEHUMIDIFIER....208
FIGURE 176: DESICCANT WHEEL-VCC PROTOTYPE AS IT STOOD BEFORE THE RECONNECTION OF PIPES - ONE CAN SEE THE DESICCANT WHEEL FRAME ON LEFT WITH THE REQUIRED REGENERATIVE AIR DUCTS AND HEATERS. THE SOLO COMPRESSOR STANDS IN THE MIDDLE. ON THE RIGHT IS A PART OF THE DUCT....209
FIGURE 177: CLOSE-UP OF THE WHEEL FRAME WITH REGENERATIVE AIR CHAMBER, HEATERS AND CONDENSER AT THE BACK....210
FIGURE 178: CONDENSER ATTACHED TO THE PROTOTYPE - WITH THE REGENERATIVE CHAMBER AND THE WHEEL FRAME AT THE BACK....210
FIGURE 179: CLOSE UP OF THE EVAPORATOR AND BLOWER AT THE OTHER END....211
FIGURE 180: THE EXTRA PIPES SOLDERED TO THE CONDENSER....211
FIGURE 181: THE EXTRA PIPES CONNECTED TO THE CONDENSER WITH VALVES TO ADD/REDUCE THE AMOUNT OF REFRIGERANT....212
FIGURE 182: THE PRESSURE GAUGES USED TO MEASURE THE PRESSURE WITHIN THE VCC SYSTEM WHILE FILLING THE REFRIGERANT....212
FIGURE 183: THE DESICCANT WHEEL-VCC PROTOTYPE....213
FIGURE 184: THE FROST THAT FORMED ON THE EVAPORATOR COILS ON RUNNING THE PROTOTYPE....213
FIGURE 185: EXTRA FAN ADDED TO COOL THE CONDENSER....215
FIGURE 186: THE COLD EVAPORATOR AIR STREAM DIVERTED TO COOL THE COMPRESSOR....215
FIGURE 187: EXTRA COOLING FANS ADDED TO COOL THE COMPRESSOR....216
FIGURE 188: SUB PROTOTYPE 1....219
FIGURE 189: SUB PROTOTYPE 2, IDEA....220
FIGURE 190: STRAW PACKINGS....221
FIGURE 191: SUB PROTOTYPE 2....221
FIGURE 192: SUB PROTOTYPE 3 IDEA....222
FIGURE 193: THE FINAL LDC PROTOTYPE....224
FIGURE 194: TUBE EXTENSION....225
FIGURE 195: FAN....225
FIGURE 196: TOWER PACKINGS....226
FIGURE 197: STRAW STACK....227
FIGURE 198: TOWER PACKINGS STACK....227
FIGURE 199: PUMP....228
FIGURE 200: HEATER 1....228
FIGURE 201: HEATER 2....229
FIGURE 202: WATER EXTRACTION PROCESS....229
FIGURE 203: ROTATING NOZZLE....230
FIGURE 204: PLASTIC NOZZLE WITH HOLES....231
FIGURE 205: ROTATING NOZZLE WITH OPENINGS ON SIDE....231
FIGURE 206: THERMOMETER....233
FIGURE 207: THE DESICCANT WHEEL PROCESS....235
FIGURE 208: ACTIVE AREA....235
FIGURE 209: ENERGY EFFICIENCY AT VARIOUS RH AND TEMPERATURES....236
FIGURE 210: WATER EXTRACTION CAPACITIES AT VARIOUS RH AND TEMPERATURES....237
FIGURE 211: TOWER PACKINGS....246

1.4 List of Tables

TABLE 1: FUNCTIONAL REQUIREMENTS 27
TABLE 2: FUNCTIONAL CONSTRAINTS 28
TABLE 3: PHYSICAL REQUIREMENTS 30
TABLE 4: PHYSICAL CONSTRAINTS 31
TABLE 5: TABLE SHOWING THE PORTS THAT CONTROL VARIOUS INPUT AND OUTPUT DEVICES 122
TABLE 6: RELEVANT SPECIFICATIONS OF THE PRESSURE SENSOR 131
TABLE 7: SPECIFICATIONS FOR THE RELAYS 132
TABLE 8: MIMIR'S PERFORMANCE COMPARISON WITH THE SET DESIGN REQUIREMENTS 136
TABLE 9: DELIVERABLES AND MILESTONES FOR FALL QUARTER 143
TABLE 10: DELIVERABLES AND MILESTONES FOR WINTER QUARTER 144
TABLE 11: DELIVERABLES AND MILESTONES FOR SPRING QUARTER 144
TABLE 12: STANFORD TEAM EXPENSES FOR THE WHOLE PROJECT 146
TABLE 13: LULEÅ TEAM EXPENSES FOR THE WHOLE PROJECT 149
TABLE 14: DATA FROM THE PELTIER EXPERIMENTS. 186

1.5 Glossary

AWG - Atmospheric Water Generator

Compressor - a machine that compresses gases such as air.

Dark Horse Prototype - a challenging prototype that has a bleak chance of success but potentially provides a completely new design direction

Dehumidifier - A machine that reduces the humidity of air

Desiccant - Hygroscopic substance that adsorbs or absorbs water, used as a drying agent.

Desiccant wheel - A wheel/rotor impregnated with solid desiccant particles, usually in a honeycomb structure

EPA - US Environmental Protection Agency

Evaporator - An evaporator changes liquids, for example water into its gaseous state, vapor (in conventional vapor compression cycle, the evaporator gets cold due to the heat of vaporization needed to vaporize the refrigerant liquid)

Expansion Valve - A valve that allows gas to expand rapidly reduces pressure

HEX - Heat exchanger, a device for heat transfer from one medium to another

HMI	- Human Machine Interface
HVAC	- Heating, ventilation & air conditioning. Also a department at Stanford Utilities which helped with the construction of the desiccant wheel - VCC prototype
KTH	- Royal Institute of Technology, located in Sweden
LCD	- Liquid Crystal Display
LDC	- Liquid desiccant cycle; refers to a continues process where water is absorbed by a desiccant solution and then extracted
LTH	- Lund Faculty of Engineering, located in Sweden
LTU	- Luleå University of Technology, located in Sweden
Mimir	- a deity in Norse mythology, guard of the 'well of knowledge'.
pH	- A measure of the acidity or alkalinity of a solution.
Pre-cooling	- System used in conventional VCC cycle to cool the incoming air before it reaches the evaporator.
Process air	- The airstream that passes through the desiccant wheel and gets dried.

Pump IN - The pump that pumps the desiccant solution from the heat exchanger to the heater

Pump OUT - The pump that pumps the desiccant solution from the heater to the heat exchanger

Regenerative air - The hot air stream that passes through the desiccant wheel and dries it in a desiccant wheel system.

Relative Humidity - Is defined as the ratio of the partial pressure of water vapor in a gaseous mixture of air and water vapor to the saturated vapor pressure of water at a given temperature.

RH - Relative humidity

Reverse Osmosis Process - Reverse osmosis, the process of forcing a solvent from a region of high solute concentration through a semi-permeable membrane to a region of low solute concentration by applying pressure. the reverse to normal osmosis.

RO - Reverse osmosis

SS - Solid State relay, An electronic switch used together with Lab jack

SU - Leland Stanford Junior University, located in the United States.

TDS - Total Dissolved Solids, the total mass content of dissolved ions and molecules or suspended microgranules in a liquid medium.

Throttle Valve	- Same as expansion valve
TKK	- Teknillinen korkeakoulu, Helsinki University of Technology, located in Finland.
Test rig	-Steel wireframe structure on which the desiccant wheel - VCC prototype was built.
Ultra Filtration	-A filtration technique to separate very small floating particles like bacteria and virus.
Vapor Compression Cycle	-By adding energy in the form of a pump, the vapor compression cycle transports heat from a lower temperature source to a higher temperature source.
VCC	- Vapor compression cycle
VOC	- Volatile Organic Contaminants

2 Context

2.1 Need Statement

The lack of safe drinking water and sanitation is the single largest cause of illness in the world today. According to the May 2007 issue of *Vanity Fair*, Green Issue edition, almost one out of every three people on the planet currently lacks reliable access to fresh water. With ever-increasing water pollution and global warming, the conventional sources of pure water are fast depleting and increasingly proving inadequate to feed the needs of the vast global population. Also, due to their inherently fixed nature, the water generated from traditional sources such as rivers, lakes and ground need to be transported over long distances before final consumption. This increases costs and requires immense amounts of energy.

Figure 4: Where there is a lack of clean water, polluted water is used instead

There is an urgent need to develop an alternative source of fresh drinking water that is universally available and able to reliably meet the vast global water needs. Creating a new sustainable pure water solution would not only save millions of lives but also raise the quality of human life. A solution that can cope with extreme conditions where there is very little ground water, no reliable energy source, extreme variation in temperatures and humidity will also prove beneficial in disaster management and for military purposes in remote locations.

2.2 Problem Statement

Atmospheric water generators have been addressing the need to provide pure drinking water for the past two decades; however the design that is presently in use has limited applicability. The present technology is not a reliable option in adverse climatic conditions, like low relative humidity and extreme temperatures.

The objective of the project is to design and develop a new generation AWG that is able to produce 10-20 liters of water daily in various climate conditions, and can deliver water in conditions below 30% relative humidity. The machine should produce great-tasting water and be energy efficient with an implemented alternative power source for energy conservation. The product should also be portable.

2.3 Design Team

The Immerse Global design team has a unique setting of members from five different universities – Helsinki University of Technology (TKK), Lund Faculty of Engineering (LTH), Luleå University of Technology (LTU), Royal Institute of Technology (KTH), and Stanford University (SU). KTH, LTH and LTU are universities from different locations in Sweden (See Figure 5). The student from TKK, Finland, is situated at Stanford University during the project and is counted as a Stanford student.

Figure 5: The different universities: SU, LTU, KTH and LTH

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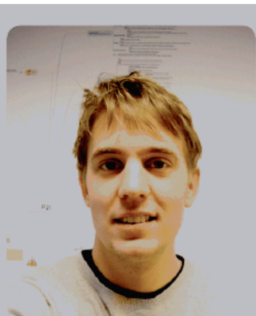

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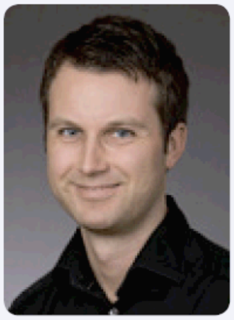

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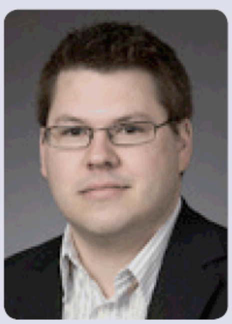

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3 DESIGN REQUIREMENTS

3.1 Introduction

Design requirements are the defining goals that the product has to achieve. There are some requirements that are critical, which implies that the product cannot be complete without those requirements being fulfilled. There are others that are not as critical but, if present, greatly increase the functionality of the product. Let us consider an example of a ball. A critical requirement could be that it should bounce, while a non-critical requirement could be that the material should be rubber.

The challenge for the team is to make an atmospheric water generator that has universal applicability, produce very pure, safe drinking water at a highly affordable price. The machine should be a style icon that revolutionizes the water drinking experience across the globe. The machine could also be powered with alternate sources of energy, like solar or wind energy.

There are a lot of design requirements to achieve the objectives laid above. These can be distinctively categorized into four headings:

- Functional Requirements
- Physical Requirements

3.2 Functional Requirements

These are the set of requirements that define the functionality of the design. Considering the example of the ball again, a functional requirement can be that the ball should be able to bounce. The functional requirements are listed below, along with the rationale and the criticality of each (see Table 1)

S No.	Description (Functional Requirement)	Critical/ Non Critical	Measure
FR-1	Should operate at low RH values. Rationale: Target market has low RH values	Critical	30 % RH
FR-2	Should operate even at extreme temperatures. Rationale: Target markets may have extreme temperatures	Critical	20 - 40 °C
FR-3	Should consume power on the order of an avg. household appliance. Rationale: Should not be too expensive to operate	Critical	<1000 W
FR-4	Should produce enough water/day for an average household. Rationale: Is designed to fulfill the requirements of an avg. household	Critical	10-20 liters/day
FR-5	Should be powered by alternative sources of energy. Rationale: To target the entire world as a potential market	Non-Critical	Using power other than electricity
FR-6	Should be a better design. Rationale: Present technology unable to produce water at the desired conditions	Non-Critical	Using something more than just Vapor Compression Cycle daily
FR-7	Should filter and produce clean, drinking water. Rationale: provide healthy water to the user	Critical	TDS < 500 ppm pH~8
FR-8	Should produce cheap water. Rationale: device needs to be competitive	Critical	< $1.00 / liter (only operating power costs considered @ $0.16/kWh)

Table 1: Functional Requirements

3.2.1 Functional Constraints

During a design process, there are always certain constraints that limit the design space. These functional constraints are the bounds within which the design must lie without compromising the functional requirements. Coming back to the ball example, a functional constraint can be that the ball has to be a solid, for it to be able to play with. The functional constraints, along with the rationale and criticality, are as follows: (see Table 2)

S No.	Description (Functional Constraint)	Critical/ Non Critical	Measure
FC-1	Should use air to draw moisture. Rationale: Under the category of AWGs	Non-Critical	No input of water to the machine is needed
FC-2	Should generate water within a defined water temperature range. Rationale: To quench the thirst of the user	Critical	5 - 20 °C
FC-3	Quality of the water produced should conform to EPA rules. Rationale: To ensure good quality drinking water	Critical	TDS < 500 ppm pH ~8
FC-4	Should be safe to operate. Rationale: Has a human interaction	Critical	No hazardous/harmful elements or parts (such as CFCs, refrigerants)
FC-5	Should operate with a low sound level. Rational: The user should not be disturbed by product noise	Non-Critical	< 50 dB
FC-6	Should have minimum production costs. Rational: Should not be too expensive to buy	Non-Critical	< $1200

Table 2: Functional constraints

3.2.2 Functional Opportunities

Functional opportunities are avenues in the design that can be possibly implemented, confirming with the above set of guidelines and constraints. Following are the opportunities:

- The device conveys a broader sense of one of the most important elements in life: water. The device would provide relevant information about the water that the user consumes. This imparts a greater sense of confidence in the user that the water consumed is of a high quality.

- The device can potentially revolutionize the water drinking experience. The device can be highly customizable, so that each user has a highly satisfying and fulfilling experience with the product. Drinking water, which is an essential part of human life, should become a lot more enjoyable.

- The device can be uniform across all geographical borders. It can be uniform in its performance, delivering the best quality water everywhere.

- The device can be based on a process that couples more than one cycle. The current vapor compression cycle (VCC) has limited operational and efficiency bounds. Therefore a solution that seeks to combine the benefits of two or more technologies can be sought.

3.2.3 Functional Assumptions

- The device will be used where it has access to large volumes of air. This is important as the target production of 20 liters a day requires processing of large volumes of air.

- The team assumes that a constant electric power supply will be available for the device. (However, in later stages of design planning, the team may look into the incorporation of alternative energy sources in the device.)

3.3 Physical Requirements

These requirements specify what the design is. These govern the components but are not the components themselves. Referring to the example of the ball again, a physical requirement for the ball can be its spherical shape, which would help it achieve the physical goal of bouncing. Following are the physical requirements for the machine: (see Table 3)

S No.	Description (Physical Requirement)	Critical/Non-Critical	Measure
PR-1	Should have a storage tank. Rationale: RH values vary with time, so production and storage should be done at all times	Critical	10 liters storage tank
PR-2	Should be easy to move around from room to room. Rational: Should have weight, size and shape to allow mobility	Non-Critical	< 2m x 1m x 1m (h x w x l) < 100 kg
PR-3	Should have a good HMI. Rational: Should give good feedback to the user and easy to operate	Non-Critical	Feedback to all senses
PR-4	Should have good ergonomics. Rational: Should be adapted for the user	Non-Critical	Standard anthropometry measurements

Table 3: Physical Requirements

3.3.1 Physical Constraints

These refer to the limits of the design. A lot of possible design solutions may need to be discarded at times, as they do not fulfill the design constraints. Hence analysis of the physical constraints of the design challenge is important. Following are the constraints that are applicable: (see Table 4)

S. No.	Description (Physical Constraint)	Critical/Non-Critical	Measure
PC-1	Electric motor rated both at 220V and 110V. Rationale: Target market is the whole globe	Non-Critical	Should have an adaptor
PC-2	Should enable maintenance. Rational: Should not be too expensive nor too time consuming to clean and service.	Critical	Service time required < 10 min weekly
PC-3	Possible lifetime of at least a few years. Rationale: Should not be frequently changed	Critical	3 years or more
PC-4	Should facilitate shipment. Rational: Should be easy to ship.	Non-critical	Collapsible
PC-5	Should be recyclable. Rational: Should be environmental friendly/healthy.	Non-critical	Recyclable materials

Table 4: Physical Constraints

3.3.2 Physical Opportunities

These are the range of physical ideas that can be implemented into the design. These are the opportunities that the design provides while being within the domain of all requirement and constraints.

Customizable design/display

Different users may want a different look and feel of the product. Also, different aspects of the design may fascinate different users. Hence, customization of the device may add to the desirability of the product.

Develop the operating manual of the device

Develop maintenance and cleaning procedures for the unit, in order to ensure efficient operation.

3.3.3 Physical Assumptions

- The device will not be tested in a more challenging environment than it has been designed for.
- The user will be responsible for the maintenance and cleaning of the machine.
- A maximum of 5 liters of water will be consumed at any one time.
- The device will not be subjected to any substantial mechanical stresses above those arising from normal operation of the unit.

4 Design Development

4.1 Design Strategy

Team Immerse' design development process began in the fall quarter with a thorough understanding and quantification of the need statement provided by the liaison. The main thrust during the fall quarter was to get an in-depth understanding of the possible solution space by an extensive technology research, benchmarking and prototyping process. The team also studied the working principles and performance of a number of allied products such as refrigerators, dehumidifiers and existing Atmospheric Water generators (AWGs). The knowledge obtained from this process was used to better formulate the project requirements and vision.

During the winter quarter, the team tested the several concepts and technologies through a series of prototypes. The tested technologies were microwave dehumidification, precooled vapor compression cycle, desiccant wheels and liquid desiccant technology. The performances of these prototypes were compared to each other, based on their water generation capacity, energy efficiency and practical implementability. The design requirements of the project were constantly refined based on the new knowledge gained from the prototypes. The team finally built and tested a liquid desiccant based Functional System prototype at the end of the winter quarter.

In the last quarter, the team used all the knowledge gained from the previous two quarters in the development of a final prototype. Special care was taken to optimize the device performance as much as possible. The efforts resulted in the development of a working liquid desiccant based atmospheric water generator that was presented at EXPE 2008.

For an overview of the design strategy see Figure 6.

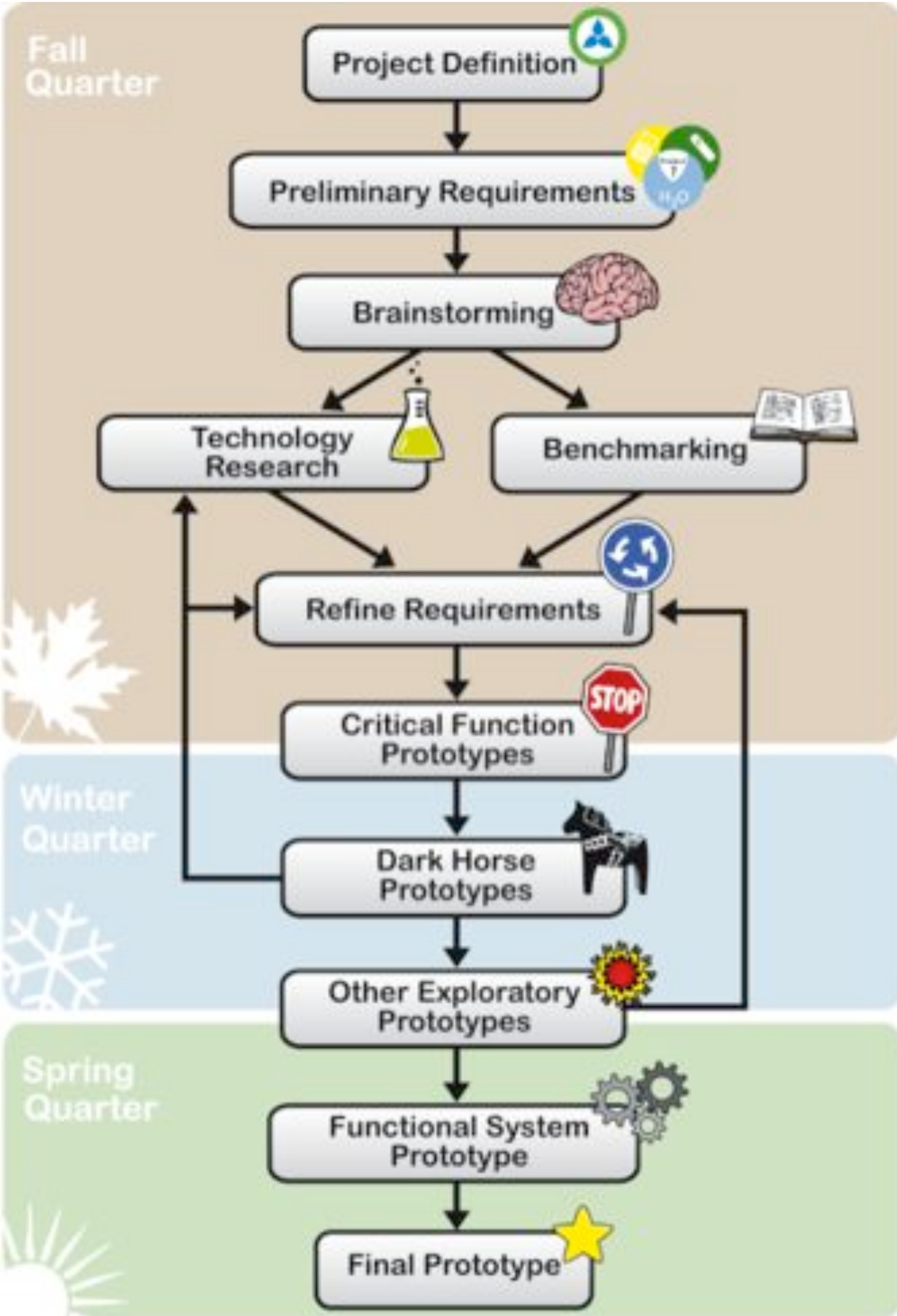


Figure 6: A flowchart showcasing the team's design development strategy

4.2 Brainstorming

The team started by performing an initial brainstorming exercise to explore all facets of the vast design space. Figure 7 to Figure 10 show some of the brainstorming exercises that the team indulged in.

Figure 7: An early brainstorming activity on Functional Benchmarking

Figure 8: A brainstorming exercise on Product Usability

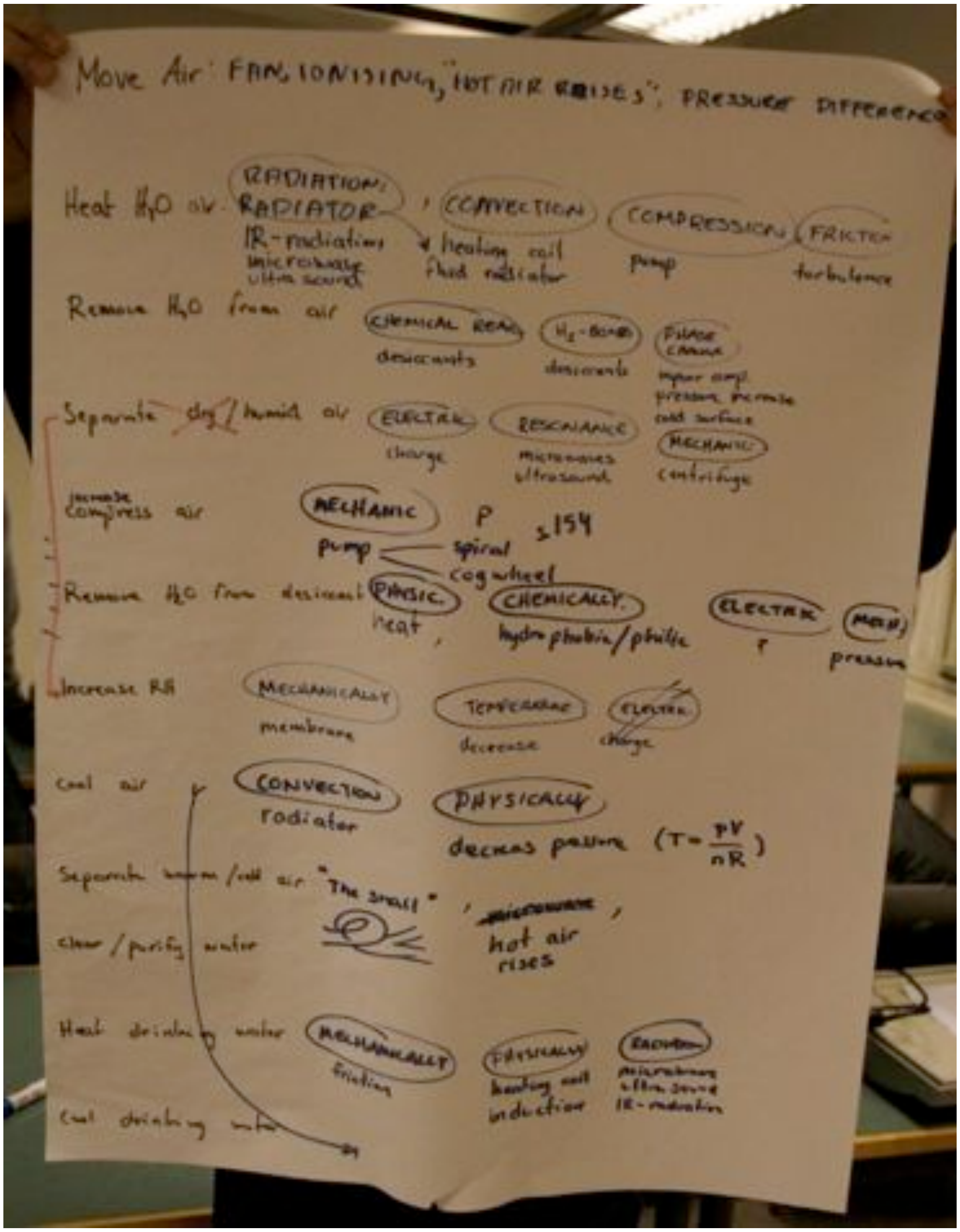


Figure 9: A brainstorming exercise on different technologies that can be used for various required processes

Figure 10: A brainstorming exercise on intra team communication performed by the global team

Based on the results of the brainstorming exercises, the team identified three key focus areas for the project. They were: (See Figure 11)

• Performance: Reliable production of at least 10 liters of drinking water under extreme climatic conditions.

• Energy Efficiency: Efficient implementation of alternative energy source.

• Product Design: To create a novel interactive user experience.

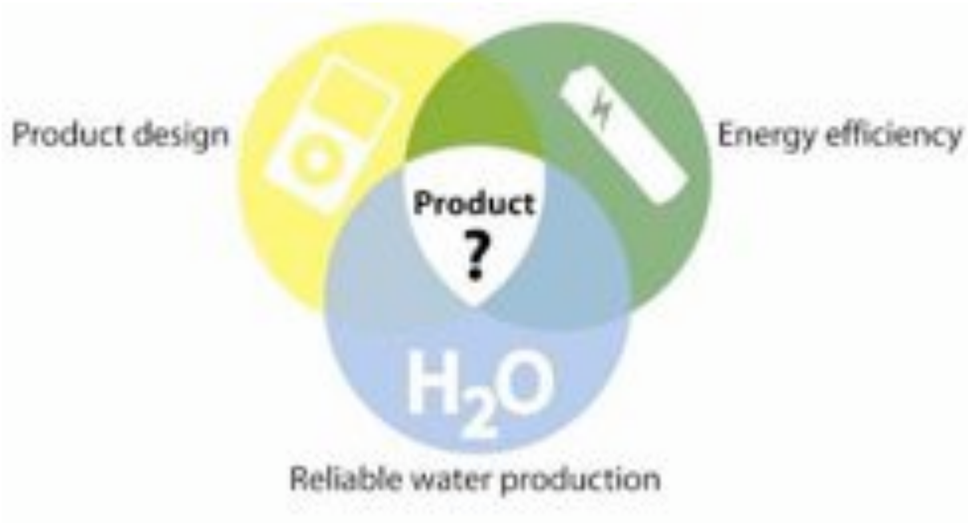


Figure 11: Three major project focus areas

However, considering the vastness of the prospective solution space for each of the above three focus areas, the team decided to prioritize them on a need basis. After due consideration and in consultation with the corporate liaisons, the team decided to focus on enhancing the device performance. Henceforth, the team set on the task of finding a solution that would best meet the intense performance requirements of the machine.

4.3 Benchmarking

The team conducted a series of benchmarking activities to understand the design problem better. These activities included an extensive study of the global geographical conditions (see Appendix 2), technology research and existing products' survey. In addition, the team also indulged in a series of hands-on benchmarking exercises in an effort to gain a better understanding of the underlying principles involved. The objective of the entire gamut of activities was to gain an in-depth knowledge about the numerous nuances of the water industry, both from a commercial and a technological perspective.

4.3.1 Amount of Water in Air

The team started by estimating the amount of water that the air around us normally contains. Since one of the major requirements of the project was to generate water at RH values of around 30%, the team tried to gauge how much air needed to be processed in order to generate a particular amount of water.

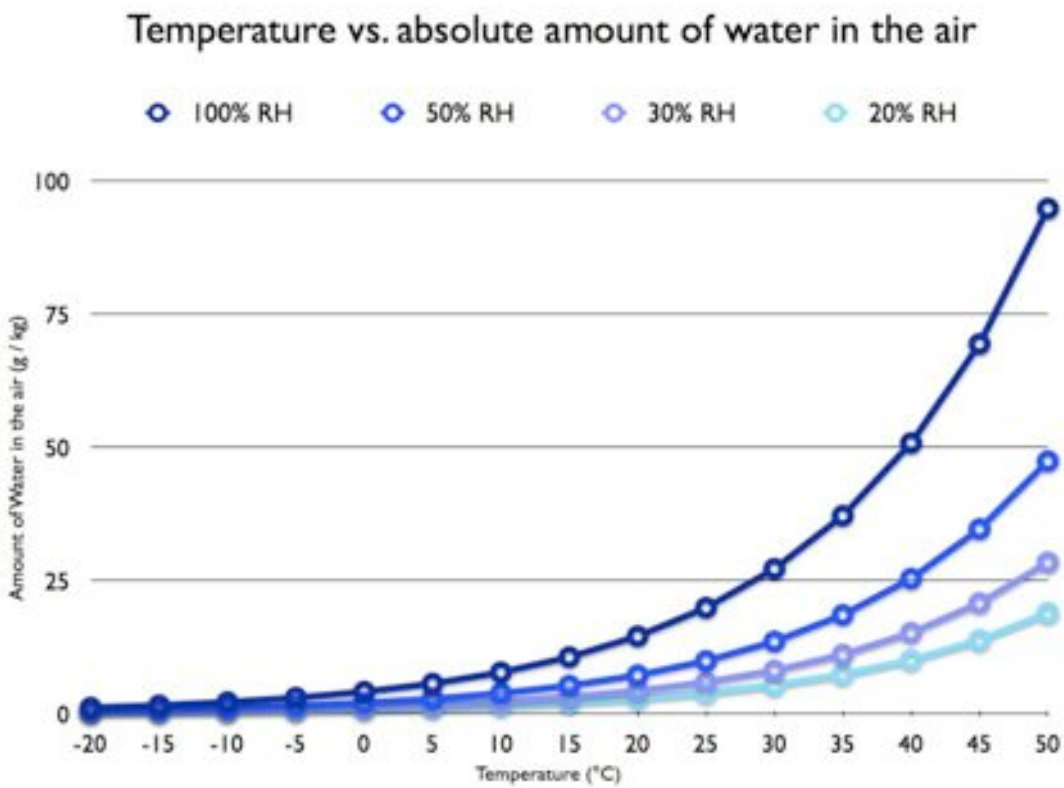


Figure 12: Amount of water vapor in air and its dependence on temperature and relative humidity

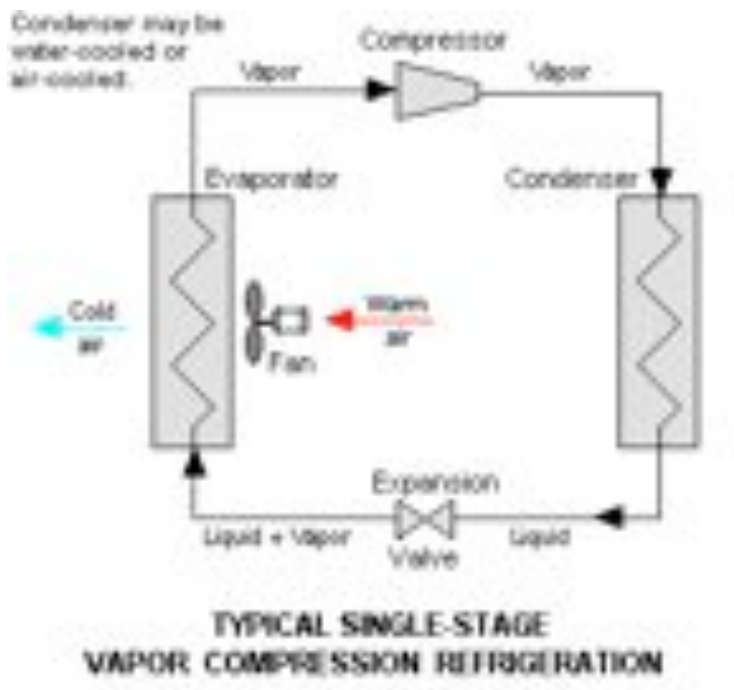
As can be seen from Figure 12, the absolute amount of water that air can hold without precipitation, is a strong function of temperature. In areas with low temperatures, even if the relative humidity is high, there is little water in the air that can be removed. Therefore, one cannot expect the same machine to work with equal efficiency at both the Sahara desert and Arctic, even though the RH values may be identical at both places. Thus, it is necessary to specify an operating temperature range for the machine in addition to the operating RH values. This study prompted the team to include the desired operating temperature range as one of the 'discovered requirements' of the project.

4.3.2 Technology Research

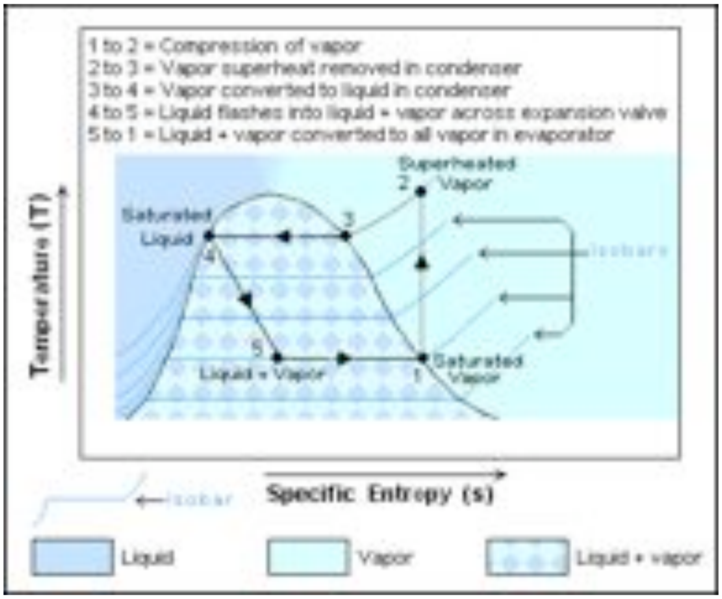
The team studied the various technologies that are currently being exploited in commercial Atmospheric Water Generators and other related devices such as refrigerators, air conditioners and dehumidifiers. Due to the inherent technological nature of the project, it involved a lot of literature survey, scientific analysis and study of various thermodynamic cycles. Refer Appendix 3 for a detailed technology survey.

Vapor Compression Cycle

This is the preferred technology for most of the commercial products today. It is presently being used in most of the commercial AWGs, refrigerators, ACs and dehumidifiers. The advantages of this technology are that it is well documented, reliable and consistent. However, it does not work well for a relative humidity level less than 30%.



(a)



(b)

Figure 13: (a) A Schematic of the Vapor Compression Cycle Showing the Four Components (b) The Temperature – Entropy Diagram for the Cycle [Courtesy: wikipedia.org]

The vapor compression cycle consists of a refrigerant that passes through a series of changes in a closed continuous cycle. It consists mainly of four steps:

1. Refrigerant gas at low pressure enters the compressor and leaves it pressurized. In the process, the gas temperature also increases and it makes it easier to process the heat transfer due to take place in the next step.

2. The high temperature, high pressure gas then enters the heat-exchanging (condenser) coils and releases the heat to the surroundings. In this step, the refrigerant gas becomes a sub-cooled high pressure liquid.

3. The high pressure liquid then passes through the expansion valve that instantly reduces the pressure and temperature of the refrigerant.

4. The cold liquid refrigerant goes through the evaporator, absorbing heat energy from the surroundings. The heat absorbing leads to an evaporation of the refrigerant liquid into low pressure gas. The low pressure gas then flows back to the compressor and the cycle continues.

In case of AWGs, the heat absorbed by the refrigerant in the evaporator step cools the coils and, therefore, the water vapor in the air being passed over them condenses on the cold coil surfaces. This water is then collected and filtered to generate pure, drinking water.

Thermoelectric Cooling - Peltier Effect

This principle is presently used in few commercial dehumidifiers and refrigerators. It works on a principle called Peltier effect that generates a temperature difference across a peltier element (thermocouple) when an electric current is passed through it. The key advantages of using this principle are that it makes the devices highly compact, noiseless and light in weight. However, this technology is not scalable and cannot be presently used for high power applications (see Figure 14).

Figure 14: A peltier element

Desiccant based technology

Desiccants are chemical substances that have a unique property to absorb moisture from atmosphere. Desiccants may absorb atmospheric moisture by several methods: by physical absorption, forming chemical bonds (chemisorption) or adsorption (surface phenomenon). The water intake capacity of the desiccants depends on their physical composition, chemical properties and atmospheric conditions. Silica Gel, Calcium Chloride and Lithium Chloride were some of the desiccants that the team studied in detail.

The team also studied several other substances that may be used to extract large amount of moisture. These included super absorbents, molecular sieves, glycols and other polymers (see Figure 15).

• Super Absorbents: These are water-gel polymers that may absorb up to 400 times their own weight. These are presently used in baby diapers. The absorbed water may easily be extracted by adding salt to the gel.

• Molecular Sieves: These are materials containing tiny pores that are used as an adsorbent for gases and liquids. They can absorb water to up to 22% their own weight. Some of the many types of molecular sieves are: Activated carbon, Lime and Zeolite.

• Glycols: The key advantage of glycols is that they can be easily regenerated. These are presently being used in several gas dehydration systems.

Figure 15: Different desiccants – a) clay desiccant, b) lithium chloride desiccant (salt), c) calcium chloride desiccant (salt) and d) calcium chloride desiccant (salt)

Patented Technologies

Besides the technologies normally available in the public domain, the team also focused on the various patented processes for water extraction from air. Most of the patents found in the literature were developed for minimal energy input but were silent on the efficiency of extracting water. Many of the processes used the Vapor Compression cycle with an improved feature to increase its efficiency. There were also some processes using pressure chambers. An exhaustive list of the related patents can be found in Appendix 4.

4.3.3 Existing Products

The team explored the various commercial products and services available throughout the world in an effort to understand the design problem more closely. The search domain included all the various facets of the portable water's life cycle, ranging from its production techniques to purification methods and transport mechanisms.

Atmospheric Water Generators

All the AWGs presently available use the Vapor Compression Cycle. Their performance is highly unreliable and they do not work for relative humidity values less than 40%. There is also an urgent need to improve the product design and create a new interactive user experience. See Figure 16 for examples of AWGs.

Figure 16: Two different AWGs, from Immerse Global and Aquosus

Water Treatment Products

Since an important project focus area is to provide great tasting, clean drinking water to the user, the team benchmarked several water purification mechanisms presently in existence. They ranged from the study of state of the art ozonization techniques to the simple solar based water cleaning processes.

- Stationary Water Filters.
- Portable Water Filters.

4.3.4 Benchmarking Exercises

While still in the preliminary stages of the project, the team considered it imperative to get a hands-on experience of the various principles and technologies that the project involved. As a result, the team went on to perform various benchmarking exercises. These included conducting a condensation experiment to gauge the magnitude of the design problem at hand and disassembling several household appliances. Among the various products that the team studied were a hair drier, a domestic refrigerator and a Kenmore dehumidifier (see Figure 17 to Figure 19). For detailed information about benchmarking exercises see Appendix 5.

Figure 17: Condensing experiment and dissembly of Kenmore dehumidifier

Figure 18: Dissembled hair drier

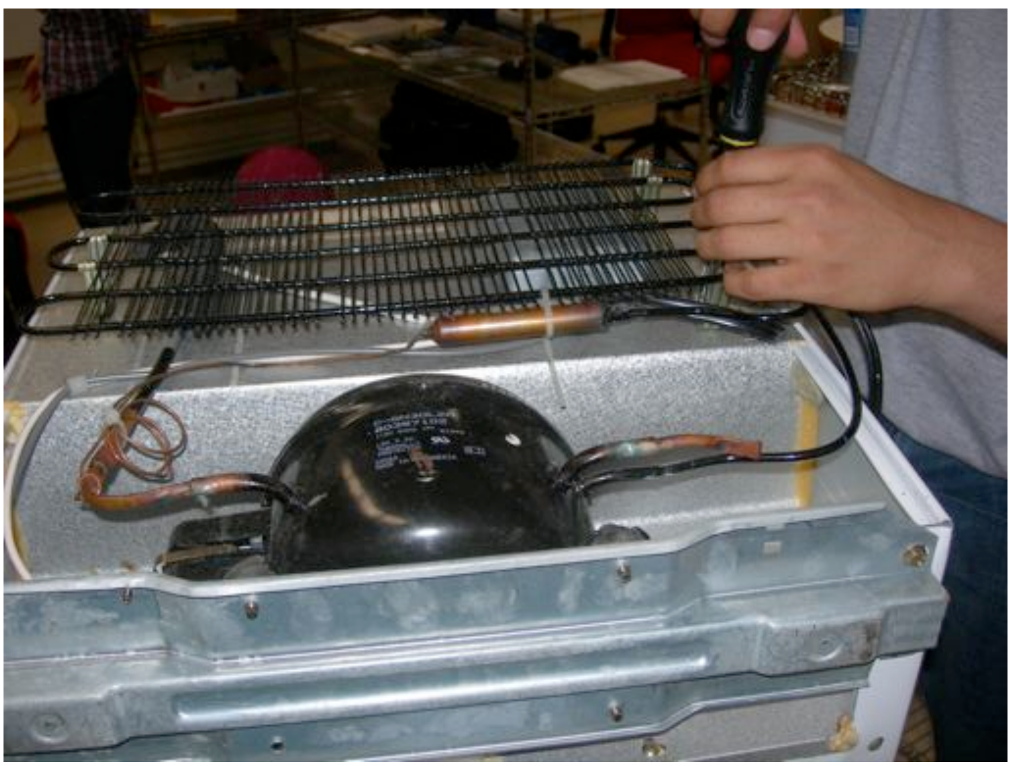


Figure 19: Disassembled refrigerator

The team also disassembled an existing product provided by the corporate liaison. An analysis of the present product gave it an insight into the various technologies presently being employed in a standard AWG.

The machine was run under different climatic conditions and the amount of water generated measured in an effort to get an idea about the performance of the current AWGs. It was found that the machine performed much below its rated performance levels (see Figure 20).

Figure 20: The dissembling of the existing product

4.3.5 Lesson learned from Benchmarking

The extensive benchmarking process proved highly instructive and beneficial to the whole team. The team was able to learn the various underlying processes, their controlling parameters, advantages and drawbacks. Through the process, the team received a sound technical background and gained a first hand experience of the various challenges involved in the project. Some of the more important lessons learned in the benchmarking process that served as the guidelines for the subsequent prototyping activity were:

General Lessons

1. The absolute water content in air depends on two parameters – Relative Humidity and atmospheric temperature. It is, therefore, required to include desired operating temperature conditions as one of the design criteria (Discovered Requirement)

2. At some places, there might be, at times, huge diurnal variations in RH values. One may harness this fact as part of a possible design solution.

3. The condensation process is not a viable option to generate water from air. As relative humidity decreases, it becomes increasingly difficult to get water out of the air through this process.

4. Exploring alternative sources of water like soil or rocks may be a viable option in some places.

Technology based Lessons

1. Vapor Compression cycles are the norm in the AWG industry.

2. However, vapor cycles do not work well for RH values less than 30%.

3. Desiccants may be a good solution for low relative humidity conditions.

4.4 Critical Function Prototypes

Based on the results of the benchmarking process, the team identified the desiccants and the peltier effect as two of the candidate technologies that had the potential to be successfully harnessed for water generation under extreme conditions. Therefore, the team decided to explore these two technologies further. Besides, there were a few creative ideas relating to the improvement of the existing heat transfer process that the team wanted to pursue.

The key questions that needed to be answered were:

Question 1: How do desiccants behave under extreme conditions (RH < 30%)? Which desiccants are most efficient under these conditions and by how much?

Question 2: How to regenerate the water once the desiccant has absorbed it?

Question 3: Can Peltier devices be successfully used to extract water from atmosphere?

Question 4: Is there a better way to increase the heat transfer between the air and the cooling element?

The four critical function prototypes built by the team at three separate locations were aimed at answering each of the above questions. Since vapor compression cycle was a fairly established and well documented technology, the team did not feel the need to test it further. Besides, the team had already established its efficacy under dry conditions during the benchmarking process.

4.4.1 Prototype 1: Comparing different desiccants

Questions Addressed

The behavior of the desiccants under humid conditions (relative humidity of 40-60%) is fairly well known. However, there was an ambiguity regarding their behavior under dry conditions (RH < 30%). A well characterized performance data for desiccants under extreme climatic conditions was essential for the team to proceed further with the technology development.

There was also a need to have a comparative study of different types of desiccants in order to ascertain the best desiccant for the purpose. Therefore, the team decided to pursue with this prototype. Through this prototype, the team also gained hands on experience with the handling of different types of desiccants and the subtle nuances involved.

Prototype Details

An artificial controlled humidity chamber was built in order to maintain the ambient humidity at desired levels during the course of the experiment. This was done by putting a humidifier inside a closed glass chamber. A wind tunnel was also made with an air blower at one end. The different desiccants to be analyzed were put inside the wind tunnel. This prototype was built at Luleå University of Technology, Sweden (see figure 21).

Figure 21: Experiment with different desiccants

The different desiccants that were tested were (see Figure 22):

- Calcium Chloride ($CaCl_2$)
- Lithium Chloride (LiCl)
- Water Gel Crystals
- Water Gel Powders

Figure 22: Tested desiccants

Results

	$CaCl_2$	LiCl	Liquid LiCl	Water Gel Crystal	Water Gel Powder
16-17°C & 34-36% RH, 1h	0.88%	0%			
20°C & 80% RH, 13h	10.43%	580%		50%	40%
19-20°C & 34-35% RH, 10.5h	8.57%	90%	60%	100%	0%

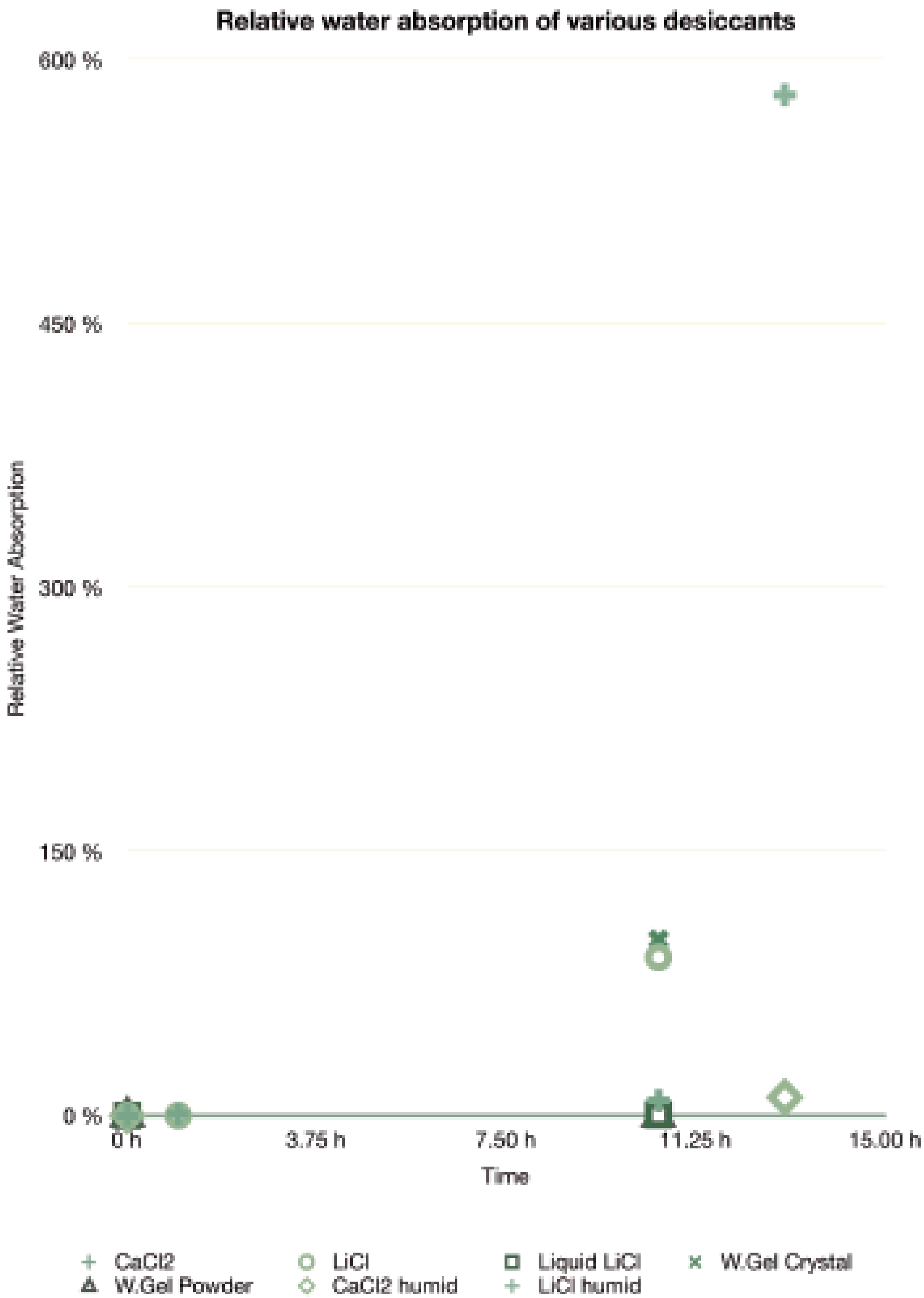


Figure 23: Results from desiccant experiment

Sources of error

- In case of some of the desiccants, due to the extremely low quantities used, the error in the measurements is very high. For instance, in case of water gel crystals, an error of 1 gram may give rise to considerable percentage changes in water absorbing capacity.
- On the other hand, using large quantities of the desiccants might also not be useful as all of it might not be properly exposed to air. This explains low water absorption for $CaCl_2$ at 80% RH.

Lessons Learned

The prototyping exercise helped the team gain a better overview of the desiccant behavior under dry conditions. The key lessons learned were:

- Most desiccants seem to work reasonably well even at low humidity levels. This is promising especially when compared to vapor compression cycle whose efficiency decreases drastically at low humidity values.

- LiCl is the best desiccant used. Even at 35% RH, it absorbed water upto 90% of its own weight in 10 hours.

- Water Gel crystals also seem a promising opportunity at the moment. The team intends to explore them in greater detail in future.

- Calcium Chloride, though a commonly used drying agent, was not found to absorb large amounts of atmospheric water.

4.5.2 Prototype 2: Water extraction from desiccants using RO process

Questions Addressed

Though most desiccants absorb reasonably well under dry conditions, extracting the absorbed water back from the desiccants presently pose a major bottleneck in the further development of the desiccant technology. One method that was proposed as a part of the benchmarking process was the use of reverse osmosis (RO) to extract water from the desiccant-water system.

Theory

The process uses a semi permeable membrane. This membrane has microscopic openings that allow water molecules, but not larger particles, to pass through. When an external pressure is applied, water is forced through the membrane leaving behind the solute particles. As a result, the water on the other side of the membrane is cleaner, while that left behind has an even higher particle concentration than before (see Figure 24).

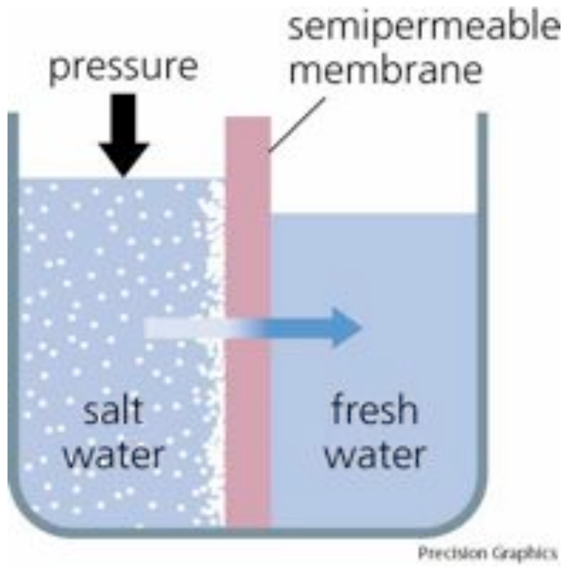


Figure 24: A schematic for the reverse osmosis process

The idea was to pass the desiccant-water solution through an RO filtration process and test whether one would get pure water on the other side of the membrane, leaving the desiccant behind.

Prototype details

A commercially available Reverse Osmosis drinking water system was adapted for this purpose (see Figure 25). The pressure required for the RO process was manually generated using a standard bicycle pump. The filtered water and the waste water were collected through pipes in water containers. The prototype was set up at Stanford University (see Figure 26).

The desiccant-water mixture (10,000 ppm) was passed through the RO system. The waste water collected was again passed through the system and the process was repeated a few times till no further purification took place.

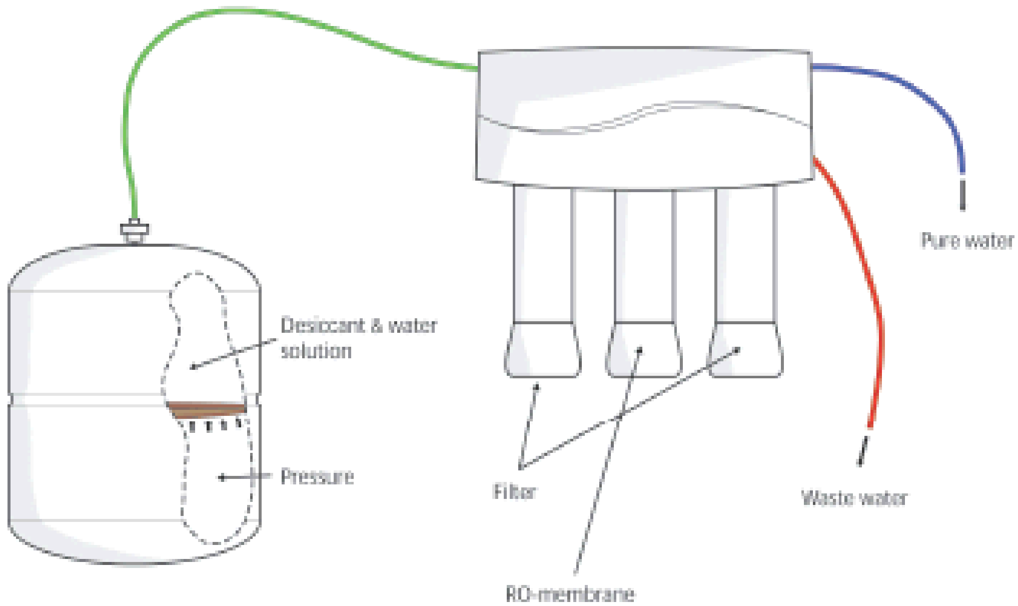


Figure 25: The RO system

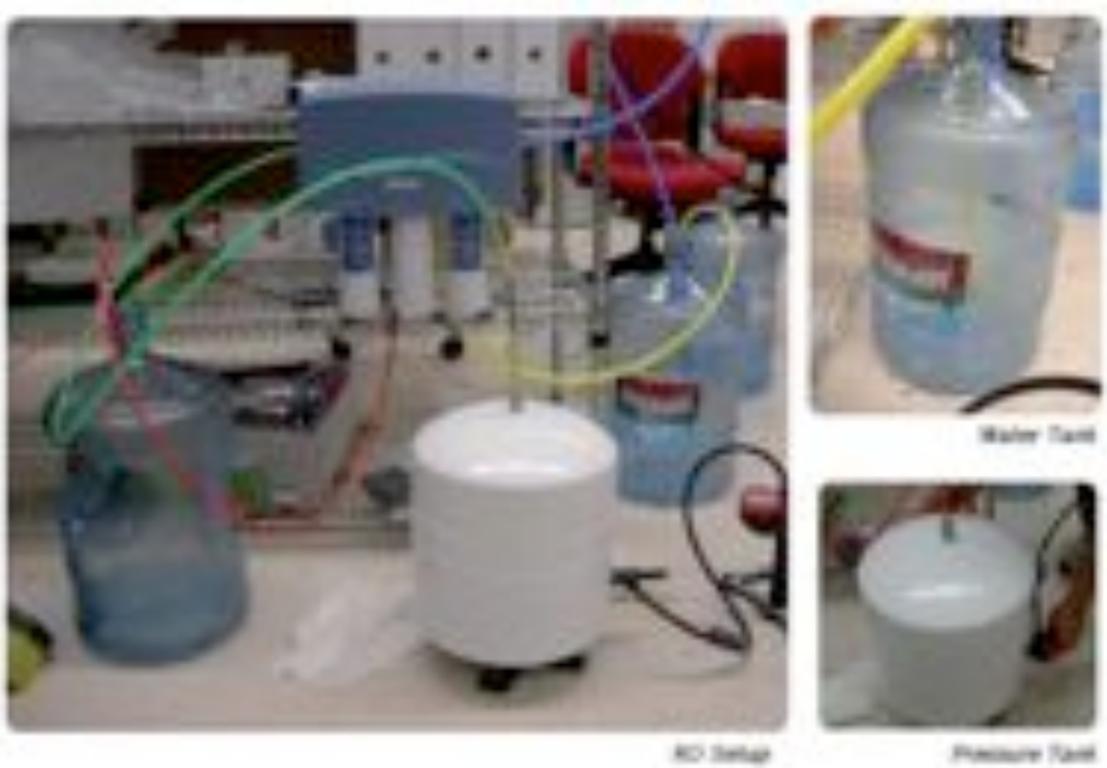


Figure 26: RO experiment setup

Results

Figure 27: TDS graph

The pure water stopped coming out of the system after the fourth time. The TDS count, a measure of impurity content in water, in the waste water kept increasing at each successive round. This was as expected.

Lessons Learned

This prototype was very significant as it involved testing of a new idea that was critical to the implementation of desiccant technology in the intended device. The team gained some significant insights into the RO process and the desiccant-water mixture. Some of the key lessons that the team learnt were:

- The amount of clean water obtained was insignificant compared to the large quantities of waste water that was generated. For a given amount of water used, only about 10% clean water was obtained. This limited the use of this technique in practical applications.
- It is hard to extract pure water out of the desiccant-water mixture using this process. This is due to the fact that the efficiency of the RO process reduces as the concentration of solute particles in the incoming water stream increases. In case of desiccant-water mixture, the solute (desiccant)

concentration is high to begin with (close to 100%). This reduces the filtration efficiency drastically.
- Even though the RO filtration efficiency is very low for desiccant-water mixture, one may still expect to get some clean water out upon the application of a large pressure. The team plans to pursue this possibility further in near future. The adverse effect of the extremely high pressures on the membrane needs to be looked into though.

4.5.3 Prototype 3: Water Extraction using Peltier element

Questions Addressed

The objective of this prototyping process was to get a better idea about the working principles of a peltier cooler. The key question addressed was whether a peltier cooler may be used to condense water out of the atmosphere. The various controlling parameters of the process were altered to optimize the condensation rate.

Prototype details

A Peltier cooler was used to achieve condensation by cooling the warm surrounding air on the cold side of the element. A Peltier cooler is a solid-state active heat pump that transfers heat from one side of the device to the other side against the temperature gradient, with consumption of electrical energy. The prototype was built at the Royal Institute of Technology, Stockholm (see Figure 28).

In particular, the following effects were analyzed:
- The area of the cooling plate was changed to analyze its effect on the condensation rate.
- The effect of imperfections on the condensation rate was also studied.
- The angle of the cooling plate was changed to see the affect of drainage on the condensation rate, if any.

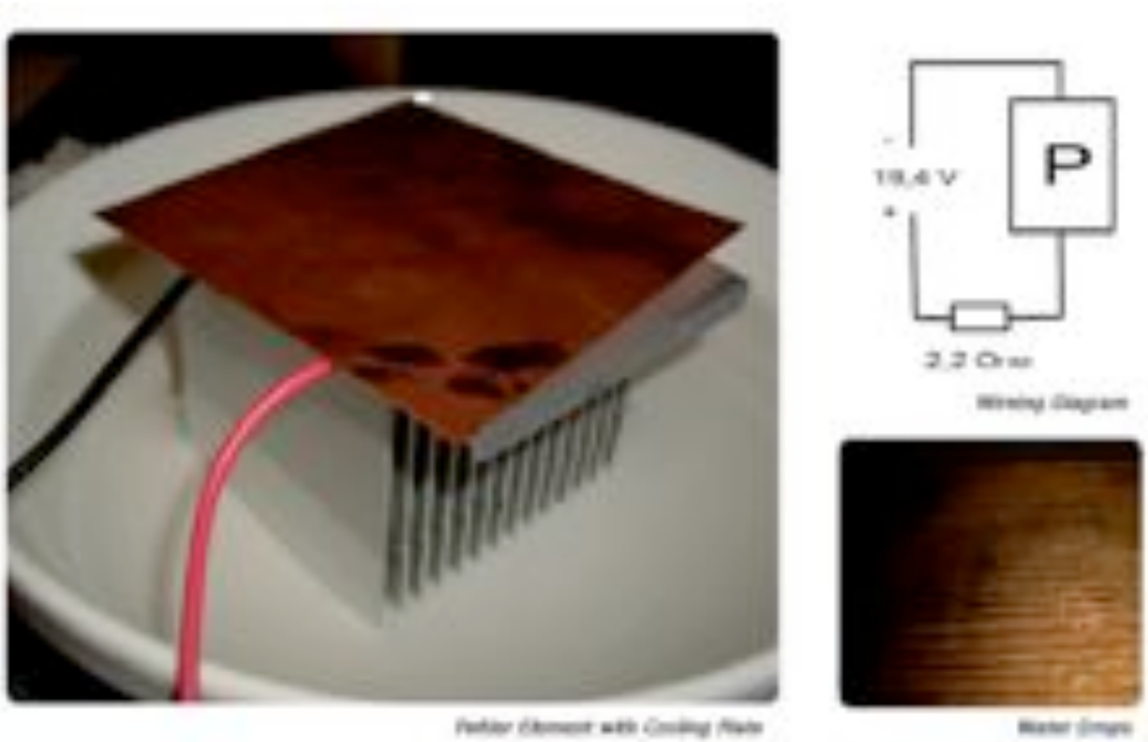


Figure 28: The peltier experiment

Results

Experiments were made during two days under different circumstances and different conditions. The results are presented below in the following chapter.

Day 1:

Temperature: 24 °C	Relative Humidity: 35%	Metal: Cu	Size: 4*4 (units in cm)
Experiment	**Time (min)**	**Result (Scale: 0-5)**	**Additional Info.**
1	1	Ice on sheet (0)	Horizontal
2	3	Ice on the sheet (0)	Added cooling elements to keep the heat down on the hot side, horizontal

Day 2:

Temperature: 24 °C	Relative Humidity: 46%	Metal: Cu	Size: 8*8
Experiment	**Time (min)**	**Result (0-5)**	**Additional Info.**

3	4	-	-
4	20	Moisture (1)	-
5	10	One or two water drops (2)	Scratches on metal, horizontal
6	20	Condensed water all over the sheet (3)	Scratches on metal, horizontal
7	20	Droplets covering the sheet (4)	Horizontal
8	20	Homogenous layer of moisture (3)	Peltier tilted 45°
9	20	A high concentration of water, but only on a limited part of the sheet (the part in contact with the cooling element and some centimeter above) (5 in the parts where condensation was achieved)	Peltier tilted 90° Size: 4*16

Lessons Learned

The lessons that were learnt from the process were:

- The smaller sized cooling plate became so cold that the condensed water froze. On the other hand, if the plate is quite large, the cooling might not be uniform and sufficient to decrease the temperature below dew point. Hence, a proper optimization of the cooling plate area is essential
- It is easy to get moisture on the sheet but when the drop increases in size it is hard to make it drip down. One should try another kind of surface with less friction. If the droplets are not removed for a long time, they form an insulating layer, thus inhibiting further condensation.
- The surface imperfections had no effect on the condensation rate, but it affects the droplet-dripping rate as explained above.

- The hot side of the Peltier element needed to be constantly cooled. This entails additional energy, and increases the overall energy consumption

4.5.4 Prototype 4: Better Heat transfer

Questions Addressed

The purpose of this prototype was to test a better way of enhancing the heat transfer rate between the air and the cooling medium. Conventional methods, currently being employed, involve heat transfer between a cold metal surface (evaporator coils in an AWG, or cooling plate in a peltier cooler) and the passing air stream. The idea was to bubble the air through a liquid cooling medium. This would enable better mixing between the medium and the incoming air and, hence, would result in better condensation rate.

A natural extension of this logic would be to bubble air through a liquid desiccant to further enhance the desiccant-air interaction.

Prototype details

A container filled with oil was taken and cooled below the dew point (6°C under experimental conditions). In the first case, air from lungs was passed through the oil for 2 minutes. In the second case, air was pumped through the oil using an air pump for 15 minutes. The air temperature was 21°C and the humidity 80% RH. When the temperature rose, snow was stacked around the container to keep the temperature low. The prototype was set up at Luleå University of Technology, Sweden (see Figure 29 to Figure 32).

Figure 29: Blowing bubbles in the oil

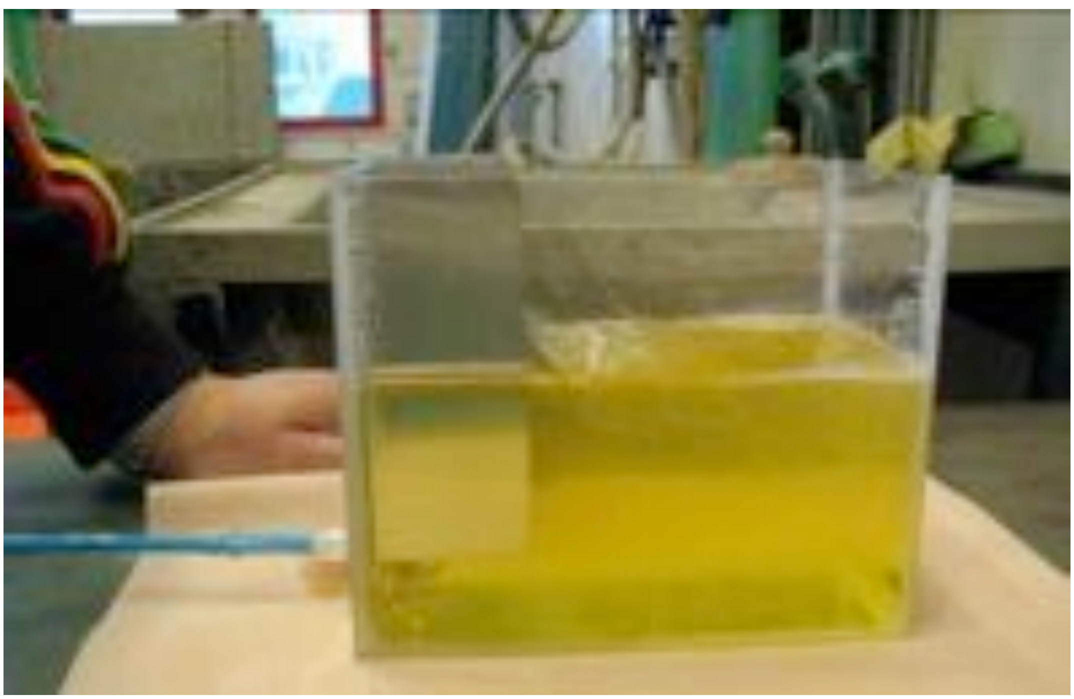


Figure 30: Air being blown into the oil through mouth

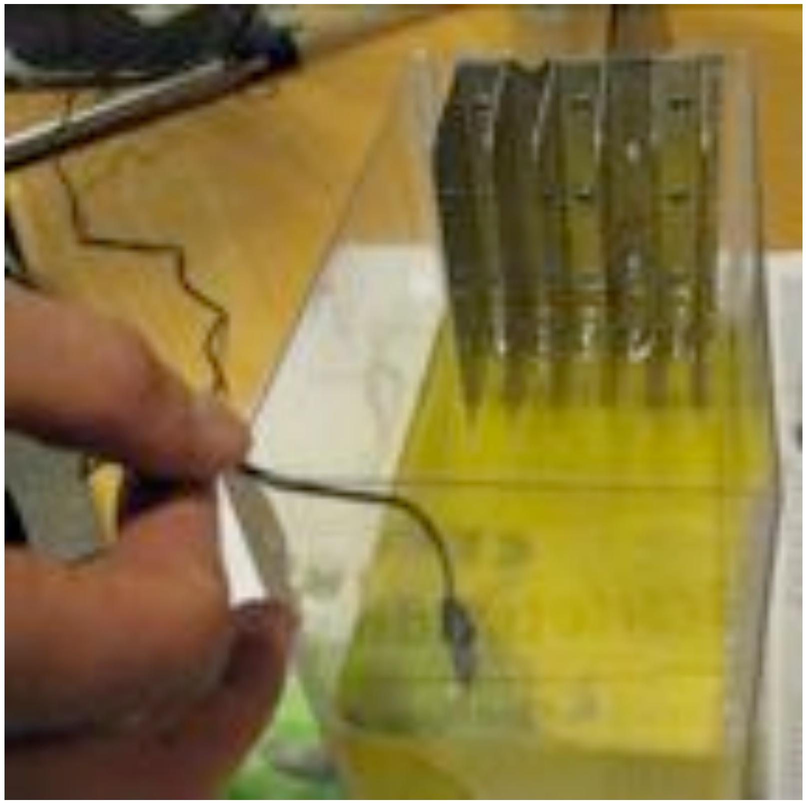


Figure 31: Air being blown into the oil through an air pump

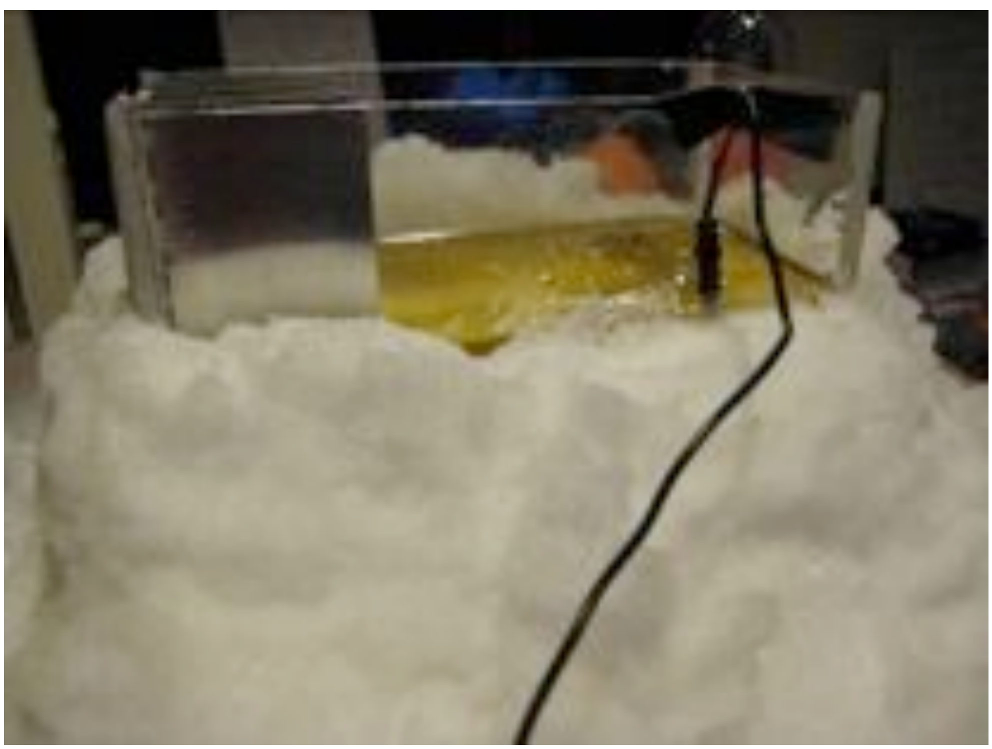


Figure 32: The fluid test using snow to keep the oil cold

Results

When the air was manually blown though mouth, one could immediately see clouds being formed in the oil. These clouds soon settled down as small water bubbles at the bottom.

One could also clearly observe very small water bubbles being formed when the air pump was used to blow in the air. However, in this case the number of bubbles formed were much less. This is expected since the exhaled air from the lungs is often saturated (100% RH).

Lessons Learned

The lessons learnt as a result of this prototype were:

- Condensation does, indeed, take place using this method.
- If the liquid being used is lighter than water, the water bubbles would settle down, thus eliminating the risk of water loss due to evaporation.
- For low air speeds, the mixing between liquid and air is enhanced and condensation rate is high. However, if the air flow is increased, it might slightly reduce the heat transfer rate

Some possible ideas that were generated as a consequence of this prototyping exercise were:

- A higher liquid column should increase the pressure at the bottom of the container and this should make condensation easier without any additional energy consumption.
- Using a better conducting liquid should increase the condensation process
- Bubbling air directly through liquid desiccants is also a promising option that the team intends to pursue in near future.

4.5 Dark Horse Prototype – Microwave Heating

4.5.1 Questions addressed

Having reached a point where the team had a direction to proceed in, the team decided to explore a completely different tangent to see if there was any other direction that could be used to achieve the design goals. The main question addressed in this prototype was whether it was possible to use the concept of microwave heating to make a stratified layer of moisture laden air that could then be used to extract water.

4.5.2 Concept – The key idea

The main concept was derived from the heating concept of a microwave. Microwave technology uses electromagnetic waves that pass through the material, causing only the water molecules to oscillate (via resonance) and generate heat. This heating is carried out from within the material, unlike conventional heating where only the surface is heated, and hence is, in theory, more uniform throughout the whole object being heated.

Building upon this concept, the team ran an air stream into a microwave oven. The idea was that the microwaves would excite the water molecules in the air, generating heat. This would raise the temperature of the water molecules in the air compared to the other molecules present in the air. This increase in the temperature would cause the water molecules to rise up within the air stream itself due to natural convection.

Thus from the stream of air that is injected into the microwave, the output would be a stratified stream of air which has a higher density of air molecules in the top layer. Subsequently the top layer of this stream can be separated out, and used to generate water (see Figure 33).

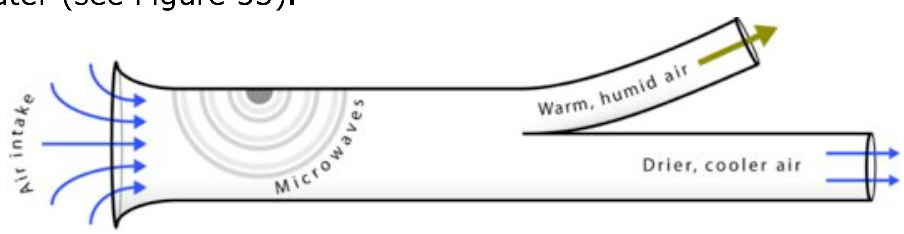


Figure 33: Microwave Prototype: The Idea

4.5.3 Prototype details

The team conducted a number of different tests to explore the efficacy and applicability of microwaves to humidity stratification. In short, two different cases were tested:

1. Static Air case: In this case, there was no external air flow inside the chamber. The air inside the chamber was allowed to stratify due to microwave heating.
2. Moving Air case: In this case, a fan was used to blow air into the microwave oven. It was necessary to test this case since in the actual implementation of the process, one would constantly need to replenish

the heated air inside the oven in order to get a continuous process (see Figure 34 and Figure 34).
For a detailed description of the prototype, see Appendix 7.

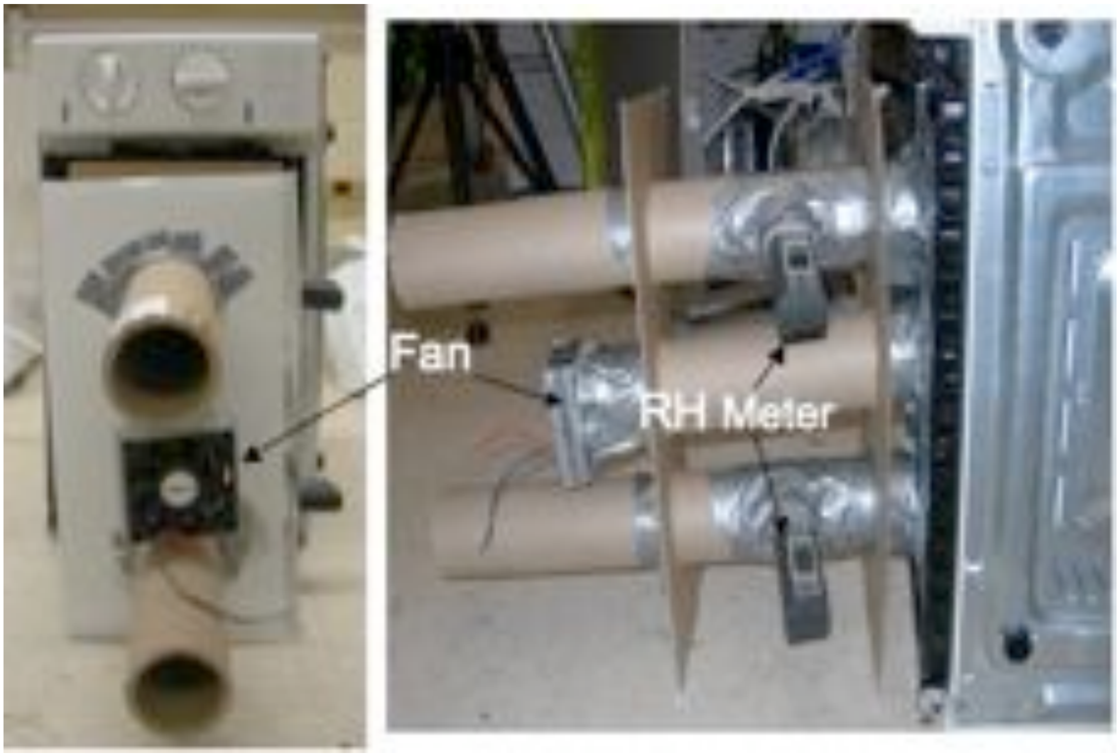


Figure 34: The Dark Horse Prototype for the moving air case. The fan was used to push the air in and the RH meters in the two ducts measured the RH segregation.

Figure 35: Holes drilled to the back wall for air flow and duct tapes used to close other holes inside the microwave

4.5.4 Results

It was hard to get any conclusive results from the experiments. There were some runs in which the results conformed to the concept; however the advantage gained in getting a slightly denser stream of air from the initial input was far less than the amount of power that the microwave was consuming. Utilizing this much power could vaporize a significantly larger amount of water if the energy went directly into vaporizing the water. The vast amount of energy that the microwave consumed can be gauged from the fact that additional cooling was required to keep the microwave body and the magnetron from overheating (see Figure 36).

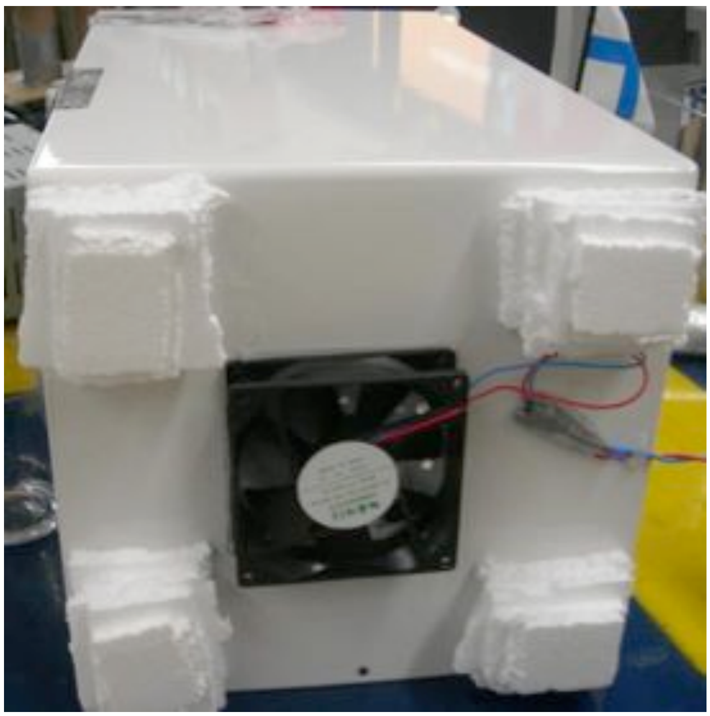


Figure 36: An extra fan used to circulate air through the magnetron and inside oven walls

4.5.5 Lessons learned

The learning from this prototype was that microwave heating cannot be used to economically extract water from air. The power consumed to raise the temperature of the water molecules is very large compared to the degree of RH segregation achieved. The readings from the meters were also not very consistently obtained, with large variations with each run. Thus the team decided not to continue with this idea, and to pursue the desiccant technology further.

4.6 Other Exploratory Prototypes

The results from the Critical Function prototypes had revealed that the desiccant based technology might be an ideal solution for the design problem at hand. There are two ways in which one can implement the desiccant technology – using desiccants either in the solid form or in liquid form. Besides, the team had a few innovative ideas through which the efficiency of the Vapor compression cycle could be improved. The team decided to pursue each of these technologies in parallel and pursued a number of exploratory prototypes throughout the winter quarter. These prototypes helped the team comparatively analyze the merits of each technology and the team finally converged on the liquid desiccant technology by the end of the winter quarter.

4.6.1 Exploratory Prototype I: Pre-cooled Vapor Compression Cycle

Questions addressed

The main question addressed in this prototype concerned the possibility to improve the efficiency of the vapor compression cycle by using a pre-cooling system. This prototype intended to prove the practical feasibility of using the cold air stream exiting the evaporator to pre-cool the ambient air stream entering the evaporator, thus creating a cooling effect.

Concept – The key idea

Most of the conventional AWGs use a Vapor Compression cycle (VCC). The basic principle of VCC has already been detailed in Section 4.3.2. In the conventional AWG set up, the cold air stream coming out of the evaporator is directly exhausted to the atmosphere (through the condenser). However, in this prototype the concept was to use this cold air stream to 'pre-cool' the incoming evaporator stream. Thus, the incoming stream would already be colder than the ambient by the time it would reach the evaporator coils. This would decrease the amount of cooling required at the evaporator for water generation and improve the efficiency of the cycle (see Figure 37 and Figure 38). For detailed prototype specifications and results, see Appendix 8.

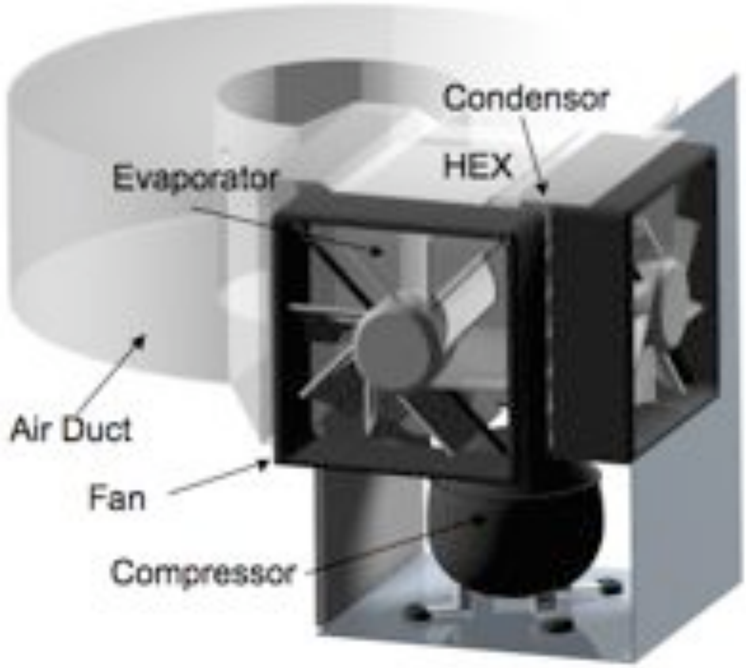


Figure 37: Mockup of the pre-cooled VCC prototype

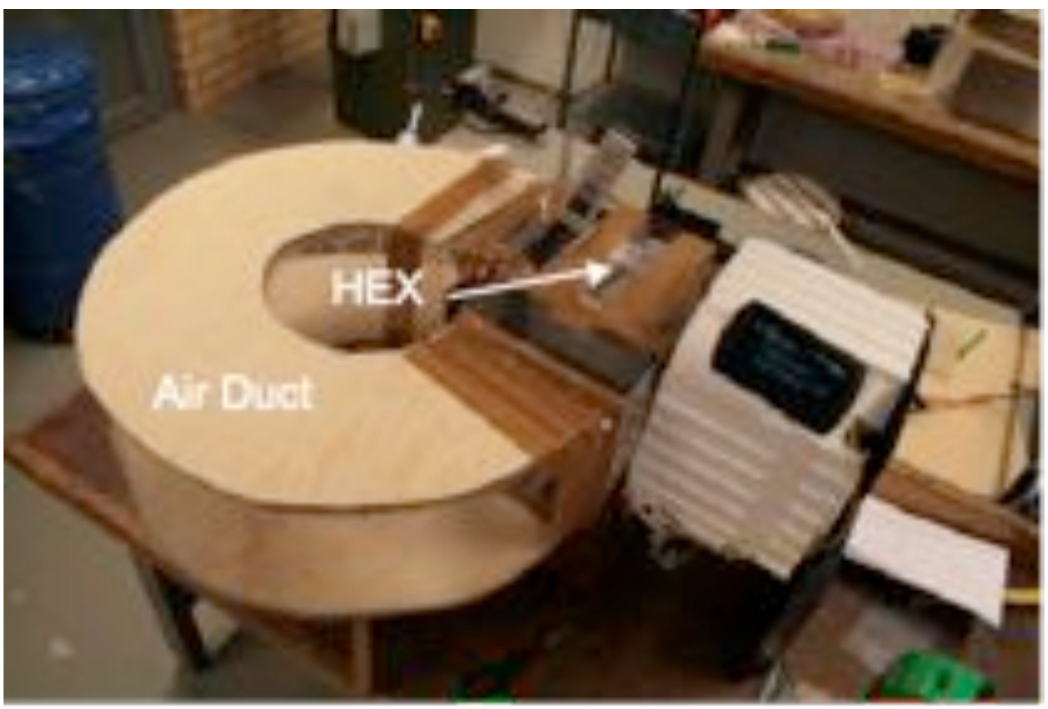


Figure 38: The final Pre-cooled VCC prototype. The ducts were added to divert the airflow through the Heat exchanger (HEX)

Lessons Learned

The detailed results of the tests can be seen in Appendix 8. The prototype managed to lower the temperature of the processed air entering the evaporator from 8.4°C down to 4.9°C. This means that the air was 41.6% cooler than without the pre-cooling. This results in a lower additional energy demanded in order to cool the air down to the required temperature.

The key lessons learned were:

- Pre-cooling works
- Need to minimize losses to the surrounding by
    - Using material with better insulation properties.
    - Using a small contact area with the surroundings so that losses are minimized.
- Need to minimize flow losses.
- Need to use a fan with the right qualities; built for this kind of duct, with high friction.
- Extra product cost because of heat exchanger, duct and fan.
- Due to the heat exchanger and extra ducting necessary, the product will be bigger and heavier. However, there are room for improvements.

With the addition of pre-cooling to the vapor compression cycle the cost for the product will increase, the duct, cross-flow heat exchanger and extra fan/more powerful fan are the extra components needed. These disadvantages can, however, be offset by the increased efficiency.

4.6.2 Exploratory Prototype II: Desiccant Wheel - VCC

One idea that the team actively pursued during the winter quarter was the use of solid desiccants in the form of a rotating desiccant wheel. The idea behind this prototype was to couple the desiccants with the conventional vapor compression cycle in order to harness the advantages of both the processes. The objective was to use desiccants in an ingenious way to increase the amount of moisture in the air stream that was afterwards passed through the evaporator coils of VCC to extract water.

Questions Addressed

The key questions and functions that were addressed through this prototype were:

- Is it practically feasible to couple desiccant wheels with the VCC?
- How much water can be extracted?
- What is the energy consumption per liter of water produced?
- Does this process give better results than the conventional VCC?

- What are the important parameters of the system?
- What are its benefits/drawbacks?

Concept – The key Idea

Desiccant Wheels are typically employed in industrial desiccant based dehumidification systems. These are rotating wheels that are impregnated with solid desiccant particles (ex. Silica gel or molecular sieve). As the wheel rotates, the desiccant passes alternately through the incoming 'process air' where the atmospheric moisture is adsorbed by the desiccant and through a 'regenerating' zone where the desiccant is dried and the moisture expelled. The wheel continues to rotate and the adsorbent process keeps being repeated (see Figure 39 and Figure 40).

Figure 39: A commercial desiccant wheel

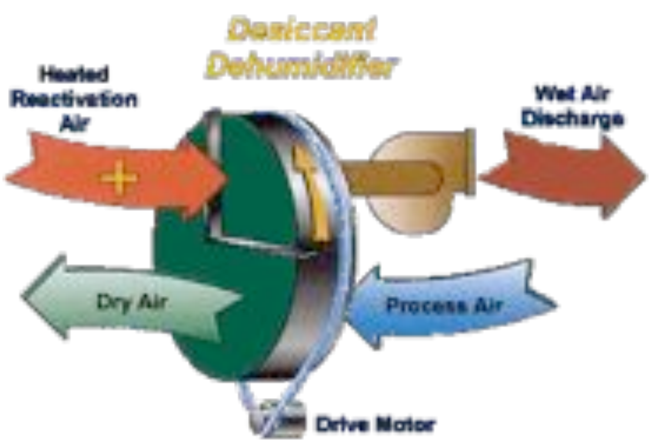


Figure 40: Schematic of the desiccant wheel operation

Typically, regeneration is performed by passing another stream of hot 'regenerative air' that picks up moisture from the wheel due to its high temperature (and hence, enhanced water capacity). The regenerative air is heated using heaters. Under normal operation, about three-fourths of the desiccant wheel is exposed to the incoming 'process air' and the remaining one-fourth to the 'regenerative air'.

A desiccant based system is able to extract water from air even at very low relative humidity. The Vapor Compression system, on the other hand, does not perform well in dry conditions but becomes economical and more efficient in humid conditions. It is also a well-characterized and researched process and hence, is easier to implement. The team decided to design a system that harnessed the advantages of both these systems and came up with several alternative designs to couple the two effectively.

Figure 41 show the schematic and picture of the final design that was implemented. At any given time, the process air passed through three-fourth of the wheel before being exhausted back into the atmosphere. The moisture (from the process air) that was thus absorbed by the desiccant wheel was released into the regenerative air that passed through the remaining one fourth of the wheel. This moisture transfer was accomplished due to the fact that though the absolute amount of moisture in the regenerative air is same as that in the process air, its water holding capacity was greatly enhanced due to its high temperature. Since the regenerative airflow is only one-third of the process airflow, the absolute water content in the regenerative air is greatly increased.

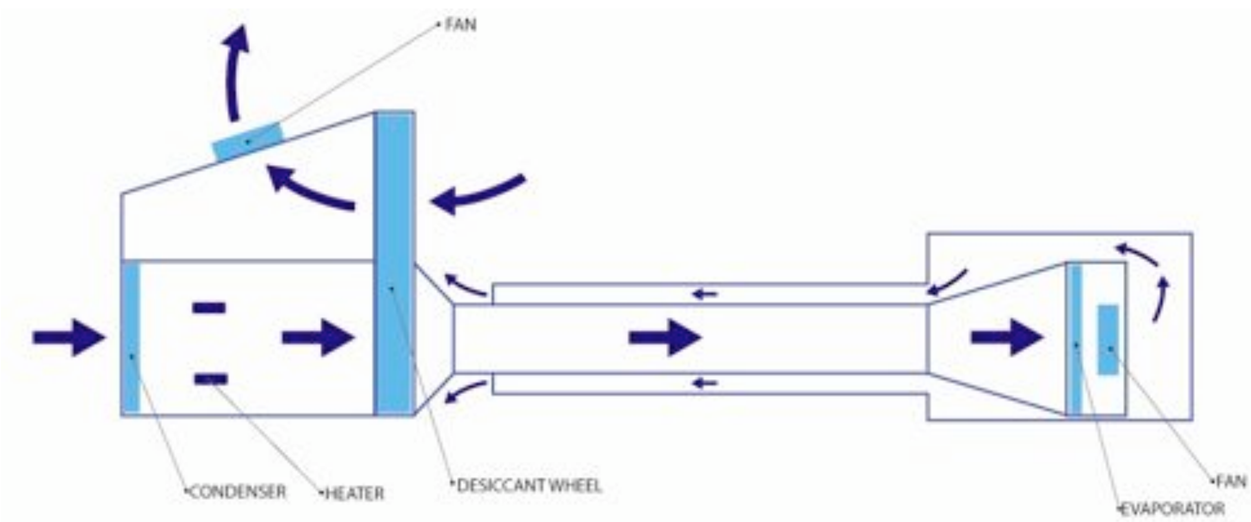


Figure 41: Schematic of the final desiccant wheel-VCC idea that the team pursued

Before being passed through the wheel, regenerative air is passed through the condenser coils of the VCC and gets heated in the process. The condenser coils get cooled in the process. An extra set of electric heaters further increase the air temperature to desired temperature of 120°C necessary to regenerate the desiccant wheel.

This high moisture content regenerative air is then passed through the evaporator coils. Here, the air gets cooled down and the condensed moisture is thus collected. The cold air is then passed over the top of the hot regenerative air channel to ‘pre-cool’ the air, thus optimizing the process. Figure 42 shows the prototype that was built on this principle. For a more detailed description of this prototype, other sub prototypes and results, see Appendix 9.

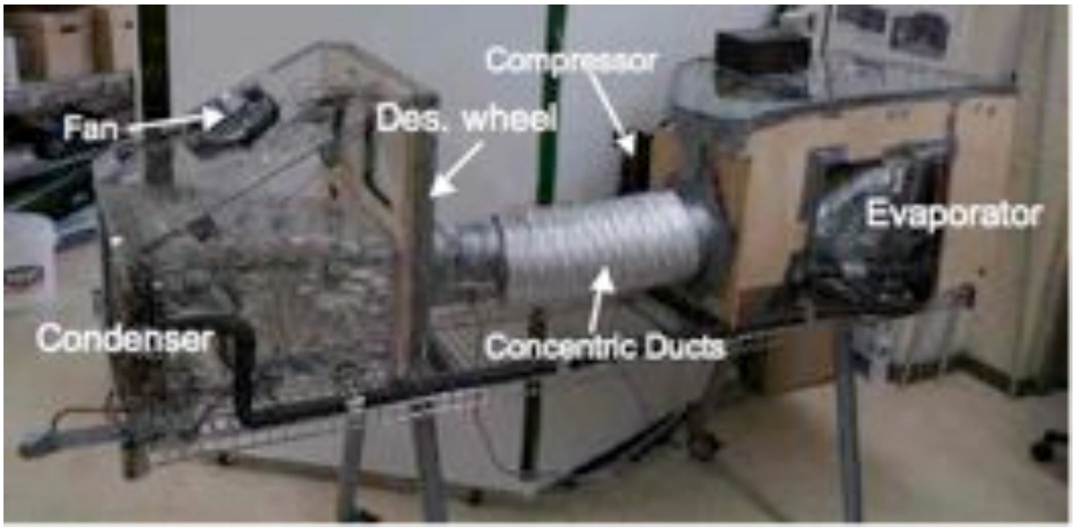


Figure 42: The Desiccant Wheel-VCC prototype

Lessons Learned

Although the team was unable to test the desiccant wheel-VCC system in its entirety due to overheating issues, the entire process was a great learning experience for the entire team. Few lessons that the team learned in the process were:

- The entire desiccant wheel-VCC system was extremely large, bulky and cumbersome. As such, it will be hard to implement this technology in a commercial portable AWG.
- The design is not very flexible in the sense one cannot tinker much with the position of the regenerative air ducts, wheel, compressor or condensers, once the refrigerant pipes have been rewelded.
- The vapor compression cycle is very sensitive to its operating parameters, namely, the refrigerant charge, the air flow rate, air temperature and coil locations. Even a slight change in any of these parameters may severely hamper the performance.

- Even a slight modification in the VCC system consumes much time, energy and manpower. This is because the services of experienced HVAC professionals need to be hired every time a modification needs to be made. Therefore, it becomes very hard to pursue this technology given the time constraints of the project.

- The heating of the regenerative air requires large amounts of energy. The prototype used two electric heaters of 450W each. However, they were barely sufficient to heat the regenerative air to the desired 120°C temperature. This also imposes severe restrictions on the airflow rate that cannot be large in the regenerative chamber. Thus, this technology is less energy efficient compared to the liquid desiccant based system.

4.7 Functional System Prototype : Liquid Desiccant Cycle (LDC)

4.7.1 Questions Addressed

- What are the important parameters in the liquid desiccant cycle?
- How much water can be extracted per hour?
- How much energy is used per liter of extracted water?
- How much air can be processed per hour?
- What are the benefits/drawbacks with this concept?

4.7.2 Concept - The Key Idea

The objective of this prototype was to build a fully functional liquid desiccant based water generation system that does not need to be coupled to a vapor compression cycle for efficient operation. The entire exercise involved building, testing and analyze several sub-prototypes (see Appendix 10). The insight gained from the intensive testing resulted in the development of a process schematic shown in Figure 43.

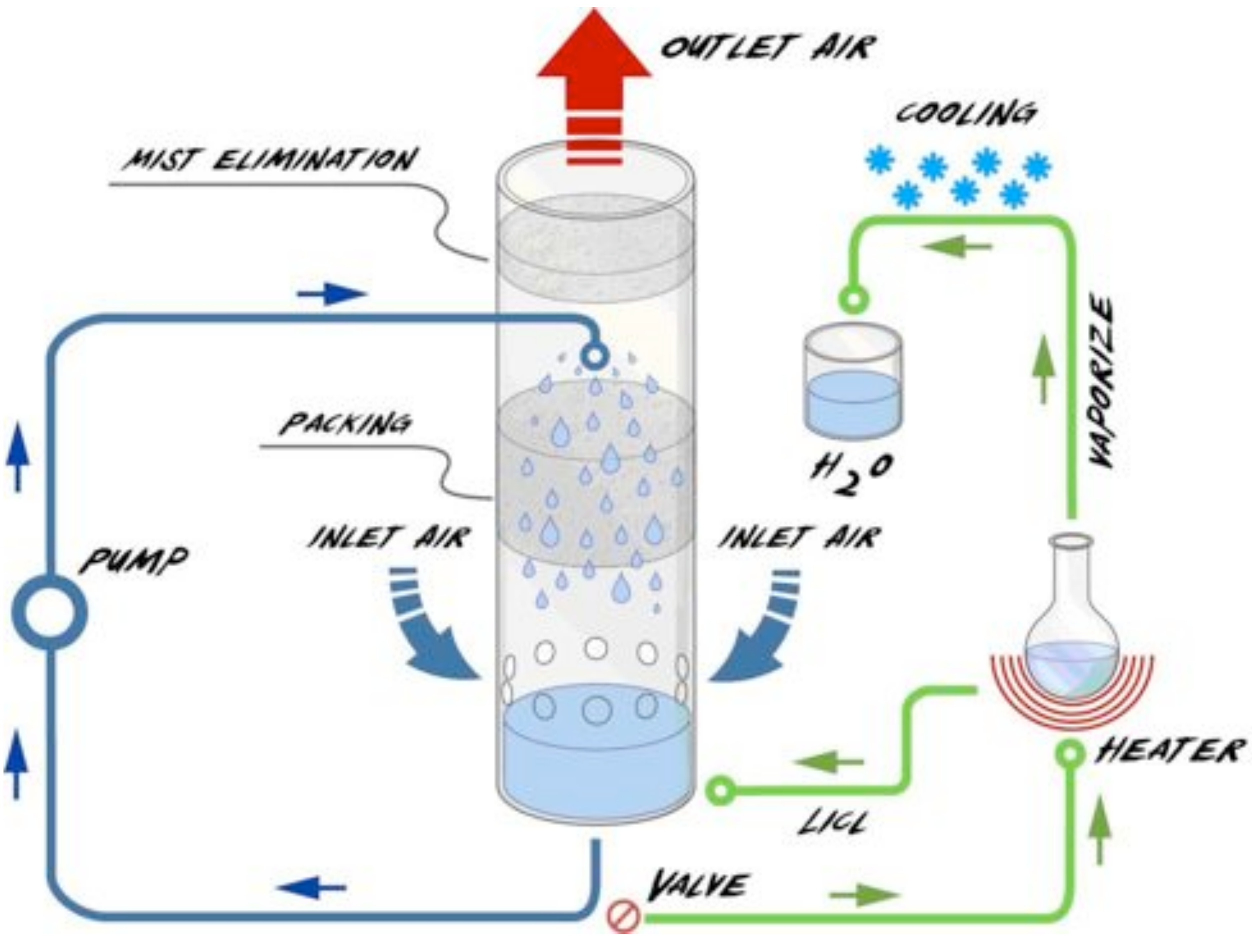


Figure 43: Functional System Prototype idea : Liquid desiccant cycle

An aqueous lithium chloride (LiCl) solution was used as the desiccant. The solution was sprayed from top in a cylindrical absorption chamber. A fan at the top of the chamber sucked in air in the opposite direction of the desiccant flow. The absorption chamber was filled with packingss to increase the surface area of contact between the air and the desiccant. Once the desiccant solution had absorbed sufficient atmospheric moisture, it was transferred through a valve to a heater. The absorbed moisture was vaporized and re-codensed to get pure distilled drinking water. The heated solution was then passed to the absorption chamber and the whole process repeated. Figure 44 shows the functional system prototype that was built. See Appendix 10 for detailed description, specifications and results of the prototype.

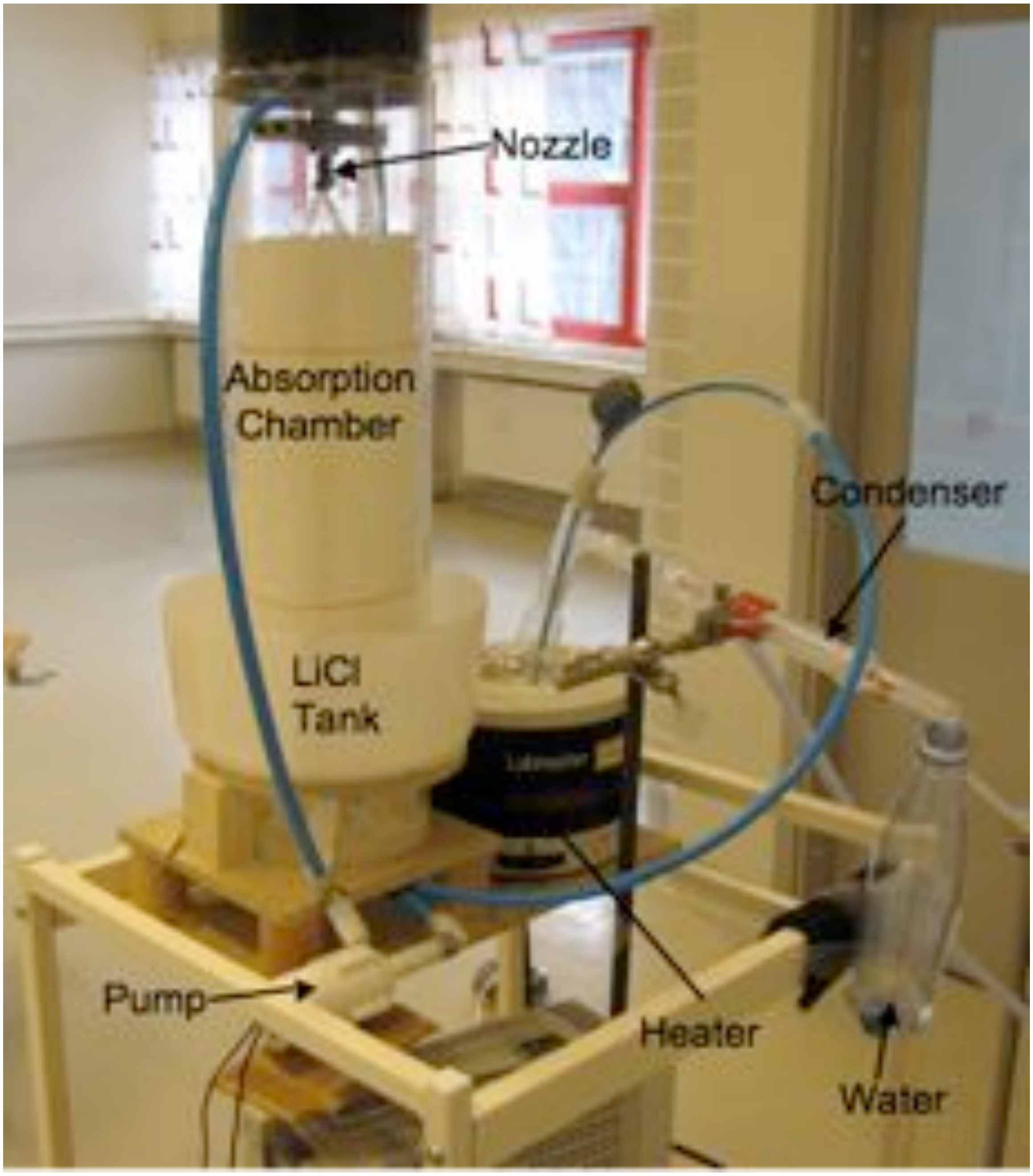


Figure 44: The final LDC prototype

4.7.3 Results

The functional system prototype extracted approximately 60g of water per hour (at 38% RH and 19°C) during the 6.5-hour test. The energy consumed per liter of extracted water was approximately 3.5 kWh (see Appendix 10 for detailed calculations). Assuming an electric power cost of 16 cents per kWh, this turned out to be 56 cents per liter of water produced. This value was within the design requirement bounds. Also, there was a lot of scope for reducing the heat losses in the system. The heating system used in the prototype was not optimized. Once all these issues are dealt with and the process optimized, the cost/liter should further decrease.

4.7.4 Lessons Learned

The key lessons learned from the LDC prototype were:

- The liquid desiccant cycle is capable of water generation.
- It is not necessary to couple the LDC with other technologies such as VCC. An ingenious way to couple the two may, however, be devised to harness the advantages of both of these.
- The LDC technology is energy efficient, especially compared to desiccant wheels and VCC at low humidity. There is a scope for further increasing the energy efficiency by lowering the heat losses.
- LDC offers a flexible geometry as the various components such as pump, air chamber or heater can be placed wherever needed. This provides flexibility in product design.
- The purity of the water produced is still a concern.
- The scalability of the prototype was an issue that was not adequately dealt with in this prototype. This was dealt in the final prototype that was developed in the final quarter.

4.8 Final Prototype - Mimir

Based on the positive results of the functional system prototype, the team decided to implement the liquid desiccant cycle in its final prototype. The functional system prototype of the fall quarter had served as a 'proof of concept' for the liquid desiccant technology. However, there were still several issues that had not been dealt with in the prototype.

Firstly, the winter quarter prototype was a 'scaled-down' version. It was capable of producing only around 1.5 liters of water (at 38% RH and 19°C) per day. This was one-tenth the design requirement. Secondly, it was designed as an 'experimental set-up' instead of a product that could be used by a consumer. Important issues such as portability, thermal insulation, filtration and durability had not been considered. Therefore, one of the objectives of the spring quarter was to build upon the knowledge gained by the functional system prototype and construct an improved, working, final prototype that is able to achieve most of the design requirements within the given time constraints.

The Mìmir prototype was designed not only as an enhanced proof of concept for the liquid desiccant technology but also to show how this technology could be integrated in an appliance for an American home. In order to integrate the technology much of the focus was set on the size of the prototype and the requirements given by the liaisons. The team also implemented new requirements from their own knowledge about the product so that the technology could be realized in the best possible way. The price per liter of water produced was one such requirement that the team discovered during the course of the project.

The main focus of the design process was to achieve a working implementation of the technology. The idea was to first get the machine running and look at the ancillary features afterwards. These ancillary features included the exterior look, filtration system, dispenser mechanism and the display.

4.8.1 The Mímir process

The process of water extraction in this prototype is simple and an improved version of the desiccant cycle employed in the earlier prototype (see Figure 45).

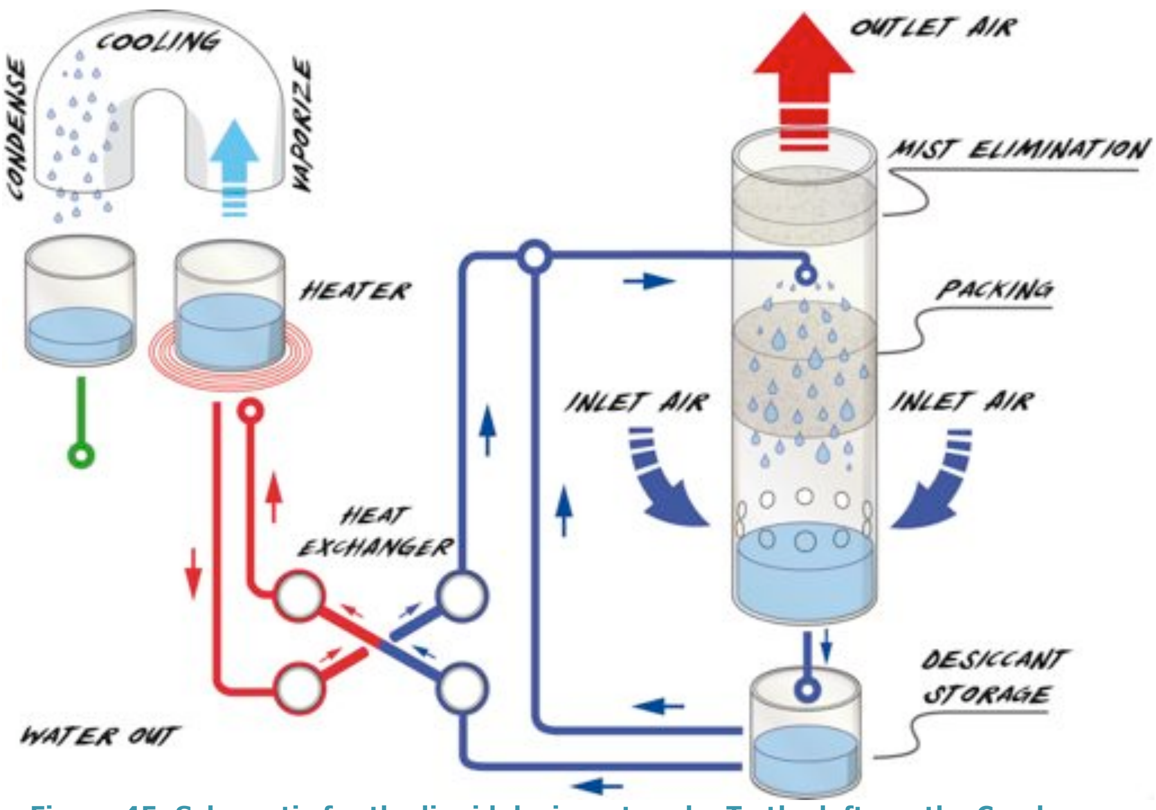


Figure 45: Schematic for the liquid desiccant cycle. To the left are the Condenser and the heater. To the right is the absorption chamber.

The water absorption takes place in the absorption chamber. The concentrated liquid desiccant solution is poured into the chamber through a nozzle at the top. The fan at the chamber top draws in air through ducts at the bottom and the passing air is dehumidified as it comes in contact with the desiccant spray. The chamber is filled with tower packings that increase the surface area of contact between the liquid and air, thus enhancing the absorption process. A mist eliminator at the top traps any LiCl particles carried away by the air stream.

The diluted desiccant solution is then pumped to the heater through a heat exchanger where the excess moisture is vaporized. The steam thus generated is re-condensed in a condenser to get pure distilled water. Excess heat energy of the solution left in the heater is utilized in preheating the incoming dilute solution. This is achieved by a heat exchanger. Apart from reducing the energy requirement of the system, it also reduces the temperature of the solution inside the absorption chamber. Since, the absorption efficiency of the desiccant decreases with temperature, this increases the overall efficiency of the system.

Figure 46 and Figure 47 show in detail the various internal parts that have been implemented in Mìmir. A detailed description of the each part of the process and its implementation is given next.

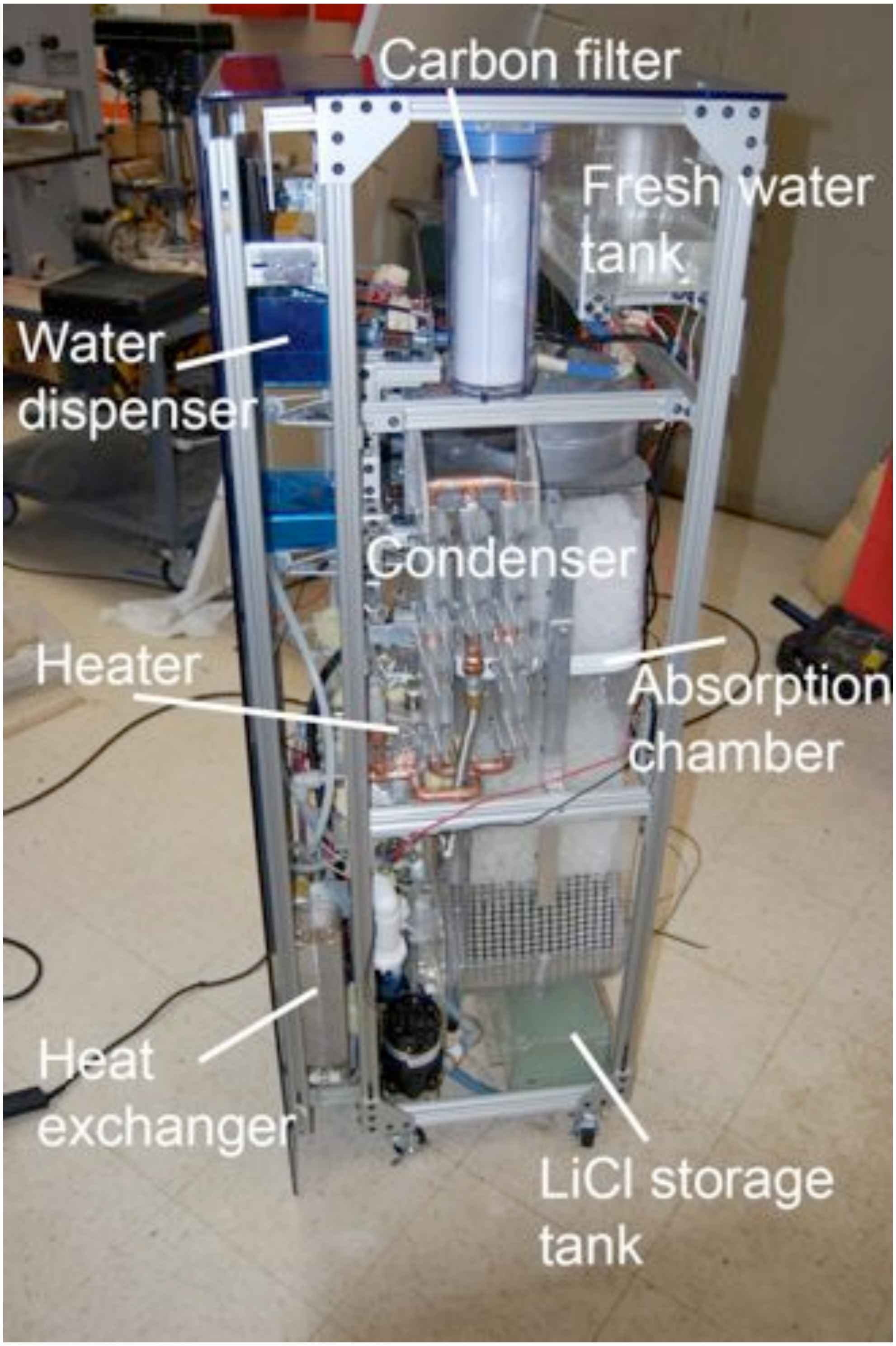


Figure 46: The parts visible from the right side of Mímir.

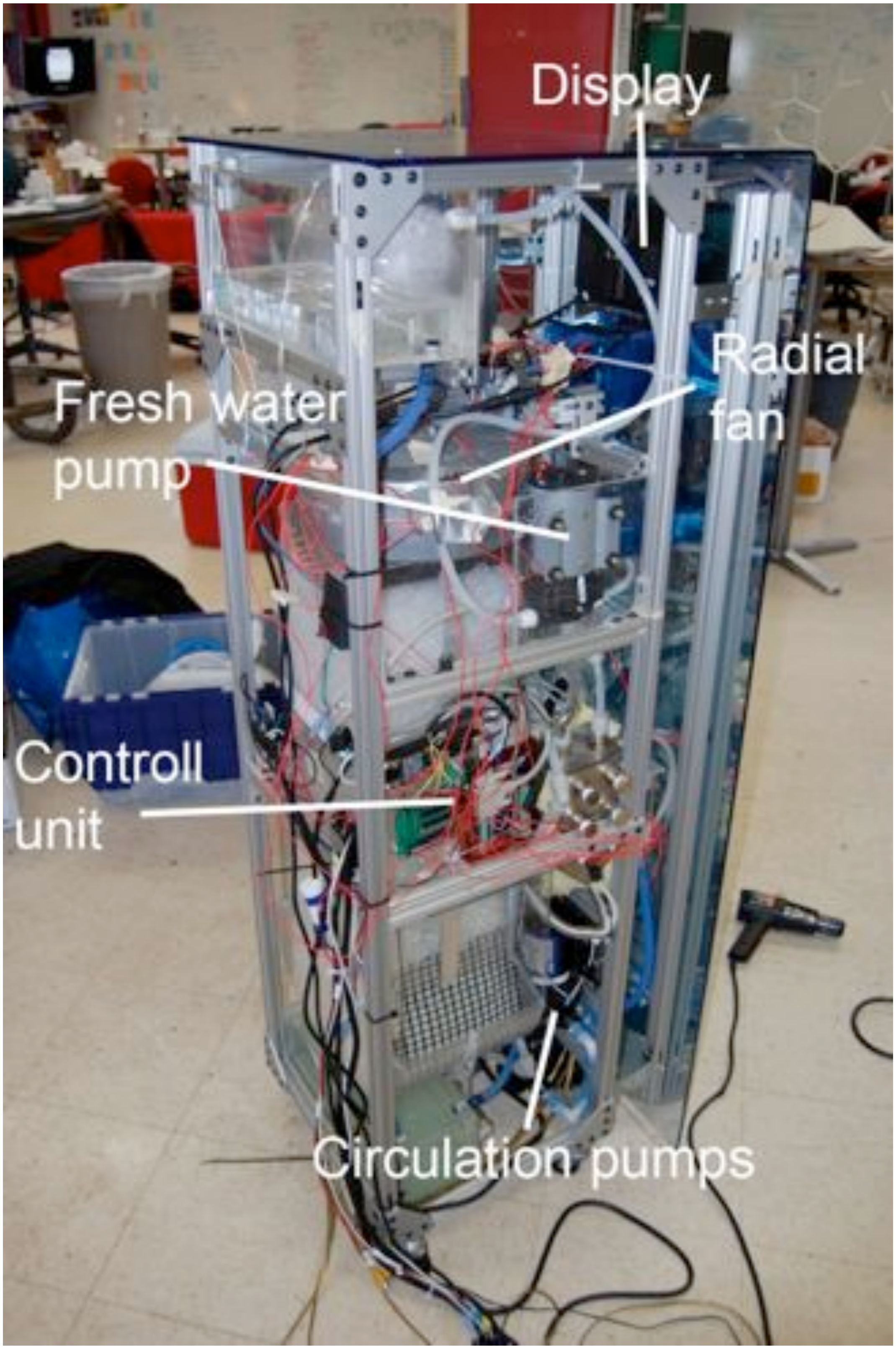


Figure 47: the parts visible from the left side of Mímir.

4.8.2 The absorption cycle

The ambient air first goes through two air filters on each side of the machine entering the absorption chamber (see Figure 48 and Figure 49). These filters stop dust and other particles from mixing with the desiccant solution and thus prevent clogging of important parts in the process. The air is pulled through the absorption chamber by a radial fan located on the top of the chamber.

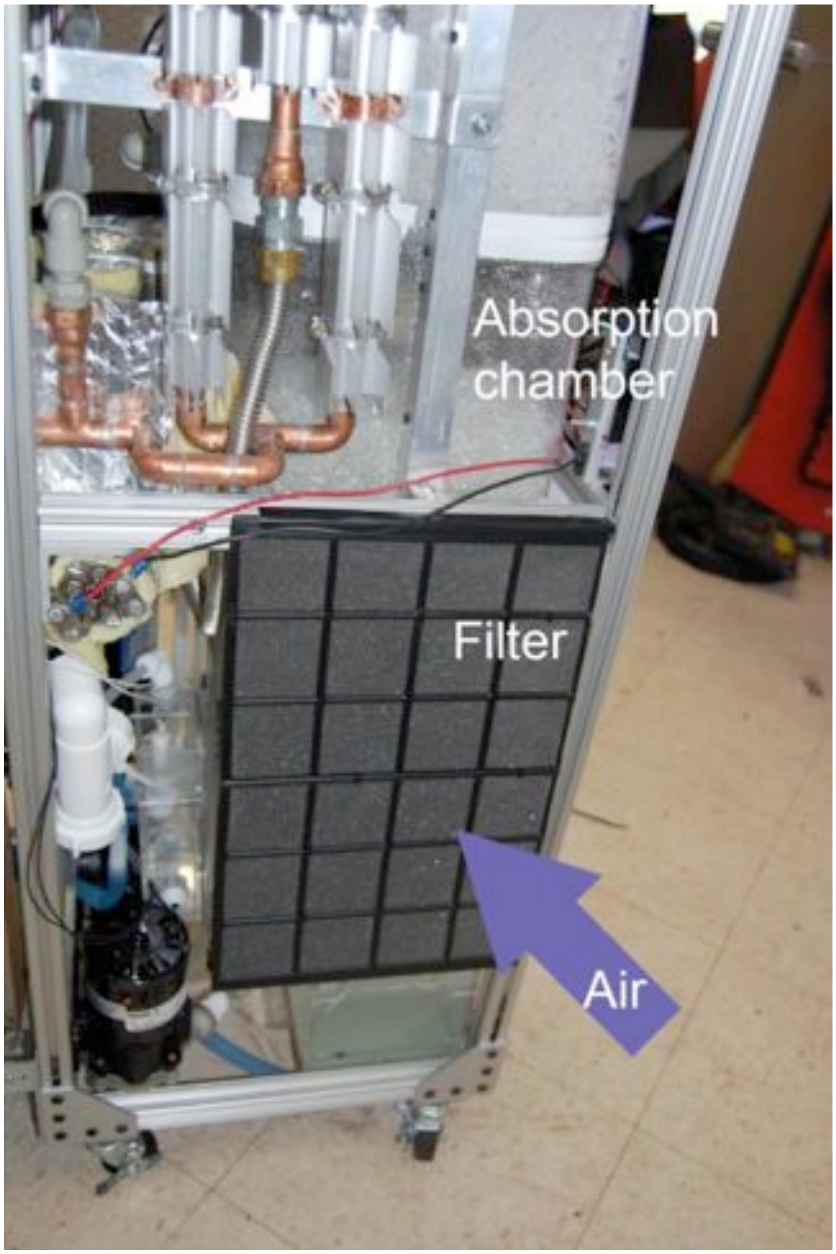


Figure 48: Air enters the absorption chamber trough the air filter (right side view)

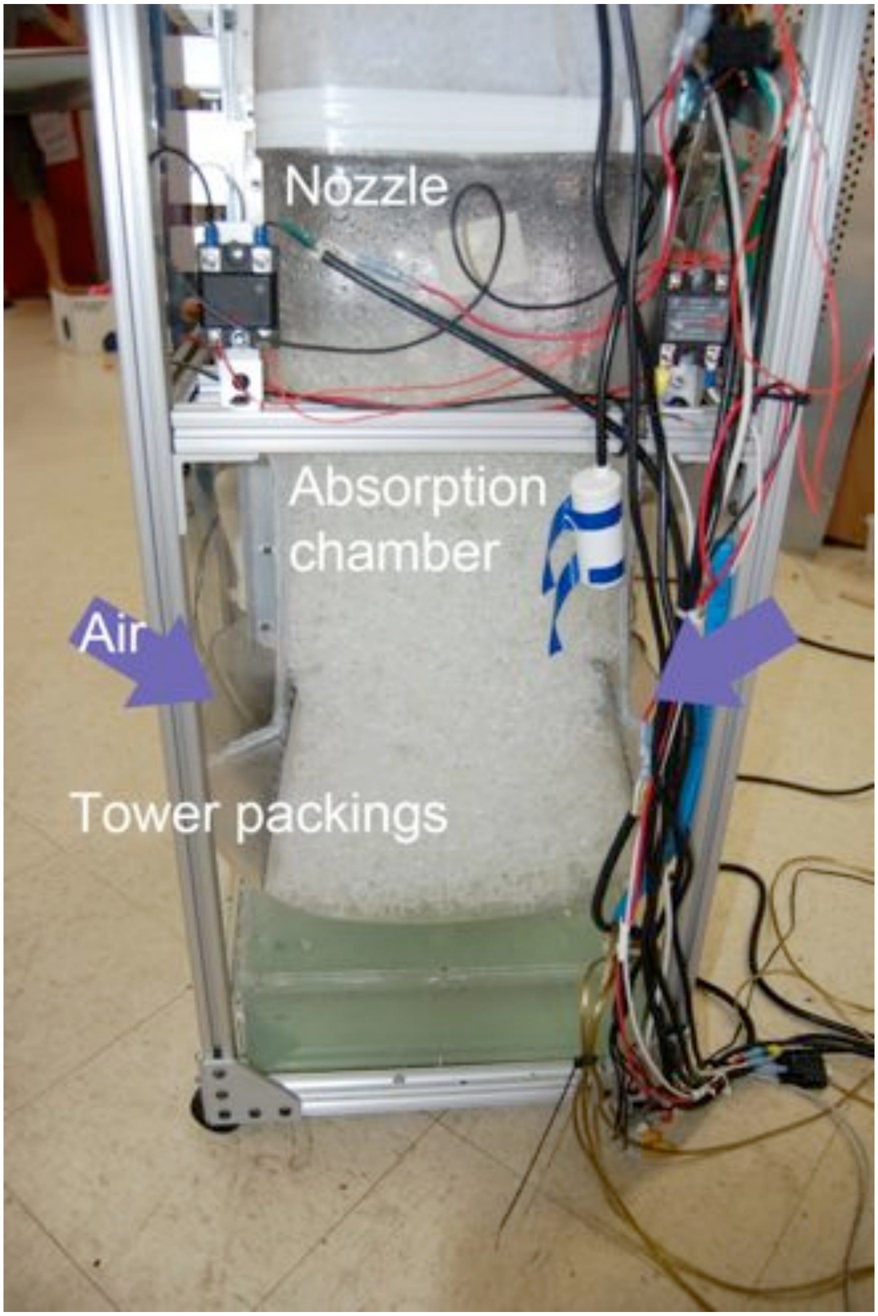


Figure 49: Air enters the absorption chamber trough the air filter (back side view)

Inside the chamber a bed of tower packings, 400 mm of depth, increases the wet surface area to ensure good absorption of water vapor from the ambient air. A nozzle located 100 mm above the top of the tower packings sprays concentrated LiCl solution in opposite direction to the airflow onto the tower packings.

The air goes through a layer of mist eliminators positioned above the nozzle in order to minimize the dissipation of solution particles that may get entrapped in the air stream (see Figure 50).

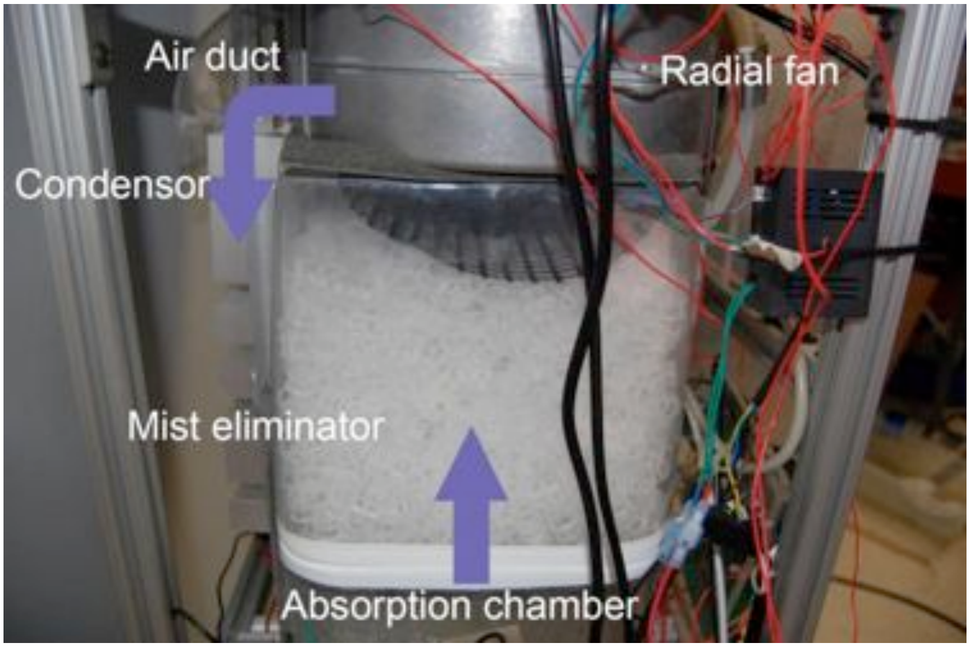


Figure 50: The mist eliminator

The LiCl solution dripping down from the tower packings is collected in a storage tank under the absorption chamber.

A pump circulates the solution from the storage tank to the chamber in a continuous process so that absorption of water is always going on whenever the machine is on (see Figure 51).

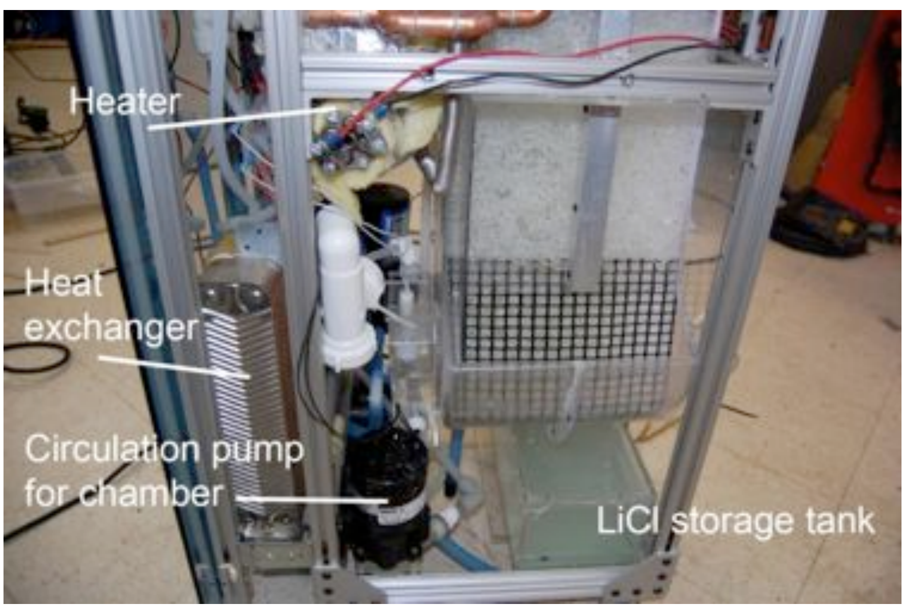


Figure 51: The storage tank and chamber pump circulating the solution.

4.8.3 The extraction cycle

In a parallel process, the water is extracted from the LiCl solution almost as soon as it is being absorbed in the chamber. It is important that the extraction process runs parallel to the absorption process in order to make the whole process as efficient as possible. This is because the desiccant's absorption capacity decreases with its dilution. Hence, if the water extraction is unable to keep pace with the absorption process, this leads to desiccant dilution and consequent reduction in water absorption capacity.

In the extraction process, a heater heats the solution to its boiling point so that water leaves the solution in form of vapor. A heat exchanger ensures that the energy contributed by the heat coils in the heater is minimum as the solution entering the heater is already 'pre-heated by the earlier batch of the heated desiccant solution. This not only heats the cold solution entering the heater but also cools the solution going into the absorption chamber (see Figure 52). To ensure that the concentration is correct, a thermo sensor measures the boiling point temperature in the heater. This measurement controls how much energy is to be contributed by the heater coils. To avoid flooding and dry running in the heater a pressure sensor measures the solution level in the heater. To keep the process as efficient as possible, a process has a continuous flow through the heat exchanger.

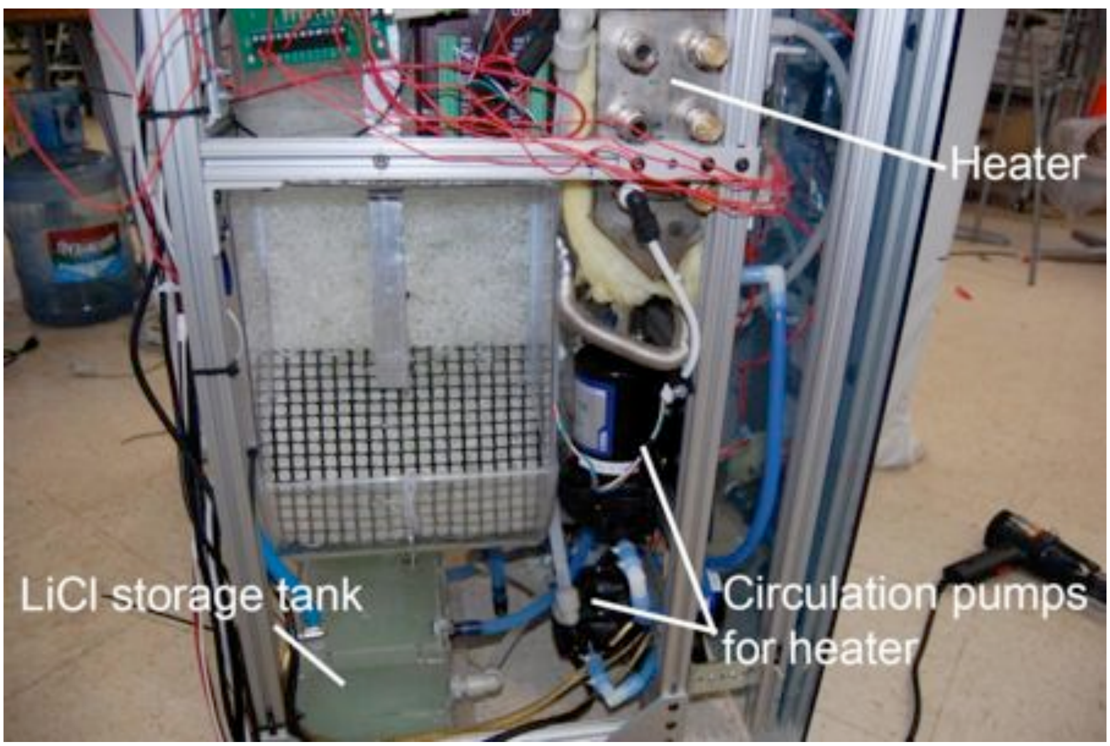


Figure 52: The heat system

The hot steam inside the heater rises up through a column of about 100 mm in the condenser. The high condenser column ensures that no desiccant particles reach the final distilled water. The condenser cools down the vapor to fluid form and the liquid water is then collected in a condensed water tank (see Figure 53). A water trap ensures that the hot water vapor goes through the whole length of the condenser. To increase the cooling effect of the condenser the outlet air from the chamber fan is diverted through the condensers cooling fins, thus allowing forced convection to occur.

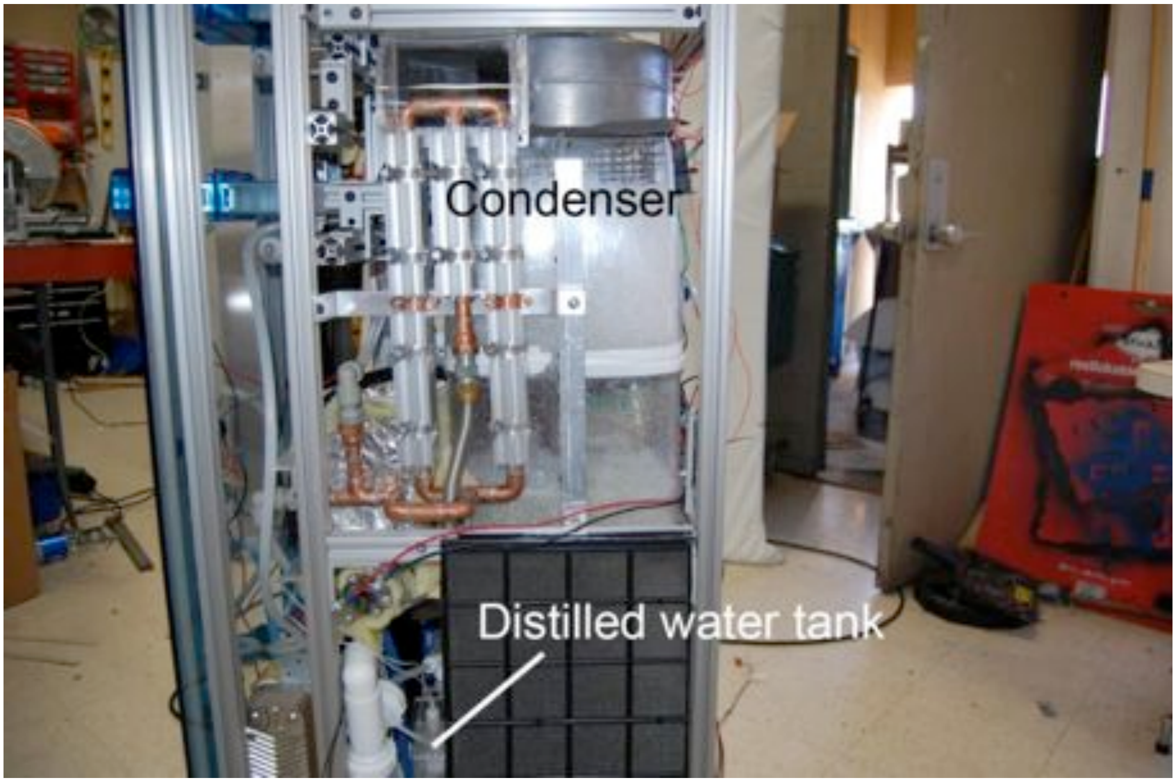


Figure 53: The condensing system

Inside the condensed water tank, the water is allowed to stay till its temperature is lowered to room temperature. Two level sensors are used to determine when the tank is full or empty.
When the condensed water tank is full the condensed water is pumped through a carbon filter to a fresh water tank, located at the top of the machine. The fresh water tank is the last storage tank before the water dispenser and to ensure that the water inside is pure and clean at all times, even after a prolonged period of storage, an UV-lamp is used to kill bacteria and algae (see Figure 54). A level sensor inside the fresh water tank determines when the tank is full to avoid flooding.

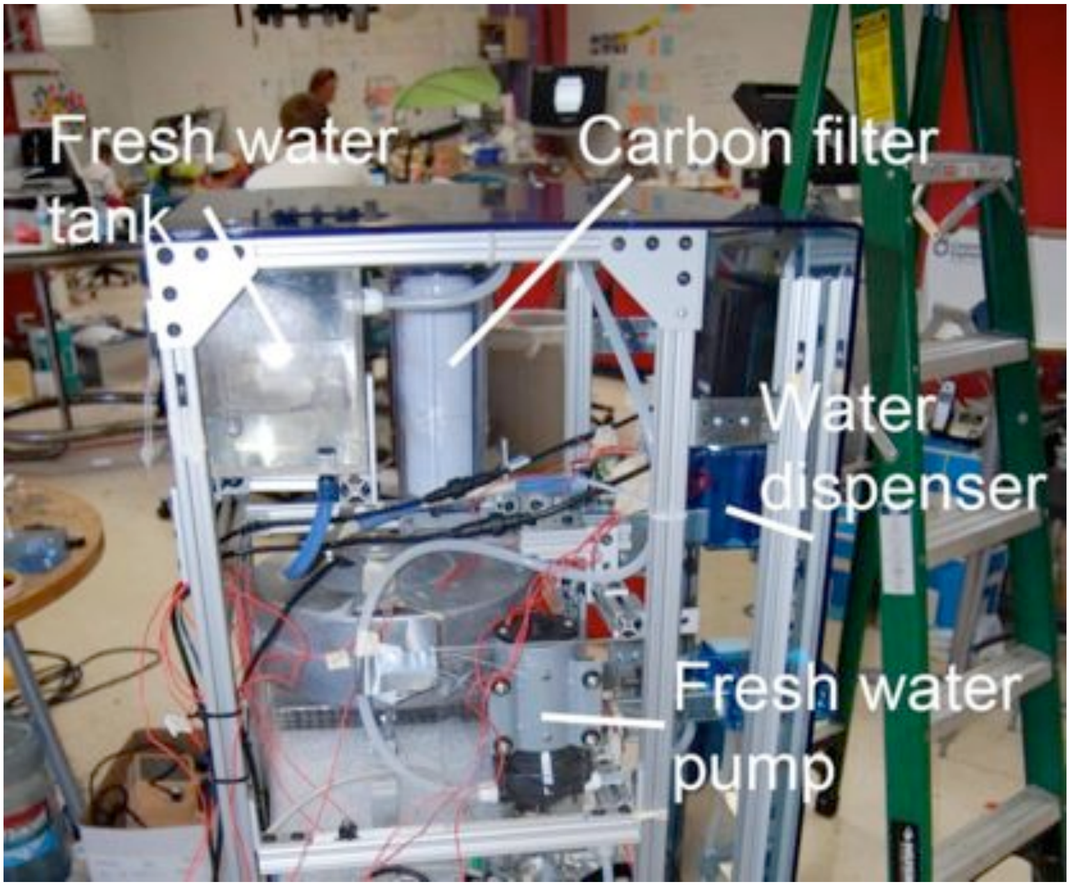


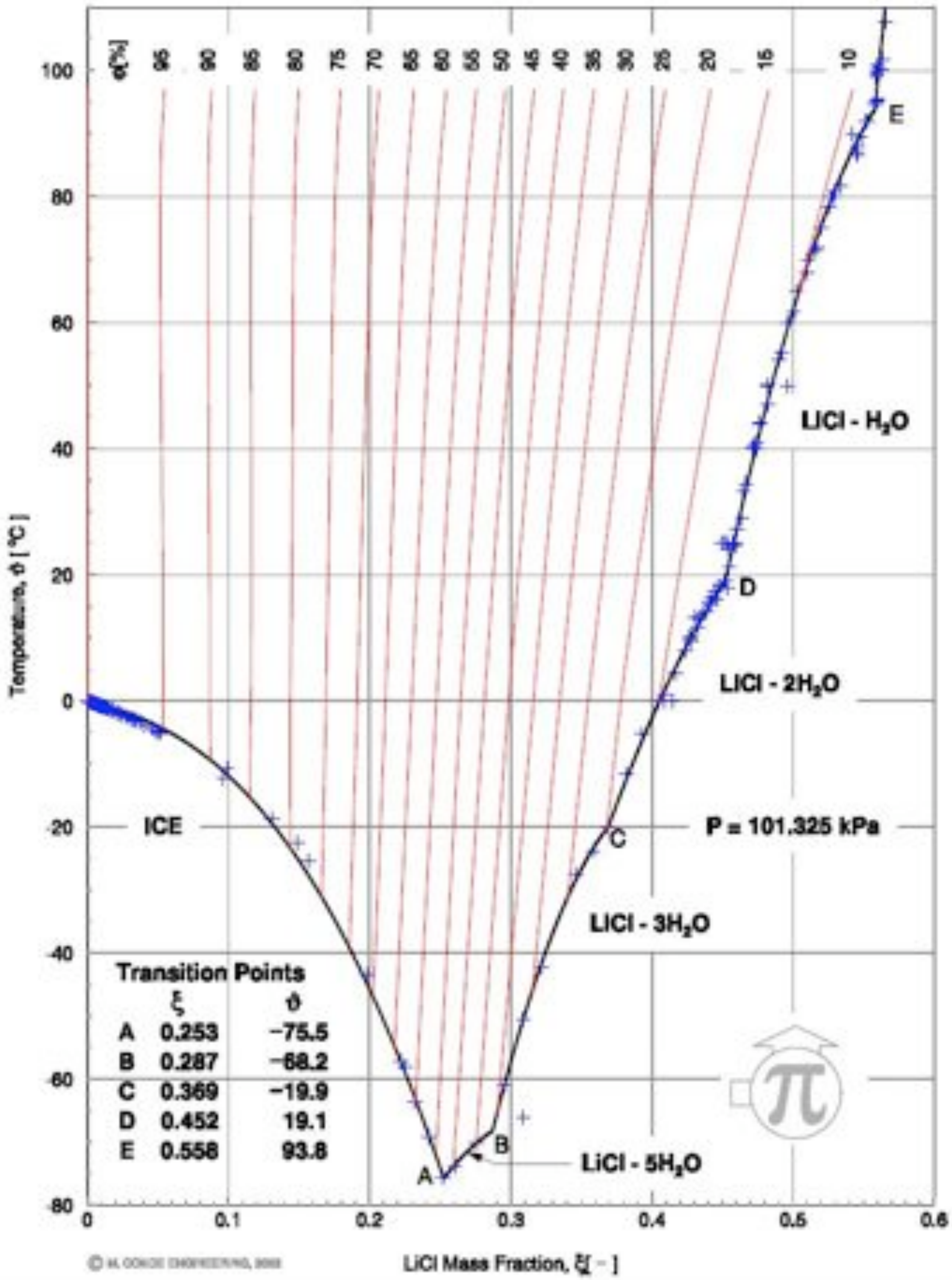
Figure 54: The dispenser system

The next few sections deal with the details of the design process, the concepts and the thought process that went into the development of each component.

4.8.4 LiCl cycle

Lithium Chloride is a salt with very hygroscopic ability. It has high solubility in water and is able to absorb water even in low relative humidity. The absorption of water takes place when the vapor pressure on the surface of the salt particles is lower than the vapor pressure of water molecules in the ambient air. The bigger this difference is between the two substances' vapor pressure, the stronger is the driving force for water absorption. When the water molecule is absorbed on a salt particle, it releases heat to the surrounding which increases the temperature in the outgoing air. This heat release is due to the strong water-LiCl ionic bonds that are formed.

The graph in Figure 55 shows the solubility boundary of LiCl together with corresponding RH-levels in the ambient air. Looking at the solubility boundary in normal room temperature around 20°C for LiCl, it gives a corresponding RH level of about 12 % when the concentration of the solution is about 43 % mass fraction. This means that, in theory, an infinitively long absorption chamber with LiCl dissolved in water to 43 % concentration could dehumidify the ambient air going in to the chamber down to 12 % relative humidity.



Fig

Figure 55: Graph showing LiCl solution concentration with corresponding RH level and temperature. Source: M. Conde Engineering 2004

In real life, however, a number of different factors must match to achieve this value. Based on the extensive literature study and experiments conducted with the functional prototype, the team concluded that the following design parameters need to be satisfied if optimum absorption is to take place:

- The absorption bed has to be around 300 mm of depth in order to dehumidify the ambient air to 70% of the amount that is theoretically possible to absorb
- The nozzle that wets the tower packings must reach the whole top surface and the flow rate of the solution has to be 10 l/min or higher.
- A heat exchanger is needed to ensure energy efficiency
- To minimize the dissipation of solution from the chamber the air velocity should not exceed 2 m/s and mist eliminators must be employed
- The water extraction process must be run parallel to the absorption process in order to keep the whole process to ensure high desiccant concentration at all times
- The air stream in the chamber must be as homogeneous as possible to ensure that ambient air is in contact with as much of the tower packings as possible

The graph in Figure 56 shows the LiCl solution temperature together with corresponding vapor pressure. Assuming that the vapor pressure in the ambient air is close to 1 atm, one can see that the boiling point for the LiCl solution increases with higher concentration. A LiCl concentration of about 40 % gives a boiling point of around 133°C and 45 % concentration gives a boiling point of about 145° C.

This boiling point elevation in the solution makes it possible to optimally extract water from the solution by distillation since the solution boiing point may be directly correlated to its concentration.

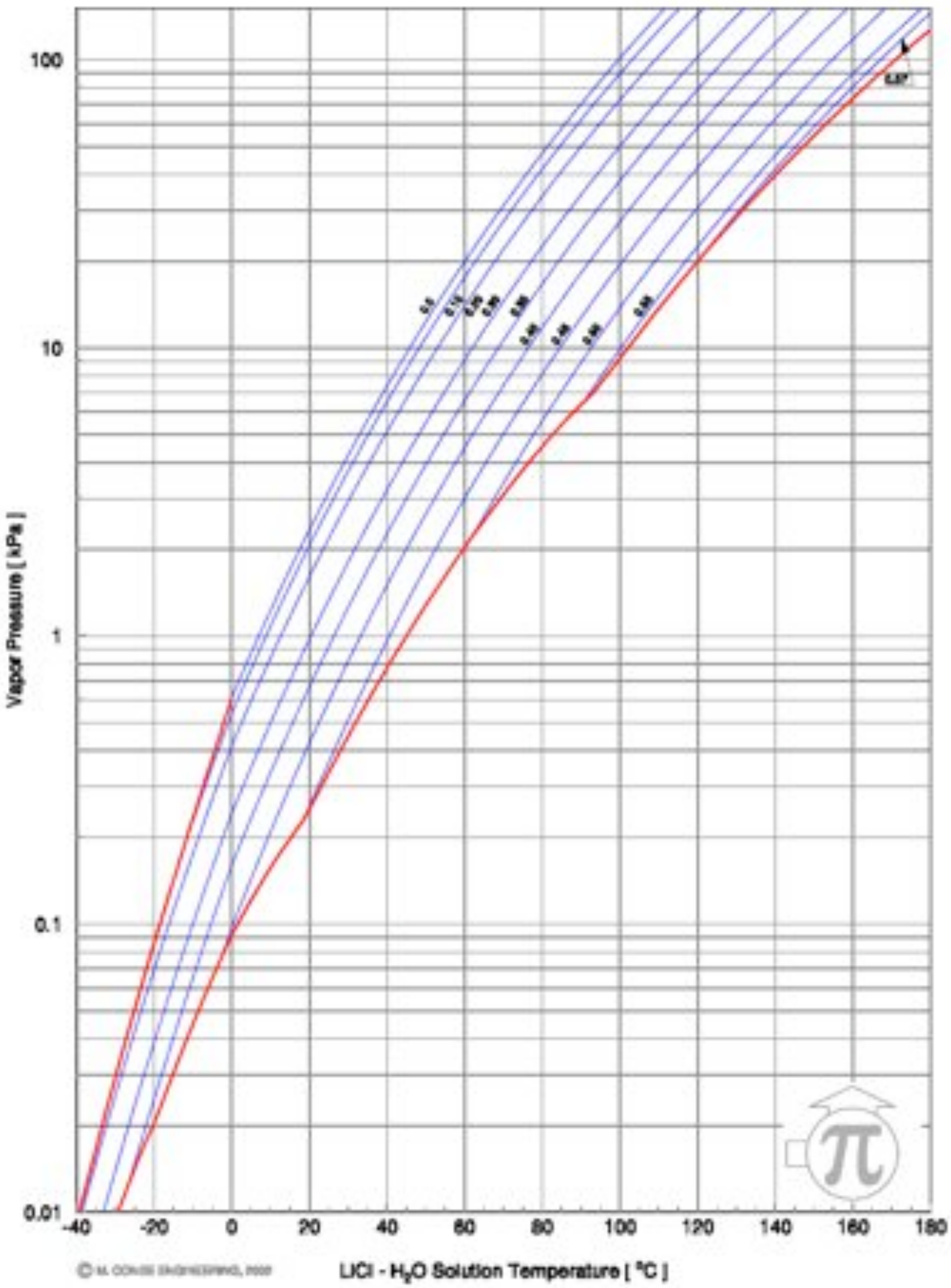


Figure 56: Graph showing the boiling point of different LiCl solution concentrations. Source: M. Conde Engineering 2004

4.8.5 Extraction of water

The amount of water that can potentially be absorbed by the LiCl solution depends on the RH level and temperature of the ambient air. From Figure 57 above, one can infer that it is theoretically possible to absorb ambient air down to 12% RH. With a packing depth of 300 mm, it is possible to absorb ~70% of the theoretically limit. Hence, care was taken that the packing depth in the final prototype was kept at 300mm. The chamber in the prototype has a cross-section that can process up to 9000-10 000 m^3/day with an air velocity of about 2 m/s. All these factors indicate that the amount of water that is possible to extract is approximately 10-20 liters per day at RH values of 30-40% and 20°C. See Appendix 13 for more information about water extraction.

4.8.6 Chamber

There are several factors that strongly affect the performance of an Atmospheric Water Generator. One of the main factors that must be adjusted in order to attain maximum water absorption is the amount of ambient air that comes in contact with the desiccant solution. In the final prototype, this process happens in the absorption chamber. There are several key issues that need to be accounted for in order to utilize the chamber in the most effective way.

The first task was to design the airflow through the chamber in such a way that allows maximum contact between the desiccant solution and the humid air stream. For this purpose a pulling fan and a nozzle was used. The radial fan sucks the airstream through the chamber while the nozzle sprays a fine flow of LiCl in the opposite direction of the airstream. This technique is called counter-flow which indicates that the airflow is in opposite direction to the liquid solution.

The two most effective ways of exposing the desiccant to the moist airstream is through counter and cross airflow. These two techniques were found to be approximately equally effective but some inherent design constraints favored the application of counterflow design. One of the constraints imposed by the corporate liaison was that the final product should be no wider than 500 mm. However, theoretical calculations and simulations showed that an optimum crossflow design required an absorption chamber wider than 500mm. On the other hand, it was possible to design a crossflow airflow chamber while remaining within the set design constraints. On the other hand, the counter-flow chamber is easier to implement in a tall structure but has a weakness since the air needs to be redirected in the inlet.

The design of the chamber has a big affect on the absorption process in many ways. One central requirement is to have a uniform velocity profile inside the chamber. Unwanted flow asymmetries may result in air stagnation in certain parts of the chamber, thus decreasing its active area. The main objective is to ensure that maximum volume of air is processed while keeping the velocity of the air stream lower than 2m/s. At higher flow rate, there is a risk that substantial amount of LiCl may get trapped in the air stream and escape from the chamber.

Another very effective way to ensure maximum contact surface between the humid airstream and desiccant solution is to physically add to the inner surface area of the chamber. This is done through the use of tower packings (see specifications section for details). These are small hollow plastic bodies that are designed to have a maximum area without increasing the pressure drop too much. These tower packings are used to fill the inside of the chamber for two main reasons. Firstly, these delay the 'run-off time', i.e, the time it takes for a desiccant particle to traverse through the chamber. This increases the amount of time the desiccant stays in contact with the air. Secondly, the desiccant solution gets distributed onto these packings and this increases the area of the wet surface in contact with the airstream. Through experiments conducted with the functional system prototype, it was found that a packed bed of tower packings must be 300 mm of depth in order to absorb about 70% of the possible amount of water from the ambient air.

The geometry should also facilitate the installation of other complementary parts such as pumps and tubings. A geometry that minimizes the risk of the desiccant liquid splashing or running out of the chamber is also of importance.

Early design of a cross-flow packed bed absorber with two chambers is shown in Figure 57. Air inlets are located to the right and a combined outlet with a radial fan to the left. The tower packings are showed in grey in the upper chamber.

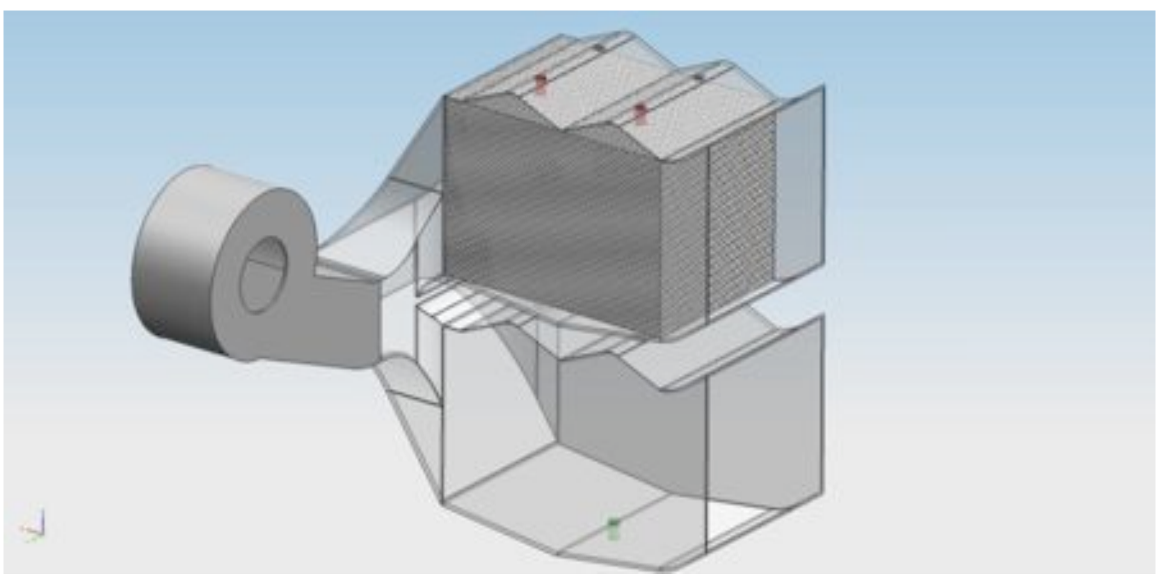


Figure 57: Cross-flow chamber design with two chambers

Several air flow simulations of different designs were made to evaluate their efficiency (see Figure 58 to Figure 61).

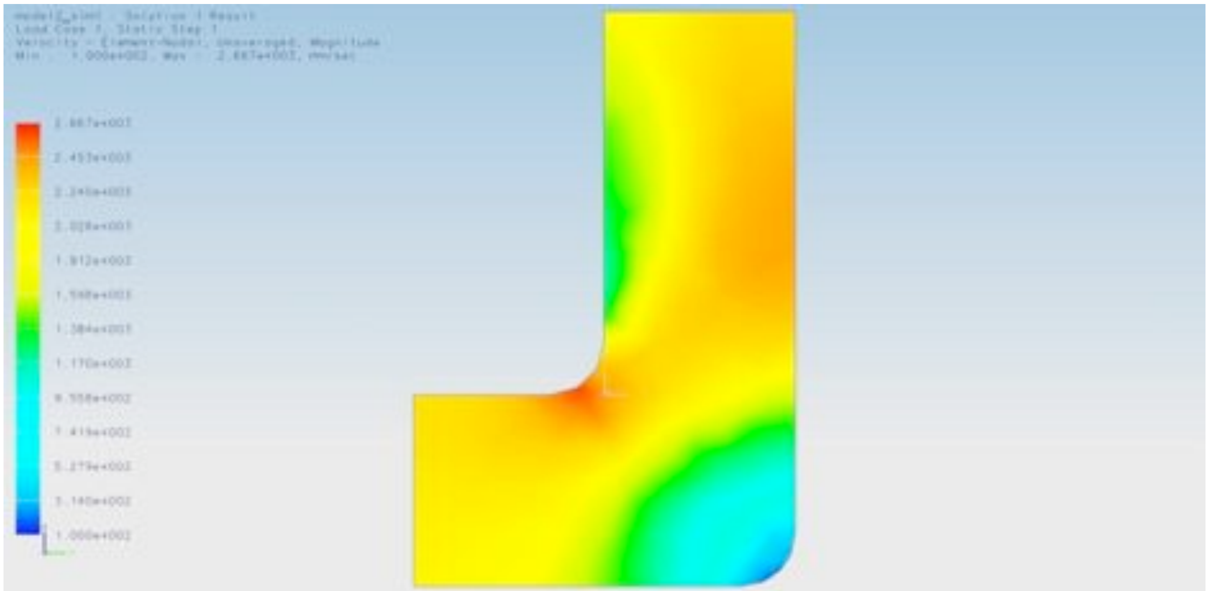


Figure 58: Graph of simulation with less suiting geometry. Air inlet located at down to the left and outlet at the top.

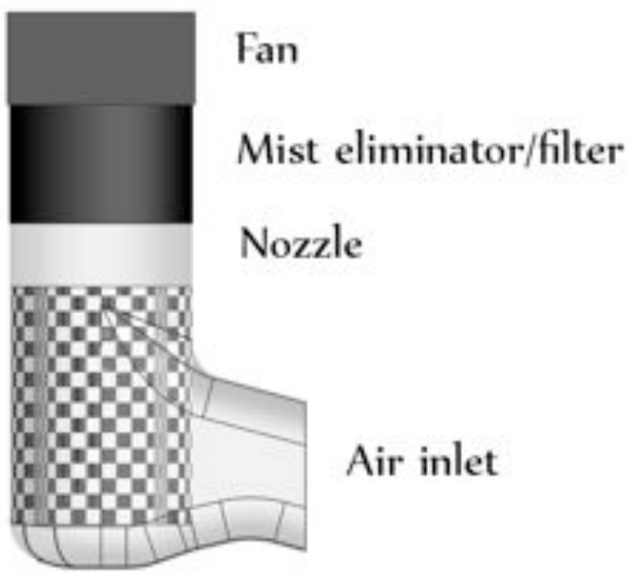


Figure 59: An earlier counter flow design

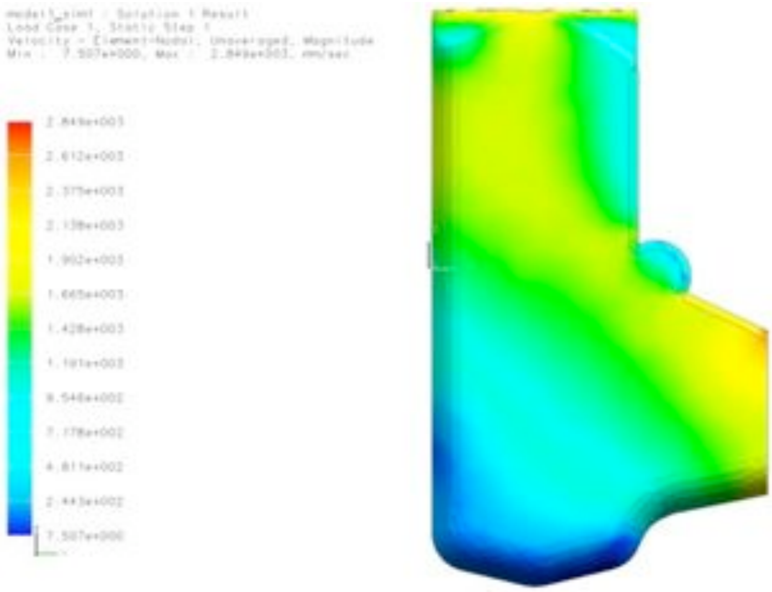


Figure 60: Air flow simulation in a counter-flow packed bed absorber with less suiting geometry of the previous figure. Air inlet is located down to the right and outlet in the top. Green color shows the wanted flow rate.

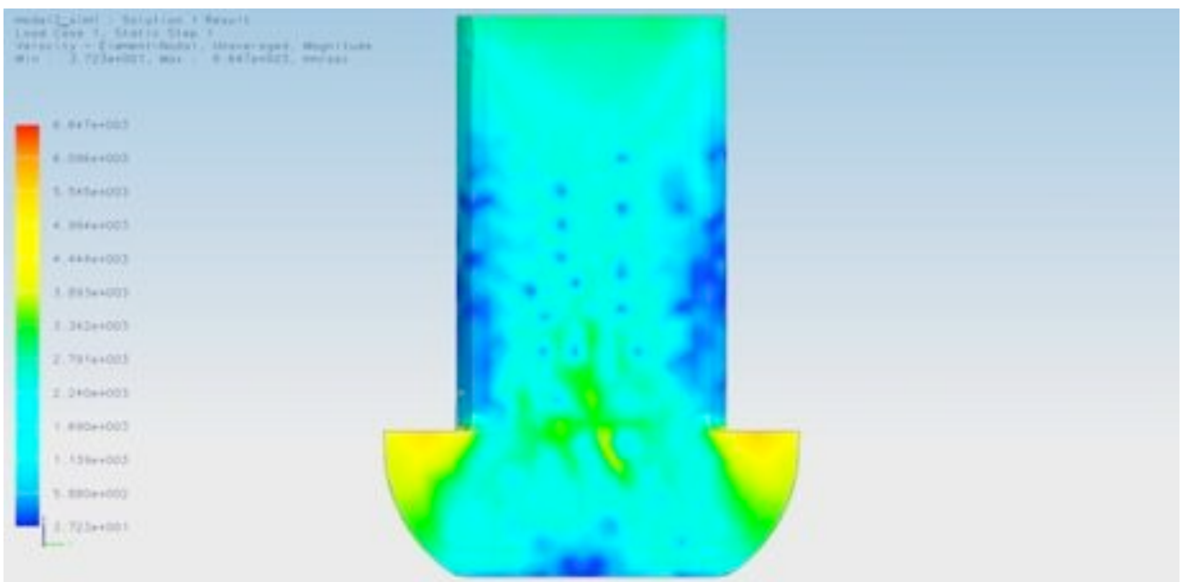


Figure 61: Graph of simulation with more suiting geometry. Air inlets located on both sides at the lower part and outlet at the top.

In the selected prototype (see Figure 61 and Figure 61), a cross-flow packed bed absorber chamber was designed with a cross-section of about 0.057 m^2 so that the total amount of air passing through the chamber is almost 10,000 m^3 per 24 hours with an air velocity of about 2 m/s. The cross-section is slightly square shaped despite the fact that a round geometry might have been much better for the air stream. This was done since a square shape was easier to implement in this type of product when there was a lack of available space inside the machine due to the size constraints.

The packed bed depth was set to 400 mm. However, the effective length in this design was lesser due to the design of the air inlets. The total effective depth of the tower packings, according to simulations, was estimated to be at least 300 mm, as was required for maximum efficiency (see Figure 62).

The flow rate of the solution was set to approximately 10 l/min. This value was taken as a default value from the literature.

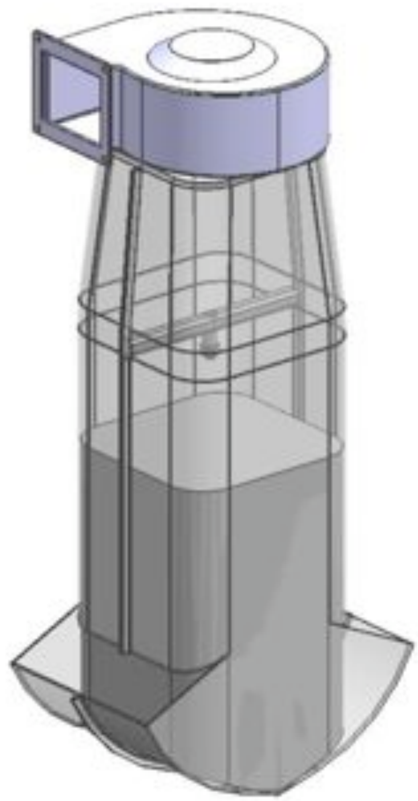


Figure 62: Picture showing the final design of the chamber with radial fan, nozzle and tower packings.

4.8.7 Fan

In order to pull the moist air stream through the absorption chamber, a radial fan was used. The fan used in the prototype needed to meet a number of constraints. The first of these was to achieve an appropriate flow rate. A too low flow rate would have resulted in a system unable to achieve the needed performance while too high flow results in an air velocity higher than 2 m/s. Other than the flow rate, the fan must be able to handle a pressure drop of approximately 500 Pa. This is to overcome the pressure drop due the geometrical obstructions restraining the airflow. These obstacles can be categorized into two categories: geometrical losses deriving from the design of the chamber, and losses related to dense bodies covering the geometry over which the air is flowing. Filters and mist eliminators can be included in the latter category. The tower packings also add to a significant pressure drop. Information from suppliers of tower packings showed that they resulted in a pressure drop of 400 Pa per meter covered.

Also, the fan needed to be light and small in order to fulfill the constraints related to the size of the machine. A heavy fan could cause problems and pose challenges in its mounting. Even though the fan was supposed to be mounted directly on to the chamber, it could not be exposed to a great amount of stress.

Considering the constraints related to the flow rate, pressure drop, size and weight of the machine, radial fans were found to be the most suited category of fans. This was mostly due to the fact that conventional axial fans rarely handle pressure drops greater than 300Pa.

4.8.8 Nozzle

Apart from the absorption chamber, radial fan and tower packings, the nozzle is another important component in the water absorption. The nozzles should spread the water and liquid desiccant solution equally over the total cross section of the chamber. The type and placement of the nozzle is crucial in order to achieve this.

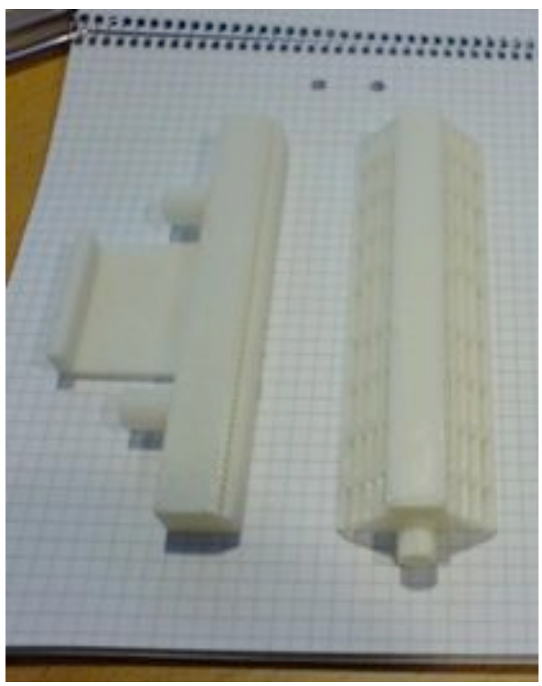


Figure 63: Two early designed nozzles for a cross-flow chamber.

The most suited nozzle type to cover a surface without affecting the airflow too much is the full cone spray nozzle. The cross section of the liquid stream coming out of this nozzle is circular. In order to get the best dissemination of the solution, the nozzle needs to be placed at a suitable height over the tower packings. If the distance is too short, the solution does not get the chance to fully spread. On the other hand, a too large distance results in the solution hitting the walls of the chamber and running along the walls and not through the tower packings as desired. The optimal distance for the type of nozzles used in the final prototype is approximately 100 mm with a cone angle of 120°.

The size of the droplets produced and distributed by the nozzle is also of great importance. If the size of the droplets is too small, these can easily be sucked through the system by the fan while a droplet size exceeding the optimal one results in less efficient absorption.

Figure 64: A swirl nozzle characterized by small droplet size.

Figure 65: The whirl nozzle that was finally used in the prototype, characterized by medium droplet size.

4.8.9 Heater

In the reactivation process the absorbed water is extracted by heating the desiccant solution. The distilling process separates the water from the liquid desiccant simply by breaking the ion bonds. In order to do so, the solution has to be heated to a certain temperature, referred to as the reactivation temperature, which is highly dependent on the concentration of the liquid desiccant. A lithium chloride solution with a concentration of 43% requires a temperature of about 140°C in order to start the regeneration process, releasing the vapor enabling the extraction of water. When testing the machine a concentration of 35% was used which has lower reactivation temperature, about 120°C, but is not as effective concerning the absorption capacity compared to higher concentrations. A lower concentration was used due to operational difficulties in dealing with higher temperatures in the heater. Also, as we will see later, the pressure sensor used in the heater had an operating temperature range upto only 125°C.

The heater was provided with mounting holes in order to attach a sight glass, temperature sensors, inlet/outlet for the desiccant solution as well as an outlet to direct the vapor into the condenser (see section 5 for specifications). The material used for the heater was the stainless steel 316 which is LiCl resistant to some extent. In future prototypes, however, a more suitable material would probably have to be used that has a better ability to withstand the presence of corrosive substances.

The heating coil, attached inside the heating chamber, used in the prototype had a power consumption of 2000W, which is very high compared to the actual required energy value. A highly rated heating coil was used to ensure that the device is able to function even with high heat losses and without a heat exchanger. In order to control the process, the heater was turned on and off when the temperature reached the required reactivation threshold.

4.8.10 Heat Exchanger

The heater is a very important part for the functionality of the product. One component that greatly influences the effect of the heater is the heat exchanger. The function of the heat exchanger is to pre-heat the LiCl solution that is pumped into the exchanger and, equally importantly, to lower the temperature of the LiCl solution that exits the heater chamber and goes to the absorption chamber. There exist heat exchangers that can reach an efficiency of of as high as 98% (Appendix 12). This means that the temperature of the solution going in to the heater just have to be heated by a couple of degrees Celsius before it starts to boil and the most of the energy applied would be just the heat of vaporization.

Figure 66: First prototype tube-in-tube heat exchanger. Inlet and outlet can be seen in the foreground.

The heat exchanger used in the prototype was a plate heat exchanger working with the counter-flow principle (see Figure 67 and Figure 68). The driving factor behind the heat exchanger choice was its low cost and quick availability.

Figure 67: The plate heat exchanger used in the prototype.

Figure 68: Exploded view of a plate heat exchanger used in the prototype

A very positive quality with the plate heat exchanger is that it is compact. This makes it easy to place the exchanger and still leave space for other components inside the product.

However, one drawback of a plate heat exchanger is that it can have a major pressure drop, but with the low flow rate in the prototype, this was not estimated to be a major concern.
The energy efficiency of the product highly depends on the heat exchanger. Since the heat exchanger is most efficient in a specific flow rate, this sets the value for the flow rate to and from the heater. In the final prototype, a flow rate of about 0.7 l/min was used but since the particular heat exchanger used was not developed for such a flow rate, the efficiency was low and a lot of energy was lost in the process. There is ample scope to improve the heat exchanger performance further and achieve increased overall efficiency. One of the more efficient heat exchangers is detailed in appendix 12. The heat exchanger was, however, very expensive and difficult to procure at a short notice.

4.8.11 Condenser

The design development of the condenser has been a tough challenge. This was due to the fact that a large amount of heat had to be dissipated during a short period of time without using an active energy consuming process. The cooling effect had to be efficient enough in order to prevent steam losses to the surroundings. The aim was, therefore, to gradually decrease the vapor temperature until it reaches room temperature. No suitable condenser was found on the market that corresponded to the requirements set up for the prototype concerning dimensions and efficiency.

Also, due to time restrictions a custom made condenser could not be ordered. Hence, a condenser based on brazed copper pipes was constructed. The reason for choosing copper pipes was due to its excellent ability to conduct heat.

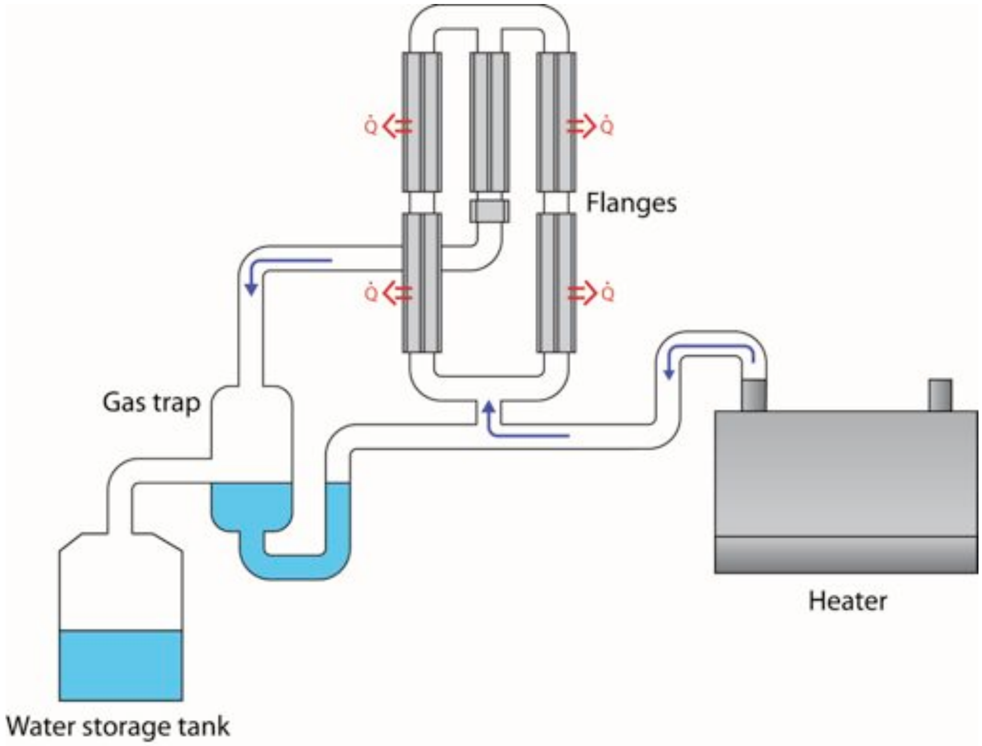


Figure 69: Schematic of the Condenser system

Five flanges were attached to the pipe construction using heat transfer paste and metal straps to keep them in place (see Figure 69). By using flanges, the surface area for emitting heat energy to the environment increases considerably, making the cooling process more efficient. The air outlet of the fan was diverted through the outside of the condenser to cool it effectively through forced convection.

The designed construction basically makes the vapor to flow through the condenser, thus condensing it inside the pipes. By using a gas trap the vapor is forced through the whole pipe construction while still enabling the water to flow off from more than one place without using several water storage tanks. When the air had been cooled to room temperature, it was let out to the surroundings.

4.8.12 Filter

In order to protect the LDC system and to make the water clean, there are some areas that need filtration. These areas are very important to filter in order to prevent dangerous particles and organic contaminants to get in to the LDC system. Hence, an adequate filtration system is necessary as it affects both the performance and safety of the product.

Filtration systems implemented in the AWG (see Figure 70):

- Mist Eliminator
- Distillation
- Active Carbon Filter
- UV Light

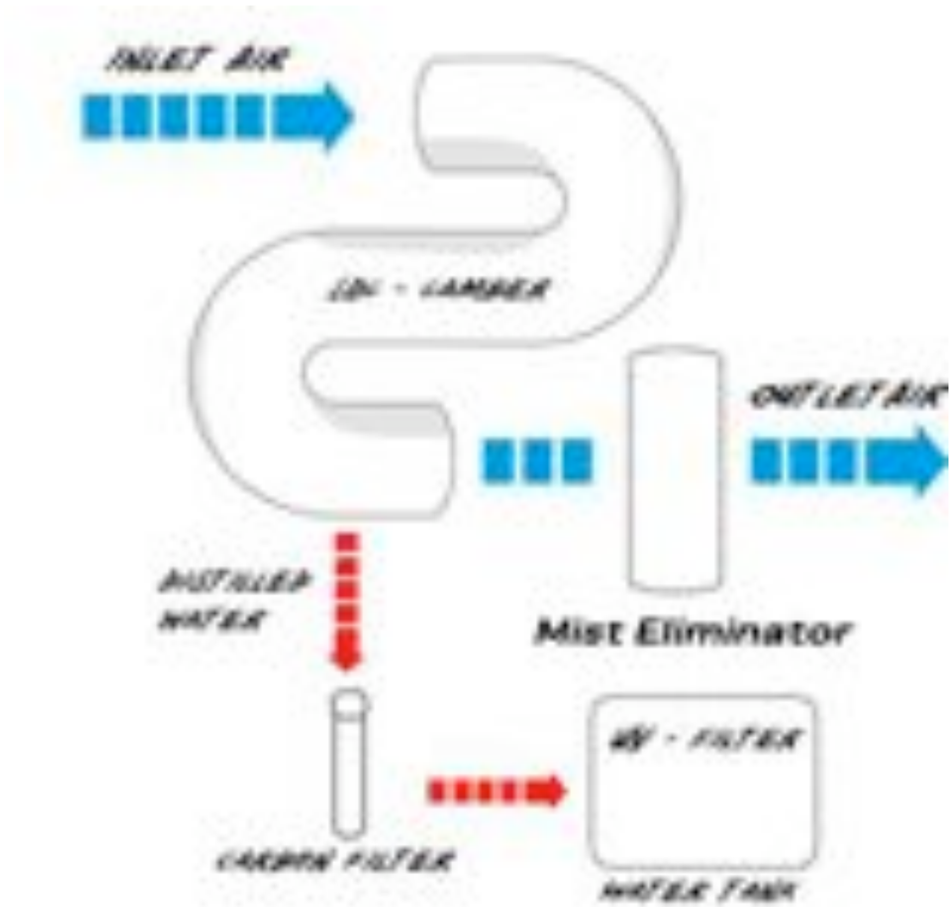


Figure 70: ***The filter system***

Mist Eliminator

To prevent the LiCl mist from leaving the machine via top chamber outlet, a mist eliminator is used. This is needed for two reasons: firstly, LiCl inhalation may be potentially harmful to humans, and secondly, excessive loss of LiCl will reduce the amount in the system and adversely affect its performance. The design requirements set up of the team was that the demister should prevent dissipation of particles down to 5 μm and also allow the particles to go back to the chamber. Mist eliminators used in the industry are very efficient for this purpose and the several alternatives that were discussed were:

- **Dry bed of tower packings.** 350 mm packings depth should prevent the dissipation down to 99%. It also allows particles to drip back into the chamber.

- **Zig-zag baffles.** Very effective and with low pressure drop. Increases the air velocity and traps the particles in small pockets. Allows particles to go back into the chamber (see Figure 71).

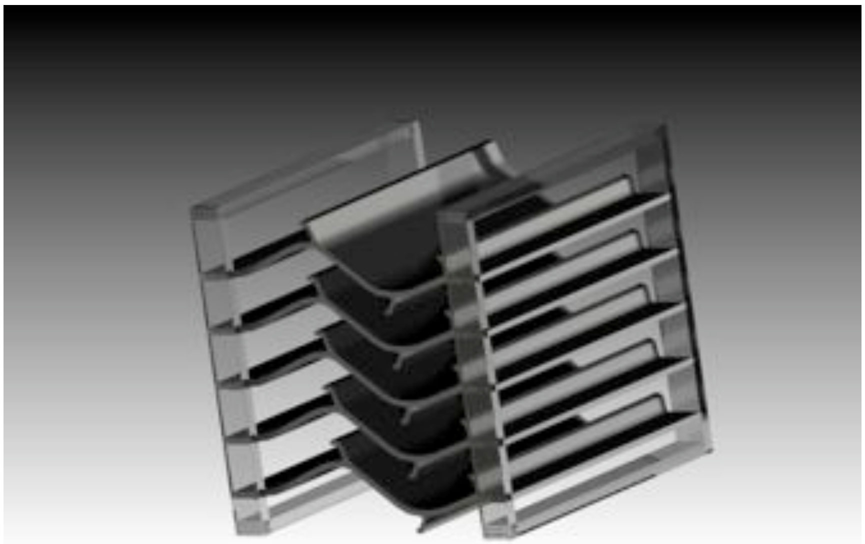


Figure 71: CAD-model of early designed zig-zag baffles for a horizontal air flow. The baffles should, according to simulations, prevent particles down to 7 μm from leaving the chamber.

- **Absolute filter**. Higher pressure drop but highly efficient.

- **Wire mesh demister.** Efficient in small applications. Up to 100% efficient for particles of about 5 μm. Allows particles to go back into the chamber (see Figure 72).

Figure 72: Wire mesh demister from Begg-Cousland.

In this prototype, a wire mesh demister was planned to use. This demister was suitable not only due to the small space it occupied, but also for its efficiency. However, due to shipment delays the demister was not received and tower packings were used instead. This did not stop the dissipation of particles to the extent desired but worked as an adequate supplement for the real demister.

Distillation

Condensed water has virtually all of its impurities removed through distillation. Distillation involves boiling the water and then condensing the steam into a clean container, leaving nearly all of the solid contaminants behind. Continuous distillation is an ongoing separation in which a mixture is continuously fed into the process and separated fractions are removed continuously as output streams as time passes during the operation. In a continuous distillation, each of the fraction streams is taken simultaneously throughout operation; therefore, a separate exit point is needed for each fraction. Distillation was an inbuilt feature in our technology as it was the very process through which the tam extracted water from the desiccant solution.

Active Carbon Filters

Activated carbon is a highly porous material that can absorb volatile chemicals on a molecular basis, but does not remove larger particles. It can efficiently remove Volatile Organic Contaminants (VOC), chemicals, and strong odors from the air. Other materials can also absorb chemicals, but at a higher cost. VOCs are organic chemical compounds that have high enough vapor pressure under normal conditions to significantly vaporize and enter the atmosphere.

Features:

- Reduces bad taste, odor and chlorine
- Great VOC reduction
- Post-filter to reduce carbon fines
- Post filter helps remove carbon fines and other suspended particles from the filtered water

UV-light

The final destination of the water is in the main water tank. An Ultraviolet (UV) filter is placed in the water chamber in order to prevent bacteria and virus growth within the chamber and keep the water fresh. UV light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than soft X-rays (see Figure 73).

UV filters are able to kill a majority of bacteria and viruses in the water that passes through them. However, they do not remove chemical pollutants from the water. UV filters use high frequency light to irradiate water through a glass element. Water passing the element is exposed to the light, which kills all living organisms.

Features:

- UV does not change taste, odor, color or pH of the water
- UV does not impart toxic by-products into the water
- Lowers overall bacterial count
- UV systems require very little maintenance

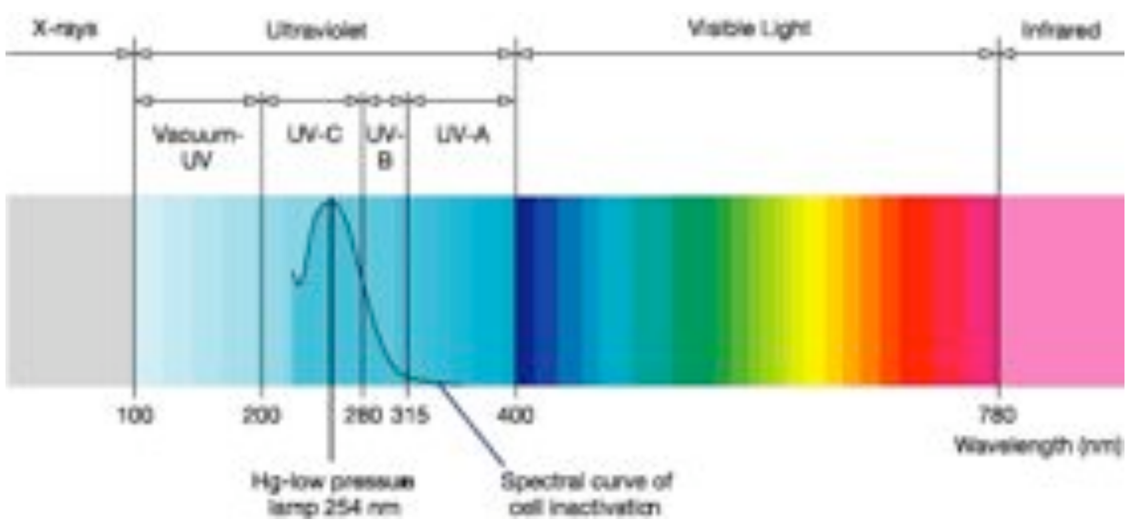


Figure 73: UV light spectrum showing UV-A, UV-B and UV-C

UV-light with a wavelength of 200-280 nanometer, called UVC light, is particularly efficient in killing bacteria and viruses.

4.8.13 Display

In order to display the RH level and the amount of water in the fresh water tank, a 7” TFT display was used (see Figure 74).

Figure 74: TFT display

A number of display designs were developed for future use (see Figure 75). The main goal was to have a good looking design and user friendly interface. The display also needed to blend with the exterior. Three concepts were made and considered.

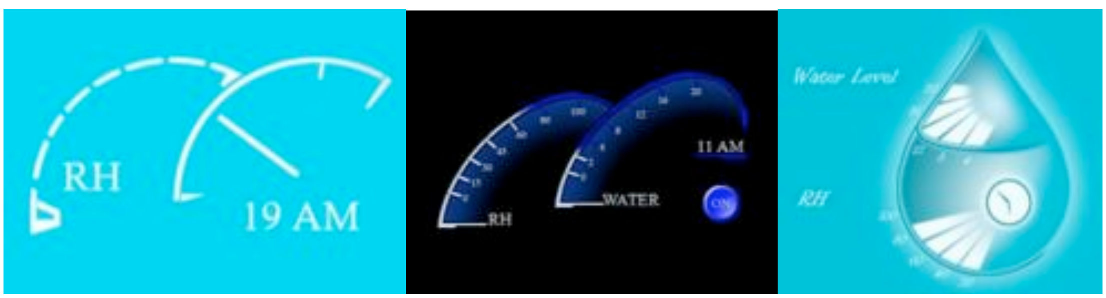


Figure 75: Display concepts

4.8.14 Choice of material

Liquid desiccants such as LiCl are highly corrosive in high concentrations and more specifically in high temperatures. Therefore, the choice of material is of great importance. The parts that are most exposed to corrosion are the ones that are integrated in the hot cycle of the process, like the heater and the heat exchanger. The heat exchanger, for example, needs to sustain the corrosion but also transport heat efficiently.

In the final prototype, the choice of material was sometimes compromised because of lack of time. The plan was to use plastic material as much as possible in the cold cycle and acid resistance stainless steel in the hot cycle. 316 SS and 316 L SS seem to be resistant to LiCl even at high temperatures, but further testing is needed to ensure that they will last under prolonged use.

4.8.15 Control System

Design Issues

The LDC functional system prototype did not contain any control system. The transfer of desiccant solution from the absorption chamber to the heater and back was done manually. This was due to the fact that the main objective of the functional prototype was to demonstrate the functioning of the liquid desiccant cycle. However, as the team started the design of the final product, a need for a separate control system was soon felt. The control system was needed to perform the following functions:

Task 1: to control the flow and/or timing of desiccant transfer from the absorption chamber to the heater and back
Task 2: to control the duration and/or magnitude of heating in the heater
Task 3: to operate and control the filter and the dispenser system
Task 4: to control the display screen

However, before starting with the technical details of the control system, the team found that it was necessary to answer some basic design issues.

Determination of the desiccant solution concentration

This was necessary since the concentration of lithium chloride in the solution determines the amount of moisture that has been absorbed. Besides, optimum absorption performance requires lithium chloride concentration to be as close to 45% w/w as possible. Above this concentration, LiCl starts precipitating and a lower concentration leads to low moisture absorption rate. The determination of LiCl concentration was also necessary to determine the extent of heating that needed to be performed in the heater. After extensive technology research, it was decided that the concentration would be measured in the prototype by finding the boiling point of the solution in the heater. This was based on the fact that as the concentration of LiCl increases, the boiling point of the mixture also increases.

Batch process vs. Continuous Process

The team initially considered two different processes for the desiccant solution treatment. One idea was the batch process that involved transferring the desiccant solution to the heater in separate batches (see Figure 76). Another idea was the continuous process in which a (variable) quantity of the solution always flowed into the heater and the boiling process took place continuously.

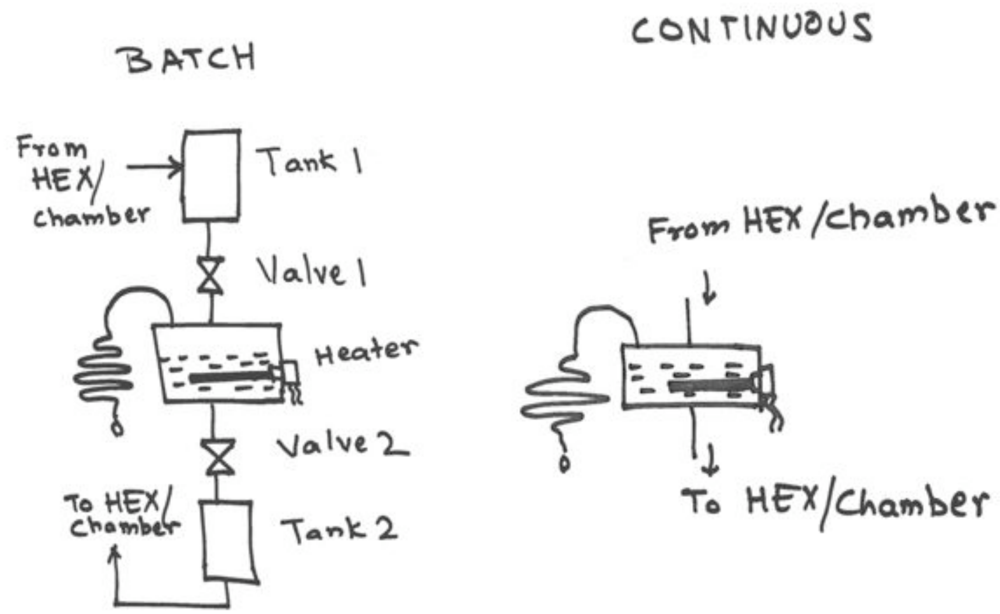


Figure 76: Batch process vs. Continuous Process. The batch process requires the use of two extra tanks and valves. This complicates the fabrication and control process.

One advantage of the batch process was that it allowed better control on the rate and quantity of the boiling process. Since the team was initially uncertain about the magnitude of losses in the system, one concern that the batch process addressed was the freedom to provide almost infinite amount of heat to a given solution quantity. This could be achieved in the batch process by just increasing the amount of time for which the solution stayed in the heater. This freedom was not available in the continuous process. The team, however, went with the continuous process due to the following reasons:

- The batch process requires two extra valves and tanks. This complicates the fabrication process. Since both the valves need to be controlled through relays, the control system becomes complicated and cumbersome.
- An efficiently executed and optimized continuous process is capable of keeping the LiCl concentration at a constant value (of ~45% wt/wt). This is not possible in a batch process as the solution concentration in the chamber necessarily oscillates with the opening and closing of the valves.
- Heat Exchanger is more efficient when the flow through it is continuous. Though it can still be achieved in a batch process through the use of tanks 1 and 2, it requires precise control of the flow rates and timings of the valve.

Microcontroller-based control system vs. laptop-based control system

Another trade-off that the team faced was to choose between the elegance of a microcontroller-based system and the simplicity of a laptop based system. A microcontroller-based system is, of course, a more compact and stable solution. However, it is time consuming and complex. A laptop-based system, on the other hand, is simple to implement and flexible. But it is bulky as it requires a laptop and a external data acquisition device. However, due to paucity of time and considering that the prototype was not designed to be a final 'ready to ship' product, the team decided to implement the laptop based system.

System Overview

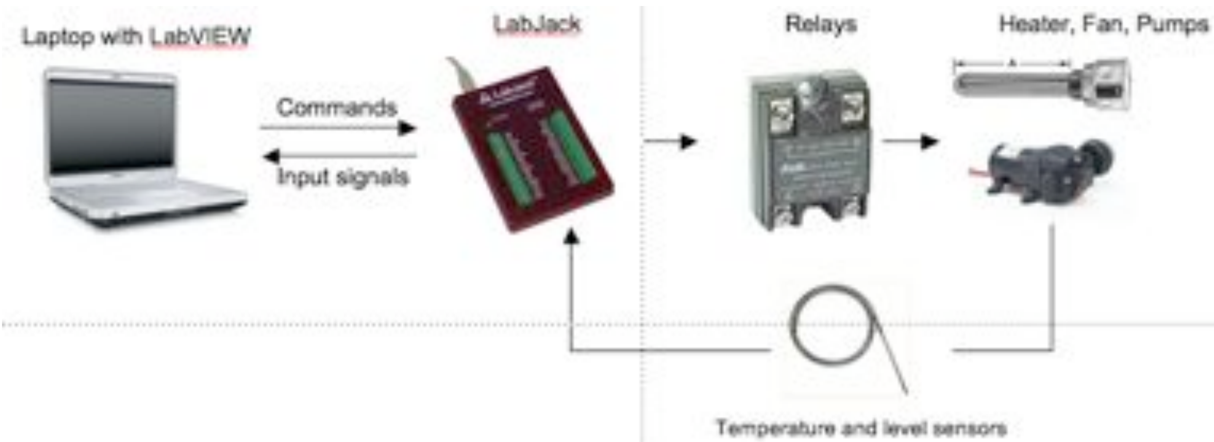


Figure 77: Control System Block diagram

A commercially available automation device, called LabJack, is used as an interface between the laptop and the machine. LabJack receives input signals from the various sensors in the device and controls the electrical components (heater, fan, pumps) via relays. The logic is programmed into LabJack via commercial virtual instrument software called LabVIEW. Detailed information about specifications, wiring and functioning of each system component can be found in the design specifications section. A brief rationale behind the selection of the components is given below.

Sensors

Sensors are required to gauge the machine state (temperature, water level etc.) and provide this information to LabJack. The sensors have been used in the machine to fulfill the following functions:

- **Heater temperature measurement:** Heater temperature is needed to measure the concentration of the heated desiccant solution in the heater. The heater remains on until the solution concentration is below a certain threshold value. Once the threshold has been reached, the heater is switched off. The threshold value is obtained empirically through heater test runs. Care is taken to ensure that the boiling rate at the threshold value is neither too high such that spilling occurs nor is it too low.

- **Solution level detection in the heater:** Even though the final design uses a continuous process with no net 'theoretical' liquid volume change in the heater, two pumps can never provide identical flow rates in practice. Even a slight mismatch in the flow rates may give rise to overflow/emptying of the heater over the course of the machine operation. Hence, the level inside the pump needs to be maintained. Hence, a differential pressure sensor has been used to control the liquid level inside the heater within two threshold limits. A differential pressure sensor offered many advantages over a conventional liquid level sensor:

- The conventional liquid level sensors are large and it was difficult to install them into the heater. Pressure sensor, on the other hand, could be easily installed outside the heater.
- Only one pressure sensor can be used to detect both the threshold levels (top and bottom) instead of two level sensors.
- The application did not require very high precision.

The two pressure thresholds were determined empirically by reading the sensor value at the required liquid levels. Since the sensor reading was dependent on temperature, care was taken that the temperature during the calibration process was kept at close to 120°C. Figure 78 shows the flowchart showing the pressure sensor operation.

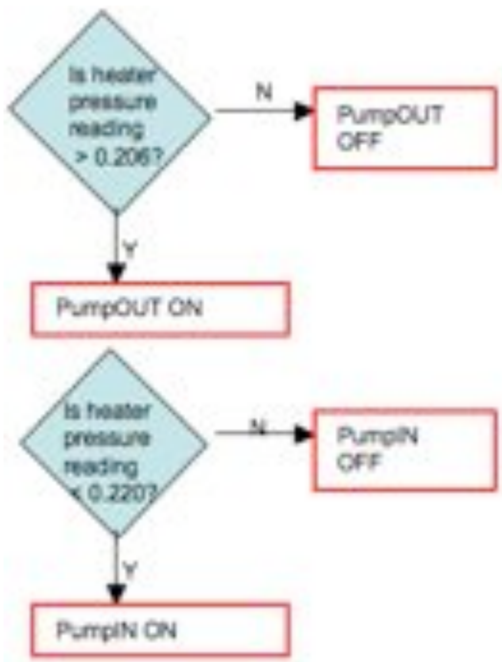


Figure 78: Flowchart showing how pressure sensor readings are used to control the pumps supplying liquid into (PumpIN) and out of (PumpOUT) the heater.

- **Liquid level detection in the main water tank and temporary water storage:** Level sensors are required in the water tanks to determine when the tanks are full/ empty. For instance, once the temporary storage tank gets filled the water is pumped through the filter till the tank gets empty. All the processes are closed one the main water tank is full of water. In all, three vertical – mount level switches have been used (two in the temporary storage tank and one in the main tank).

Relays

Since LabJack is unable to provide the necessary power to run any of the electrical components, solid state relays are used to control the on/off state of the components through LabJack. In particular, relays are used to run the heater, fan, dispenser valve and all the pumps. Detailed information about the relays and the components that they run can be obtained from the specifications section.

5 DESIGN SPECIFICATIONS

5.1 Overview

In this section, all the physical specifications are discussed. The entire CAD assembly with the bill of materials is shown in Appendix 28. The Mìmir consists of the following parts:

- Frame and exterior parts
  - Aluminum frame
  - Wheels x 4
  - Front panel
  - Side panels
    - Air filters

- Absorption chamber
  - Plastic chamber
  - Mist eliminator
    - Plastic net
  - Nozzle
  - Tower packingss
    - Plastic mesh
  - Radial fan
    - Air duct
  - LiCl storage tank
  - Circulation pump for absorption chamber
  -
- Heater
  - Immersion Heater
  - Thermo sensor
  - Pressure sensor
  - Heat exchanger
  - Circulation pump 1 for heater
    - Flow rate meter
  - Circulation pump 2 for heater
    - Flow rate meter
- Condenser

  - Condenser piping
  - Water trap
  - Distilled water tank
    - 2 x Level sensor
  - Fresh water pump
  - Active carbon filter
  - Fresh water tank
    - Level sensor
    - UV-lamp
- Water dispenser
  - Led diode
  - Solenoid valve
  - Tap
  - Sliding mechanism
  - Hot and cold water switches
- Control unit
  - Lab jack
  - Laptop with Lab view
  - Solid state relays
  - RH sensor
  - Pressure and level sensors
- Power transformers
- TFT-display
- Fittings and pipes

All parts are mounted on a frame that measures 1400x500x400 mm and is manufactured of T-slotted aluminum bars (see Figures 46 and 47).

In the bottom section the liquid desiccant storage tank, three circulation pumps and the flow rate meters are positioned.

The absorption cycle, with the absorption chamber as main part, is located in the middle of the prototype with air inlets on each side to ensure an inflow of ambient air. The heat exchanger and heater are also located in the same section.
In the top section, the fresh water tank is placed together with the carbon filter, water dispenser and TFT-display.

5.2 Frame and exterior parts

The frame and exterior parts consists of a frame, wheels, front panel and side panels.

5.2.1 Frame

The frame has the dimensions 1400 x 500 x 400 mm. It is made of extruded aluminum profiles with lengthways slots (see Figure 79). The profile dimensions are 25.4 x 25.4 mm (see Appendix 14).

Figure 79: Extruded aluminum profile

5.2.2 Wheels

4 wheels allow the machine to be portable.

5.2.3 Front Panel

The front panel has the dimensions 1460 x 510 mm. It is made of transparent blue acrylic plastic with a reflective film on the back (see Figure 80). The panel thickness is 6.35 mm (see Appendix 15).

Figure 80: Front panel

5.2.4 Side Panels

The side panels have the dimensions 1454mm x 500 mm. They are made of brushed aluminum (see Figure 81). The panel thickness is 2 mm (see Appendix 16).

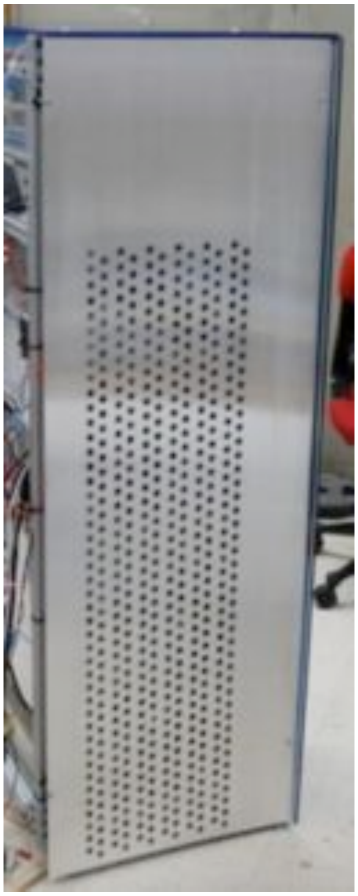


Figure 81: Side panel

5.3 Absorption chamber

The absorption chamber consists of a plastic chamber, mist eliminator, nozzle, tower packings and a fan.

5.3.1 Plastic chamber

The plastic chamber is made of acrylic plastic (Lexan) (see Figure 82). The chamber is vacuum formed from 3 mm plastic sheets (see Appendix 17).

Figure 82: Plastic chamber

5.3.2 Mist eliminator

The mist eliminator has the dimensions 250 x 250 x 200 mm. A plastic net has been used to hold the mist eliminator in position.

5.3.3 Nozzle

The nozzle is a whirl type nozzle characterized by medium atomization (relatively large drops). It gives a full cone, 120° spray pattern.

5.3.4 Tower packings

The tower packings are of 'high flow type' manufactured by *Rauschert* (see Figure 83). A plastic mesh holds the tower packings in position (see Appendix 18).

Figure 83: Tower packings

5.3.5 Radial fan

The radial fan is manufactured by *EBMpapst* with the product number G2E180EH0301 (see Figure 84 and Appendix 19). It has a fan duct to bend the air flow to cool the condenser.

Figure 84: Radial fan

The LiCl storage tank has the dimensions 350 x 110 x 150 mm.

The circulation pump pumps the LiCl through the chamber with a liquid flow rate of 10 l/min (see Appendix 20).

5.4 Heater

The heater consists of a heat chamber, immersion heater, sensors, pumps and a heat exchanger.

5.4.1 Heat chamber

The heat chamber is designed by the team as seen in Figure 85. It is manufactured by tig-welding and made in stainless steel 316 (see Appendix 21). It was manufactured at EM Manufacturing, Manteca, CA.

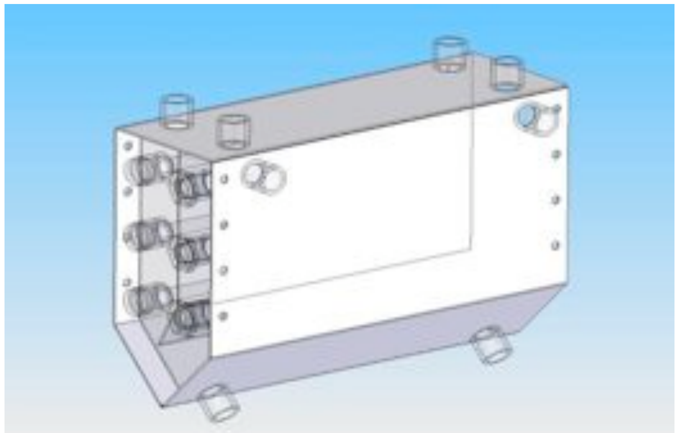


Figure 85: Heat chamber

5.4.2 Immersion heater and heat exchanger

The immersion heater is a product from McMaster-Carr with product no. 3656K346 (see Figure 86).

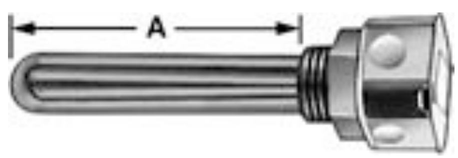


Figure 86: Immersion heater

The heat exchanger has the dimensions 315 x 71 x 74 mm (see Figure 87). It is manufactured in 316 L Stainless steel.

Figure 87: Heat exchanger

Two pumps control the flow in and out from the heater: Circulation pump 1 (PumpIN) to the heater and circulation pump 2 (PumpOUT) from the heater. See Appendix 20 for details.

5.4.3 Sensors and meters

Thermo sensors and pressure sensors are described in the LabJack section. The pumps flow are visualized in a High-Performance Acrylic flow meter from McMaster-Carr with product n0. 4350K41 (see Figure 88).

Figure 88: Flow meter

5.5 Condenser system

The condenser system consists of a condenser, water trap, distilled water tank system, water pump, active carbon filter and a fresh water tank (see Figure 89).

5.5.1 Condenser

The condenser is manufactured using copper pipes and heat sinks. Its specifications are:

- 5 flanges
- Copper pipe construction (350 mm high and 150 mm wide)
- Flanged aluminum pipe (1 meter long)

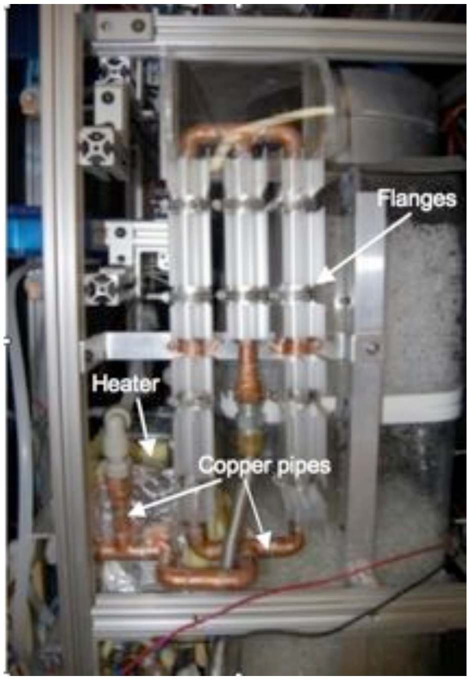


Figure 89: The Condenser system

5.5.2 Water tank

The water tank is manufactured in acrylic plastic with the dimensions 160 x 150 x 160 mm.

5.6 Dispenser system

The water dispenser system consists of a LED (Light emitting diode) tap (see

Figure 90).

Figure 90: LED tap

The system also has a solenoid valve, a sliding mechanism (see Figure 91) and hot & cold water switches to provide the water to the user.

Figure 91: Sliding mechanism

5.7 Control system

The Mimir Atmospheric Water Generator requires a laptop to control the functioning of the device. The laptop-machine interface is achieved using LabJack U12, a USB-based multifunction data acquisition and control device. LabJack U12 receives the required information from the temperature and level sensors and communicates with the electrical devices (pumps, fan, LEDs and valves) through the ON/OFF relays. The logic is programmed into LabJack using LabVIEW.

5.7.1 LabJack

LabJack is implemented into Mímir (See Figure 92) with various ports controlling different devices, as seen in Table 5. The complete LabJack wiring diagram is shown in Figure 93. LabJack perfoms three broad range of functions:

- Receives input from various sensors (temperature, pressure and level sensors)
- Provides ON/OFF output to various relays that control the pumps
- Provides +5 volt output to power the temperature sensor, pressure & level sensors, the dispenser valve and buttons

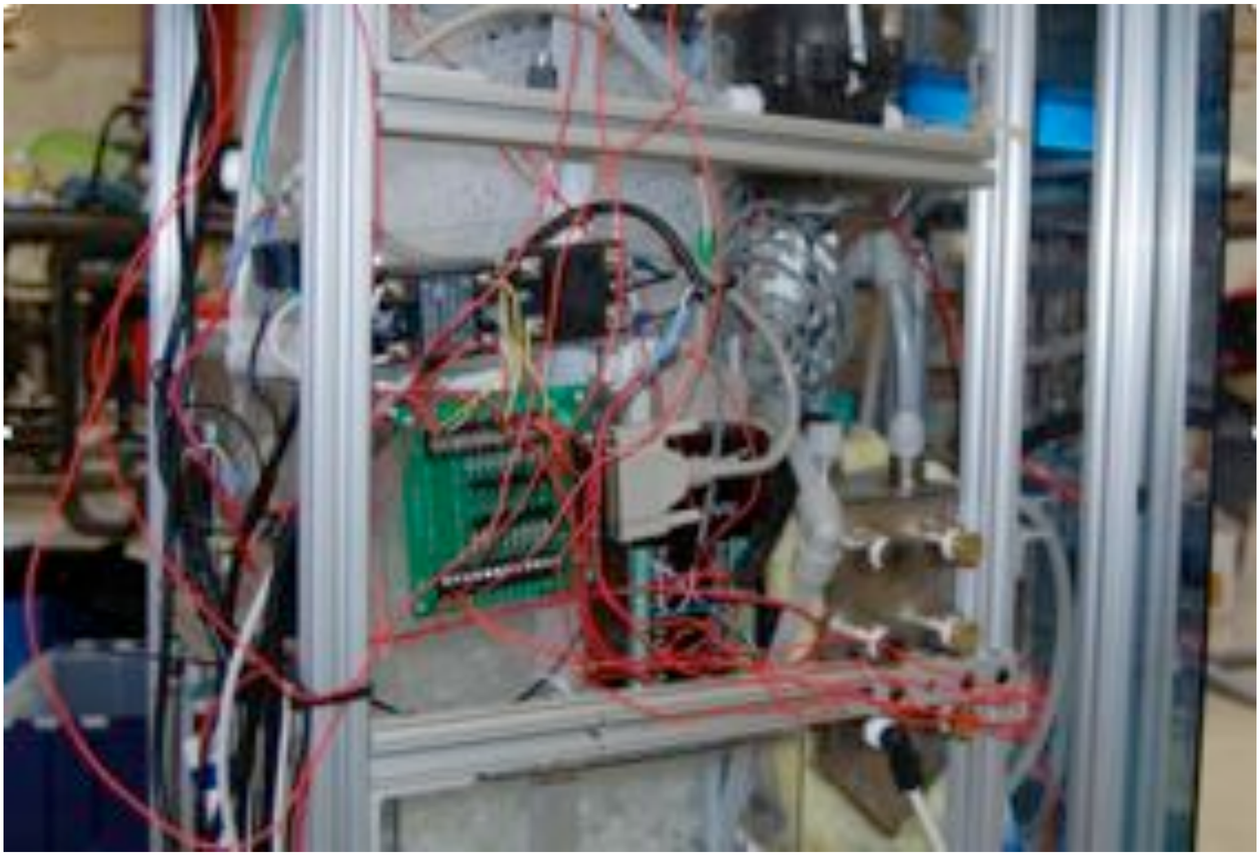


Figure 92: An actual picture of the LabJack wiring as it looks in the machine

Input ports	Sensor	Output ports	Control Relay
AI0	Temp. Sensor	D0	Heater
AI1	Pressure Sensor	D1	PumpIN
AI2	Top Level Sensor (Temporary water storage)	D2	PumpOUT
AI3	Bottom Level Sensor (Temporary water storage)	D3	Filter Pump
AI4	Main water tank level sensor	D4	Fan
		D5	Chamber Pump
		D6	UV Light
		+5V	Dispenser Valve

+ 5V	Dispensor switches, LEDs and Level Sensors

Table 5: Table showing the ports that control various input and output devices

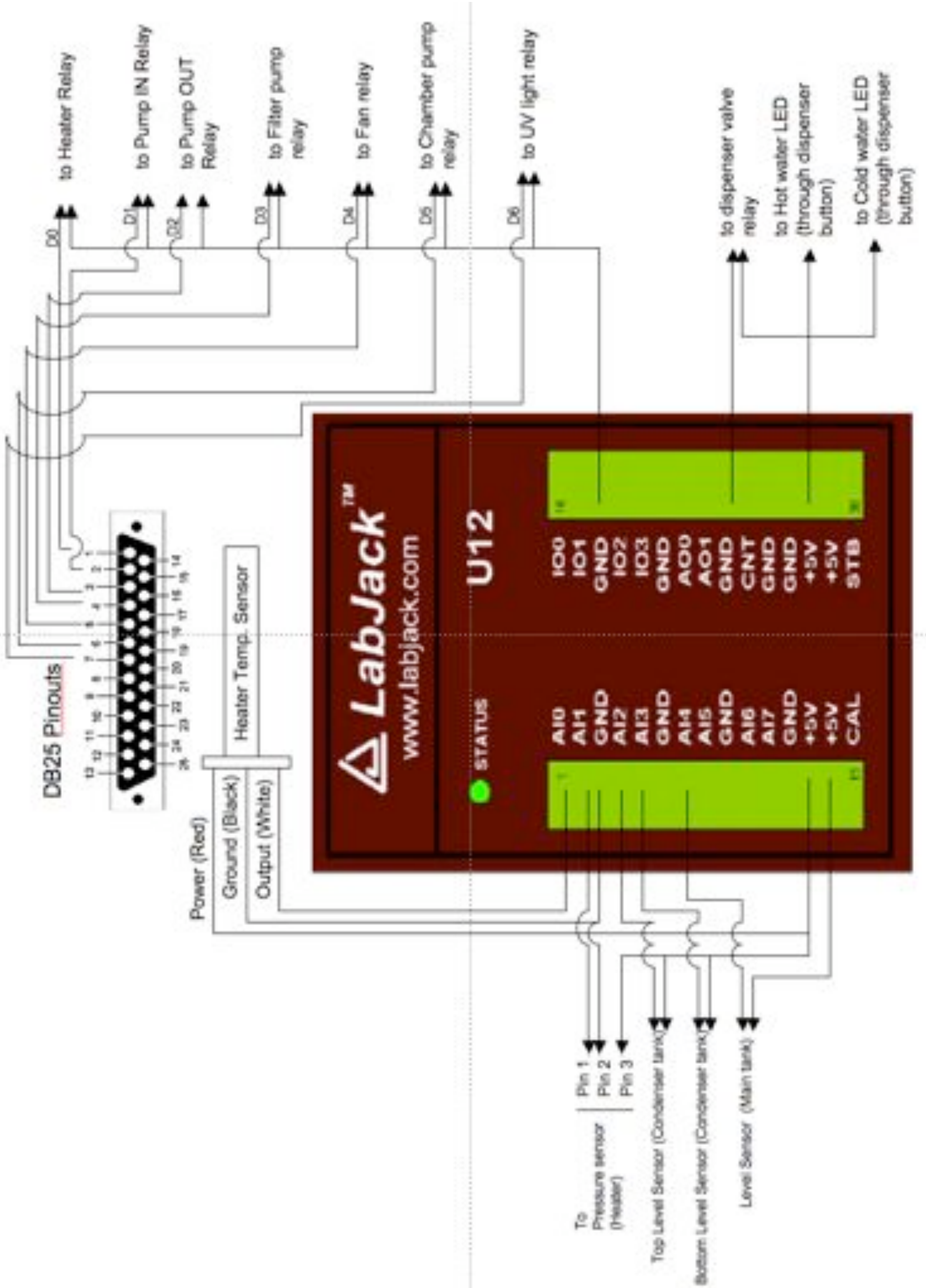


Figure 93: LabJack Wiring diagram

5.7.2 LabVIEW

LabVIEW is a commercial graphical programming software for measurement and automation. It is used in the product as an interface between laptop and LabJack. LabVIEW processes the input signals obtained by LabJack and provides appropriate instructions to LabJack based on the programmed logic (See Figure 94 and Figure 95).

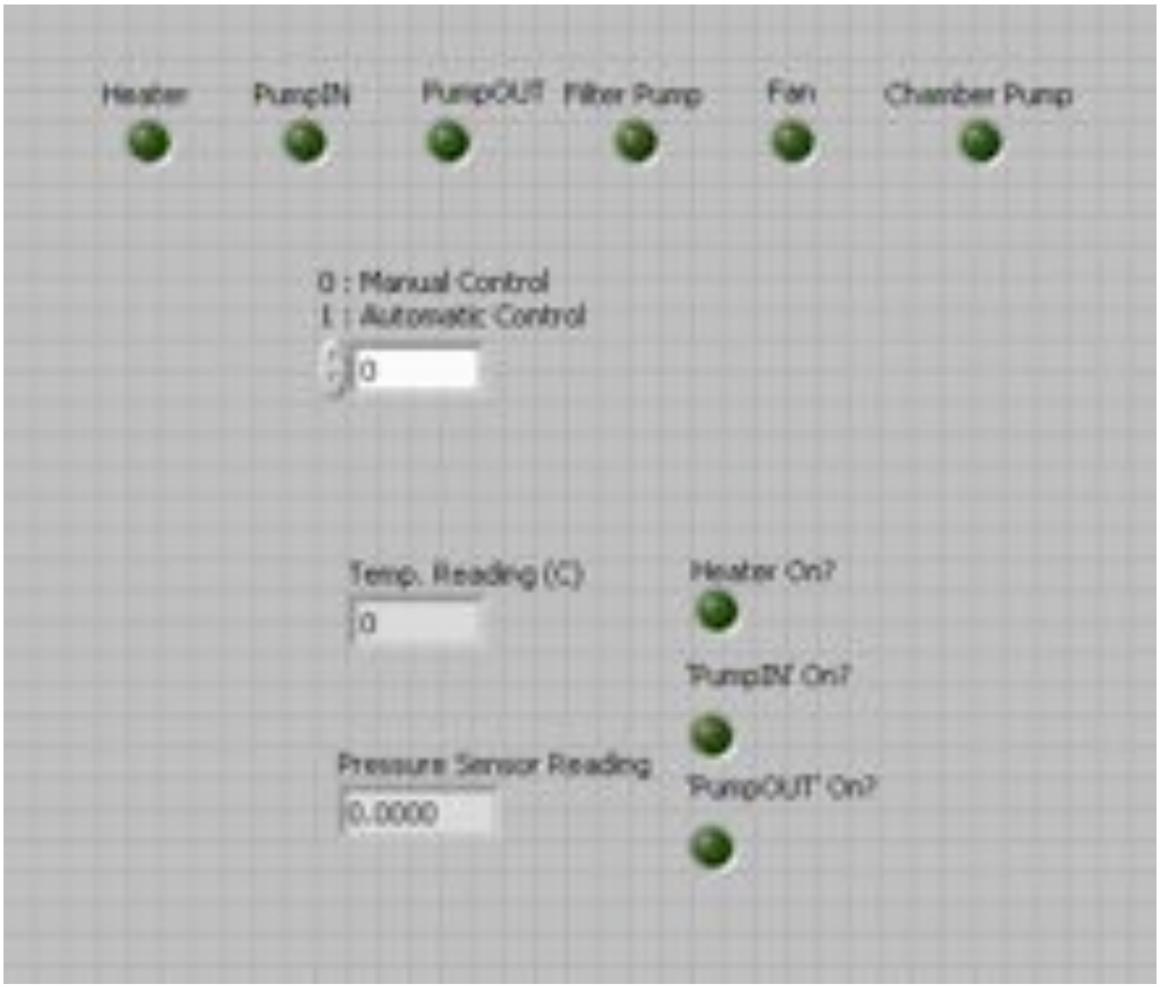


Figure 94: Output screen of LabVIEW showing the temperature and pressure sensor readings and the electrical devices' states

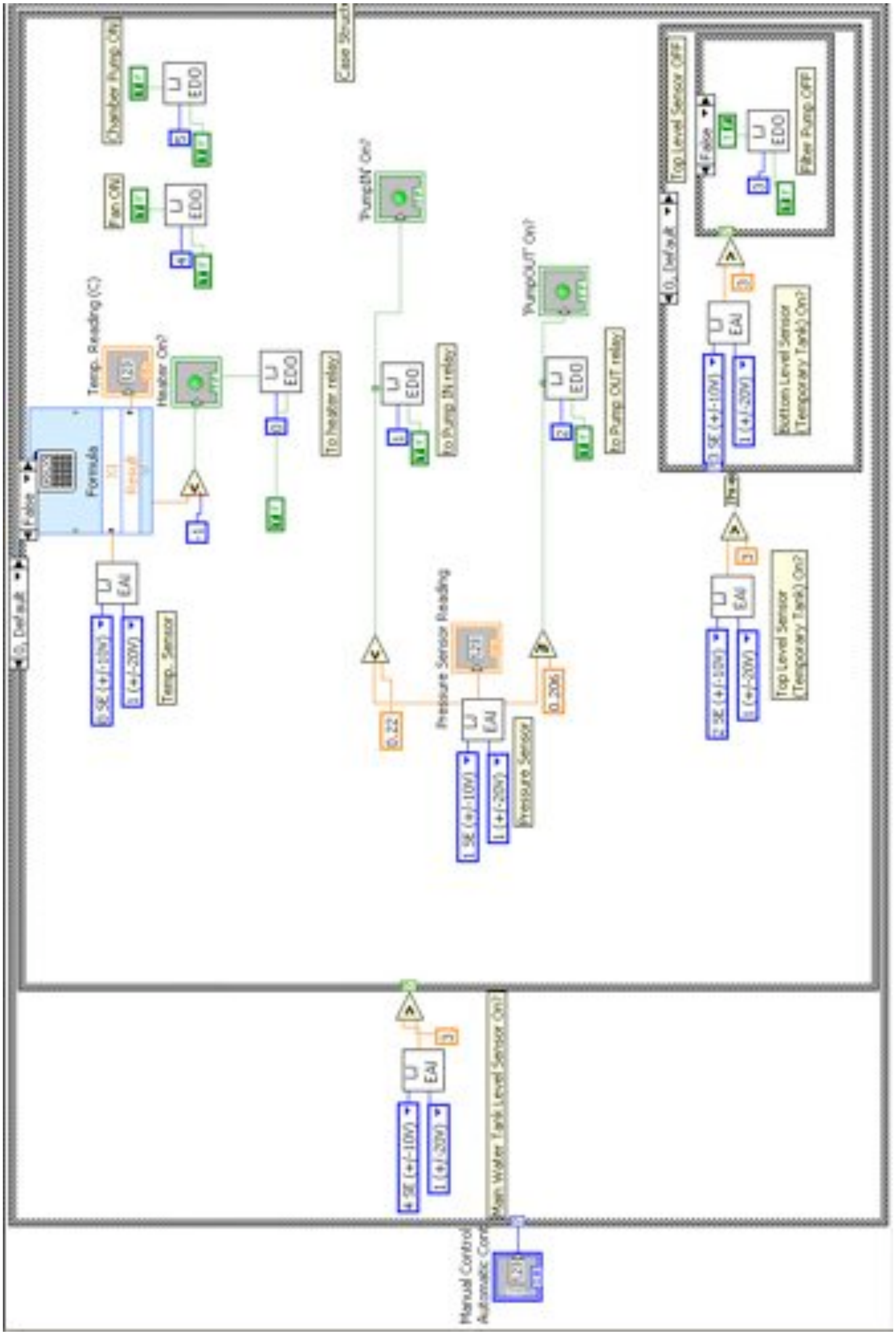


Figure 95: The complete Block diagram of the .vi program in LabVIEW

LabVIEW enables the machine to run in two modes:

- Manual Mode
- Automated Mode

Manual Mode

In this mode, the user can manually control the ON/OFF state of each electrical device. This is done by clicking on the control switch for the respective device (see Figure 96). Specifically, the devices that can be controlled are:

- Heater
- Fan
- Pump IN
- Pump OUT
- Filter Pump
- Chamber Pump

The Manual (or Automated) mode can be switched on by toggling the control switch to 0 (or 1). The manual mode enables the user to gain control of the machine and helps him in calibrating the temperature and the pressure sensors. The manual mode is also an invaluable tool for the service technicians and aids in testing the machine.

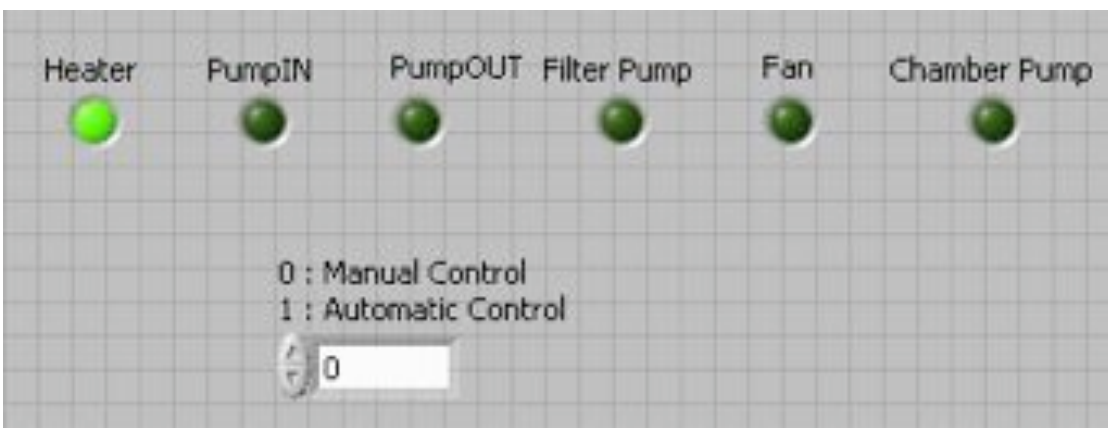


Figure 96: LabVIEW running on the manual mode. The heater is currently switched on. Automated mode can be set by changing the control from 0 to 1

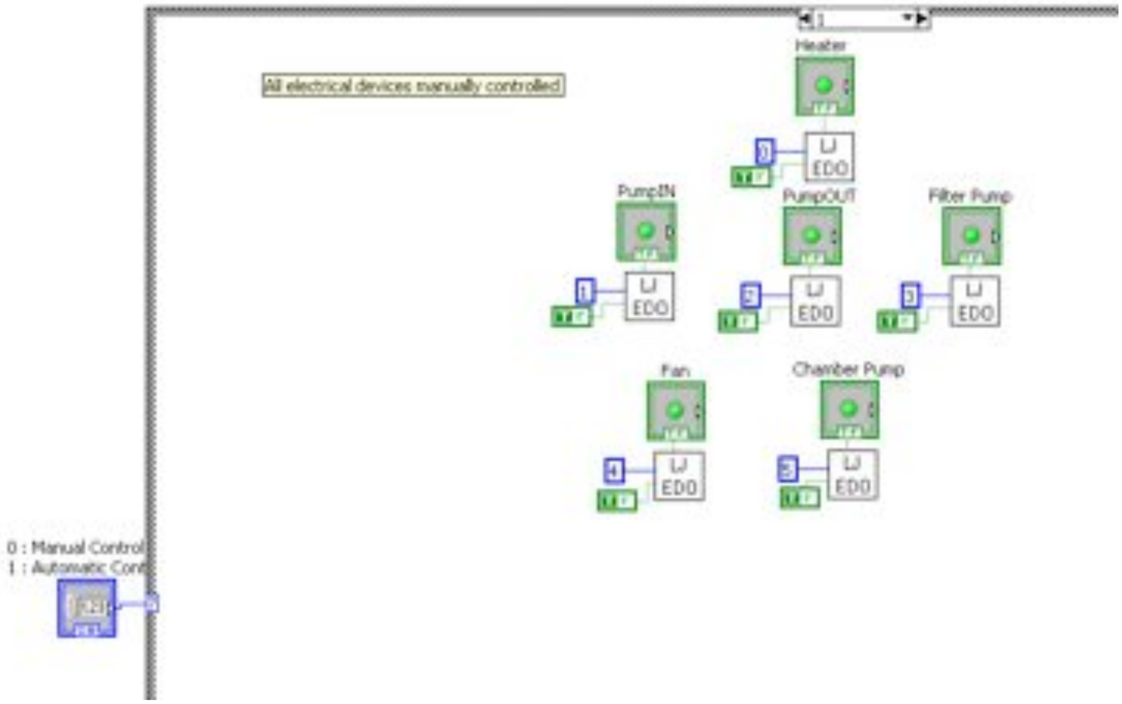


Figure 97: Block diagram for the manual mode as implemented in LabVIEW. This block diagram is activated when the control switch is set to 0.

Automated Mode

In this mode, the machine runs automatically with minimum intervention from the user. The heater temperature and pressure readings are displayed on the LabVIEW output display. The on/off states of the heater and the pumps into and out of the heater are also displayed (see Figure 97). This information helped the team in judging the functioning of the machine while it was being tested in the automated mode. A complete flowchart of the functioning of the automated mode is shown in Figure 99.

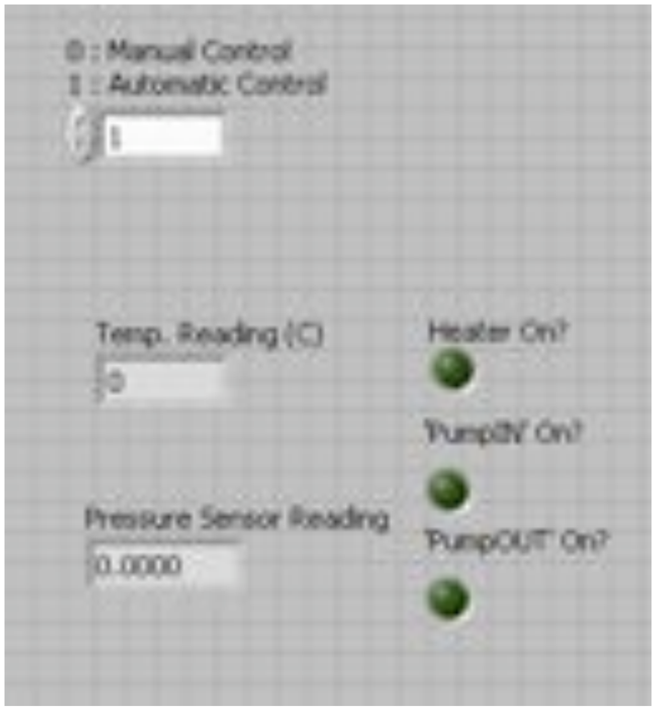


Figure 98: Automated mode display. The temperature and pressure readings can be read directly on the display.

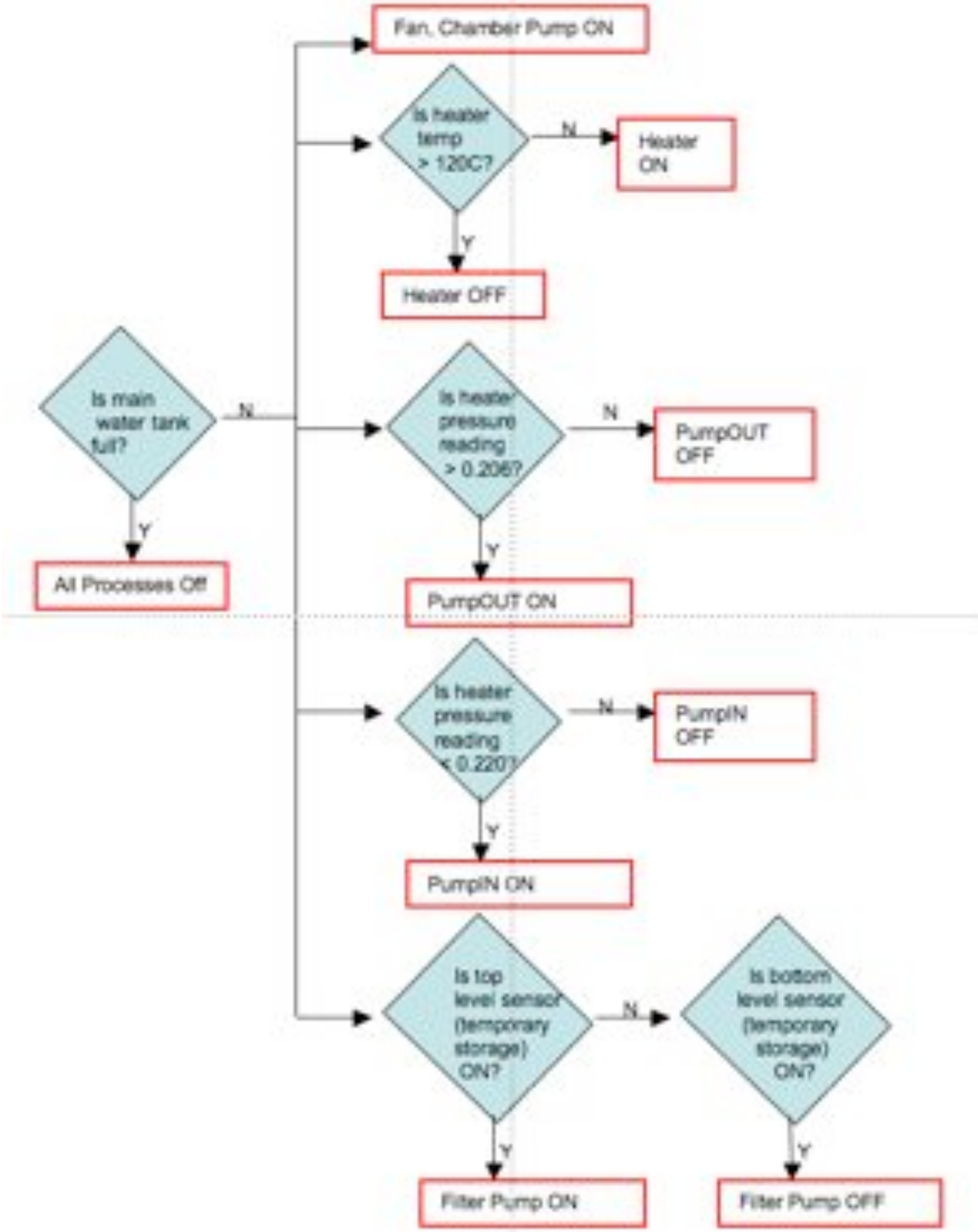


Figure 99: A flowchart showing the logic that has been implemented in LabVIEW

5.7.3 Sensors

Sensors have been used to sense the heater temperature and liquid level in various tanks. The product uses following sensors:

Temperature sensor

Temperature Sensor: A universal Temperature probe (Model No. EI-1034) has been used to monitor the temperature inside the heater (see Figure 100).

Figure 100: The Universal EI-1034 temperature sensor

The sensor specifications are:

Range with 0/5 volt supply:	+10 to +300 °F (-12 to +150 °C) with the LabJack U12
Output to LabJack or Meter:	10 mV per °F
Accuracy:	
+/- 0.4°F Typical	Room Temperature
+/- 1°F Max	Room Temperature
+/- 2°F Max	0°F to 230°F
+/- 3°F Max	-40°F to 0°F
+/- 1°F Typical	-50 °F to 300 °F
Sensor device in probe:	LM34CAZ
Cable length:	6 ft supplied max 25 ft user extended
Probe dimensions:	6 in x 0.25in diameter
Power:	+4 to 35 VDC at 90 uA

Output Current: 10 mA

The probe required three connections:
Red: +5 volts port of LabJack
Black: ground port of LabJack
White: Output signal (AI0 port of LabJack)

The output voltage can be converted into temperature readings using the formulae given below:
°F = 100*volts
°K = (55.56*volts) + 255.37
°C = (55.56*volts) + 255.37 - 273.15

The detailed instruction manual for the temperature probe can be seen in Appendix 25.

Pressure Sensor

The pressure sensor has been used to gauge the top and bottom liquid level inside the heater. The information is used to control the on/off states of the pumps (PumpIN and PumpOUT), thus controlling the water flow in and out of the heater. The control logic and connections have already been shown in Figures 93 and 99)

The sensor used is the Motorola MPX5100D Differential port pressure sensor (see Figure 101) The datasheet is attached as Appendix 25. Relevant specifications for the sensor are: (See Table 6)

Characteristic	Value
Operating Temperature	-40C to 125C
Differential Pressure Range	0-100kPa
Output Voltage	0.2V to 4.7V
Sensitivity	45mV/kPa

Table 6: Relevant specifications of the pressure sensor

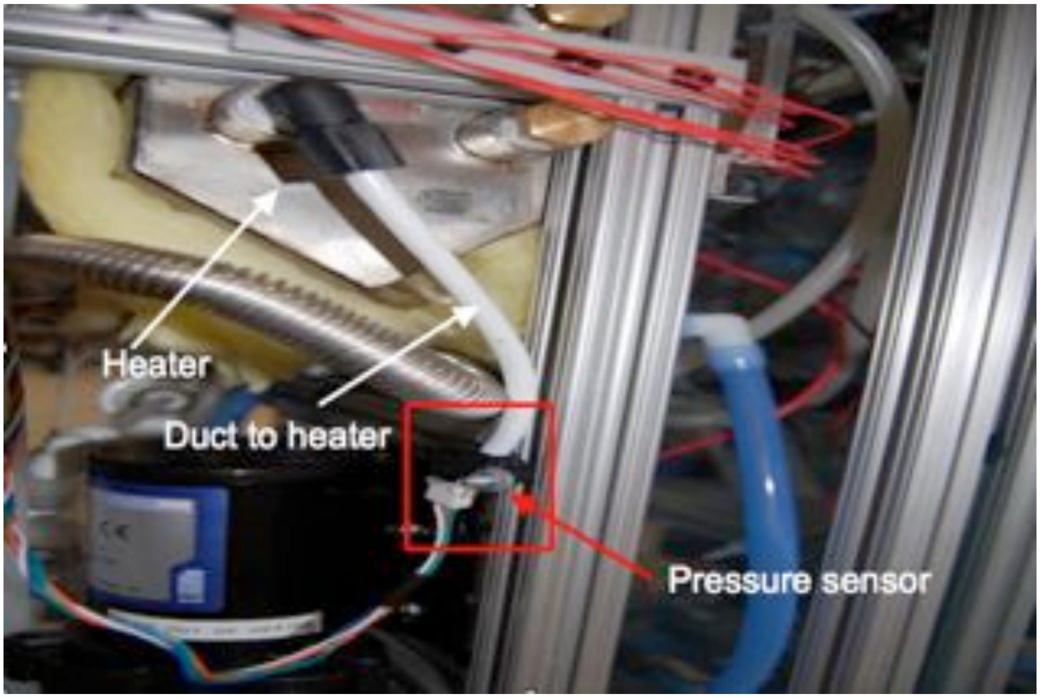


Figure 101: The pressure sensor in operation

5.7.4 Relays

Eight relays have been used to control various electrical components used in the system. Depending on the power rating of the device, the relay output is either DC or AC (see Figure 102). The output power rating of the relays also vary based on the device requirement. The specifications of the relays are: (See Table 7)

Relay	Type	Input	Output	Controls
Cosmo KSD240AC8	SS, DC/AC	4-32 V DC	240V AC @ 40A	Heater
Cosmo KSD240AC8	SS, DC/AC	4-32 V DC	240V AC @ 40A	UV Light
ECE S-2181	SS, DC/AC	3-32 V DC	24-240V AC, 10A	Chamber Pump
ECE S-2181	SS, DC/AC	3-32 V DC	24-240V AC, 10A	Fan
Kyoto KF0604D	SS, DC/DC	3-32V DC	60V DC @ 4A	PumpIN
Kyoto KF0604D	SS, DC/DC	3-32V DC	60V DC @ 4A	PumpOUT
Kyoto KF0604D	SS, DC/DC	3-32V DC	60V DC @ 4A	Filter Pump
Kyoto KF0604D	SS, DC/DC	3-32V DC	60V DC @ 4A	Dispenser Valve

SS: Solid State

Table 7: Specifications for the relays

(a) (b) (c)

Figure 102: (a) Cosmo DC/AC SS Relay, (b) ECE DC/AC SS Relay and (c) Kyoto DC/DC SS Relay

5.7.5 Dispenser Control System

The dispenser control system consists of a valve, two LEDs (for hot and cold water each) and two buttons. Figure 103 shows a schematic of the circuit diagram for the dispenser control.

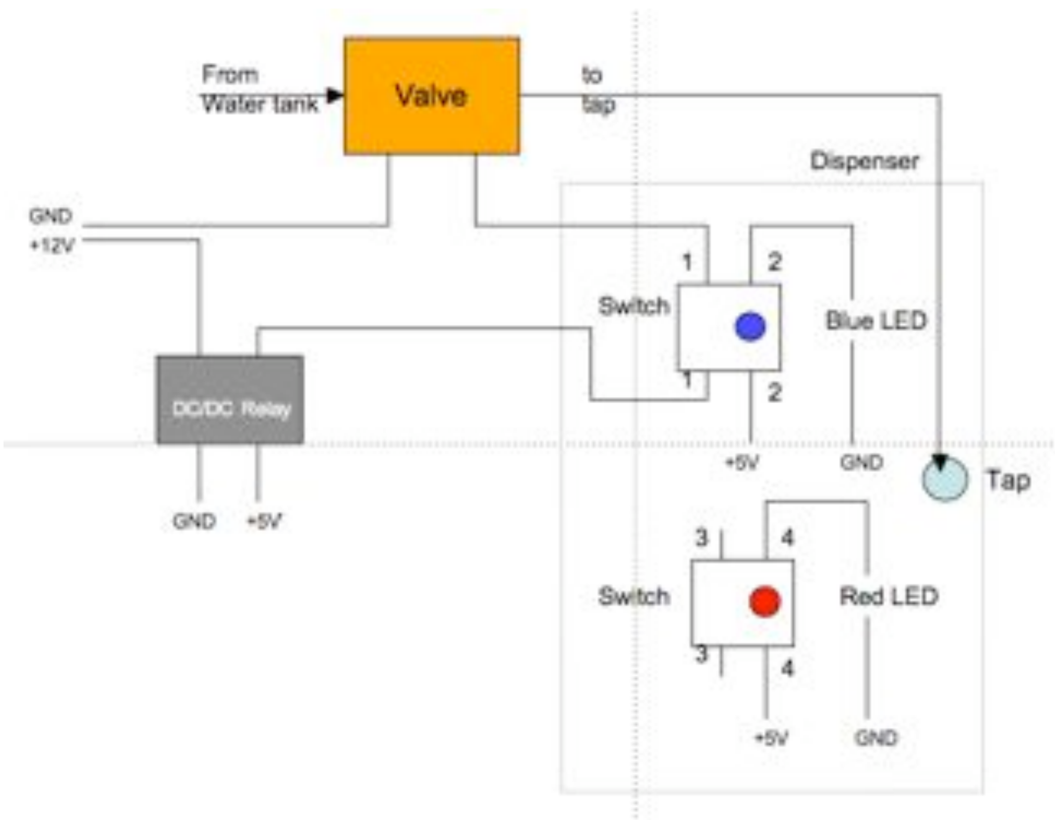


Figure 103: Schematic of the Dispenser control System. The valve has not been connected to the hot water switch (Red) as the hot water function was not implemented

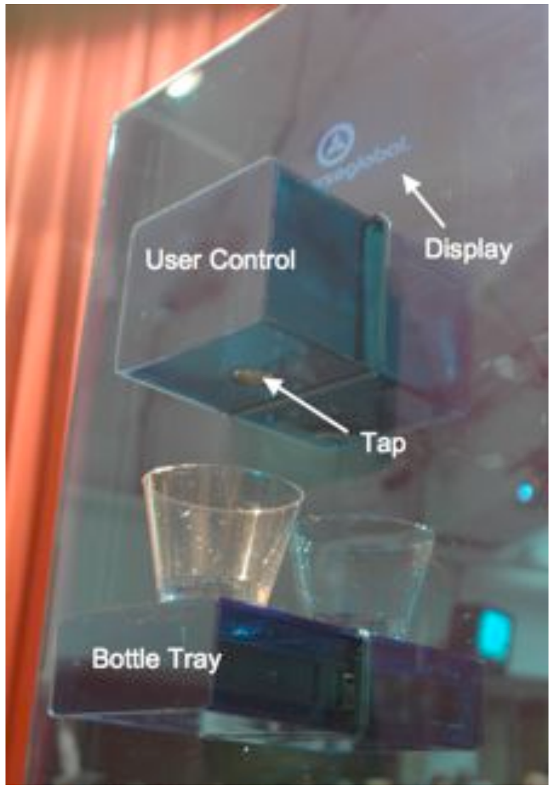


Figure 104: The Dispenser system. The LED buttons are on the top panel of the User Control.

5.8 Power supplies used

Variac or variable transformer (for absorption chamber fan): used to control voltage input to fan between 0-240VAC)

Company:	Powerstat
Model:	3PN1168
Current:	10A
Voltage:	0-140V

Transformer (for Variac): used to convert 120VAC supply to 240 V (feeds power to the variac)

Company:	Voltage Valet
Model:	TGC500
Step up:	120V to 240V, 60 Hz
Step down:	240V to 120V, 50 Hz
Max output:	500W

Power supply (pump into heater):

Company:	BK Precision
Model:	1670A DC
Current:	5A
Voltage:	0-30V

Power supply (pump from heater):

Company:	BK Precision
Model:	1670 DC
Current:	3A
Voltage:	0-30V

5.9 Requirements vs. Specifications

Due to paucity of time, the team was not able to test the system as rigorously as it had hoped. The team ran the machine for four hours at 41% Relative humidity and 22°C temperature. The desiccant solution at the time of testing was 35% w/w. The obtained results are tabulated in Table 8. Even with this 'proof of concept' prototype, the team has been able to nearly achieve its three most important critical requirements: water production, energy efficiency and cost of the water produced (see Figure 105).

The amount of water production would increase as the LiCl concentration is increased from 35% to 45%. Further testing is necessary to gauge the performance of the machine under different atmospheric conditions and prolonged operation periods.

Description	**Required Value**	**Validation Method**	**Actual Value**	**Measured/Esti -mated**
Water Production	10-20 liters per 24 hours	Running the machine for 4 hours	10.2 liters[1]	Measured
Power consumption	Comparable to normal household appliances (refrigerators, ACs etc.), i.e < 1000W	Testing while machine is in operation	1.2 kW[1]	Measured
Price/liter of water produced	Comparable to competitive sources of drinking water (< $1.00/liter)	Testing the volume of water generated and power consumed; only power cost ($0.16/kWh) considered	45 cents / liter[1]	Estimated using measured data
Water quality	Should meet EPA guidelines	Testing for TDS and pH values	TDS < 500 ppm	Estimated
Sound level	< 50 dB	Measured using a sound level sensor	< 50 dB	Measured
Size	Should not be larger than existing AWGs,i.e., < 1300 x 350 x 350 mm	Measured by team	1400 x 500 x 400 mm	Measured
Weight	Should be comparable to existing AWGs (< 60kg)	Estimated using team team wisdom	< 70 kg	Estimated

[1] at 41% RH, 22°C, 35% LiCl concentration

Table 8: Mimir's performance comparison with the set design requirements

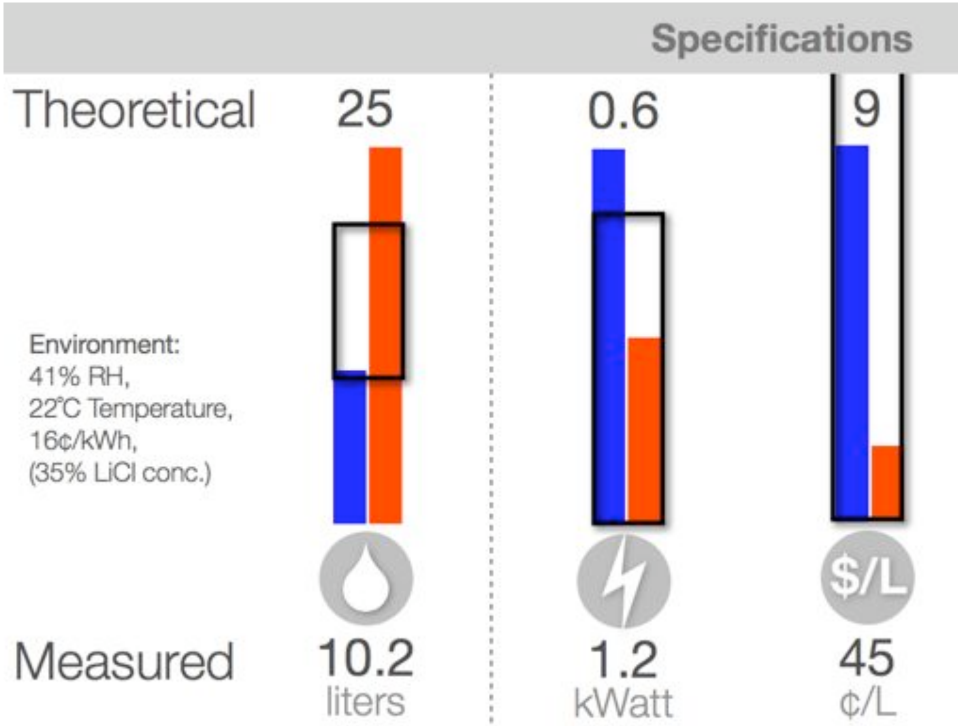


Figure 105: Three most critical requirements of the system, namely water production, energy efficiency and cost of the water produced, have been met

5.10 Energy consumption

The following calculations give an idea about the theoretical energy consumption limits of the system at **45% RH and 22° C.**

Input:

- Relative humidity: 35 %
- Room temperature: 22° C
- Solution concentration: 43%
- $Cp_{\text{LiCl sol. (45\%) 100°}}$=2.85 kJ/kg-K[A]
- $Cp_{\text{LiCl sol. (45\%) 20°}}$=2.55 kJ/kg-K[A]
- Total amount of desiccant solution in system: 7 liter
- Absorbed amount of water:14 kg →0.583 kg/h
- Boiling point (43% conc.): 143° C[A]
- Density (43% conc.): 1.3kg/liter[A]
- Weight of solution: 9.1 kg
- Heat exchanger efficiency: 0.97[B]
- Solution flow rate to heater chamber: 0.7 liter/min → 42 liter/h (assumed value)
- Heat of vaporization, water: 2.27 MJ/kg
- Energy consumption (Tot. fan, pumps etc): 300 Wh/h (measured value)

Solution temperature to heater:
0.97*(143°C-22°C)= 3.63°C
Energy needed to extract 0.583 kg water per hour:
2.85kJ/kg*K*3.63°K*42 liter/h*1.3kg/liter + 0.583 kg/h*2.27 MJ/kg →
564864.3J+1323410J=1888274 J/h
1 888 274 joules = 0.524 kilowatt hours

Total energy consumption per 0.583 kg extracted water:
0.524 kWh + 0.3 kWh = 0.8524 kWh →
Total energy consumption per liter:
0.8524 kWh/0.583 kg = 1.46 kWh/liter (without safety factor or other losses)

A - LiCl specifications are from *"Aqueous solutions of Lithium and Calcium Chlorides: -Property formulations for use in air conditioning equipment design. M. Conde Engineering. 2004".*

B - Efficiency of heat exchanger

6 FUTURE DEVELOPMENT

The final prototype built by the team fulfills major design requirements and works admirably well, especially considering the time constraints that the project had. However, there are still many improvements that can be made to improve its efficiency and performance. Presently, the prototype is not highly optimized. Many design compromises needed to be made in the final stages due to paucity of time and lack of available components.

6.1 Heat exchanger

Since the LiCl solution is highly corrosive, the material used in the heat exchanger has to be resistant to this solution. The heat exchanger that was used for the prototype was copper-brazed. As was shown during earlier prototypes, this is not suitable since copper gets corroded and in turn, destroys the LiCl solution too. However, the team had gone for the copper brazed time for this prototype due to lack of availability of a better alternative. A heat exchanger made of stainless steel 316L should work better. An even better alternative would probably be Titanium or plastic.
Another aspect that needs to be improved is the heat exchanger's efficiency. The heat exchanger used in this prototype is designed for a higher flow rate than needed and, therefore, the heat transfer across the heat exchanger is not sufficient. Team's research indicates that it is possible to have a heat exchanger with very high efficiency (around 98%). This would improve the energy efficiency of the whole product as less energy would need to be contributed by the heater. Besides, the temperature of the solution in the absorption chamber would also be lower.

6.2 Heater

The heat losses in the heater can be reduced. More testing needs to be done with several alternatives to find an optimum solution. Some possible alternatives may be:
- Manufacturing the heater container in either heat resistant plastic, Teflon laminated steel, ceramics or glass: The present heater is made of stainless steel 316. As steel is a good thermal conductor, the heat losses in the present design are large.
- Manufacturing the immersion heater with a ceramic or Teflon layer
- Optimizing the volume of the heater: The heater volume is presently larger than required. This leads to increased losses.

In the present process, the heater was turned on and off when the temperature reached the required threshold. A continuous heat infusion would probably be a better solution in order to avoid the solution to be too heavily boiled, thus increasing the risk of lithium chloride getting mixed together with water vapor. A continuous heating process will also make the condensation uniform.

6.3 Condenser

Some possible alternatives in the condenser design that may be tested further are:
- Increasing the heat transfer to the ambient by increasing the exposed surface area of the flanges
- Controlling the vapor flow (by better control over heat rate) in order to make sure that the vapor generated is always commensurate with the cooling capacity of the heater

6.4 Demister

The team had ordered a commercial demister but due to the delay in its arrival, the team used tower packingss as demister. This is clearly not the best solution. In future, one should use better filters.

6.5 Air filter

The air filters that are presently used are not adequate. They should be replaced by better and deeper filters.

6.6 Water filter

The condensed water is presently passed through a single active carbon filter. Since the water collected is in distilled form, it lacks essential minerals that impart the necessary taste and nutrients to the user. Extra mineral filters should be used.

6.7 Refilling of desiccant solution

One improvement to the present design may be to include a storage tank to hold the extra desiccant that may be used to change/refill the used solution from time to time

6.8 Tilt and transport system

Since the machine contains liquid, it may be difficult to transport it. One might need to empty the desiccant solution before transporting the machine from one place to another. There is also a scope to include safety features (tilt sensors, auto lock mechanisms) in the device.

6.9 Better Control System

There are many ways in which the present control system can be improved. There is a need to explore a better mechanism to measure the LiCl concentration in the solution. It is hard to get a precise concentration measurement with the present method as it is very hard to judge the exact temperature at which boiling commences inside the heater. One can only switch the heater on or off in the present design. Further, the flowrate through the pumps need to be changed manually. The efficiency of the boiling process will increase if the heater magnitude and the pump flow rate could somehow be adjusted depending on the solution concentration. Also, the present laptop-based control system should necessarily be programmed into a microcontroller before the next 'ready to ship' prototype is built.

6.10 Additional features

There is ample scope for introducing additional features in the machine. Some of these are:

- Hot and cold water capability can be introduced as an added utility to the consumer
- The display can be improved to inform the user about the environmental conditions (temperature, humidity values etc.), amount and quality of water in the machine, calender, time etc.

6.11 Extensive Testing

Lastly, extensive testing needs to be done to gauge the performance of the machine over prolonged duration and under varied atmospheric conditions. Prolonged tested will also provide information about machine durability, corrosion resistance and desiccant lifetime.

The purity of the water produced must be tested by a certified chemical laboratory. The distillation process is inbuilt into the machine cycle. Hence, the team estimates the generated water to be extremely pure. However, further testing should be performed to ensure that the water is free of even minute quantities of lithium chloride.

7 PROJECT MANAGEMENT

7.1 Overview

The composition of team Immerse was very different from a regular Engineering 310 team. The project team was composed of 10 members dispersed over four different universities. The vast team strength enabled the team to explore a vast solution space, especially during the early phases of the project. This proved extremely advantageous, especially due to the highly technical nature and limited time span of the project. However, the management of such a large and dispersed team proved particularly challenging. The loss of one team member in winter quarter and another one in spring quarter reduced the Stanford team to just one member. There was a consequent mismatch between the global and local team strength, especially during the end of the quarter. However, the team was able to overcome all the challenges and kept its focus on the development of a high quality, working prototype.

Having demonstrated the efficacy of the liquid desiccant cycle in its functional prototype at the end of the winter quarter, the team devoted the whole of spring quarter to the implementation of the technology in a working, full-scale product. In order to achieve the task within the stipulated time frame, a schedule for the entire spring quarter was formulated (see Appendix 27 for a detailed Gantt chart for the spring quarter). Care was taken to allot ample time for manufacturing, assembly and testing of the product. A buffer time of few days was reserved at the end of every activity to account for unforeseen delays. However, as the quarter progressed, the schedule shifted from the initial planning. It was found that the time taken to design the products took more time than expected. Another activity that consumed bulk of the time was to find appropriate vendors for the different parts. On the other hand, the manufacturing of the parts took less time than expected, with the only exception of the heater.

7.2 Communication

The primary mode of communication within the team for most of the project was bi-weekly video-conferencing. The frequency of the video-conferences were increased near the deadlines and the end of the quarters. The team used the software Marratech for its conferences. During the spring quarter, the video conferences were reduced as half the global team (Lulea) came to Stanford for last 1.5 months. Other modes of information and data sharing that the team used were emails, wiki and shared folders.

7.3 Deliverables and Milestones

The deliverables and milestones for the fall, winter and spring quarters are shown in Tables 9, 10 and 11 respectively.

Fall Quarter	Dates
310 Registration and Idealogs	26th Sept 2007
310 Orientation	27th Sept 2007
Corporate Project team formation	22nd Oct 2007
Corporate Project Selection	24th oct 2007
Design Knowledge Sharing	30th Oct 2007
Launch Your Venture	30th Oct 2007
Fall-Winter Global Planning	2,9,12 Nov 2007
Benchmarking reviews	13th Nov 2007
Critical Function Prototypes	29th Nov 2007
Fall Design Abstracts	3rd Dec 2007
Final Presentations	6th Dec 2007
Final Design Documents	11th Dec 2007
Exit Summary	14th Dec 2007

Table 9: Deliverables and Milestones for fall quarter

Winter Quarter	Earlier Deadline	Updated Deadline / Date Finished
Dark Horse/horselets	15th Jan	23rd Jan
Reality Check	8th Jan	1st Feb
Choose Direction: Africa/USA	16th Jan	1st Feb
Functional Prototype		
Order parts	1st Feb	Distributed*

Begin Manufacturing	15th Feb	Distributed*
-Begin Assembly	21st feb	Distributed*
Testing and review	25th Feb	Distributed*
Begin Winter Report Doc.	28th Feb	Distributed*
Func. Prototype finished	4th March	4th March
Draft deliverable document	26th February	26th February
Quarter presentation	13th March	13th March
Quarter Documentation	18th March	24th March

- All distributed tasks competed on or before 4th March 2008

Table 10: Deliverables and Milestones for winter quarter

Spring Quarter	Dates
Team Reflection Exercise	1st April 2008
Spring Quarter Planning	8th April 2008
Final Deliverables Contract	17th April 2008
Xis finished	29th April 2008
Penultimate Hardware Review	20th May 2008
Final Brochure for EXPE	29th May 2008
Final Presentations	5th June 2008
EXPE Design Fair	5th June 2008
Final Documentation	10th June 2008
Parting Shots Disposal	13th June 2008

Table 11: Deliverables and Milestones for spring quarter

7.2 Project Budget

7.2.1 Stanford Team Budget

The total Stanford budget for the project was $16,500. The detailed expenses list for the Stanford team over the whole course of the project is: (See Table 12)

Ref. no.:	Date of purchase	Purchaser	Description	Vendor	Cost slot	Approval		Amount
02	01-Nov-07	Harshit Gupta	Office supplies for project		Project Related Material	N/A	$	29.71
03	01-Nov-07	Harshit Gupta	Whiteboard		Project Related Material	N/A	$	32.46
06	07-Nov-07	Anders Häggman	Plant and fabric for loft space		Loft Space	N/A	$	11.33
07	12-Nov-07	Harshit Gupta	SEARS dehumidifier used for benchmarking		Prototype	Micah Linde	$	194.84
08	12-Nov-07	Harshit Gupta	WAL*MART hair dryer		Prototype	N/A	$	8.94
01	26-Nov-07	Harshit Gupta	Reverse osmosis apparatus for CFP		Prototype	Micah Linde	$	313.88
04	27-Nov-07	Anders Häggman	Loft space entertainment		Loft Space	N/A	$	54.10
05	27-Nov-07	Anders Häggman	RadioShack Hygrometer		Tools	N/A	$	16.23
10	28-Nov-07	Anders Häggman	TDS and pH meter for experiments		Tools	N/A	$	118.37
09	02-Dec-07	Anders Häggman	Different kinds of bottled waters for testing		Prototype	N/A	$	18.08
10	12-Jan-08	Anders Häggman	Duct tape, plywood, etc	Home Depot	Prototype	N/A	$	33.62
11	12-Jan-08	Anders Häggman	Taxi ride to Home Depot (no car available)	Yellow Checker Cab	Other	N/A	$	40.00
12	12-Jan-08	Harshit Gupta	Microwave for Dark Horse prototype	Wal Mart	Prototype	N/A	$	36.66
13	08-Jan-08	Harshit Gupta	Aluminium foil for Dark Horse prototype	Target	Prototype	N/A	$	12.32
14	11-Jan-08	Anders Häggman	Microwave leak detector, humidity meter	McMaster-Carr	Tools	N/A	$	343.26
15	26-Feb-08	Anders Häggman	Insulation material for functional proto	McMaster-Carr	Prototype	N/A	$	35.98
16	31-Jan-08	Anders Häggman	Working lunch with George Alvarez	CIAO Cafe Terman	Meals	N/A	$	6.00
17	31-Jan-08	Anders Häggman	Working lunch with George Alvarez	Darbar Indian Cuisine	Meals	N/A	$	47.58
18	18-Feb-08	Anders Häggman	Working lunch with Brad Basler	The Counter	Meals	N/A	$	55.00
19	08-Feb-08	Anders Häggman	Heater and temp swithc for Func. proto	McMaster-Carr	Prototype	N/A	$	224.68
20	28-Jan-08	Anders Häggman	Measuring tools for prototypes	McMaster-Carr	Tools	N/A	$	236.29
20	28-Jan-08	Anders Häggman	Additional Heater for proto	McMaster-Carr	Prototype	N/A	$	272.79
21	09-Feb-08	Anders Häggman	Desiccant wheel for prototype	On Time Mall	Prototype	N/A	$	322.99
22	12-Feb-08	Anders Häggman	Strip heater for prototype	McMaster-Carr	Prototype	N/A	$	77.91
23	12-Feb-08	Anders Häggman	Lab manual on refrigeration	Amazon / Mickeala's	Other	N/A	$	8.90
24	12-Feb-08	Anders Häggman	Materials for building prototypes. (bolts etc	Home Depot	Prototype	N/A	$	260.03
25	20-Feb-08	Anders Häggman	Materials for building prototypes. (bolts etc	Home Depot	Prototype	N/A	$	185.37
26	11-Feb-08	Anders Häggman	Car rental for collecting large proto parts	Enterprise	Other	N/A	$	64.02
27	21-Feb-08	Anders Häggman	Gasoline for borrowing VW project car	Shell	Other	N/A	$	18.17
28	Feb-Mar-08	Team Immerse	Stanford HVAC Services for Functional prot	Stanford HVAC	Prototype	N/A	$	358.45
29	11-Apr-08	Team Immerse	Santa Fe Dehumidifier for Prototype	Santa Fe	Prototype	-	$	1,364.23
[redacted]	May 2, 2008	Team Immerse	Dinner Meeting with Brad		Meals	-		100
31	02-May-08	Harshit Gupta	Lab View for control System	Academic Superstore	Final Product	-	$	98.45
32	02-May-08	Harshit Gupta	2 Solenoid Valves (Low Temp)	Asco Valves	Final Product	-	$	265.76
33	02-May-08	Harshit Gupta	2 Solenoid Valves (High Temp)	Assured Automation	Final Product	-	$	641.54
[redacted]	05-May-08	Erik Brannstrom	Faucet Light	Perpetual Kid	Final Product	-	$	45.00
35	05-May-08	Anders Häggman	Band Saw Blade for Loft replacement	Sears	Replacement	-	$	71.93
36	05-May-08	Anders Häggman	Pump,Filter,Bracket	Fresh Water Systems	Final Product	-	$	61.44
37	06-May-08	Anders Häggman	Frame,Tubings,Fittings,Sensors etc.	McMaster-Carr	Final Product	-	$	233.71
38	06-May-08	Anders Häggman	Heater, Tube Fitting	McMaster-Carr	Final Product	-	$	368.49
39	08-May-08	Jenny Ahman	Frame,Tubings,Fittings,Sensors etc.	McMaster-Carr	Final Product	-	$	496.49
40	09-May-08	Jenny Ahman	Frame,Tubings,Fittings,Sensors etc.	McMaster-Carr	Final Product	-	$	63.43
41	13-May-08	Harshit Gupta	Relays, Temp sensor, resistances etc.	Jameco	Final Product	-	$	220.56
42	16-May-08	Harshit Gupta	LabJack,Temp Sensor etc.	LabJack	Final Product	-	$	331.10
43	16-May-08	Harshit Gupta	Water Tanks	Chemistry Store (Fisct	Final Product	-	$	86.58
[redacted]	16-May-08	Johan Wenngren	Heater Manufacturing	E.M.Manufacturing	Final Product	-	$	250.00
45	19-May-08	Johan Wenngren	Plastic	Tap Plastics Inc	Final Product	-	$	20.30
[redacted]	19-May-08	Team Immerse	Couplings,Mufflers etc	Physics Store	Final Product	-	$	100.00
47	22-May-08	Team Immerse	Pumps	Hargraves Fluidics Stc	Final Product	-	$	273.50
48	23-May-08	Team Immerse	Welding and fitting the heater	Advanced Welding	Final Product	-	$	535.84
49	30-May-08	Harshit Gupta	Temperature Sensors (3 in no.)	LabJack	Final Product	-	$	168.40
						Final Produ	$	4,260.59
						Prototype	$	3,720.77
						Meals	$	208.58
						Outsourcing	$	0.00
						Project Related Material	$	62.17
						Loft Space	$	65.43
						Tools	$	714.15
						Replacement	$	71.93
						Other	$	131.09
						TOTAL	**$**	**9,066.31**

Table 12: Stanford team expenses for the whole project

7.2.2 Global Team Budget

The travel budget for the Swedish teams is separate from their regular budget. KTH/LTU and LTH each have their own budget for international travelling and a common budget for domestic travelling, $11,840 and $6,500 respectively.

Below is a list of all expenses for Lulea university (1 U.S. dollar approximately equals 6.50 SEK). (See Table 13)

LTU Budget

Item	Amount [USD]
Supplies	500
Prototyps	16500
Domestic travel	3250
International travel	11840
Buffert	-3000
Total	29090

Travel Expenses

	Date	Purpose	Amount [USD]
Domestic	2007-12-17	Flight to Stockholm	415
Domestic	2007-12-17	Hotel in Stockholm	452
Domestic	2007-12-17	Taxi Arlanda	123
Domestic	2008-03-25	Immerse meeting in Stockholm	261
International	2007-10-27	Flight to Stanford	6203
International	2007-10-27	Hotel in Stanford	626
International	2007-10-27	Phonecalls	185
International	2008-05-01	Flight to Stanford	4804
International	2008-05-01	Hotel in Stanford	2829
International	2008-05-01	Hotel internet	5
International	2008-05-01	Car fuel	600
International	2008-05-01	Rental car	1585
International	2008-05-01	Roadside service	200
International	2008-05-01	Travel allowance	3077
		Total:	21365
		Remaining:	-6275

Prototype Expenses			
	Date	Purpose	Amount [USD]
Plexiglas	2007-11-22	Critical Function Prototype	108
Glue	2007-11-22	Critical Function Prototype	8
Peltier element	2007-11-22	Critical Function Prototype	23
Cooling paste	2007-11-22	Critical Function Prototype	18
Nylon stocking	2007-11-22	Critical Function Prototype	7
Plastic tape	2007-11-22	Critical Function Prototype	7
Soldering	2007-11-22	Critical Function Prototype	9
Banana plug	2007-11-22	Critical Function Prototype	6
Battery 9V	2007-11-22	Critical Function Prototype	6
Air pump	2007-11-22	Critical Function Prototype	31
Calcium Chloride	2007-11-22	Critical Function Prototype	13
Rapeseed oil	2007-11-22	Critical Function Prototype	4
Air dryer	2007-11-22	Critical Function Prototype	46
Hygrometer	2007-11-22	Critical Function Prototype	23
Litiumklorid 450g	2008-01-03	Dark Horse Prototype	69
Plexiglasstube	2008-01-03	Dark Horse Prototype	107
Pump	2008-01-03	Dark Horse Prototype	15
Pestle	2008-02-22	Functional Prototype	15
Fan	2008-02-22	Functional Prototype	26
Thermometers	2008-02-22	Functional Prototype	30
Cord	2008-02-22	Functional Prototype	22
Plug	2008-02-22	Functional Prototype	6
Glue	2008-02-22	Functional Prototype	17
Thermoplast	2008-02-22	Functional Prototype	30
Switch	2008-02-22	Functional Prototype	4
Glowes	2008-02-22	Functional Prototype	8
Rubber bands	2008-02-22	Functional Prototype	3
Straws	2008-02-22	Functional Prototype	6
Litiumklorid 500g	2008-02-22	Functional Prototype	364
Nozzles	2008-02-22	Functional Prototype	125
Kemi Equitment	2008-02-22	Functional Prototype	52
Pumps	2008-04-25	Final Prototype	430
Chamber	2008-04-25	Final Prototype	160
Weather Station	2008-05-05	Final Prototype	100
Cellphone	2008-05-10	Final Prototype	50
McMaster	2008-05-15	Final Prototype	100
Refill Cellphone	2008-05-15	Final Prototype	25
Home Depot	2008-05-15	Final Prototype	300
Heat Exchanger	2008-05-15	Final Prototype	150

		Total:	2523
		Remaining:	13977

Suplie Expenses

	Date	Purpose	Amount [USD]
Computer locks	2007-11-12	Office Supplies	276
Post-its	2007-11-12	Office Supplies	8
Watches	2007-11-12	Office Supplies	56
Other office supplies	2007-11-12	Office Supplies	230
Ink cartridge	2008-02-04	Office Supplies	29
		Total:	599
		Remaining:	-99

Total

Expenses	Amount [USD]
Spent	24487
Remaining	4603

Table 13: Luleå team expenses for the whole project

8 REFERENCES AND RESOURCES

A literature study has been made as part of the project and to help us understand the problem and achieve our goals, more information can be found in the following chapters.

8.1 Literature

Tekn.Dr. Knut Claesson, Avfuktningsteknisk handbok, 1985
Scott Fogler H., LeBlance Steven H., Strategies for creative problem solving, 2nd edition, 2008
Ekroth, I., Granryd, E., Tillämpad termodynamik, 1999
Peterson Folke. Värmebehovsberäkningar, Second edition.1980
Westerlund Lars, Open absorption system for drying of moist air, 1995, Doctoral thesis. LTU

8.2 Articles

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Åsa Ericson, Tobias Larsson, Andreas Larsson, In search of what is missing – Needfinding the SIRIUS way, Division of Computer Aided Design, LTU
Safe Drinking Water, WHO/UNICEF Joint Monitoring Programme, 2001
Vanity Fair, Green Issue edition, May 2007

8.3 Websites

http://blog.wired.com/cars/2007/10/toyotas-calming.html
http://forums.vogue.com.au/showthread.php?t=279933
http://gizmodo.com/348386/samsung-thinks-they-know-what-women wantreleases-two-fashion-phones
http://jumpboots.com/
http://news.bbc.co.uk/2/hi/business/3528757.stm
http://www.bottledwaterblues.com/ - 1/19 – 2008
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http://www.ijdesign.org/ojs/index.php/IJDesign/article/view/71/76
http://www.kitchendesignersideas.com
http://www.mathworks.com
http://www.mapsofworld.com/world-freshwater-resources.htm 1/19 - 2008
http://www.nyfikenvital.org/?q=node/2028, 080204, 14.10.
http://www.osim.com/SE/product/igallop.aspx?category_id=952F899D-CB394EB4-9A5C-3F81B4BB6AAD
http://www.snopes.com/medical/toxins/petbottles.asp

8.4 Words used in the literary search

Air-conditioning
Atmospheric Water Generator – AWG
Condensation
De-humidifier
Desiccants
Drinkable Water
Humidifier
Humidity
Hygrometer
Mollier
Peltier
Usability testing
Vapor-compression refrigeration
Water extraction
Water filtering
Water production
Water quality

9 APPENDICES

Appendix 1: Original Project Abstract

A PURE WATER SOLUTION FOR THE WORLD

immerseglobal

COMPANY OVERVIEW:

A Closer Look at Immerseglobal, Inc.

PROJECT BACKGROUND

One out-of-every three persons on the planet currently lacks reliable access to fresh water, as reported in the May 2007 issue of Vanity Fair, Green Issue Edition. According to the World Health Organization, The World Bank, USAID, and other global agencies, the damaging effects of global warming are causing an immeasurable impact on our most valuable resource—Water. After three decades in advancements in atmospheric technology and research, the stage has been set for Immerse Global to spark a revolution in worldwide water availability.

At Immerse Global, we believe in three key elements: atmospheric water generation, renewable energy application and cross industry applications, including agriculture and pharmaceuticals. Proven technology and experienced leadership has positioned Immerse Global to become the industry leader in the rapidly growing market that is known as atmospheric water generation.

LOOKING TOWARDS THE FUTURE:

- Reliable and consistent water production across diverse climate zones
- Product design must be modern and a compelling for household and commercial use
- Integration of solar power application will be explored

PROBLEM DESCRIPTION

Immerse Global is looking to develop a new generation atmospheric water dispenser that is able to produce 5–7 gallons of water daily in various climate conditions, including arid zones. We want to improve the water production level from 30% currently, to 20%. The device should also provide solar power capability for areas in the world where electricity availability is scarce. The look and feel of the new device will create a new user interaction from point of use and provide added comfort and portability for home and office use.

PROJECT REQUIREMENTS

Project scope suggests the following requirements:

- Deliver consistent water supply across climate zones that are below 30% humidity levels
- Provide new product design creating a new user experience
- Implement cost effective solar power for energy conservation
- Supply great-tasting PH positive water
- Create LCD to display water quality
- No comprise on overall product safety

immerseglobal.

A PURE WATER SOLUTION FOR THE WORLD

Appendix 2: Geographical Climatic Distribution

As part of its market research, the team also studied regions around the world that may serve as prospective markets for the product. The product has a natural market in the vast arid zones of the world that have average relative humidity values of 20% or above, and lack all other conventional water sources such as perennial rivers or lakes.

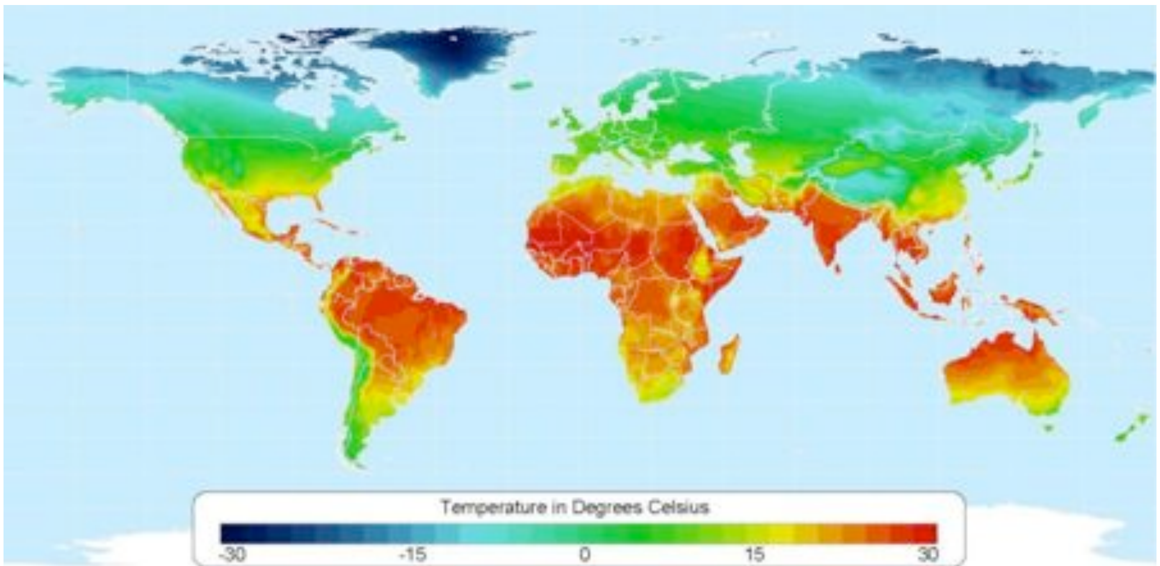


Figure 106: Yearly average temperature distribution around the world

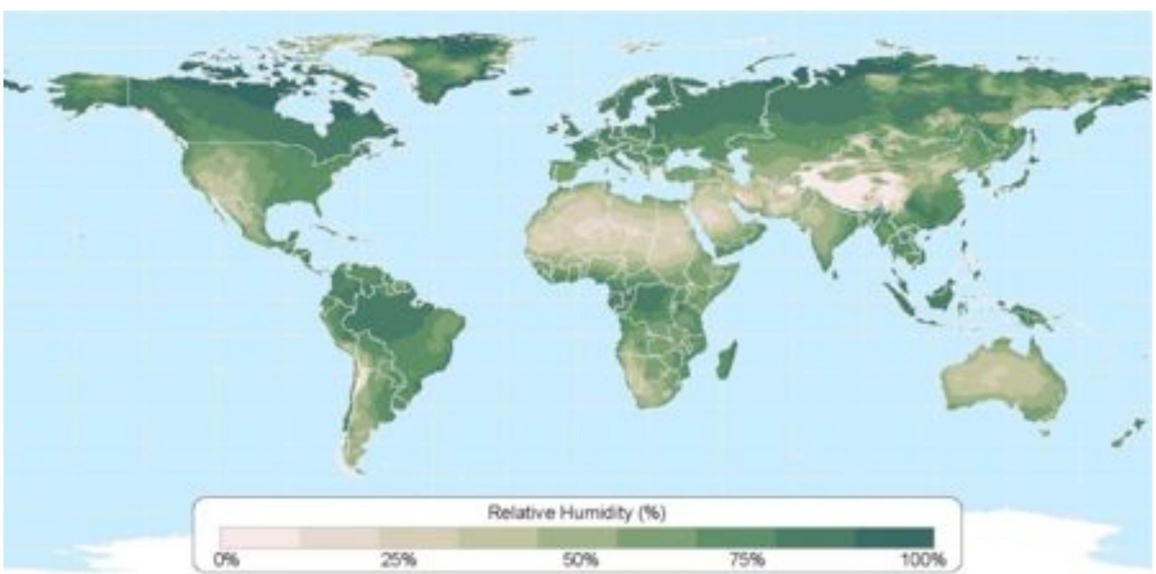


Figure 107: Yearly average relative humidity distribution around the world

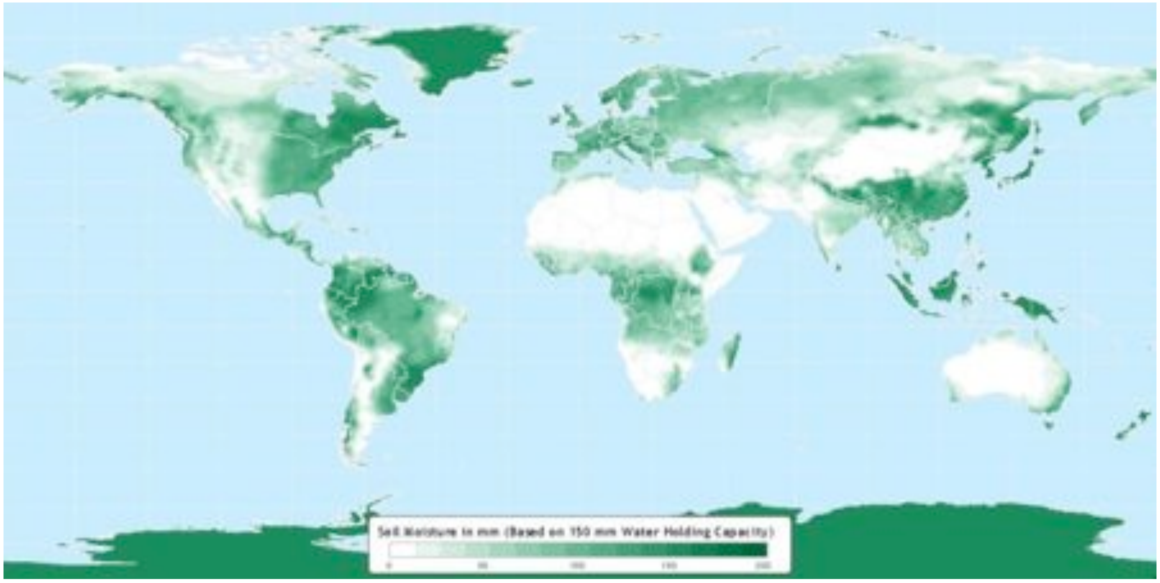


Figure 108: Yearly average soil moisture distribution around the world

Appendix 3: Related Technologies

Refrigerators

Refrigerators use closed vapor/liquid systems to transfer heat from one place to another in order to lower the temperature in a certain space. The five basic parts of a common refrigerator device includes (figure 109):

- Evaporator (A) - serpentine or coiled set of pipes outside the unit
- Compressor (B)
- Heat-emitting pipes - serpentine or coiled set of pipes inside the unit
- Expansion valve (C)
- Refrigerant - liquid that evaporates inside the refrigerator to create the cold temperatures

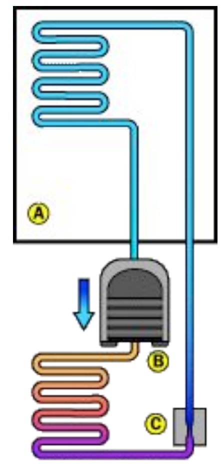


Figure 109: ***Basic Refrigerator***

The vapor compression cycle consists mainly of four steps (figure 110):

1. Refrigerant gas at low pressure enters the compressor and leaves the device pressurized. Along with the increasing pressure the gas temperature raises which makes the emitting of heat energy easier to process.

2. The high temperature, high pressure gas then enters the heat-exchanging coils in order to release the increased heat to the surroundings. In this phase the refrigerant gas becomes a sub-cooled high pressure liquid.

3. The high pressure liquid then passes through the expansion valve which reduces the pressure instantly. By lower the pressure the refrigerant liquid temperature drops below the refrigerated space causing a cooling effect.

4. In the following step the cold liquid refrigerant goes through the evaporator, absorbing heat energy from the refrigerated space. The absorption of heat leads to an evaporation of the refrigerant liquid into low pressure gas. The low pressure gas then flows back to the compressor and the vapor compression cycle starts all over again.

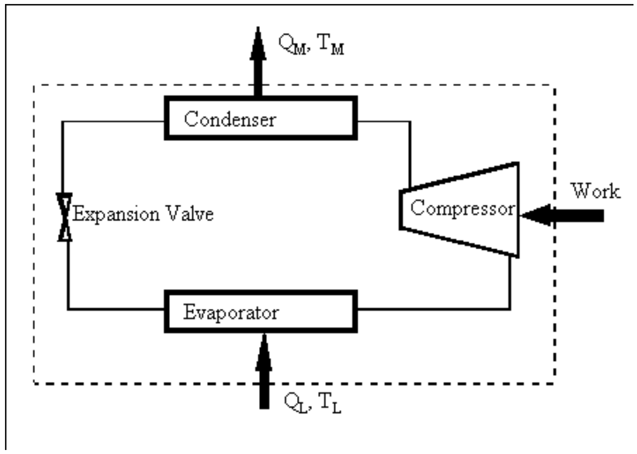


Figure 110: *Energy Flow of the Vapor Compression Cycle*

Peltier Devices

Peltier devices act like small heat pumps that transfer heat from one side to the other. The devices are just a few millimeters thick which make them suitable for applications where the space is scarce (figure 111). One example is the cooling of processors in computers where Peltier elements often are used.

The Peltier effect is based on the reversed Seebeck effect where direct current is produced by heat differences. The heat transfer in the Peltier element is conducted by electricity by letting current pass through two dissimilar semiconductors, showing as n-type and p-type in the picture. These are connected to each other by metal joints showing as electrical conductors in the picture. The circuit is enclosed by electrical insulators on both sides which often consist of a ceramic.

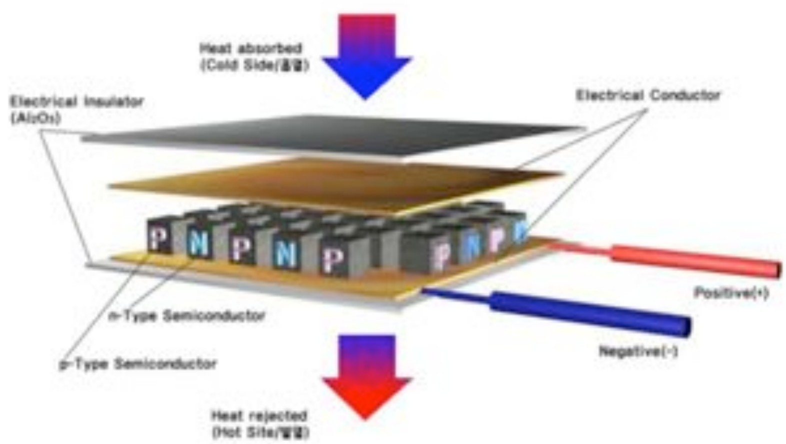


Figure 111: *Basic parts of Peltier device*

The Peltier coefficient represents the ability of a certain material to transport heat current per unit charge. While the charge current in the circuit is constant the differences of the Peltier coefficient in the two types of semiconductors cause a discontinuity in the heat flow which leads to one warm and one cold side. The p-type semiconductor had a positive Peltier coefficient and n-type a negative and by calculating the difference between these multiplied by the current flow the heat transfer can be estimated.

$$\dot{Q} = \Pi_{AB} I = (\Pi_B - \Pi_A)$$
$$\dot{Q} = energy\ flow$$
$$\Pi = Peltier\ coefficient$$
$$I = current$$

The advantages of using Peltier elements are that they are small (figure 112), precise, silent and long-lasting. On the negative side is primary the cost. In order to increase the cooling effect it is common practice to connect several Pelter elements. The effect can also be adjusted by changing the voltage input (www.wikipedia.org).

Figure 112: ***Picture of Peltier device***

Condensers

Condensers are used in many air-drying and water extracting applications like in the most common atmospheric water generators, dehumidifiers and air conditioners. These kind of condensing systems work mainly by letting humid air pass through cold refrigerated coils, described earlier in the vapor compression cycle. The moisture in the air is condensed into droplets when the temperature drops below the current dew point and is then collected in a container (figure 113). The amount of water that can be produced in a certain period of time depends on the climate conditions such as humidity level and temperature as well as the volume of air passing through the coils and the cooling capacity (www.humiditycontrol.co.uk).

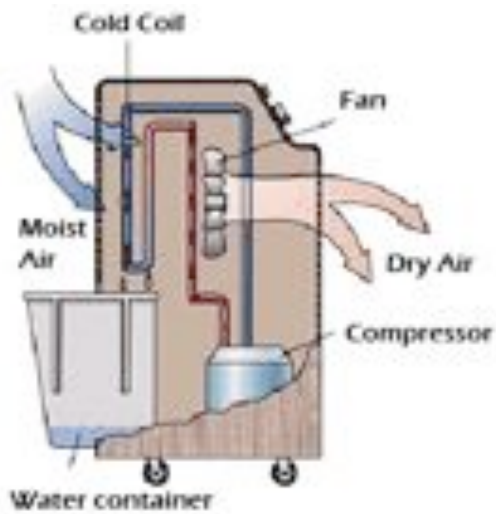


Figure 113: ***Basic principle of condensers***

Desiccants

Desiccants are hygroscopic substances that are using different techniques to attract water. The hygroscopic substance sustains a state of dryness, desiccation, to attract water in a fairly closed container or room.

There are two kinds of desiccants, porous and chemisorbents absorbents. The porous absorbent uses physical adsorption i.e. uses relatively weak intermolecular forces (van der Waals forces and electrostatic interactions) between the moisture and surface of the desiccant. The Chemisorbents absorbent on the contrary uses an actual chemical bond.

Most common desiccant is the pre-packaged that is used to remove humidity that would normally degrade or even destroy products sensitive to moisture.

Hydration occur when water molecules transforms from solid to gas form., The degree of hydrating (the number of H_2O bounded) decreases when the ion radii increases. That is because the degree of bounding decreases with the ion charge´s distant. If the degree of bounding reduces, the water molecules can be ripped off by the motion of the heat. Another fact is that hydrating increases with the ion charge (school.chem.umu.se).

Calcium chloride is a salt. It contains a positive calcium ion and the negative chloride ion. In a water solution, two calcium ions are surrounded by about six water molecules. When the salt is crystallizing it creates calcium chloride hexahydrate, CaCl2·6 H2O. The included water is called crystal water. If the hexahydrate loses the crystal water it becomes dihydrate ($CaCl_2 \cdot 2\ H_2O$), monohydrate ($CaCl_2 \cdot H_2O$) or even water free calcium chloride (CaCl2) if heated. In air, calcium chloride is found as dihydrate, (school.chem.umu.se). The Dry Ball is one of the most common types of calcium chloride desiccant (figure 114). It is often used in caravans or boats to remove water from air (school.chem.umu.se).

Figure 114: ***Different kinds off Dry Balls***

Silica gel is a porous form of silica made synthetically from sodium silicate (figure 115). Despite the name, silica gel is a solid. Silica gel is most commonly encountered in everyday life as beads packed in a semi-permeable plastic. In this form, it is used as a desiccant to control local humidity in order to avoid spoilage of goods (waltonfeed.com).

Figure 115: ***Dry Silica Gel***

Activated clay is a porous absorbent and is the umbrella term of argillaceous silicates, with similar behavior under certain conditions, but more or less different in composition and structure. A particular group of clays appears in triplets of crystalline layers. Because of their laminar or more or less distorted form, these minerals are classified as phyllosilicates. Although not yet 'activated', all are characterized by substitutions of metal ions within their structure, and are therefore electrically unbalanced. These clays are grouped under the name "smectite" (en.wikipedia.org).

Molecular sieve is a material containing tiny pores that is used as an adsorbent for gases and liquids. Molecules that are small enough pass through the pores while larger molecules are not. It is different from a common filter though it operates on a molecular level. A molecular sieve can adsorb water up to 22% of its own weight. Some of the many types of molecular sieves are: Activated carbon, Lime (mineral) and Zeolite (en.wikipedia.org).

Rice is a common "low-tech" alternative, frequently used for example in salt-shakers to maintain granularity of table-salt for effective pouring or shaking (en.wikipedia.org).

Super Absorbent or water gel polymer is odorless water-absorbing polymers (polyacrylamide) used every day in such diverse applications as: planting/transplanting trees and evaporative. These little water crystals absorb, called super absorbents, up to 400 times their weight in water and sometimes more, and expand to make beautiful clear gel-like water crystals (figure 116). 1 oz. of crystals will absorb over 1 gallon of water. When you add water the polymer will absorb the water into a gel like substance. They can also be found in diapers and can both frozen and heated. When you add salt to the gel, the water will then be released again (en.wikipedia.org).

Figure 116: ***Hydrated Super Absorbent***

Lithium Chloride

Lithium chloride (figure 117), LiCl, behaves as a fairly typical ionic compound (en.wikipedia.org). The LiCl and water combination results in a liquid solution after each LiCl molecule has absorbed three water molecules. LiCl continues to absorb water even after a solution has formed (www.linric.com).

Figure 117: *Dry Lithium Chloride*

Glycols

The three most common glycols that can be regenerated are diethylene, triethylene and tetrahylene. Regenerated means that the water absorbed can be separated. These desiccants are often used in gas-dehydration system (glycol dehydrator), (glossary.oilfield.slb.com), and are byproducts from making ethylene (en.wikipedia.org).

Microwaves

Microwave ovens (figure 118) are popular because of their ability to warm up food in a short amount of time. They are very efficient in their use of electricity because the microwave only heat the water molecules in the food and do not waste energy on heating the surrounding air.

Microwaves are radio waves that have a frequency of about 2,500 megahertz. Radio waves in this frequency range will be absorbed by water, fats and sugars and converted into atomic motion causing an increased temperature. The microwaves are not absorbed by most plastics, glass or ceramics which explains why these not get warm

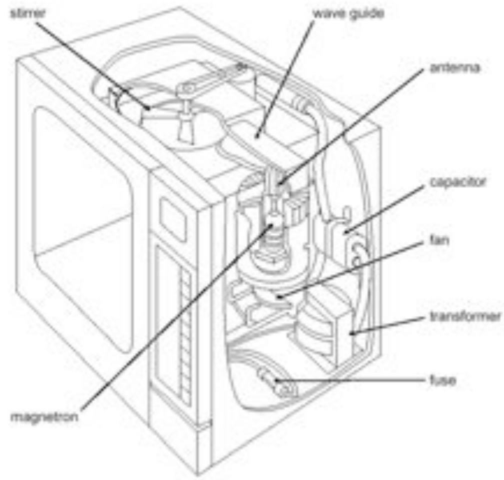


Figure 118*: Microwave own*

Wind turbine

The basic function of a wind energy system is to transform kinetic energy into electrical energy figure 119). The rotor blades capture the wind energy and convert it into mechanical energy keeping a shaft rotating. The shaft is linked to a generator that produces electrical energy.

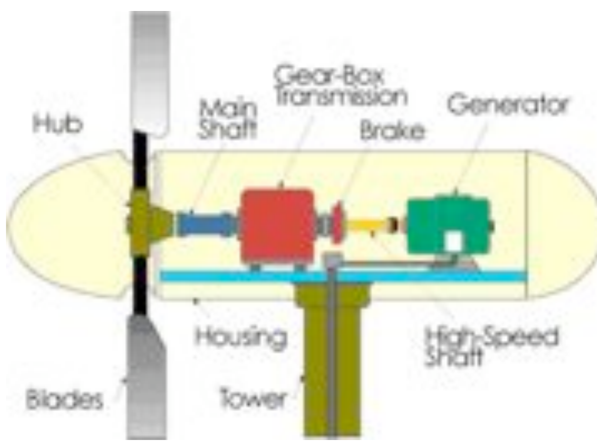


Figure 119: *Basic principle of a condenser*

There are two major designs of wind turbines. The most common one is the horizontal-axis type but the vertical-axis type is also accessible on the market. The usable power output from wind energy systems is highly dependent on the efficiency of the turbine, dimensions of the rotor blades along with density of air and wind velocity according to the equation below (www.bcsea.org, en.wikipedia.org).

$$P = \frac{1}{2}\alpha \rho \pi r^2 v^2$$

$$P = useful\ energy$$
$$\alpha = efficiency\ of\ generator$$
$$\rho = density\ of\ air$$
$$r = radius\ of\ rotor\ blades$$
$$v = velocity\ of\ air$$

Reverse osmosis

Reverse osmosis or RO as it often is abbreviated is a process of cleaning water. One side of the RO device is pressurized which forces water molecules to go through a membrane with microscopic holes in order to filter out larger particles. The water that comes out from the other side of the membrane is free from dust and other unwanted particles (figure 120).

The membrane also reduces salts and minerals in the water solutions which makes the water very pure. Some of these salts and minerals are therefore added to the water after the RO process by using different kind of filters.

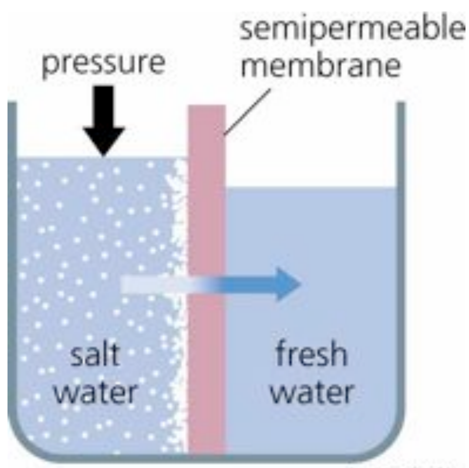


Figure 120: ***Basic principle of RO systems***

Compressor

When atmospheric air is compressed the humidity level in the gas will increase quickly causing the moist in the air to condense almost immediately. When the relative humidity level reaches past 100% water droplets will occur which makes it possible to extract water. Many compressors in the industry build up a pressure of around 8 bars far enough to make moisture condensate (figure 121). The same phenomenon occurs in airplane turbines where the air is compressed and condensed leaving a white cloud behind (www.plant-maintenance.com, www.about-air-compressors.com).

Figure 121: *Compressor*

Solar cells

A solar cell is a device that converts light energy into electrical energy by the so called photovoltaic effect. The cells are made out of semiconductors that have the ability to absorb photons. The energy absorbed by the semiconductors influence electrons to move within the cell causing an electrical flow (figure 122). The solar cells then use an electric field in order to direct all the electrons to a direct current. Solar cells are used in many products as calculators and space satellites. They are long lasting but not very efficient while they are often absorbing one kind of rays (en.wikipedia.org, library.thinkquest.org).

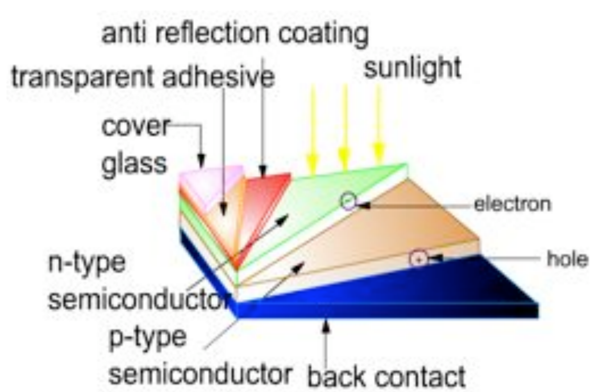


Figure 122: *Solar cell*

Ultra sound

Ultra sound can be used to heat up water and are used in some humidifiers (figure 123).
Read more about ultra sound: http://en.wikipedia.org/wiki/Ultrasound

Figure 123: *Ultra sound humidifier Honeywell EH-5200E*

Ion wind generators

Ion wind generators can be used instead of a fan. An ion wind generator ionizes the air and creates a silent air flow. Read more about Ion wind generators:
http://en.wikipedia.org/wiki/Ion_wind,
http://inventgeek.com/Projects/IonCooler/Overview.aspx

Air ionizer

An air ionizer purifies the air by ionizing (figure 124). Read more about Air ionizer:
http://en.wikipedia.org/wiki/Air_ioniser

Figure 124: *Ionic Whisper Silent Air Purifier/Ionizer*

Snow cannon

Snow cannons produces artificially snow from a special mix of compressed air and water (figure 125). Read more about snow cannons: http://en.wikipedia.org/wiki/Snow_cannon

Figure 125: *Snow cannon*

Catalytic converters

Palladium, a precious metal, is used in catalytic converters due to its great affinity for hydrogen (figure 126). Read more about catalytic converters: http://en.wikipedia.org/wiki/Catalytic_converter

Figure 126: *Catalytic converter on a Saab 9-5*

Fuel cells

A fuel cell is an electrochemical energy conversion device with water as bi-product (figure 127). Read more about fuel cells: http://en.wikipedia.org/wiki/Fuel_cell,
http://auto.howstuffworks.com/fuel-cell.htm

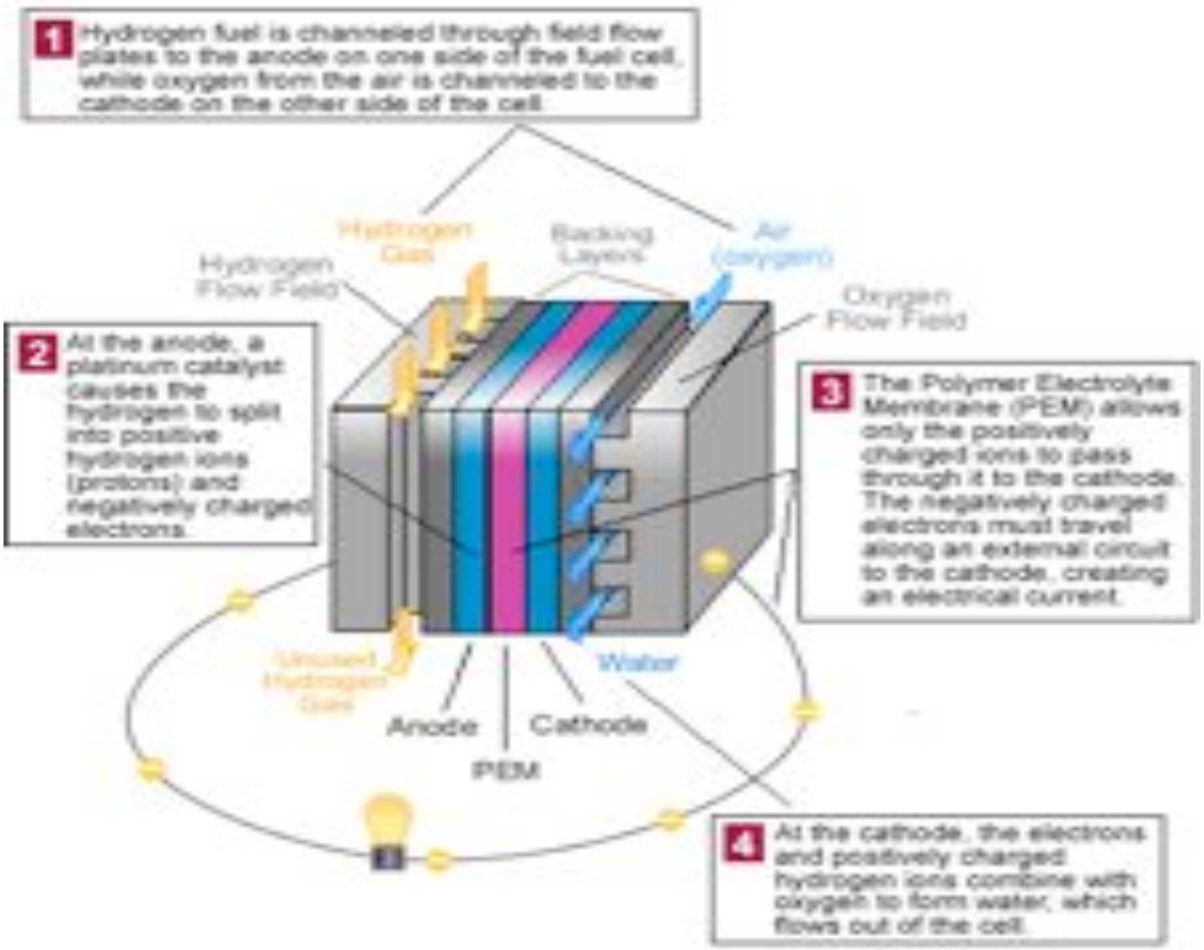


Figure 127: ***Fuel cell***

Condensers

Different ways to condense a substance from its gaseous to its liquid state (figure 128).
Read more about condensers:
http://en.wikipedia.org/wiki/Condenser_%28heat_transfer%29

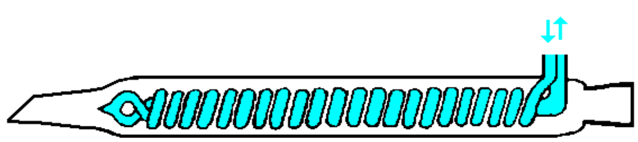


Figure 128: ***Dimroth condenser***

Micro cooling

Micro cooling systems are used to cool electronic parts for example diode lasers (figure 129).

Read more about micro cooling: http://www.prolas.de/en/mikrokuehlsysteme.html

Figure 129: ***Micro cooling copper flanges***

NASA technology

NASA uses a system of different technologies to gather and produce water in space stations (figure 130).
Read more about: http://members.nova.org/~sol/station/life-sup.htm

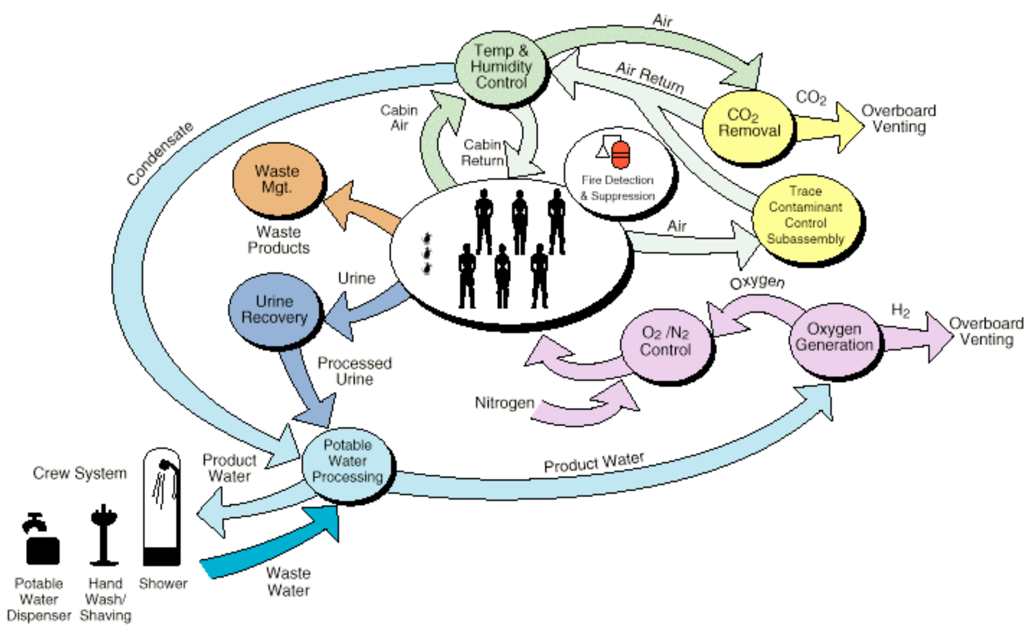


Figure 130: ***Schematic figure of water cycle***

Air conditioner

Air conditioners works in a similar way as refrigerators (figure 131).
Read more about air conditioners:
http://www.energyquest.ca.gov/how_it_works/air_conditioner.html

Figure 131: ***Air conditioner***

Dehumidifier

Most common dehumidifiers use mechanical or desiccative methods to extract water from air.
Read more about dehumidifiers: http://en.wikipedia.org/wiki/Dehumidifier

Appendix 4: Patent list

Following patent was found on www.freepatentsonline.com, keyword AWG.

With absorbing material

http://www.freepatentsonline.com/6511525.html
http://www.freepatentsonline.com/20020189448.pdf
http://www.freepatentsonline.com/6960243.html
http://www.freepatentsonline.com/20070095209.pdf
http://www.freepatentsonline.com/20070101862.pdf
http://www.freepatentsonline.com/20060130654.html
http://www.freepatentsonline.com/4285702.html
http://www.freepatentsonline.com/20060272344.pdf
http://www.freepatentsonline.com/6336957.pdf
http://www.freepatentsonline.com/20070220843.html
http://www.freepatentsonline.com/20060278089.html
http://www.freepatentsonline.com/6644060.pdf
http://www.freepatentsonline.com/20060191411.html

Using cooling system

http://www.freepatentsonline.com/20070256430.html
http://www.freepatentsonline.com/5203989.html
http://www.freepatentsonline.com/20040040322.html - Refrigerator system
http://www.freepatentsonline.com/20050097901.html - Refrigerator system
http://www.freepatentsonline.com/7000410.html - Refrigerator system
http://www.freepatentsonline.com/4351651.html
http://www.freepatentsonline.com/6302944.html - Dehumidifier condensation
http://www.freepatentsonline.com/6755037.html - Dehumidifier condensation
http://www.freepatentsonline.com/20040123607.html-Dehumidifier condensation
http://www.freepatentsonline.com/5106512.html
http://www.freepatentsonline.com/5729981.html - Peltier principal

Using pressure chambers

http://www.freepatentsonline.com/6230503.pdf
http://www.freepatentsonline.com/6453684.pdf
http://www.freepatentsonline.com/6360549.pdf
http://www.freepatentsonline.com/4050262.pdf
http://www.freepatentsonline.com/4080186.pdf
http://www.freepatentsonline.com/7043934.html
http://www.freepatentsonline.com/20040244398.html

Other interesting patents

http://www.freepatentsonline.com/5672277.html - Water from oil
http://www.freepatentsonline.com/4205529.html - Dehumidifier by LiCl

Appendix 5: Benchmarking Exercises

While still in the preliminary stages of the project, the team considered it imperative to get a hands-on experience of the various principles and technologies that the project involved. As a result, the team went on to perform various benchmarking exercises. These included conducting a condensation experiment to gauge the magnitude of the design problem at hand and disassembling several household appliances.

Benchmarking Exercise 1 : The Cone Experiment

When a cold soda can or water bottle is taken out from a refrigerator and placed in ambient room temperature, if the conditions are right, droplets of water will form on the cold surface. This is a common phenomenon which most people have experienced, especially during summer. In order to get a rough idea of how difficult it is to condense water out of the air, and to get an idea of the quantities of water produced, the following simple experiment was devised.

Purpose

- To get a rough idea of how easily stagnant air condenses into water on a cold surface
- To get a rough idea of how much water can be extracted from the air through a *'first principles'* process of condensation

Background

When air is cooled down, depending on the temperature and relative humidity, water condenses out of the air. This is due to the fact that the air cools down to such an extent that it reaches its dew point, at which the moisture in the air condenses into water.

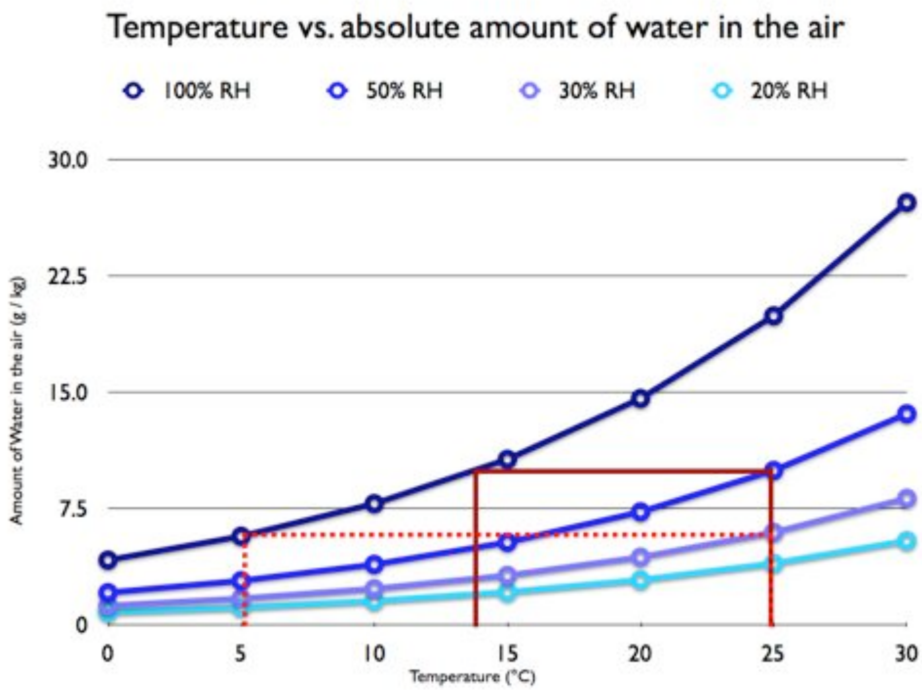


Figure 132: Amount of cooling needed for condensation to take place at different RH values

One can easily see how a decrease in the relative humidity adversely affects the amount of cooling that needs to be done to condense out the water from atmosphere. In figure 132, it can be seen that at 25°C and 50% relative humidity, one must cool down the air to approximately 14°C. Now, keeping the temperature constant, if the RH value reduces to 30% (the dotted red line), one must cool the air down to nearly 5°C (a whopping 20°C change against just 11°C earlier. Besides, if the temperature goes below 0°C the water will condense into its solid form, (i.e. snow, if the condensation happens in the air, or frost if the cooling takes place on a surface, such as a "cold finger").

Procedure

An aluminum cone was fabricated and hung from the ceiling. Ice was then inserted into a plastic bag, which in turn, was placed inside the cone. This was done because of the fact that the cone was not water tight. The idea was to get the atmospheric moisture condensed upon the cold conical walls. The water would then trickle down to an improvised plastic receptacle. The design of the container was such that the loss of water due to evaporation was minimized, and maximum water was collected.

Figure 133: The Setup

Figure 134: The receptacle

Observations

0-3 minutes : Small water droplets started condensing on the outer surface of the metal cone.

3 minutes - 1.5 hours: The water droplets that were initially condensed kept getting bigger with time. But there was still no sign of any water droplet dripping down.

Figure 135: The mist developed on the cold surface

At 1.5 Hours: The first water droplet started to drip down.

Figure 136: Water Droplets dripping down

After 2 hours: The first droplet is still clinging to the tip, instead of dropping down.

Figure 137: The first water droplet still clinging to the tip

Table 14: Estimated experimental Conditions (based on measurements taken afterwards)

Ambient Temperature	20 – 30 °C
Relative Humidity	25 – 50 %
Cone Surface Temperature	10 °C
Water Temperature	0-10 °C

Since the experiment was simply devised in order to provide a rough idea of the mechanisms involved, just a rough estimate of the prevailing atmospheric conditions were used.

Inferences

1. The plastic bag, used to keep the ice in, inhibited a proper contact of the ice with metal. Had the ice been put directly in the metal funnel, there would have been more condensation. But then, it would have been more difficult to change the water every time. (The metal funnel would also need to be water tight, in that case.)

2. The heat transfer from the upper surface of the funnel needed to be minimized, perhaps with some sort of insulating lid.

The most important outcome of the exercise was that the team was able to appreciate the magnitude of the design problem. It learned that it was a lot harder to get appreciable amount of water out of air, than it had earlier anticipated. At any rate, the condensation process was not a reliable and efficient method.

Benchmarking Exercise 2: Disassembly of hair dryer

The team started by understanding the working principle of a very simple device. A hair dryer was chosen for this purpose as it was cheap, very readily available and fairly simple. The team gained some valuable insights into the importance of getting a hands on experience and the activity provided it a good background upon which it could build the more involved technical concepts that soon followed.

Disassembly of a Hairdryer

Hairdryer Function

Benchmarking Exercise 3: Disassembly of Refrigerator

As Vapor Compression cycle was found to be the dominant technology used in most of the appliances, the team decided to study it in more detail by disassembling a common household refrigerator.

Frontside of the Refrigerator

Backside of the Refrigerator

Benchmarking Exercise 4: Disassembly of Dehumidifier

In order to further understand and analyze the Vapor Compression cycle in detail, the team studied the components of a standard room dehumidifier. The advantage of using a dehumidifier was that its working principle was identical to the conventional AWGs and being a common household appliance, it was easily available. The team also analyzed the dehumidifier in its working condition in order to gain insights into the performance capacity of the conventional Vapor Compression cycle under extreme weather conditions.

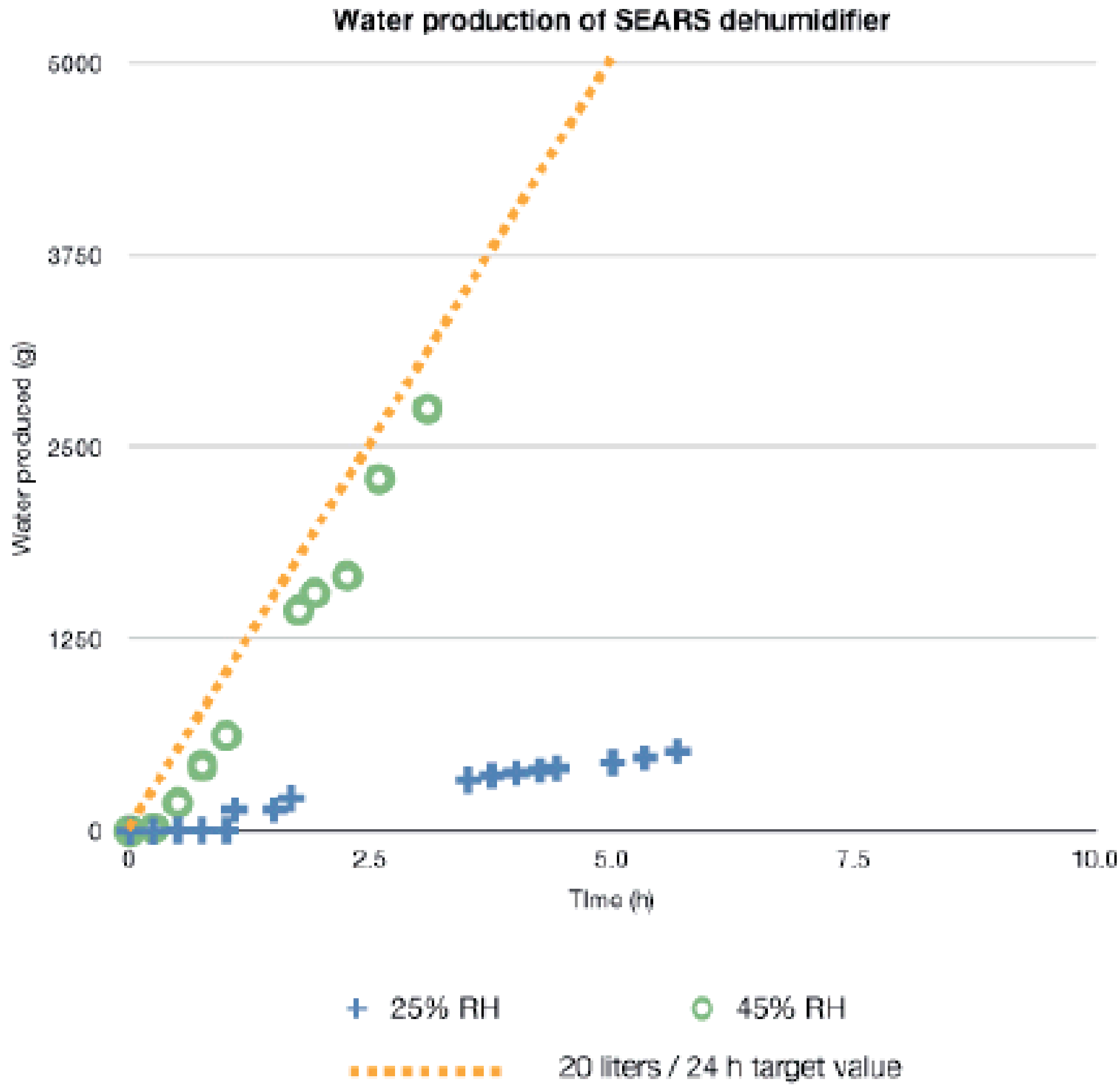
The appliance used for this purpose was a Kenmore 70 pint capacity Low Temperature Dehumidifier.

Kenmore 70 Machine

Blowing Components

Closeup of the Intercooler

The dehumidifier was run for the relative humidity levels of 25% and 45% and the amount of water generated measured.



As can be seen, even with significantly higher power consumption (860W), the dehumidifier is barely able to meet the target production values at 45% RH. Clearly, the Vapor Compression cycle is ill equipped to operate efficiently at low RH values.

Appendix 6 : Critical Function Prototype

Desiccant CFP

Comparing Desiccants CFP

The relative humidity level in the northern parts of Sweden is very low (>15% RH) so to be able to do tests in both low and high humidity, in a controlled environment, a climate system was created. The climate system consisted of an open transparent box (600 x 600 x 900 mm) in plexi glass and a lid of plywood. Inside the box an air humidifier was placed to increase the humidity inside the box. A combined thermometer/hygrometer was also placed inside the box to measure the level of humidity and the temperature of the climate system. The humidity was controlled by changing the level on the air humidifier and changing the position of the lid.

Figure 138: The set up

A square "pipe" (1000 x 120 x 120 mm) was made from plexi glass were the desiccants should be placed during the tests. To get enough air flowing through the pipe (and the desiccant) a fan was mounted to it on one side. Then the pipe was mounted to a hole (100 x 100 mm) on the side of the box with the fan mounted between. This enabled air to flow out from the box. This is illustrated in figure 1 above.

Different containers for the desiccants were also constructed to fit the pipe. The container for the $CaCl_2$ (crystals) was a textile net placed in a metal bar (120 x 120 mm). The container was placed vertically in the pipe allowing the air to flow through the desiccant. The LiCl (powder) was placed in a container created by plexi glass (120 x 80 x 20 mm) with a ramp allowing air to flow into it. The container was wrapped with a piece of nylon textile to prevent the powder from blowing away. The container was placed tilted with 45 degrees angle ins ay.

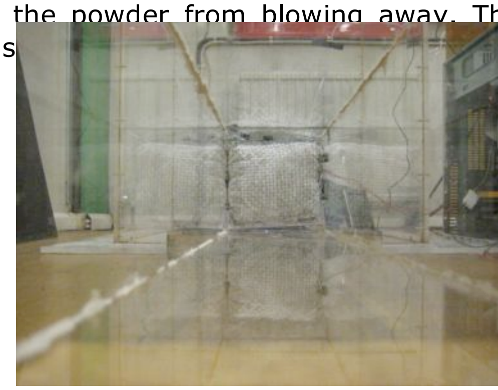


Figure 139: The $CaCl_2$ placed inside the "pipe" Figure 140: The LiCl placed inside "pipe"

To compare desiccants with cooling, a peltier element was used. The peltier element was applied between the two heatsinks with the smaller heatsink with the fan on the hot side. To get the best contact between the different materials, a cooling paste was applied on both sides of the peltier element. A power converter was used to transform 230 V AC to 15.8V DC due to the high current (10A).

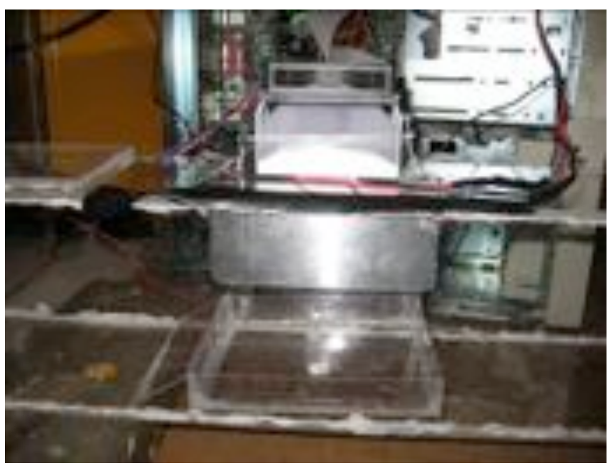


Figure 141: Peltier system mounted on the "pipe"

Tests were also made with all desiccants placed inside the box at the same time. This simplified the comparison of the different desiccants since they were all exposed to the same humidity level and temperature. The desiccants were $CaCl_2$, LiCl, Water Gel powder, and Water Gel crystals.

Equipment

- Box (600 x 600 x 900 mm)
- Square "Pipe" (1000 x 120 x 120 mm)
- Different containers
- A piece of nylon
- Fan Antec P180, see figure 142 below (Source: archive.64bits.se)

	120x120x38		
	RPM	CFM	dBa
High	1500	60	28
Medium	1200	48	23
Low	900	36	17

Figure 142: Antec P180

- Air Humidifier (620 x 530 x 370 mm)
  Volume: 2.8 liter. 40 W, 230 V. Weight: 6,5 kg. (www.jula.se) Prod. Nr: 416031

- Combined thermometer/hydrometer (www.clasohlson.se) Prod. Nr. 36-2536
- Heatsink, aluminium, 120x120x50mm
- Peltier element 75 W 10A 15.8V(www.kjell.com) Prod. Nr: 90357
- Heatsink with fan from stationary PC
- Cooling paste Arctic Silver 5, 3.5g 7.5W/mK (www.kjell.com) Prod. Nr: 36009

•Power converter 230V ACà 15.8V DC

Chemicals

- $CaCl_2$
- LiCl
- Water Gel powder
- Water Gel crystals

RO with desiccants CFP

One of the major challenges with using desiccants to collect moisture from the air is how to extract the moisture from the desiccants. A reverse-osmosis experiment was devised to get a rudimentary feel for how well it is suited for the task.

Physical Specifications

A reverse-osmosis system was purchased. All unnecessary components were discarded until the system consisted simply of the reverse-osmosis module, pressure tank and piping. The pressure tank was setup so that the desiccant solution was inserted into the top part, and pressure was applied to the lower part using a bicycle pump.

Functional Specifications

In order to provide the reverse-osmosis module with the required minimum 40 psi of pressure, air was pumped into the lower section of the pressure tank. This was done using a standard bicycle pump.

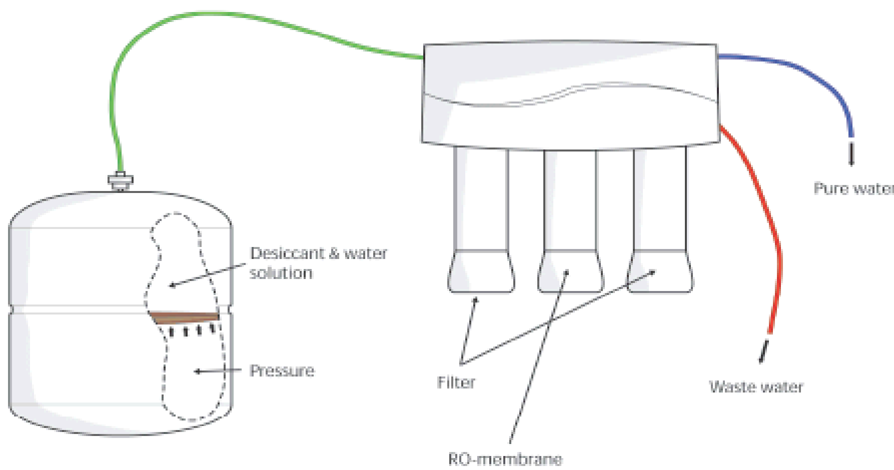


Figure 143:The RO CFP

Since the working pressure range was from 40 psi to 100 psi, the experiment was performed at roughly 60 psi – 80 psi. Due to the functioning principle of the reverse-osmosis apparatus, a substantial amount of water is diverted into the waste water pipe. Both the clean water and waste water was collected, and sampled for TDS (total dissolved solids) as well pH. The waste water was run through the RO equipment repeatedly in order to observe the increase in ppm and determine a TDS level at which the apparatus stops functioning adequately.

Fluid CFP

The container (180 x 150 x 100 mm) fabricated from 1 mm Plexi glass with an aluminium heat sink on one of the short sides was filled with approximately 1.5 l of rapeseed oil. Underneath the heat sink a perforated air hose dispense air from an air pump through the oil in the container. The idea was to cool the heat sink and use the circulation from the airflow to cool the total volume of fluid. This circular motion would also allow small bubbles of condensed vapour to sink to the bottom of the container.
The air pump used in the prototype test was an ordinary pump used for fish aquariums.

Peltier CFP

Material
To execute the experiment a simple circuit had to be made, this circuit consisted of a power source, a Peltier-cooler, a resistor, some cooling elements for the Peltier-cooler, the resistor and cables.

Peltier-cooler
The Peltier-cooler was a simple cooler with no cooling-elements or fan attached on the hot side.

Cooling	*Effect Current*	*Voltage*
P = 75 W	I = 10 A (max 10A)	U = 9-10V (max15.6)

Power source
The Peltier-cooler needed a specific voltage and ampere which was delivered by a Mean Well SP-200-24 power unit, the unit itself was connected to a socket.

AC Input: 100-240VAC, 50/60Hz
DC Output: I_{max} = 8.7 A   U = 19-24 V

Resistor
Because of the high output voltage of the power unit a resistor was used to lower it to a suitable level.
R = 2.2 Ohm
Cooper sheet sizes: 4x4, 8x8 and 4x16

Method
The different units needed to execute the experiments were connected according to the wiring diagram illustrated in figure 4. After a few modifications were made, such as adding extra cooling-elements to the resistor, the experiments were conducted with the following variations:

1. Varying the sizes of the conducting sheet to investigate the impact of the cooling area.

2. Investigating the impact of local geometric flaws such as scratches.

3. Examining the influence of draining by tilting the copper sheets 45 & 90 degrees.

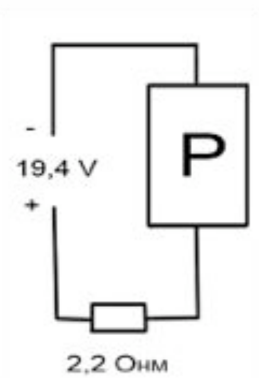


Figure 144: Wiring diagram for the Peltier CFP experiment

This technology have some very interesting features that is suitable for the kind of product that this project is aiming for; it has a low sound level and it doesn't have any cooling medium which could have a negative effect on the environment.

The reason for doing these experiments is to get a more information and to understand how a peltier cooler would work in this situation. For example, how long time would it take to get some moisture on the sheet of metal or would it get to cold and create frost?

Results

Experiments were made during two days under different circumstances and different conditions. The results are presented below in the following chapter, see table 14.

Day 1:

Temperature: 24 °C	Relative Humidity: 35%	Metal: Cu	Size: 4*4
Experiment	**Time (min)**	**Result (0-5)**	**Additional Info.**
1	1	Ice on the sheet (0)	Horizontal
2	3	Ice on the sheet (0)	Added cooling elements to keep the heat down on the hot side, horizontal

Day 2:

Temperature: 24 °C	Relative Humidity: 46%	Metal: Cu	Size: 8*8 4*16
Experiment	**Time (min)**	**Result**	**Additional Info.**
3	4	-	-
4	20	Droplets covering the sheet, mostly by the edges	-
5	20	Droplets covering the sheet	Scratches on metal, horizontal
6	20	Droplets covering the sheet	Horizontal
7	20	Homogenous layer of moisture	Peltier tilted 45°
8	20	Droplets covering the sheet, but only on a limited part of the sheet (the part in contact with the cooling element and some centimeter above)	Peltier tilted 90° Size: 4*16

Table 14: *Data from the Peltier experiments.*

For pictures from experiments, see figures 145 - 151:

Figure 145: ***Basic equipment used in the experiments***

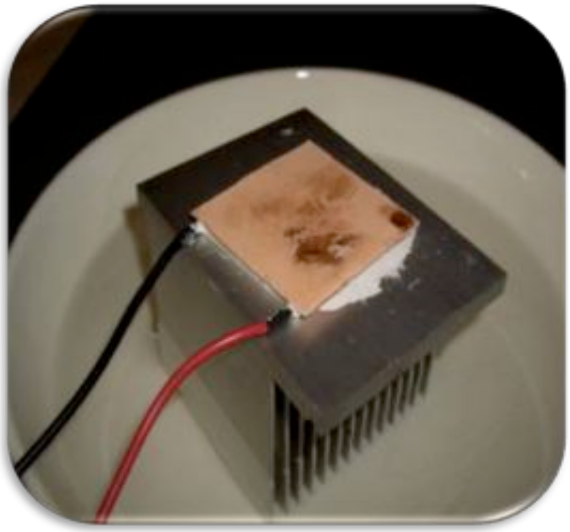


Figure 146: ***Ice on copper sheet, experiment 1***

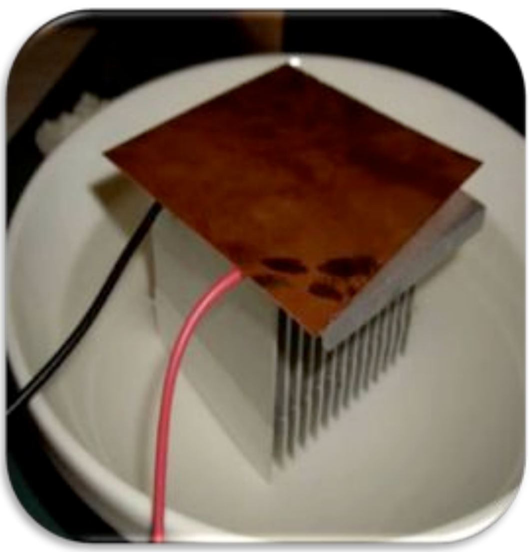


Figure 147: ***During, and after experiment 4***

Figure 148: ***After experiment 4***

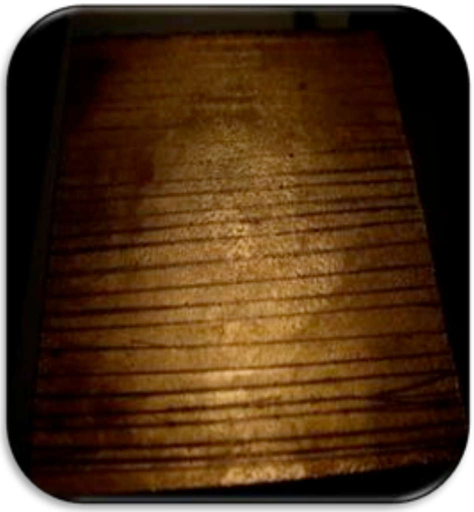


Figure 149: Experiment 5, moisture on scratched Copper shee

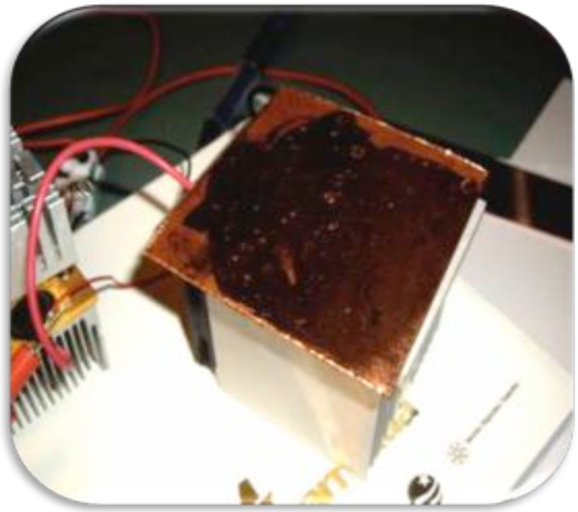


Figure 150: *Result from experiment 6, poured the water together*

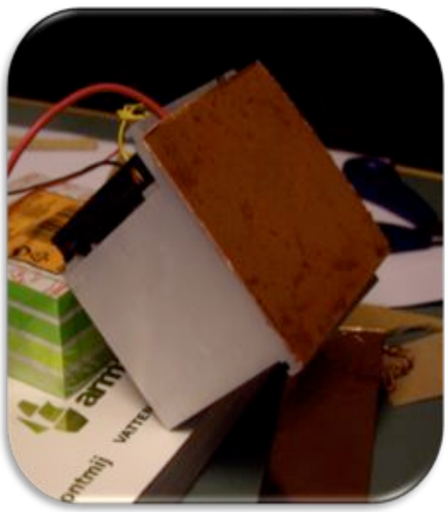


Figure 151: *Experiment 7, tilted Peltier, 45°*

Discussion

- A small sheet, same size as Peltier cooler, was to cold and the moisture freeze.
- A copper sheet four times bigger than the Peltier cooler was used, this resulted in that the cooler managed to keep the whole sheet below the dew point.
- The Peltier cooler has a hot side which needs plenty of cooling. This was mounted to an aluminum cooling element from a stationary computer which was put in water and cooled with a fan, the fan was more efficient.
- It is easy to get moisture on the sheet but when the drop increases in size it won't move. We should try another kind of surface with less friction. When the droplets don't move they form an insulating layer.
- The effect for the setup should be about 70W, see formula below this was to cool a copper sheet of 8*8 cm=64cm^2 which produced a few drops of water in 20 minutes. This means that the setup isn't energy effective enough.

$$P = U \times I \rightarrow 10 \times 7 = 70W$$

Conclusion

The importance of the area for an effective heat flow. If the area is too small the cooling will be too effective so that not enough heat can be absorbed while the sheet is getting colder which will result in ice.

Newton's cooling law:

$$\dot{Q} = \alpha \times A \times \vartheta$$

$$\dot{Q} = Heat\ flow$$
$$\alpha = Heat\ transfer\ constant$$
$$\vartheta = Temperature\ difference\ between\ plate\ and\ surrounding\ air$$
$$A = Cooling\ Area$$

The heat transfer constant gets smaller as the layer of condense gets thicker. The conclusion is that condensed water must be drained. If not, it will act like an isolating layer which will make condensation less efficient.

$$\alpha = \frac{\beta}{\delta}$$

$$\alpha = Heat\ transfer\ constant$$
$$\beta = Condense\ heat\ conduction\ constant$$
$$\delta = Thickness\ of\ the\ layer\ of\ condense$$

If the geometry of the copper sheet is changed to a rectangular piece and mounted vertically, the height of the piece will affect the heat transfer constant thus the condensation.

$$\alpha = \frac{K}{(\Delta t \times H)^{1/4}}$$

$$\alpha = Heat\ transfer\ constant$$
$$K = Material\ condensation\ constant$$
$$H = Height$$

None of the variations had any extreme effects on the amount of water produced. The factors with most influence over the result in the experiments were the cooling of the hot side of the cooler, size of the cooling area and the placement of the cooler.
The final conclusion, it's a way to achieve a cold surface, but not effective enough for the purpose of this project. With the area needed to produce the necessary amount of water the energy consumption can't be motivated by the positive qualities.

Appendix 7: Dark Horse Prototype – Microwave Heating

The team used a standard 0.034 m^3 ordinary counter-top microwave for the dark horse prototype. The experiment was performed in two different conditions:

1. The Static Air Case:

In this experiment, the glass cover of the front door was removed, with just the grill of the door remaining. The size of the pores in the grill was checked and found to be smaller than microwave wavelength (12.24cm), which meant that there would be no substantial leakage of microwaves. Next, two 7.6 cm diameter cardboard tubes were fitted across the grill, with the rest of the area of the grill being covered.

The two cardboard tubes were to act as passages for the flow of the air out from inside of the microwave. The two tubes were so placed that one of them is towards one end of the grill, while the second at the other end. These tubes had holes cut on to them, to accommodate RH meters (see figure 152), the purpose of which was to measure the amount of water in the particular stream of air.

Figure 152: The cardboard tube with the RH meter

The microwave was run for about 5 min., and the readings of the two meters were noted on a periodic basis. Since the streams also differed in their temperatures, proper care was taken to measure the absolute humidity of these air streams, rather than the relative humidity.

2. The Moving Air Case:

In the previous experiment, there was no inflow of the air into the microwave, and the static air inside it was stratified. In the second experiment, a stream of air was blown into the microwave. Since turbulence needed to be checked, as it would have affected the stratification process, the flow of air into the microwave was made to be laminar at all times by using a cooling fan of very low air flow rating.

The basic set up was the same as in the previous case, but there was a third cardboard tube put in the middle, between the other two tubes (see Figure 153). There was a fan on the other end of the third tube that would blow air into it. This tube was put in the middle so that it would distribute the flow of air equally into the microwave.

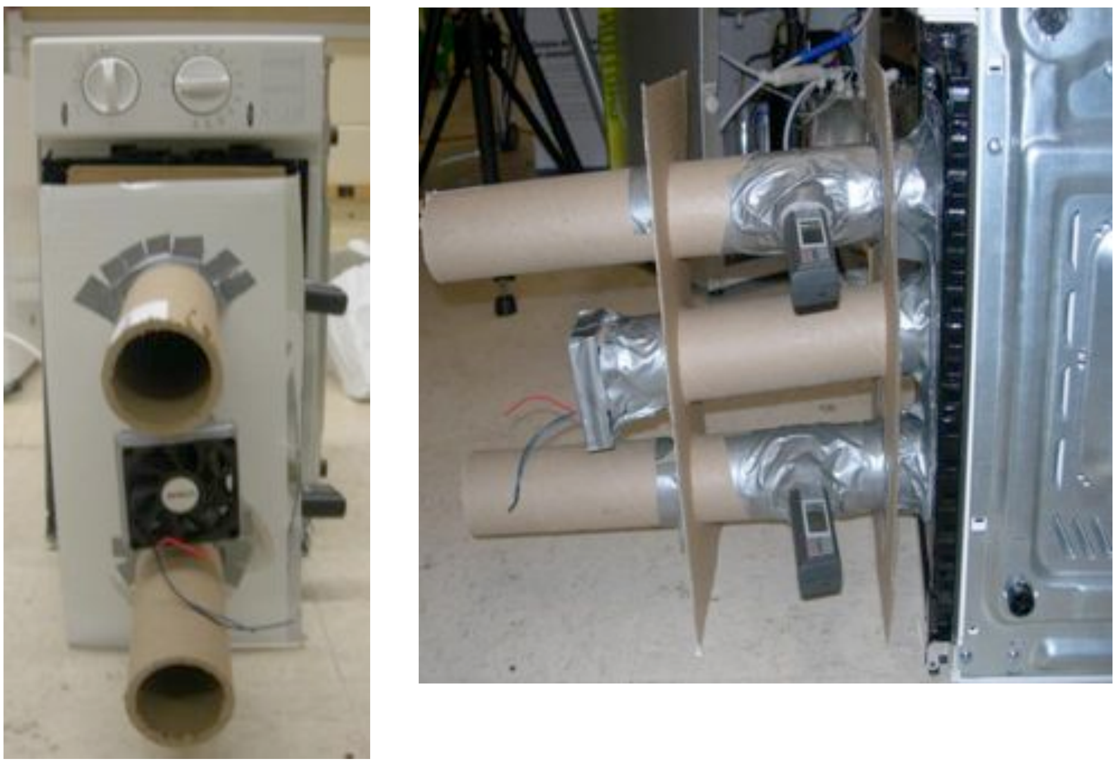


Figure 153: The third tube with fan attached to blow in air

The microwave was again run for 5 min., with the readings being taken periodically from both the meters.

There was a concern that the change of direction that the air needed to undergo in this set up might give rise to undue mixing. Hence, the set up was modified with the fan at the back wall of the channel. Holes were drilled into the back wall of the oven for this purpose. This changed the direction of air inflow and thus, a straight channel was provided to the air (see Figures 154,155,156).

Figure 154: Holes drilled to the back wall for air flow. Duct tapes were used to close other holes inside the microwave (side walls and floor)

Another slight variation was also incorporated in the moving air experiment. Since the readings obtained were not very conclusive, it was thought that maybe since there was no load into the microwave, it might not be performing to its full capacity. So a fake load in the form of a tightly sealed water bottle was put into the microwave. Proper sealing of the bottle was necessary so that there would be no leakage of water molecules from the bottle itself.

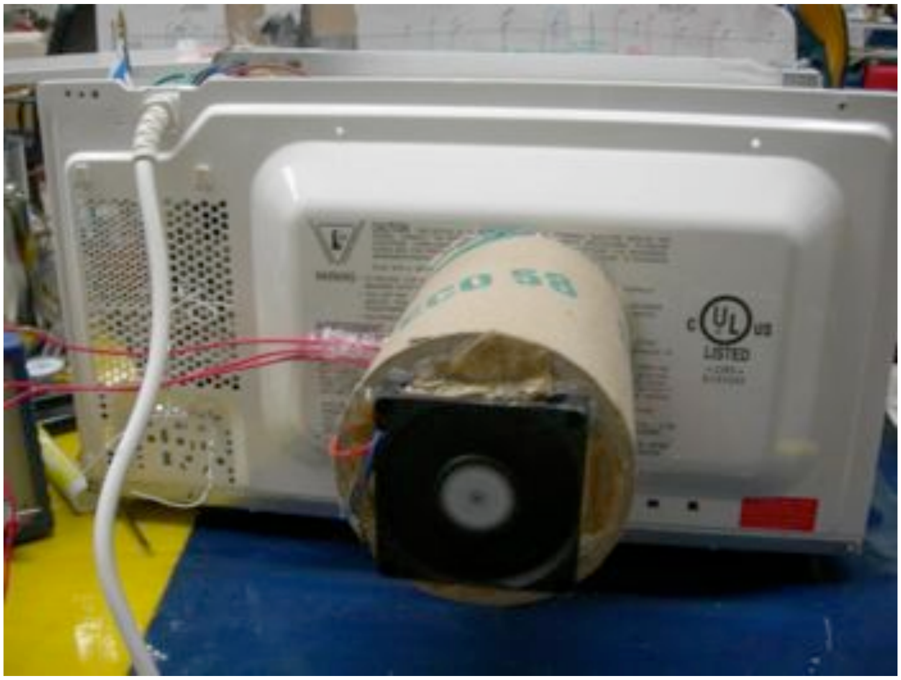


Figure 155: Fan added at the back wall of the oven

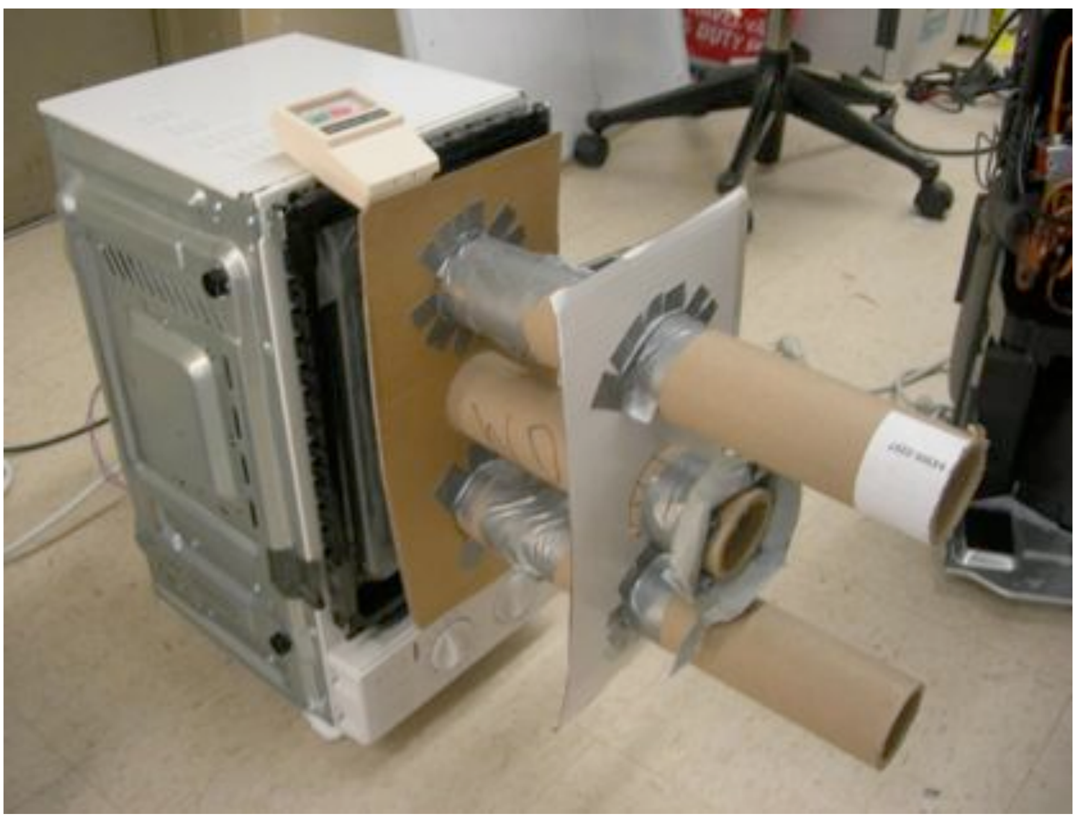


Figure 156: Microwave prototype with straight, laminar air flow

Appendix 8: Exploratory Prototype I - Pre-cooled VCC

Physical Specifications

Data of all the components and materials used in the pre-cooled vapor compression cycle prototype are as follows:

Duct:

Top and bottom of duct, Plywood, 10mm
Walls of duct, PVC plastic, 2mm
Insulation, Silicone
Inner radius 120mm, outer radius 320mm

Evaporator, Condenser (Honeywell Dehumidifier):

Rated Power 288W
Dimensions (210mm*220mm)
Cooling medium, 134a 250g
Min/Max working temperature, 5-32°C max

Pulling fan:

Revolutions per minute 1300-1550
Rated current 0,25A
Max Airflow 190m3/h

Pushing fan:

Revolutions per minute 1400
Rated Current 0,68A
Mac Airflow 120m3/h

Heat Exchanger (cross flow):

Dimensions 200*200*200(mm)
In air temperature 22°C
Out air temperature 5°C
Coefficient of performance (at 190m^3/h) ca 55%

Digital thermo-Hygrometer (DVM 321):

Accuracy (between -20°C-60°C, and 5%-95% RH)

Temperature ± 2, 5°C
Relative Humidity ±3, 5%
Measuring interval 2, 5 measurements/second
Resolution 0, 1% RH and 0, 1°C Temp

Functional Specifications

A Honeywell domestic dehumidifier was used and modified to be able to build the prototype. The existing dehumidifier had the evaporator and the condenser placed next to each other with very little space in between. The dehumidifier had to be evacuated, evaporator and condenser had to be separated from each other. The cooling substance R134a was then refilled. To pre-cool the air, a cross flow heat exchanger was positioned in the space between the evaporator and the condenser.

Figure 157: Cross flow heat exchanger used in the prototype

The air leaving the heat exchanger had to go to the evaporator without any big losses. To solve this, a duct shaped like a loop was made with plywood and PVC plastic and attached to the heat exchanger outlet and the evaporator inlet.

With the duct and the heat exchanger attached to the prototype the air flow losses within the system increased. To compensate for the higher friction two different fans were used - one to push, and one to pull the air through the system. The push fan was positioned on the inlet to the heat exchanger and the pull fan was placed directly after the condenser.

When turning on the machine the fans push and pull the air through the system, i.e. through the heat exchanger, via the duct to the evaporator, then back to the heat exchanger and out through the condenser and the pulling fan. After running the machine for 30 minutes the temperature and the relative humidity was measured at five different measuring points.

To be able to notice any differences in temperature when adding the pre-cooling device, two tests were made, one with the duct connected and one without the duct.

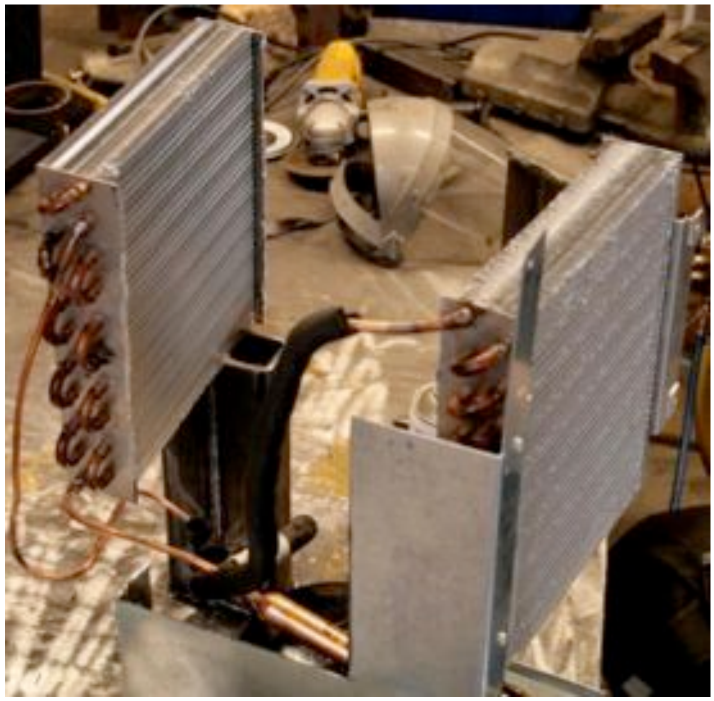


Figure 158: Honeywell dehumidifier after being taken apart, evacuated and repositioned

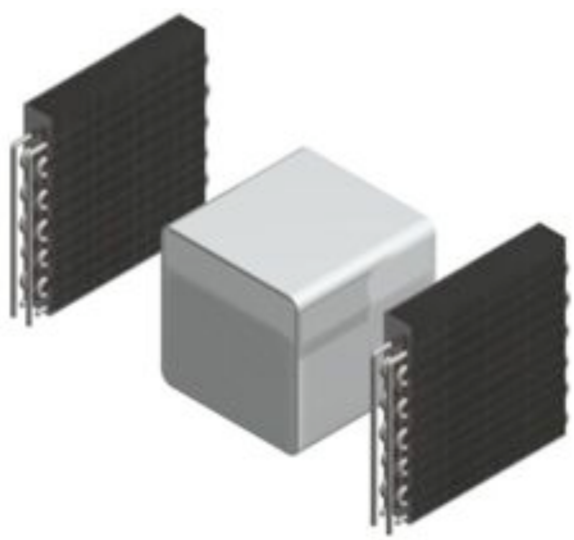


Figure 159: 3D CAD picture of precooling setup

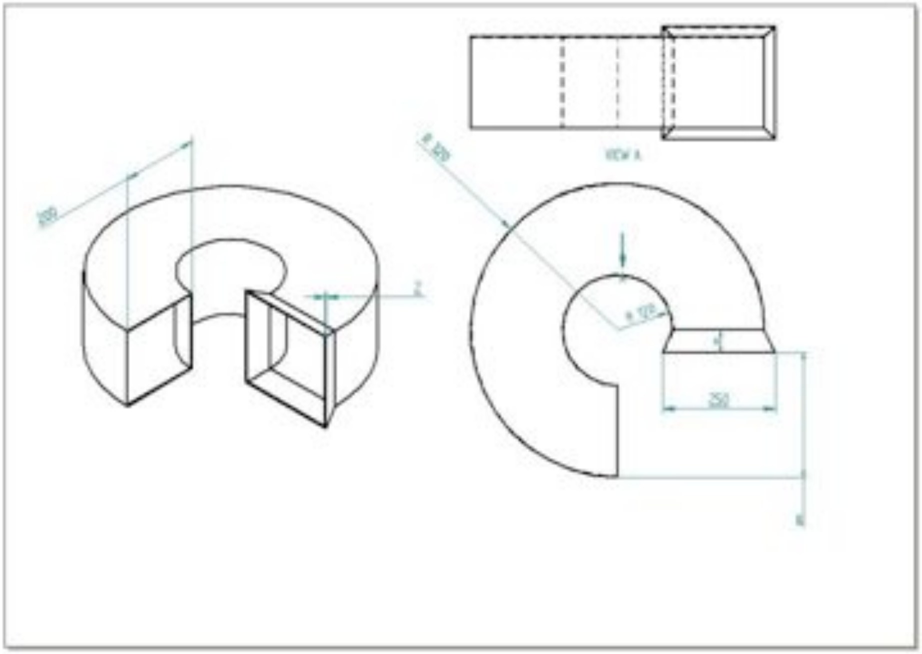


Figure 160: The loop shaped duct

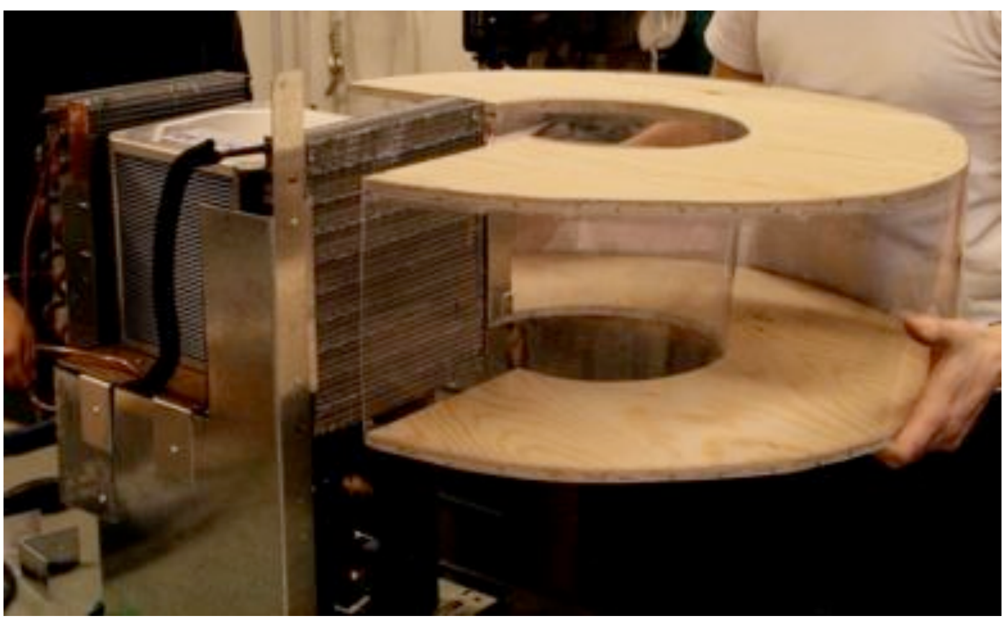


Figure 161: The duct attached to the evaporator and the heat exchanger

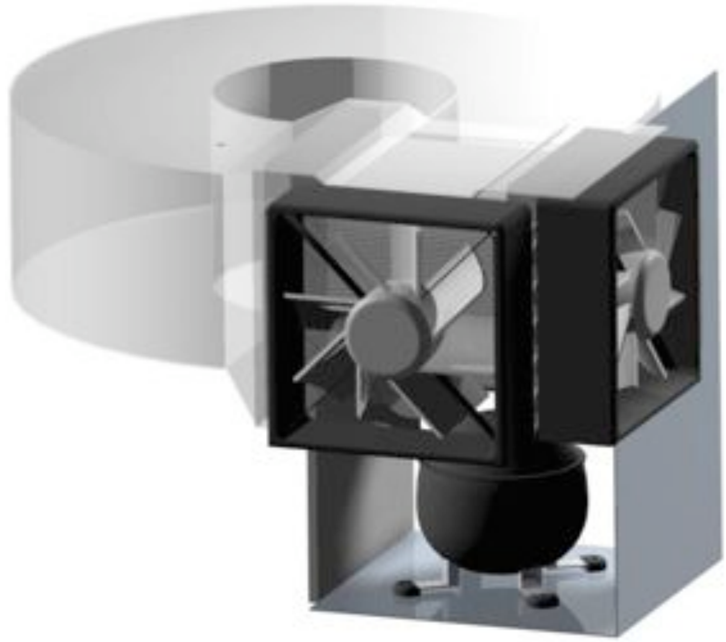


Figure 162: Complete CAD setup

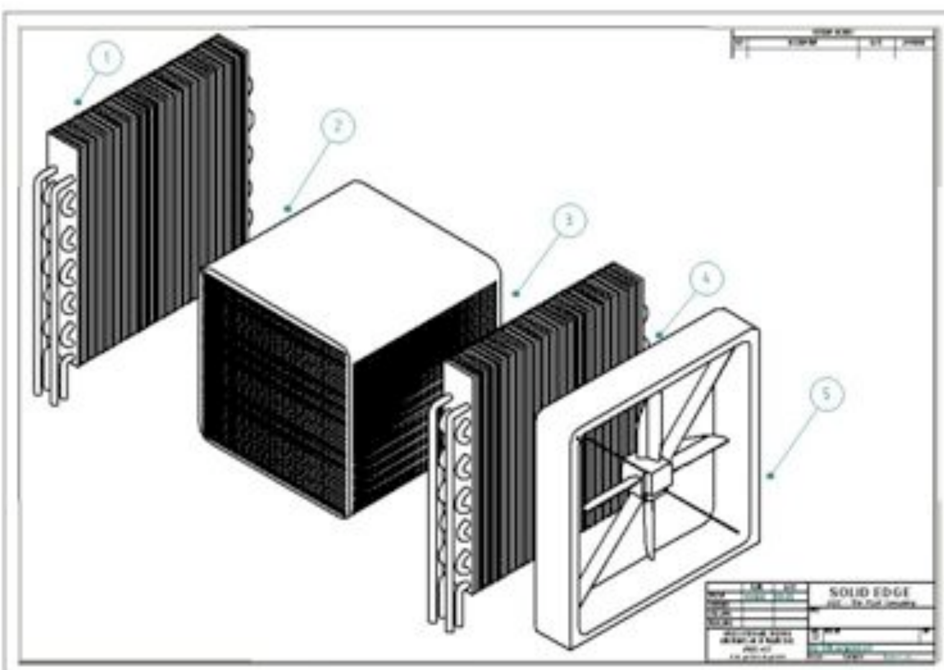


Figure 163: Exploded view of the Pre-cooled VCC. The numbers denote the locations of the temperature and humidity probes.

Results

The results of the prototype were based on measurements made at five measuring points. The relative humidity and temperature values were registered at these points with and without pre-cooling. The measured results are presented below:

Measuring Point	Temperature(°C)	Relative Humidity(%)
1 (*key point*)	17.5	37.5
2	8.4	49.0
3	12.7	37.5
4	23.0	31.7
5	20.5	33.5

Table 1. Without pre-cooling

Measuring Point	Temperature(°C)	Relative Humidity(%)
1 (*key point*)	14.2	34.9
2	4.9	41.0
3	8.4	45.3
4	21.4	31.7
5	20.0	23.0

Table 2. With pre-cooling

Measuring Point	Temperature difference(°C)	Relative Humidity difference (percentage point)
1 (*key point*)	-3.3	-2.6
2	-3.5	-8.0
3	-4.3	7.8
4	-1.6	0
5	-5.0	-10.5

Precooling Prototype: Difference in readings with and without pre-cooling

The measured results showed that the temperature of the air stream was lowered implying that the experiment was successful.

Possible Improvements

In the construction of the prototype there are some important aspects of the device that can be improved further. There are several aspects of the construction that are not optimal.

Since the device is producing cold air it is very important that the 'coldness' is kept inside the device and not lost through the walls of the duct or any other parts. This is accomplished by using an insulating material where needed. Since the amount of energy transported through a wall also depends on the area it is important to keep the contact area with the ambient air as small as possible, at the same time the contact area between the air stream inside the machine and the different components should be maximized.

When using a cross-flow heat exchanger, the friction factor increases significantly. This results in a need for a fan that produces a greater pressure in order to keep the airflow at a similar level. Since every bend and physical obstacle in the way of the air stream causes an increase in friction factor, it's important to minimize this when designing the device.

Because of the design of the pre-cooling system, the size of the final product will be bigger than a product using a regular vapor compression cycle. But there are still some choices in the layout available as the duct and the different components included can be designed without any immense restrictions.

A basic calculation is done below to estimate the amount of temperature change needed to justify the modification with pre-cooling, due to the extra effect used by the fan.
Assuming the extra power required by the fan to be approximately 40W,

$$\dot{Q} = \dot{m} \times C_P \times \Delta t$$

$$40 = 0.0697 \times 1005 \times \Delta t \Rightarrow \Delta t = \frac{40}{0.0697 \times 1005} = 0.57^{\circ} C$$

The value of the mass flow of air is the one used in the pre-cooling prototype (a fan with airflow of ca 200m^3/h was used). This shows that a temperature decrease of 0.57° C is needed to validate the use for pre-cooling in this case. Considering that a temperature decrease of 3.3° C was obtained even with this highly unoptimized prototype, the pre-cooling mechanism seems highly promising.

Appendix 9: Exploratory Prototype I - Desiccant Wheel & VCC

Prototype Design

The team came up with several possible designs that combined the desiccant wheel and VCC. The pros and cons of each of these designs were compared and the best design was selected. Some of the ideas that were discussed in detail were:

Design Iteration 1

The idea was to use the desiccant wheel as a 'RO membrane' to transfer moisture from low moisture content air to high moisture content. This was possible due to the fact that the parameter governing the water absorbing capacity of air is its relative humidity and not its absolute moisture content. Thus, moisture could be transferred from a low absolute moisture content air to a high moisture content air if the temperature of the latter is sufficiently high (such that its relative humidity is less than the former). The moisture content in the air masses were thus to be successively increased at each desiccant wheel (see Figure 164). The 'wettest' air stream was then used to extract water using a conventional vapor compression cycle.

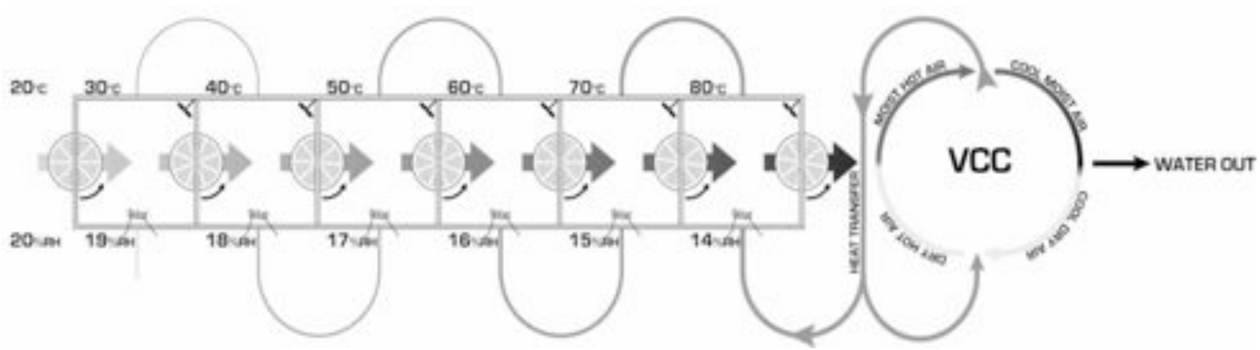


Figure 164: Design Iteration 1: One of the earlier mechanisms considered to couple desiccant wheels with VCC

Though the idea was theoretically sound, it was discarded due to practical constraints. The limitations of the design were:

- Need to have airtight chambers with rotating wheels on both sides
- Need to have very good heat insulation
- The performance characteristics of the desiccant wheel under static air conditions were not known

Design Iteration 2

The idea behind this concept was to further extract the residual moisture left in the air once it has passed through the evaporator coils of VCC. This was done by passing this air through a rotating desiccant wheel (see Figure 165). The moisture thus absorbed by the desiccant wheel was then transferred to the condenser stream. The condenser stream was hotter than the ambient due to the heat expelled by the condenser and added heaters (if necessary) and hence had higher water absorbing capacity. This stream was then fed to the evaporator where the excess moisture content was condensed.

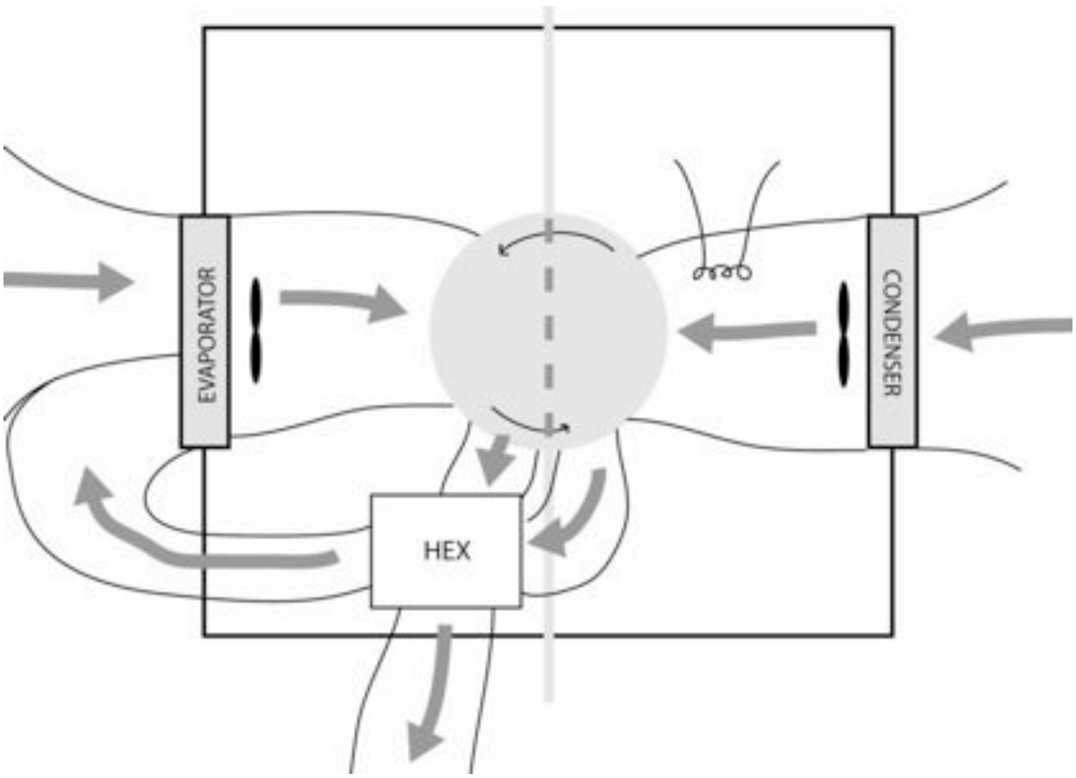


Figure 165: Design Iteration 2, idea: The moisture left in the air stream after condensation at the evaporator was retrieved using desiccant wheel

The main drawbacks of this concept were:

- The moisture absorbed by the wheel, if any, would have been less as the air being passed through it was already depleted.
- The building of a prototype might have been difficult because of a maze of circuitous air ducts needed (see Figure 166).

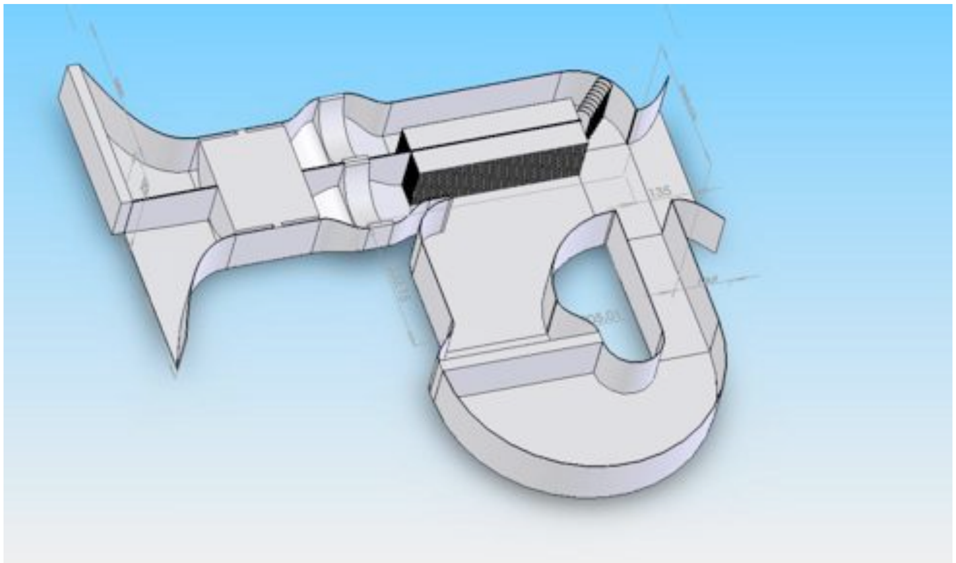


Figure 166: Design Iteration 2, design: The circuitous air duct designed to implement the above idea in practice

Final Design

The design that was finally pursued did not use the air coming out of the evaporator as the process air, but instead used a separate air stream for this purpose. This greatly simplified the fabrication process. Also, the moisture content now being transferred across the wheel at every rotation was enhanced (see Figure 167).

At any given time, the process air passed through three-fourth of the wheel before being exhausted back into the atmosphere. The moisture (from the process air) that was thus absorbed by the desiccant wheel was released into the regenerative air that passed through the remaining one fourth of the wheel. This moisture transfer was accomplished due to the fact that though the absolute amount of moisture in the regenerative air is same as that in the process air, its water holding capacity was greatly enhanced due to its high temperature. Since the regenerative airflow is only one-third of the process airflow, the absolute water content in the regenerative air is greatly increased.

Before being passed through the wheel, regenerative air is passed through the condenser coils of the VCC and gets heated in the process. The condenser coils get cooled in the process. An extra set of electric heaters further increase the air temperature to desired temperature of 120°C necessary to regenerate the desiccant wheel.

This high moisture content regenerative air is then passed through the evaporator coils. Here, the air gets cooled down and the condensed moisture is thus collected. The cold air is then passed over the top of the hot regenerative air channel to ‘pre-cool’ the air, thus optimizing the process.

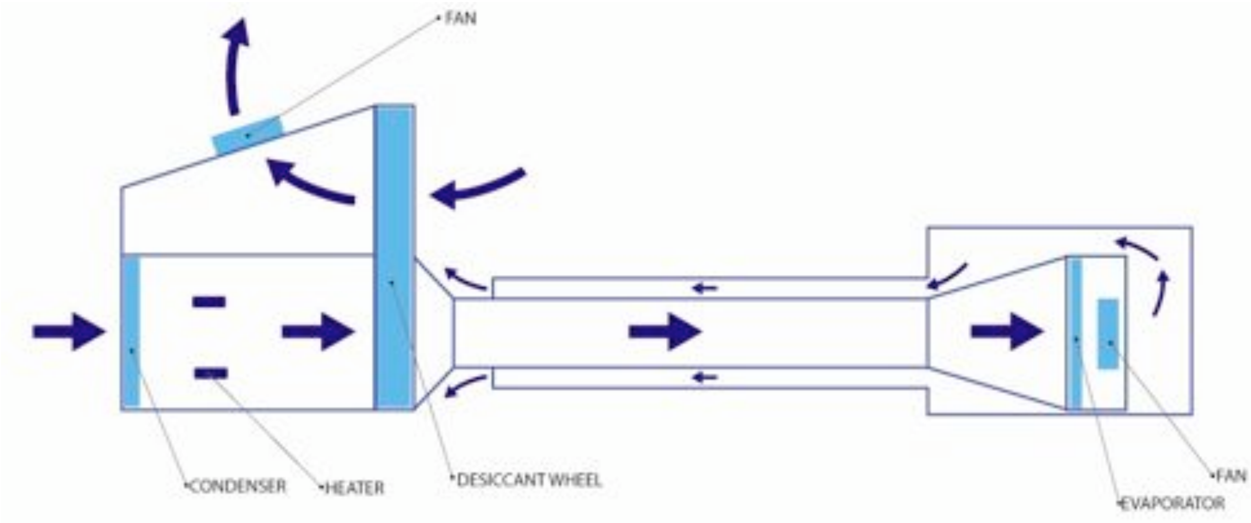


Figure 167: Schematic of the final desiccant wheel-VCC idea that the team pursued

Prototype Construction

Figure 168: Desiccant Wheel used in the prototype

Figure 169: Frame for the wheel. The rubber partitions are used to ensure that there is no mixing between process air and regenerative air

Figure 170: Desiccant wheel inside the wheel frame

Sub Prototype 1

An initial mini prototype was quickly set up to test the efficiency of the desiccant wheel. Two 450W heaters were used to heat the air that was then passed through the desiccant wheel. Thermocouple probes were inserted both inside the polythene duct and outside the wheel to measure air temperature before and after the wheel.

Figure 171: Prototype 1: The objective was to test the desiccant wheel efficiency

Figure 172: The electric heaters connected inside the air chamber of sub prototype 1

Figure 173: The thermocouple probes used to measure air temperature outside the desiccant wheel

Results

The air temperature was raised to a maximum of ~65°C. Since the desiccant wheel had been absorbing from the atmosphere for past many days, the need to pass extra air through it (to saturate it) was not felt. The amount of air extracted from the desiccant was found by weighing the wheel before and after the experiment. It was found that under the prevalent conditions, the air was able to drive off 6gms of water from the wheel. It was not possible to increase the air temperature further due to the huge losses present. The airflow was controlled crudely by restricting the air passage (see Figure 174).

Figure 174: The contraption used to crudely control the air flow through the wheel

Lessons Learned

Through this simple and quickly set up prototype, the team was able to ensure that the desiccant wheel is able to absorb and desorb atmospheric moisture. Though the amount of moisture that was driven off in the experiment was low, it may be due to following reasons:

- The wheel may not be fully saturated to begin with
- The regenerative air temperature was lower than required

Through this experiment, it was also realized that the heating the regenerative airflow to the desired operating temperature (~120°C) would involve large amounts of energy. Hence, it was imperative that the final prototype used as little regenerative airflow as possible. The heat losses also needed to be minimized.

Final Prototype

The vapor compression cycle for the prototype was adapted from a Sears Kenmore 70 pint dehumidifier's refrigeration system.

Figure 175: The Sears dehumidifier

The normal Sears dehumidification system was initially evacuated. The evacuated system was then cut and reconfigured. The various components such as evaporator and condenser were placed at appropriate positions in the 'test rig' and extra copper piping was soldered. Some peripheral structure was also built along this vapor compression system. These peripheral structures included heaters, wheel frame and regenerative air chamber.

Figure 176: Desiccant Wheel-VCC Prototype as it stood before the reconnection of pipes - One can see the desiccant wheel frame on left with the required regenerative air ducts and heaters. The solo compressor stands in the middle. On the right is a part of the duct

The detailed close-ups of the above ‘incomplete’ prototype are appended below:

Figure 177: Close-up of the wheel frame with regenerative air chamber, heaters and condenser at the back

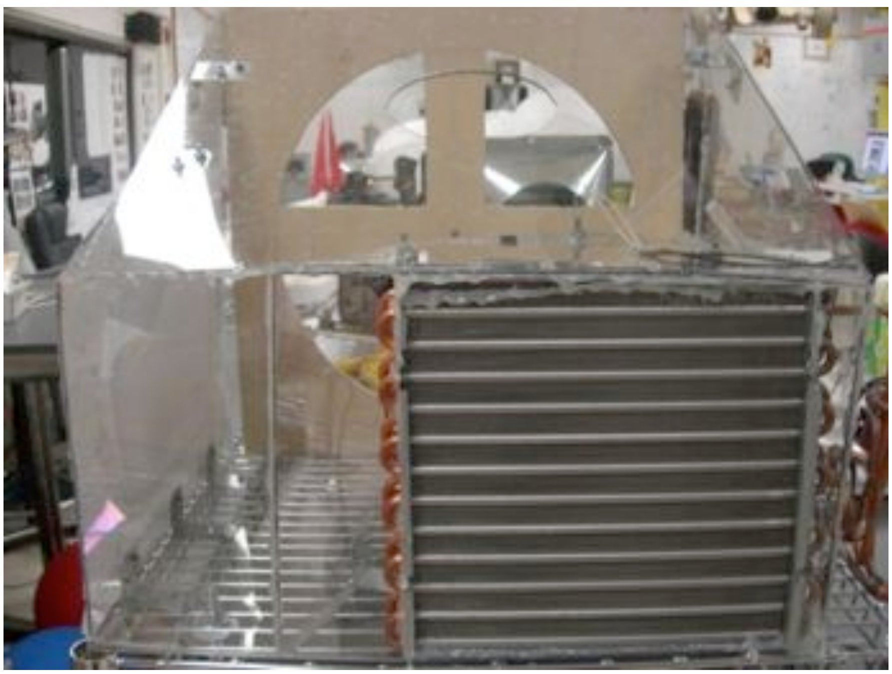


Figure 178: Condenser attached to the prototype - with the regenerative chamber and the wheel frame at the back

Figure 179: Close up of the evaporator and blower at the other end

After the cut dehumidifier parts were reconnected through additional copper pipes (see Figure 180 and Figure 181), the VCC system was refilled with refrigerant. The services of Stanford Facilities' HVAC department were hired for refitting the entire VCC system. The evaporator chamber, ducts and fans were then built on top of the system to finish the prototype (see Figure 182).

Figure 180: The extra pipes soldered to the condenser

Figure 181: The extra pipes connected to the condenser with valves to add/reduce the amount of refrigerant

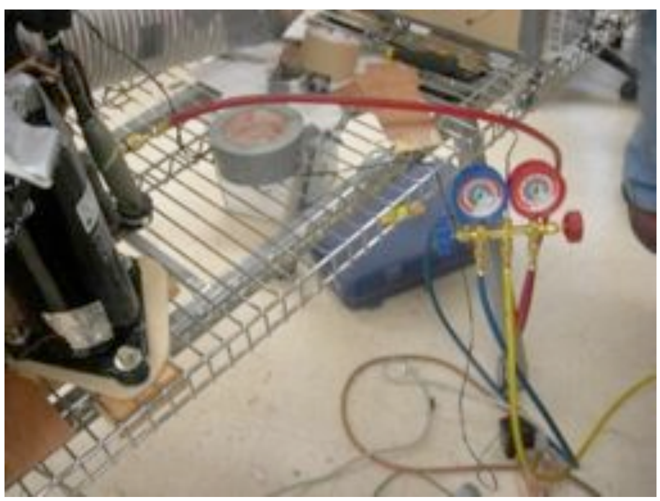


Figure 182: The pressure gauges used to measure the pressure within the VCC system while filling the refrigerant

Figure 183: The Desiccant Wheel-VCC prototype

Results

The prototype was first run with the regenerative chamber heaters switched off. Frost formed within a minute of running the system, even at a low relative humidity of ~25%.

Figure 184: The frost that formed on the evaporator coils on running the prototype

However, the vapor compression system became hot within 10 minutes of operation. The frost that had initially developed on the evaporator coils began to melt and within 15 minutes the condenser and compressor became too hot for efficient operation to take place any longer.

Modifications

The overheating of the system may have been due to following reasons:

- **Undercharging/Overcharging of the vapor compression system**

The original Sears dehumidification system contained 8.8 ounces of R22 refrigerant. Due to increase in the coil length, the new amount of refrigerant that needed to be filled into the system had to be more than 8.8 ounces.
The test was started with 14 ounces of refrigerant filled into the system. A rough estimation was done to find out the new amount of charge needed based on the fraction of coil length increased. It was found that the new refrigerant amount should be around 11 ounces. The charge was successively reduced till 11 ounces and the apparatus retested. Slight improvement was observed as the charge amount was reduced. However, the issue of overheating was not completely resolved.

- **Inadequate airflow over the condenser**

Initially, a single blower at the evaporator end was used to suck air in through the condenser and the wheel. An additional fan was attached to the condenser to increase the airflow through the condenser (see Figure 185). The cold air stream from the evaporator was also diverted to the condenser in an effort to cool it (see Figure 186).

- **Inadequate cooling of the compressor**

Separate cooling fans were attached to the compressor to cool it down (see Figure 187).

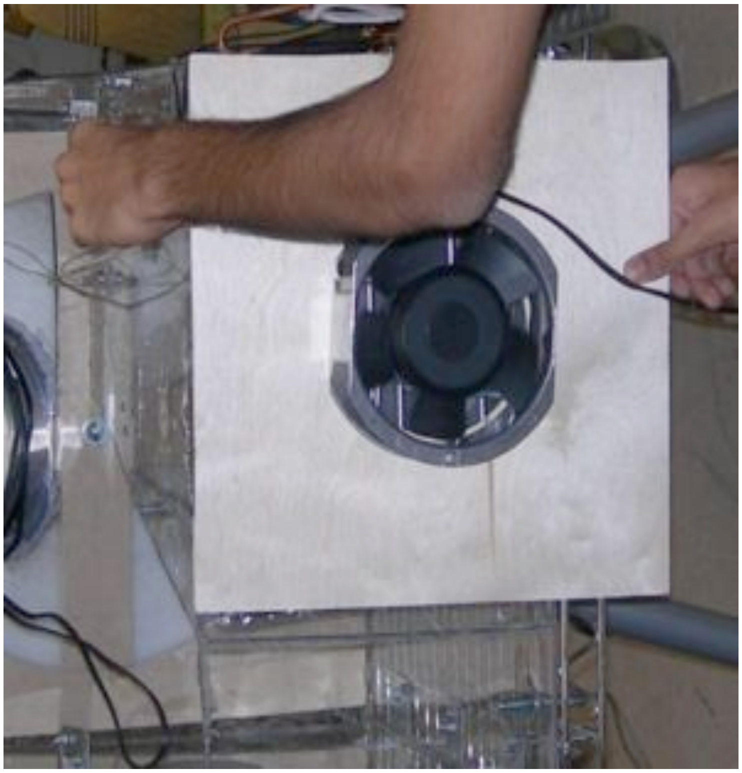


Figure 185: Extra fan added to cool the condenser

Figure 186: The cold evaporator air stream diverted to cool the compressor

Figure 187: Extra cooling fans added to cool the compressor

The various modifications made in the system resulted in an improvement in the performance. As a result, the prototype worked well for about half an hour. However, the issue of overheating was never completely resolved.

Therefore, the results obtained from this prototype were not as encouraging as had earlier been hoped. Due to these heat transfer issues, the team was unable to test the desiccant wheel-VCC coupled concept in as much detail as was hoped.

Appendix 10: Functional System Prototype - Liquid Desiccant Cycle

Prototype Design

In an early stage of testing, it became obvious that liquid desiccants offered several design and performance advantages over solid desiccants. The prototype needed to have two things - an effective water collecting system and a high airflow. The airflow needed to be high because of the small amount of water at low RH levels. The LDC prototype managed air velocities around 2 m/s.

Another aspect is that the prototype uses a true distillation process when it is extracting the drinking water. This means that the prototype condenses the steam of boiled water, and the boiling process kills any microbes and fungi that may be present in the solution. A variety of aqueous salt solutions have been proposed as possible working fluids. Tests have also been conducted to investigate different desiccants and their unique properties. The three most common desiccants are, LiBr, LiCl, and $CaCl_2$.

The liquid desiccant used for testing is a salt solution with Lithium Chloride (LiCl) and water and it is chosen for its combination of advanced hygroscopic properties and long-term stability leading to good cycle performance. It is preferred over LiBr for reasons of cost and long-term stability, while it is preferred over CaCl2 for its better hygroscopic properties leading to better cycle performance. However, there are some concerns over the potentially corrosive and poisonous nature of LiCl. This will require good filtration system and corrosion resistant materials.

Sub prototype 1

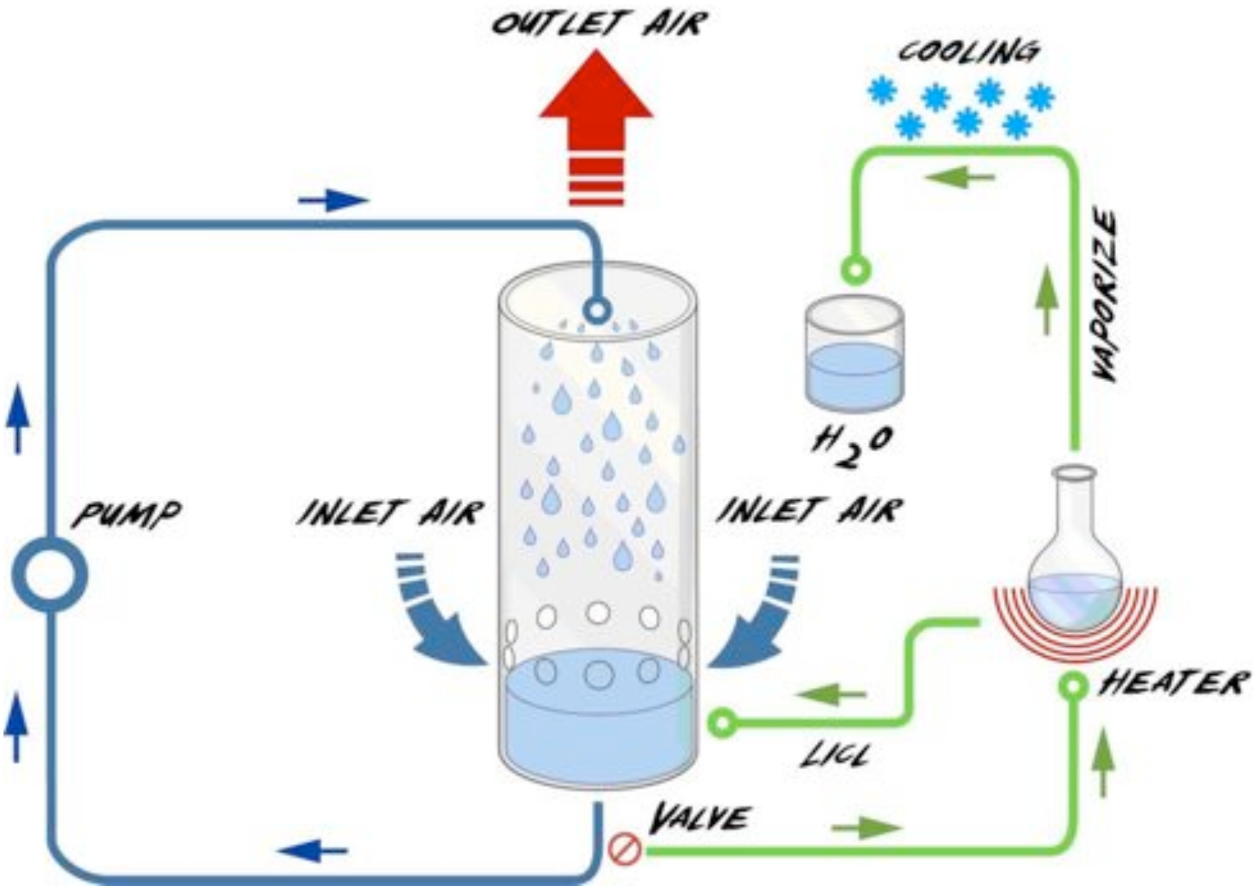


Figure 1. Sub prototype 1, Idea

The first prototype was based on basic physical principles governing water extraction from air using liquid desiccants. This prototype was developed to understand the parameters that affect the result. The prototype was tested with different nozzles, air filters and LiCl concentration. The result for this first test was a little bit inconclusive due to a number of problems. Only a small amount of water was collected due to the low RH values (about 12%) and because of the low airflow. Another problem was the lack of surface area where the desiccant solution and the air could mix. Finding the right concentration was also a problem: too high and the solution loses efficiency, too low and no water is collected.

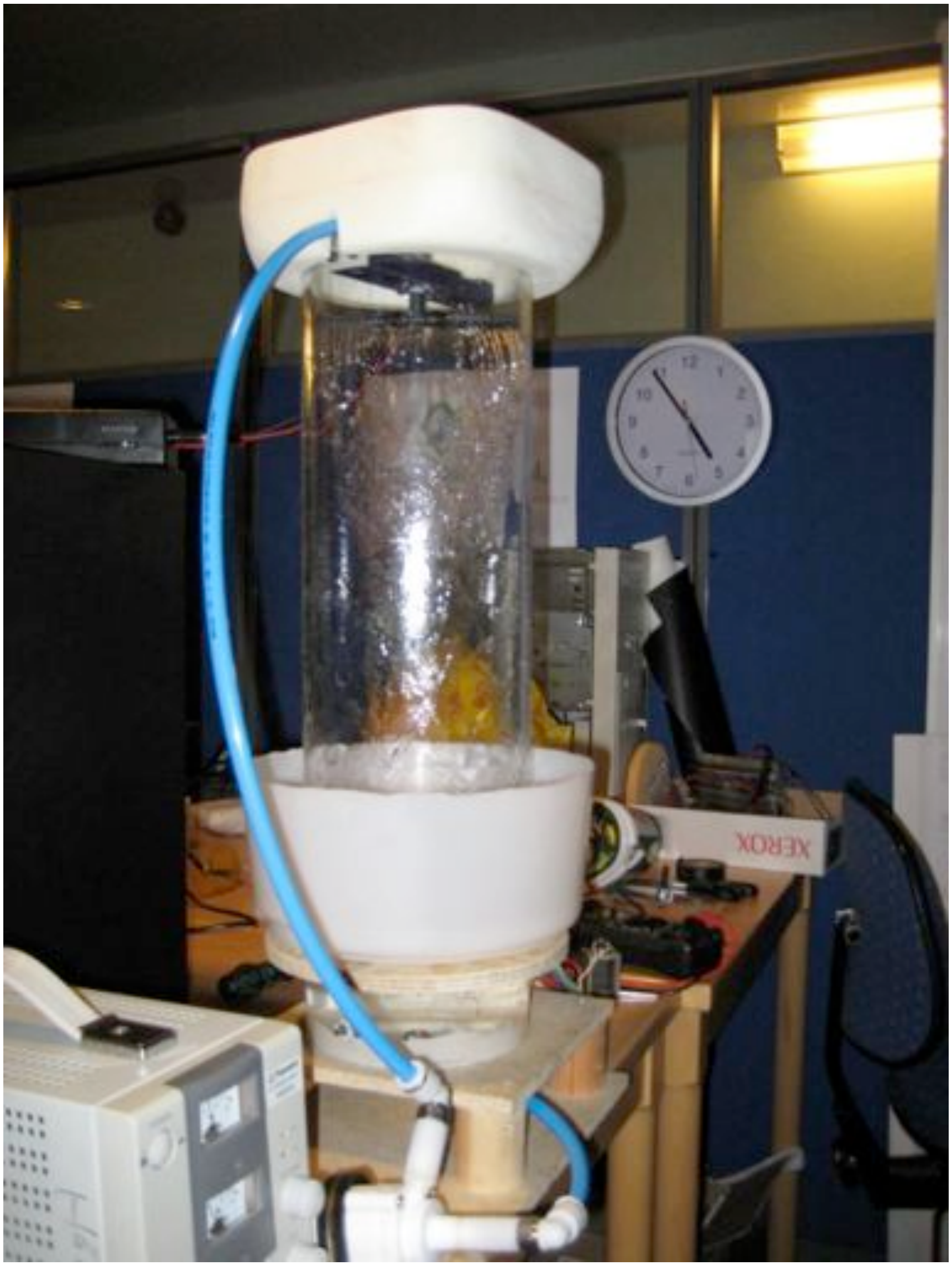


Figure 188: Sub prototype 1

Sub prototype 2 – Nozzle 3, Straws, Electrical heater 1

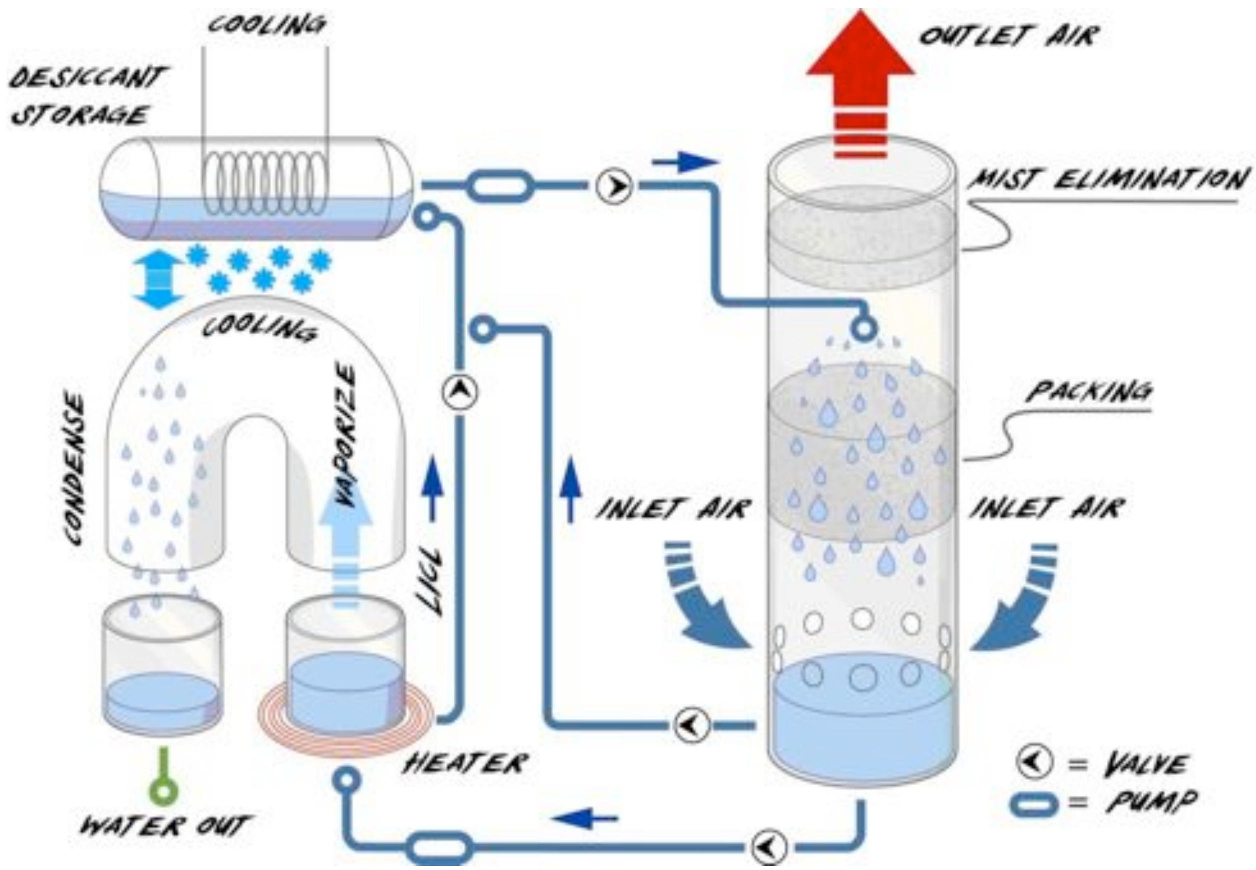


Figure 189: Sub prototype 2, Idea

The second LDC prototype was built based on the first one (see figure 189). The major difference was that the inner surface of the adsorption chamber was improved by using straws as packings material. By using straws, the wet surface in the tube was increased. The result obtained was once again small and one of the reasons was that the air flow was too low, due to the straw packings, but also due to the fact that the air and the solution didn't mix inside the straws and missed each other (see figure 190).

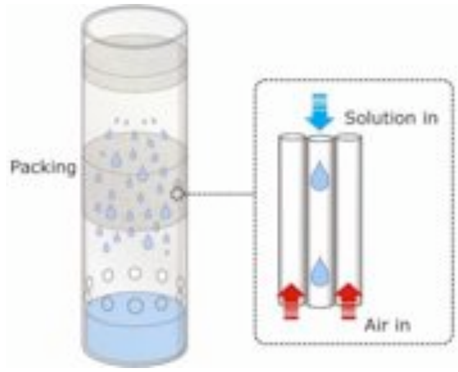


Figure 190: Straw packings

A water extraction system was also included in the test rig (see figure 191) heater was used to vaporize the solution so that water was extracted from the solution. The amount of solution heated was manually controlled by an electrical switch. After the heater the steam was condensed and collected in a separate storage container. Unfortunately the system was over dimensioned and the heat effect was much greater than the cooling applied at the condenser. This made hot steam escape into the ambient air. Another problem was that the copper pipes of the heater corroded much more than was expected, and the solution got contaminated.

Figure 191: Sub prototype 2

Sub prototype 3 - Nozzle 3, Tower packings, Electrical heater 2

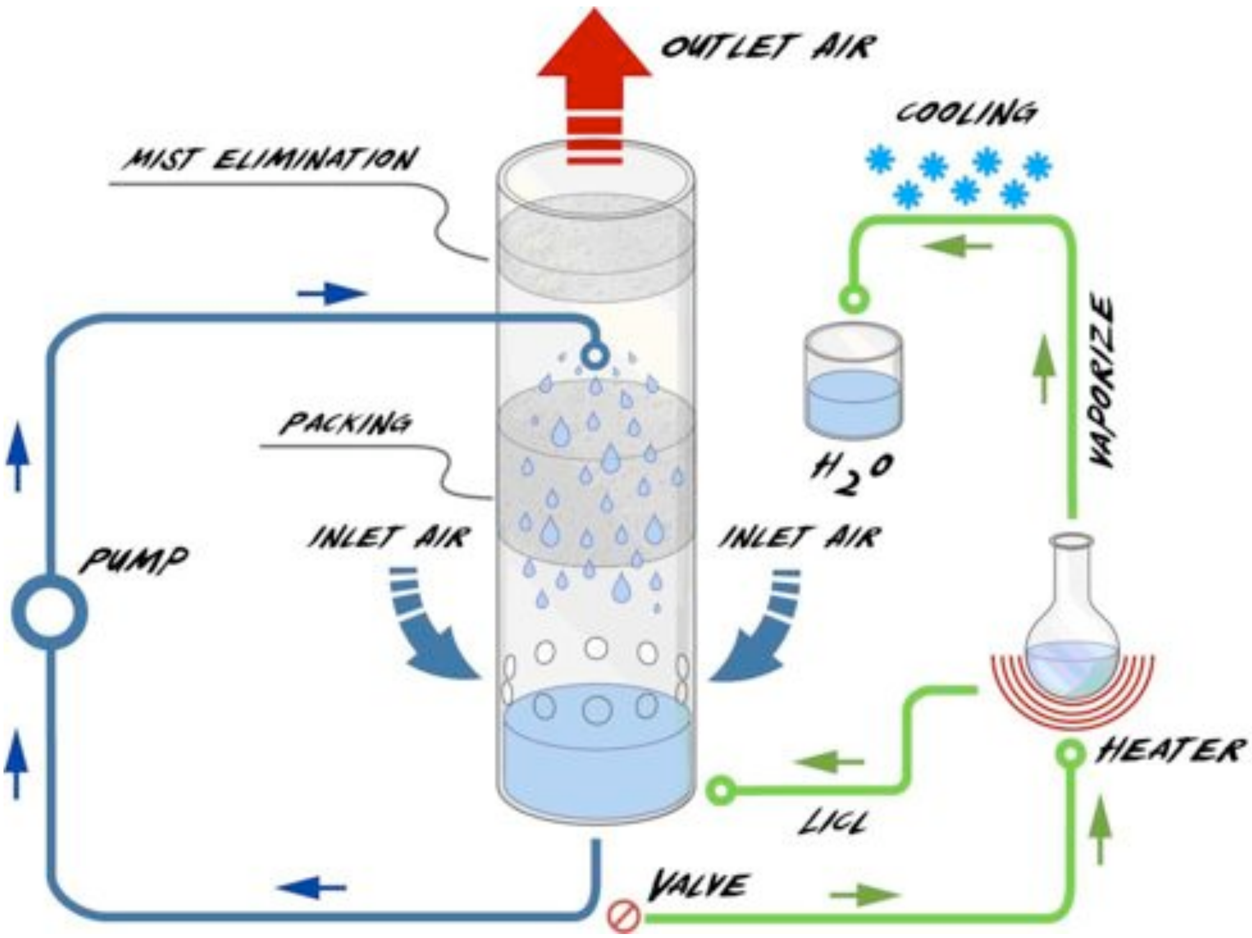


Figure 192: Sub prototype 3 idea

On the last prototype version, two tests were performed, the first test during one hour and a second test during six and a half hours. The procedure and the conditions were the same for both tests.

First the solution was mixed together to a known concentration (45% mass fraction of salt). To control the amount of solution during the experiment, the liquid level inside the solution container was measured after the pump had wetted the inner surface of the plexiglass tube. This was done to ensure that the extracted water actually came from the ambient air. A better way to measure the amount of solution could have been weighing the test rig on a scale, but a quick test showed that the scale wasn't steady enough. However, the element of uncertainty was within bounds, at least if the test was performed during a long period of time.

The extraction of water from the desiccant solution was controlled by hand through the whole test. The amount of heated solution was controlled by changing the height of the container that was used to evaporate the water from the solution. When the solution reached the boiling point it was boiled until salt crystals started to form on the inner surface of the container. Then the solution was put back into the adsorption chamber (plexiglass tube). This procedure was then repeated throughout the whole test. The energy used to heat the solution was not reused in this method. With two thermometers the temperature in the adsorption chamber and the water vapor was accurately measured.

Cold tap water was used in the condenser to ensure that most of the vapor was collected. The condensed water was then collected in a storage container that was weighted at the end of each experiment. The test was stopped after the decided time period. However, before stopping the experiment, it was ensured that the solution level in the adsorption chamber was the same as the start level.

The air velocity was measured in order to calculate the airflow in the adsorption chamber. The actual airflow was found to be much lower than expected, only 10 – 30 m^3/h. The heater lost a lot of the energy to the surroundings due to bad insulation and large contact area to the surroundings. This provides a lot of scope for further increasing the energy efficiency in the final design of the product.

The purity of the extracted water was measured with a conductivity meter. The sample was compared to ordinary Swedish tap water. More details about the test equipment and procedure can be found in design specification section.

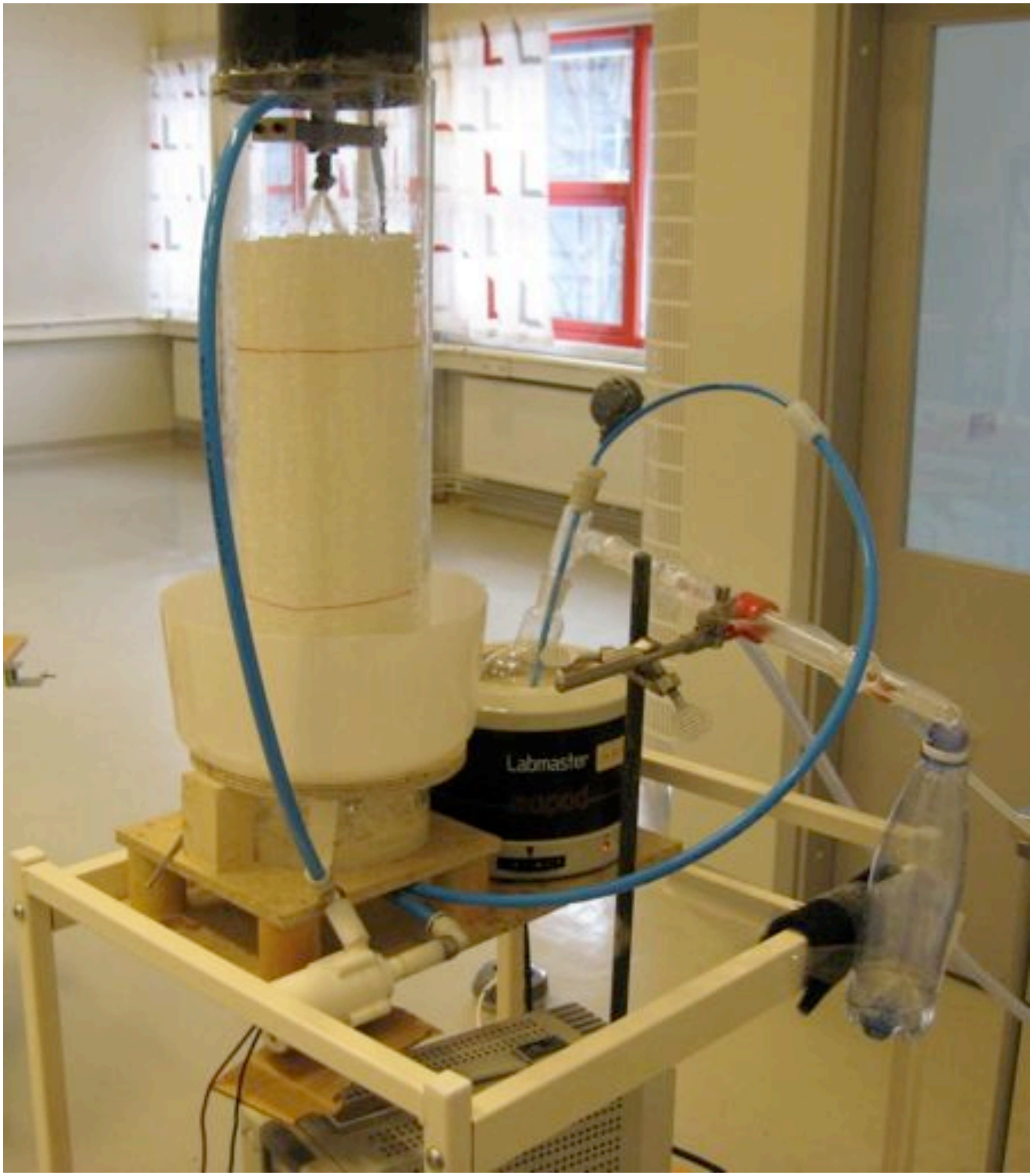


Figure 193: The final LDC prototype

Physical Specifications

A plexiglass tube with height 550 mm, inner diameter 140 mm and outer diameter 150 mm was used as the adsorption chamber. An extension was used at the top of the Plexiglas tube to eliminate any mist that could escape through the fan (see figure 198 and figure 195).

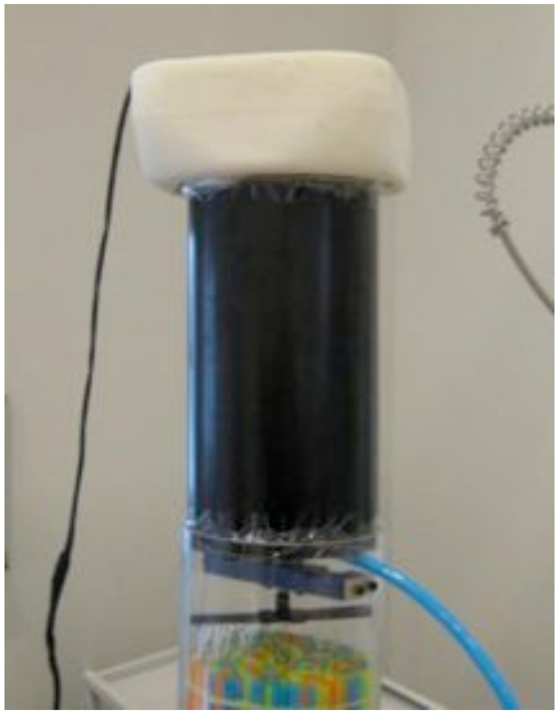


Figure 194: Tube extension

Figure 195: Fan

The fan was mounted at the top and sucked the air in through 20 holes with 16 mm diameter each that were drilled on the bottom side of the tube. The air then went through the Plexiglas tube and up through the fan. To stop any mist escaping out from the absorption chamber a mist eliminator was mounted under the fan. To maximize the contact surface area between the air and the liquid desiccant, packings was used in the tube. There were two types of packings used. The first one was made of straws that were 6 mm in diameter (see figure 196). The other packings consisted of high flow tower packingss that were glued on top of each other. The tower packingss was 16 mm high and had a diameter of 17 mm (see figure 197 and 198). Both packingss were formed into a 300 mm high stack.

Figure 196: Tower packings

Figure 197: Straw stack

Figure 198: Tower packings stack

The liquid-pump that circulated the solution had a flow rate of 6.6 l/min and an energy rating of 14.4 W (see figure 199). The tubing that was used throughout the prototype had an inner diameter of 8 mm and an outer diameter of 10 mm.

Figure 199: Pump

The solution contained 500 g LiCl and 611 g water, which is approximately 45 % of LiCl (by weight). The evaporator consisted of a glass container and a heater. Two heaters were tested, heater 1 and 2 (see figures 200 and 201).

Figure 200: Heater 1

Figure 201: Heater 2

The condenser was a water-cooled glass pipe that went to a collecting vessel. The water extraction process is seen in figure 202 below.

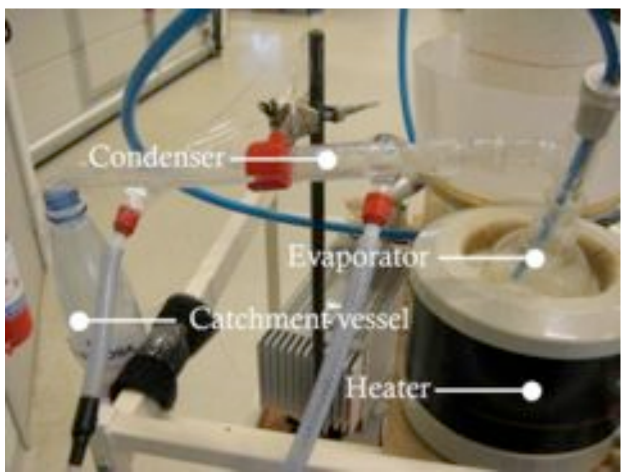


Figure 202: Water extraction process

There were three different types of nozzles tested in the prototype. The first one was a rotating nozzle that spread the liquid in the tube. The next nozzle was constructed by a plastic ring with holes placed against the surface of the tube allowing the liquid to spread evenly on the inside surface (see figure 204). The third nozzle was a rotating nozzle but the openings were only at the sides allowing the water to spread over the inner tube surface (see Figure 205).

Figure 203: Rotating nozzle

Figure 204: Plastic nozzle with holes

Figure 205: Rotating nozzle with openings on side

Specification	Value
Room humidity	38 % RH
Room temperature	19 °C
Plexiglass tube height	550 mm
Plexiglass tube inner diameter	140 mm
Plexiglass tube outer diameter	150 mm
LiCl concentration	45 % (mass)
LiCl mass	500 g
Total solution mass	1111 g
Tower packings diameter	17 mm
Tower packings height	16 mm
Packings height	300 mm
Total wet area - straws	1000 m^2/m^3 → 7.5 m^2
Total wet area - tower packings	313 m^2/m^3 → 1.65 m^2
Pump fluid flow	6.6 l/min
Pump Power	14 W
Fan air flow	140 m^3/h
Fan Power	30 W
Heater 1 Power	600W
Heater 2 Power	240 W
Thermometer	Minus 40 to 200 °C

Physical specifications of the Functional system prototype

Functional Specifications

The prototype was tested in a room that had a controlled climate with constant relative humidity, 38 % and constant temperature, 19 °C. The air that was dragged into the Plexiglas tube by the fan had a constant airflow and was measured with a velocity meter. To observe the amount of water that was adsorbed, the level of liquid in the Plexiglas tube was visually measured. Both the temperature in the evaporated water and the liquid desiccant in the Plexiglas tube were measured with a thermometer. The thermometer could measure both liquid and gas and could measure a temperature difference from -40 to 200 °C (see figure 206).

Figure 206: Thermometer

Liquid LiCl was circulated by a pump and sprayed into adsorption chamber with a nozzle. The fan that was mounted on top of the Plexiglas tube let air flow through the tube in opposite direction to the aqueous LiCl. When aqueous LiCl solution got in contact with the air, water was adsorbed causing the LiCl concentration to drop. Different nozzles and packings were used to optimize the contact area surface between the air and liquid LiCl. Water was then separately extracted from the solution by heating in a heater. The steam then continued into a glass tube and was condensed in to a catchment vessel and LiCl was returned to continue the process.

Results

The last edition of the prototype extracted approximately 60g of water per hour during the 6.5-hour test. The energy consumed per liter of extracted water was approximately 3.5 kWh (see calculations below). Assuming an electric power cost of 16 cents per kWh, this turns out to be 56 cents per liter of water produced. This value is considered high but is within the design requirement bounds. Also, there is a lot of scope for reducing the heat losses in the system. The heating system used in the prototype was not optimized. Once all these issues are dealt with and the process optimized, the cost/liter should further decrease.

Calculations

Purity of extracted water - LDC

Conductivity – Tap Water (cold): 0.46 mS/cm
Conductivity – Extracted water: 1.7 mS/cm
Comparison:
1.7/0.46= 3.7, i.e, 3.7 times more particles in the extracted water

Measuring of airflow in absorption chamber

The air velocity in the absorption chamber was measured with a velocity meter during the test. The airflow was later calculated since the diameter of the tube was known.

Figure 21. Air Velocity meter probe

Measured air velocity: 0.2 – 0.5 m/s
Diameter absorption chamber: 1.5 dm^2
Actual airflow:
0.2 m/s $*0.015m^2=0.003\ m^3/s$ à11 m^3/h
0.5 m/s $*0.015m^2=0.0075\ m^3/s$ à27 m^3/h
The actual airflow in the absorption chamber is between 11-27m^3/h.

Energy Calculations - LDC

Energy consumption:

- Fan: 30 W
- Pump: 14 W
- Heater: 240 W (used 70% of time)
- Extracted water: 60 g/h

Energy per liter:
1kg/0.06kg=16.7
E_{Tot} = (30 W + 14 W+ 240*0.7 W)*1h*16.7= 3.5 kWh/liter

Appendix 11: Dimensioning and Evaluating the Desiccant Wheel

Dimensioning the desiccant wheel

When dimensioning the desiccant wheel, factors like mass flows of the drying and the regenerating fans as well as the sizes of the drying and the regenerating sections have to be taken into consideration. According to the software Procalc2 provided by the desiccant wheel supplier Proflute the mass flow per area is restricted to range between 1 to 8 kg/m^{2}s. The maximum flow the wheel can stand is by that means approximately 1,6 m/s. Calculations has shown however that the desiccant wheel adsorbs moist most effectively in the range of 5-7 kg/m^{2}s and gives off air at higher water concentration in the range of 2-3 kg/m^{2}s. So these two parameters have to be regulated and coordinated according to these values in order to select a suiting wheel dimension.

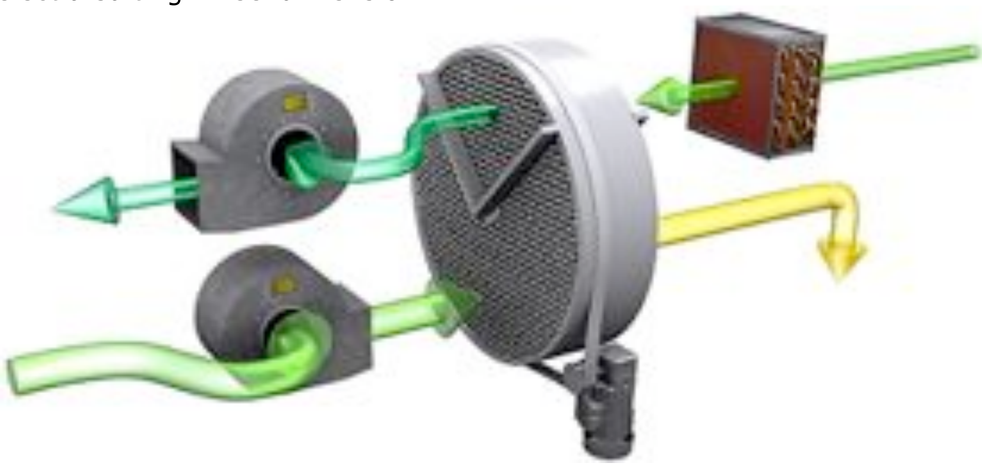


Figure 207: The desiccant wheel process

$$mass\ flow = \frac{\dot{m}_{inlet\ flow}}{A_{active}} \qquad [\mathrm{kg/m^2s}]$$

To calculate the mass flow per area the inlet mass flow has to be divided by the area of the active section. Therefore the angles of the drying respectively the regenerating sections first have to be determined as well as the inlet mass flow. Thereafter calculations of the mass flow per area for different desiccant wheel dimensions can be executed and evaluated according to desired values.

Figure 208: Active area

Starting from a drying fan with a speed of 370 m^3/h and a regenerating fan with a speed of 50 m^3/h the calculations showed that a desiccant wheel with a diameter of 200 mm and a thickness of 200 mm was the best suiting dimension. The drying and the regenerating sections of the wheel were in these calculations set to 270º respectively 90º and the rotation speed was estimated to around 8-10 rotations per hour.

Energy efficiency

The primary idea of the desiccant wheel process is to increase the water concentration of the outlet air flow in the regenerating process in order to increase the energy efficiency by avoiding cooling large amounts of dry air. However if the water contents already is high this process would be quite useless and ineffective. To get a better view of the situation calculations were made on various relative humidity conditions and temperatures.
In the following tables a study of combining the desiccant wheel and the VCC in comparison with solely using the VCC has been done. In these calculations the processed air is expected to be cooled-down to 1 ºC. Due to lack of accurate figures concerning the efficiency factor of the vapor compression cycle this is approximated to 85%.
No efforts of improving the energy efficiency of the process by for example implementing heat exchangers in the system have been taken in consideration in these calculations. By doing this the result would be improved considerably.

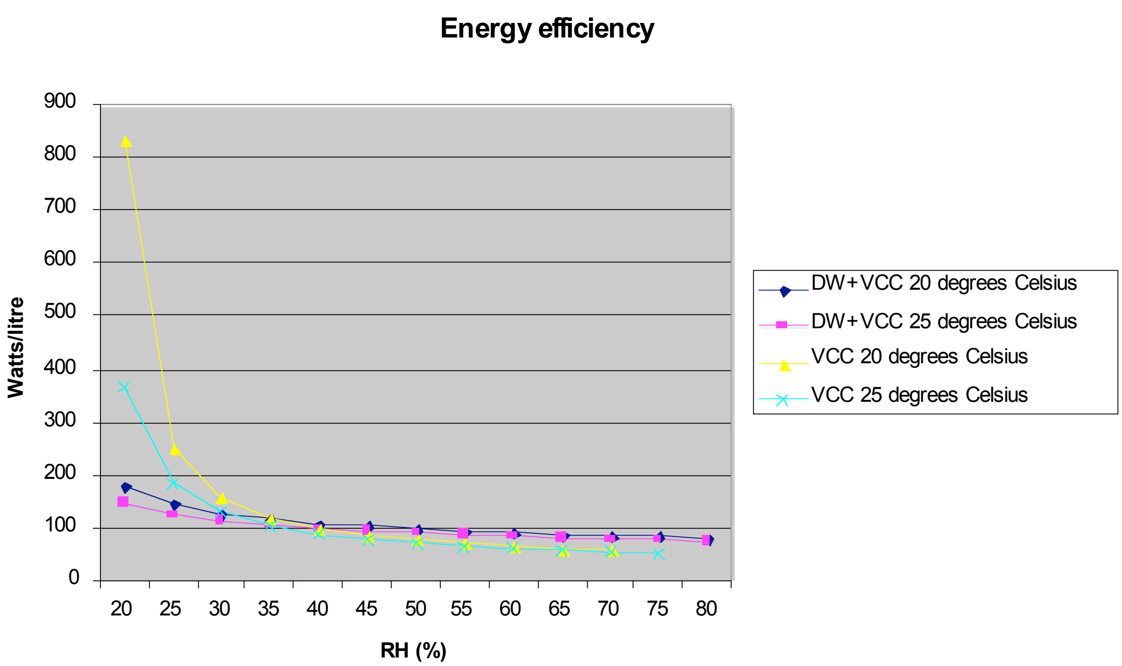


Figure 209: Energy efficiency at various RH and temperatures

Water efficiency

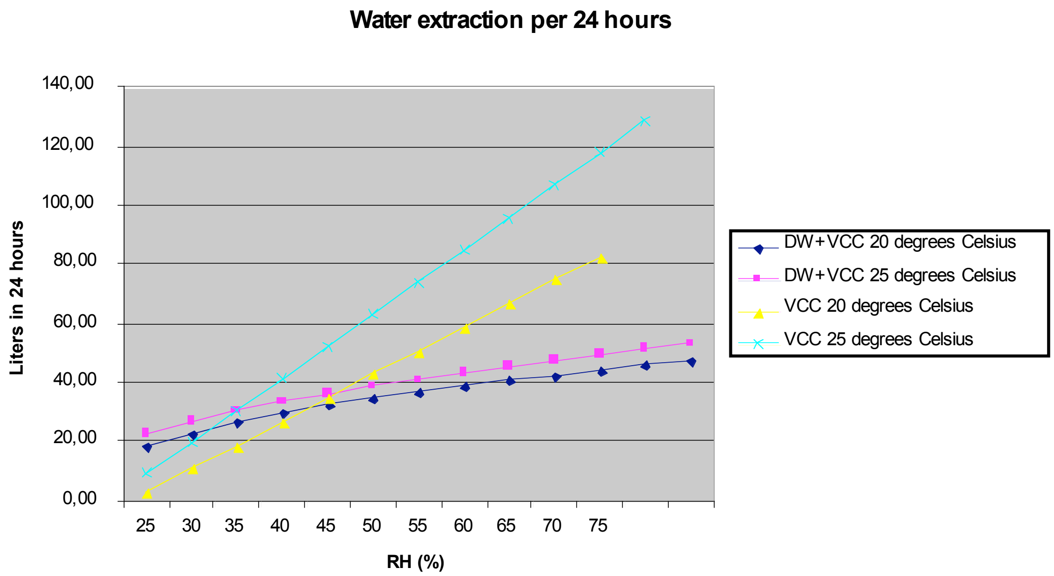


Figure 210: Water extraction capacities at various RH and temperatures

To be critical about these calculations, the assumption of extracting 100% of the condensed water without losses might not be likely. Also cooling an airflow of 370 m^3/s in the VCC process might also be hard to do. This would require a cooling effect of 2500-6500 W for the VCC.

Conclusion

The calculations show that the VCC solely is the best choice in conditions where the relative humidity exceeds 35-45%. The VCC becomes however highly ineffective in dryer conditions. To solely use the VCC in high relative humidity and changing to the desiccant wheel in low relative humidity might be a possible solution, to get the best out of both technologies.

Appendix 12: Heat exchanger

EXERGY, LLC
MINIATURE HEAT EXCHANGERS

Customer Name		Stanford University
Heat exchanger model		00486-9 or equiv.

	Tube Side	Shell Side	
Fluid type	45% LiCl & Water	45% LiCl & Water	
Temp in	248.00	68.00	F
Temp out	85.44	242.24	F
Mass Flow	130.83	134.08	lb/hr
Vol. Flow	0.20	0.21	gpm
Pressure drop	0.12	0.00	psi
Heat transfer		14229	BTU/hr
Effectiveness		0.968	

Customer Name		Stanford University
Heat exchanger model		00486-9 or equiv.

	Tube Side	Shell Side	
Fluid type	45% LiCl & Water	45% LiCl & Water	
Temp in	120.00	20.00	deg C
Temp out	29.69	116.80	deg C
Mass Flow	16.48	16.89	g/sec
Vol. Flow	0.76	0.78	lpm
Pressure drop	0.81	0.02	kPa
Heat transfer		4169	Watts
Effectiveness		0.968	

Appendix 13: Water extraction

In the following appendix the amount of water that is possible to absorb is shown with three scenarios.
Air velocity: 2 m/s
Chamber cross-section: 0.057 m^2
Solution concentration: 43-45 %
Room temperature: 20° C
→
Airflow: 2 m/s x 0.057 m^2 = 0.114 m^3/s
410 m^3/h
9849 m^3/24 h
Airflow in kg: (9849 m^3/24 h) / (1.2 kg/m^3) 8207 kg/24 hrs (air processed in the chamber)
Assuming an adiabatic process where the temperature in the chamber is close to the temperature in the ambient air the amount of water that could be absorbed with this configuration is following:

S 1	Wet Bulb		Absolute	Relative	Dew Point	Excess	
Temp.	Temp	Enthalpy	Humidity	Humidity	Temp	Water	
(T)	(Twet)	(Ht)	(w)	(phi)	(Tdew)	(w - wsat)	
°C	°C	kJ/kg (dry air)	kg water/kg dry air	%	°C	kg water/kg dry air	
20	20	77,43	0,01469	100	20	0	
41,7	20,22	77,43	0,006008	12	6,527	0	
		Difference x 0.7	0,0060774	kg			
S 2	Wet Bulb		Absolute	Relative	Dew Point	Excess	
Temp.	Temp	Enthalpy	Humidity	Humidity	Temp	Water	
(T)	(Twet)	(Ht)	(w)	(phi)	(Tdew)	(w - wsat)	
°C	°C	kJ/kg (dry air)	kg water/kg dry air	%	°C	kg water/kg dry air	
20	11,61	52,99	0,005064	35	4,094	0	
26,35	11,66	52,99	0,002539	12	-4,708	0	
		Difference x 0.7	0,0017675	kg			
S 3	Wet Bulb		Absolute	Relative	Dew Point	Excess	
Temp.	Temp	Enthalpy	Humidity	Humidity	Temp	Water	
(T)	(Twet)	(Ht)	(w)	(phi)	(Tdew)	(w - wsat)	
°C	°C	kJ/kg (dry air)	kg water/kg dry air	%	°C	kg water/kg dry air	
20	10,07	49,3	0,003609	25	-0,532	0	
23,65	10,09	49,3	0,00216	12	-6,587	0	

		Difference x 0.7	0,001014	kg			

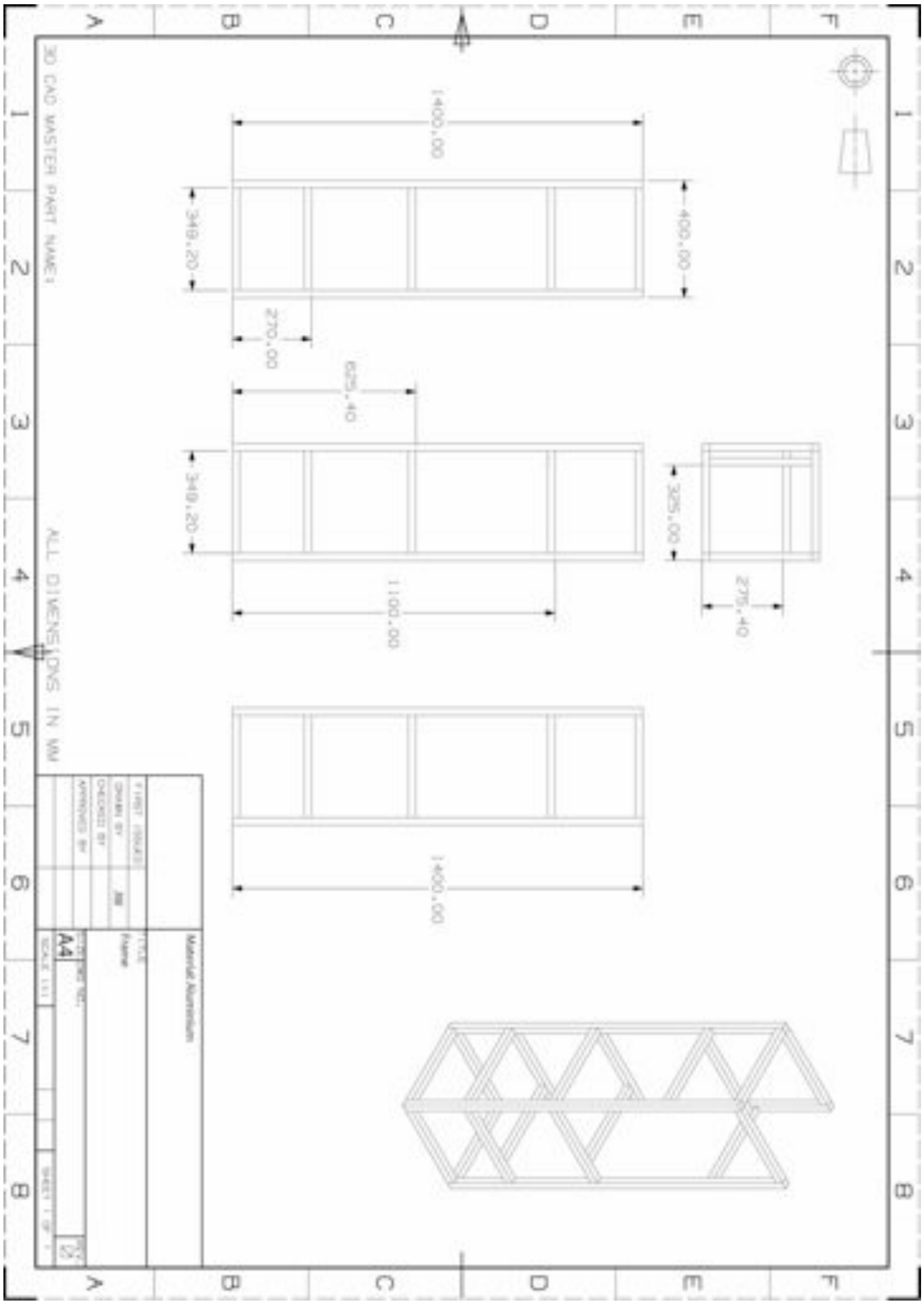
Scenario 1, RH 100%
Amount of water: 8000 kg/24 h x 0.0060774 kg = 48.6 Kg water per day.
This amount is not likely since the temperature raise is almost 22° C. To reach this value with configuration cooling of the solution is most likely needed.

Scenario 2, RH 35%
Amount of water: 8000 kg/24 h x 0.0017675 kg = 14.4 kg water per day
The temperature raise is not that large so this is a possible value. Nonetheless, it is a theoretical value without safety factors.

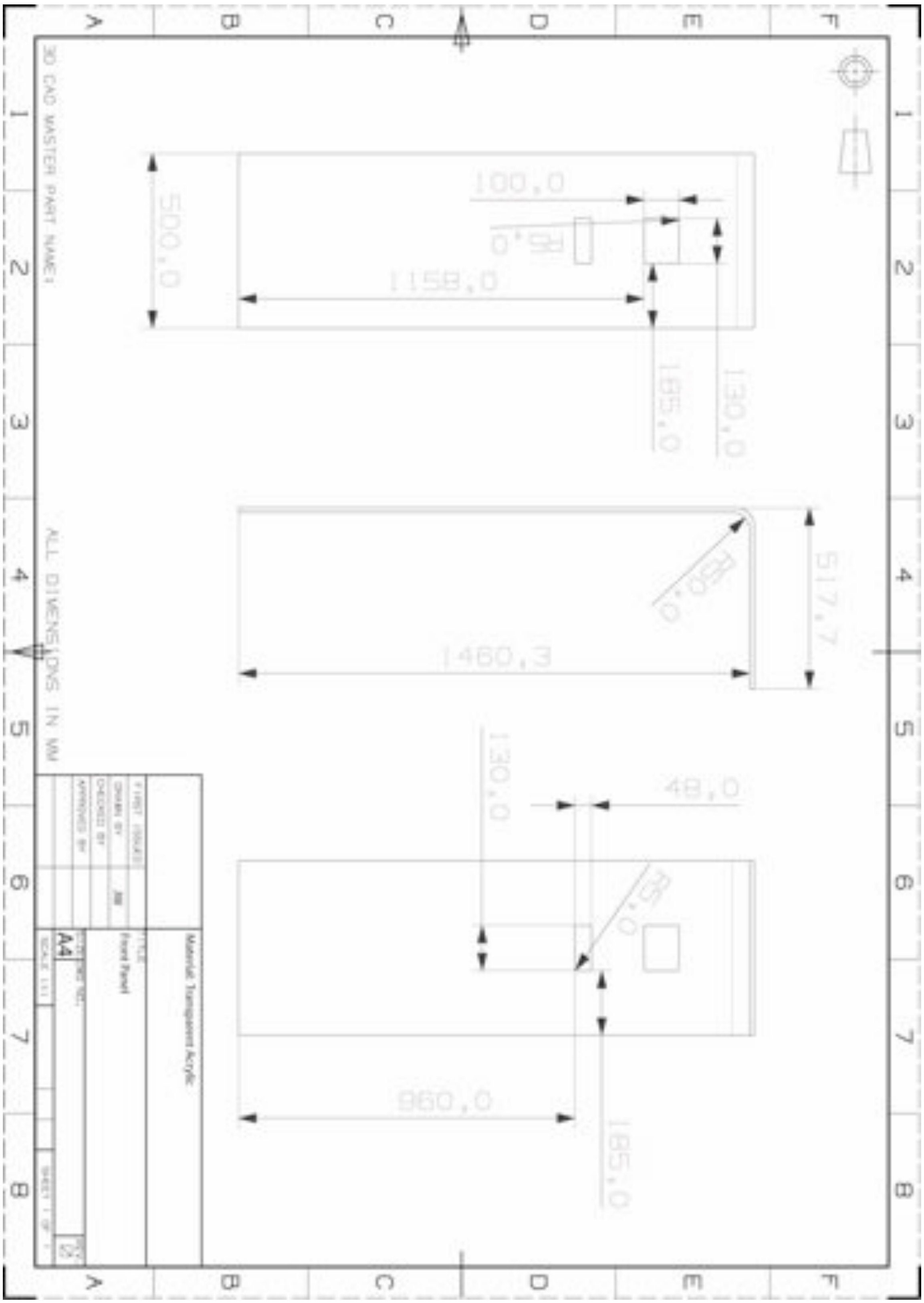
Scenario 3, RH 25%
Amount of water: 8000 kg/24 h x 0.001014 kg = 8.1 kg water per day
The temperature raise is not that large so this is a possible value. Nonetheless, it is a theoretical value without safety factors.

Appendix 14: Frame

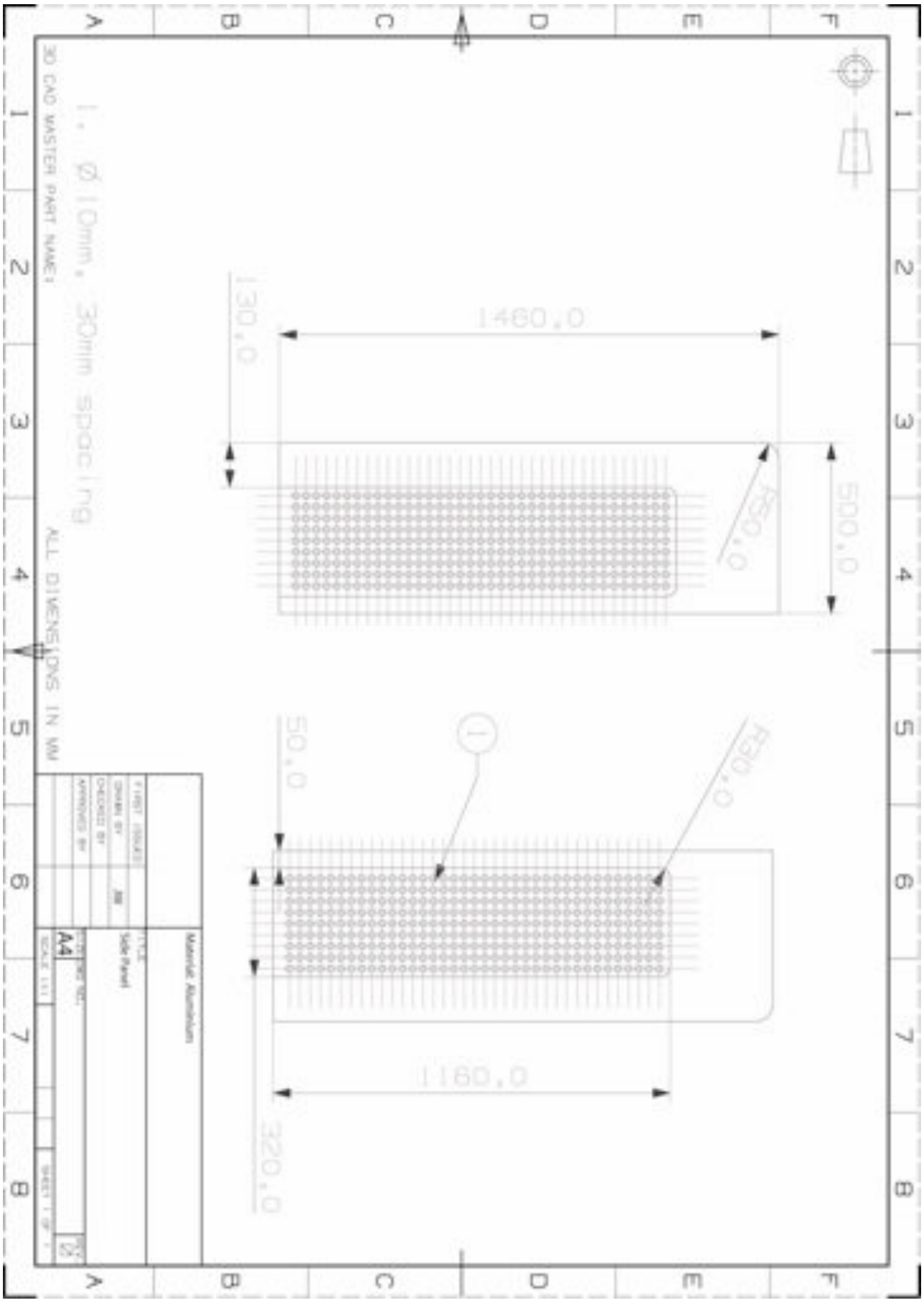
Aluminum Fractional T-Slotted Framing System.



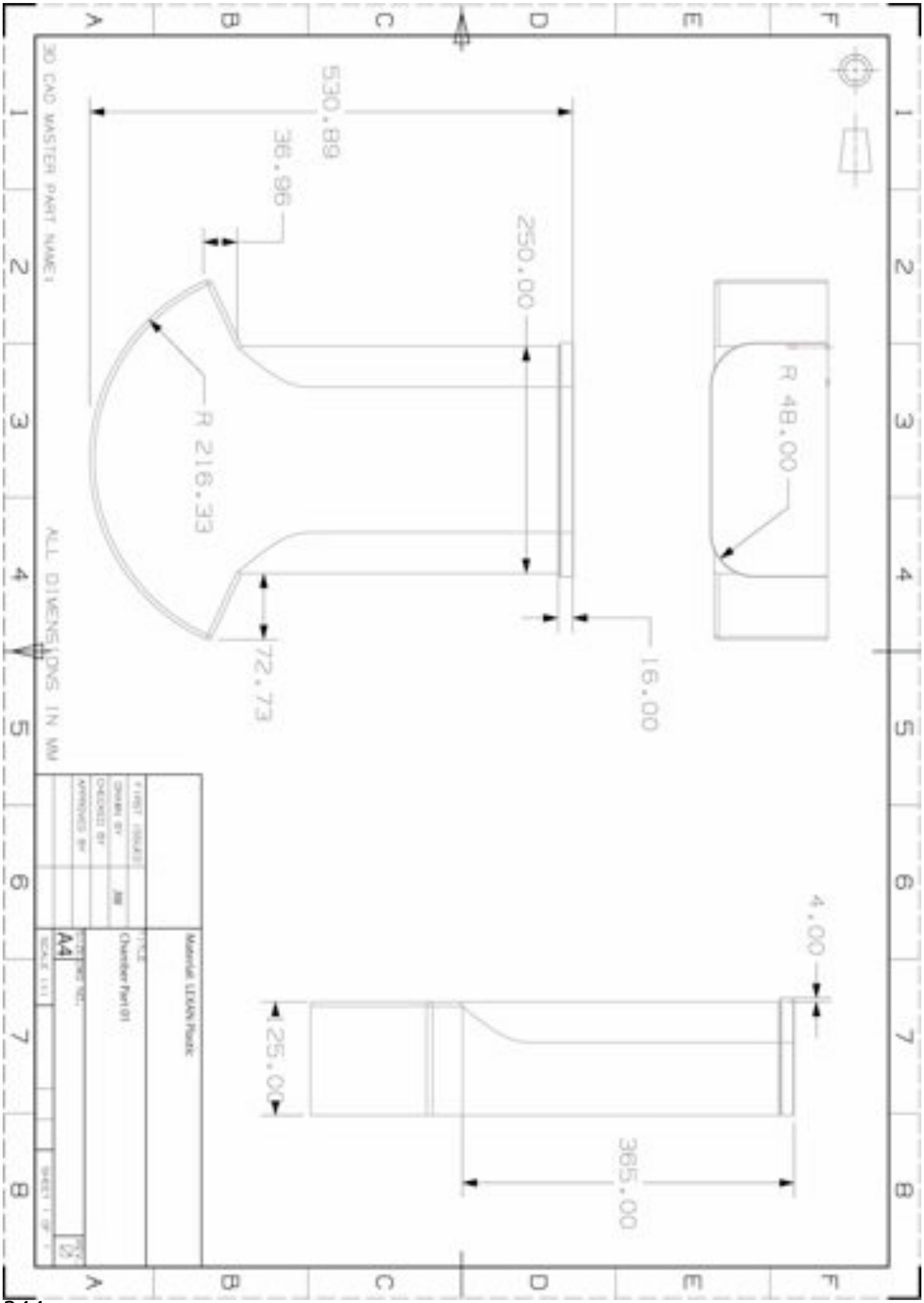
Appendix 15: Front panel

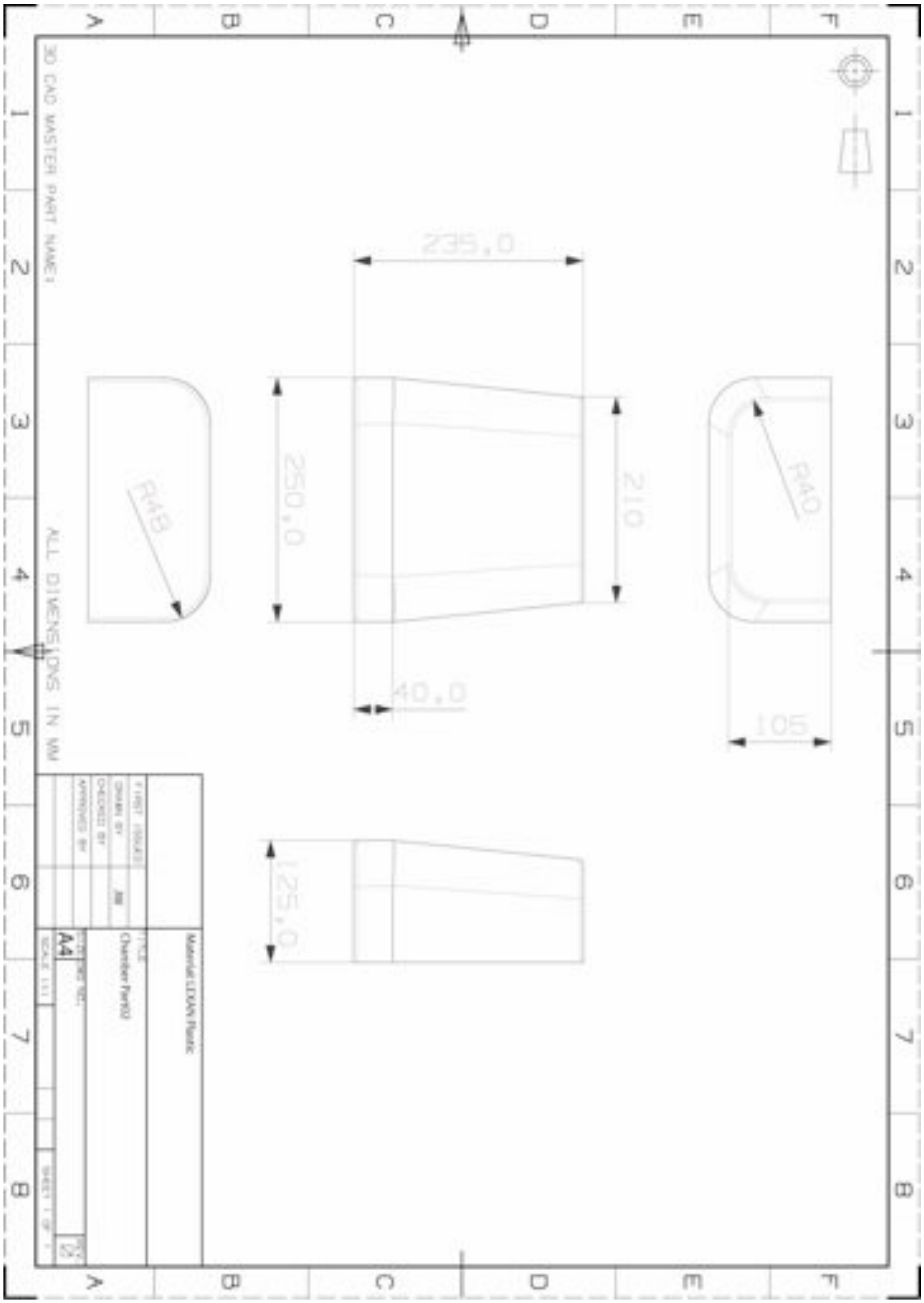


Appendix 16: Side panels



Appendix 17: Plastic chamber




3D CAD MASTER PART NAME1
ALL DIMENSIONS IN MM
235,0
250,0
210
R48
R40
40,0
105
125,0
Material:LEXAN Plastic
Chamber Part02
A4

Appendix 18: Tower packings

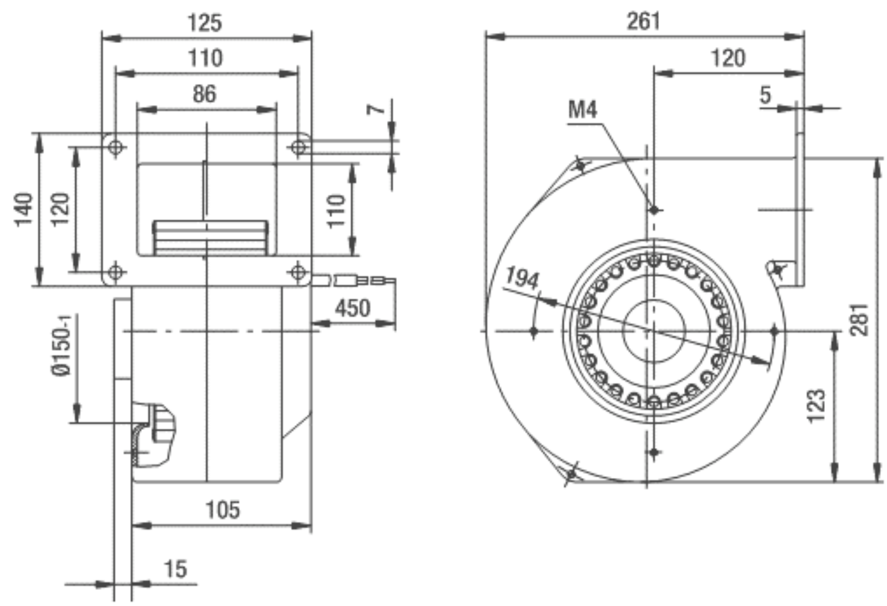
Figure 211: Tower packings

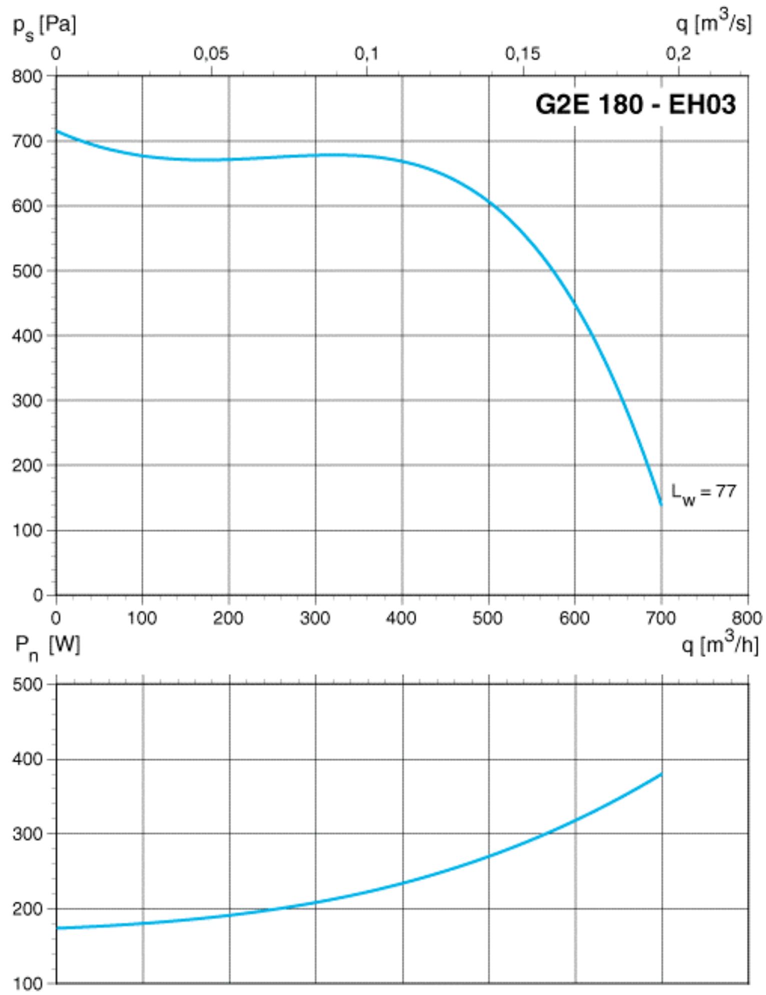
Dimension	**Magnitude**
Height	16 mm
Diameter	17 mm
Amount	25 liter

Physical Specifcations

Appendix 19: Radial fan

Manufacturer: EBMpapst, Product number:G2E180EH0301





Appendix 20: Pumps

1. Fresh water tank pump

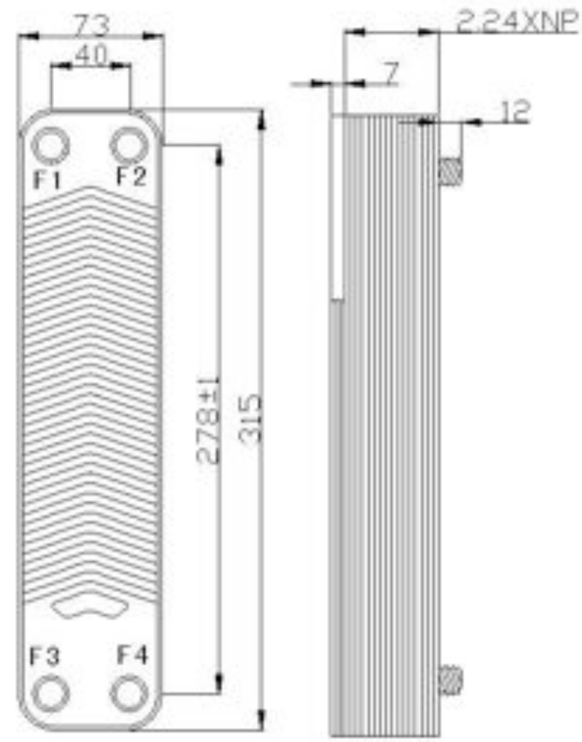
2. Heater pump

3. Nozzle

Pump	Use	Name	Voltage	Amps	Flow rate
1	Pumps the water to the fresh water tank	Extended-Life Seal less Centrifugal Pump	115 VAC	0.85	5.0 GPM
2	Pumps the solution to/from the heater	Aqua King Junior 2.0 Fresh Water Pump Diaphragm Pump	12 VDC	4.0	2.0 GPM
3	Pumps solution to the nozzle	E-CHEN Diaphragm Boost Pump	24 VCD	1.0	2 GPM

Pump specifications

Appendix 21 Heat exchanger



Dimensions	L: 12.4" W: 2.8" H: 2.9"
Ports	3/4" Male NPT
Heat Transfer Area/Plate	.023 m^2/plate (.24 ft^2/plate)
Thickness of plates	.3 mm
Max Flow Rate	1050 gph
Channel Capacities	.04 L/channel
Design pressure	3.0 Mpa to 4.5 Mpa (435 psi to 650 psi)
Test Pressure	4.5 Mpa to 6.0 Mpa (650 psi to 870 psi)
Design Temperature	-195 ? ~+220 ? (-319 F - 430 F)
Max Heat Transfer	5-25 KW
Flow direction	F1-F3 and F2-F4 (see diag above)
Welding Material	99.9% Copper
Corrosion Resistance	Will NOT rust under normal usage (regular pH levels)
Manufacture Material	316L Stainless Steel (9% better heat transfer than 304)
Applications	Heat pump system, household type central air conditioning, afterheatrecycling, refrigeration equipment, industry cold water machine,cooleroil and so on

http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&ssPageName=ADME:B:EOIBSAA:US:11&Item=250237355750

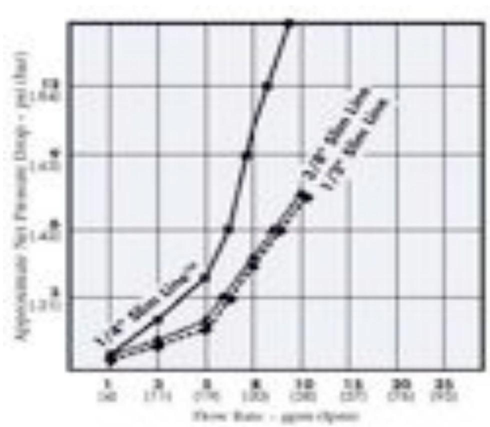
Appendix 22: Active carbon filter

10" Slim Line Housing 3/8" FPT; Clear Sump

Features:
Slim design reduces space required for installation without sacrificing capacity. An excellent choice for low-flow applications & when space and chemical compatibility are primary concerns. Stress relieved for added clarity and strength

Specifications:

- Materials of Construction
  - -Housing: SAN (Clear)
  - - Cap: Reinforced Polypropylene
  - - Button Assembly: 300-series Stainless Steel
  - - O-Ring: Buna-N
- Maximum Dimensions: 12-1/8" x 4-5/8"
- Maximum Temperature: 125°F (51.7°C)
- Maximum Pressure: 125 psi (8.62 bar)
  - Initial psi @ Flow rate (gpm): 3/8" NPT - 2 psi



9-3/4" x 2-1/2" CC-10 Coconut Granular Ativated Carbon Filter

Features:
Fits in Most 10" Housings Fits Culligan HF-150, HF-160, and HF-360 Housings
Reduces bad taste, odor, chlorine, and MTBE* Greater VOC reduction than standard GAC cartridges* Post-filter to reduce carbon fines The construction of the cartridge allows water to enter at one end and pass through the entire length of the carbon bed before exiting the other end of the cartridge, while an internal expansion pad minimizes channeling or bypass Before the water exits the cartridge, a 20-micron postfilter helps remove carbon fines and other suspended particles from the filtered water

Specifications:

- 9-3/4" L x 2-7/8" D (248mm x 73mm)
- Micron rating: 20 micron nominal
- Initial ΔP (psi) @ Flow Rate (gpm): 4.5 psi @ 1 gpm
- Chlorine Taste & Odor Reduction @ Flow Rate (gpm)*: 7,500 gallons @ 1 gpm
- Materials of Construction:
  - Filter Media: Granular Activated Carbon
  - End Caps & Outer Casing: Polystyrene
  - Post-Filter & Expansion Pad: Polypropylene
  - Gaskets: Buna-N (Top); Santoprene (Bottom)
- Tested and certified to NSF/ANSI Standard 42 for material requirements only

Appendix 23: Heat chamber

The heater container was manufactured using stainless steel 316 sheets, which are acid resistant. These were laser cut, bent at four locations (2x45 degrees and 2x90 degrees) and welded together.

Top wall:	100x300 mm
Parallel walls:	150x300 mm
Tilted bottom walls:	70x300 mm
Short side walls:	Custom made to fit top, parallel and bottom walls
Total volume:	5 liters
Heating coil:	2000 Watts
Mountings:	1/2 inch, threaded (4 on top, 6 on one short sided wall, 2 on one parallel wall and 2 on one tilted bottom wall)

Appendix 24: Temperature and pressure sensor

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

Order this document
by MPX5100/D

MPX5100 SERIES

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX5100 series piezoresistive transducer is a state–of–the–art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller–Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Available in Absolute, Differential and Gauge Configurations
- Durable Epoxy Unibody Element
- Easy–to–Use Chip Carrier Option

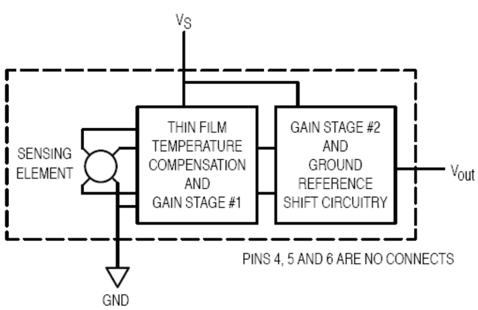


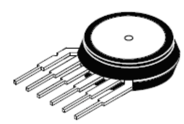
Figure 1. Fully Integrated Pressure Sensor Schematic

MAXIMUM RATINGS(1)

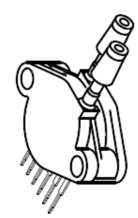
Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2) (P2 > P1)	P_{max}	400 400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	– 40° to +125°	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING OVERVIEW
INTEGRATED PRESSURE SENSOR
0 to 100 kPa (0 to 14.5 psi)
15 to 115 kPa
(2.18 to 16.68 psi)
0.2 to 4.7 Volts Output



BASIC CHIP CARRIER ELEMENT
CASE 867–08, STYLE 1



DIFFERENTIAL PORT OPTION
CASE 867C–05, STYLE 1

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground.

REV 6

MOTOROLA

Universal Temperature Probe MODEL EI-1034
Instruction Manual

November 20, 2006

Description

The EI-1034 is a universal temperature probe that consists of a silicon type temperature sensor mounted in a waterproof stainless steel tube. It uses the highest grade available of the LM34 sensor from National Semiconductor with a typical room temperature accuracy of ±0.4 °F (±1.0 °F max). Because of the high-level linear voltage output and high accuracy, this probe is easier to use and superior to thermocouples, thermistors, or RTDs, for many applications in the range of 0 to 300 °F (temperature range varies with positive supply voltage, negative supply voltage, and LabJack model). The probe is suitable for air and liquid applications, and can be conveniently secured into pipes, vessels and chambers by using available ¼ inch compression fittings.

The EI-1034 is intended to be connected to a LabJack for 5-volt power but can be used as a stand-alone temperature sensor when connected to a DVM and a power supply in the range of 5 to 30 volts.

Electrical Connections

Three wires require connections; they are +5 volts (red), ground (black) and output (white). These wires can be connected to the appropriate terminal on the LabJack or other power supply in the case of using the sensor as a stand-alone unit. The output wire (white) will normally output a voltage of approximately 0.77 volts at room temperature.

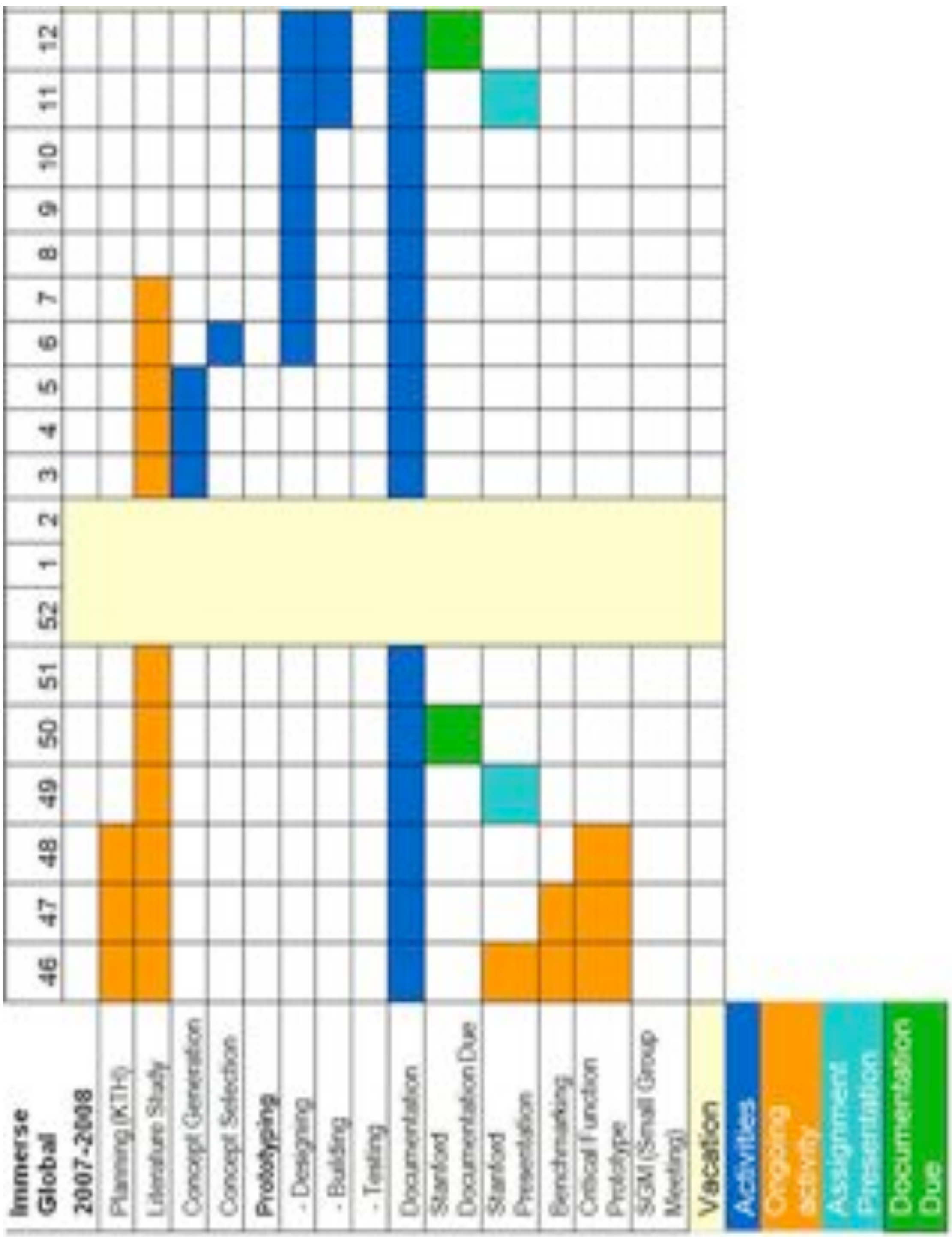
Cable Length

The maximum cable length of the probe can be extended to 25 ft without serious degradation in performance. If the user desires to extend the length of the cable beyond 25 ft (up to 500 ft) then a resistor of 10K ohms should be inserted in series with the white wire. The resistor should be placed at the 5 ft length of the probe. When using a series resistor of 10K ohm the user should consider the voltage drop across the resistor when calculating the final temperature measurement.

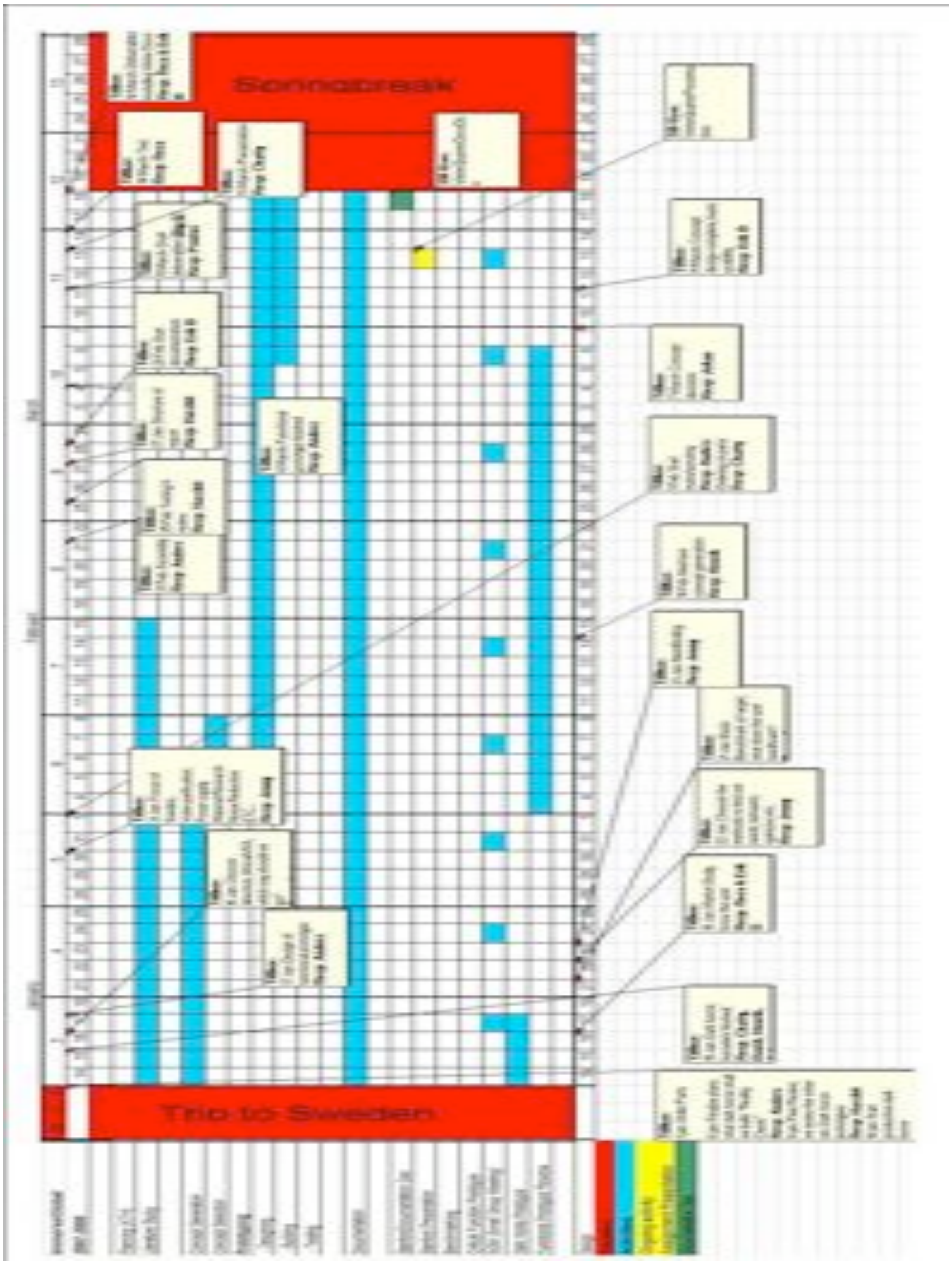
Low Temperature Operation

The low temperature range of the EI-1034 can be extended to -50 °F by adding a 100K resistor to an isolated negative supply voltage (typically -5 volts) as shown in Figure 1. A standard wall plug-in supply can be used in the range of 5 to 15 volts. A 9-volt battery is also a good source for a negative voltage. Care must be taken to connect the positive terminal of the isolated supply to the GND wire (black) of the EI-1034 and the negative terminal of the supply in series with a 100K resistor to the white wire of the EI-1034.

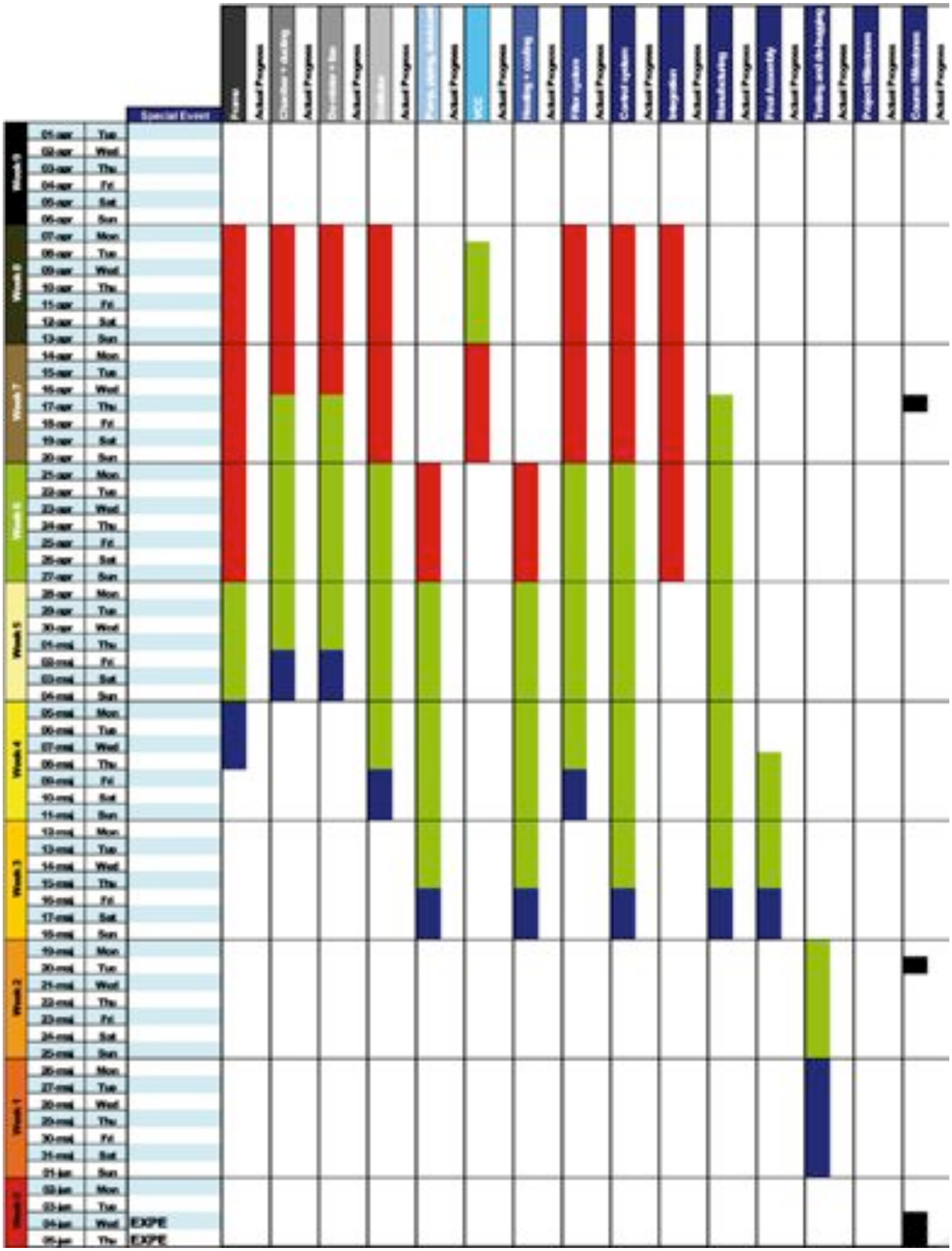
Appendix 25: Gantt chart for the fall and winter quarters



Appendix 26: Detailed Gantt chart for the winter quarter

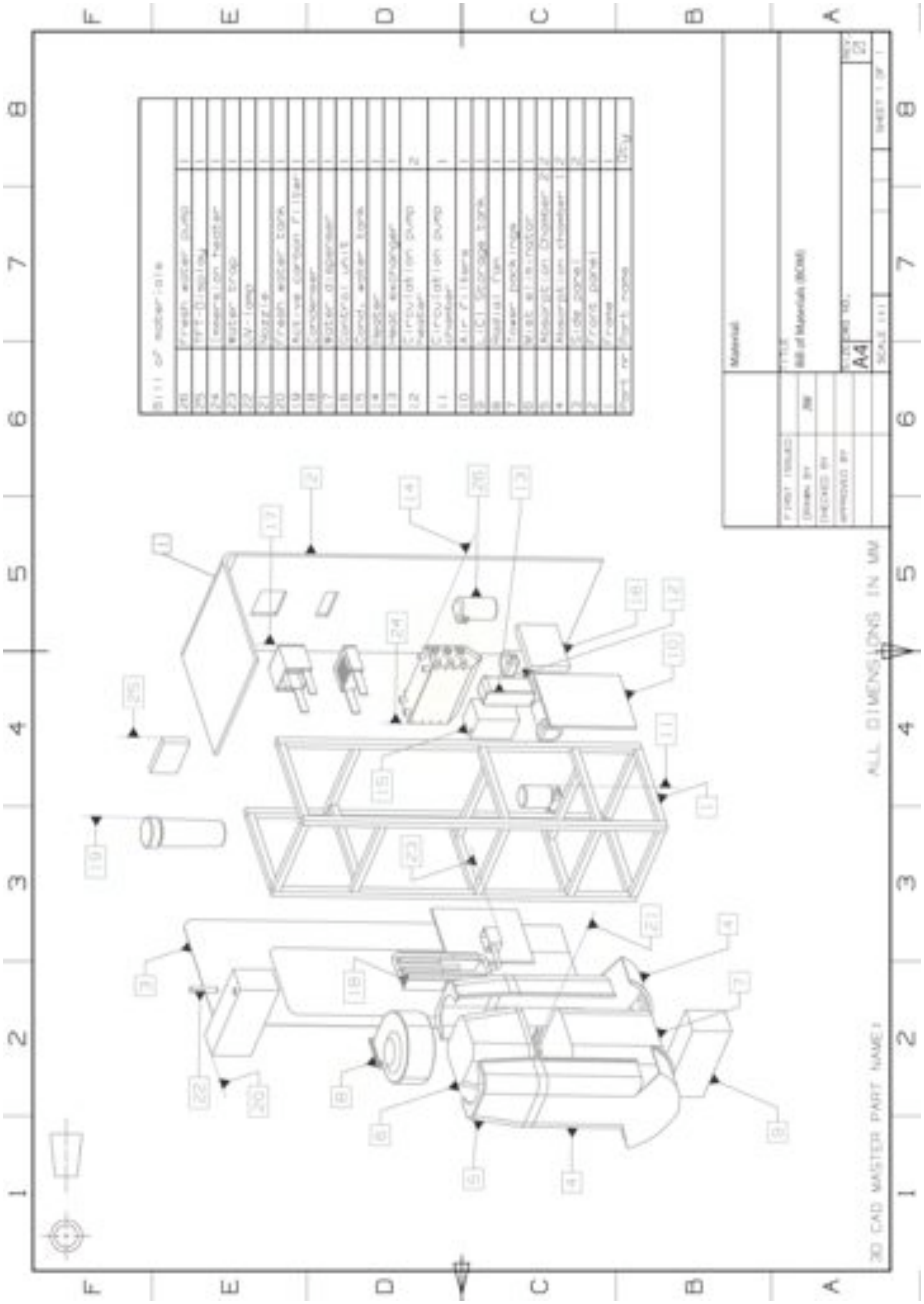


Appendix 27: Gantt Chart for the Spring quarter



Index: Red = Design, Green = Implementation, Blue = buffer zone

Appendix 28: CAD drawing of the assembly



Atmospheric Water Generator Spring Quarter Report 2008

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