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A user-built system for automated monitoring and controlling of controlled atmosphere apple storages /

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A USER-BUILT SYSTEM FOR AUTOMATED MONITORING AND CONTROLLING OF CONTROLLED ATMOSPHERE APPLE STORAGES

A Thesis Presented

By

Katrin Slosser Kaminsky

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

JUSTIFICATION

PART I. INTRODUCTION

Growing conditions in the Northeastern United States are ideal for production of the apple cultivar McIntosh. Since its commercial introduction in 1870 (9), it has provided a competitive alternative to other cultivars, such as Delicious, which can be grown more efficiently in other areas. However, McIntosh has a high rate of deterioration and therefore a fragile postharvest life.

Development of controlled atmosphere (CA) storage, in the 1950s, revolutionized the McIntosh industry. The CA process is based upon control of oxygen (O_2) and carbon dioxide (CO_2) at specific levels and the use of refrigeration to retard fruit respiration. The result is inhibition of ripening and extension of storage life. The current recommendations for McIntosh storage at 3% O_2 and 5% CO_2 were published in 1960 (14). O_2 level is the more critical factor, since levels too low will result in fruit injury, while levels too high will compromise storage life. Raising CO_2 level provides some benefit in fruit quality, but levels too high can result in fruit injury. Recommendations are based on maximizing fruit quality while minimizing the risk of fruit injury.

Accurate monitoring and precise control of the CA atmosphere are critical. Currently, the Orsat gas analyzer (16) is used almost exclusively in New England to determine the concentrations of O_2 and

CO_2 within a CA storage. Control of these levels is accomplished manually by the storage operator when needed. Although the Orsat method is inherently accurate, the procedure itself contains much opportunity for human error. Also, since it is time consuming, atmospheres are generally analyzed and adjusted only once per day, which can result in considerable fluctuation of the storage O_2 level (11).

Alternatives to the Orsat method do exist. Automation of the monitoring and controlling process has been accomplished successfully in England and package systems are available to growers at this time. However, the cost of such a system would be prohibitive for the small storages typical of the New England apple industry. Another alternative is the user-built system. This system employs separate components which are available for O_2 and CO_2 analysis, a personal computer for data handling and initiation of atmosphere control measures, and the necessary pump, valves, and relays to facilitate the whole process (1). This approach has now been successfully applied to both research and commercial facilities at a cost greatly reduced from that of the package system (1,7,12).

PART II. OBJECTIVES

It was the goal of this study to design, set up, and run such a system at the University of Massachusetts Horticultural Research Center (HRC), and to evaluate any appreciable benefits it provides as compared to the conventional Orsat-run system. The system was assembled during the summer of 1986 and run during the 1986-87 and 1987-88 storage seasons. The task of evaluating potential benefits of the system for

Massachusetts storages was addressed in the 1986-87 storage season. First, to determine the current state of Massachusetts CA storage operation, a questionnaire was sent to each of the 29 licensed CA storage operators in the state, as listed by the Massachusetts Department of Food and Agriculture. Questions were developed that related to capacity, desired control setpoints, current monitoring and controlling technique, current degree of precision, and other factors. Results of this survey were collected and tabulated, and conclusions have been drawn as to the role automation might play in the Massachusetts CA storage industry. Secondly, an experiment was conducted through the 1986-87 storage season comparing various aspects of CA management using two storage rooms at the HRC facility. Setpoints and experimental fruit corresponded between rooms. However, one room was automatically monitored and O_2 level was automatically controlled, while the other room was monitored by an Orsat with O_2 level controlled manually. Time spent daily on each room was recorded. Results of this experiment are included in this paper. A final goal of this study was to make recommendations to interested CA operators as to how they might go about establishing a user-built system of their own. Included in this paper is an extension bulletin which makes available those recommendations. The automated system at the HRC continues to function and will be used as a demonstration model for apple growers and others.

CHAPTER II

PROCEDURES

PART I. SURVEY

In 1986, a detailed CA storage questionnaire was mailed to each of the 29 licensed storage operators in Massachusetts (Table 1). The questions, described in Chapter I, were designed to determine the current state of Massachusetts CA storage operation and therefore, to aid in drawing conclusions as to the suitability of user-built automated atmosphere monitoring and controlling systems for these operations. A cover letter (Figure 1), mailed with the survey, urged operators to respond. Several months later, not having received all the responses, a follow-up letter (Figure 2) was mailed. Response rate was then 100%. However, one of the licensed storages indicated that it had never achieved CA storage of fruit (according to legal definition, fruit stored at less than 5% O_2 for 90 days). Therefore, responses from this questionnaire were not tabulated, bringing the total number of Massachusetts CA storages to 28.

PART II. AUTOMATION OF THE CA STORAGE FACILITY

In 1986, a grant was received from the Massachusetts Society for Promoting Agriculture, for the purpose of establishing a demonstration, "user-built" automated system at the Horticultural Research Center (HRC), Belchertown, Massachusetts. The proposal for this grant is included as Appendix A.Assembly of the system was begun that summer, and it was operated during the 1986-87 storage season (September-

Table 1. Massachusetts CA storages as licensed by the Massachusetts Department of Food and Agriculture.

---

1. David Cheney, Cheney Orchards, Inc.
   Apple Road, Brimfield 01010

2. Robert Tuttle, Breezeland Orchards
   Southbridge Road, Warren 01083

3. Hamilton Lincoln, Brookfield Orchards
   Orchard Road, North Brookfield 01535

4. David Shearer, Pine Hill Orchards
   Box 105 Greenfield Road, Colrain 01340

5. Dana Clark
   RR1 Box 114, Ashfield 01330

6. Donald Green, Westward Orchards
   Oak Hill Road, Harvard 01451

7. David Chandler, Meadowbrook Orchards
   Chase Hill Road, Sterling Junction 01565

8. John Blanchard, Justice Hill, Inc.
   Box 523, East Princeton 01517

9. David Bishop, Wellsmont Orchards
   RR 1 Box 148, Shelburne 01370

10. Marvin Peck, Valley View Orchards
    Peckville Road, Shelburne 01370

11. Roger Peck, Mohawk Orchards
    Colrain-Shelburne Road, Shelburne Falls 01370

12. Atkins Farm Fruit Marketing, Inc.
    1150 West Street, Amherst 01002 and
    Mill Valley Road, Belchertown 01007

13. Louis Jascik, View North Orchards
    Baptist Hill Road, Three Rivers 01080

14. Elmer Fitzgerald, Fitzgerald Fruit Farm
    150 Joslin Street, Leominster 01453

15. Devens Cold Storage Trust
    Barnum Road, Ayer 01432

Table 1. Continued

16. George Marshall, Marshall Farm
    340 Marshall Road, Fitchburg 01420

17. Edward Jensen, Mountain Orchard
    Main Street, Granville 01034

18. Frank Lanni, Lanni Orchards
    294 Chase Road, Lunenburg 01462

19. Steve Smedberg, Green Acres Fruit Farm
    868 Main Street, Wilbraham 01095

20. H.M. Smith, Apex Orchards
    Peckville Road, Shelburne 01370

21. Walter Carlson, Carlson Orchards
    Oak Hill Road, Harvard 01451

22. Gordon Kimball, Flat Hill Orchards
    321 Elmwood Road, Lunenburg 01462

23. Jaeschke Bros. Farm
    West Road, Adams 01220

24. Joseph Listowich, Wyndhaven Farm
    Worcester Road, Sterling 01564

25. Richard Bartlett, Bartlett's Orchard
    Swamp Road, Richmond 01254

26. James Molitoris, Molitoris Orchards
    95 Park Hill Road, Easthampton 01027

27. Tom Luippold, Long Hill Farms
    514 Main Street, West Newbury 01985

28. Donald May, Gibbett Hill Orchard
    Shirley Road, Groton 01450

29. University of Massachusetts Horticultural Research Center
    Sabin Street, Belchertown 01007

UNIVERSITY OF MASSACHUSETTS
AT AMHERST

Department of Plant and Soil Sciences

MEMORANDUM

Date: June 18, 1986

To: Massachusetts CA storage operators

From: William J. Bramlage, Katrin Kaminsky, and Wesley Autio

Subject: CA storage operation questionnaire

If Alar is not used on McIntosh, it will become more important than before that you operate your storages precisely if you are to obtain long-term retention of apple quality. Over the years, different growers have adopted many different styles of storage operation and management. In trying to analyze opportunities to improve storage management practices, we have become aware that we really do not know how CA storages are operated in Massachusetts.

The attached questionnaire is being sent to all Massachusetts CA storage operators who are certified by the Department of Food and Agriculture. It is part of a Master's Degree program of Ms. Katrin Kaminsky and is designed to update our awareness of how the industry actually manages its storages. We hope that it also will be informative to you. We shall provide each respondent with a summary of responses, and you will be able to compare your responses to those of the other Massachusetts CA operators.

To be meaningful, your responses must be accurate. Please take the time to examine your records before providing answers to the questions. Even though this will be time-consuming, we believe that it will be well worth the time you invest. Please be assured that your responses will be confidential. Please place your name on the "return address" portion of the envelope so that we can monitor responses on receipt. At that point the envelopes will be destroyed and you will not be identified with your response (unless, of course, you wish to be identified). No individual will be identified in any compilation of results. For reference, please keep a copy of your own responses.

In part, this questionnaire is intended to determine how a computer-operated, automatic sampling and measuring system might fit into our storage management operations. We have received a grant from the Massachusetts Society for Promoting Agriculture to assist in purchasing components and placing such a system in operation at the Horticultural Research Center in Belchertown. We plan to have it in operation by September and will compare its costs and benefits with conventional Orsat operation. Results from the questionnaire will aid us greatly in evaluating the usefulness of such a system within the Massachusetts industry.

Figure 1. Cover letter for Massachusetts CA storage survey.

Please give this questionnaire your thoughtful consideration and return it by July 15 to:

Katrin Kaminsky
Department of Plant and Soil Sciences
French Hall
University of Massachusetts
Amherst, MA 01003

We thank you in advance for your time and cooperation in responding to our questions.

Sincerely,

Katrin Kaminsky,
Senior Technical Assistant

William J. Bramlage,
Professor

Wesley R. Autio,
Assistant Professor

Figure 1. Continued

UNIVERSITY OF MASSACHUSETTS
AT AMHERST

Department of Plant and Soil Sciences

MEMORANDUM

Date: July 23, 1986

To: Massachusetts CA Storage Operators

From: William J. Bramlage, Katrin Kaminsky, and Wesley Autio

Subject: Controlled Atmosphere Storage Questionnaire

On June 18 we sent you a questionnaire about CA storage operation, but to date we have recorded no response from you. (Several responses lacked return addresses and could not be recorded, so if you have returned your questionnaire, please ignore this reminder.)

It is very important to our study that we receive this information. If you have not yet responded, please do so at your earliest convenience. In case you have mislaid the questionnaire, another copy is enclosed. Please answer the questions as completely and accurately as possible.

We thank you for your assistance to us in this study.

Enclosure

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Figure 2. Follow-up letter for Massachusetts CA storage survey.

March), with ongoing modifications. The goal was to achieve automatic, electronic monitoring of O_2, CO_2, and temperature levels, and to automatically control O_2 level. The following is a description of this automation.

THE STORAGE FACILITY BEFORE AUTOMATION

The apple storage facility at the University of Massachusetts HRC was built in 1971. Due to the presence of Dr. Franklin Southwick and Dr. John Zahradnik on the design staff, construction followed state-of-the-industry standards. The storage consists of four CA rooms and one common storage room. CA capacity is 6,200 bushels, with two rooms holding 2,500 bushels each, and two rooms holding 600 bushels each.

The HRC storage has several features which facilitated automation. Each CA room is equipped with a breather bag and a U-tube for pressure relief. The CA rooms are located contiguously along an L-shaped hallway (Figure 3). In the hallway are the external lime boxes and a central analysis station. The storage already had a centralized atmosphere sampling system. An electric vacuum pump draws air samples from each room, via 1/4" copper tubing, to the analysis station. The operator selects the room to be sampled, via an electronic switch at the analysis station, which opens the sample solenoid valve located at each room. Atmosphere for the CA rooms was originally generated by an Arcat system. This equipment, marketed by Atlantic Research Corporation, Alexandria, VA, cycles storage room air through a catalytic O_2 burner and a CO_2 scrubber. Therefore, centralized, separate plumbing systems for both input and exhaust are attached to the rooms. These systems

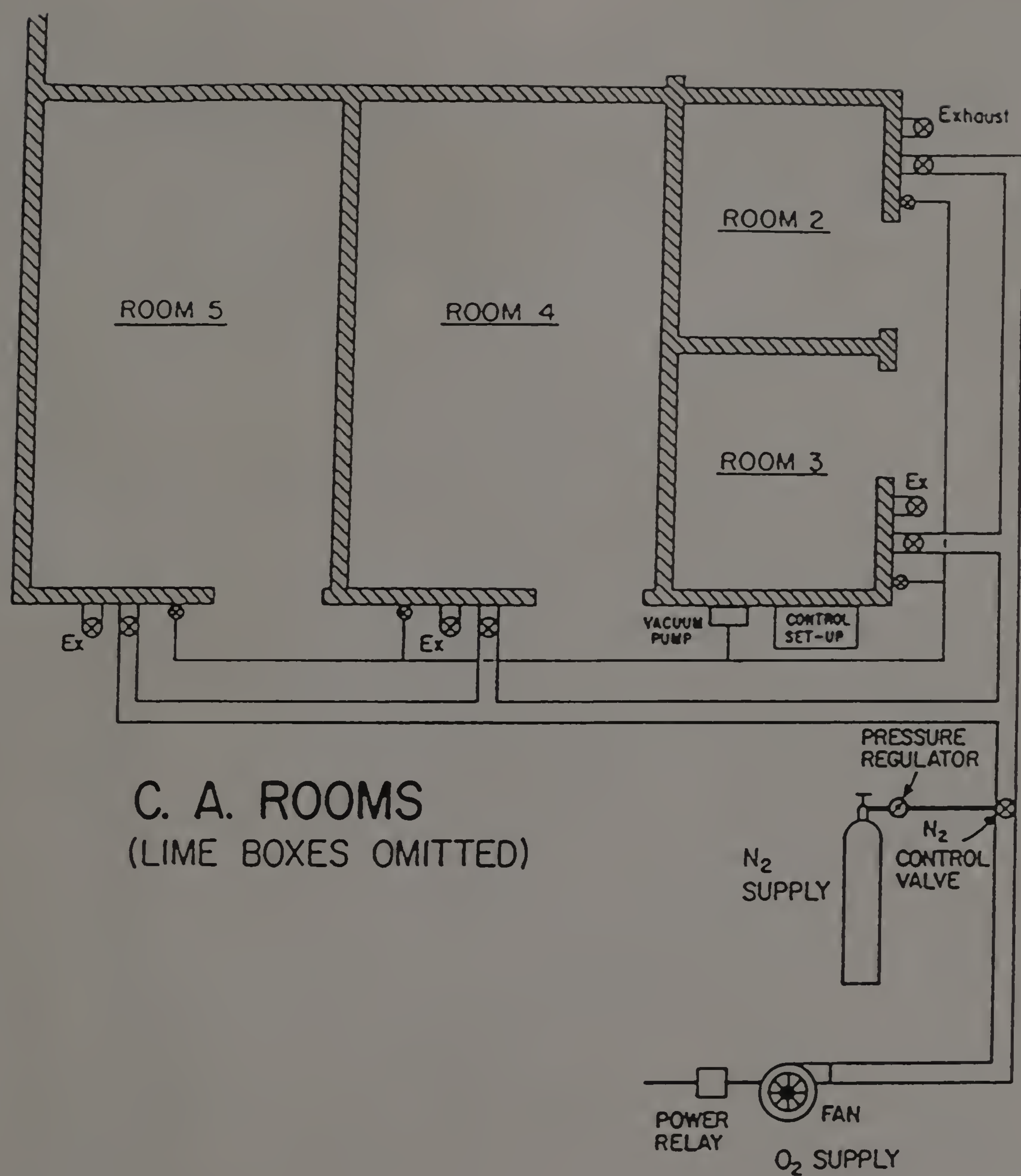

Figure 3. Plumbing lay-out for automated monitoring and controlling.

originate in the hallway, across from the analysis station. Each consists of 4" PVC pipe with a 3" solenoid valve at each room. The two solenoid valves for each room are also accessed through the switch at the analysis station, and are wired so that they are either both open or both shut.

Atmosphere analysis is performed with an Orsat gas analyzer. Chemicals in the Orsat are usually changed at the beginning and the midpoint of each CA season. Setpoints for McIntosh rooms are 37^{o} F, 3% O_2, and 5% CO_2. Freon compression systems provide cooling for the rooms. The compressor for each room is controlled by a thermostat located just inside the door of that room. CO_2 control is accomplished by an external lime box at each room. A fan is positioned at a lime box port, inside the room, and runs constantly. The operator controls air flow through the lime box by adjusting external valves. O_2 is added either through a controlled leak, or by blowing in air, using a small fan. O_2 level is reduced by adding nitrogen (N_2) gas to the room. Each room has a standpipe where the fan or the N_2 cylinder is attached. One of three operators performs an atmosphere analysis once per day. Room temperature is read from a single thermometer located directly inside the door. Daily O_2, CO_2, and temperature readings are recorded in a log book. Adjustments, if needed, are made, and these are also noted in the log book.

ELECTRONIC MONITORING

Previous work (11) suggested that the types of electronic gas analyzers most suitable for this application are the paramagnetic O_2

analyzer and the infrared CO_2 analyzer. The paramagnetic, or magnetic susceptibility, analyzer is limited to the analysis of O_2 and the oxides of nitrogen. This situation is because these are the only paramagnetic gases, that is, gases attracted by a magnetic field. Since oxides of nitrogen are not found in CA atmospheres, the instrument is suitable for this application (16). Infrared analyzers are designed to measure CO_2 concentrations in flowing gas streams and are better suited for incorporation into automated systems than are other types. CO_2 absorbs infrared radiation at a specific wavelength, a property which is used to produce an electrical signal related to the CO_2 concentration in the test gas stream (16).

Widespread experience in England and Europe has shown that Servomex produces a very reliable pair of such instruments. Through the generosity of the regional United States Servomex distributor (SYR Technology, Northboro, MA), a pair of gas analyzers was provided for use on this project. The O_2 analyzer has a range of 0-100% with an accuracy of 2% full scale. A range of 0-10% is also available and would be more desirable since it would provide better accuracy over the range of O_2 values found in CA rooms. The CO_2 analyzer has two ranges, 0-1% and 0-10%, both with an accuracy of 2% of full scale. Both instruments are calibrated by means of set screws at zero and at span. For zero calibration, a small cylinder of N_2 gas was used. For span calibration, a small cylinder of a gas mixture containing 3% O_2 and 5% CO_2 was used. The mixture is certified to be within 0.1% O_2 and 0.25% CO_2. This mixture was chosen because it represents the O_2 and CO_2 setpoints used in most of the HRC CA storage rooms. Calibrating span is thus more accurate at the applicable O_2 and CO_2 levels than if gases were used which represented the true spans of the instruments. Both instruments hold calibration very well, as had been found previously (11), but are checked weekly.

PLUMBING

Automation of atmosphere monitoring and controlling requires the use of centralized plumbing systems fitted with solenoid valves. The previously described systems already in place at the HRC were well suited to this project. A relay at the computer was connected to the existing solenoid switching panel for each of the CA room sample line solenoids. Also, the central 4" PVC system was adapted for use as a gas supply line. In this system, N_2 gas is called for when room O_2 level exceeds setpoint, and air is called for when O_2 level is below setpoint. Both gases are supplied through the same piping system (Figure 3). As with the sampling system, a relay at the computer was connected to the switching panel for each of the CA room control line solenoids. Venting occurs automatically whenever gas is added to a room, due to the previously described nature of the existing setup.

A sealed, oil-free pump is required to bring room atmosphere samples to the instruments. A Gast pump (Cole-Parmer Instrument Company, Chicago, IL, model J7061-20) was purchased for this purpose and it served well. The vacuum side of the pump was attached to the central sample line, via flexible Tygon tubing. The positive pressure side, again via flexible tubing, was attached to the inlet on the O_2 analyzer. Outflow from the O_2 analyzer was directed to the inlet of the

CO_2 analyzer and the spent sample gas was then vented through the outlet side (Figure 4).

Initially, during automatic operation, the pump was left running constantly. To help avoid excessive wear on the pump and to maintain airtight sample solenoids, this method was changed. Pump operation is now controlled via a relay at the computer, so that the pump only operates during sampling.

A 300 cubic foot cylinder of N_2 gas served as the N_2 source to reduce O_2 concentration when needed. A pressure regulator, adjusted to a specific, constant setting, was attached to the cylinder. A 1/4" solenoid valve, controlled by a relay at the computer, was placed immediately after the pressure regulator. A heavy, rubber hose then was used to channel the N_2 flow through a hole drilled in the PVC control line.

A small squirrel-cage fan served as the air source to increase O_2 concentration when needed. The fan was operated by a power relay, which was controlled by a relay at the computer. The positive pressure side of the fan was secured so that discharge flowed directly into the control line.

Control of O_2 level proceeded in the following way. If, for example, room O_2 level exceeded the programmed setpoint, the N_2 solenoid and the two control solenoids at the room were opened. N_2 gas then flowed into the room for a time-controlled interval, which was programmed based upon operator experience. If O_2 level was below the programmed setpoint, the two control solenoids at the room were opened and the fan was turned on. Air then flowed into the room for a

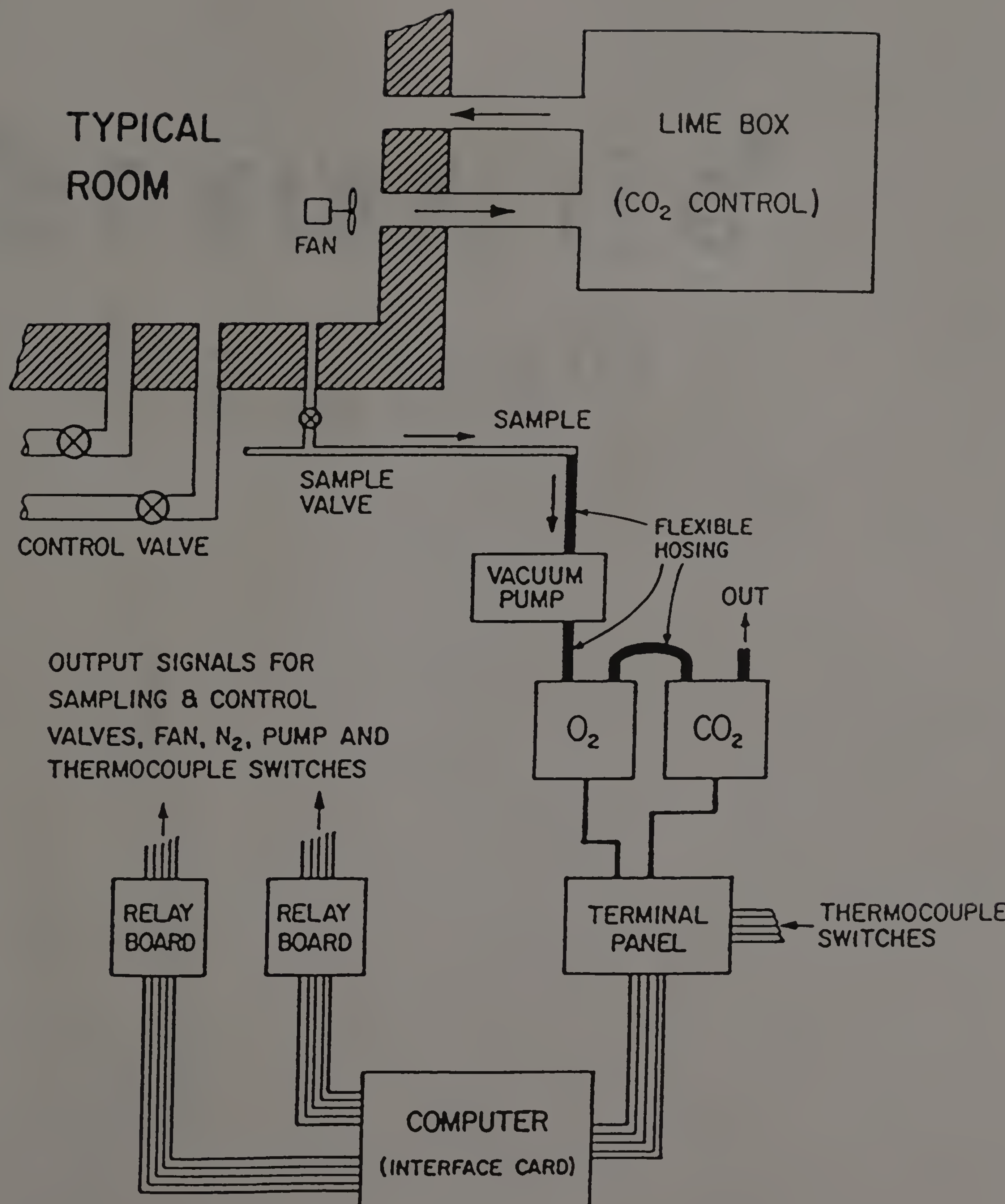

Figure 4. Equipment lay-out for automated monitoring and controlling.

programmed, time-controlled interval.

COMPUTER HARDWARE AND SOFTWARE

Automation of this system was achieved via a personal computer (Figure 4). A Leading Edge (model DC2011) with monitor was chosen, simply because it was available locally at a competitive price. It performed very well. However, it is probable that any IBM-compatible computer should be satisfactory. A data acquisition program well suited to this application was available through Strawberry Tree Computers, Sunnyvale, California (STC). An ACPC-12-8C interface card was purchased from this source and installed in the computer. Also, a STC T11 terminal panel with an isothermal block for thermocouples, was purchased and assembled, along with a Crydom NS-8N relay board, purchased from Newark Electronics. Although the latter board was less expensive than a comparable board from STC, it was not available with relays preinstalled. This difference necessitated a complex wiring job once it was received. A T31 relay board was later purchased to supply additional outputs needed as the project developed.

TEMPERATURE MONITORING

As previously described, the existing temperature monitoring system at the HRC was inadequate. Upgrading this system according to Cornell University recommendations (3) was accomplished, resulting in placement of 6 to 14 thermocouples per room. In addition, temperature monitoring was automated, since most of the equipment needed was already in place.

Multiple type-T thermocouples were placed in each room. The wires were passed through a hole and terminated on the outside wall of each room. A rotary switch was purchased for each room. The thermocouples were then attached to their appropriate positions on the switches, and a single thermocouple wire lead was run from each switch to an input on the T11 terminal panel. Electronic operation of each switch was controlled by a relay at the computer. A software modification was added to the STC program so that temperature could be monitored each time atmosphere was monitored for a room. After obtaining O_2 and CO_2 levels for a room, the program began pulsing the thermocouple switches and continued until readings had been obtained from each point in the room.

PART III. EFFECTS OF AUTOMATED VERSUS MANUAL ATMOSPHERE MANAGEMENT IN CONTROLLED ATMOSPHERE (CA) APPLE STORAGE ROOMS ON FRUIT QUALITY AND LABOR INPUT

In the CA apple storage industry world-wide, a shift is being made from manual to automated atmosphere management. An experiment was conducted during the 1986-87 season, at the University of Massachusetts Horticultural Research Center (HRC), which compared two different atmosphere management systems. One was a user-built automated monitoring and controlling system, described in Part II. The second system used an Orsat gas analyzer, the current Massachusetts apple industry standard, for monitoring and was controlled manually. Differences in fruit quality and labor input between systems were quantified, to determine whether automation might offer Massachusetts storages an improvement in either or both.

Samples of McIntosh apples were harvested from three blocks of trees on September 10, 1986. Blocks were chosen, by means of the starch-iodine test (13) and the flesh firmness test (using a Magness-Taylor pressure tester), to include fruit having received daminozide (immature), and fruit not having received daminozide and which were at two different levels of maturity. Samples were replicated six times within blocks, with one tree equaling one replication, and the total volume of 72 bushels was divided between two experimental CA rooms. Ten fruit from each sample were evaluated for maturity at harvest, using the starch-iodine and flesh firmness tests as criteria. The CA rooms were then sealed on September 15, 1986. After 90 days of storage (the legal minimum for CA), ten fruit per sample were compared, using the flesh firmness test, at three one-month intervals. After this time, a bushel of fruit from each sample was evaluated for shelf life and condition by leaving it at room temperature (70° F) for one week and then determining the number of fruit with senescent breakdown or rot.

Temperature, O_2, and CO_2 setpoints and experimental fruit were identical in each room. These were 37° F, 3% O_2, and 5% CO_2. However, O_2 and CO_2 levels in Room B were allowed to fluctuate. The fluctuation allowed was the average "typical fluctuation", as reported by Massachusetts CA storage operators in a 1986-87 survey. This fluctuation was plus or minus 0.8% O_2 and 1.2% CO_2. Room A was automatically monitored once per hour with O_2 level controlled by the automated system. The programmed deadban, or allowed fluctuation, for both O_2 and CO_2 control was plus or minus 0.1%. Room B was monitored with an Orsat gas analyzer once per day with O_2 level controlled manually. Room B was also monitored hourly by the automated system in order to provide a record of actual atmosphere composition between Orsat readings. A detailed log book was kept concerning time spent daily on each room and problems encountered.

A statistical analysis of variance was performed on starch and firmness data, using the SAS (2) program.

CHAPTER III

RESULTS

PART I. A SURVEY OF MASSACHUSETTS CONTROLLED ATMOSPHERE (CA) STORAGES

During the 1986-87 storage season, a survey was sent to each of the 28 CA storage operators in Massachusetts. Response rate was 100%. Responses represented 28 facilities having a total of 83 storage rooms with a total capacity of 588,650 bushels. The survey consisted of 43 questions, which related to capacity, desired control setpoints, monitoring and controlling techniques, degree of precision, and other factors. This information was necessary in order to accurately assess the potential benefits of a user-built, automated monitoring and controlling system to the Massachusetts apple storage industry. Table 2 tabulates survey results.

SIZE OF FACILITY AND DESTINATION OF FRUIT STORED

Responses represented 28 CA facilities having a total of 83 storage rooms with a total capacity of 588,650 bushels. The average sized storage was 21,000 bushels. Fifty percent of the facilities had a capacity of 15,000 bushels or less. CA room size ranged from 600 bushels to 33,000 bushels, with an average size of 7,100 bushels. The total number of CA storage rooms was 83. Thirteen of the 28 storages had one or two CA rooms, while 10 had 3 or 4 rooms, 4 had 5 rooms, and one had 7 rooms. All but four of the operators stored exclusively their own fruit, and an average of 84% of that was destined for the wholesale market. On average, 77% of the stored fruit was McIntosh.

Table 2. A survey of Massachusetts controlled atmosphere (CA) storages.

1. In what year was your CA storage built?

1950's	10
1960's	12
1970's	14
1980's	6
multiple response	13
no response	1

2. Was it built for CA, or was it converted from a regular storage?

Converted	8	29%
For CA	18	64%
no response	2	7%

3. a) How many bushels of apples do you store under CA conditions each season?

2,400- 6,000	4	
6,001- 9,000	6	50%
9,001-12,000	4	
12,001-15,000	2	
15,001-18,000	1	14%
18,001-21,000	1	
21,001-24,000	1	
24,001-27,000	2	18%
27,001-30,000	2	
43,000	1	
50,000	1	11%
53,000	1	
71,000	1	
60,000-90,000	1	7%
no response	0	

b) What percent of these are McIntosh?

40- 60%	4	14%
60- 80%	11	39%
80-100%	11	39%
no response	2	7%

4. What percent of these apples are your fruit (as opposed to those you may store for others)?

100% own	24	86%
75-85% own	3	11%
0% own	1	3%
no response	0	

Table 2. Continued

5. What percent of your apples are for direct retail sale?

less than or equal to 10%	: 15	54%
11- 20%	: 5	18%
21- 30%	: 5	18%
90-100%	: 2	7%
no response	: 1	3%

6. a) How many individual CA rooms do you have?

1	: 5	18%
2	: 8	29%
3	: 5	18%
4	: 5	18%
5	: 4	14%
7	: 1	3%
no response	: 0	

b) What is the approximate capacity (in bushels) of each room?

0- 1,000	: 2	
1- 2,000	: 2	18%
2- 3,000	: 11	
3- 4,000	: 13	
4- 5,000	: 4	34%
5- 6,000	: 11	
6- 7,000	: 9	
7- 8,000	: 5	19%
8- 9,000	: 2	
9-12,000	: 10	12%
12-16,000	: 8	10%
30,000	: 1	1%
no response	: 5	6%

7. How often are rooms sealed and checked for leaks before filling?

never	: 1	4%
sporadically	: 3	11%
biannually	: 6	21%
annually	: 18	64%
no response	: 0	

8. What kind of refrigerant do you use?

freon	: 19	68%
ammonia	: 9	32%
no response	: 0	

Table 2. Continued

9. Do you measure temperature in individual apples during precooling?

yes	6	21%
no	22	79%
no response	0	

10. a) How long, on the average, does it take you to fill a room?

1 week or less	11	39%
1-2 weeks	14	50%
2 weeks or more	1	4%
no response	2	7%

b) How long, on the average, does it take you to empty a room?

2- 4 weeks	6	21%
4- 8 weeks	10	36%
8-12 weeks	6	21%
no response	6	21%

11. What method for atmosphere pulldown do you use?

liquid Nitrogen	12
solely or mainly fruit generated	10
catalytic generator	6
fossil fuel burner	5
multiple response	5
no response	0

12. How long does it typically require to reach 5% O_2 in your rooms?

within 3 days	11	39%
4-7 days	4	14%
more than 7 days	11	39%
no response	2	7%

13. How do you measure temperature in your CA rooms?

thermometers	27
thermocouples	9
thermistors	1
multiple response	8
no response	0

Table 2. Continued

14. How many temperature-measuring instruments do you have in each room?

one	:	10	36%
two	:	11	39%
more than two	:	7	25%
no response	:	0	

15. Where are the temperature-measuring instruments located in a room?

near door	:	21
near refrigeration unit	:	6
other areas	:	7
multiple response	:	6
no response	:	2

16. How frequently do you calibrate temperature-measuring instruments?

annually	:	20	71%
biannually	:	3	11%
never	:	4	14%
no response	:	1	4%

17. What do you use to compensate for changes in atmospheric pressure?

breather bags	:	23
U-tube	:	6
nothing	:	2
multiple response	:	3
no response	:	0

18. a) Do you cover the floor with water before sealing?

yes	:	19
no	:	12
multiple response	:	3
no response	:	0

b) If so, is water still on the floor when you open the rooms?

yes	:	18	95%
no	:	1	5%
no response	:	0	

19. Do you measure humidity?

yes	:	4	14%
no	:	24	86%
no response	:	0	

Table 2. Continued

20. How do you measure atmosphere in your CA rooms?

Orsat with bulb/syphon	21
Orsat with pump	8
multiple response	1
no response	0

21. Do you need to replace chemicals in your Orsat during a CA season?

yes	11	39%
no	16	57%
no response	1	4%

22. a) Approximately how long are your sample lines?

1 -25 ft.	25
26-50 ft.	5
more than 50 ft.	3
multiple response	5
no response	0

b) What material are they made of?

copper	17
rubber or plastic	12
multiple response	3
no response	2

23. What O_2, CO_2, and temperature levels do you attempt to maintain in your McIntosh rooms?

O_2:	2.1-2.5%	3	
	2.6-3.0%	16	(13 stated 3% exactly)
	3.1-3.5%	8	
	3.6-4.0%	3	
	4.1-4.5%	2	
	4.6-5.0%	3	
	multiple response	4	
	no response	1	
CO_2:	2.5%	1	
	3-4%	5	
	4-5%	21	(14 stated 5% exactly)
	5-7%	1	
	multiple response	2	
	no response	2	

Table 2. Continued

temp:	34° F	:	2
	35	:	4
	36	:	8
	37	:	4
	38	:	5
	multiple response	:	6
	no response	:	14

24. How often is the atmosphere in each room measured?

less than once per day	:	3	11%
once per day	:	18	64%
more than once per day	:	7	25%
no response	:	0	

25. How many people do the analyzing?

one	:	14	50%
two	:	12	43%
three or more	:	2	7%
no response	:	0	

26. Who does the analyzing?

respondent	:	23
other	:	11
multiple response	:	7
no response	:	1

27. Do atmospheres in some rooms fluctuate a great deal more than those in others?

yes	:	11	39%
no	:	12	43%
not applicable	:	5	18%
no response	:	0	

28. In what you consider to be a good room, how much do temperature, O_2, and CO_2 usually fluctuate during a season above or below what you want them to be?

temp.:	$0\text{-}1^{\circ}$ F	:	12	43%
	1-2	:	9	32%
	no response	:	7	25%

Table 2. Continued

O_2:	0-.5%	15	54%
	.5- 1%	3	11%
	1- 2%	4	14%
	more than 2%	2	7%
	no response	4	14%
CO_2:	0-1%	15	54%
	1-2%	7	25%
	more than 2%	2	7%
	no response	4	14%

29. In what you consider to be a difficult room, how much do these conditions typically fluctuate?

temp.:	0-2° F	7	25%
	4° F	1	4%
	never bad	7	25%
	no response	13	46%
O_2:	0-2%	7	25%
	3%	1	4%
	4%	1	4%
	5%	2	7%
	never bad	7	25%
	no response	10	36%
CO_2:	0-2%	5	18%
	3%	1	4%
	4%	1	4%
	5%	1	4%
	8%	1	4%
	never bad	7	25%
	no response	12	43%

30. a) How often must you adjust the atmosphere in a good room?

less than once per week	4	14%
once per week	5	18%
twice per week	5	18%
more than twice per week	9	32%
no response	5	18%

b) In a difficult room?

every one to two days	8	29%
other	5	18%
no difficult rooms	6	21%
no response	9	32%

Table 2. Continued

31. Which component of the atmosphere is most difficult to maintain in your situation?

no difference	7
temperature	0
O_2	14
CO_2	8
multiple response	1
no response	0

32. What procedure or procedures do you use to add O_2?

never done	1
blow in air	8
controlled leak	22
multiple response	3
no response	0

33. a) What procedure or procedures do you use to scrub CO_2?

lime box	22
lime in room	8
water scrubber	2
charcoal	4
multiple response	7
no response	0

b) If you use a lime box, do you use a fan for your lime box?

always	7	32%
sometimes	5	23%
never	10	45%
no response	0	

34. On the average, how much time per day do you estimate is spent maintaining one room?

6-15 minutes	14	50%
16-26 minutes	10	36%
40-64 minutes	4	14%
no response	0	

35. How often do you see low O_2 injury, high CO_2 injury, freezing injury or brown core on fruit coming from storage?

never	8	29%
occasionally a small amount	17	61%
regularly a small amount	2	7%
no response	1	4%

Table 2. Continued

36. If you see such damage, which form is most often a problem for you?

freezing	7
brown core	6
high CO_2	2
low O_2	1
multiple responses	2
no response	5

37. In general, are you satisfied with your storage operations?

yes	26	93%
no	2	7%
no response	0	

38. What aspect or aspects of storage management would you most like to improve?

atmosphere generation	3
temp. monitoring	4
temp. control	1
O_2 and CO_2 monitoring	2
CO_2 control	2
pressure relief	1
multiple response	3
no response	19

39. How much do you spend each year, per room, for chemicals for your Orsat?

$ 10- 30	14	50%
$ 31- 50	7	25%
$ 51- 70	2	7%
$ 71-100	2	7%
no response	3	11%

40. How much do you estimate that you spend each year, per room, for labor to maintain storage atmospheres?

$ 100- 200	6	21%
$ 201- 300	6	21%
$ 301- 450	4	14%
$ 600- 715	2	7%
$1000-1500	2	7%
$3750	1	4%
no response	7	25%

Table 2. Continued

41. Do you own and use a personal computer?

yes	: 11	39%
no	: 17	61%
no response:	0	

42. Have you ever considered using automated measurements and/or controls for your CA storage management?

yes	: 11	39%
no	: 16	57%
no response:	1	4%

43. Additional comments.

ROOM CHARACTERISTICS

Survey participants reported that 68% of CA facilities used freon refrigeration systems, and 32% used ammonia. Sixty-four percent of the operators sealed and tested rooms for leaks annually, 21% biannually, and 15% sporadically or never. Breather bags were the predominant pressure relief system. Eighty-two percent of the CA operations had breather bags, while 21% used U-tubes, and 7% used nothing. Twenty-one percent of the operators reported checking fruit temperature during precooling, while 79% did not. Thirty-nine percent of respondents typically filled a room within a week of initial fruit loading. Twenty-one percent of respondents typically finished packing out a room within a month of unsealing it. When a CA room required O_2, 22 operators used controlled leaks and 8 used blown in air. To control CO_2 level, 22 operators used lime boxes, 8 used lime directly in the room, 2 used water scrubbers, and 4 used charcoal-type absorbers. Of the 22 lime box users, 10 never used a fan, 7 always used a fan, and 5 sometimes used a fan.

TEMPERATURE MONITORING

Thermometers were used more often than more sophisticated devices for measuring temperature. Twenty-seven of the 28 storages used thermometers, while 9 used thermocouples, and 1 used thermistors. Seventy-five percent of respondents monitored temperature in one or two locations per room, and 25% placed more than two devices per room. Forty-six percent of the operators monitored temperature near the door of the room only, while 54% noted other monitor locations, these being most often near refrigeration units. Temperature monitoring devices were reportedly calibrated annually by 74% of the respondents, biannually by 11%, and never by 14%.

ATMOSPHERE GENERATION

Forty-three percent of the facilities reported using liquid nitrogen for generation of the initial CA atmosphere. Fruit respiration was the sole or main generator for 36%, while 18% used a fossil fuel burner, and 21% used a catalytic generator. Thirty-nine percent of the operators reported achieving a 5% O_2 atmosphere within 3 days of sealing a room, while 14% required 4 to 7 days, and 39% took more than 7 days.

HUMIDITY

Water was added to the floors of all or some of their rooms by 68% of the operators. In all but one of these facilities, water still covered the floor when rooms were opened. Relative humidity within rooms was never tested at 86% of the storages.

ATMOSPHERE MONITORING

Gas analysis was performed with an Orsat analyzer at all 28 facilities. Eight of the facilities used a pump to draw the air sample to the Orsat, while 21 used an aspirator bulb or simply siphoned in room air. Sample lines of length greater than 25 feet were reported by 8 operators. Sixty-one percent of the storages used copper sample lines. Orsat chemicals were replaced during the storage season by 41% of respondents. Frequency of atmosphere monitoring was less than once per day at 3 facilities, once per day at 18 facilities, and more than once per day at 7 facilities. At 50% of the storages, the same person performed the gas analysis every day, while 43% reported one of two people doing it, and 7% used more than two people.

O_2, CO_2, AND TEMPERATURE LEVELS

Responses indicating a range of values as setpoints were tabulated at each level of the range given. For example, the response "2.1-3.0%" was tabulated once in the 2.1-2.5% range and once in the 2.6-3.0% range. Fifty percent of the operators did not respond to the question on desired temperature in a McIntosh room. Of the respondents, 26% kept rooms at 34 or 35° F, 35% kept rooms at 36° F, and 39% kept rooms at 37 or 38° F. Nearly all (96%) storage operators answered the question on desired O_2 level in a McIntosh room. Responses varied widely, but 46% named 3% O_2 as their specific setpoint. Of the others, 6 noted 2.1 to 3.0% as all or part of their range, 11 noted 3.1-4.0%, and 5 noted 4.1-5.0%. Similarly, 50% of the operators said that 5% CO_2 was their desired setpoint for McIntosh rooms, while other responses varied widely. These were: 2.5% CO_2, noted once; 3.0-4.0%, noted 5 times; 4.0-5.0%, noted 7 times; and 5.0-7.0%, noted once.

ATMOSPHERE CONTROLLING

When asked if atmosphere in some of their rooms typically fluctuated more than in others, 39% of the respondents answered yes and 43% said no. Storage operators were then asked to quantify typical fluctuation of temperature, O_2, and CO_2 levels in what they considered to be a good room. For temperature, 12 responses were in the 0 to 1° F range and 9 were in the 1 to 2° F range. For O_2, 15 responses were in the 0-0.5% range, 3 noted 0.5-1.0%, 4 noted 1.0-2.0%, and 2 noted fluctuation greater than 2.0%. For CO_2, 15 responses were in the 0-1.0% range, 7 noted 1.0-2.0%, and 2 noted fluctuation greater than 2.0%. Operators were also asked to quantify typical fluctuation in what they considered to be a difficult room. Seven operators stated that they had no difficult rooms. Twelve operators quantified fluctuation, but some gave only partial answers. For temperature, 7 responses were in the 1 to 2° F range, and 1 noted a 4° F fluctuation. For O_2, 7 responses were in the 0-2% range, and 4 noted a 3-5% fluctuation. For CO_2, 5 responses were in the 0-2% range, 3 noted 3-5%, and 1 noted an 8% fluctuation. Ninety-six percent of the operators responded to the question, "Which of the three variables is most difficult to hold?" Seven stated that they found no difference, 14 noted O_2, 8 noted CO_2, and none noted temperature. Operators were also asked to quantify any injury to fruit occurring during CA storage. Of the 17 respondents, 8 never saw injury, 17 occasionally saw a small amount, and 2 regularly saw a small amount. Freezing was noted as the most common type of injury by 7 operators, brown core by 6, high CO_2 by 2, and low O_2 by one.

COSTS

For annual labor costs, per room, to maintain storage atmospheres, 6 of the operators spent $100-200, 6 spent $201-300, 4 spent $301-450, 2 spent $600-715, 2 spent $1000-1500, and 1 spent $3750. In annual expenditures on Orsat chemicals, per room, 14 facilities spent $10-30, 7 spent \$31-50, 2 spent \$51-70, and 2 spent \$71-100.

AUTOMATION

When asked if they had ever considered automated monitoring and controlling, 11 operators said yes and 16 said no. Eleven of the storage facilities currently used a computer for some part of their business and 17 did not.

PART II. AUTOMATION OF THE CA STORAGE FACILITY

The automation of the storage facility at the University of Massachusetts Horticultural Research Center was described and illustrated in a paper, prepared for publication as a University of Massachusetts Cooperative Extension bulletin. A summation of this bulletin is provided here. The complete bulletin is included as Appendix B.

The bulletin contains five sections, these being the introduction, three sections which describe automation, and the conclusion. In the introduction, limitations of the Orsat gas analyzer are discussed. Both user built and package systems for automation are mentioned as alternatives to the Orsat. The user built method of automation is then described in three separate steps, these being electronic monitoring, automated monitoring, and finally, automated monitoring and controlling of O2 level. Necessary components are listed for each step and costs are given. Figures are provided for each step, which illustrate the equipment configurations. A table was included to assist readers in selection of appropriate hardware and software, based on the number of CA rooms to be automated. The conclusion states the final cost of \$8200 for automation of monitoring and O2 control in the four CA rooms at the HRC. The time input and dedication required to install such a system ls emphasized.

PART III. EXPERIMENTAL RESULTS

Time required to obtain an atmosphere reading, using the Orsat with a vacuum pump, was monitored on 50 separate occasions for the same operator. Average time elapsed for the procedure was 8.2 minutes. Time required to obtain stable readings with the electronic O_2 and CO_2 analyzers was monitored on the same occasions. Average time elapsed was 35 seconds.

Table 3 shows that fruit of three different conditions were stored, these being as follows: relatively mature, but with and without daminozide (Blocks 1 and 2), and relatively immature with daminozide (Block 3).

Table 4 shows that the main effects of storage rooms, orchard blocks, and months in storage all were significant factors in fruit firmness after storage. The significance of Storage rooms was the focus of this experiment and is elaborated upon in the discussion section. The significance of Orchard blocks showed that fruit of differing initial condition responded differently to the storage regimes. The significance of Months in storage simply indicated that fruit lost firmness over time.The significance of Rooms by months, Blocks by months, and Rooms by blocks by months interactions was discounted since these factors had very small mean square values.

Table 3. Starch scores at harvest of McIntosh apples from three different blocks. 1986.

Block	Starch score [z]
1	5.8 a [y]
2	6.3 a
3	3.7 b

z. Score: 1 to 9, with 1= most starch and 9= least starch (4).
y. Means followed by the same letter are not significantly different at P= 0.05, using Duncan's New Multiple Range Test.

Table 4. Analysis of variance, firmness changes in McIntosh apples during storage.

Source	df	MS	F	Sig[z]
Storage rooms	1	22.88	62.1	***
Orchard blocks	2	20.19	54.8	***
Months in storage	3	200.26	1160.5	***
Rooms x blocks	2	0.58	1.6	NS
Rooms x months	3	2.82	16.3	***
Blocks x months	6	2.52	14.6	***
Rooms x blocks x months	6	0.66	3.8	**
Rep (Rooms x blocks)	30	0.37		
Month x rep (Rooms x blocks)	90	0.17		

z. Level of significance: **, P= 0.01; ***, P= 0.001; NS, not significant.

Table 5 shows the average loss of firmness for each orchard block under the two storage regimes. Fruit from Blocks 1, 2, and 3 from Room A and Block 1 from Room B all lost the same amount of firmness. Fruit from Blocks 2 and 3 from Room B lost significantly less firmness. This difference simply shows that fruit of different initial conditions responded differently to the two storage regimes.

Table 6 shows the average flesh firmness for fruit from each orchard block over time under the two storage regimes. Fruit from each block in each room lost firmness over time. The greatest losses occurred between months 3 and 4 of the storage period. Average firmness was greater for fruit from Room B than for those from Room A. These results show that the overall effect of the fluctuating atmosphere conditions in Room B was to decrease fruit softening.

A bushel of fruit from each sample was evaluated for shelf life and condition after the CA storage period. After one week at room temperature, no senescent breakdown or rot was found in any of the samples.

Table 5. Loss of firmness after five months in storage of McIntosh apples that were harvested from three different blocks of trees and stored under two different regimes at the University of Massachusetts Horticultural Research Center, Belchertown, MA. 1986-87.

Block	Room A [z]	Room B [y]
	(lbs. pressure)	
1 [x]	5.3 a [w]	5.1 a
2 [v]	5.5 a	3.4 b
3 [u]	4.9 a	3.5 b

z. Operated at 3° C, 3 plus or minus 0.1% O_2, and 5 plus or minus 0.1% CO_2.
y. Operated at 3° C, 3 plus or minus 0.8% O_2, and 5 plus or minus 1.2 % CO_2.
x. Block treated with daminozide, fruit relatively mature.
w. Mean separation within room by single degree of freedom comparisons (P= 0.05).
v. Block not treated with daminozide, fruit relatively mature.
u Block treated with daminozide, fruit relatively immature.

Table 6. Changes in firmness during storage of McIntosh apples that were harvested from three different blocks of trees and stored in two different controlled atmosphere storage rooms maintained under different management systems. 1986-87.

Months of storage	Firmness (lbs) of apples from: Block 1	Block 2	Block 3
		Room A	
0	17.3	16.0	17.6
3	15.2	15.1	16.4
4	11.5	12.0	12.8
5	12.0	10.5	12.7
Mean	14.0	13.4	14.9
		Room B	
0	17.7	15.8	17.4
3	16.1	16.2	17.1
4	13.0	13.1	13.5
5	12.5	12.4	13.8
Mean	14.8	14.4	15.5

CHAPTER IV

DISCUSSION

Recent work in British Columbia shows that a "rapid CA" procedure can significantly improve fruit quality of McIntosh apples (10). A combined short time of loading (2 to 3 days) and rapid reduction of storage O_2 level to the desired setpoint (2 to 3 days) had been recommended. Rapid cooling of fruit prior to CA storage also provides significant improvements in quality (15). Massachusetts CA storage operation contains considerable room for improvement in these areas. Eighty percent of the operators do not monitor fruit temperature during pre-cooling. Only 40% are able to load rooms in a week or less. Storage O_2 level is attained in three days by just 40% of the facilities. In addition, 80% of the operators are unable to market all the fruit from a storage room within a month of removing CA conditions. Smaller CA rooms, improved temperature monitoring, and faster methods for generation of the storage atmosphere offer solutions to these problems.

The CA apple storage industry in Massachusetts is relatively small. A total of 28 facilities, with an average capacity of 15,000 bushels, represent a state-wide CA capacity of just 588,650 bushels. As a point of comparison, Michigan, which in 1986 was the third largest apple producing state (6), has a total of 99 facilities, with an average capacity of 67,000 bushels, which make up a state-wide CA capacity of about 6 million bushels (5). Average CA room size in Massachusetts is 7,000 bushels, compared to 16,500 bushels in Michigan.

About half of the storages in Massachusetts have just one or two CA rooms. For these small CA operations, the high cost of a "package" system for automated atmosphere monitoring and controlling probably cannot be justified. If automated systems are to be installed in Massachusetts facilities, the less expensive user-built type is probably more economically feasible.

Conclusions as to the potential benefits of automated systems to CA fruit quality in Massachusetts are speculative. In storages where O_2 and CO_2 are kept at the recommended levels, and where relatively little (less than 0.5%) O_2 fluctuation is noted, an automated system perhaps offers no significant improvement in fruit quality. However, many storage operators do not maintain O_2, CO_2, and temperature levels in McIntosh storage rooms at the recommended setpoints (Table 2). For temperature, most survey respondents noted setpoints below the recommended level. Also, 75% monitored temperature at just one or two locations in a room. Although operators stated that of O_2, CO_2, or temperature, temperature was the easiest factor to maintain, low temperature disorders were the most frequently reported injury to CA fruit. This contradiction clearly points to the need for better temperature monitoring in CA rooms. The use of multiple thermocouples according to Cornell University recommendations (3) is one way to solve this problem. Such a system has been installed at the HRC and should be easily adapted to automatic monitoring. The basic system used in automating temperature monitoring at the HRC works well; however, the switches that were purchased are not suited for this application, failing to provide proper readings in a consistent manner. We are currently searching for suitable switches with which to replace them. Therefore, recommendations for automated temperature monitoring are not available at this time. Further work to determine the best method is proceeding.

As regards O_2, over half of the facilities are maintained at levels higher than the recommended 3%. Very few operators reported maintaining O_2 levels below 3%. Perhaps this is because of the prevalent opinion that the risk of fruit injury from lowering O_2 level far outweighs the proven benefit of increased flesh firmness. However, this reasoning does not explain the fact that many growers allow O_2 levels to exceed the recommended 3% level. The 3% recommendation is a conservative one, in that it sacrifices some potential fruit quality in order to incorporate margins for error due to the Orsat method of monitoring. The survey revealed that all Massachusetts CA atmospheres are monitored with an Orsat gas analyzer, and that at the great majority of facilities, reading is done only once per day. Half the operators stated that O_2 level was the most difficult factor to maintain. A logical conclusion, then, would be that many storage operators are not confident in the Orsat method for monitoring and controlling O_2 level.

As regards CO_2 level, about half the survey respondents used setpoints below the recommended 5%. This may also be due, in part, to a lack of confidence in the Orsat method. In addition, over half of the CA fruit stored in the state is of the cultivar McIntosh. With its inherently fragile postharvest life, this cultivar requires good storage management. Reports of "soft" McIntosh being removed from CA storages are relatively common (4). By enabling storage operators to improve the precision and frequency of atmosphere monitoring, proper McIntosh storage setpoints could be maintained with confidence. Thus, automated systems could significantly improve CA fruit quality in Massachusetts.

Unmeasured fluctuation of storage O_2 level is inherent in an Orsat-controlled system (11). At the HRC, we also found this to be the case, if air or N_2 gas was blown into a room to correct O_2 level. When monitoring frequency is just once per day, these types of control necessitate overcompensation or undercompensation by the operator so that O_2 will be at the anticipated level when atmosphere is next monitored. If instead, a "controlled leak" was used to maintain O_2 level, less fluctuation was noted. About 75% of Massachusetts CA operators use "controlled leaks" to maintain O_2 level. Therefore, it may be assumed that unmeasured fluctuation of O_2 level is not as great a detriment to fruit quality as is improper setpoint in Massachusetts CA storages.

Average measured fluctuations of O_2 and CO_2 levels, according to the storage survey, were 0.8% and 1.2% ,respectively. However, it cannot be assumed that these are "plus or minus" with respect to setpoint, due to ambiguity of the responses. In fact, the few operators who specifically noted "plus or minus" in their responses all reported the greatest fluctuation on the plus side for O_2 level and on the minus side for CO_2 level. The nature of this fluctuation, in combination with typically high setpoints for O_2 level, probably compounds any detriment to fruit quality resulting from current Massachusetts CA management.

The storage experiment conducted as part of this project did not properly address the effects of measured fluctuation in O_2 and CO_2 levels, typical of the Orsat method and once-per-day monitoring frequency, on fruit quality. It is apparent from the experimental results (Table 5) that the amount of fluctuation imposed in Room B had a confounding effect on the data. Fruit from two of the three experimental blocks softened less under fluctuating conditions than when atmosphere levels were relatively constant. This situation could be explained based on the non-linear relationship between fruit softening and both O_2 and CO_2 levels, as they fluctuate around 3% and 5%, respectively. Previous work has shown that the effect of O_2 level on fruit softening diminishes sharply above 3% (8), and increases sharply below 3%. Although less well documented, the influence of CO_2 could be similar at levels below and above 5%. Therefore, it could be reasoned that the cumulative effect on the experimental fruit in Room B of low O_2 and high CO_2 levels outweighed the effect of high O_2 and low CO_2 levels. Thus, less softening occurred in Room B than in Room A, where O_2 and CO_2 levels fluctuated less.

Although none of the experimental fruit from Room B were affected, other fruit from that room were found to have high CO_2 injury upon removal from storage. It is known that CO_2 levels higher than the recommended 5% can benefit fruit quality, but at a risk of injury. The logical conclusion is that the maximum CO_2 levels, during the fluctuations maintained in Room B were sufficient to be injurious to the most sensitive fruit. Thus, the amount of fluctuation that existed in the atmosphere in Room B actually reduced softening of fruit, but did so at the risk of fruit injury.

The following are some specific comments about the choices of hardware made in automating the HRC storage facility. Firstly, the ACPC-12-8C interface card includes a clock. However, in running the program, we found that it performs better using the clock in the computer Therefore, we could have saved money and confusion by omitting the clock when purchasing the interface card. Secondly, we chose to buy the T11 terminal panel, which is relatively expensive, because of the increased accuracy with which it reads thermocouples (within 0.7° F for the T11, as opposed to within 2° F for the T31 relay board without an isothermal block). We also used inputs on the T11 for signals from the O_2 and CO_2 analyzers. If we had not included temperature monitoring in the system, we could have purchased a T41 terminal panel, which combines both inputs and outputs on one component.

Finally, automation of monitoring and controlling results in a significant time savings on daily atmosphere management. In the experiment at the HRC, obtaining an atmosphere reading with an Orsat took an average of 8 minutes, as opposed to 45 seconds with the electronic instruments. The initial set-up of a user-built system requires a great deal of time and dedication on the part of the storage operator. In Massachusetts, 50% of CA storages are currently monitored and adjusted by the same person every day. In most cases, this would be the logical person to install such a system, since he or she would possess the required knowledge of the facility. After the basic system is installed and the initial computer programming is accomplished, changes to sampling frequency, setpoints, and control timing can be made very quickly. Aside from weekly calibration of the gas analyzers, no routine maintenance of the system is required.

In conclusion, automation of atmosphere monitoring and controlling offers several potential benefits to storage operators. The electronic analyzers are capable of more accurate O_2 and CO_2 measurement than is possible with an Orsat analyzer. Automated monitoring results in more frequent monitoring, and thus, in better maintenance of the CA atmosphere. Automation of the CA monitoring and controlling procedures results in significant daily time savings for the operator. Finally, automated data logging at each sampling period results in a detailed record of atmosphere levels. This record can be used to identify potential problems as they develop and to diagnose problems discovered after storage. All of these factors point to a potential benefit of automated monitoring and controlling for improving fruit quality in Massachusetts.

APPENDIX A.
AUTOMATIC MONITORING AND CONTROLLING OF
CONTROLLED-ATMOSPHERE APPLE STORAGES

A. A grant-proposal submitted by the Department of Plant and Soil Sciences, in conjunction with the Department of Food Engineering, University of Massachusetts, Amherst.

B. REASONS FOR UNDERTAKING THE PROJECT, AND ITS RELATIONSHIP TO AGRICULTURE AS PRACTICED IN MASSACHUSETTS.

Northeastern U.S. growing conditions are ideal for producing McIntosh apples: the motto "This is McIntosh country" is apt. With McIntosh, the Northeast can produce an unique alternative to varieties such as Delicious, Golden Delicious, and Granny Smith that can be grown more efficiently in other parts of the world. The strength of the Northeastern fruit industry rests upon the competitiveness of this alternative.

Even grown in the Northeast, however, McIntosh has a high rate of deterioration and therefore an inherently fragile postharvest life. Storage at 32°F slows deterioration markedly, but at this temperature McIntosh are subject to low-temperature disorder called "browncore", in which the core area deteriorates and turns brown, and the apple loses its market appeal.

Development of controlled atmosphere (CA) storage revolutionized the McIntosh industry. By maintaining an atmosphere of 3% oxygen (O_2) and 5% carbon dioxide (CO_2) rather than air in the storage, ripening is greatly depressed and temperature can be maintained at 36-38°F to avoid browncore. Even at this higher temperature McIntosh can be stored until late spring and still retain high quality, whereas in 32°F air they cannot be stored and marketed past early March. Thus, the McIntosh market was extended from a maximum of 6 months in air storage to nearly year-round in CA, and a far stronger and more orderly marketing situation resulted.

However, longterm CA storage is possible only with careful management of the apple harvest, rapid development of the storage atmosphere, and precise maintenance of the storage conditions. Frequently, inferior-quality fruit are removed from storage because of failure to properly manage these operations. In some years, prevalence of these inferior-quality fruit severely depresses McIntosh prices and profitability.

A critical feature of storage management is control of the atmosphere. Temperature may be monitored by many means but is often measured only by a single thermometer on the storage door. In Massachusetts, O_2 and CO_2 concentrations are measured probably exclusively by an Orsat analyzer. This device uses very precise chemical reactions to measure these gases, but the reactants are contained in a manual system that cannot be read accurately. Furthermore, time limitation usually results in no more than one reading per day, at best. When the O_2 is too low or CO_2 too high, adjustments are made with manual controls. The result is that the atmospheric composition is continually fluctuating. Commercial recommendations for the CA atmosphere take this into account by incorporating margins for error, thus sacrificing some potential for better storage. Even with the "cushion", storage operators frequently do not stay within safe limits or within beneficial conditions, and fruit quality deteriorates accordingly.

During the past 20 years, the growth regulator Alar^{TM} has been used on most of the McIntosh stored for long periods. Alar^{TM} is a powerful management tool, because it slows down fruit ripening. This has allowed growers to stretch out their harvest period of fruit for long-term storage, to get away with delays in cooling fruit and getting them under the desired atmosphere, and in many cases to get away with considerable sloppiness in storage operation. The likely loss of Alar^{TM} will greatly increase the need for better harvest and storage management if McIntosh are to be suitable for late-season marketing.

Technology is readily available to assist the storage operator in better monitoring and controlling the storage atmosphere. Temperature can be accurately monitored by either thermistors or thermocouples, both of which can be placed in key locations in the storage room and attached to an external monitor. Highly reliable paramagnetic O_2 analyzers and infrared CO_2 analyzers are available for rapidly and accurately measuring the composition of the storage atmospheres. Computers can be used both to control the operation of these monitors and to handle the data they generate.

The monitoring operations can also be tied into automatic adjustments of the atmospheric conditions, or at least to activate alarms when set limits are reached. It is also possible to utilize sensors for relative humidity and for ethylene concentration, two parameters not monitored or controlled in conventional CA but which are significant factors in quality maintenance of McIntosh apples.

Technology for automatically monitoring and controlling apple storage atmospheres was pioneered in England and has rejuvenated its apple industry. England's leading variety, Cox's Orange Pippin, can be stored at 1% O_2 and less than 1% CO_2. In this low O_2 atmosphere, its ripening is delayed much more than in conventional CA, and its marketing period is extended by at least 2 months. However, exacting control of the storage atmosphere is essential; temperature, O_2 and CO_2 must be monitored hourly and automatically, and O_2 concentration must be controlled automatically. Currently, at least 15% of the English apple crop is kept under these conditions, and the controlling systems are so effective and (reputedly) labor-saving that they are being applied very rapidly to storages containing fruit under conventional CA conditions.

The majority of English fruit are stored in large cooperative facilities. This provides economy for purchase and use of large "package" systems which are produced by several engineering companies. This equipment is available to all parts of the world and has spread rapidly. A number of large cooperative storages in the U.S. and Canada have purchased the equipment and are employing it with success.

In New England, and especially in Massachusetts, few cooperative storages exist. Most growers store their own fruit in relatively small facilities. For them, purchase of a "package" system may be prohibitively expensive, especially now when many growers are in difficult financial situations.

It should be possible for an individual storage operator to purchase a series of components on the open market, interface them to a personal computer, and accurately and frequently monitor storage conditions. If desired, it should also be possible to develop automatic controls of O_2, temperature, and CO_2 in the storage environment. However, background information on the specifications required for components, the proper positioning, numbers and types of sensors, and necessary operating conditions is not available.

We propose to purchase a set of components, apply them to a series of CA storages at the University of Massachusetts Horticultural Research Center in Belchertown, and combine the expertise of the University's horticulturists, agricultural engineers, and computer technicians to develop these components into an automatic monitoring and controlling system.

C. SIGNIFICANCE OF PROJECT IN THE FIELD

Information gained from this project would be used to prepare guidelines for storage operators interested in developing such a system. Furthermore, the system would be available for inspection by storage operators, and personnel involved in the project would be able to freely relay their experiences to interested parties.

We believe that improved storage management will become essential if Alar™ is no longer available for use, and automatic monitoring and control is a proven technique for more accurate and efficient storage management. Even if Alar™ continues to be available for use, automatic storage operation is a technique for reducing dependence on this chemical. We view automatic storage operation as a significant response by apple growers to the "Alar™ problem".

If a storage atmosphere is monitored accurately and frequently, and at least temperature and O_2 are strictly controlled, it may be possible to reduce the O_2 concentration in the storage to 2.5% or 2.0%. This would add considerably to the storage potential of the apples and help offset the likely loss of Alar™ in providing McIntosh for late-season marketing.

We believe that individual storage operators can develop their system from available components, thus tailoring a system to their individual needs and finances. What they need is guidance and this proposal is developed to produce that guidance.

D. BUDGET:

Direct costs:

Computer, Leading Edge (PC compatible)	$1200
Data interface, "Metrabyte A/D converter"	400
Input accessory board	125
I/O accessory board	125
Thermocouple amplifier and multiplexer	400
Input module for I/O board	20
Output module for I/O board	60
Printer and driver	500
Subtotal, sensor equipment	$2830
Oxygen sensor, "Teledyne", with output signal	$1500
Carbon dioxide sensor, "Horiba", with output signal	1500
Thermocouple wire and supplies	1000
Dewpoint sensor, "EG & G", with output signal	1295
Subtotal, sensor equipment	$5295
Summary Salary, 1 month, E.A. Johnson	$4096
Subtotal, personnel	$4096
Total direct costs:	$12,221
Indirect costs (10%):	1,222
Total costs:	13,443

To be supplied by institution:

a. Controlled atmosphere storage facility, Horticulture Research Center, Belchertown. Five CA rooms.
b. Fruit stored in this facility.
c. All personnel involved in project except for E. A. Johnson

E. DATE OF COMMENCEMENT:

July 1, 1986. Duration: 1 year
(Note: "Duration" includes purchase of equipment, its installation and 1 season of operation. However, once installed the system would be an on-going model capable of change, refinement, and continued development.)

F. PERSON TO BE RESPONSIBLE:

William J. Bramlage, Professor

Qualifications:

B.S., Horticulture, The Ohio State University, 1959
M.S., Horticulture, University of Maryland, 1961
Ph.D., Horticulture, University of Maryland, 1963
Horticulturist, U.S. Dept. of Agriculture, Fresno, CA, 1963-64
Postharvest Physiologist, University of Massachusetts, 1964-present
Sabbatical Leave, East Malling Research Station, Kent, England
January - August, 1984.

Previous work related to the proposal:
Since 1964, conducted research on storage problems in apples in Massachusetts.

G. PERSONS DIRECTLY ENGAGED:

1. Katrin Kaminsky, Technical Assistant, Dept. of Plant and Soil Sciences, University of Massachusetts.

Qualifications and background:
Associate Degree, Fruit and Vegetable Crops, Stockbridge School of Agriculture, 1982.
B.S., Plant and Soil Sciences, University of Massachusetts, 1984.
M.S. candidate, Plant and Soil Sciences, University of Massachusetts. 1985-present.
—Has taken engineering and computer courses at the Univ. of Mass.
—Works as storage operator, Horticultural Research Center, Belchertown.

2. Ernest A. Johnson, Associate Professor, Department of Food Engineering, University of Massachusetts.

Qualifications and background:
B.S., Agricultural Engineering, University of Massachusetts, 1953.
M.S., Agricultural Engineering, Purdue University, 1959.
Agricultural Engineer, U.S. Dept. of Agriculture, Agricultural Engineering Research Branch, and Instructor, Agricultural Engineering, Purdue University 1953-1959.
Agricultural Engineer, Food Engineering Dept., University of Massachusetts, 1959-present.
—Development of microprocessor-based control systems for fermentation processes.
—Teaches course entitled "Instrumentation and Control" that includes principles of data gathering and analyses, and control theory.

MASSACHUSETTS SOCIETY FOR PROMOTING AGRICULTURE
MARCH — THE SOURCE OF WEALTH — 1792

June 23, 1986

Mr. Lee D. Beatty
Office of Grant and Contract Administration
Munson Hall
University of Massachusetts
Amherst, MA 01003

RE: University of Massachusetts proposal NO. 86A971

Dear Mr. Beatty,

Our Society approved a request from Dr. William Bramlage for $9,000.00 to be used as follows:

$4,096.00 - Salaries
$3,904.00 - Equipment
$1,000.00 - Supplies.

The Society requires a report of all Grant recipients within one year of receipt of the Grant.

Sincerely Yours,

David Chandler

David Chandler
Secretary

ACCEPTED:

By L D Beatty 86-1235
Director
Grant and Contract Administration

Date 6/26/86

APPENDIX B.

A USER-BUILT SYSTEM FOR AUTOMATED MONITORING AND CONTROLLING OF CA APPLE STORAGES

The Orsat gas analyzer is used almost exclusively in New England to determine the concentrations of oxygen (O_2) and carbon dioxide (CO_2) within a controlled atmosphere (CA) storage. Control of these levels is performed manually by the storage operator. Although the Orsat method is inherently accurate, the procedure itself for sampling and measuring the atmosphere in the rooms contains much opportunity for human error. Also, since this operation is time-consuming, atmospheres are generally measured and adjusted no more often than once per day. Under this type of management considerable fluctuation of the storage atmosphere can occur, and problems can go unnoticed or uncorrected for some time. To compensate for these potential problems, significant margins of error are incorporated into standard CA recommendations. Even so, serious errors in atmosphere maintenance are still common.

There are alternatives to the Orsat method of measuring storage atmosphere concentration. Electronic devices for measuring O_2 and CO_2 are widely available. A system using these devices to frequently and automatically measure O_2 and CO_2 levels was developed in England, and quickly was expanded to provide automatic adjustment of O_2 and temperature when they exceeded set tolerance levels. More recently, automatic adjustment of CO_2 has also been developed. These systems are controlled by a custom-built, programmed computer, and can be purchased as "package" units, designed to meet operator specifications. Such units include the computer, O_2 and CO_2 analyzers, and atmosphere sampling and controlling systems. These "package" units have proven to be a successful way to automate atmosphere monitoring and controlling, with the advantages that very little operator input is required, and service of equipment is provided after the sale. However, the cost of such units is discouraging for operators of the relatively small storages that are typical of the New England apple industry.

Another alternative is the "user-built" system, in which a user assembles his own system from available components, developing a system to meet his needs and to stay within his financial resources. Such a system employs separate components which are available for O_2 and CO_2 analysis, a personal computer for data handling and initiation of sampling, measuring, and controlling devices, and the necessary pump, valves, and relays to facilitate the whole process. This approach has been applied successfully to both research and commercial systems at a cost less than that of a package system (1,2).

It is our conviction that automatic monitoring and controlling of CA storage atmospheres can significantly improve operation of New England apple storages. It is generally accepted that lowering O_2 level in CA storages only starts to become effective in delaying senescence changes of the fruit at concentrations below 5%. Furthermore, it is necessary to lower O_2 concentrations to 3% in order to obtain significant commercial benefits (3). According to a 1987 survey of all Massachusetts CA storage operators, over half the facilities are being operated at setpoints above the recommended 3% O_2. Since this recommendation is not new by any means, and has been continually reiterated at fruit growers' meetings, we assume that all storage operators are aware of it. Therefore, the logical explanation for the persistence of O_2 setpoints above 3% must be a lack of confidence in the Orsat method of analysis. Operators lack faith either in the accuracy of their readings, or in the precision of O_2 control which stems from the typically once-per-day frequency of these readings, or both. Automatic monitoring and controlling would serve to alleviate both concerns. The electronic gas analyzers are accurate, consistent, and easy to use. Even if these were employed in a manual fashion, as a simple replacement of the Orsat, they deliver atmosphere readings so quickly that monitoring frequency could be greatly increased with very little demand on the operator. Automation of atmosphere control would provide for correction of O_2 level as soon as it was found to be needed.

In 1986, we received a grant from the Massachusetts Society for Promoting Agriculture to establish a demonstration, "user-built" system for use with the storage rooms at the University of Massachusetts Horticultural Research Center (HRC), Belchertown. During the 1986-87 and 1987-88 seasons, we assembled and operated this system. It is the purpose of this bulletin to provide guidance, based on our experience, to storage operators who would like to establish "user-built" systems of their own. The approach described here is divided into three steps of accomplishment, each step representing substantial improvement of operation without requiring that the operator proceed to the next step.

Step 1: Electronic Monitoring.

The first step in upgrading CA management is to replace the Orsat with faster, more reliable, and easier-to-use analyzers. There are a number of such devices available.

For O_2, we are using a Servomex analyzer. It is available locally and has been used extensively for CA storage monitoring, especially in Europe. This unit is a paramagnetic O_2 analyzer. It is designed to measure O_2 concentrations in flowing air streams. The paramagnetic, or magnetic susceptibility, analyzer is limited to the analysis of O_2 and the oxides of nitrogen. This is because these are the only paramagnetic gases, that is, gases attracted by a magnetic field (4). Since oxides of nitrogen are not found in CA atmospheres, the instrument is suitable for this application. The Servomex analyzer is easy to use, holds calibration for several weeks, and gives a steady reading in about 30 seconds, using a sampling line of about 70 feet. The instrument can be purchased with a range of 0-100% O_2, or of 0-10% O_2. Accuracy of the 0-100% range is plus or minus 2% of the full scale reading. A range of 0-10% O_2 is advisable because it has better accuracy within the O_2 range that we are concerned about. Our unit has been completely reliable and trouble-free, and makes atmosphere sampling quick, accurate, and easy. The Servomex is perhaps the most expensive O_2 analyzer, but it has an excellent record of use with CA storage management. The instrument has a digital read-out and a built-in flow control valve to protect against damage from high sample gas pressure. It requires no routine maintenance. Other instruments may be as reliable, but we are very pleased with this one.

For measuring CO_2 electronically, there are also various instruments available. All are relatively expensive because of the relative complexity of measuring CO_2. We are using a Servomex CO_2 analyzer, which performs infrared analysis of the gas mixture. Infrared analyzers are designed to measure CO_2 concentrations in flowing gas streams and are better suited for incorporation into automated systems than are other types. CO_2 absorbs infrared radiation at a specific wavelength, a property which is used to produce an electrical signal related to the CO_2 concentration in the test gas stream. Commercial instruments are not flow-sensitive (4). The Servomex CO_2 analyzer has a digital read-out. This is an important feature, since response to CO_2 concentration is non-linear, and can be a source of error when reading a needle gauge. Our analyzer has two ranges of operation, 0-1% and 0-10%, chosen by means of a switch on the front of the instrument. Accuracy for both ranges is plus or minus 2% of the full scale reading. Like the Servomex O_2 analyzer, the CO_2 analyzer has been completely trouble-free and dependable, gives a steady, accurate reading quickly, and holds its calibration for several weeks.

Both the O_2 and CO_2 analyzers require an oil-free, vacuum pump. In most situations, a pump with a capacity of about 1 cubic foot per minute should be sufficient to obtain stable readings quickly. The instruments can be purchased with a pump, but the operator can save money by purchasing a pump separately. We tried fitting a simple fish-tank pump to the system but could not make it airtight. Although this might work if a pump was placed inside each room, we preferred an external pump, since it is simpler to automate.

Both the O_2 and CO_2 analyzers must be calibrated periodically.

Calibration is performed at two points for each analyzer, these being the zero and the span. For the zero, nitrogen (N_2) gas is adequate. Air normally contains 21% O_2 and 0.03% CO_2 and can be used to calibrate the span, as with the Orsat. However, these O_2 and CO_2 levels are not close to those in the storage, and it is best to calibrate with approximately the storage atmosphere. Furthermore, if the O_2 analyzer has a 0-10% range, as is best, then air cannot be used to calibrate the span because its 21% O_2 concentration exceeds the range. Thus, we recommend purchase of a cylinder of gas certified to be 3% O_2 and 5% CO_2, with an accuracy of 0.1% for O_2 and 0.25% for CO_2. This gas should be used to check the instruments weekly.

Some amount of flexible tubing (such as Tygon) is also needed. Since the instruments are expensive and delicate, they should be moved around as little as possible. This flexible tubing is used to connect either room sampling portals, or existing sample lines, to the pump, and from there to the analyzers.

Costs (1988) for electronic monitoring are as follows:

ESSENTIAL COMPONENTS:

O_2 analyzer	$2,000	
CO_2 analyzer	3,000	
Sealed, oil-free pump	172	(Cole-Parmer model J7061-20)
Calibration gas (span)	100	(122 cubic feet)
Calibration gas (zero)	37	(122 cubic feet)
Tygon tubing	$1/ft.	

OPTIONAL:

Pressure regulator (for use with calibration gas cylinders)	$86

There is no inexpensive way to achieve the necessary speed and accuracy of readings. However, this step is rather simple to take, in that it merely requires purchase of some instruments and placing them in operation (Figure 5). These analyzers give atmosphere readings in 30 seconds, as opposed to about 7 minutes for the Orsat. This time-savings is an obvious benefit, especially during rapid atmosphere generation, as with liquid N_2. It also encourages operators to verify immediately the effects of atmosphere adjustments they make, and to increase the frequency of routine atmosphere monitoring.

Step 2: Automatic monitoring.

Once the monitoring equipment is in place, the operator can then take the second step if he so chooses --- to automate the monitoring.

To do this, you must have a centralized sampling system, that is, sample lines must come from each room to the sampling site. This may already be in place, but if not, then it must be provided. We recommend using 1/4" flexible copper tubing, since it is durable and easy to work with. If lines are in place, then each must be fitted with a solenoid valve that will open and close on an electrical impulse. This will require some electrical work as well as purchase of the valves and coils.

Automation is achieved via a computer. We purchased a Leading Edge personal computer with a monitor, and it has served us well. To our knowledge there is nothing unique about this computer for automating the CA monitoring: it was simply available locally at a competitive price. A "software" program must be purchased to be used in the computer. A data acquisition program that is well suited to

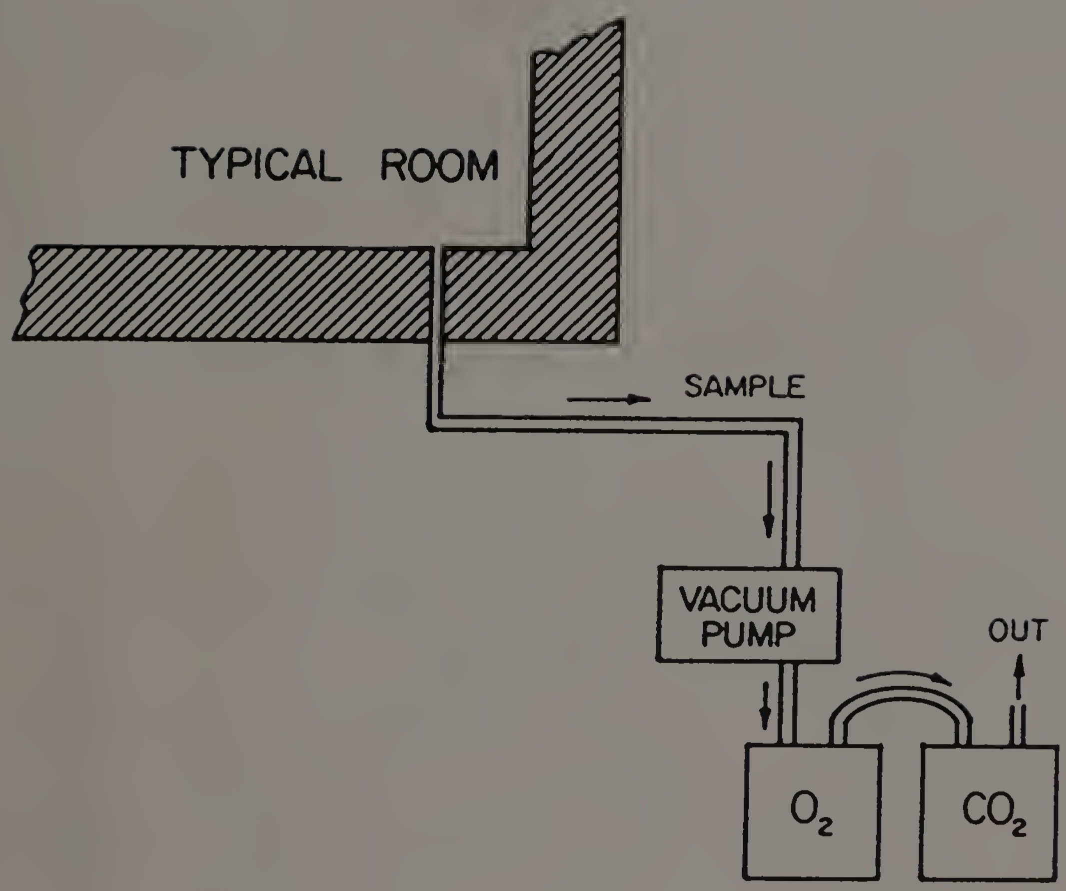

Figure 5. Electronic monitoring.

this application is marketed by Strawberry Tree Computers (STC), Sunnyvale, CA. It includes an A/D Interface Card, to be installed inside the computer, and a detailed manual of operation. A terminal panel, containing both input and output capabilities, must also be purchased. The input side receives signals from the gas analyzers. The output side, which must be equipped with relays, controls the switching of the valves and sample pump. Continuous operation of the sample pump is not advisable, due to excessive wear. By providing a relay at the computer, and attaching a power relay to the pump, its operation can be automated to run only when needed. To select the appropriate interface card, terminal panel, and number of relays, refer to Table 7.

You also need something on which to record the information. The Leading Edge computer has 2 floppy disk drives, so the data can be recorded on disks. However, you would then need a program (e.g. Lotus 1-2-3) to translate the stored data into an intelligible format. This method would be a considerable added expense and would require operator expertise. Therefore, we recommend purchase of a printer, so that you get automatic printout of the data and can see at a glance what the analyses are for each room.

It is important to note that while the computer is running the automated program, it cannot be used for any other purpose without interrupting the program. Keep this in mind if you are considering using one computer for both automation and business purposes. The computer should be plugged into a surge protector to prevent damage in case of voltage fluctuations. Also, the recommended relay board comes

Table 7. Interface card and terminal panel recommendations.*

# of Rooms	Monitoring Only: # of Relays***	Monitoring Only: Card	Monitoring Only: Terminal Panel	Monitoring and Controlling**: # of Relays****	Monitoring and Controlling**: Card	Monitoring and Controlling**: Terminal Panel
1	2	ACJr-12-8	T41	5	ACJr-12-8	T41
2	3	ACJr-12-8	T41	7	ACJr-12-8	T41
3	4	ACJr-12-8	T41	9	ACJr-12-8	(2)T41
4	5	ACJr-12-8	T41	11	ACJr-12-8	(2)T41
5	6	ACJr-12-8	T41	13	ACPC-12-8	(2)T41
6	7	ACJr-12-8	T41	15	ACPC-12-8	(2)T41
7	8	ACJr-12-8	T41	17	(2)ACJr-12-8	(3)T41

* Interface cards, terminal panels, and relays available from Strawberry Tree Computers. The relay model number is OAC5; model numbers for the cards and panel are listed in the chart.

** Number in parentheses in front of card and panel model numbers indicates how many of each would be needed.

*** One relay for the sample solenoid at each room. Continuous operation of the pump is not advisable, due to excessive wear, so an additional relay is provided to control its operation.

**** Combines original relays required for automated monitoring with an additional relay for air source, N_2 source, and control solenoid at each room.

with a cable connection which is not suitable for frequent unplugging, thus rendering the computer fairly stationary. Relay boards with "quick connect" cables are readily available, but are more expensive.

Figure 6 diagrams equipment layout for automated monitoring.

The costs (1988) for automated monitoring are as follows:

ESSENTIAL COMPONENTS:

Computer (Leading Edge-DC2011 with monitor-DR1240)		$854
Interface Card (Strawberry Tree Computers)	ACJR-12-8	595 OR
	ACPC-12-8	790
Relay Board * (Strawberry Tree Computers)	T41	149 each
Relays ** (Strawberry Tree Computers)	OAC5	15 each
Power relay (for pump)		11
Printer (Epson-LX800)		224
Paper (for printer)		29/box
Surge Protector (6 outlet)		35

* Less expensive boards are available but will require you to do complicated wiring.

** Cost given is when installed on board by Strawberry Tree. Specify installation when ordering to avoid complicated wiring.

SAMPLING SYSTEM (if needed):

1/4" Copper Tubing	$0.57/ft.	
1/4" Solenoid Valves and Coils	24/each	(1 per room required)

It was less expensive to automate the monitoring than it was to purchase the monitoring equipment (Step 1). However, this second step is the most complicated and frustrating one, and may require some outside consulting unless you have some expertise with electronics and computers.

Automated monitoring is far more than a convenience. It provides the storage operator with extremely useful information. Room atmospheres can be monitored virtually as often as the operator chooses. This documents fluctuations in storage conditions, and gives

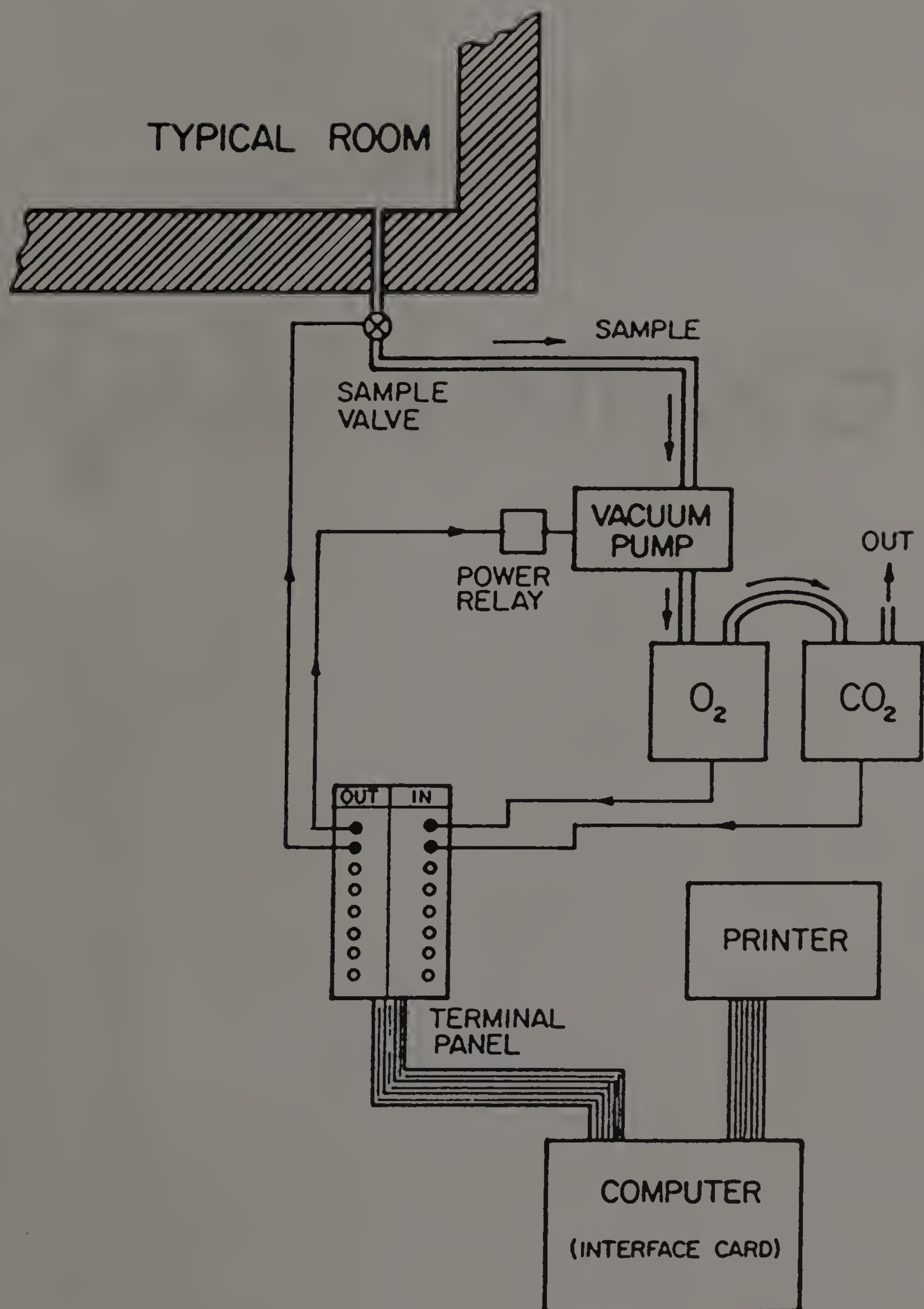

Figure 6. Automated monitoring.

the operator the opportunity to identify the sources of variations by seeing to what they are related. The automatic monitoring and recording also can allow the operator to identify a problem and correct it before it affects the fruit adversely. With accurate, frequent readings, the operator is able to do a better job of operating the storage, and of retaining fruit quality.

Step 3: Automatic control of storage atmosphere.

After automating the monitoring procedure, the operator can then take the logical next step, automating the adjustment of storage atmospheres. This step is considerably less expensive than either Step 1 or Step 2. However, since the best implementation of automatic control will depend entirely on individual storage situations, specific recommendations and exact costs for this step are not possible.

In our storage rooms, we now automatically adjust O_2 levels when they exceed set limits during the monitoring. For example, if we want 3% O_2 and we do not want it to vary more than 0.1% O_2, and a reading shows O_2 in a room to be 3.2%, then the system automatically adds an increment of nitrogen (N_2) gas. If it shows O_2 to be 2.8%, then the system automatically adds an increment of air. To achieve this, the main requirement is more plumbing.

To control O_2 in this way, another centralized piping system must be installed, designed to supply the gases when they are called for. Needed are sources of air and N_2 gas, lines running to each room, and solenoid valves that can open and close these sources upon receipt of electrical impulses from the computer. The same line is used for both gases. Pipe of 3/4" diameter, fitted with 3/4" solenoids, is adequate for this method. Our system requires a solenoid at each gas source and at each room to control this operation. We used an air compressor as a central source of air, so that when the computer calls for O_2 to be added to the room, a programmed, time-controlled amount of compressed air is sent into the room. As a source of N_2 when O_2 needs to be lowered in a room, we use a cylinder of compressed N_2 gas; on command from the computer, valves open and a time-controlled amount of this gas is added to a room. To ensure delivery of low pressure air, pressure regulators were plumbed into the control line directly after both gas sources.

There are several alternatives to this method of O_2 control. The appropriate choice will depend on each operator's specific situation. We used the compressor as an air source simply because it was conveniently located, and was not often used for other purposes. We had equal success with a similar method of control, wherein the only difference was that a squirrel-cage fan replaced the compressor as the air source. A power relay on the fan is controlled by a relay at the computer. This method turns the fan on for a programmed time interval when a room needs air. Another alternative is to have a valve at each room that opens and closes a vent ("controlled leak") for a set interval of time. As a N_2 source, cylinders of N_2 gas will not be economically feasible for larger storage rooms. A possible alternative might be use of liquid N_2. Although we have not tried this approach, freeze-up of valves is a forseeable difficulty due to the extremely low temperature of the material. It may be possible to automate some types of atmosphere generators, but experience with this has been very limited and each situation would need to be individually assessed. If an operator has experienced good control of O_2 level in the past by simply opening and closing "controlled leaks" in his rooms, a source of N_2 may not be required. However, it must be realized that without it, O_2 reduction in a room, when needed, will depend on fruit respiration. Therefore, control will not be immediate, as it is when a N_2 source is available.

We have not automated CO_2 scrubbing because it is not necessary in our system. We have an external lime box at each room, with a small fan near the port in the room, and the fan runs constantly. By properly adjusting the valve on the port, CO_2 remains constant in the room. If we needed to automate scrubbing, it could be done by controlling from the computer whether or not the fan was running. This would work only because, in our situation, little or no scrubbing occurs when the fan is off. Recently, automation of CO_2 scrubbing has been accomplished successfully in England. However, this is a complex task and its feasibility for a "user-built" system is, as yet, undocumented.

Control of this automation is via the computer, interface card(s), and terminal panel(s) already in place to control monitoring. Thus, most, or all, of the necessary equipment is already purchased. Refer to Table 7 for the appropriate interface card(s) and terminal panel(s) to automate control in your situation. The operator will have to invest time in determining how large an increment of air or N_2 needs to be added to adjust the atmosphere, but once these increments have been determined and the computer programmed to call for them, delivery will be automatic. It is essential that a room have a "burp tube" to release pressure, since gas will be added on call. Also it is extremely convenient to have "breather bags" on the rooms when you are determining the time interval for adding gases.

Figure 7 diagrams equipment layout for our method of O_2 control.

The cost of automating control will depend on the amount of plumbing required and the approach taken. Other than labor costs for plumbing, and wiring of the solenoid valves, our costs (1988) were as follows:

ESSENTIAL COMPONENTS:

3/4" Solenoid valves and coils (1 per room and 1 for each gas source)	$ 57/each
Relays * (1 per room, 1 for each gas source)	15/each
N_2 gas ** (300 cubic foot cylinder)	20/each
Pressure regulator (for N_2 cylinder)	86
Pressure regulator (for compressor)	15
3/4" PVC pipe	0.38/foot

* As before, specify that you want relays to be installed on the relay board.
** Plus $3.30/month tank rental.

All equipment mentioned in this bulletin, with the exception of plumbing components and the sample pump, should be protected from dust and dirt. This can be accomplished very simply with a loosely draped sheet of plastic, since heat output is minimal. Otherwise, no routine maintenance is required by any component.

The total cost of this automatic monitoring and controlling system was approximately $8,200 for four CA rooms at the HRC. However, it

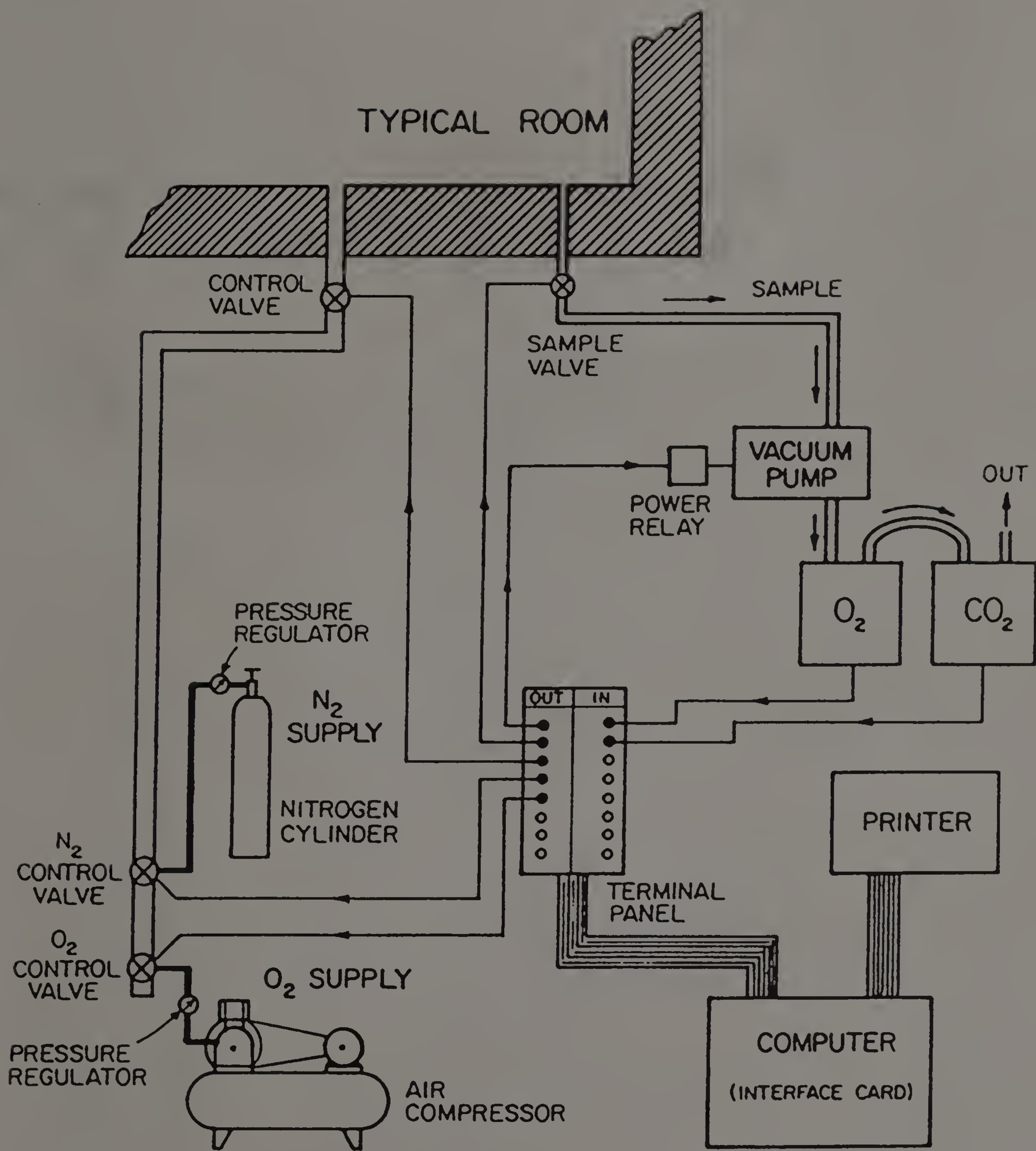

Figure 7. Automated monitoring and controlling.

must be remembered that the operator must invest significant time in designing and assembling the system to fit his storage, obtaining the components, becoming familiar with the computer operation, and determining the proper timings to meet the needs of his storage rooms. Although it is a difficult, time-consuming, and often frustrating project, the end result is a significant upgrading in atmosphere management and a system which works extremely well.

APPENDIX 1. SOURCES OF EQUIPMENT USED IN UNIVERSITY OF MASSACHUSETTS SYSTEM

Aero All Gas 3150 Main St. Hartford, CT 06120 1-800-255-4277	(gas cylinders, N_2 pressure regulator)
Cole Parmer Instrument Company 7425 North Oak Park Ave. Chicago, IL 60648 1-800-323-4340	(sample pump)
W.W. Grainger 790 Cottage St. Springfield, MA 01104 1-413-781-7525	(solenoid valves, power relay, pressure regulator for air compressor)
Strawberry Tree Computers 150 North Wolfe Rd. Sunnyvale, CA 94087 1-408-736-3083	(computer software/hardware)
SYR Technology 9 Juniper Brook Rd. Northboro, MA 01532 1-617-393-9307 (Richard Syrjala)	(Servomex gas analyzers)
Validata Triangle St. Amherst, MA 01002 1-413-549-1017	(computer, printer and 259 paper, surge protector)

APPENDIX 2. COMPONENT MODEL NUMBERS NOT PREVIOUSLY MENTIONED

Component	Source	Model #	Price
3/4" Solenoid Valve	W.W. Grainger	1A578	$46
Coil for above		6X543	11
1/4" Solenoid Valve	"	1A575	13
Coil for above		6X543	11
Power Relay	"	5X835	11
Socket for above		2A582	
Pressure Regulator (for compressor)	"	1Z696	15
N_2 Pressure regulator	Aero-All Gas	Meco 05390020C	86

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