A MODEL FOR MINIMIZING COST FOR HOUSING LABORATORY MICE

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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Dedicated to my parents.

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Past research has been conducted in analyzing different aspects for housing laboratory animals at animal care facilities. Animals (mice) are typically housed in two different types of caging systems at animal care services, University of Florida, i.e., static micro-isolator and ventilated cages. Animal rooms with cages need to be maintained at a required air exchange rate. The cages also undergo a cleaning and bedding change process. Significant costs are incurred in maintaining air conditions and in the cleaning process of the cages. This thesis identifies an optimal balance between Air Changes Per Hours (ACPH) and Bedding Change Frequency (BCF) making sure that all the required parameters are satisfied. The objective is to minimize the cost by keeping specific environmental parameters under control. In order to solve this problem, functional relationships were defined to optimize the cost for housing laboratory animals as a function of ACPH and BCF and all the constraints as a function of ACPH and BCF.

Relationship models were developed based on these analyses and solved to get the desired results.

Three different models were constructed to find an optimal solution. These models are developed in the thesis. Current practice at the animal care services at the University of Florida is to provide 60 ACPH with BCF of 14 days for ventilated cage systems. Optimal results were found to be 60 ACPH for the ventilated cages at a BCF of 20 days. The cost difference between the optimum and the current practice was $14.00 per cage annually.

Current practice for static micro-isolator cages at animal care services requires cages to be changed twice a week. Optimum results were found at cage changing frequency of 6 or 7 days with cages autoclaved with corncob bedding. The cost saving for the optimum model for static micro-isolator cages was $40.00 per cage annually. But in order to implement either of the optimum models, it is recommended that additional experiments be conducted to provide data for analysis and validation of the research assumptions.

CHAPTER 1
INTRODUCTION

There have been significant changes in medical research in the past few years. Since mice can be genetically altered to model human reactions to illness, most of the medical research today uses mice as the research model. Mice used in medical research are often housed in ventilated cages. *Guide for the Care and Use of Laboratory Animals* (National Research Council [NRC] 1996) specifies conditions under which mice are to be housed. These conditions include temperature and level of humidity. To maintain these conditions, the air exchange rate with 100% outdoor air needs to be maintained. In addition, for the Allentown cage racks (Figure 4-1) used in the animal care services at the University of Florida, individual cages are mechanically ventilated at a rate of 60 air changes per hour (in these cages air is circulated separately in the cages at a rate of 60 changes per hour by way of mechanical fans mounted on the rack).

The cages in which mice are housed go through a periodic cleaning process. Mice are transferred to the new cleaned cage and old cages are cleaned. Cages are changed routinely as the concentration of ammonia in the cages increases. At the University of Florida, animal care facility, cages are cleaned, provided with new bedding and then autoclaved at regular intervals. This helps destroy all enzymatic activities and bacteria (Gale and Smith 1981). After autoclaving, the cages are ready to be used again for animal housing. Increased cage changing frequency leads to high cage inventory costs. Significant labor and material costs are incurred in one cage changing cycle. Bedding itself is found to be an important parameter for generation of ammonia in the cages.

Different types of bedding with their respective ammonia concentration with respect to days between successive bedding changes elapsed is shown in (Figure 2-2). Of all these beddings, use of corncob is preferred at the animal care services at University of Florida.

To this end, the cost for housing mice used for these research efforts has become a significant budget issue for animal care facilities. Little past research exists which relates critical environmental cage parameters to Air Changes Per Hour (ACPH) and Bedding Change Frequency (BCF) and which relates these same parameters to the costs associated with housing these laboratory animals. This thesis analyzes many of these costs. Spreadsheets were developed to identify the costs as a function of air exchange rates for cages and rooms with micro-isolator static cages and ventilated cages. Costs associated with cleaning and changing cages were calculated based on the number of changes i.e. periodic frequency of changing the cages in an animal room. These costs were further analyzed as a function of several critical environmental factors. The data published from past research was used to develop functional relationships for these environmental factors. Our objective was to find the optimal cost for housing laboratory animals as a function of ACPH and BCF, satisfying the critical environmental parameters.

The remaining parts of this thesis are as follows. Chapter 2 covers a brief history and literature review for issues to be considered in analyzing the problem. It includes brief explanations of past research conducted and addresses the issues related to strains of mice, housing, exhausts for animal housing rooms and environmental parameters.

Chapter 3, “Problem Definition,” covers basic issues related to key parameters considered in analyzing the problem. These are, the different types of caging systems used to house mice, the process of cleaning cages at the animal care services facility, air ventilation rates for mice cages and types of bedding used in the cages.

In Chapter 4, the cost analysis conducted for ACPH for both conventional and ventilated caging systems at University of Florida is presented. Graphs were plotted for cost as a function of room air exchange rates to develop a cost equation. Further, the cycle of operation and cleaning mice cages at animal care services facility are explained. A schematic explains the steps performed along with times taken by each activity. Cost analyses were conducted for the cage changing cycle. Graphs were plotted for cost as a function of time interval between successive bedding changes for micro-isolator static and ventilated caging systems. Lastly, the optimization model used is explained. The associated discussion explains the relationship model, data used, different approaches adapted to get optimal results and the final model used for analysis. Due to a lack of data required for efficient analyses, data published by Reeb-Whitaker et al. (2001) were used to develop functional relationships and certain assumptions were made which are discussed in this chapter and in the next chapter, Chapter 5, “Results and Conclusions.”

CHAPTER 2
LITERATURE REVIEW

Brief History

Significant research has been conducted on the way mice cages should be housed in an animal room. There are many factors that must be considered, especially since the norms for the conditions under which they should be housed lead to significant costs. The most important factors that go into this are temperature, humidity, ammonia level, the type of bedding being used, type of caging system used (static micro-isolator or ventilated), level of exhaust and frequency of bedding change (National Institute of Health [NIH] 1998).

The concentration of ammonia in the cage environment is one of the key factors to be considered. The production rate for ammonia is a function of relative humidity in the cages and the number of days that have elapsed since bedding in the cage was last changed. Ammonia production by bacteria can also be influenced by the strain/stock of animal as well as population density, and type of cage bedding (Lipman 1992, Gale and Smith 1981). The influence of humidity is recognized as one of the more significant factors in ammonia generation. The rate of generation increases three times as much in high humidity environments as compared to low humidity environment (Guidelines, page 4, NIH 1998). Although temperature has a direct effect on relative humidity, the rate of generation of ammonia is not a direct function of temperature (Guidelines, page 4, NIH 1998). “The American Conference of Government Industrial Hygienists recommended a time- weighted average, threshold limit value of 25 ppm to protect against irradiation to eyes and the respiratory tract and minimize discomfort among workers" (Volume I, page I – 24,25 NIH 1998).

Studies also show that conditions cannot be improved just by increasing the air ventilation rate. Room air exchange rates in excess of 10 ACH do not materially improve environmental conditions within the cages (static micro-isolator cages; there should be greater emphasis on the proper arrangement of cages and air distribution between the room and cages. Therefore, various factors like positioning of cages, level of exhaust in an animal room, type of exhaust, i.e., low level exhaust or high-level exhaust or cage rack systems that force ventilated air through individual cages should be taken into consideration for proper animal housing in static micro-isolator cages (NIH 1998).

Summary of Research Papers

Reeb et al. (1997) have studied static micro-isolator filter top rodent caging systems with varying air changes per hour from 5 to 20. Room temperature was maintained at 21$\pm$ 2 °C (69.8 +3.6 °F) with relative humidity at 45%. This study used 9-week-old C57BL/6J mice in polycarbonate cages with a bonnet shaped snuggly fitted top made of a nonwoven filter composed of natural and synthetic fiber, with pine shaving bedding. Ammonia was measured using sorbent sampler and by infrared gas analyzer. Increases in the ACPH led to decreases in relative humidity. There was a significant decrease in relative humidity from 55% to 36% as the ACPH rate was increased from 5 to 20 at a constant temperature (an increase in ventilation rate decreases the level of ammonia in an animal room). There was a gradual decrease in the concentration of carbon dioxide as ACPH rate was increased from 5 to 10. The level of decrease observed was from 2500 ppm to 1900 ppm. But there was no significant decrease in the level of carbon dioxide as the ACPH rate was increased to 20. It was concluded that only increasing ACPH did not result in considerable improvements in the conditions of the cage.

"After six days of soiled bedding, the intracage ammonia concentration was less than 3 ppm at all room ventilation rates and was not affected by increasing room ventilation" (page 74, Reeb et al. 1997). This concentration of 3 ppm is well below the required threshold value of 25ppm (Broderson et al. 1976, Schoeb et al. 1982). Thus, more emphasis should be placed on factors like bedding type and position of cages. Also, there was a temperature difference found between the cages and the room. Temperatures in the cages were normally higher than in the room. There was a difference of about 1-3 °C (33.8-37.4 °F) between room temperatures and the temperature inside cages. The temperature inside the cage was thus slightly higher than the temperature in the animal room. This is an important factor to be taken into consideration in designing the facility and room. The strain of mice also plays an important role, as ammonia is found to be strain dependent. Strain C57BL/6J is the most common of all. No ammonia detected for this strain was reported, but ammonia was detected for the following strains: DBA, CD-1 and BALB/C (Reeb et al. 1997)

For a room with static micro-isolator cages, the air change rates inside the cages vary according to the arrangement of cages. For cages arranged in the top row, the air change rate was the same as the room ventilation rate. For the middle or the bottom rows, there was not much effect of change in room ventilation rate on intracage air change. There was no impact on intracage air change rate as air exchange rate for the room was increased from 0 to 20 (Reeb et al. 1997).

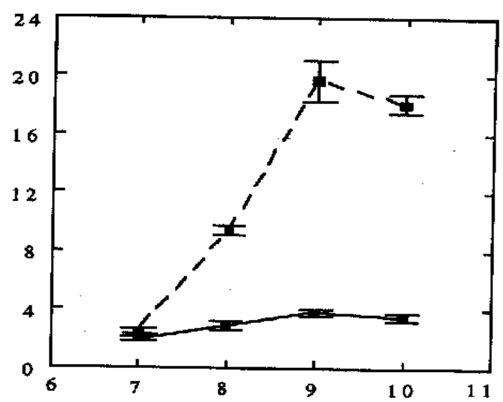

Figure 2-1. Variation of ammonia level (ppm) as a function of time interval between successive bedding changes (days); solid line shows the top row and the dotted line shows the level of ammonia for cages in middle row (X axis- Level of ammonia and Y axis- time interval in days between successive bedding change)

Riskowski et al. (1996) concluded that the type of caging system used to house rodents is an important factor in analyzing these conditions. The way the cages are placed in the room is one of the key factors in controlling the atmospheric conditions in the animal room. In general, room air exchange rates, the velocity approaching the cage, the number of returns, location of exhaust, and supply diffuser type did not influence cage conditions considerably for the range of factors studied during this project.

Perkins and Lipman (1995) studied the various types of bedding used in the rodent cages (Micro-BARRIER, standard height, #MBT7115HT, Allentown Caging Equipment Co., N.J.). The room temperature was maintained at 21.8 $\pm$ 0.21 °C (71.17 + 0.31 °F) with a relative humidity at 48.86 $\pm$ 0.18. This study used female DBA/1J mice with different types of bedding. Modified isolator type cages made of polycarbonate were used for the study. The study was conducted for a period of 7 days, and after 7 days, the study was terminated. Concentrations of hydrogen gas, 2-butanol, ethanol, acetone, carbon monoxide, acetic acid, hydrogen sulfide, sulfur dioxide and formaldehyde were measured. Figure 2-2 shows the mean daily environmental concentration for ammonia in the cages. The ranking of different beddings based on ammonia generation is as follows:

Type of Bedding	**Day Ammonia detected**
1. Aspen Shavings	Day 2
2. Pine Shavings	Day 2
3. Reclaimed wood pulp bedding	Day 3
4. Virgin pulp loose bedding	Day 4
5. Hardwood chip bedding	Day 4
6. Recycled paper bedding	Day 6
7. Virgin cellulose pelleted bedding	Day 7
8. Corn cob bedding	Not detected by the end of day 7

For virgin cellulose, ammonia was detected on 7th day of experiment. The corncob bedding had no detectable ammonia over the 7 day testing period. The mean ammonia concentrations for virgin cellulose and corncob were lower compared to other beddings. The concentration of acetic acid and sulphuric acid detected when corncob bedding was used were below OSHA (Occupational Safety and Health Administration) TWA (Time Weighted Average) (10 ppm and 5 ppm respectively). The contribution of factors like temperature, humidity, and carbon dioxide was low but significant. They had a contribution of 23.9% to the variation of concentration of ammonia under different types of contact beddings. This study was conducted for DBA/1J type of mice (Perkins and Lipman 1995).

When autoclaved pine shaving bedding was used ammonia was reported for strain DBA (Reeb et al. 1997) while no ammonia was detected for CB57/15, but when corncob bedding was used, no ammonia was detected strain DBA for 7 days. This further reinforces the belief that corncob bedding can help suppress ammonia for longer duration of time for other strains of mice as well.

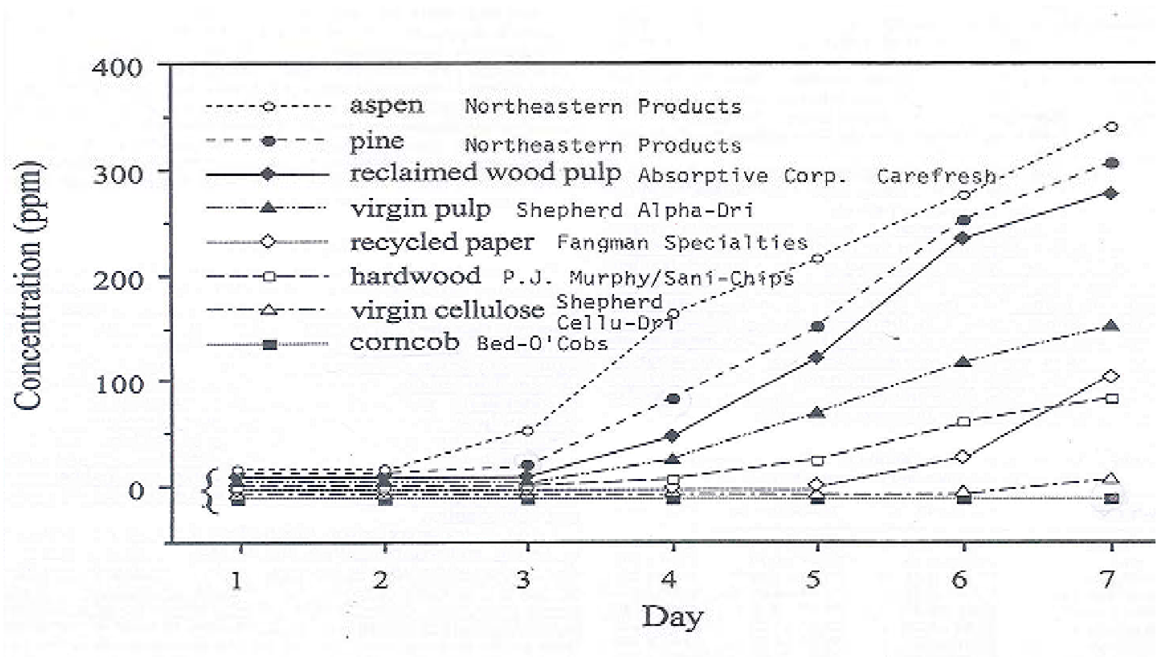

FIG. 2. Mean daily microenvironmental ammonia concentration in cages with mice.

Figure 2-2.Mean daily micro-environmental ammonia concentrations in cages with mice.

Choi et al. (1994) conducted a study to check the effect of various factors, and in particular, the ammonia generation between ventilated caging systems (air/water polycarbonate shoebox cages, Lab Products, Inc., Maywood, N.J.) and static micro-isolator rodent caging systems. This study used Female Crl: CF1 BR mice with combinations of 1/8 and 1/4 inch diameter corncob bedding with an ACPH rate of 15$\pm$1 for the room. The amount of bedding used was 135 to 140 grams per cage (360cm^3). The period of study was 32 days for the ventilated caging system and 10 days for static rodent caging system after which study was concluded due to excessive development of fecal materials inside the animal cages.

It was concluded that the number of mice per cage (maximum of 4 mice per cage), shelf height, or cage position did not have a significant effect on the relative humidity in the cage. The relative humidity inside and outside the cages was related. Population density of more than 4 mice per cage tends to have positive effect on ammonia production (Peters and Festing 1990).

In static micro-isolator cages, with a density of 3-4 mice per cage, ammonia was detected after 8 days. The time spent by mice in moving the bedding around was greater when compared to a ventilated caging system. All of the bedding used in this study was autoclaved. This helped in reducing the endogenous urease levels and also destroyed any residual enzymatic activity (Gale and Smith 1981). The two studies in which ammonia was not detected for a period of 7 days used autoclaved cages with corncob bedding (Choi et al. 1994, Perkins and Lipman 1995).

Reeb-Whitaker et al. (2001) conducted experiments for 9 different conditions, i.e., three different cage-changing frequencies (7, 14, 21 days), and three different cage ventilation rates (30, 60, 90). Each experiment was conducted on 12 breeding pairs and 12 breeding trios of C57BL/6 mice for 7 months. A HEPA (high efficiency particulate air) filter with an ACPH at a rate of 15±1 with autoclaved pine shaving bedding was used. The temperature was maintained at 22±2 °C (71.6 ± 3.6 °F) with relative humidity at 45± 5%.

Of all the three cases, ideal conditions were maintained when cages were changed every 14 days with a ventilation rate of 60 air changes per hour. Temperature, relative humidity, concentrations of ammonia and carbon dioxide were measured over a period of 4 months. All the factors were evaluated over the period to find the relative importance of different factors with respect to the varying air changes per hour both for the room and ventilated rodent cages. In some cases the ammonia concentrations exceeded the permitted level of 25 ppm (parts per million). Pup mortality was found to be greater at

BCF of 7 days when compared to 14 and 21 days and at 30 air changes per hour for the cages when compared to higher ventilation rates of 60 and 90 ACPH.

Murakami (1971) studied the relationship between conditions inside and outside mice cages. Based on tests performed separately on male and female mice in aluminum and plastic cages, he developed several conclusions. Relative humidity inside the cages was found to be slightly higher than outside the cage. The difference was higher in the case of aluminum cages (4.5%) as compared to plastic cages (1.3%). The concentration of ammonia was found to be greater in aluminum cages compared to plastic cages. Another interesting observation was that ammonia generation in cages with male mice was greater than the concentration resulting from female mice.

Krohn and Hansen (2000) examined the effects of carbon dioxide with respect to recent developments in laboratory animal housing. Increased levels of CO_2 led to increased stress in animals. There is no specific limit for acceptable exposure to CO_2 for mice. It is only suggested that animals exposed beyond 1.5% should be allowed a few days of recovery before experiments are conducted on them.

Huerkamp (1999) examined the benefits of using a ventilated caging system over conventional static caging systems. Ventilated caging systems help in reducing the unwanted variability in environmental conditions in rodent cages by controlling temperature and relative humidity within a cage (Cont Top Lab Anim Sci. 33 (2): 58, 1994) and also by reducing the concentration of ammonia in the cages. Above all, the reduction in expenses for housing animals compared to conventional cages is an important factor. Other factors, like the number of cages required per room make ventilated caging systems more affordable. But providing facilities with automatic watering systems sometimes increases the loss of research rodents from events like flood, a failed valve, etc.

CHAPTER 3
PROBLEM DEFINITION

Different Types of Caging Systems

At animal care services rodents are housed in both static micro-isolator and ventilated cages. In rooms containing static micro-isolator cages (Figure 3-1 and 3-2), air is supplied to the room. These cages typically have filter tops. Ventilated air must pass through this filter top to reach the inside of the cage. In the case of ventilated caging systems, air supplied to the room controls the atmospheric conditions of the room, while air supplied to the cage (Figure 3-3) is used to keep environmental conditions inside the cage within limits. Air supplied to the cages and the room controls the environmental conditions. It helps in keeping various parameters such as temperature, humidity, carbon dioxide, and ammonia within the permissible limits. Apart from providing air through a blower mounted on rack, there are other methods of moving air in an animal room, for example; direct connection of room air and exhaust to cage rack.

Figure 3-1. An Allentown manufactured static micro-isolator plastic rodent cage. (Picture courtesy of Allentown Caging Equipment Company)

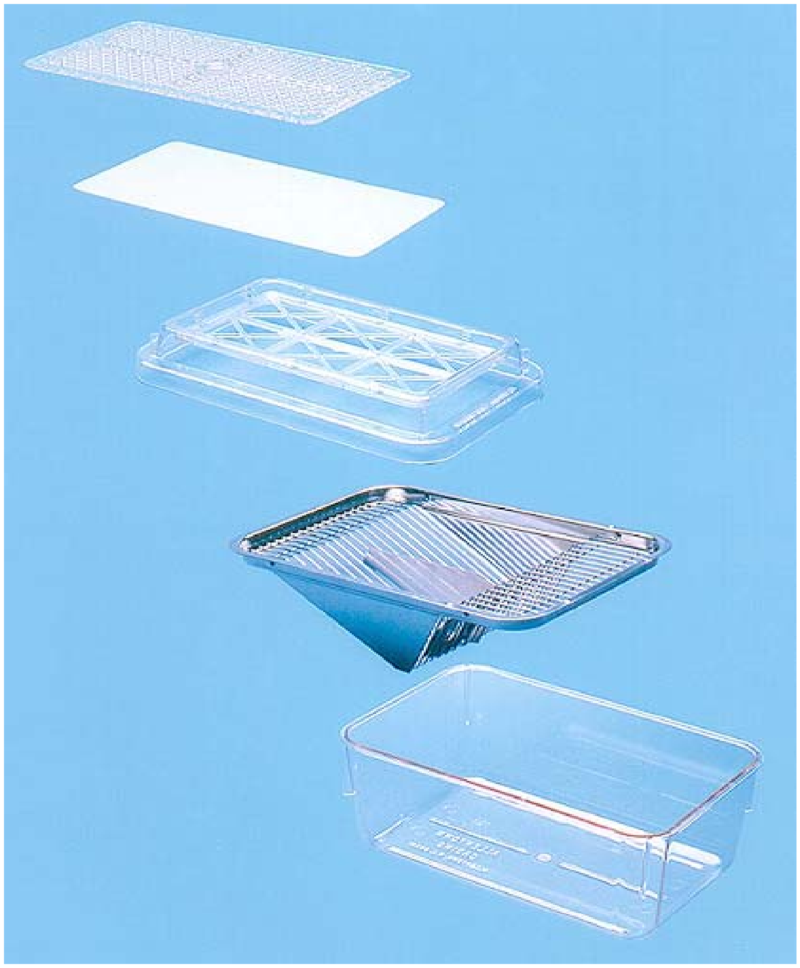

Figure 3-2. Exploded view of static micro-isolator cage. (Picture courtesy of Allentown Caging Equipment Company)

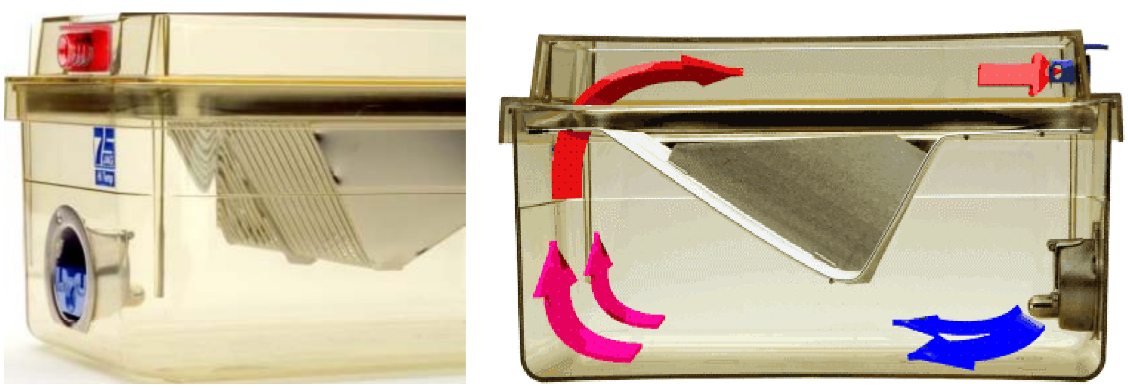

Figure 3-3. Airflow pattern in an individually ventilated rodent cage. (Picture courtesy of Allentown Caging Equipment Company)

At University of Florida, for static micro-isolator caging systems, cages are changed at frequencies as high as twice per week. This is totally in contrast in comparison to ventilated caging systems where cages are changed once every two weeks. This shows that ventilated caging systems, can control environmental conditions for a longer duration of time as compared to the static micro-isolator caging system. This can reduce the cost of housing mice in an animal facility to a great extent.

The placement of cages in the animal room is another important criterion to be taken into consideration. If cages are placed properly in the room, this can reduce the cost associated with air ventilation in an animal room. Extensive research has been done on different ways and factors relating placement of cages and movement of air within an animal room by the National Institute of Health (NIH 1998).

Cleaning of Cages

Due to the development of ammonia and fecal material over time, cages need to be subjected to washing and cleaning processes. This is a mandatory process required to maintain the environmental parameters (like ammonia) within the specified limits. Also the guide (NRC 1996) requires the cages to be sanitized at a regular interval of time. It recommends sanitization of static cages twice every week, but there is no specific time interval for ventilated cages. Cage washing involves several steps. At animal care services, University of Florida, there are two sides of the typical cage washing process. One is the “clean side” and the other is the “dirty side”. Used and dirty cages are placed on the dirty side after they have been removed from the rodent housing room. The contents of the dirty cages are dumped and the cages are placed in a cage washer. After going through the cage washer, the cages are collected on the clean side and stacked for further use. Cages are filled with bedding, packed in paper bags, and placed in an autoclave where they are sterilized. They are then removed from the autoclave and placed on the rack ready to be changed in the animal room. The schematic of cage cleaning process with respective time taken by each process is shown in Appendix C. High costs are associated with this process in the form of labor, energy and material. A cost analysis and schematic of the cage cleaning process is presented in the next section. The cleaned cages are then used to replace the dirty cages in an animal room.

Air Ventilation Rate

Air ventilation rate is an important criterion to be considered in trying to keep the cage environmental conditions under control. 10 to 15 changes per hour for are recommended for an animal room. One of the most important factors is the type of caging system used in the room. For the static micro-isolator caging system, air is only moved inside the room. But for the ventilated caging system, air is circulated both for the room and the cages separately. The rate of exchange for cages at University of Florida is set 60 changes per hour. This rate of 60 ACPH for the ventilated cages is not a standard specified by *The Guide for Animal Care and Use of Laboratory Animals* (NRC 1996), but an industry practice that is being followed. Studies (Reeb-Whitaker at al. 2001) were done for varying ACPH for the cages of 30, 60, and 100 for a constant ACPH for the room. The optimum was found to be at 60 ACPH for the cages (micro-isolator with HEPA air filter) with a bedding change (autoclaved pine shavings) frequency of 14 day for C57BL/6 mice.

Types of Bedding

The type of bedding used in the cages also plays an important role in controlling the environmental conditions in cages in an animal room. Bedding helps in absorbing all the fecal development, along with suppressing the ammonia produced over time. This determines the rate at which cages need to be changed in an animal room to keep the environmental conditions in the room under control. Figure 2-1 illustrates the level of ammonia for different type of contact beddings with respect to time. Corncob has been found to be best, as it can keep the environmental conditions in the cage under control for a greater number of days as compared to the other bedding types (Choi et al. 1994, Perkins and Lipman 1995).

CHAPTER 4
ANALYSIS

This study focuses on determining an optimal combination of ACPH and BCF, which is cost effective and satisfies most of the constraints as specified by *Guide for the Care and Use of Laboratory Animals* (NRC 1996).

Cost Analysis for ACPH

The air exchange rate is one of the most important factors in order to keep environmental conditions in the room and animal cages within the specified limits. As discussed in previous chapters, at University of Florida there are two types of cages used to house mice in an animal room; static micro isolator cages and individually ventilated cages. Separate air exchange for ventilated cages helps in drying them at a faster rate (especially bedding) as compared to static micro-isolator caging system. Due to constant air exchange, significant costs are incurred to maintain the required climatic conditions in the room. To evaluate the cost of moving fresh air inside an animal room, a spreadsheet was developed. The data were collected for one of the rodent housing rooms at University of Florida Communicore. This spreadsheet calculates the cost required to circulate air in an animal room based on following parameters.

Table 4-1. List of parameters for calculation of energy cost

Parameters	**Range/values**	**Units**
Size of the room (L x B x H)	16.70x12.54x8.5 (5.07x3.82x2.59)	Feet (Meters)
Supply air temperature	64.99 (18.32)	°F (°C)
Coil entering air temperature	97 (36.11)	°F (°C)
Supply air enthalpy	25.932 (58.55)	btu/lb (kJ/kg)
Coil entering air enthalpy	40.796 (94.19)	btu/lb (kJ/kg)
Number of mice	3.25	per cage
Number of personnel working in the room	1	per room
Number of light fixtures	6	95 watts each
Number of hours of operation (winter) Assumed full load equivalent operating hours.	1200	hours/year
Number of hours of operation (summer) Assumed full load equivalent operating hours.	2000	hours/year
Desired number of ACPH	15 ± 1	air changes per hour
Number of cages (static micro-isolator cages in an animal room)	125	Number of static cages
Number of cages (ventilated cages in an animal room)	350	Number of ventilated cages

Assumptions

The facility in which the analyses were conducted was in a basement, so there was no heating or cooling load, confutation due to windows or surrounding walls in the animal room. Schematic of ventilation system for rodent housing facility at animal care services is shown in (Figure B-1). The air conditioning system for this room is provided by the way of a central station handling unit, using chilled water for cooling and steam for heating. The unit supplies conditioned 100% outside air to reheat coils in each zone. Infiltration of air into the animal room was neglected. Based on these assumptions and the given dependent variables, the cost of moving air in an animal room was calculated. Cost was calculated for an operational schedule of 7 days per week, 24 hours per day, and 365 days per year.

The cost structure for the above-mentioned two types of cages is different. Moving air in rooms with static micro-isolator cages is cheaper as compared to ventilated cages. In ventilated caging systems, air exchange takes place both for cages and the room. The air exchange rate for the room is usually the same as in the case of conventional caging systems. The ventilated cages achieve a higher exchange rate; using a fan mounted on every rack of the ventilated caging system (Figure 4-1). The fan motor speed can be varied based on the number of air exchanges required in the mice cages. The operational cost for this ventilated system is calculated based on the power consumption of the rack fans. The total cost of moving air in ventilated caging systems is the sum of the cost of moving air in the room and the additional cost of moving air in the racks.

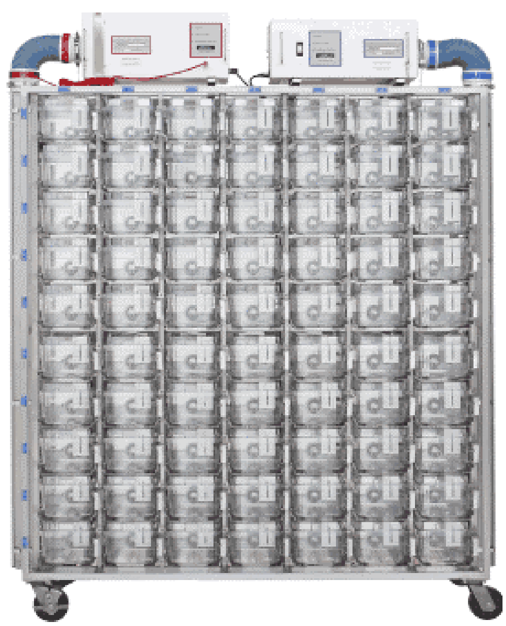

Figure 4-1. Micro Vent ventilated rack. (Picture courtesy of Allentown Caging Equipment Company)

Figure 4-2 was produced using the following data:

- Cost (energy cost) – static micro-isolator cages with room ACPH varying from 5 to 18 changes for the room (this range was assumed), keeping other parameters constant. The graph was plotted for the values obtained. (This was based on 125 static micro-isolator cages in an animal room)

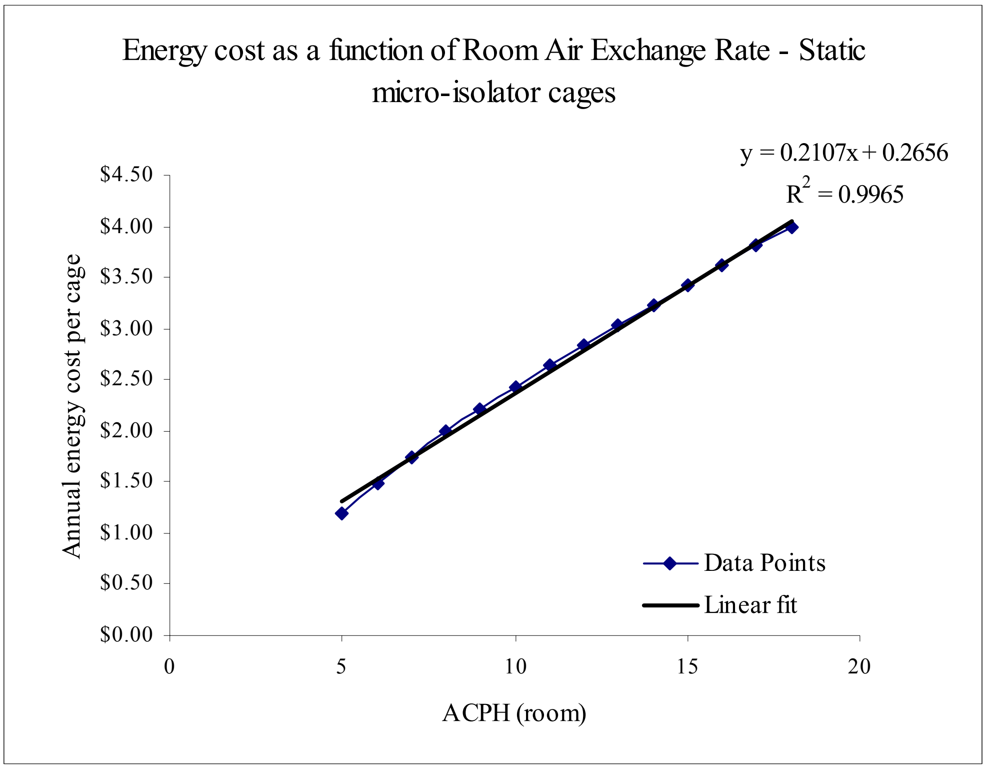

Figure 4-2.Cost as a function of Room Air Exchange Rate – static micro-isolator cages

The cost function in Figure 4-2 is almost linear, i.e., cost is directly proportional to the ACPH for the room. As is evident from the curve, there is a significant increase in cost that can be determined from the slope of the line (the slope of line is 0.2107 i.e. cost increases by $0.21 per cage for unit increase in ACPH). Because the room is connected to a large central air conditioning system, the changes in power consumption of the blower were not considered as the ACPH for the room varied.

Figure 4-3 was produced based on the following data:

- Cost (energy) – ventilated cages for cage ACPH varying from 30 to 100 changes for cages in increments of 10, keeping the room ACPH constant at 15 and other parameters constant.

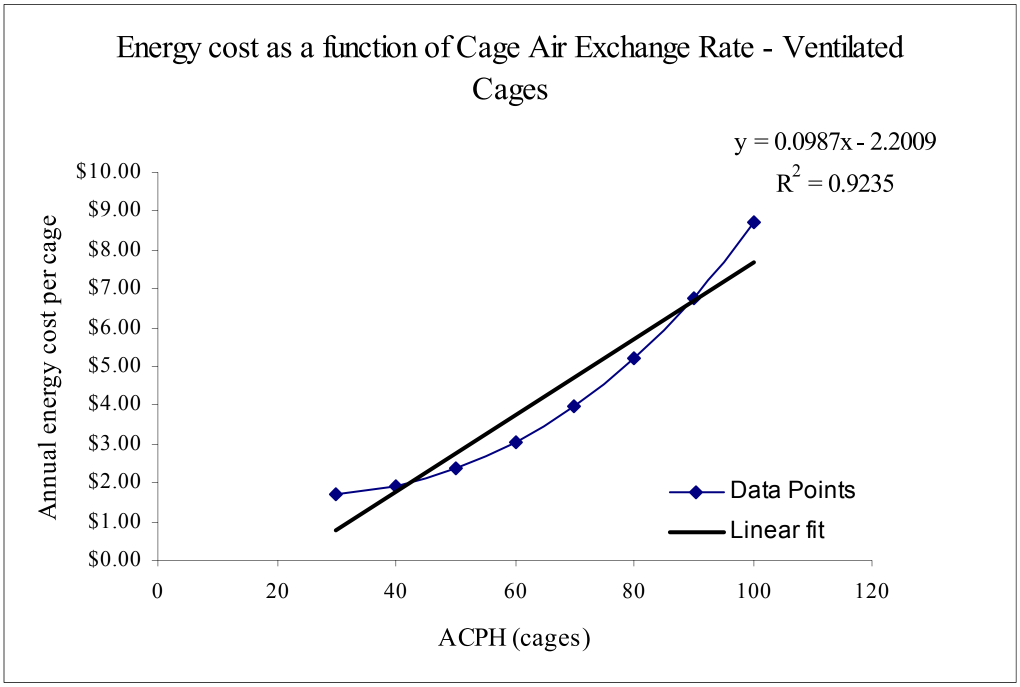

Figure 4-3.Cost as a function of Cage Air Exchange Rate – Ventilated Cages

For ventilated caging systems, Figure 4-3 illustrates the results for a fixed value of 15 ACPH for the room. This is due to the fact that the data available for analysis was based on a fixed value of 15±1 ACPH (Reeb-Whitaker et al. 2001) for the room while varying the ACPH for the cages between the values of 30, 60, and 100. The cost for different ACPH rate for the room can be calculated using the spreadsheet. For analysis, a linear relationship was assumed. As is evident from the figure, the rate of increase, i.e., slope, for ventilated cages is different from conventional cages (the slope of the line is 0.0987 i.e. cost increases by $0.987 with every 10 units increase in ACPH for the cages, based on a linear approximation). In ventilated cages, cost increases drastically as ACPH for the cages goes to 80 and beyond. This was because the pressure drop is not measured. This is superimposed on the linear cost increase of the room ACPH.

Cost Analysis for Cycle of Cleaning and Changing Cages at Animal Care Facility

When corncob bedding was used for the study, there was no detectable ammonia for eight days in static micro-isolator cages (Choi et al. 1994). This helps in the cost reduction of the overall operation of housing mice. This reduces the overall cost of housing mice, i.e., cost decreases as the time interval increases.

The costs associated with cage changing and cleaning at animal care services, University of Florida were evaluated. A calculation spreadsheet was developed. This spreadsheet calculates the total cost as a function of the time interval between successive bedding changes. The cost function is based on the cost of labor required in the whole process, the cost of supplies (which vary as the time interval between successive bedding change changes) and the depreciation of equipment used in the whole process (autoclave, cage washer, animal cages).

The cost spreadsheet developed was based on several assumptions. All the equipment used in the process was depreciated using a straight-line depreciation method. Cages were depreciated based on the number of times cages are autoclaved. This is because the life cycle of an animal cage is a function of the number of times it goes through the autoclaving process. The autoclave was depreciated based on the number of operating cycles per day for a useful life cycle of 15 years, and the cage washer was depreciated based on a utilization factor. This factor depends on the number of hours of operation and the number of cages that can go through the cage washer per hour. Administrative expenses were not taken into account (administrative expenses are constant and do not vary with change in time interval between successive bedding changes). For all the analysis, linear cost approximations were assumed.

For static micro-isolator cages, the time intervals were 3.5, 4, 5, 6 and 7 days. Presently, for static micro isolator cages bedding is changed twice a week and cages are not autoclaved. So in the cost analysis, for a cage changing cycle of 3.5 and 4 days, autoclaving cost was not considered. But for the cage changing cycle of 5, 6, and 7 days, (for static micro isolator cages) the cost of autoclaving the cage with bedding was considered. Figure 4-4 illustrates the cost function based on the time interval between successive bedding changes for static micro-isolator cages. As is evident from the graph, the slope of the equation is negative, i.e., cost decreases with an increase in the time between successive bedding changes. Cost decreases by $10.24 per cage per year for unit increase in BCF (days).

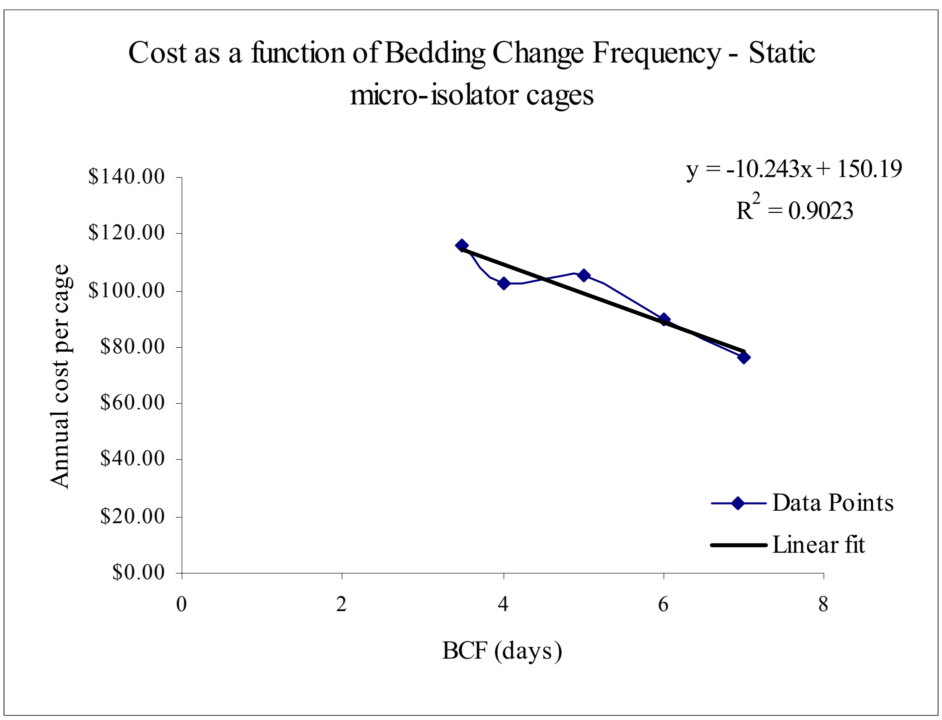

Figure 4-4.Cost as a function of Bedding Change Frequency – static micro-isolator cages

For ventilated cages, the cost was calculated for time intervals of 11, 13, 14, 17, 18, 19, 20 and 21 days between successive bedding changes. The trend line as shown in the figure 4-5 is not similar to the case of static micro-isolator cages. Even though the cost function had a negative slope, it was slightly more nonlinear. As is evident from the graph, cost decreases by $2.77 per cage annually for unit increase in BCF (days).

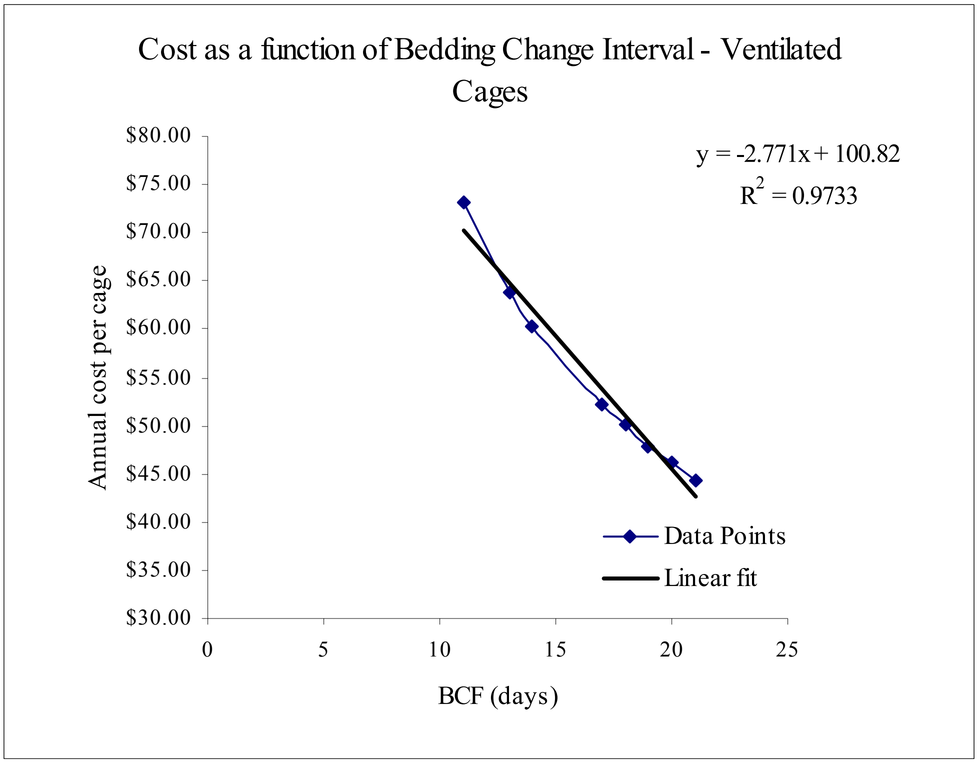

Figure 4-5.Cost as a function of Bedding Change Frequency – Ventilated Cages

Optimization Model

The Relationship Model

In order to find the minimum cost for housing laboratory animals satisfying all the constraints, an economical model needs to be developed. The main contributors to the cost function were the cost of moving air in the animal room and cages (ACPH) and the cost of cage bedding changing and cleaning after a required interval of time (BCF). It was also recognized that ACPH and BCF are related to each other. The relationship between the two parameters is difficult to define. The relationship is more of a concern in designing and manufacturing of animal cages. No relationship was considered for this evaluation, i.e., we assume these parameters are independent. The cost function was considered to be an additive function of ACPH and BCF, where *F_1 (ACPH)* represents cost function for ACPH per cage for ventilated cages and *F_2 (BCF)* represents the cost function for BCF per cage per year. Let “T (ACPH, BCF)” represent the temperature of the system as a function of ACPH and BCF, where t_1 and t_2 are upper and lower constraint values for temperature. These upper and lower constraint values are the limits within which the variable should lie. “C (ACPH, BCF)” represents the concentration of carbon dioxide in the system as a function of ACPH and BCF, and c_1 and c_2 denote upper and lower constraint values. “A (ACPH, BCF)” represents ammonia as a function of ACPH and BCF and a_1 and a_2 denote upper and lower constraint value. “H (ACPH, BCF)” represents humidity as a function of ACPH and BCF, and h_1 and h_2 denote upper and lower constraint values. These relationships were determined by plotting a 3D graph based on available experimental data, and developing an equation for different parameters as a function of ACPH and BCF, explained in the section below. Using the previous notation, the mathematical model for this problem can be written as:

Minimize F_1 (ACPH) + F_2 (BCF)

Subject to:

$$t_1 \leq T(\text{ACPH, BCF}) \leq t_2 \qquad (2)$$

$$c_1 \leq C(\text{ACPH, BCF}) \leq c_2 \qquad (3)$$

$$h_1 \leq H(\text{ACPH, BCF}) \leq h_2 \qquad (4)$$

$$a_1 \leq A(\text{ACPH, BCF}) \leq a_2 \qquad (5)$$

ACPH, BCF $\in$ S (set of feasible values) (6)

ACPH, BCF ≥ 0 (7)

Constraint (2) makes sure that the temperature is below its upper specified limit and above the minimum required value. Equation (3) ensures that boundary conditions for carbon dioxide are satisfied. Similarly, (4) ensure that boundary conditions for humidity are satisfied and (5) satisfy the boundary conditions for ammonia. Constraint (6) states that all the variables are from a set of feasible values and (7) is the non-negativity constraint, i.e., all values are greater than or equal to zero.

There were certain limitations in the construction of the model for optimization of cost. ACPH and BCF were assumed independent. The data available was for autoclaved pine shavings bedding only (Reeb-Whitaker at al. 2001). In the cost analysis for the cage cleaning and bedding changing process, corncob bedding was assumed. This is because corncob bedding is currently used in mice cages. The non-availability of performance data for corncob bedding necessitated our use of pine shaving data. However, the actual cost of cleaning cages with pine shavings does not differ appreciably from cages with corncob bedding. Also, adequate data were not available for extensive analysis and construction of the model. Therefore we propose this model as general approach for optimizing the cost of housing laboratory mice. Future research can serve to refine the model parameter estimates and functional relationships in order to provide a more accurate cost model. To this end, we might propose an interactive cost function e.g. component, F_3 (ACPH, BCF).

Data Analysis

Extensive data were required in order to construct an ideal model to get better results for the problem. Lack of funding prohibited any experiments that could be conducted to collect data for analysis. Therefore data published by other researchers was used to construct a model and conduct the analysis. Data published in a paper by (Reeb-Whitaker et al. 2001) was used to develop a relationship for various constraints with respect to ACPH and BCF. The data were available for 30, 60, 100 ACPH for the cages at a fixed 15.37 ACPH rate for the room. Bedding change intervals considered were 7, 14 and 21 days.

The type of bedding used in this experiment was pine shavings. To characterize C, T, H and A as a function of ACPH and BCF using a linear approximation in order to create a linear model, three different approaches were made to find a relationship for the respective constraints. There were in all 16 data points available for the analysis as shown in Table B-6. Separate 3D graphs were plotted for ammonia, temperature, humidity and carbon dioxide. The X-axis was ACPH, the Y-axis the BCF, and the Z-axis contains the constraint value. Equations were developed for approximating the Z-axis (variable) as a function of the X and Y-axis values. We next discuss the three approaches used.

In the first approach, all data points for each of the variables were plotted using a Sigma Plotter (sigma plotter 2001) on a 3D graph. An average best-fit linear plane was plotted for all the data points (Figure A1 to A4 in appendix). An equation was generated for the average plane of data points for each constraint. The equation of these planes was used to determine the relationship for parameters as a function of ACPH and BCF. This equation was bounded by upper and lower constraint values for each parameter. The model was constructed using the equations developed. Because the standard error for the data available from previous study (Reeb-Whitaker at al. 2001) was very high, the regression equation developed from an average plane equation proved to be a poor approximation. The points were scattered around and as seen in the graph, and some points were far off the track from the average plane. A different approach was therefore adapted to seek better results.

Three data points with maximum values and three data points with minimum values for each parameter from the available set of data were used to plot the graph in the second approach (Figure A5-A6 in Appendix). The equation of the plane from maximum value data points was termed as F_{max}. The equation of the plane from minimum value data points was termed as F_{min}, i.e. for temperature, T_{max} represents the equation for the upper plane (3 data points with maximum value) and T_{min} represents the equation for the lower plane (3 data points with minimum value).

The constraint equations were thus written as:

$$T_{max}\ (ACPH, BCF) \leq T_1 \quad (8)$$

$$T_{min}\ (ACPH, BCF) \geq T_2 \quad (9)$$

Constraint (8) ensures that value of equation is below the upper bounded plane and (9) makes sure that it lies above the lower bound plane. In a similar way, equations were developed to identify the relationships of various parameters as a function of ACPH and BCF using the same approach. When the results and graphs from the first two approaches were analyzed, the optimal region was found to be concentrated in a particular area. Dividing the whole region into certain subsets, thus making the region to be analyzed smaller would help in seeking better results.

Therefore, in the third and final approach, the feasible region was subdivided into 4 sub regions, and a model was developed for each sub region. We were thus able to obtain a more accurate model by developing a linear approximation model unique to each sub region. We can then optimize within each sub region and take the best solution among each sub region. The first subset consisted of data points for ACPH values of 30, 60 and BCF of 7and 14 days. Subset 2 consisted of data points for ACPH of 30, 60 and BCF of 14 and 21 days. Similarly, for subset 3, ACPH was 60, 100 and BCF was 7 and14 days and subset 4 was combination of ACPH 60,100 and BCF 14 and 21 days. There were 4 parameters. For all 16 sets, data points were to be plotted and analyzed. A graph was plotted for each parameter temperature, humidity, ammonia and carbon dioxide as a function of ACPH and BCF for 4 sets of data points in accordance to each subset (Figure A7-A10 in Appendix). Best-fit linear equations were used to analyze the available results and to construct a model. Four different models were constructed and results were analyzed.

T_a represents temperature as a function of ACPH and BCF for subset 1. Similarly, T_a, H_a, A_a, C_a were defined for subset 1, subset 2, subset 3 and subset 4, respectively. Let m_1 represent the upper bounded value for ACPH for subset 1 and m_2 represent lower bound value for ACPH for subset 1. For BCF, b_1 represents the upper bound value for BCF and b_2 represents the lower bounded value for BCF for subset 1. Upper and lower bounded values for subset 2, 3, 4 were defined similarly.

Present Model

Subset 1:

Objective function:

Minimize $F_1\ (ACPH) + F_2\ (BCF)$

Subject to:

$$t_1 \leq T_a\ (\mathrm{ACPH, BCF}) \leq t_2 \tag{10}$$

$$c_1 \leq C_a\ (\mathrm{ACPH, BCF}) \leq c_2 \tag{11}$$

$$h_1 \leq H_a\ (\mathrm{ACPH, BCF}) \leq h_2 \tag{12}$$

$$a_1 \leq A_a\ (\mathrm{ACPH, BCF}) \leq a_2 \tag{13}$$

$$m_1 \leq \mathrm{ACPH} \leq m_2 \tag{14}$$

$$b_1 \leq \mathrm{BCF} \leq b_2 \tag{15}$$

$$\mathrm{ACPH, BCF} \in \mathrm{F}\ \text{(set of feasible values)} \tag{16}$$

$$\mathrm{ACPH, BCF} \geq 0 \tag{17}$$

Constraints (10) to (13) are same as constraints (1) to (4) except for the fact that they are restricted to their respective subsets. Constraint (14) ensures that ACPH lie within the defined subset, i.e., for subset 1; ACPH should lie between 30 and 60. Constraint (15) makes sure BCF lie between specified regions of subset 1 i.e. for subset 1 BCF should be between 7 and 14 days. Constraints (16) and (17) are feasibility and non-negativity constraint.

CHAPTER 5
RESULTS AND CONCLUSIONS

Analysis of Results Obtained

In this thesis, to minimize the cost of housing laboratory mice, different variables affecting ACPH and BCF as a function of ACPH and BCF were analyzed. Data from research (Reeb-Whitaker at al. 2001) conducted in the past were used to construct the model and conduct analysis. The formulation for all the subsets was solved using Lindo (Lindo 6.1). Lindo is an optimization software tool, which solves the formulation as shown in the previous chapter to provide optimal results with allowable increases and decreases in the constraint value. This helps in analyzing, how results will vary by changing the constraint value in the formulation. After analyzing the results from all the four subsets, it was found that formulation for subset 2 and 4 gives us optimal results satisfying all the constraints.

Table 5-1. Results from optimization model

Subsets	ACPH	BCF	Cost ($)
1. ACPH (30,60) and BCF (7,14)	56.25	14	$67.45
2. ACPH (30,60) and BCF (14,21)	60	20.14	$50.78
3. ACPH (60,100) and BCF (7,14)	60	14	$67.82
4. ACPH (60,100) and BCF (14,21)	66.25	21	$49.04

But the cages used currently at animal care services are designed for an air exchange rate of 60 per hour. Therefore, results from subset 2 at 60 ACPH can be used to develop a relationship for future work.

The data used in the analysis was for autoclaved pine shaving bedding (Reeb-Whitaker at al. 2001). Pine shaving bedding has a lower capacity of suppressing ammonia levels. From the (Figure 2-2) it can be seen that on the scale of 1 to 7, if corncob bedding stands on number 1, than pine shavings is at number 6. For static micro-isolator cages, corncob had no detectable ammonia for study period of 7 days, while pine shavings bedding had detectable ammonia on day 4 during the study while the study was being conducted. A separate study (Choi et al. 1994) was conducted using corncob as bedding, for both static micro-isolator and individually ventilated rodent caging systems. It was concluded that, corncob bedding could suppress ammonia level in individually ventilated cages for 32 days and for 8 days in conventional cages. The ventilated cage study was terminated after 32 days due to the development of fecal material inside the cages.

Relating these studies with results obtained from the analysis conducted, it can be concluded that current practice of changing cages animal rooms every 14 days for ventilated cages can be extended. Considering the practical scenario with changes in climatic conditions and air exchange rate for the animal room, the practice of cage changing cycle every 14 days can be extended to 20 or 21 days. With autoclaved pine shavings bedding, all the constraint values are satisfied for a 20-day cage changing cycle. But in this case ammonia reaches its threshold value of 25 ppm. If we relate the studies as explained above, corncob bedding should be able to sustain ammonia with in allowable limits for 20 or 21 days for individually ventilated cages and would provide us with total savings of $14.00 per cage annually for a 20 day cage changing cycle and $15.84 for a 21 day cage changing cycle.

For static micro isolator cages, current practice requires cages to be changed twice a week. These cages are not autoclaved i.e. cages undergo a cleaning and bedding change process but are not autoclaved with bedding. The study conducted showed that for static micro-isolator cages there was no ammonia detected for 8 days when corncob bedding used was autoclaved (Choi et al. 1994). With the current practice the average cost of housing at animal care services; University of Florida is $116.22 per cage per year (table B-3). This is for cage a BCF of 3.5 days (twice per week). If we autoclave the bedding in static micro isolator cages, the cage changing cycle (BCF) can be extended to 7 days. This can reduce the total cost to $76.22, i.e. the total cost savings of $40.00 per cage per year (Table B-5). The cost decreases despite an increase in autoclaving cost because reduced supplies required, reduces the cost. As we increase the BCF to 7 days, depreciation cost on the cages goes down. Supplies are used in the same quantities irrespective of the BCF. Therefore as the time interval between successive bedding changes goes up, cost decreases.

- Cage changing cycle for individually ventilated cages can be extended from current practice of 14 days (at 60 ACPH for cages) to 20 days (60 ACPH for cages), which results in a cost saving of $14.00 per cage per year.
- For static micro-isolator cages, the cage changing cycle can be extended from current practice of twice a week to once a week, but the cages need to be autoclaved with corncob bedding. This would result in a cost saving of $40.00 annually per cage.
- Based on 1300 number of static micro-isolator cages and 3450 ventilated cages at Communicore facility, University of Florida, total cost savings would be $100,300.00.

Future Work

An experimental evaluation needs to be conducted to validate the results of this study. An experiment using the results as stated above should be conducted for the following set values:

Table 5-2. Data for proposed experiment

Parameters	***Values***	***Comments***
Room ACPH	15-17 per hour	
Cage ACPH	60 per hour	
Type of bedding	Corncob	Autoclaved- corncob bedding, 130 to 140 grams per cage, combination of ¼ & 1/8 inch diameter.
BCF	20-21 days	
Cage density	3 to 4 mice per cage	

For concentration of ammonia below 0 ppm during the period of experiment, time interval between successive bedding changes can be increased to 21 days. Even though the acceptable limit is 25 ppm, by keeping it 0 ppm during the testing period, we make sure that concentration will be well below 10 ppm under extreme inevitable macro and micro environmental conditions.

Some exceptions need to be considered while setting up cages for the proposed experiments. In some cases it was found that cages with trio-mated mice tend to produce more ammonia as compared to cages containing pair mated mice (Reeb-Whitaker et al. 2001). Also ammonia production is dependent on strain of mice. Therefore while conducting experiments; cages with a proper mix of mice i.e. cages with different kinds of mice which addresses the problems stated above, can help in achieving better results.

Similarly, an experiment for static micro isolator cages can be conducted, by increasing the cage change frequency to 6 or 7 days and autoclaving the cages. Since all other parameters were within limits and not a concern, in this experiment we need to check the concentration of ammonia for cages in all the racks for the specified duration of time. This is because concentration at times does vary according to the position of cages i.e., top, middle and bottom row. For the concentration of 0 ppm, cage changing cycle can be shifted from twice a week to 6 days or 7 days.

APPENDIX A
GRAPHS FOR FUNCTIONAL RELATIONSHIPS FOR VARIOUS PARAMETERS
AS A FUNCTION OF ACPH AND BCF

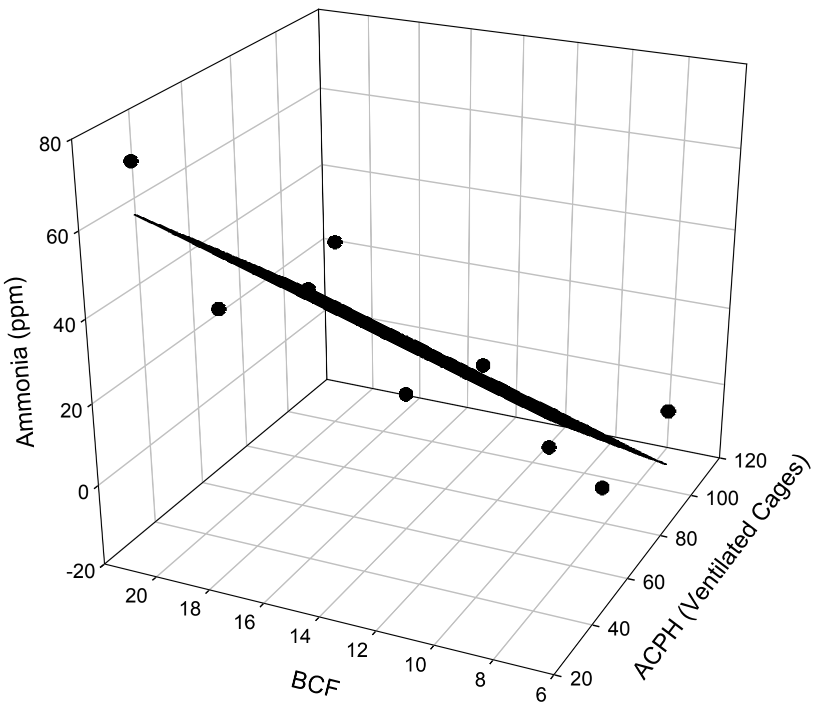

Figure A-1. Ammonia as a function of ACPH (Ventilated Cages) and BCF

(•) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points available)

Equation of plane:
F= 37.362 – 0.6495*(X) + 2.0571*(Y)
Where F represents the function i.e. ammonia
X – ACPH
Y - BCF

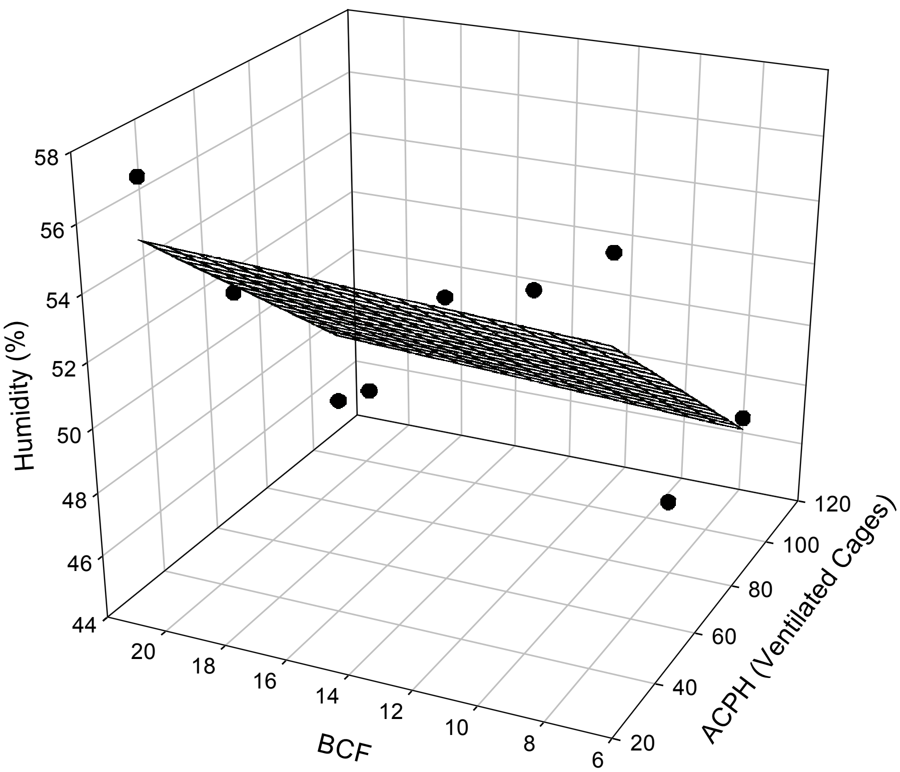

Figure A-2. Humidity as a function of ACPH (Ventilated Cages) and BCF

(•) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points available)

Equation of plane:
F= 57.1089 – 0.0982*X + 0.0476*Y

Where F represents the function i.e. humidity
X – ACPH
Y - BCF

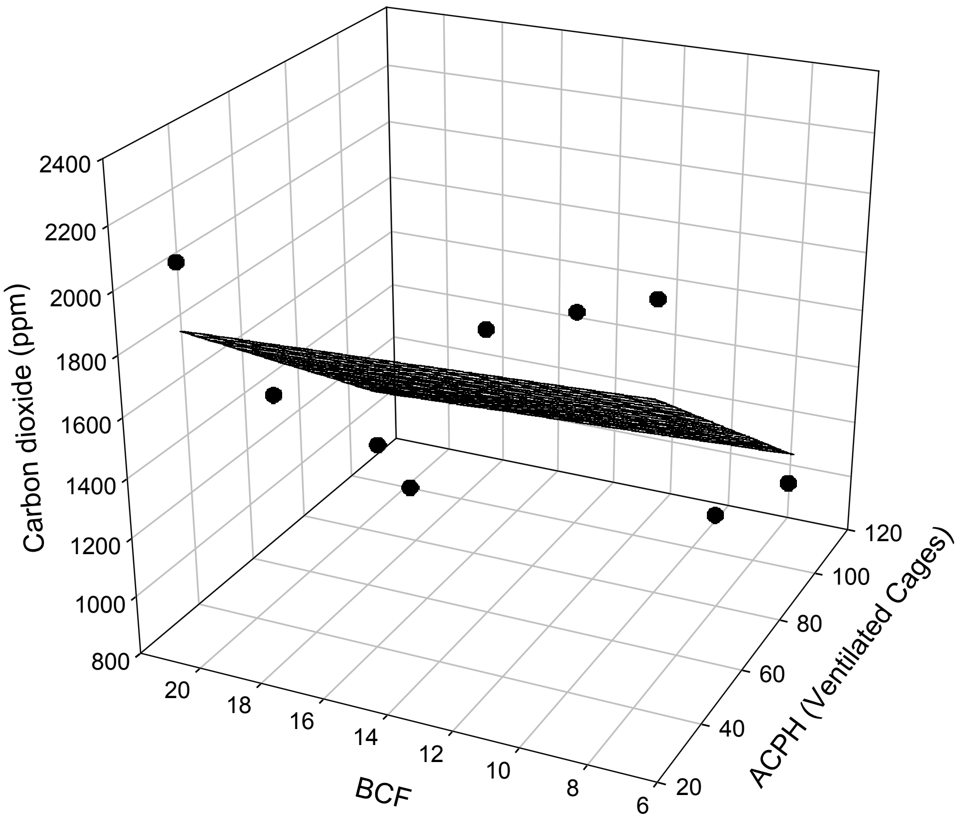

Figure A-3. Carbon dioxide as a function of ACPH (Ventilated Cages) and BCF

(•) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points available)

Equation of plane:
F= 2224.5577 – 9.7833*X – 4.7588*Y

Where F represents the function i.e. carbon dioxide
X – ACPH
Y - BCF

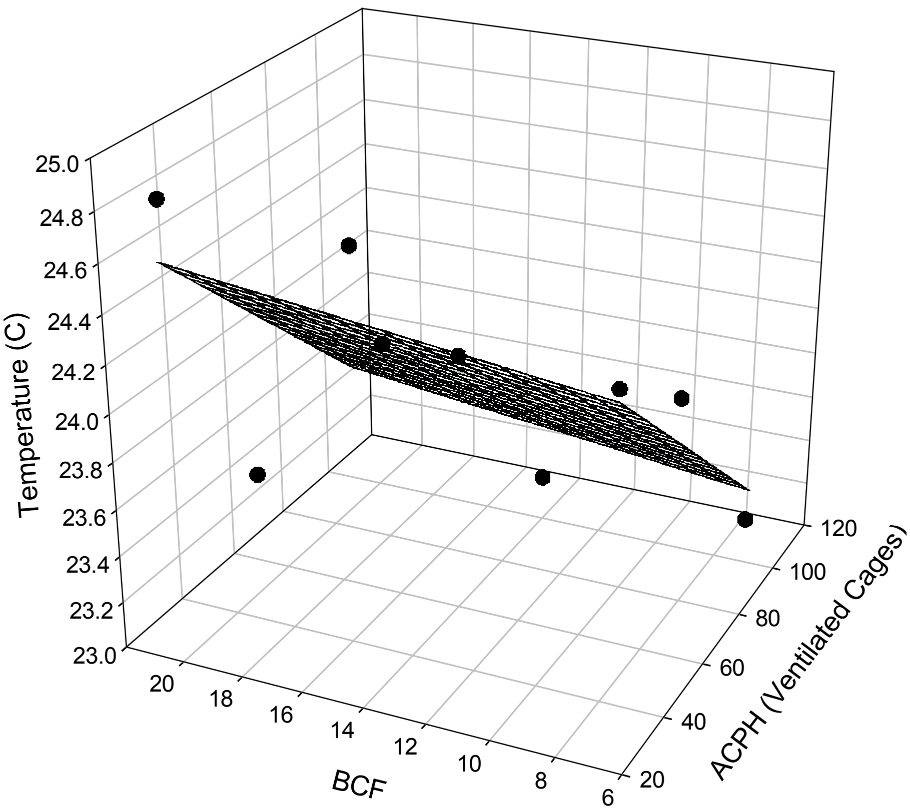

Figure A-4. Temperature as a function of ACPH (Ventilated Cages) and BCF

(•) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points available)

Equation of plane:
F= 24.6827 – 0.0145*X + 0.0143*Y

Where F represents the function i.e. temperature
X – ACPH
Y - BCF

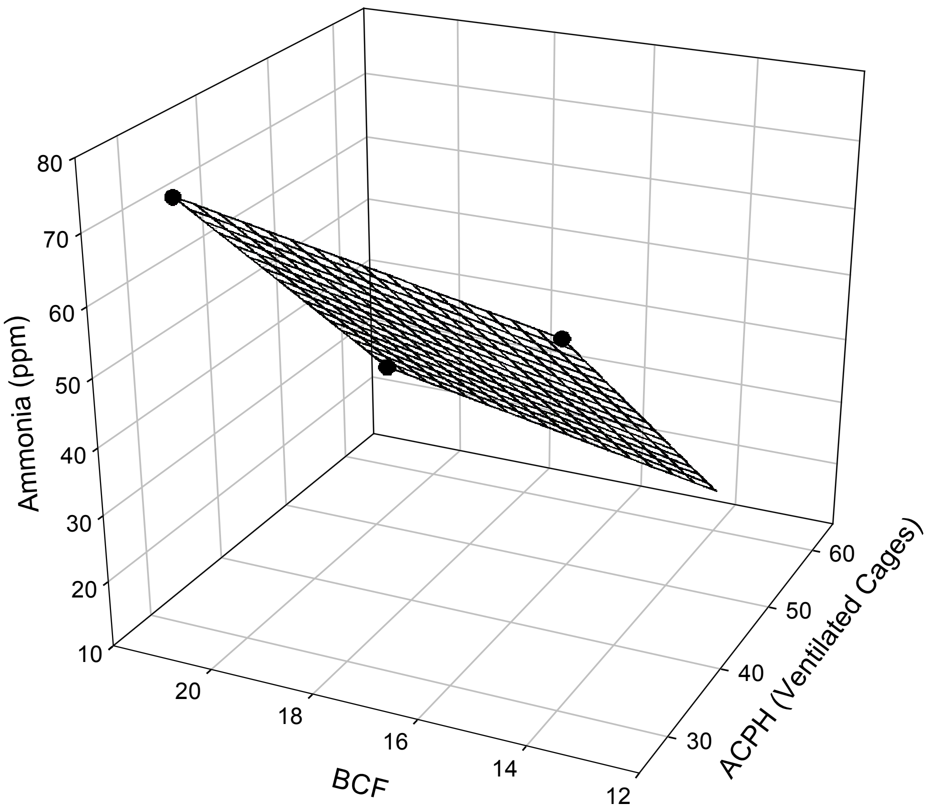

Figure A-5. Ammonia as a function of ACPH (Ventilated Cages) and BCF - The graph is plotted for three data points with maximum value for concentration of ammonia form the available data set

(•) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points available)

Equation of plane:
F= 88.500 – 1.5367*X + 1.4571*Y

Where F represents the function i.e. ammonia
X – ACPH
Y - BCF

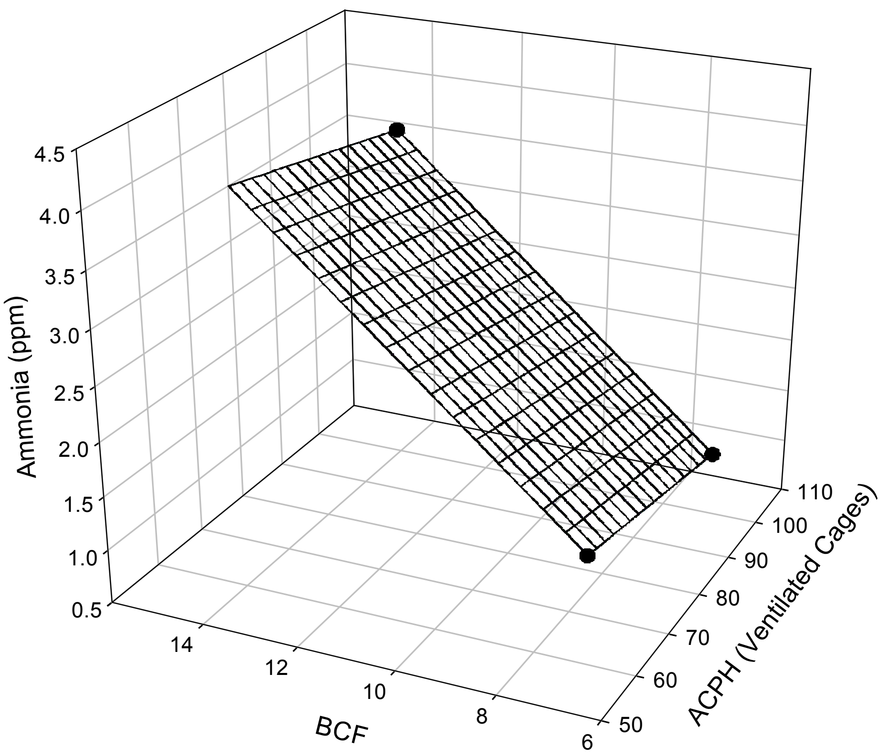

Figure A-6. Ammonia as a function of ACPH (Ventilated Cages) and BCF - The graph is plotted for three data points with minimum value for concentration of ammonia form the available data set

(●) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points available)

Equation of plane:
F= -0.500 – 0.01*X + 0.3714*Y

Where F represents the function i.e. ammonia
X – ACPH
Y - BCF

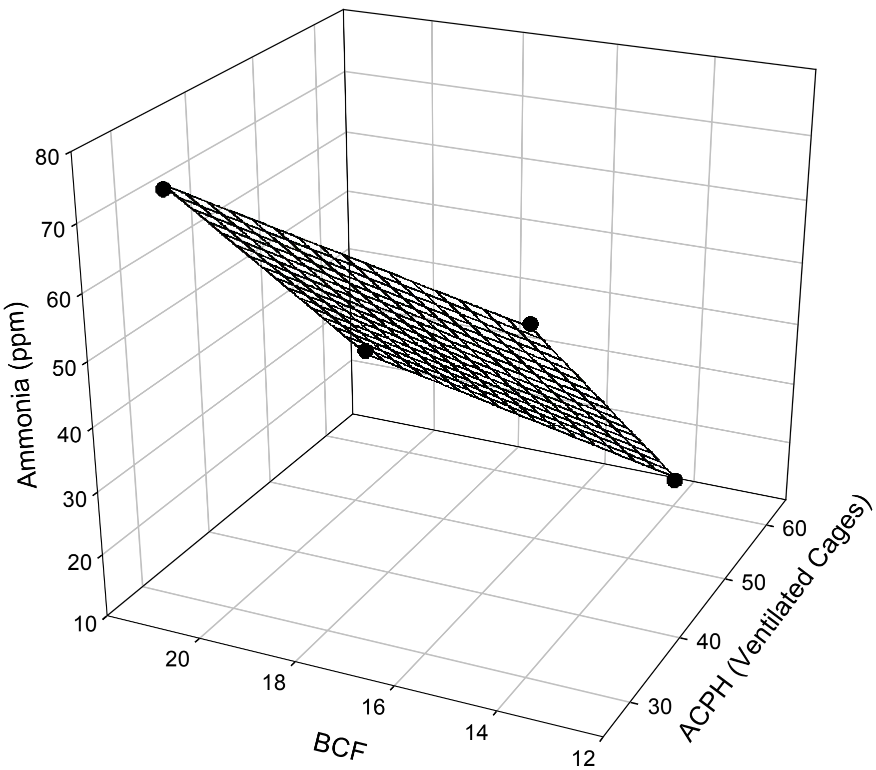

Figure A-7. Ammonia as a function of ACPH (Ventilated Cages) and BCF – (Subset 2: Data plotted is for subset of ACPH of 30 and 60 with a BCF of 14 and 21 days)

(●) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points available)

Equation of plane:
F= 86.9251 – 1.5717*X + 1.6071*Y

Where F represents the function i.e. ammonia
X – ACPH
Y – BCF

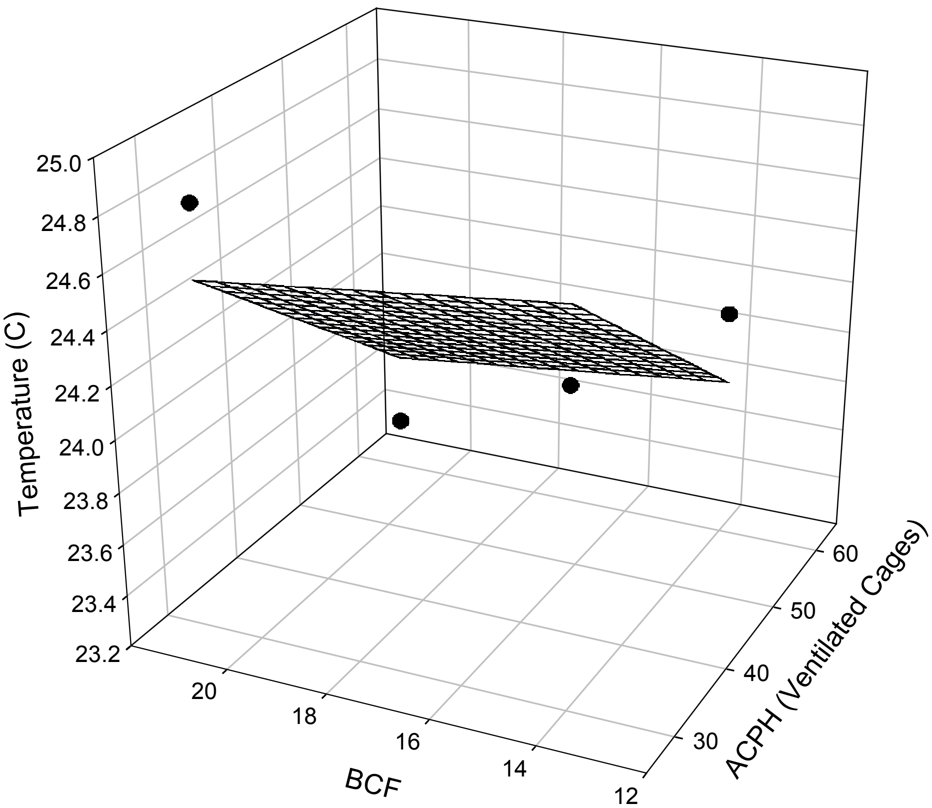

Figure A-8. Temperature as a function of ACPH (Ventilated Cages) and BCF – (Subset 2: Data plotted is for subset of ACPH of 30 and 60 with a BCF of 14 and 21 days)

(•) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points available)

Equation of plane:
$F = 25.4289 - 0.0283*X - 0.0214*Y$

Where F represents the function i.e. temperature
X – ACPH
Y – BCF

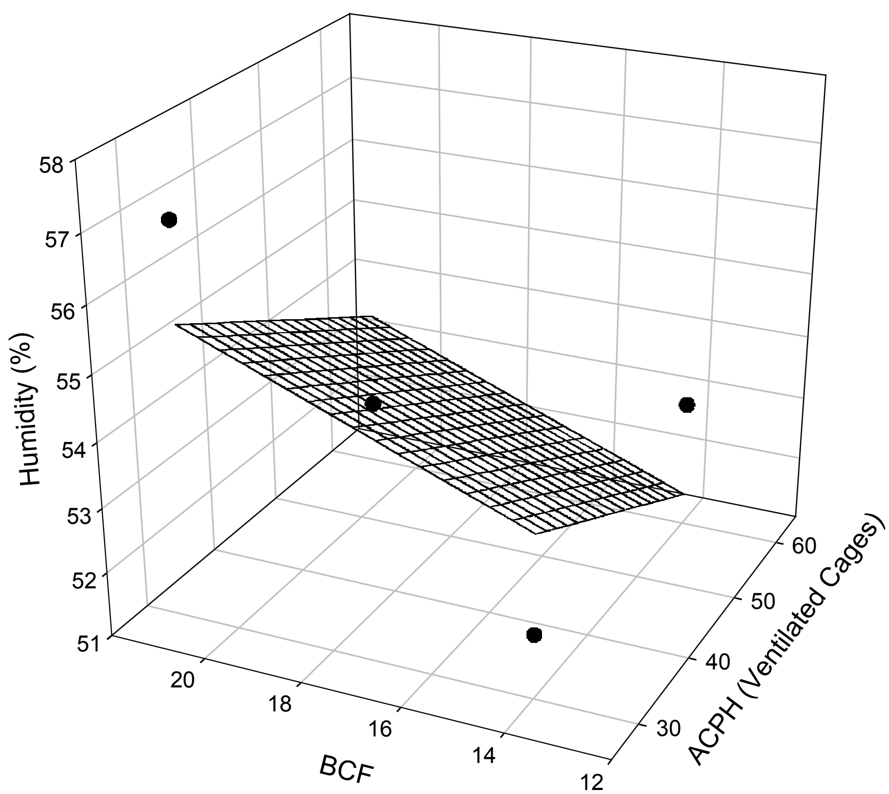

Figure A-9. Humidity as a function of ACPH (Ventilated Cages) and BCF – (Subset 2: Data plotted is for subset of ACPH of 30 and 60 with a BCF of 14 and 21 days)

(•) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points for subset 2)

Equation of plane:
F= 51.5017 – 0.0667*X + 0.2856*Y

Where F represents the function i.e. humidity
X – ACPH
Y - BCF

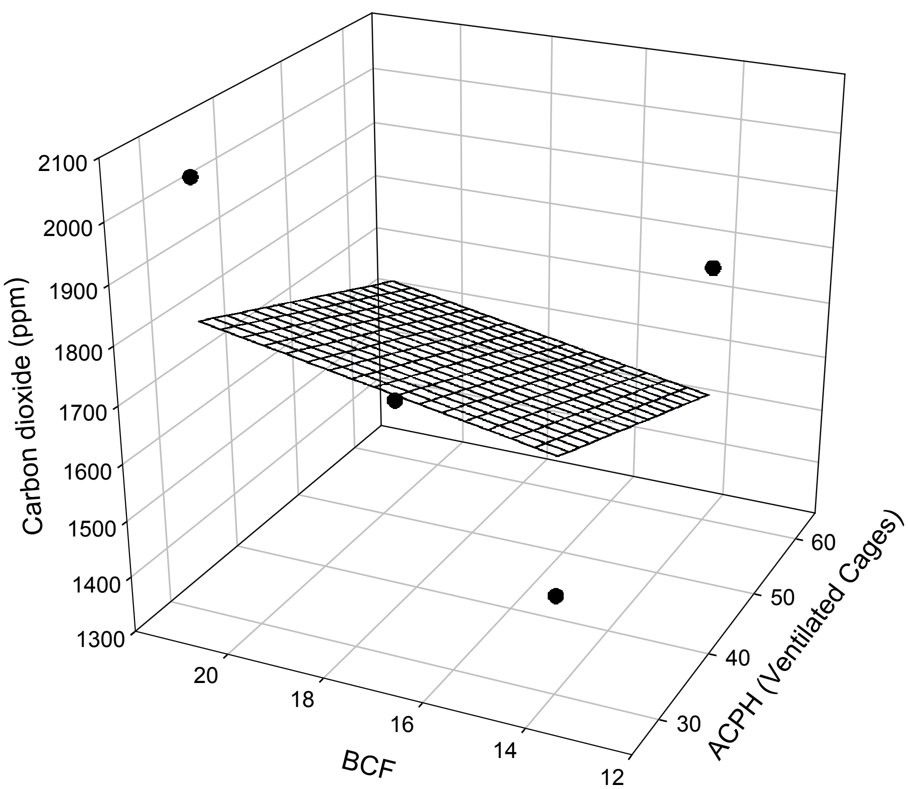

Figure A-10. Carbon dioxide as a function of ACPH (Ventilated Cages) and BCF – (Subset 2: Data plotted is for subset of ACPH of 30 and 60 with a BCF of 14 and 21 days)

(•) – Data points

Solid plane – Best fit linear curve for the data points (Graph is plotted for all the data points for subset 2)

Equation of plane:
F= 1661.3389 – 5.5837*X + 15.3531*Y

Where F represents the function i.e. carbon dioxide
X – ACPH
Y - BCF

APPENDIX B
SPREADSHEETS FOR COST ANALYSIS AND RESULTS

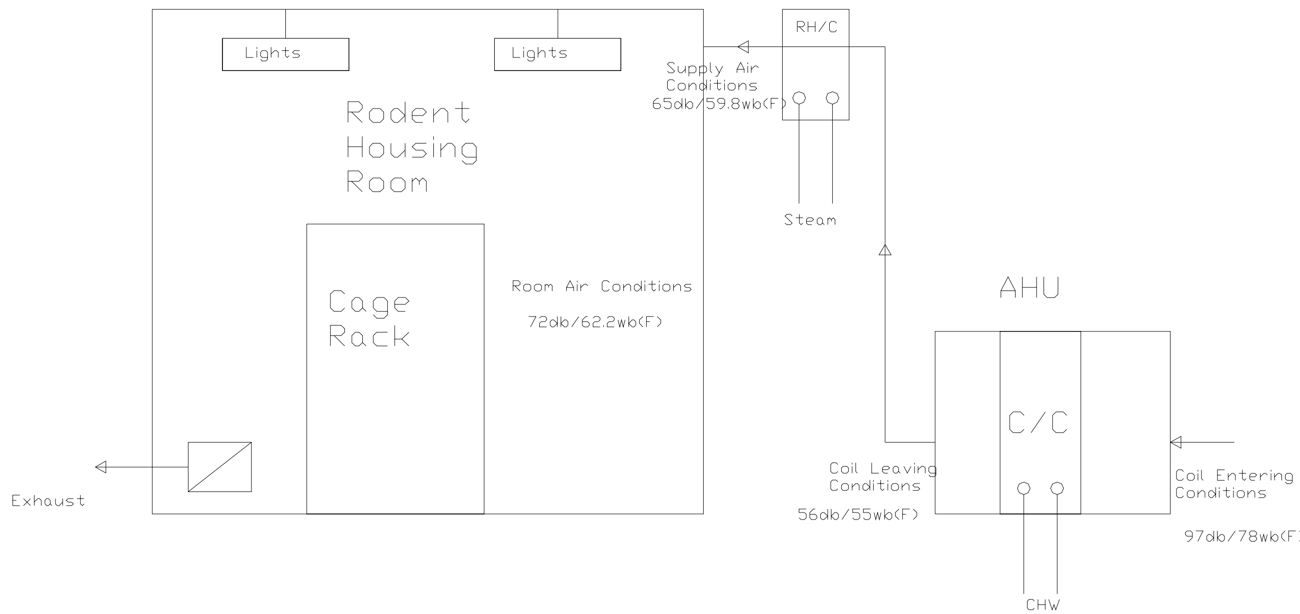

Figure B-1 Rodent housing ventilation schematic

Table B-1. Energy cost analysis for air exchange rate for rooms with static micro-isolator cages

Dimensions (Typical UF Rodent Housing Room)		
Length	16.708	ft
Breadth	12.54	ft
Height	8.5	ft

Pressure	100000	kPa	14.696	lb/sqin		
Temperature (Typical Design Conditions)		Dry bulb			Wet bulb	
Coil leaving air temperature	**LAT**	56	F	**LAT***	55	F
Supply air temperature	**SAT**	64.99	F	**SAT***	59.8	F
Room air temperature	**RAT**	72	F	**RAT***	62.2	F
Coil entering air temperature	**EAT**	97	F	**EAT***	78	F

Enthalpy (Calculated from db and wb temperature)			
Coil leaving air	**LAE**	22.88	btuh
Supply air	**SAE**	25.93	btuh
Room air	**RAE**	27.58	btuh
Coil entering air	**EAE**	40.80	btuh

Air changes per hour (Variable)	ACH	15

Number of fixtures (Typical UF Housing Room)		N1	6	
Power consumption (Typical UF Housing Room)		W1	95	Watts

Number of full load equivalent hours of operation/ year		1200	hrs/yr	Winter
Number of full load equivalent hours of operation/ year		2000	hrs/yr	Summer
Number of cages		N3	125	
Number of mice/cage		N4	3.25	per cage
Number of persons		N2	1	

Table B-1. Continued

Rate /kw		8		
Efficiency		0.8		

45.3704

326.4

Volume of room	1780.91	cu feet

Sensible heat from mice (From ref No. 20)		1.11	btu/hr
Latent heat from mice (From ref No. 20)		0.54	btu/hr
Total heat from mice		1.65	btu/hr

Total heat from people		HN2	500	btu/hr
Sensible heat from people		Hs	250	btu/hr
Latent heat from people		Hl	250	btu/hr

Total sensible heat from lights			570	Watts

Total Internal Loads, btuh					
QLights		2332.44	btu/hr		
			(Category D)		
Qhuman		500	btu/hr		
Qmice (Latent+Sensible)		536.25	btu/hr		
Total Internal Loads		3368.69	btu/hr		

Q Sensible Load (Qlights+Qhuman+Qmice)					
Qsensible lights		2332.44			
Equipment		1750		464.032	1279.5
Qsensible human		250			
Qsensible mice		360.75			
Total Internal Sensible, btuh		4693.19	btuh		
Cooling load from cycle 4 to 1					

Table B-1. Continued

Air is taken from outside at normal temp and humidity and					
cooled and dehumidified to saturated temperature and humidity					
Q1	80.62	btuh/cfm			
Qroom (cfm to comply with 15 ACH)	445.23				
(Volume of room*ACH/60)					
Estimate of supply air flow	419.04	cfm to AC room			
Estimate of supply air flow	620.28				
Qcool	35892.24	btu/hr	(Q1+Qroom)		
SAT	64.99	F			

Assume full load equivalent hours			2000	hrs/yr
Cooling by chilling with efficiency of		6	kW/ton	
Assume 24/7 operation				

Cooling required	5.98	ktonhrs	$	$418.74	
Q reheat	4324.82	btu/hr			
Steam consumption due to reheating		8.65	klb steam		$33.04
Power consumption due to reheating (during winters)			22.03	kW/yr	$84.17

Total annual cost				**$535.96**	**per year**
Air changes per hour (ACPH)	**Energy cost ($)**				
5	$149.58				
6	$188.22				
7	$226.86				
8	$265.49				
9	$304.13				
10	$342.77				
11	$381.41				
12	$420.04				

Table B-1. Continued

13	$458.68
14	$497.32
15	$535.96
16	$574.60
17	$613.23
18	$651.87

Table B-2. Energy cost analysis for air exchange rate for rooms with ventilated cages.

Dimensions (Typical UF Rodent Housing Room)		
Length	16.708	ft
Breadth	12.54	ft
Height	8.5	ft

Pressure	100000	Pa	14.696	lb/sqin		
Temperature (Typical Design Conditions)						
Leaving air conditions	**LAT**	56	F	**LAT***	55	F
Supply air	**SAT**	62.21	F	**SAT***	59.8	F
Room air temp	**RAT**	72	F	**RAT***	62.2	F
Coil Entering Air Conditions	**EAT**	97	F	**EAT***	78	F

Enthalpy (Calculated from db and wb temperature)			
Leaving air	**LAE**	22.88	btuh
Supply air	**SAE**	25.92	btuh
Room air	**RAE**	27.58	btuh
Coil entering air	**EAE**	40.80	btuh

Air changes per hour (Variable)	**ACPH**	15	

Number of fixtures (Typical for UF Housing Room)		N1	6	
Power consumption (Typical for UF Housing Room)		W1	95	Watts

Number of blowers		1
Number of hoods		3

Number of full load equivalent hours of operation/ year		1200	hrs/yr	Winter

Table B-2. Continued

Number of full load equivalent hours of operation/ year		2000	hrs/yr	Summer
Number of cages		N3	350	
Number of mice/cage		N4	3.25	per cage

Number of persons		N2	1
Rate /kw		8	
Efficiency		0.8	

Calculations

Volume of room	1780.91	cu feet	

Sensible heat mice		1.11	btu/hr
Latent heat mice		0.54	btu/hr
Total		1.65	btu/hr

Heat generated		HN2	500	btu/hr
Sensible heat		Hs	250	btu/hr
Latent heat		Hl	250	btu/hr

Total load lights			570	Watts
Total Internal Loads, btuh				
Qlights (category D)		2332.44	btu/hr	
Qhuman		500	btu/hr	
Qmice (Latent+Sensible)		1876.875	btu/hr	
Total Internal Loads, btuh		4709.315	btuh	

Q Sensible Load (Qlights+Qhuman+Qmice)					
Qsensible lights		2332.44			

Table B-2. Continued

Equipment		1750		464.032	1279.5
Qsensible human		250			
Qsensible mice		1262.625			
Total Internal Sensible, btuh		5595.065	btuh		
Cooling load from cycle 4 to 1					

Air is taken from outside at normal temp and humidity and		
cooled and dehumidified to saturated temperature and humidity		
Q1	80.62	btuh/cfm

Qroom (cfm to comply with 15 ACH)	445.23			
Estimate of supply air flow	419.04	cfm to AC room		
Estimate of supply air flow	528.97			
Qcool (Q1+Qroom)	35892.24	btu/hr		
SAT	62.21	F		
Assume design conditions where in chiller works for			2000	hrs/yr
Cooling by chilling with efficiency of		6	Kw/ton	
Assume 24/7 operation				

Cooling required	5.98	ktonhrs		$418.74	
Q reheat (Qroom*1.08*(SAT-LAT))	2984.20	btu/hr			
Steam consumption due to reheating		5.97	klb steam		$22.80
Power consumption due to reheating (during winters)			20.17	kW/yr	$77.06

Total annual cost				$1,066.63	per year

Air supply system			Rate/kWh	
	0.068	kW		
	595.68	kWh	0.92	548.0256

Table B-2. Continued

Calculation of power consumption					
Q1	29.8	ACPH	kW	Cost	
Q2	49.66666667	30	0.0085	1.68	587.11
N1	1422	40	0.0195	1.93	675.76
N2	2370	50	0.0394	2.39	835.74
H1	0.068	60	0.068	3.05	1,066.63
H2		70	0.1079	3.97	1388.19
		80	0.1611	5.19	1816.94
N2	2370	90	0.2295	6.77	2368.19
H2	0.314814815	100	0.3148	8.73	3055.64

Air changes per hour (ACPH)	**Energy cost ($)**	**Energy cost per cage**	
30	$587.11	$1.68	
40	$675.76	$1.93	
50	$835.74	$2.39	
60	$1,066.63	$3.05	
70	$1,388.19	$3.97	
80	$1,816.94	$5.19	
90	$2,368.19	$6.77	
100	$3,055.64	$8.73	

Table B-3. Cost analysis for cage changing cycle for static micro-isolator cages.

Static cages

400 cages						
Supplies	**Quantity**	**Unit**	**Price**	**Unit**	**Total cost**	
[5] Corn Cob Bedding	2.5	bags	$11.75	per bag	$29.38	
[5] Food	13	bags	$12.40	per bag	$161.20	
[3] Chlorine Dioxide	0.5	gallons	$29.90	per gallon	$14.95	
[3] Paper Towel	0.1	cases	$78.00	per case	$7.80	
[3] Gloves	0.1	boxes	$5.50	per box	$0.55	
[3] Sleeves	20		$34.00	for 200	$3.40	
[3] Shoecovers	0.1	cases	$22.50	per case	$2.25	
[3] Masks	0.25	box	$6.34	per box	$1.59	
[2] Trash bags	24	bags	$18.95	50 bags	$9.10	
[4] Energy (cage washer)					$26.24	
[4] Disposal					$9.00	
[2] Gowns	0.25	cases	$29.80	per case	$7.45	
[5] Labor (cage changing)	560	min	$0.15		$84.00	
[5] Labor (cage cleaning)	420	min	$0.15	min	$63.00	
[5] Depreciation					$2,820.64	per year

Static cages are not autoclaved

$419.90	
$11,622.46	**per year for 100 cages**
$116.22	**per year per cage**

Table B-3. Continued

Depreciation (Straight line depreciation)

Based on 400 units

			Cost per unit	Number of units	Total Cost	Life cycle
(1) Conventional cages			$40.00	400	$16,000.00	10
Cost of extra cages			$40.00	100	$4,000.00	10
Cage Washer	0.05556		$221,555.00	1	$12,309.60	15
Depreciation					**$2,820.64**	per year

(1) Cage cost includes cost of water bottles and other accessories required for static micro isolator caging system
(2) Data from observation at University of Florida
(3) Data from staff
(4) Data from manufacturer
(5) Data calculated

Table B-4. Cost analysis for cage changing cycle for ventilated cages

400 cages						
Supplies	**Quantity**	**Unit**	**Price**	**Unit**	**Total cost**	
[4] Corn Cob Bedding	2.5	bags	$11.75	per bag	$29.38	
[4] Food (Irradiated)	17	cases	$23.95	per case	$407.15	
[2] Chlorine Dioxide	0.5	gallons	$29.90	per gallon	$14.95	
[2] Paper Towel	0.1	cases	$78.00	per half case	$7.80	
[2] Autoclave Tape	1	rolls	$2.88	per roll	$2.88	
[4] Paper Bags	25		$8.90	for 200	$1.11	
[2] Gloves	0.1	boxes	$5.50	per box	$0.55	
[2] Sleeves	20		$34.00	for 200	$3.40	
[2] Shoe covers	0.1	cases	$22.50	per case	$2.25	
[2] Masks	0.25	box	$6.34	per box	$1.59	
[1] Trash bags	24	bags	$18.95	50 bags	$9.10	
[3] Disposal					$9.00	
[1] Gowns	0.25	cases	$29.80	per case	$7.45	
[4] Labor (cage changing)	480	min	$0.15	min	$72.00	
[4] Labor (cage cleaning)	560	min	$0.15	min	$84.00	
[3] Energy cost					$28.28	
[4] Depreciation (autoclave)					$920.00	per year
[4] Depreciation (cages)					$5,458.64	per year

	$680.88	400 cages		
Total cost	**$6020.40**	**per year for 100 cages**		
	$60.20	**Annual cost per cage**		

Energy usage of an autoclave: Model Amsco S 350: Steris

	water	steam	hp	cycles	cycle time	cost per cycle	cost per hour	

Table B-4. Continued

Autoclave (Energy)	320 gal/hr	148lbs/hr	1	6.25	42 mins	$0.93	$1.33	$7.28
Cage washer (energy)	2640 gal/hr	2800lbs/hr						$13.12

Depreciation (Straight line depreciation)

Number of cages per cycle		81		
Life cycle of an autoclave		15	year	
cycle for 400 cages		4.9382716		
Depreciation	$120,000.00	$8,000.00	$153.85	**$6.15**

per cycle based on 5 cycles per day

As cage washing cycle is increased from 7 to 14 days, cost structure changes, life cycle of cages increases)

Based on 400 units

			Cost per unit	Number of units	Total Cost	Life cycle	
Ventilated cages			$9.25	400	$3,700.00	7	years
Cost of extra cages			$9.25	100	$925.00	7	years
Cost of rack			$20,000.00	2.86	$57,200.00	20	years
Cage Washer	0.01389		$221,555.00	1	$4,554.55	15	years
Blowers			$4,000.00	2.86	$11,440.00	7	years
Depreciation					**$5,458.64**	per year	

1) Data from observation at University of Florida
2) Data from staff
3) Data from manufacturer
4) Data calculated

Table B-5. Summary of cost analysis based on frequency of cage changing cycle for static micro-isolator and ventilated cages

Static micro-isolator cages
Cost based on frequency of cage changing cycle for static micro-isolator cages

BCF (days)	Annual cost per mouse	Cost difference between successive BCF	Cumulative savings	
3.5	$116.22			
4	$102.58	*$13.64*	*$13.64*	
5	$105.29	*($2.71)*	*$10.93*	*(Cages are autoclaved)
6	$89.45	*$15.84*	*$26.77*	*(Cages are autoclaved)
7	$76.22	*$13.23*	*$40.00*	*(Cages are autoclaved)

* - Initially, static micro-isolator cages are not autoclaved. For the cost analysis if cage changing interval is increased beyond 5 days, then autoclaving cost for cages is taken into consideration.

Ventilated Cages
Cost based on frequency of cage changing cycle for Individually Ventilated Cages

BCF (days)	Annual cost per mouse	Cost difference between successive BCF	Cumulative savings
11	$73.18		
13	$63.90	*$9.28*	
14	$60.20	*$3.70*	
17	$52.21	*$7.99*	*$7.99*
18	$50.08	*$2.13*	*$10.12*
19	$47.91	*$2.17*	*$12.29*
20	$46.21	*$1.70*	*$13.99*
21	$44.36	*$1.85*	*$15.84*

Table B-6. Data points used developing functional relationships (Reeb-Whitaker et al. 2001)

Ammonia (ppm)

	BCF-7	14	21
ACPH-30	26.3	62.8	73
60	1.5	14.6	26.9
100	1.1	3.7	15.4

Subset1	30	7	26.3
30, x, 60	30	14	62.8
7, y, 14	60	7	1.5
	60	14	14.6

Subset 2	30	14	62.8
30, x, 60	30	21	73
14, y, 21	60	14	14.6
	60	21	26.9

Subset 3	60	7	1.5
60, x, 100	60	14	14.6
7, y, 14	100	7	1.1
	100	14	3.7

Subset 4	60	14	14.6
60, x, 100	60	21	26.9
14, y, 21	100	14	3.7
	100	21	15.4

Temperature (C)

	BCF-7	14	21
ACPH-30	24.4	24.4	24.8
60	24.1	24.1	23.4
100	23.2	23.2	24.1

Subset1	30	7	24.4
30, x, 60	30	14	24.4
7, y, 14	60	7	24.1
	60	14	24.1

Subset 2	30	14	24.4
30, x, 60	30	21	24.8
14, y, 21	60	14	24.1
	60	21	23.4

Subset 3	60	7	24.1
60, x, 100	60	14	24.1
7, y, 14	100	7	23.2
	100	14	23.2

Subset 4	60	14	24.1
60, x, 100	60	21	23.4
14, y, 21	100	14	23.2
	100	21	24.1

Table B-6. Continued

Humidity (%)

	BCF-7	14	21
ACPH-30	57	52	57
60	48	53	52
100	48	51	46

Subset1	30	7	57
30, x, 60	30	14	52
7, y, 14	60	7	48
	60	14	53

Subset 2	30	14	52
30, x, 60	30	21	57
14, y, 21	60	14	53
	60	21	52

Subset 3	60	7	48
60, x, 100	60	14	53
7, y, 14	100	7	48
	100	14	51

Subset 4	60	14	53
60, x, 100	60	21	52
14, y, 21	100	14	51
	100	21	46

Carbon dioxide (ppm)

	BCF-7	14	21
ACPH-30	2190	1475	2050
60	1310	1775	1415
100	1110	1575	945

Subset1	30	7	2190
30, x, 60	30	14	1475
7, y, 14	60	7	1310
	60	14	1775

Subset 2	30	14	1475
30, x, 60	30	21	2050
14, y, 21	60	14	1775
	60	21	1415

Subset 3	60	7	1310
60, x, 100	60	14	1775
7, y, 14	100	7	1110
	100	14	1575

Subset 4	60	14	1775
60, x, 100	60	21	1415
14, y, 21	100	14	1575
	100	21	945

Table B-7. Lindo formulation and output for subset 2 (ACPH of 30 and 60 with a BCF of 14 and 21 days)

Formulation:

Min $0.0987x - 2.771y + a$

Subject to

Ammonia
$-1.5717x+1.6071y + b \geq 0$
$-1.5717x+1.6071y + b \leq 25$

Temperature
$-0.0283x - 0.0214y + c \geq 17.77$
$-0.0283x - 0.0214y + c \leq 26.11$

Humidity
$-0.060x + 0.2856y + d \geq 40$
$-0.060x + 0.2856y + d \leq 70$

Carbon dioxide
$-5.5831x + 15.3531y + e \geq 0$
$-5.5831x + 15.3531y + e \leq 5000$

$a = 100.70$
$b = 86.92$
$c = 25.82$
$d = 51.5017$
$e = 1661.3389$

$x \geq 30$
$x \leq 60$
$y \geq 14$
$y \leq 21$

End

Where x = ACPH and y = BCF

Table B-7. Continued

Lindo Output

LP OPTIMUM FOUND AT STEP 1

OBJECTIVE FUNCTION VALUE

1) 50.78819

VARIABLE	VALUE	REDUCED COST
X	60.000000	0.000000
Y	20.149336	0.000000
A	100.699997	0.000000
AMM	0.000000	0.000000
B	86.919998	0.000000
TEMP	0.000000	0.000000
C	25.820000	0.000000
HUM	0.000000	0.000000
D	51.501701	0.000000
CO2	0.000000	0.000000
E	1661.338867	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	25.000000	0.000000
3)	0.000000	1.724224
4)	5.920804	0.000000
5)	2.419196	0.000000
6)	13.656352	0.000000
7)	16.343649	0.000000
8)	1635.707642	0.000000
9)	3364.292236	0.000000
10)	0.000000	-1.000000
11)	0.000000	-1.724224
12)	0.000000	0.000000
13)	0.000000	0.000000
14)	0.000000	0.000000
15)	30.000000	0.000000
16)	0.000000	2.611262
17)	6.149336	0.000000
18)	0.850664	0.000000

Table B-7. Continued

NO. ITERATIONS= 1

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X	0.098700	2.611262	INFINITY
Y -	2.771000	2.670077	INFINITY
A	1.000000	INFINITY	INFINITY
AMM	0.000000	INFINITY	0.000000
B	0.000000	INFINITY	INFINITY
TEMP	0.000000	INFINITY	0.000000
C	0.000000	INFINITY	INFINITY
HUM	0.000000	INFINITY	0.000000
D	0.000000	INFINITY	INFINITY
CO2	0.000000	INFINITY	0.000000
E	0.000000	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	0.000000	25.000000	INFINITY
3	25.000000	1.367102	9.882599
4	17.770000	5.920804	INFINITY
5	26.110001	INFINITY	2.419196
6	40.000000	13.656352	INFINITY
7	70.000000	INFINITY	16.343649
8	0.000000	1635.707642	INFINITY
9	5000.000000	INFINITY	3364.292236
10	100.699997	INFINITY	100.699997
11	86.919998	9.882599	1.367102
12	25.820000	2.419196	5.920804
13	51.501701	16.343649	13.656352
14	1661.338867	3364.292236	1635.707642
15	30.000000	30.000000	INFINITY
16	60.000000	0.869823	6.287840
17	14.000000	6.149336	INFINITY
18	21.000000	INFINITY	0.8506

APPENDIX C
CYCLE OF OPERATION FOR CAGE CLEANING CYCLE AT ANIMAL CARE SERVICES UNIVERSITY OF FLORIDA

A motion study was performed for the cage changing process. The study was conducted at the McKnight Brain Institute at the University of Florida. While analyzing the process, a standard process for cleaning and stacking cages was defined and delays were identified. A reduction of delay time can increase efficiency of the whole operation. The following is a detailed list of steps describing the changing process:

1. Bedding in used cages is dumped in the trash bin and cages are stacked on the floor.
2. Cages are placed in the cage tunnel washer.
3. Three cages at a time are manually stacked on the pallet.
4. Since the roller speed is slow, the time gap between the transfer of cages from dirty side to clean side can be utilized in the rearrangement of cages (this is required to make more space available for the cages to be stacked on the floor).
5. Cages are manually stacked on the pallet and filled with bedding (cages are stacked again on the pallet because they are now arranged on pallet after being placed in the paper bags, i.e., in sets of 4 cages).
6. The clean filled cages are wrapped and the packages are stacked on the autoclave cart (After cages have been wrapped, the autoclave cart is brought in to the vicinity to place the packages).
7. The number of wrapped packages should completely fill the autoclave cart (time can be wasted in changing the operation from stacking of packages on autoclave cart to wrapping of cages).
8. All the packages are dated, identified, and temperature indicator strips are stuck to the packages.
9. The cart is loaded into the autoclave and the autoclave cycle is started.
10. The cart is removed when the cycle is finished.

11. The cart is pushed to the shelving area.
12. The sterilized packages are placed on the shelving.
13. Supplies are restocked.

During the cage cleaning process, several delays were identified, which increased the cycle time for the whole operation. The following is a summary of some of the problems observed in the cage cleaning process.

1. Bedding is not readily available on the fifth floor of the facility at the McKnight Brain Institute. It is generally brought from the first floor of the facility.
2. Bedding may not be in stock at the Brain Institute. In that case it is brought from another facility and time is wasted.
3. Un-availability of space required for moving the cart on the ground floor near elevator (for supply of material to the fifth floor of facility at the McKnight Brain Institute).
4. Un - availability of floor space to stack clean cages in the cage storage room.
5. The number of wrapped packages is less than the autoclave cart capacity (then the cycle is disturbed and the worker needs to go back and wrap additional animal cages in paper bags).

The following diagram shows the process flows, along with the average time to perform each step.

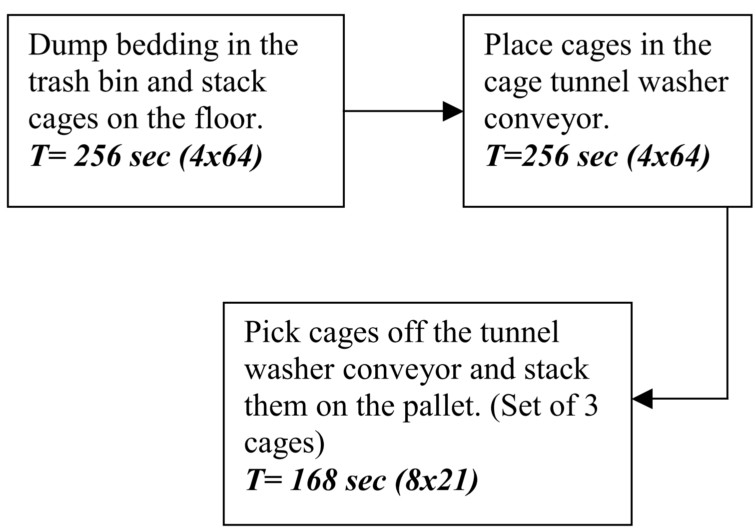

Figure C-1. Cycle on dirty side of the cage cleaning operation

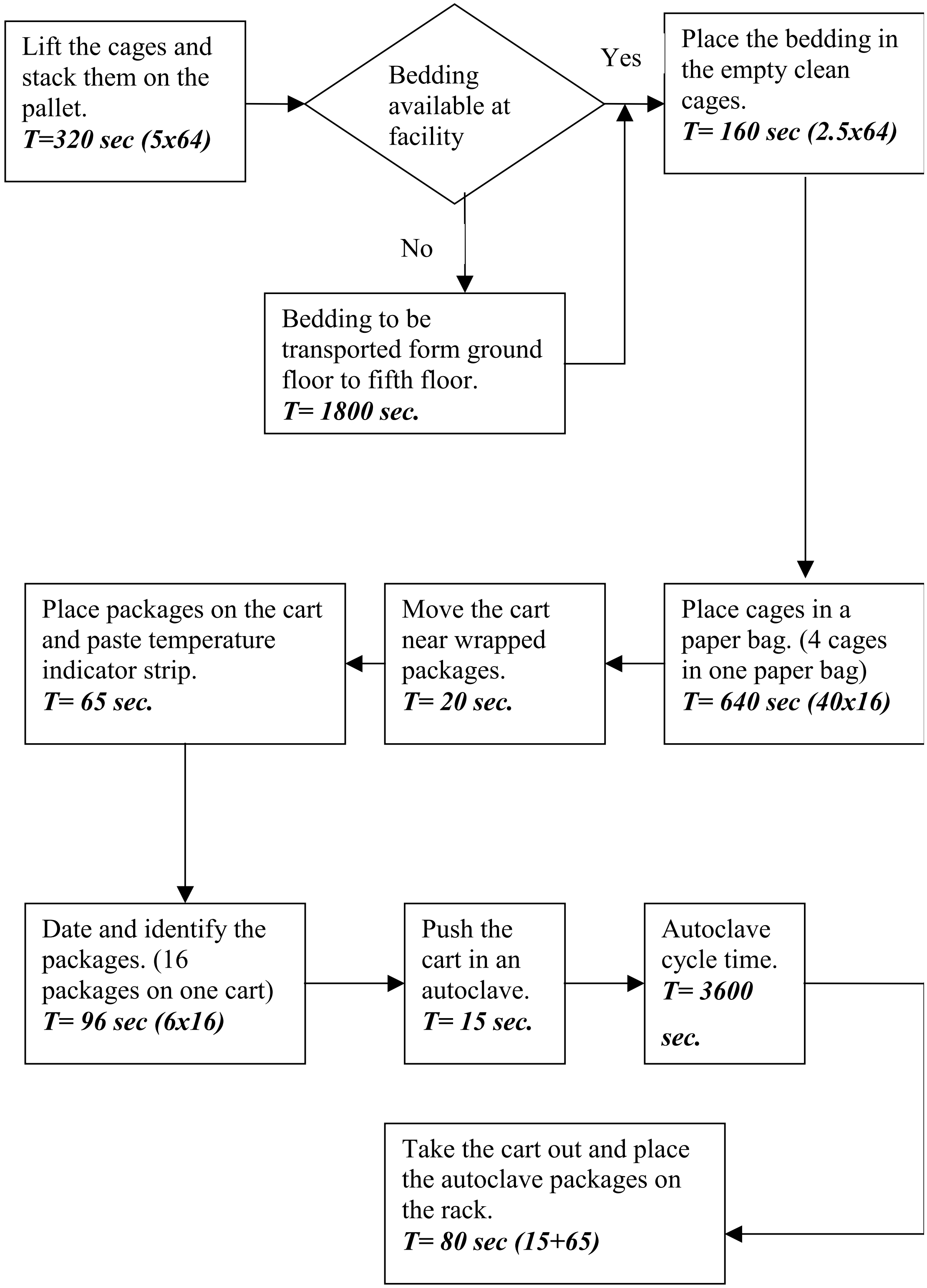

Figure C-2. Cycle on clean side of cage cleaning operation

The bottleneck operation (Goldratt and Cox 1992) in the cage changing cycle is the process of autoclaving the cages i.e. this operation governs the speed of the whole cage cleaning cycle. Currently there are two autoclaving machines at the Brain Institute Facility at University of Florida. Average autoclave cycle time is 3600 seconds. Under ideal conditions, demand meets the supply currently required at the Brain Institute, and also the line of operation is balanced. To reduce delays and inefficiencies in the system, a daily chart can be prepared for inventory required. Also a safety stock of autoclaved cages on the clean side can help in dealing with the unavoidable circumstances.

The whole cage cleaning process can be divided into several steps. The first two activities are performed at the dirty side of the operation (Figure C-1) i.e. dumping the bedding in the trash bin and stacking cages on the floor is the first step. Placing the cages in the cage tunnel washer conveyor is the second step. These two activities can be combined and can be performed as one single operation of dumping the bedding in the trash bin and directly placing the cages on the conveyor. This would help in reducing the total time required for these activities.

The total time required for dating and identifying the package, (Figure C-2) can be reduced by using a bar code label. In this case, a worker can just paste the bar code label on the packages instead of marking them using a marker.

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