IPRO 348: Design a System to Recycle Condensate from Residential Air Conditioners

Summer 2009

FINAL REPORT

IPRO Team Members	Anam Abro Syeda Ahmed Niravkumar Hazariwala Cari Hesser Malisa Ismail Jessica Martinez Siddhartha Raghuvanshi Erich Ruszczak Nicole Specht Rachel Yanover
Instructor	Philip Lewis
Collaborator	Professor Paul R. Anderson, CAE Department

Illinois Institute of Technology

July 24, 2009

Table of Contents

I. Abstract

The goal of IPRO 348 was to first find a use for the condensate produced by air conditioners, and then to create a product that recycled the condensate for said use. The first task for IPRO 348 was to collect information on how condensate is formed, its purity, and the amount that is produced by a central air conditioning system. The end goal of the IPRO was to have a marketable system that collects and stores the condensate produced by the air conditioning units and then proceeded to use the condensate in the form of irrigation water. After creating a viable product, the IPRO team would like to make the product scalable, expanding its market from residential to commercial industries. To fulfill these goals, the IPRO team was broken down into subgroups which were each responsible for a different objective. The first subgroup was responsible for the creation of a device that allowed for the condensate to be collected and stored. The second subgroup was responsible for analyzing the collected sample's composition and checking for bacterial growth. The third subgroup was responsible for setting the parameters and methods for condensate collection. The fourth subgroup was responsible for obtaining the condensate samples from various sites, as well as collecting environmental data. The fifth subgroup was responsible for the marketing aspects of the project. As a whole, the IPRO team made suggestions as to how future IPROs should progress.

II. Background

Condensation is the process by which water vapor becomes a liquid (condensate). Condensate is a naturally occurring substance on surfaces cooler than the ambient temperature, such as an air conditioning (A/C) unit. To date, there is no known product that collects condensate from A/C units. Moreover, condensate is not even considered a valuable resource due to the cheap price of water in Illinois. However, A/C condensate is a wasted resource that has many uses in a residential setting, many of which can be scaled up for commercial use. Recently, condensate has been used for irrigation purposes. In Texas, condensate has been used for landscaping, gathering as much as 60,000 gallons a day for usage. At Arizona State University, a bio-design institute has gathered 6,000 gallons of condensate per day and has used it for irrigation. A/C condensate is a resource that should not be wasted, but many consumers and companies have no intention of harnessing this resource at the current time. Since condensate is an overlooked resource, this IPRO was designed to look more in depth at, and create a system for, recycling the condensate for everyday uses in residential and eventually commercial situations.

III. Objectives

A. Design Oriented Objectives

The overarching objective of IPRO 348 was to design and create a system to capture and reuse the condensate that forms on home A/C units. The team has come up with a more specific set of desired qualities for the end product in that it should be:

1. Marketable to a large consumer group.
2. Scalable both upwards and downwards so that similar designs may be applied to both window units in apartments and large split A/C systems.
3. Inexpensive to manufacture and thus inexpensive to purchase.
4. Easy to install and operate.

B. General Project Objectives

For the project in general, the team set and completed these goals:

1. Visited six different sites to collect condensate and determine the rate of condensation with respect to various atmospheric conditions.
2. Tested various samples of condensate to determine the chemical makeup and if any bacteria are present and, thus, determine if any filtration is necessary.
3. Kept a comprehensive and well organized record of all research conducted, collected results, and valuable sources of information for future IPROs.

IV. Methodology

A. Problem

Air conditioner condensate is a wasted resource, since it is drained out through plumbing in most buildings. Yet, despite the recent attempts by society to "go green", there has been only minimal research conducted regarding the reuse of A/C condensate and no attempt to create a system to recycle condensate for residential or commercial use. Thus, this IPRO is determined to design a system to capture and reuse the condensate for non-drinking applications, such as irrigation or toilet water.

B. Plan of Action

1. We will begin the semester by conducting initial research on several topics related to A/C systems, condensate, and prior research completed by other institutions and companies. We will then analyze the results of this initial research and brainstorm to identify a list of tasks/goals that need to be accomplished during the first half of the semester. The team will be grouped into sub-teams each charged with a specific task, based on their skills and academic interests.
2. Initial field research will then be conducted at several testing sites (compiled by another sub-team).
    a. A collection/ measuring device created by one sub-team will allow us to measure the amount of condensate produced under standardized conditions (set by a sub-team).
    b. 500 ml samples of condensate will be collected from each site.
3. Laboratory testing will then be carried out by one sub-team using the samples collected from the test sites and will include:
    a. Biological testing for the presence of microbial growth.
    b. Chemical testing to determine the chemical constituents of the condensate, other than water.
    c. Comparison to tap water and distilled water.
4. During the second half of the semester, we will analyze the results of the field and laboratory tests to determine potential and practical uses for recycled condensate.
    a. This includes a discussion of the method of filtration needed, if any.
    b. Also includes research of codes and regulations that we need to meet in order to use the condensate for our desired purpose(s).
5. Once we determine the potential uses, we can begin to design a system prototype, as well as establish the potential market and calculate a cost/benefit analysis. In order to complete these tasks, the team will regroup into sub-teams, each charged with one of these tasks.

C. Documentation

During the course of our research, all data acquired from field tests as well as laboratory testing will be recorded in a standard log book. This log book will also contain a compilation of all external documents related to all research conducted, including pictures, drawings, and surveys. Moreover, since this is a new IPRO, it will include detailed accounts of the team's methodology, analyses, and conclusions reached throughout the semester so that future semesters have a more solid foundation.

D. Updated Work Breakdown Schedule and Explanation of Changes

Gantt Chart

	Task Name	Duration	Start	Finish
1	Meeting the team	1 day?	Tue 6/2/09	Tue 6/2/09
2	Initial project research	3 days	Wed 6/3/09	Fri 6/5/09
3	Action plan proposal	4 days	Sat 6/6/09	Tue 6/9/09
4	Project Plan	8 days	Tue 6/9/09	Tue 6/16/09
5	Collection device prototype	28 days	Tue 6/9/09	Wed 7/8/09
6	Collection at test sites and condensate lab testing	28 days	Sat 6/13/09	Sun 7/12/09
7	Initial project assessments: Market Interest Survey	22 days	Sun 6/21/09	Tue 7/14/09
8	Mid-term reviews	4 days	Sat 6/27/09	Tue 6/30/09
9	Lab results analysis. Determine use of recycled condensate.	22 days	Tue 6/23/09	Thu 7/16/09
10	Deliverables	20 days	Tue 6/30/09	Tue 7/21/09
11	Determine use of condensate and build recycling product prototype.	12 days	Thu 7/9/09	Mon 7/20/09
12	Final Report Draft	20 days	Tue 6/30/09	Tue 7/21/09
13	Final Presentation Draft	7 days	Tue 7/14/09	Tue 7/21/09
14	Abstract/ Brochure Draft	3 days	Mon 7/13/09	Thu 7/16/09
15	Poster Draft	3 days	Mon 7/13/09	Thu 7/16/09
16	Abstract/ Brochure and Poster	0 days	Tue 7/21/09	Tue 7/21/09
17	Presentation	0 days	Thu 7/23/09	Thu 7/23/09
18	Final Report and Work Product CD	0 days	Fri 7/24/09	Fri 7/24/09
19	IPRO Day	0 days	Fri 7/24/09	Fri 7/24/09

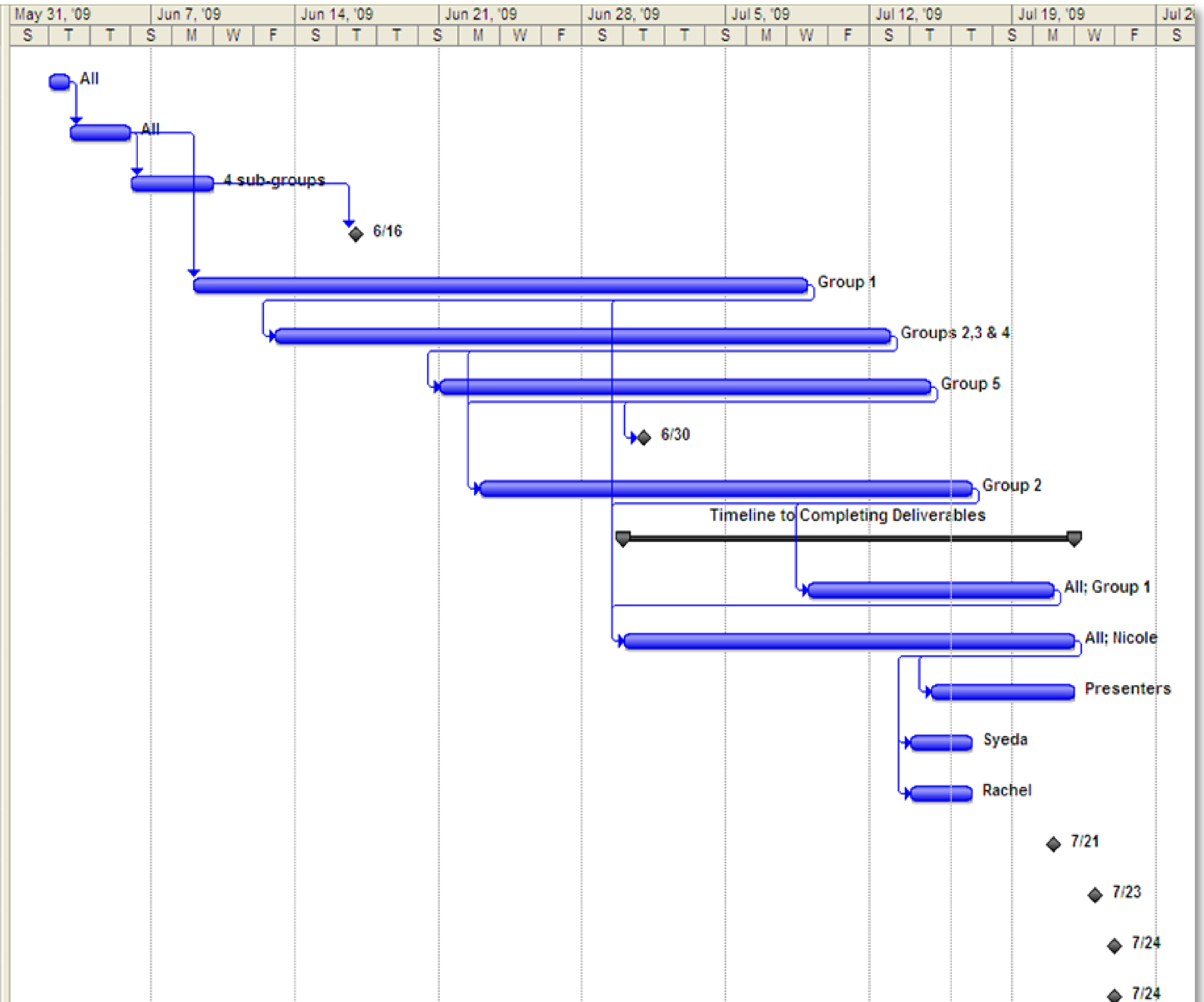

Figure 1: Gantt Chart

The revisions made to the Gantt chart for the tasks in completing this project are as listed below:

1. Extended time to build collection device
    - The materials required for building the collection device were ordered online through the IPRO office as they were not available in stores. The materials shipment timeframe was not within our control, but the time delay in obtaining the parts had initially been viewed to set the project considerably behind schedule. After careful deliberation, the team decided that we should begin to collect condensate via buckets and manual measuring tools. In doing so, we were able to begin all other tasks following the collection, such as the laboratory tests for the condensate and analyzing the relationships between humidity and condensate collected, while the collection device was built. In this course of action, tasks overlapped in time frames as indicated on the Gantt chart. As there was no crucial data or task needed to have been completed from a prior task to the next that would hinder this process, we followed this schematic throughout the rest of the semester.
2. Extended period for collecting condensate and increased the number of collection sites
    - The team considered that the initial 2-3 weeks of collection data would have yielded poor analysis and calculations. Thus, the team continued to collect condensate up until July 14 and lab tests analyzing the condensate compositions were performed almost in a parallel manner. Because the condensate amounts collected at 3 main sites were markedly different, Jessica, Erich and Syeda volunteered to collect at their homes, to better normalize the data gathered. And as soon as the collection device was built, it was installed at a newly built home that had 2 A/C central units, with an interior of more than 5,000 square feet.
3. Extended market interest analysis via survey but eliminated detailed market analysis and profit calculations
    - One of the comments made at the mid-term review was regarding poor analysis of the survey conducted. Consequently, the team decided to reach out to a bigger population of survey participants. The team decided, however, the focus of this IPRO was to build a viable condensate recycling product because we had established the market interest from analyzing the survey responses. But, because of a significant time constraint, we also decided that we should eliminate a detailed market analysis and profit calculations. It is suggested that subsequent IPROs following this semester can also create surveys to include the participants' demographics, as these were not taken into consideration because identification of target groups for marketing was not a priority for our purposes.

V. Team Structure and Assignments

A. Chart

Table 1: Team Member Descriptions

Name	Major / Year	Skills / Strengths	Experience
Anam Abro	Architectural Engineering/ 3rd	MS Word, Excel, Power point, AutoCAD, Problem solving	Internship at AF Fergusons
Nicole Specht	Biology / 3rd	MS Office, Strong organizational and writing skills	Lab experience
Erich Ruszczak	Applied Math/ 4th	Proficient in MS Word, Excel, Powerpoint, Java, MATLAB, Skilled in mathematics and problem solving	Tutoring skills
Malisa Ismail	Chemical Engineering/4th	Proficient with Aspen Hysis, Instron, Oracle, Matlab, AutoCAD, MS Word, Excel, PowerPoint, Access, Project, Outlook, Lab experience, Report writing and editing	Lab technician at Dow Automotive. Medical Receptionist/ Radiography technician, Production Planning Assistant
Jessica Martinez	Biology/ 4th	MS Word, Excel, Access, Powerpoint, Excellent research skills	REU summer intern at IIT, office assistant in provost and BME office, laboratory research
Cari Hesser	Aerospace Engineering/3rd	Microsoft Word, Excel, Powerpoint, AutoCAD, Lab view, Prompt and clear communication, Excellent research and documentation skills	Work in Fluid Dynamics Research Center
Siddhartha Raghuvanshi	Mechanical Engineering/4th	Microsoft Word, Excel, Powerpoint, Problem solving skills	Interned for company administrator
Niravkumar Hazariwala	Mechanical Engineering/4th	Thermodynamics-heat and mass transfer and thermal designs, Computer hardware and software: MATLAB, SolidWorks, ProE	Work for Geek Squad, Internship at Bipico Tools, Research in thermodynamics
Syeda Ahmed	Molecular Biochem and Biophysics/4th	MS Office, Writing and organizational skills, Excellent research skills	Biochemistry lab work, office work experience
Rachel Yanover	Architecture/4th	MS Office, Photoshop, Illustrator, AutoCAD, AutoDesk, Revit, Hand and power tool skills.	Experience in Crown Hall shop

B. Team Tasks

GROUP 1
Niravkumar Hazariwala
Siddhartha Raghuvanshi
Task: Design a measuring and collecting device for the condensate.

GROUP 2
Syeda Ahmed
Nicole Specht
Anam Abro
Task: Find the necessary resources to analyze various samples of condensate and carry out biological and chemical lab tests to analyze the samples.

GROUP 3
Malisa Ismail
Erich Ruszczak
Task: Set standards and methodology for collecting condensate.

GROUP 4
Cari Hesser
Jessica Martinez
Rachel Yanover
Task: Research common types of A/C units and their specifications. Attain samples of condensate.

GROUP 5
Malisa Ismail
Erich Ruszczak
Anam Abro
Niravkumar Hazariwala
Siddhartha Raghuvanshi
Task: Begin initial market study activities.

C. Project Monitoring Roles

TEAM LEADER
Erich Ruszczak

SECRETARY/MINUTE TAKER
Cari Hesser

D. IPRO Deliverables

IPRO Deliverables were prepared by various members of the group throughout the term. These decisions were made based upon group member strengths and skills, and work was spread out among all members.

Table 2: Deliverable Assignments

Deliverable	**Sub-Project**	**Members Involved**
Project Plan	Abstract & Background	Erich
	Objectives	Cari
	Methodology	Syeda
	Work Breakdown	Malisa
	Budget	Jessica
	Team Structure	Anam
	Compilation & Formatting	Nicole
Midterm Review Presentation		Rachel, Siddhartha, Anam, Erich
Abstract/Brochure		Syeda
Poster		Rachel
Final Presentation		Rachel, Cari, Jessica
Final Report	Background, Abstract, Objectives	Jessica
	Methodology	Malisa
	Team Structure & Assignments	Nicole
	Budget	Malisa
	Code of Ethics	Anam
	Results	Cari
	Obstacles & Recommendations	Erich
	References	Whole Team
	Resources	Nicole
	Acknowledgments	Whole Team
	Compilation & Formatting	Nicole

E. Schedule of Availability

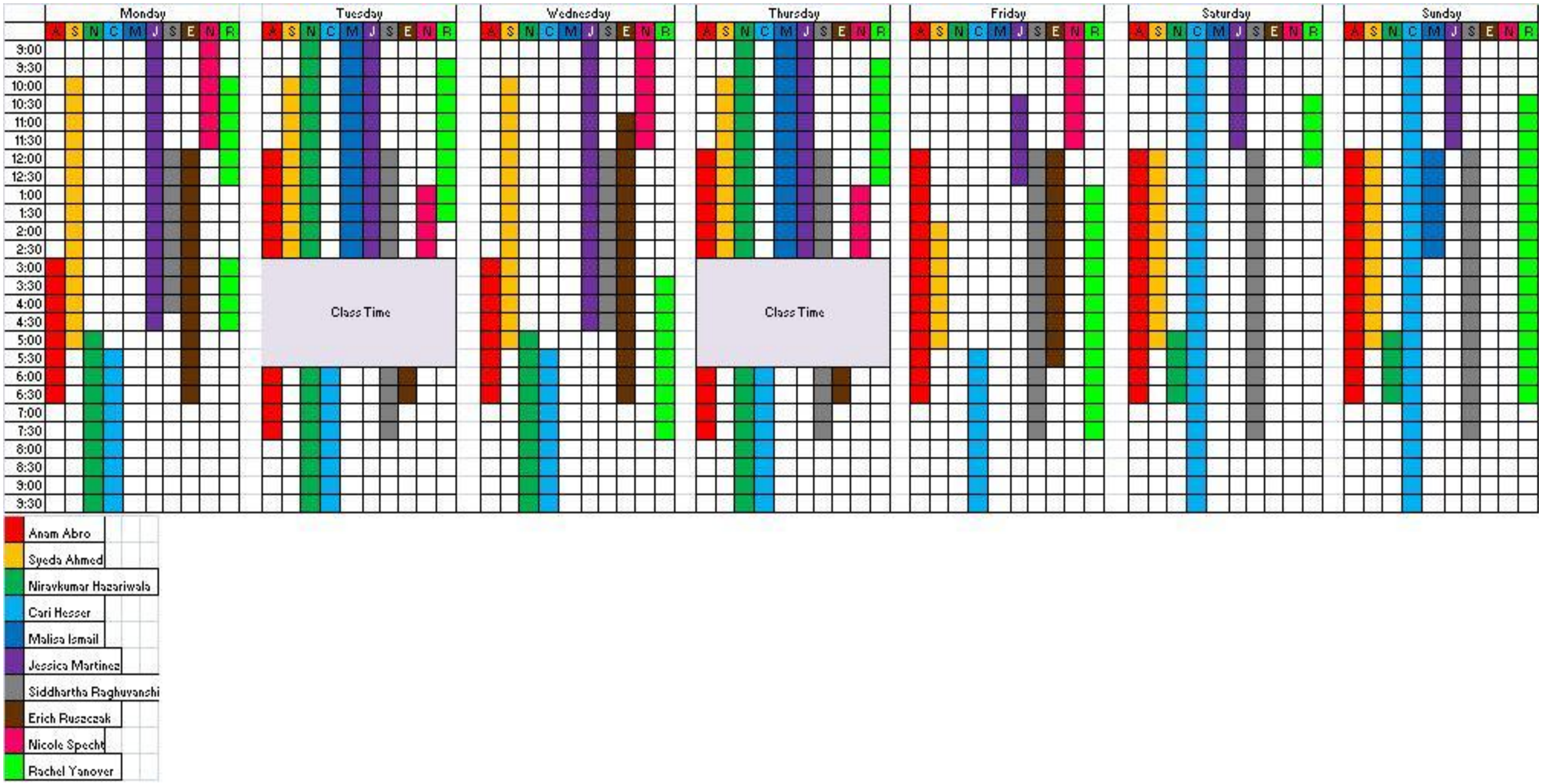

Figure 2: Member Availability Chart

VI. Budget

All items on this list are purchases related to the prototype, no other money was expended during the course of this project. All purchases are in chronological order.

Table 3: Semester Budget

Item	Price ($)	Count	Cost ($)	Purchaser
10' float switch	41.95	1	41.95	IPRO office
AC to DC converter	29.14	1	29.14	IPRO office
Bilge Pump Cycle Counter	19.95	1	19.95	IPRO office
5" Pine Bun	8.15	1	8.15	Nirav
Helms Satin	8.88	1	8.88	Nirav
4oz Gorilla Glue	6.95	1	6.95	Nirav
Plastic Bags	0.98	1	0.98	Nirav
DWV Hanger	1.56	1	1.56	Nirav
2" Copper Clip	0.32	2	0.64	Nirav
Homer Bucket	2.34	1	2.34	Nirav
10' clear flexible tubing (¾" dia)	18.82	1	18.82	Cari
¾" check valve	8.96	1	8.96	Cari
4" pipe end cap	7.35	1	7.35	Cari
4oz. PVC cement	3.76	1	3.76	Cari
¾" male insert fitting	0.37	1	0.37	Cari
¾" female fitting	0.42	1	0.42	Cari
2-way valve	4.97	1	4.97	Cari
3-way valve	4.97	1	4.97	Cari
3/4" female insert fitting	0.72	2	1.44	Nicole
¾" male PVC fitting	0.21	1	0.21	Nicole
1 ¼" drill bit	6.98	1	6.98	Nicole
5' X 4" pipe	7.99	1	7.99	Nicole
Sub-total			186.78	
Sales Tax			18.68	
Total			205.46	

VII. Code of Ethics

Overarching Principle: To design an affordable and feasible system to recycle condensate from residential air conditioners.

LAW

The team will research all applicable regulations/laws and design a product in observation of those laws.

Pressure: Limited time

Risk: The team may not carry out proper research of all applicable laws/regulations

Risk: The team might unintentionally break laws

Measure: Observation of regulations will be done by consulting those knowledgeable in US regulations.

PROFESSIONAL CODE OF ETHICS

The team will know the National Society of Professional Engineers code of ethics and be sure to follow them and will do all work within the standards of professionalism.

Pressure: The team may rush the product to complete it within a limited time span.

Risk: The team might violate the code's policy to "avoid deceptive acts."

Risk: The team might distribute work unequally.

Risk: The team might use unqualified members to do tasks.

Measure: The team will divide tasks according to expertise and be sure that several groups prepare and test the products.

INDUSTRY STANDARDS

The team will make sure that its product falls within a certain standard and has a minimum amount of failure.

Pressure: The product may be rushed through production or testing.

Risk: The product will fail to perform to the standards required by the consumer.

Risk: The product will fail to meet what it is marketed as.

Measure: The members of the team will know how the product works and the specifications for it and the product will not be released without each member agreeing to the standards set forth.

SOCIAL, CIVIC AND GEOGRAPHIC COMMUNITIES

The team will be sure to test the product to assure the safety of the community and the consumers who will use it.

Pressure: The team members may feel the need to make sure there is a market for the product.

Risk: The team may falsely advertise the product**.**

Risk: The team might compromise on the quality of the product in order to make it affordable.

Measure: The product will be tested and its safety and feasibility confirmed before any marketing is carried out.

PERSONAL RELATIONS

Everyone will work together as a team and will not deliver fraudulent data to other members.

Pressure: Team members may feel the pressure of deadlines and rush to complete their individual sections.

Risk: Team members may fabricate data.

Pressure: To work together effectively to complete the project

Risk: Difference in opinions may lead to a negative environment

Measure: Several team members are assigned to each task with the ability to overlook each other's data/research. The team member must then submit his data to a sub-team leader, who in turn, submits to the team leader. This chain of command and the involvement of several members help to eliminate fraudulent data. Conflicts are resolved through class discussions.

MORAL AND SPIRITUAL VALUES

The team will not use, prepare or test the product in any way that may offend one's moral or spiritual views.

Pressure: The team may feel pressurized to hold meetings outside of class due to the shortage of time.

Risk: Some team members may not be able to attend additional meetings due to personal or religious commitments.

Pressure: The team may feel pressurized to divide tasks equally amongst all members.

Risk: Team members may be asked to be involved in an activity that is against their moral/spiritual beliefs.

Measure: The team leader will be sure to make all meetings outside the given time optional, and be sure not to force anything upon individuals who are unable to do so.

VIII. Results

A. Initial Research

In order to design a device to recycle condensate, initial research on the subject was first needed. The team investigated the process of condensation, different types of A/C units and how they worked, and any existing condensate recycling products on the market. The highlights of the initial research are detailed below, with full documentation found in section X of this document:

1. Condensate forms on surfaces cooler than the ambient air. In the case of an air conditioner, the condensate forms on the cooling coil of the compressor.
2. One product, consisting of a drip line that the user attaches directly to their A/C unit's condensate disposal line exists on the market. There are currently no systems available that will store the condensate for use at a later time. Certain industrial buildings capable of producing thousands of gallons of condensate each day have developed systems that recycle their condensate for landscaping and irrigation.
3. The most common types of A/C units on the market today are Central Air, and Window Units, which both run on a refrigeration cycle to cool the air.
4. Condensate can be contaminated by the environment, or by coil cleaning chemicals, and is likely to contain significant amounts of heavy metals. Due to this and also the fact that even basic filtration of large amounts of condensate would not be cost effective; recycling condensate for potable uses is unwise.
5. Any water that is going back into a residence is subject to strict city codes as far as storage and cleanliness, thus it would be more realistic to develop a system that stores and utilizes the condensate for outdoor purposes.

The research conducted gave the team a good understanding of condensate, and from that, the team was able to move forward into the initial data collection, market research, and prototype design phases.

B. Condensate Collection and Analysis

Throughout the semester, the team collected condensate on nine different days from seven different sites throughout the United States, focusing mainly on the Chicago area of Illinois. The purposes of condensate collection were to collect samples for chemical and biological testing, and to learn how much condensate was produced by different A/C units, and what factors most greatly influenced the rate of condensation. All data collected throughout the course of the semester is attached in the supplementary materials.

1. Condensation Factors and Rates

   The purpose of determining the rate of condensation of various central air conditioning units, and factors that influence this rate was to determine how much condensate could be produced over a period of time. The team thought this would be a useful bit of information to know when it came to actually designing the condensate recycling product, and would potentially be a valuable marketing aspect if it turned out that significant amounts of condensate were generated.

Before collection began, it was hypothesized by the team that major contributing factors to the condensation rate would include relative humidity, outside temperature, and the power rating and efficiency of the A/C unit. With this in mind, the team developed two methodologies for collection. The first methodology involved monitoring numerous atmospheric conditions and measuring the volume produced every 30 minutes for a period of eight hours. The results of which can be found in table 4 below:

Table 4: Manual Collection Data

Location		**Vol/8hr period (gal)**	**Avg. Outside Temp. (F)**	**Avg. Humidity (%)**	**Power Rating (Tons)**	**Efficiency (SEER)**
Apple Valley, MN	Day 1	4.1	79.75	35.44	2.5	15
	Day 2	4.52	74.87	48		
Country Club Hills, IL	Day 1	3	80.84	61.94	2.5	10
St. Charles, IL (1)	Day 1	9.74	86.14	60.42	3.5	na
Bridgeview, IL	Day 1	2.4	85.82	49.17	3	10
	Day 2	3.34	80.56	33.1875		
Phoenix, AZ	Day 1	0.75	103.1	14.5	3	12
Rockford, IL	Day 1	4.2	76.91	53.18	3.4	11

As can be seen, the amount of condensate, average weather conditions, and individual A/C specs varied, and at first it seemed impossible to tell what was influencing the condensation rate. Thus, the team analysis sought to isolate variables one by one in their experiments to see if their hypothesis could be proved or disproved.

First, the team wanted to isolate humidity. This was done by taking data only from an individual trial at a time, and finding sets where the temperature was the same. The results of this process can be found in figure 3 below:

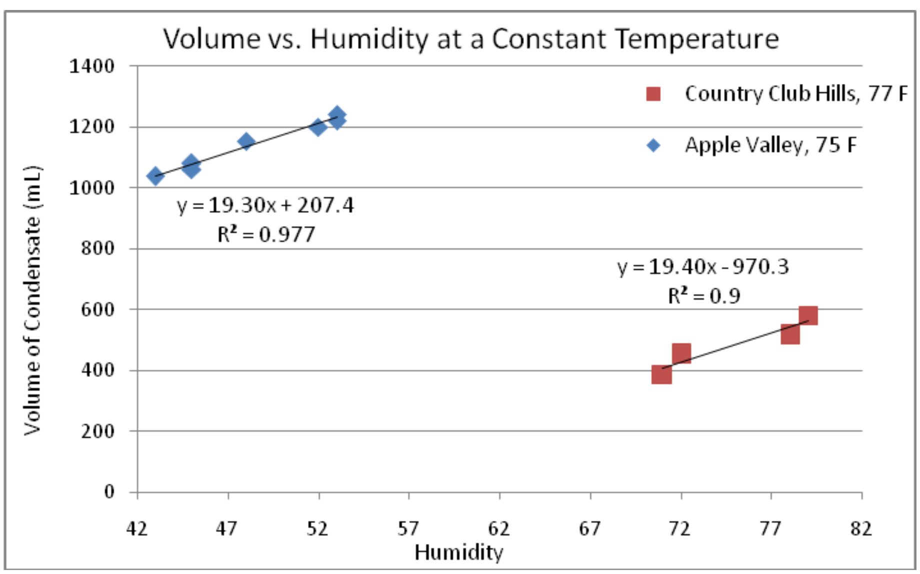

Figure 3: Isolated Humidity Chart (volume per ½ hour)

By examining the above chart, it seems clear that humidity has direct linear relationship with the rate of condensation. Also of note is that the best fit lines of the two data sets have nearly identical slopes, though more data would be necessary to determine if the slope is significant, or coincidental.

Next the team sought to do the same thing, only this time isolating temperature by finding data sets with the same humidity. There were fewer available cases for this, so the existence of a relationship is somewhat tenuous, though the results seem favorable and can be seen below in figure 4:

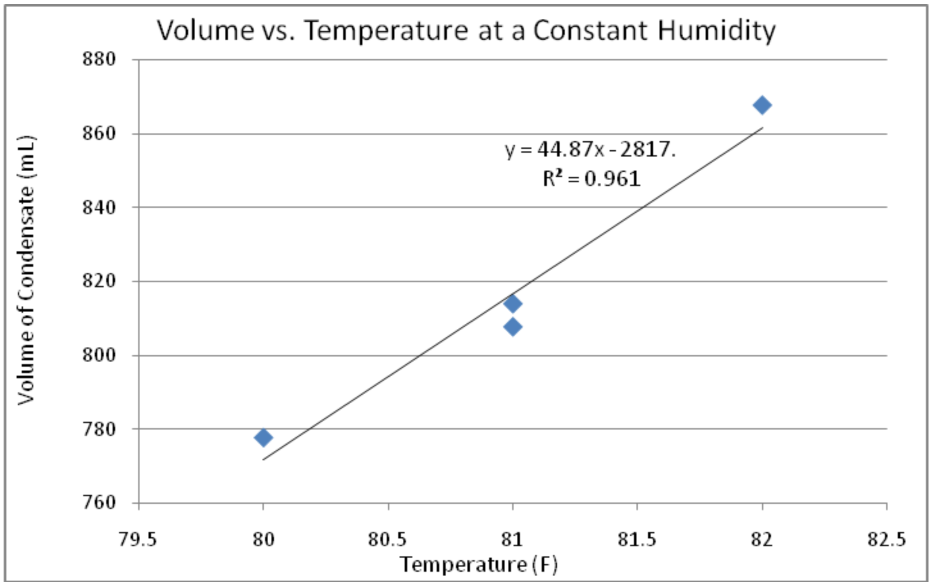

Figure 4: Isolated Temperature Chart (volume per ½ hour)

Once the analysis team had verified that the rate of condensation increased both with temperature and humidity, they referred back to the Manual Collection Data table, and drew the conclusions that as power rating and efficiency rating went up, the rate of condensation increased as well. It is fairly intuitive that the rate of condensate generation would go up as the power rating increases, since a higher power rating means a larger condensing unit, and therefore a larger cooling coil with a greater surface area on which condensate can form. The team had assumed in the beginning that higher efficiency units would generate less because they do not have to work as hard, but though the reasoning seemed logical, it was incorrect.

The second methodology that the team developed involved the creation and installation of a device that would start to fill a bucket, and when it got to a certain height, the device would pump the water out of the bucket. Each time the bucket was drained, an electric counter would increment by one. This was designed to be a less involved method of collecting condensate and data, as weather conditions could be looked up after the fact. It was also designed so that condensate could be collected over a period of days instead of hours. The results of this experiment can be found in table 5 below:

Table 5: Automated Collection Data

Location		Approx. vol. after 24 hr period (gal)	Avg. Outside Temp. (F)	Avg. Humidity (%)	Power Rating (Tons)	Efficiency (SEER)
St. Charles, IL (2)	Day 1	2.4	70.83	68.71	3	10
	Day 2	2.4+	71.54	78.58		
	Day 3	2.4+	76.25	65.58		
	Day 4	4.8	70.29	56.54		
	Day 5	4.8+	71.75	52.41		
	Day 6	7.1	70	51.92		
	Day 7	9.5	76.54	65.58		

Table 6: Condensed Automated Collection Data

total volume (gal)	Avg. outside temp.	Avg. humidity (%)
~9.5	72.45714286	62.76

As can be seen by the tables, though this method required much less effort on the team's part, it also yielded little information of real value. Each count corresponded to roughly 2.377 gallons of water being emptied from the bucket, but since there was nothing set up to tell what time the bucket was emptied, the information was useless in calculating rates of condensation. As a result, the analysis team had to use the data from the first method to calculate rates. Also of note is that the data from this method of collection does not seem to correlate with the data from the manual collection method. With a 3 ton 10 SEER unit running an average of 8 hours a day for 7 days at an average humidity of 62.76, one would expect 2-3 times as much condensate to be generated. The team has hypothesized several reasons for this incongruity, including the counter malfunctioning during the collection process, and the fact that the house it was installed in had two central A/C units, whereas all other test sites had a single unit. However, more testing would be necessary to be sure of the reason(s).

The team also thought it would be interesting to know approximately how much condensate is wasted in a major metropolitan area each day, given the assumption that no one was recycling their condensate. In order to come up with a decent estimation of this figure, first, the number of households in Chicago was looked up. Then, using the online county assessor, a random sampling of 35 households in four of Chicago's six counties was taken to determine the percentage of households in Chicago with central air. Finally, assumptions as to the amount of condensate generated per A/C unit were made based on the data collected throughout the term, as shown above in table 4. The results can be found below in table 7:

Table 7: Condensate Calculations

County	Households	% households with central air	Households with central air
DuPage	325601	71.43	232572
Will	167542	57.14	95738
Cook	1974181	68.57	1353725
Kane	133901	65.71	87992
Lake	216297	-	not sampled
McHenry	89403	-	not sampled
Subtotal	2601225	68.05	1770027
Total	2906925		1978043
Average volume generated/household (gal)			**3.5**
Total volume of wasted condensate (gal)*			**6923150.5**

This is a shockingly large volume of wasted condensate, and this data could probably be used as part of the marketing scheme for the product in future IPROs.

2. Chemical Testing

The main aims of the chemical testing were to determine the pH of various condensate samples, and to determine if any contaminants were present in the condensate. However, the chemical testing conducted by the team this semester was compromised due to improper condensate collection procedures. By the time this fact had been presented to the team, there was no longer enough time to collect and test more samples, thus proper chemical testing will have to be conducted in a future IPRO, should this continue.

Despite the failure to conduct proper chemical testing, through extensive research, the team has managed to lay a solid foundation of knowledge and proper procedure for future IPROs. This research can be found in the supplementary materials provided, and a table of possible contaminants and their expected volumes can be found below in table 8:

Table 8: Possible Condensate Contaminants

Substance	Sources(s)	Average Concentration(s)
Nitrogen Dioxide	1-Unvented gas stoves 2-Environmental tobacco smoke	1-Homes w/out combustion appliances: ~0.0025 ppm 2-Homes w/ combustion appliances: >0.01 ppm
Carbon Monoxide	1-Back-drafting from furnaces, gas water heaters, and woodstoves 2-Gas stoves 3-Automobile exhaust from attached garages 4-Environmental tobacco smoke	1-Homes w/out gas stoves: 0.5-5 ppm 2-Homes w/ properly adjusted gas stoves: 5-15 ppm 3-Homes w/ poorly adjusted gas stoves: >30 ppm

Formaldehyde	1-Pressed wood products 2-UFFI (ureaformaldehyde foam insulation) 3-Durable press drapes & textiles 4-Combustion sources 5-Environmental tobacco smoke	1-Older homes w/out UFFI: <0.1 ppm 2-New homes w/ plenty of pressed wood: >0.3ppm
Volatile Organic Compounds	Household products: paints, cleaners, fresheners, wood preservatives, stored fuel, hobby supplies, etc.	~2-5 times great than outdoors (outdoor concentration in cook county ~1265 tons/mi^2), depends on products used and frequency of use

3. Biological Testing

   Biological testing was conducted to determine if any bacteria, which could potentially limit condensate usage, were present in the condensate samples. Results from four samples can be found below in table 9, with the control again being distilled water:

Table 9: Bacterial Testing Results

Sample	Presence of Bacteria	Number of Colonies
Apple Valley, MN	no	0
Country Club Hills, IL	yes *	2
St. Charles, IL	no	0
Distilled Water (control)	yes *	1

*The colonies found on the control and Country Club Hills, IL plates were very similar in appearance (color, size, form), and can be found in figures 5 and 6 below. Since a spread-plate technique was used, any bacteria would have grown all over the plate, not necessarily as tiny discrete colonies (let alone a single colony), as was the case in the testing. Due to the aforementioned facts, and also the fact that a bacterial colony grew in the control sample, it was determined that the presence of bacteria was a result of subpar and non-sterile lab conditions, resulting from a last minute room change. Thus it was determined that presence of bacteria would not be a limiting factor in deciding what the condensate could be used for.

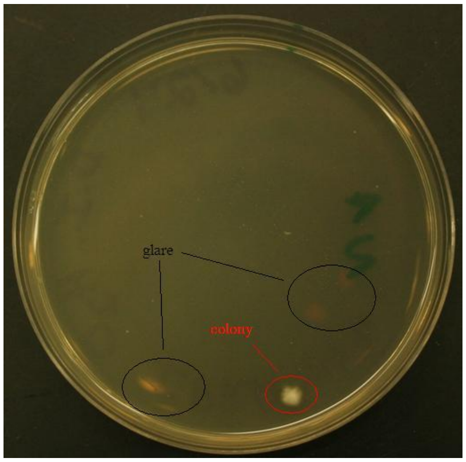

Figure 5: Control Plate

Figure 6: CCH, IL Plate

C. Prototype

When the team first started to design an automated collector, the plan was that the collector would easily be able to be worked into the overall prototype developed to recycle condensate. The design that the team chose for the collector, along with the overall design for the prototype is pictured below in a Solidworks™ drawing by one of the team members.

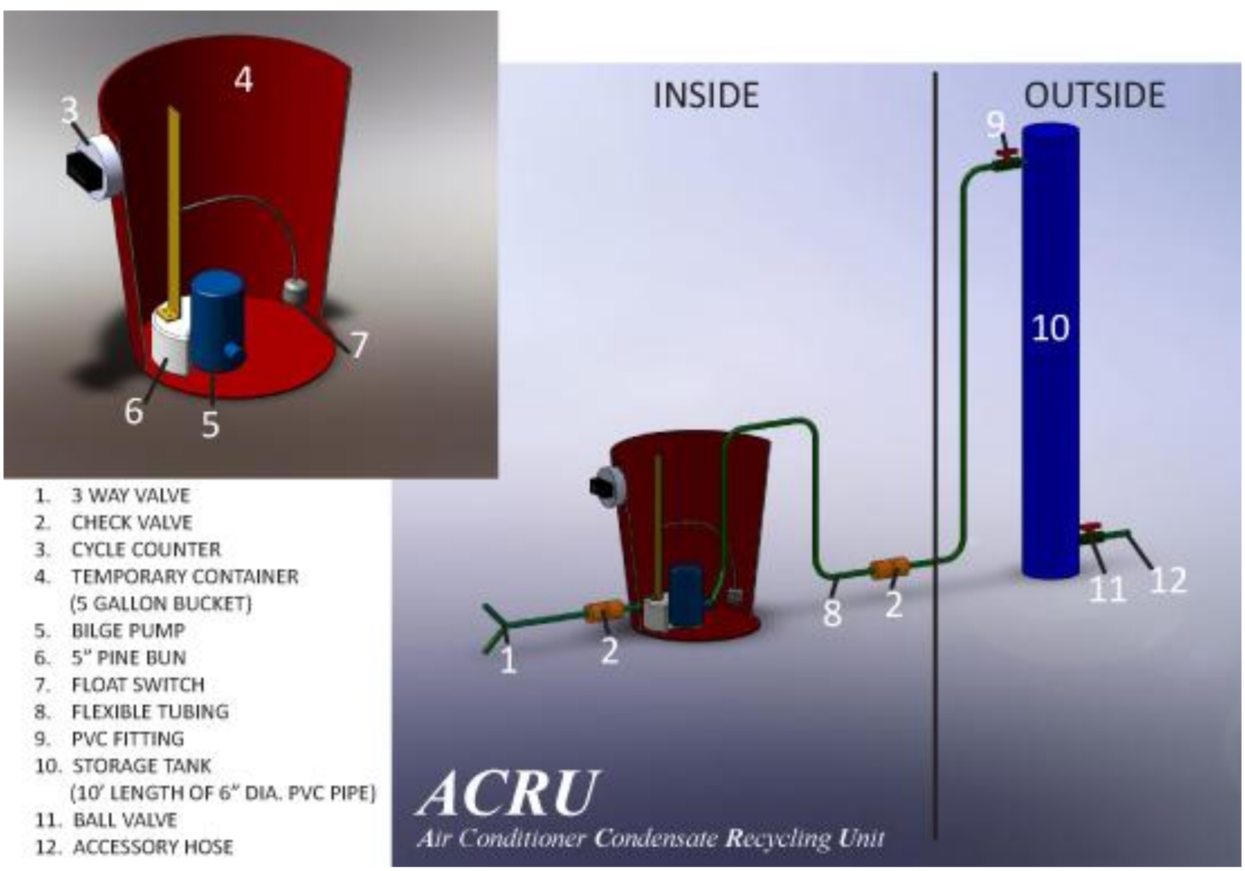

Figure 7: Collection Device

The temporary container assembly operates on a circuit. As condensate fills the bucket, the float switch rises. Once the float switch reaches a certain height, the pump turns on and drains the bucket, and a pulse is sent to the counter causing it to increment by one. Thus, the counter keeps track of each time the bucket is drained.

As can easily be seen above, the prototype of the entire recycling system was created through some simple modifications to the device

The prototype is simply the collector with a tube running from the pump to an outside storage tank which has a drip line connected to it, and a few extra valves. The three way valve before the collection bucket allows the user to decide whether to store or drain their condensate, and the check valves before and after the collection bucket only allow the condensate to flow in one direction, as a safety precaution against backflow from the storage tank or bucket. The spigot on the storage tank allows the drip line to be turned on and off. While the counter is not a part of the final prototype design, it is pictured here because it is a part of the prototype that the team actually constructed.

The storage tank is made of a 10 foot tall, six inch diameter length of PVC piping with end caps, and holds approximately 14.5 gallons (or 55.5 liters) of water

All together the parts for the prototype cost $166.83 not including the counter (as it is not to be included in the design), the pump, or some converters, which team members had on hand.

D. Marketing

1. Market Survey

   In order to determine if there was a market for the type of product that the team was going to design, they developed a survey on surveymonkey.com and sent the link to as many people as possible. All together, 134 people from across the globe (though much of the sampling was from Illinois) took the survey, which is more than enough to claim statistical reliability. The results of some of the most important questions can be seen in figures 8-11 below:

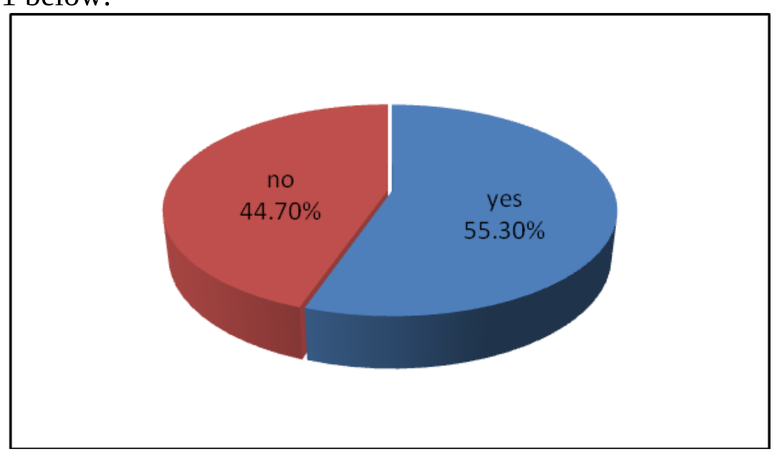

Figure 8: Did you know that your A/C unit generates condensate?

Figure 8 indicates the challenge that future teams would have marketing a product like this, in that there is a definite need to raise awareness so that more than half the market knows that their air conditioning unit generates condensate.

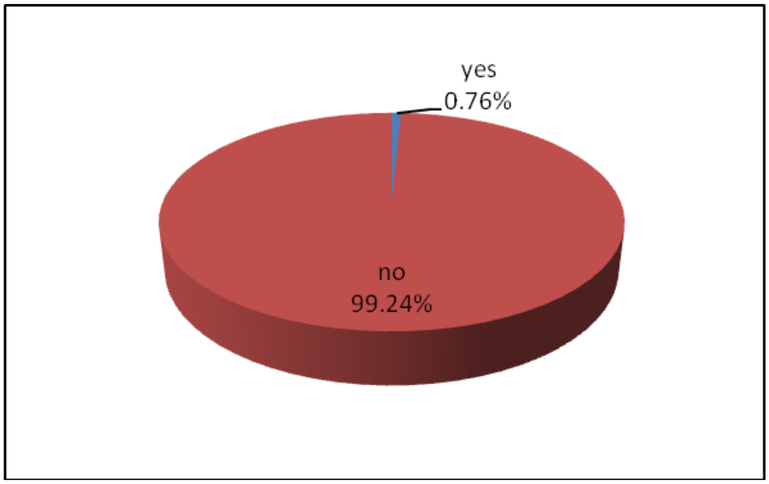

Figure 9: Are you currently recycling your A/C condensate?

Figure 9 indicates a very positive marketing aspect. The good thing about 99.24% of the market not already recycling their condensate is that there probably exists little competition as far as condensate recycling devices go. The downside is that much of the market may need to be convinced that recycling their condensate is worth their effort and money.

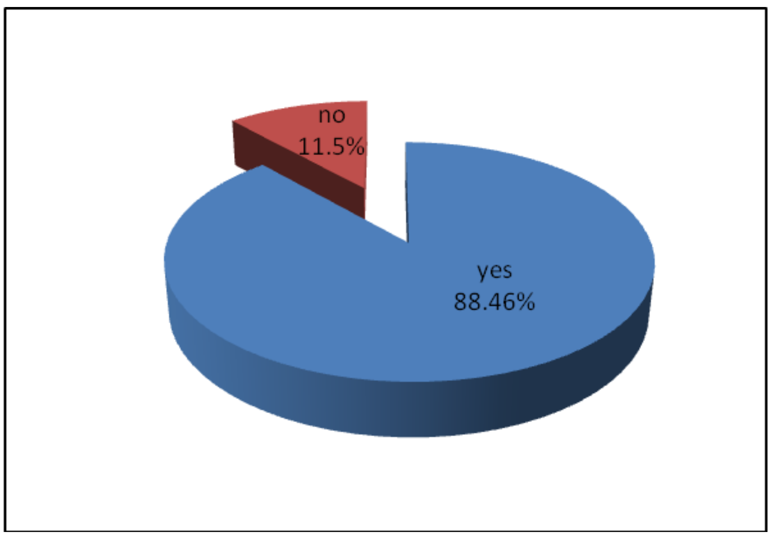

Figure 10: When developed, would you be interested in purchasing a system to recycle your A/C condensate for irrigation purposes or flushing toilets?

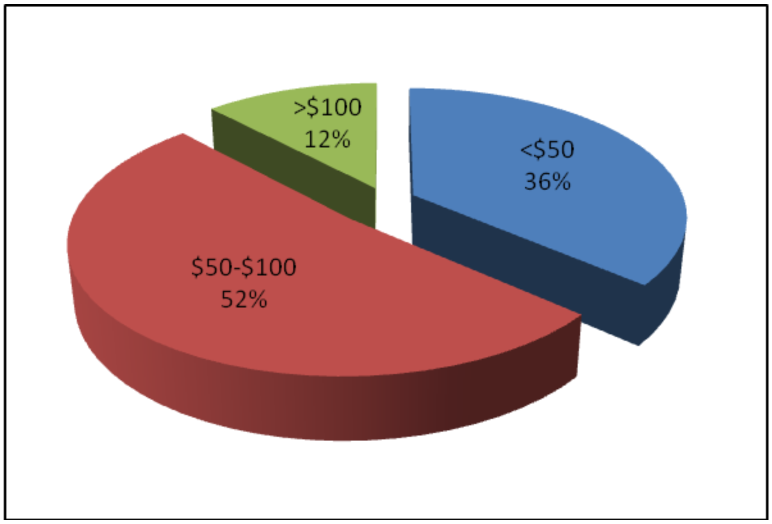

Figure 11: How much would you be willing to pay for such a device?

Figures 10 and 11 indicate an overwhelmingly positive response to the idea of a condensate recycling system. The team was not expecting almost a 90% interest rating, or a 60% willingness to pay over $50. With statistics like this, the team is confident that if the product is marketed correctly, it will have great commercial success.

2. Initial Marketing Ideas

The team chose to focus on the development and actual assembly of a prototype that would recycle condensate, and given the brevity of the semester, did not have a lot of time to develop a marketing plan. The team did, however, devote some time to discuss some initial marketing ideas, which are detailed below:

a. Product Name:

The team decided to name the prototype the ACRU, or Air Conditioning Condensate Recycling Unit for two reasons. One being that acronyms are catchy, and two, it should appear clever and amusing to the rhetorically savvy consumer, as ACRU sounds like the English word accrue, which means ‘to accumulate, collect, or build up’.

b. Product Packaging:

As this product is rather large in and of itself, the team decided that instead of all the parts coming in a large and bulky box, all the necessary parts should be packaged inside the storage tank. As the tank is 10’ long and 6’’ in diameter, it is more than large enough to hold all the necessary parts aside from the 5 gallon bucket.

It was decided that the 5 gallon bucket did not need to be included in the packaging, and would be sold separately, as they are very inexpensive, and would in all likelihood be sold in the same store as the ACRU, causing as little inconvenience to the consumer as possible. Also, however obvious it may seem to the designer that the bucket is not included, it should be indicated in a very obvious fashion on the packaging, so as not to upset the consumer.

Other aspects of the product packaging should include:

i. Condensate Production Chart

   The team thought that a map of the United States with color coded regions corresponding to the amount of condensate they should expect their air conditioner to produce would be an excellent addition to the package art. This would make it very easy for each consumer to determine if the product was worth their while. Also, it would be more convincing than a seemingly sensational claim of ‘save _____ gallons of water each month when you purchase the ACRU!’, as that sounds like something out of an infomercial. This chart does not yet exist, as this was a first semester IPRO, and not enough data was collected in the 8 weeks as would have been needed to make it valid.

ii. Catchy slogan(s)

   Works in progress include:

   - Water your garden for free, using your AC!
   - Green your garden!

iii. Diagrams and Parts List

   These should be presented in a way that emphasizes the ease of installation.

E. End Results vs. Original Goals

1. Scalability

   All aspects of the product can be scaled both up (for industrial uses), or down (for small central A/C units and potentially wall A/C units). Some features may need to be changed completely to meet installation requirements for such facilities, however it is not known right now, as no industrial air conditioning units or wall air conditioning units were investigated throughout the semester.

2. Marketability

   Obviously the end cost of the product is well out of the range that the majority of the market was willing to pay. This is something that will need to be improved upon if the device is ever to be successful on the market. The team does see the price decreasing significantly when parts are purchased wholesale rather than one at a time from outlets such as Home Depot or Menards. Aside from the cost barrier, the only other significant marketing challenge anticipated by the team is raising awareness for the usefulness of the product.

3. Ease of installation and use

   The part of the product that was the most difficult to assemble was definitely the bucket drainage system, as it required specially wiring parts. This would obviously come preassembled for the consumer, bringing down the installation time to roughly 30 minutes, and requiring minimal tools and strength.

   This product is extremely easy to use. It has features that allow the consumer to choose when to collect for storage, when to water the plants, and when to drain the condensate, each by turning a simple valve.

IX. Obstacles and Recommendations

Throughout the first semester of IPRO 348, the following obstacles were encountered and overcome.

A. Collection

1. **Obstacle:** As this was the first term of the IPRO, there were no sites collecting condensate data and samples from air conditioner units. To resolve this problem, team members gathered condensate data and samples from their own homes, when possible. There was also no protocol for the collection process. To overcome this, standards were set to be applied to the collection process. As the semester continued, a collection device was created and installed onto one of the collection sites, so that data could be collected over a longer period of time without direct supervision.
2. **Recommendation:** For subsequent IPRO teams, it is recommended to gather as much data as early as possible due to seasonal changes and possible time constraints. In addition, multiple collection devices could be installed at different sites.

B. Testing

1. **Obstacle:** Testing the condensate sample obtained from the sites was a difficult task throughout the term. A lab and necessary materials were obtained for biological testing early in the term. However, the lab space provided was not ideal for microbiological testing. Also, chemical analysis of the condensate proved to be quite difficult. It was discovered that the sample collection method was only suitable for biological analysis. In addition, the chemical analysis required more research to determine possible contaminants and their concentrations within the condensate, as well as research related to standard methods of collection and analysis of condensate.
2. **Recommendation:** For future IPRO teams, it is highly recommended to complete all analysis related research prior to stepping into the laboratory and to find a lab with all appropriate specifications and materials as soon as possible. In addition, it is recommended to perform strategic sampling of the condensate, so that more information is gained.

C. Marketing

1. **Obstacle:** In the beginning of the term, the team conducted research to see if there were existing products for condensate collection or recycling. When the research was completed, it was determined that no such product existed. A web survey was conducted to find out the general public's opinion on the topic of condensate recycling in order to begin marketing studies. It was shown that people were interested in a product as long as the price was reasonable.
2. **Recommendation:** For a subsequent term, it is advisable to give a more detailed marketing survey, and to try to find ways to distribute it to more people. Also, more research into possible existing products is always a good idea.

D. Applications/Uses

1. **Obstacle:** In the beginning of the term, research was done on possible uses for condensate. This research showed that it would be wise to focus on either indoor or outdoor uses. It was decided that indoor uses would be too costly due to plumbing code issues and expensive installation costs. Thus, outdoor uses became the focus of the project. A prototype was modeled for storage of condensate for outdoor uses, such as irrigation.
2. **Recommendation:** It is recommended that the prototype is taken as just that, a prototype. This is not a finished project and more discussion and time is needed in figuring out how the product will be used around the residential area. It is also advised to make the product scalable and focus on more uses for commercial industries. More research into uses for condensate, and further development of the prototype are also advisable.

E. Costs of Materials

1. **Obstacle:** The prices of materials needed to build the prototype of the product were a little over $200. According to the survey conducted, the average consumer would be willing to spend between $50 and $100 on this product if it were to become marketable. Therefore, the costs of these items must be cheaper if a marketable product is to be built.
2. **Recommendation:** It is recommended that more research be done into possible wholesale (bulk) costs of the items needed to build this product in mass quantities. These prices would likely be cheaper and could bring down the cost of the item. Also, new ideas to alter the existing design into a more budget-friendly design with different parts, or cheaper parts, would be beneficial to this project.

X. References

"Acid-Low pH." *Clean Water Store*. 2009. 03 Jun 2009 <http://www.cleanwaterstore.com/acid-well-water.html>.

"A/C Condensation Watering Kit." *Clean Air Gardening*. 2008. 03 Jun 2009 <http://www.cleanairgardening.com/catch-a-drop-moisture-hose.html>.

"Air Conditioning." *Wikipedia*. 2009. Wikipedia. Web.03 June 2009. <http://en.wikipedia.org/wiki/Air_conditioning>.

"Air Conditioning System with Full Heat Recovery." *Free Patents Online*. 13 May 2008. 03 Jun 2009 <http://www.freepatentsonline.com/7370490.html>.

"Atmospheric Water Generator." *Wikipedia*. 2009. Wikipedia. Web.03 Jun 2009. <http://en.wikipedia.org/wiki/Atmospheric_water_generator>.

Brain, Marshall, and Bryant, Charles W. "How Air Conditioners Work." *How Stuff Works*. 01 Apr 2000. 03 Jun 2009 <http://home.howstuffworks.com/ac.htm>.

City of Melbourne, Florida. Environmental Community Outreach Division. *Saving Water in Your Home*. Melbourne, Florida: 2007. Web. <http://www.melbourneflorida.org/watercon/saving_water_home.pdf>.

"Condensate Pump." *Wikipedia*. 2009. Wikipedia. Web.03 Jun 2009. <http://en.wikipedia.org/wiki/Condensate_pump>.

"Condensate Water Introduction." *Alliance for Water Efficiency*. 2009. 03 Jun 2009 <http://allianceforwaterefficiency.org/Condensate_Water_Introduction.aspx?terms=condensate+water+introduction>.

"Condensation." *Ask the Builder*. 2009. 03 Jun 2009 <http://www.askthebuilder.com/Condensation.shtml>.

"Department of Water Management." *City of Chicago*. 2009. City of Chicago. 03 Jun 2009 <http://egov.cityofchicago.org/city/webportal/portalEntityHomeAction.do?entityName=Water&entityNameEnumValue=43>.

Energy Star. 2009. United States EPA. 03 Jun 2009 <http://www.energystar.gov/>.

"Finance Department." *City of Rockford*. 01 Oct 2007. City of Rockford. 20 Jul 2009 <http://cityofrockford.net/government/finance/index.cfm?section=divisions&id=941>.

"Free Water." *Free Flow Water Recycling Systems*. 2008. 03 Jun 2009 <http://www.freeflowater.com/features.html>.

"A Guide to Water Filters." *Heart Spring*. 03 Jan 2009. 03 Jun 2009 <http://heartspring.net/water_filters_guide.html>.

"Instructables." [Weblog Air Conditioner Condensate] 21 July 2008. Web.03 Jun 2009. <http://www.instructables.com/community/Air-Conditioner-Condensate>.

"iVillage Garden Web." [Weblog Frugal Gardening Forum] 18 Aug 2008. Web.03 Jun 2009. <http://forums2.gardenweb.com/forums/load/frugal/msg0705130626262.html>.

"Municipal Code of Chicago, Illinois." *Americam Legal Publishing Corporation*. 18 Mar 2009. City of Chicago. 03 Jun 2009 <http://www.amlegal.com/library/il/chicago.shtml>.

"Slow Sand Filter." *Wikipedia*. 2009. Wikipedia. Web.03 June 2009. <http://en.wikipedia.org/wiki/Slow_sand_filter>.

United States. Environmental Protection Agency. *Energizing EPA*. Washington DC: 2002. Web. <http://www.epa.gov/oaintrnt/documents/issue11_02.pdf>.

United States. Patent and Trademark Office. *United States Patent and Trademark Office Pre-grant Publication*. 2002. Web. <http://www.aplegal.com/Patents/Martinez,%20Victor%20-%20Drainage%20system.pdf>.

"Using Air Conditioner Condensate for Landscape Irrigation Reduces Water Usage." *ChemAlliance Case Studies*. 03 Jun 2009 <http://www.chemalliance.org/tools/plant/case_study.asp?CSID=77#top>.

"Using Air Conditioner Condensation." *DIY Network*. 2009. 03 Jun 2009 <http://www.diynetwork.com/outdoors/using-air-conditioner-condensation/index.html>.

The Weather Channel. 2009. The Weather Channel. <http://www.weather.com/>.

"Well Water Problems." *Water Doctor*. 1999. 03 Jun 2009 <http://www.water-doctor.com/WD_wellwater.html>.

Wilson, Alex, and Navaro, Rachel. "Alternative Water Sources." *BuildingGreen.com*. 01 May 2008. 20 Jul 2009 <http://www.buildinggreen.com/auth/article.cfm/ID/3903/>.

XI. Resources

A. Team Timesheet

Table 10: Timesheet (as of 7/23/09)

Member Name	Hours Spent
Anam Abro	50
Syeda Ahmed	64.6
Niravkumar Hazariwala	50.5
Cari Hesser	111
Malisa Ismail	50
Jessica Martinez	68.5
Siddhartha Raghuvanshi	45
Erich Ruszczak	38.3
Nicole Specht	86
Rachel Yanover	58.5
Total Hours Spent	622.4

B. Student Expenditures

1. Cari

Table 11: Cari's Expenditures

Part	Cost per unit	Quantity	Total cost
10' clear flexible tubing (¾" dia)	18.82	1	18.82
¾" check valve	8.96	1	8.96
4oz. PVC cement	3.76	1	3.76
¾" male insert fitting	0.39	1	0.39
¾" female fitting	0.42	1	0.42
5' X 4' pipe end caps	7.35	1	7.35
2-way valve	4.97	1	4.97
3-way valve	4.97	1	4.97
Sales Tax			5.09
Total			54.73

2. Nirav

Table 12: Nirav’s Expenditures

Part	Cost per unit	Quantity	Total Cost
5" Pine Bun	8.15	1	8.15
Helms Satin	8.88	1	8.88
4oz Gorilla Glue	6.95	1	6.95
Plastic Bags	0.98	1	0.98
DWV Hanger	1.56	1	1.56
2" Copper Clip	0.32	2	0.64
Homer Bucket	2.34	1	2.34
Sales Tax			2.95
Total			32.45

1. Nicole

Table 13: Nicole’s Expenditures

Part	Cost per unit	Quantity	Total Cost
¾” male PVC fitting	0.21	1	0.21
1 ¼” drill bit	6.98	1	6.98
5’ X 4” pipe	7.99	1	7.99
3/4" female insert fitting	0.72	2	1.44
Sales Tax			1.5
Total			18.12

XII. Acknowledgments

We are grateful to Donna Beaver (AZ), Kristy Hesser (MN), Syed N. Ahmed (IL), Raymond and Allison Specht (IL), Philip Lewis (IL), and Michael Lewis (IL) for allowing us to use their homes as data collection/test sites. We also would like to thank licensed plumber Mr. Anthony Durkin for his counsel on plumbing aspects of this project.

We would also like to thank Professor Philip Lewis for his guidance, interest, and assistance throughout the term of this IPRO as our instructor.

We appreciate Professor Paul R. Anderson for his general interest in this IPRO and his guidance with the chemical analysis of the condensate. We are also grateful to Professor Diep Nguyen and Dr. Wenjie Zhao for their guidance, helpful discussions, and the use of their laboratory facilities.