



New Technology for Greater Ventilation, Less Energy Use, and Lower Operating Costs

MouseCare



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TRADELINE®

Leading-Edge Resources for Facilities Planning and Management

[Animal Research Facilities 2008](#)

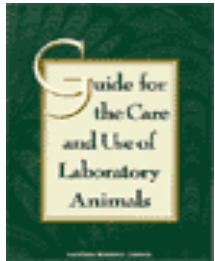
December 08 - 09, 2008, St. Petersburg, FL

Agenda



- Seven Eco-Friendly Strategies
- Background Information for NYSERDA Grant
- Energy-Efficient NYSERDA Grant
- More Eco-Friendly Strategies
- Conclusion

Maintenance and Expansion of Rodent Population



- 10-15 ACH (Dilution-Removal)
- IAQ: No harmful or unacceptable concentrations of toxic gases, odors, or particles
 - Computer Modeling
 - Heat Loads: Total-Cooling-Load Calculation Method (ASHRAE)
 - Air Diffusion Patterns

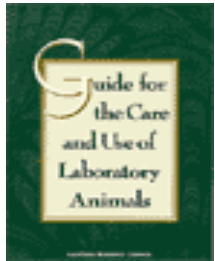
Sharp, Gordon P., Dynamic Variation of Laboratory Air Change Rates. ALN® Magazine, Nov-Dec 2008.

A Rodent Barrier facility with 10-15 ACH using plug-load devices such as IVC, Changing Station, and BSC

consumes 30 times more electricity

than a typical office building of similar size.

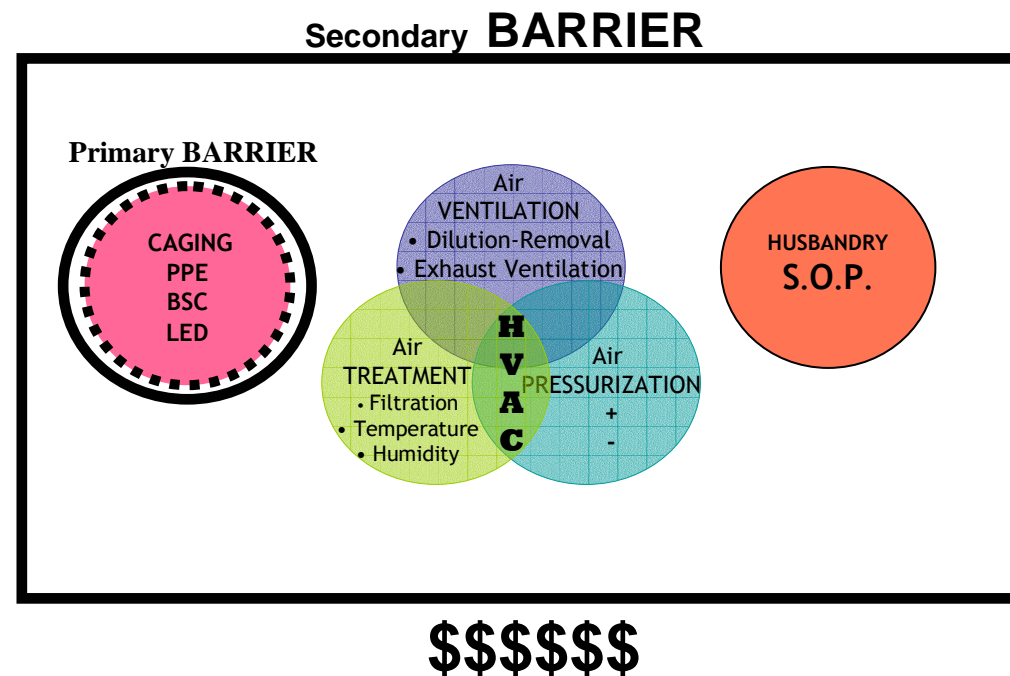
Maintenance and Expansion of Rodent Population



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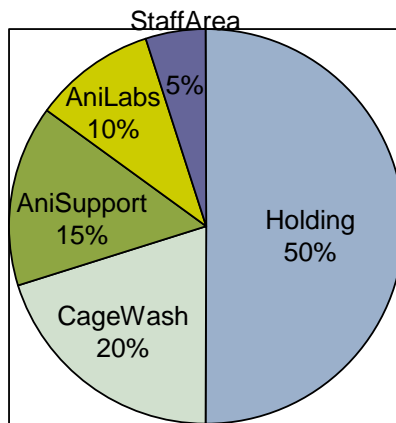
- Primary Barrier
 - Caging
 - Personal Protective Equipment
 - BioSafety Cabinet
 - Local Exhaust Device
- Secondary Barrier
 - Building
 - Floor
 - Area
 - Enclosure
- HVAC
 - Air Ventilation
 - Air Pressurization
 - Air Treatment
- S.O.P.
- Budget



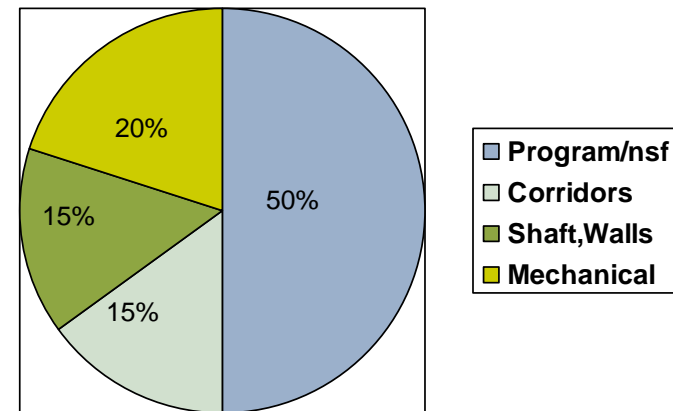
Maintenance and Expansion of Rodent Population

- Barrier Facility

Typical Program Area (nsf)



Typical Vivarium Facility (gsf)



- **6,000 cages require 15,000 gsf** (2.5 gsf/cage) = **\$6,000,000** (\$400/gsf).
- **Net program area is 7,500 nsf.**
- **Holding/procedure requirement is 3,750 nsf = \$1,500,000.**

* Cosgrove, Chris, How Much Space is Enough? LabAnimal News, Vivarium Forum March 2003.

Strategies



Benefits

↓ *perDiem*

● Multi-Point Exhaust Ventilation

- Local Exhaust Devices (**LED**)
 - Exhaust Ventilated Caging (**EVC**)
 - **Downdraft Workstation**
- Single-Pass Ventilation

● Low-Pressure-Drop Design

● Heat Recovery System

- Heat Pump Heat Recovery

● Space-Efficient Caging System

- Carousel Rack

- ↑ **Source Control of Contaminants**
- **Near-Perfect Mixing Factor**
Density, Safety, Flexibility, Comfort

- ↑ **Duct & Coil Sizes**
- ↓ **Fan HP & \$ of Equipment**
- ↓ **Energy Consumption**

- **PreHeat/Cool**
- ↓ **Size, \$ of HVAC Equipment**
- ↓ **\$ Energy of Heating/Cooling**
 - **LEED Credits**

- ↓ **\$ A&E, Energy, Maintenance**
- **Reclaim Space**
- **Space Flexibility**

Strategies



Benefits

↓ *perDiem*

● Disposable Caging

- Molded Fiber

● Waste-to-Steam

- Soiled Bedding
- Soiled Cage & Bedding
- PPE [Non-Plastic/Rubber Items]

● Stack-Ventilation

- Animal Heat Loads
- Washing/Autoclaving
- Waste-to-Steam
- Solar

- **Environmentally-Friendly**
 - Eliminate Plastic Use
 - Recyclable - Combustible

- **Avoid Cage Processing \$**
- **Water and Energy Savings**

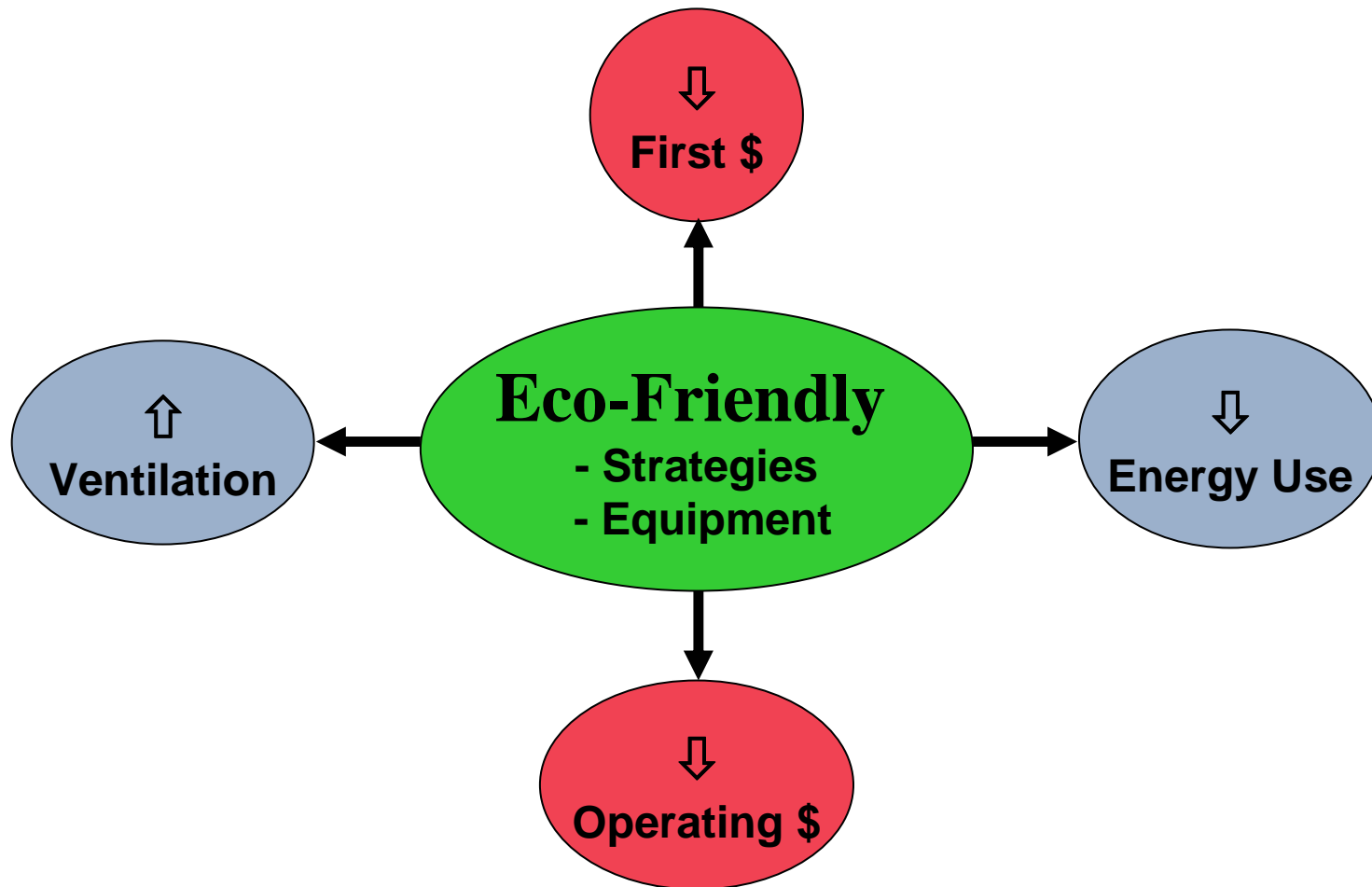
- **↑ Labor Conditions**
 - Hazard Exposure
 - Repetitive Motion

- **Renewable Energy**
- **Energy Cost Saving**
- **LEED Credits**
- **Reduce Waste Disposal Cost**

- **Sustainable**
- **LEED Credits**
- **↓ HVAC Equipment Size**
- **↓ Energy**
- **↓ Redundancy Needs**



Building or Renovating Rodent Space





Exhaust Ventilated Caging System

Animal Care Systems

OptiMICE – Carousel 100 Cages

OptiRAT – Carousel 42 Cages

M.I.C.E.[®] – Modular SS & DS from 14 up to 140 Cages



Airlaw

IVC isolator – SS & DS up to 144 Cages





Exhaust Ventilated Caging System

Animal Care Systems

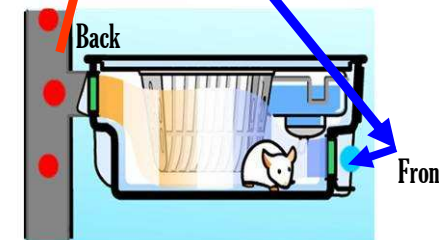
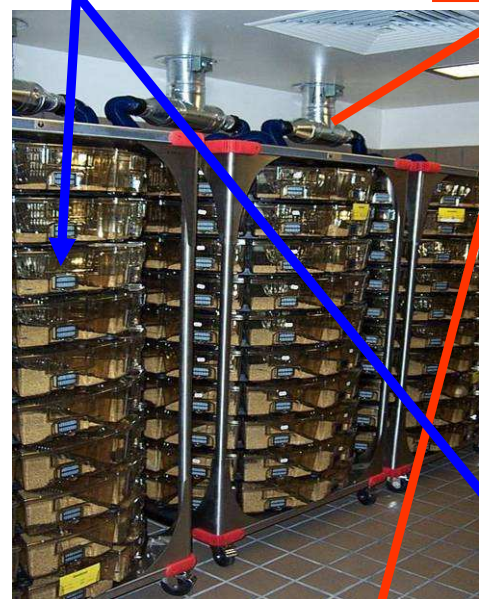
- OptiMICE – Carousel 100 Cages
- OptiRAT – Carousel 42 Cages

M.I.C.E.® – Modular SS & DS from 14 up to 140 Cages

Airlaw

IVC isolator – SS & DS up to 144 Cages

Room-Air Supply [T & RH] Direct Exhaust



Validation

Filtration

Absolute Pore Size Rating: 0.3 μ

Cage Smoke Tests

Leak-Free

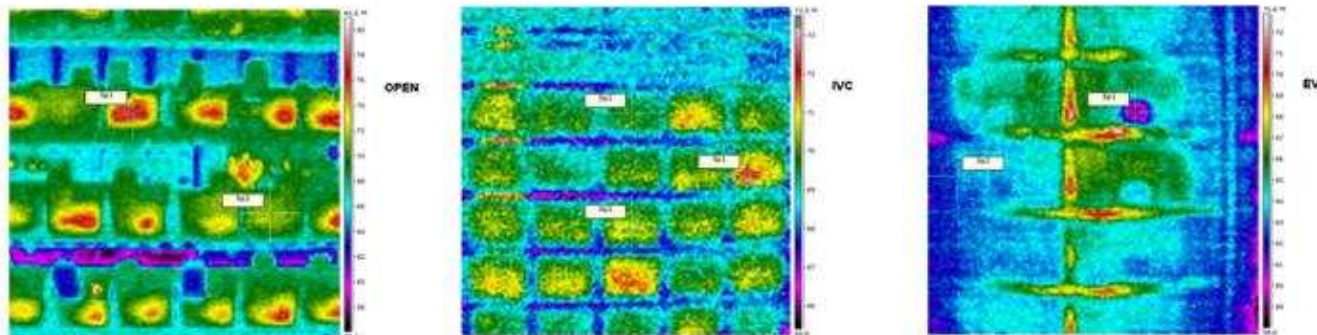
Single-Pass

4 min. for 99% Removal Efficiency

Tracer Gas [SF6] Containment Assessment

Leak-Free

Infra-Red Thermography of three (3) different caging system



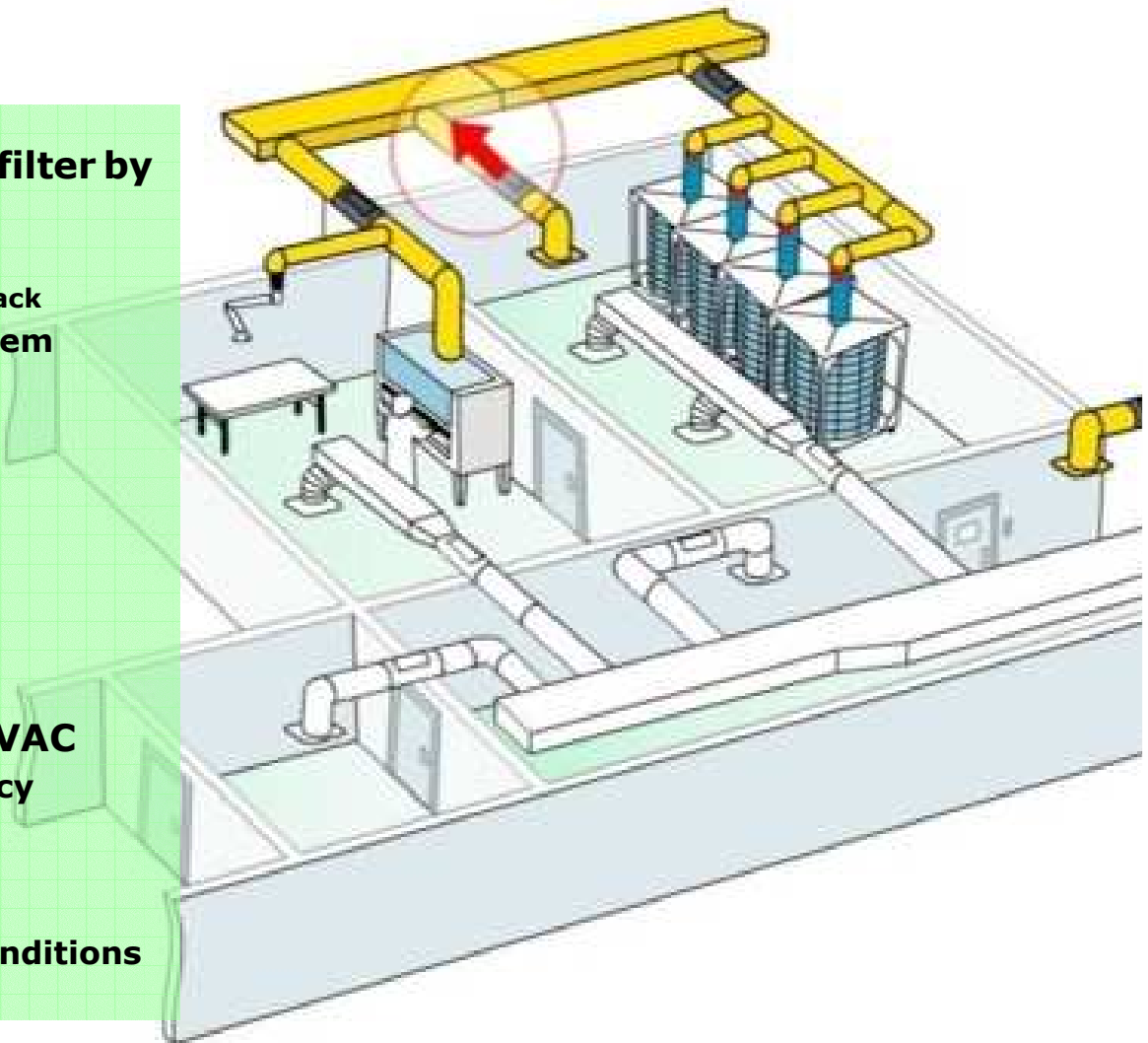
IR Thermography	Surface Temperature Differential		
	OPEN Shoebox	IVC	EVC
Sp1 Radiation to Room	3.1 to 9 °F ave. 6 °F	2 to 4.1 °F ave. 3 °F	-3.2 to 1.9 °F ave. 0 °F
Sp2 Transfer to Mass	1.6 to 16.3 °F ave. 9 °F	2 to 4.4 °F ave. 3.1 °F	0 °F ave. 0 °F

Fresh air is drawn in cage through filter by controlled exhaust ventilation

- HVAC-assist → LED
 - 60 cfm [1,680 l/m]/ 100-cage rack
- Negative Low-Pressure Drop System
 - 0.15" W.G. [38 Pa]
- In-Cage Single-Pass Airflow
 - 4 fpm [0.02 m/s]
- Control of Environmental Conditions
 - Temperature & %RH
- In-Cage Air Quality: IAQ
 - Mixing Factor @ 1.5

Both cage air and room air exhaust directly to outside via building HVAC

- 95 % Heat Load Removal Efficiency
 - ~ 200 watts/rack
- No Return of Contaminants
 - IAQ
- Maintenance of Environmental Conditions

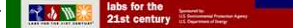


● Barrier Facility

- Space
- Energy Use
- Operating Costs



	6,000 Cages	IVC	EVC
Room Design	Surface Area (Holding Area) Density HVAC [\$50/cfm, \$1,500/ton] ACH / Noise Attenuation Plug Load & Lighting [1w/sf] First \$ Savings (%)	nsf cages/sf cfm kW \$	nsf cages/sf cfm kW \$ -\$ (%)
	HVAC & Plug Load (Holding Area) [1.5 kW/ton, 100 btu-h/cfm heat+humid]	kWh	kWh - kWh (%)
Population Density	Carbon Footprint: tons of CO2 [1,316 kW/ton] Savings (%)	tons	tons - tons
	Annual Energy [\$0.10/kW, \$10.00 MMbtu] Savings (%)	\$	\$ -\$ (%)
	Annual Maintenance \$ Savings (%)	\$	\$ -\$ (%)
	Annual Husbandry \$ Savings (%)	\$	\$ -\$ (%)
	perDiem/cage Savings (%)	\$	\$ -\$ (%)

*  Energy-Efficient and High Performance Rodent Facility, 2005. Rivard, G.F. and W.S.(Lanny) Joyce
 LAMA: Space-Efficiency and Economical Strategies for Animal Rooms, 2007. Peter Rodrigez, BBA, LATg, UMDNJ.
 Personal Communication, 2008: Adrien Poloni, P.E., CRL.
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● HVAC & Plug Load
 ● Electric
 ● Gas

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Barrier Facility

- Space
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Population Density	Carbon Footprint: tons of CO2 [1,316 kW/ton] Savings (%)	tons	tons - tons
	Annual Energy [\$0.10/kW, \$10.00 MMBtu] Savings (%)	HVAC & Caging • Service • Repairs • Filter Replacement	\$ - \$ (%)
	Annual Maintenance \$ Savings (%)	• HEPA • Absolute	\$ - \$ (%)
	Annual Husbandry \$ Savings (%)		\$ - \$ (%)
	perDiem/cage Savings (%)	\$	\$ - \$ (%)

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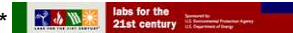
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- Space
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• Amortized First Cost/10y
 • Operating Costs

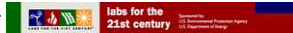
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● Barrier Facility

- Space
- Energy Use
- Operating Costs



	6,000 Cages	IVC	EVC
Room Design	Surface Area (Holding Area) Density HVAC [\$50/cfm, \$1,500/ton] ACH / Noise Attenuation Plug Load & Lighting [1w/sf] First \$ Savings (%)	3,750 nsf 1.6 cages/sf 12,000 cfm 19 / yes 11 kW \$728,250	1,000 nsf 6 cages/sf 3,000 cfm 18 / no 1 kW \$157,650 -\$570,600 (78%)
	HVAC & Plug Load (Holding Area) <small>[1.5 kW/ton, 100 btu-h/cfm heat+humid]</small>	356,800 kWh	122,250 kWh - 234,550 kWh (65%)
Population Density	Carbon Footprint: tons of CO2 [1,316 kW/ton] Savings (%)	271 tons	93 tons -178 tons
	Annual Energy [\$0.10/kW, \$10.00 MMbtu] Savings (%)	\$ 88,500	\$ 18,320 -\$70,180 (79%)
	Annual Maintenance \$ Savings (%)	\$ 22,200	\$ 7,800 -\$14,400 (65%)
	Annual Husbandry \$ Savings (%)	\$660,000	\$576,000 - \$ 84,000 (12%)
	perDiem/cage Savings (%)	\$ 0.38⁷	\$ 0.28⁴ -\$0.10³ (26%)

*  Energy-Efficient and High Performance Rodent Facility, 2005. Rivard, G.F. and W.S.(Lanny) Joyce
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PROOF-of-CONCEPT



Institut Clinique de la Souris (ICS)
Mouse Clinical Institute

www-mci.u-strasbg.fr

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The Animal Facility

The Animal Facility has been designed for the husbandry, breeding and characterization of genetically modified mice. The working area is over two floors (~ 2.200 m²) permitting accommodation of a maximum of 70 000 mice.

The facility comprises :

- A quarantine section
- 13 holding rooms 60 m²
- 8 rooms of 15 m² for animal experimentation
- 1 unit reserved exclusively for micro-injection

To maintain semi-protected sanitary standards, the facility is organised into 3 specific sections

- Access controlled entry-exit, ensuring a single direction circulation of personnel, mice and apparatus
- A housing area exclusively for the animals
- A cleaning zone divided in 2 ('clean' and 'dirty' materials) by a physical barrier comprising several components, autoclaves, tunnel and washing room, water treatment station.

The mice are housed in high-density vented caging systems MICE (Microenvironmental - Isolation - Containment - Enrichment):

- Microenvironmental ----> adequate and comfortable ventilation with good air quality and stable conditions ;
- Isolation ----> prevents environmental & biological contamination ;
- Containment ----> prevents release of allergens, odors, and infectious agents ;
- Enrichment ----> environment appropriate to the species.

In addition to these micro-isolating cages, animal experiments take place exclusively under horizontal, laminar flow hoods. This double protection assures :

- the necessary sanitary standards for the mice
- satisfactory working conditions for the operators



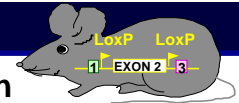
Washing tunnel



Autoventilated cages

Pierre Chambon

61,000 Citations, Science, 302:779, 2003



C.A. Argmann, Johan Auwerx

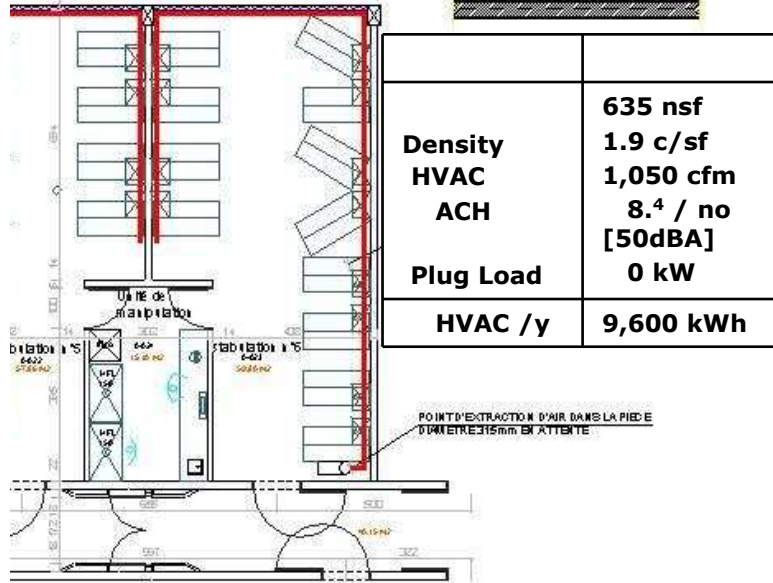
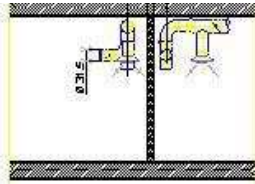
Minimizing variation due to genotype and environment

Current Protocols in Molecular Biology (Ed. D.D. Moore)

2006, 29A.2.1-29A.2.3.

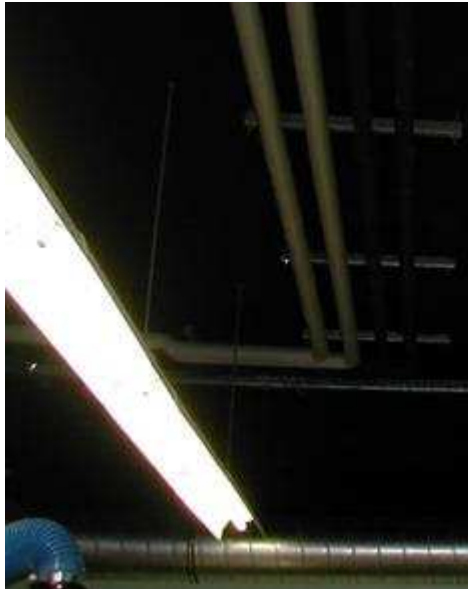
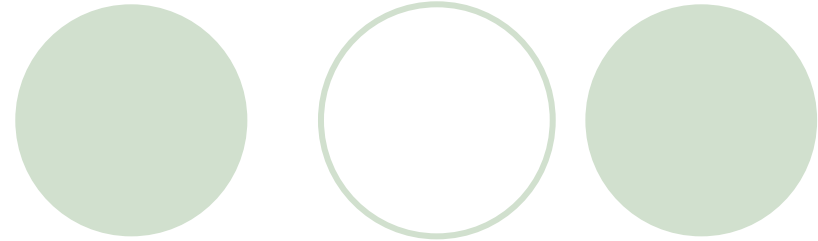


1,232 M.I.C.E. Cages



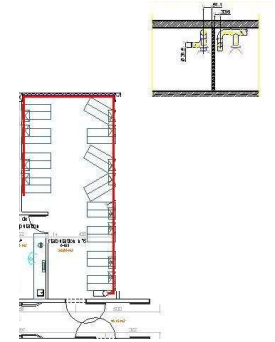
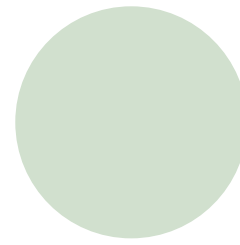
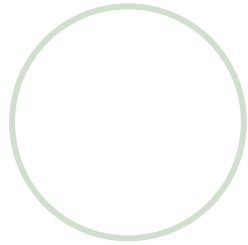
Density	635 nsf
HVAC	1.9 c/sf
ACH	8.4 / no [50dBA]
Plug Load	0 kW
HVAC /y	9,600 kWh

POINT D'EXTRACTION D'AIR DANS LA PIED
D'UN METRE 15mm EN ATTEITE





Duct Static Pressure Sensor



ENERGY AUDIT



FlexTech – Technical Assistance Program

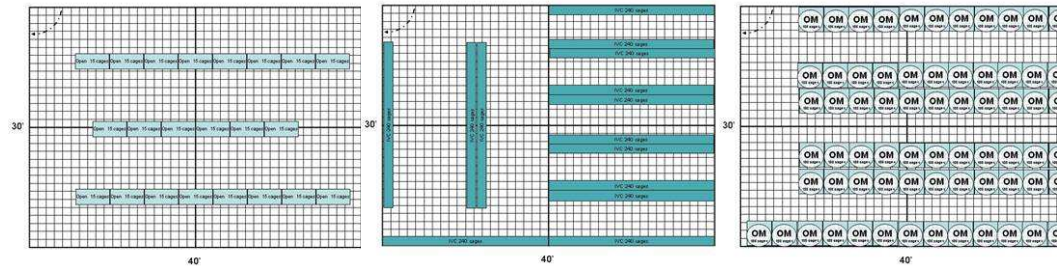
Services performed by pre-qualified FlexTech Consultants



Measure and Normalize to annual rodent housing and production

- Load Analysis and HVAC Energy Requirements
- Energy Use and Demand

ENERGY AUDIT



	1,200 nsf	Open	IVC	EVC
Room Design	HVAC ACH	3,200 cfm 16	3,200 cfm 16	3,200 cfm 16
	Nb. of Cages Density	3,200 Cages 2. ⁶ cages/sf	3,360 Cages 2. ⁸ cages/sf	6,800 Cages (+3,600, 112%) (+3,440, 102%) 5. ⁶ cages/sf



ENERGY AUDIT

- Baseline Energy Consumption
 - Energy Simulation Modeling
- Evaluation of Energy Consuming Systems
- Determination of Energy Conservation Measures
 - Customized to Animal Facilities
- Implementation
- Measurement & Verification
- Reporting

- **Demonstration Project for Innovative or Underutilized Industrial Process**
 - **Energy Efficiency**
 - **Quantifiable Energy Benefits**
 - **Improve - Productivity**
 - **Product Quality**
 - **Cost Control**

GRANT: GOALS

1. Reduce first and annual energy costs related to animal housing

Reduce mice (18,000) breeding space from 3,750 sf to 1,050 sf

Reclaim 2,700sf of space - Up to 30 mice per sf or 6 cages/sf

Save on 'typical' first and operating costs of HVAC and Plug Load by 65%

2. Provide a safe and healthy environment to the animals and their caretakers

1. Minimize cross-contamination and exacerbation of animal diseases
2. Minimize laboratory animal allergies
3. Prevent biohazard and waste gases (ammonia) contamination
4. Prevent rack air plenum, room environment, and exhaust ducting contamination

3. Provide barrier housing with optimal environmental conditions

Acquire Breeding and CRO capabilities

Increase housing applications from conventional to barrier and biosafety level 3

Meet AAALAC, OPRR, USDA, CDC, and FDA/GLP requirements

4. Increase production efficiencies of rodent inbred strains

Extend cage changing period to every two-week

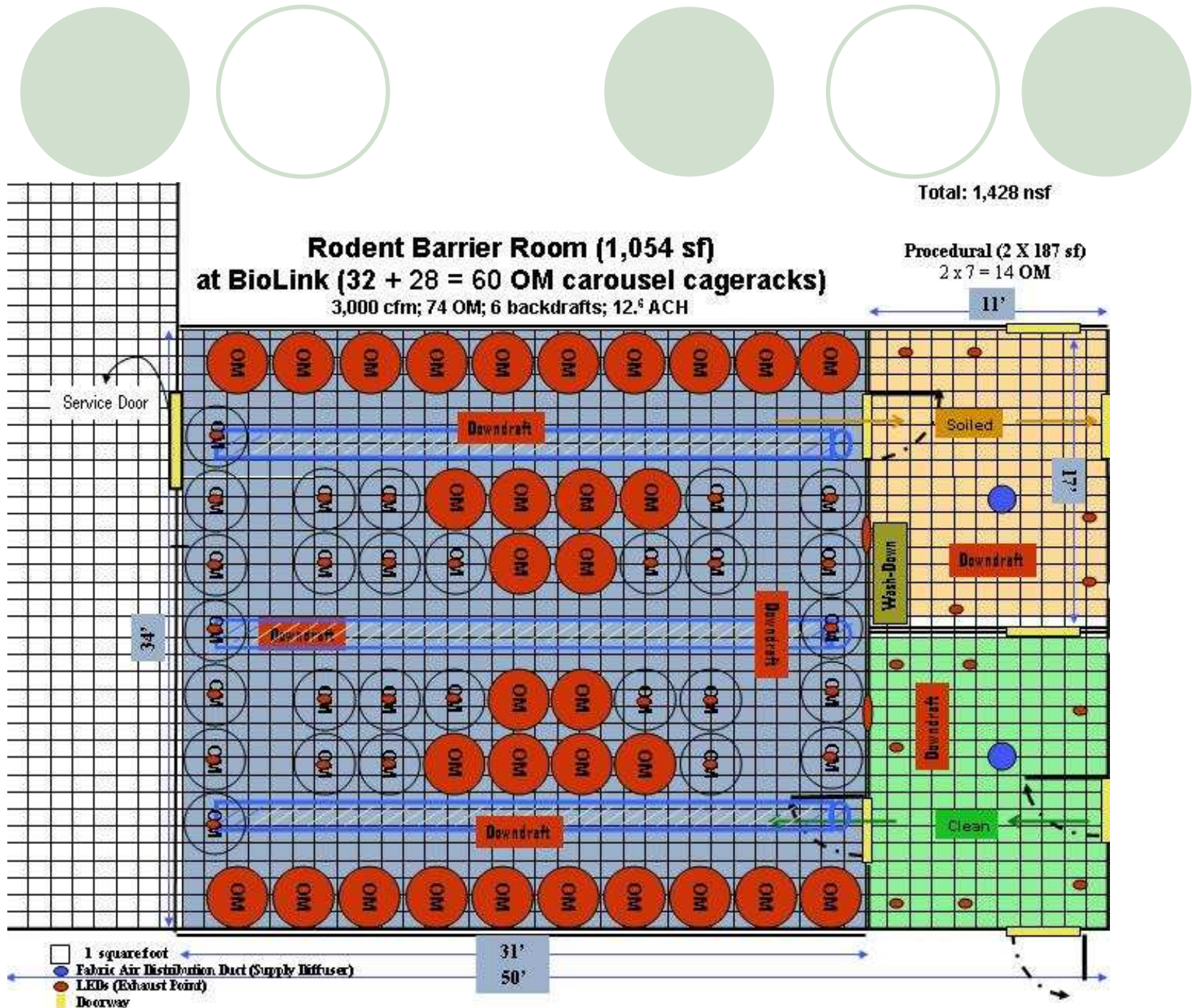
Reclaim 5 employees

Increase Breeding Performances [PEI] of C57BL/6 from 0.8 to 1.0

Decrease weekly animal purchases from \$5,000 to \$1,000 {Savings of \$208,000/y}

GRANT: METRICS

	2009	2010	2011	2012	2013
1. Electricity costs and savings over 2008 conditions (kWh, kW, \$) from HVAC and plug load normalized to annual rodent production					
2. Natural gas savings (MMBtu, \$)					
3. Job retention (#FTE)					
4. Health and comfort level of employees (T, RH, CO2, NH3, LAA)					
5. Animal production including: Laboratory Information Management Systems (LIMS)					
Breeding performances for Production Efficiency Index					
Rodent populations density to calculate Space Efficiency					
Sentinel surveillance program to assess Colony Health					
RODAC plate monitoring to assess the room Microbiological Status					
6. Technology transfer: technical article appearing in trade publications and other facilities duplicating the technology					





GRANT: DESIGN

1. Multi-point Local Exhaust Ventilation with Low-Pressure Drop Design
2. Heat Recovery (HR) System
3. Space-Efficient CageRack System
OptiMICE Carousel 100-cage Rack

GRANT: DESIGN – HVAC

Multi-Point Exhaust Ventilation-HVAC System

- **Low-Pressure Drop System Design**

Fan Input Power = $\frac{\text{Airflow [cfm]} \times \text{Air Pressure Drop [in.w.g.]}}{6345 \times \text{Fan System Efficiency}}$

Power is Reduced by Square of Velocity Reduction

- **3 Fabric Air Distribution Ducting Diffusers**

- **64 Manifolded Local Exhaust Devices**

- 60 OM Racks [100-cage]
- 4 Downdraft Workstations



- Decrease Exhaust Flow Rate
- Lower Fan Horsepower
 - Less Pressure Losses, Leakage
 - Less Airflow Velocity
 - Less Fan Energy
- Less Total Ductwork
 - Simplify Layout
- Less Internal Space
 - No Interstitial Space
- Noise Reduction
- Provide Stable Air Flow
- Increase Safety
 - Better Containment
- Flexibility

GRANT: DESIGN – HVAC

Heat Recovery System: 6,004 Local Exhaust Devices

Capture Heat Loads from Exhaust Ventilation

3,000 cfm exhaust ventilation for 1,054 sf

~ 2 w per cage to be exhausted X 6,000 occupied cages = 12 kW

PreHeat/Cool Fresh Air Supply

~3% Energy savings for every degree F. change in air temperature
between supply/exhaust air = 65% Energy Recovery in UpstateNY



GRANT: DESIGN – HVAC

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3,000 cfm exhaust ventilation for 1,054 sf

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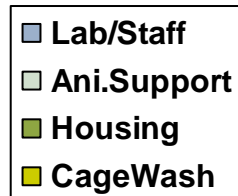
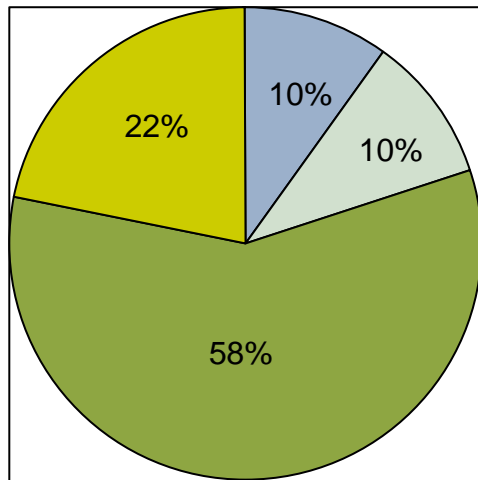
PreHeat/Cool Fresh Air Supply

~3% Energy savings for every degree F. change in air temperature
between supply/exhaust air = 65% Energy Recovery in UpstateNY

- Minimize Conditioned Supply Air
- Reduce Heating/Cooling Costs
- Safety
- Flexibility

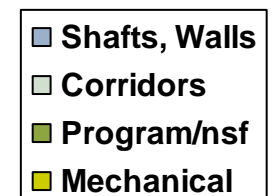
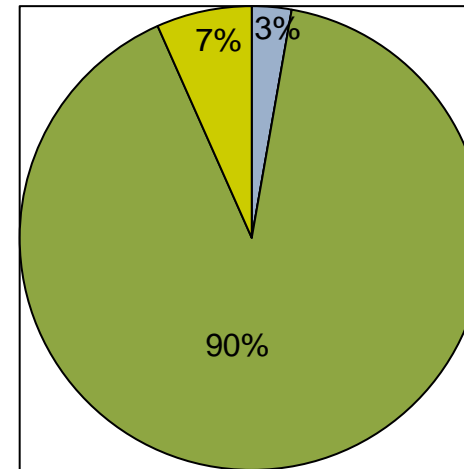
GRANT: DESIGN – Space

58% Holding (1,054 nsf)
42% Support (750 nsf)
Total: 1,800 nsf



BioLink Program Area (nsf)
5.7 cages/sf

90% Program (1,800 nsf)
10% Support (150 gsf)
Total: 2,000 gsf



BioLink Vivarium Facility (gsf)

- **6,000 cages require 2,000 gsf** (0.33 gsf/cage) = **\$ 300,000** (\$150/gsf).
Save 13,000 gsf or 87% over Typical Project
- **Net program area is 1,800 nsf**
Save 5,700 nsf or 76% over Typical Project
- **Holding/procedure requirement is 1,054 nsf = \$ 155,000**
Save 2,700 nsf or 72% over Typical Project

GRANT: GREEN BARRIER – *per Diem*

	6,000 Cages	EVC	EVC + LPD, HR
Room Design	Surface Area Density HVAC ACH / Noise Attenuation Plug Load First \$ Savings (%)	1,000 nsf 6 cages/sf 3,000 cfm 18 / no 1 kW \$157,650	1,054 nsf 5.7 cages/sf 3,000 cfm 17 / no 1 kW \$175,650 + \$ 18,000 (10%)
	HVAC & Plug Load	122,250 kWh	98,800 kWh (-23,450 kWh or 19%)
Population Density	Carbon Footprint: tons of CO2	93 tons	75 tons (-18)
	Annual Energy Savings (%)	\$ 18,320	\$ 11,652 -\$ 6,668 (36%)
	Annual Maintenance \$ Savings (%)	\$ 7,800	\$ 7,800
	Annual Husbandry \$ Savings (%)	\$576,000	\$576,000
	perDiem/cage Savings (%)	\$ 0.28⁴	\$0.28¹ -\$0.00³ (1 %)

DISPOSABLE CAGING

Disposable Filter-Cage

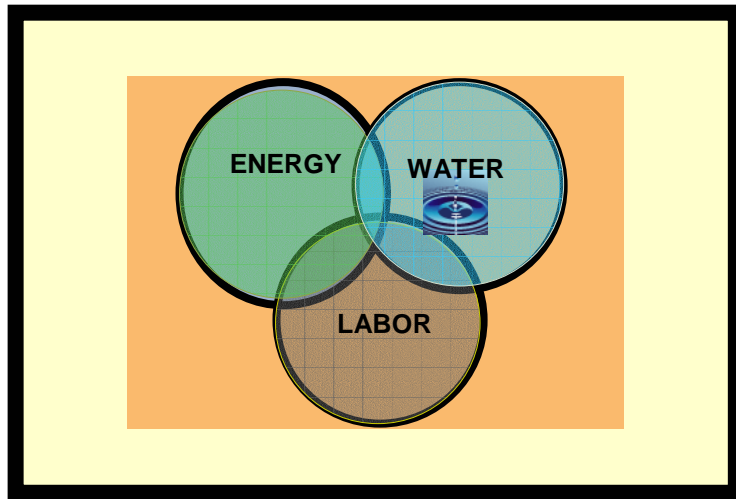
- Made of non-petroleum-based material
 - Molded- Paper or Fiber
- Single-Use Cage
- Closed-System Caging System
- Local Exhaust Device

- Environmentally-Friendly
 - Recycle
 - Compost
 - Eliminate Plastic Filling Landfills
 - Combustible
 - Heat, Steam, and Electricity
- Avoid Processing Costs
 - ↓ Use
 - Water/Energy
 - Cleaning/Disinfecting
- Extend Flexibility
 - BSL-3
- Economical
- ↑ Occupational H&S
 - Eliminate Bedding Dumping

DISPOSABLE CAGING

Typical Cage Processing

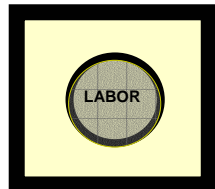
- Space
- Equipment
- Utilities and Human Resources



DISPOSABLE CAGING

Improved Cage Processing

- Space
- Equipment
- Utilities and Human Resources



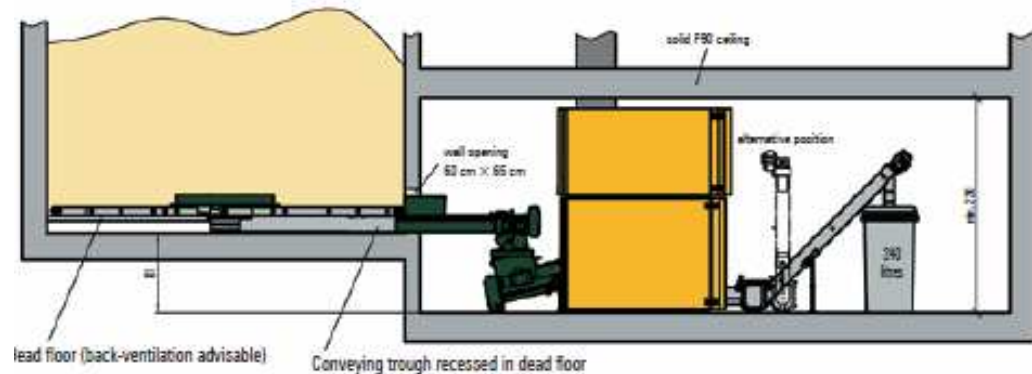
DISPOSABLE CAGING – *per Diem*

	6,000 Cages	EVC +	EVC + Molded-Fiber
Room Design	Surface Area	1,054 nsf	1,054 nsf
	HVAC [\$50/cfm, \$1,500/ton]	3,000 cfm	3,000 cfm
	ACH / Noise Attenuation	17 / no	17 / no
	Plug Load	1 kW	1 kW
	First \$	\$175,650	\$175,650
	Savings (%)		
	HVAC, Plug Load	98,800 kWh	98,800 kWh
	Carbon Footprint: tons of CO2	75 tons	75 tons
	Plastic filling landfills		3,300 lbs./y
	Water		1,860,000 gallons/y
	Detergent		1,300 lbs./y
Population Density	Annual Energy \$	\$ 11,652	\$ 11,652
	Savings (%)		
	Annual Maintenance \$	\$ 7,800	\$ 7,800/y
	Savings (%)		
	Husbandry	\$120,000/y	\$ 30,000/y
	Caging	\$ 72,000/y	\$468,000/y, [\$3 ea., 26changes/y]
	Washer	\$ 35,000/y	0
Processing/Storage Space	\$ 20,000/y [500 sf]	0	
Processing Energy	\$ 3,000/y	0	
Water	\$186,000/y [310 g ea.]	0	
Labor	\$140,000/y	\$ 35,000/y	
Annual Husbandry \$	\$576,000	\$533,000/y	
Savings (%)		- \$ 43,000 (7%)	
	perDiem/cage	\$0.28¹	\$0.26²
	Savings (%)		-\$0.01⁹ (7%)

WASTE-TO-STEAM

Waste-to-Steam

- Central Vacuum System
 - Soiled Bedding
- Shredder
 - Soiled Cage & Bedding
 - PPE [Non-Plastic/Rubber Items]
- Autofeed
- Gasification Technology
- Low Emissions
- Minimal Odor migration
- Reduction in disposal costs
- Hot Water or 15 to 75 psi Steam
- 1,000 lbs. Bedding = \$50 Gas



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 - Soiled Cage & Bedding
 - PPE [Non-Plastic/Rubber Items]
- Autofeed
- Gasification Technology
- Low Emissions
- Minimal Odor migration
- Reduction in disposal costs
- Hot Water or 15 to 75 psi Steam
- 1,000 lbs. Bedding = \$50 Gas
- 6,000 cages = 51.6 tons/year

- Eliminate
 - Waste Handling, Disposal
 - Cleaning/Disinfecting
 - Save \$5,000 Disposal \$
- ↓ Heating/Cooling \$
 - Save \$5,100
- ↓ Water/Energy Use
- Renewable Energy

Energy-Efficient Strategy

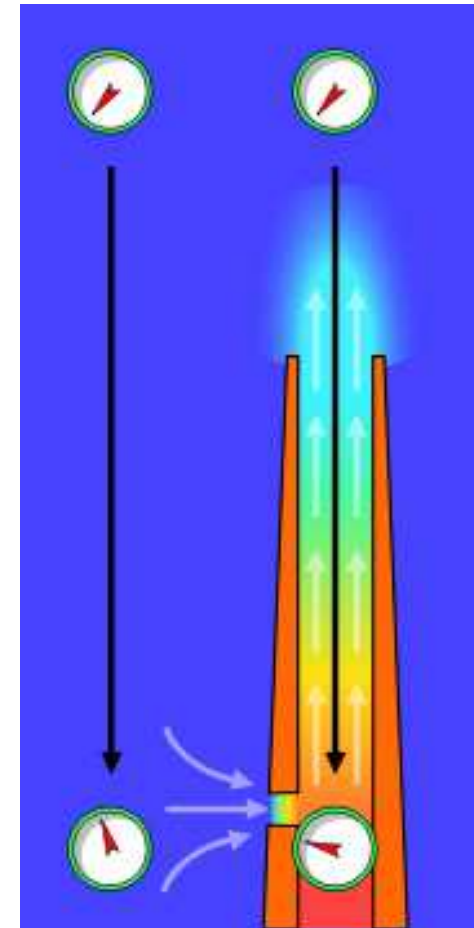
WASTE-TO-STEAM – *per Diem*

	6,000 Cages	EVC +	EVC + W2S
Room Design	Surface Area Density HVAC ACH / Noise Attenuation Plug Load First \$ Savings (%)	1,054 nsf 5.7 cages/sf 3,000 cfm 17 / no 1 kW \$175,650	1,054 nsf 5.7 cages/sf 3,000 cfm 17 / no 1 kW \$192,450 + \$ 16,800 (9%)
	HVAC & Plug Load	98,800 kWh	98,800 kWh
Population Density	Carbon Footprint: tons of CO2	75 tons (-18)	75 tons
	Annual Energy Savings (%)	\$ 11,652	\$ 11,000 - \$ 652 (5%)
	Annual Maintenance \$ Savings (%)	\$ 7,800	\$ 7,800
	Annual Husbandry \$ Savings (%)	\$576,000	\$541,000 - \$ 35,000 (6%)
	perDiem/cage Savings (%)	\$0.28¹	\$0.26³ -\$0.01⁸ (6%)

STACK VENTILATION

Stack Driven Ventilation

- Make Use of
 - Animal Heat Loads
 - Solar Gain
 - Boiler Exhaust
 - Sterilizer/Washer Exhaust



The stack effect in chimneys: the gauges represent absolute air pressure and the airflow is indicated with light grey arrows. The gauge dials move clockwise with increasing pressure.

STACK VENTILATION

Stack Driven Ventilation

- Make Use of
 - Animal Heat Loads
 - Solar Gain
 - Boiler Exhaust
 - Sterilizer/Washer Exhaust

- ↓ HVAC Size
 - ↓ Fan Horsepower
 - ↓ Energy Consumption
- ↑ Sustainability
- ↓ Redundancy Needs

Energy-Efficient Strategy

STACK VENTILATION

where:

$$Q = C A \sqrt{2 g H \frac{T_i - T_o}{T_i}}$$

Q = flue gas flow rate, m³/s

A = cross-sectional area of chimney, m² (assuming it has a constant cross-section)

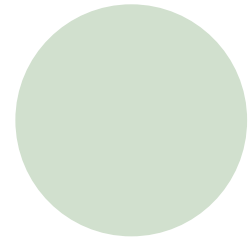
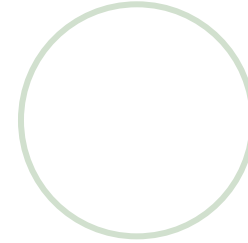
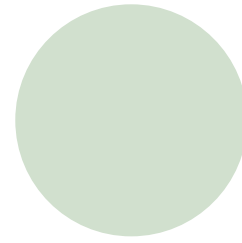
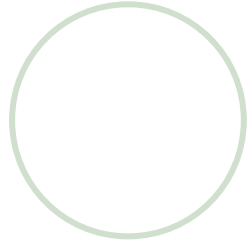
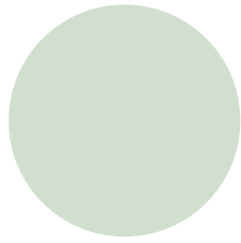
C = discharge coefficient (usually taken to be from 0.65 to 0.70)

g = gravitational acceleration at sea level, 9.807 m/s²

H = height of chimney, m

T_i = absolute average temperature of the flue gas in the stack, K

T_o = absolute outside air temperature, K



STACK VENTILATION – *per Diem*

	6,000 Cages	EVC +	EVC + SV
Room Design	Surface Area	1,054 nsf	1,054 nsf
	Density	5.7 cages/sf	6 cages/sf
Room Design	HVAC	3,000 cfm	3,000 cfm
	ACH / Noise Attenuation	17 / no	17 / no
Room Design	Plug Load	1 kW	1 kW
	<i>First \$ Savings (%)</i>	\$175,650	\$215,300 + \$ 39,650 (18%)
Population Density	HVAC & Plug Load	98,800 kWh	76,100 kWh - 22,700 (23%)
	<i>Carbon Footprint: tons of CO2 Savings (%)</i>	75 tons	58 tons -17
Population Density	<i>Annual Energy Savings (%)</i>	\$ 11,652	\$ 9,375 - \$ 2,277 (19%)
	<i>Annual Maintenance \$ Savings (%)</i>	\$ 7,800	\$ 7,800
Population Density	<i>Annual Husbandry \$ Savings (%)</i>	\$576,000	\$576,000
	<i>perDiem/cage Savings (%)</i>	\$0.28 ¹	\$0.27 -\$0.01 ¹ (4%)

CONCLUSION – *per Diem*

- Barrier Facility
 - Space, Energy Use, and Operating Costs

	6,000 Cages	IVC	EVC+ LPD, HR	EVC + DC	EVC + W2S	EVC + SV
Room Design	Surface Area (Holding Area)	3,750 nsf	1,054 nsf			
	Density	1.6 cages/sf	5.7 cages/sf			
Room Design	HVAC	12,000 cfm	3,000 cfm			
	ACH / Noise Attenuation	19 / yes	17 / no			
Room Design	Plug Load & Lighting	11 kW	1 kW			
	<i>First \$ Savings (%)</i>	\$728,250	\$175,650 \$552,600 (76%)			
Population Density	HVAC & Plug Load [kWh]	356,800	98,800 (72%)			
	<i>Carbon Footprint: CO2 Savings (%)</i>	271 tons	75 tons 196 tons			
Population Density	<i>Annual Energy Savings (%)</i>	\$ 88,500	\$ 11,652 \$76,848 (87%)			
	<i>Annual Maintenance \$ Savings (%)</i>	\$22,200	\$ 7,800 \$14,400 (65%)			
Population Density	<i>Annual Husbandry \$ Savings (%)</i>	\$660,000	\$576,000 \$84,000 (12%)			
	<i>perDiem/cage Savings (%)</i>	\$0.38⁷	\$0.28¹ \$0.10⁶ (26%)			

CONCLUSION – *per Diem*

- Barrier Facility
 - Space, Energy Use, and Operating Costs

	6,000 Cages	IVC	EVC+ LPD, HR	EVC + DC	EVC + W2S	EVC + SV
Room Design	Surface Area (Holding Area) Density HVAC ACH / Noise Attenuation Plug Load & Lighting	3,750 nsf 1.6 cages/sf 12,000 cfm 19 / yes 11 kW		1,054 nsf 5.7 cages/sf 3,000 cfm 17 / no 1 kW		
	<i>First \$</i> Savings (%)	\$728,250		\$175,650 \$552,600 (76%)		
Population Density	HVAC & Plug Load [kWh]	356,800		98,800 (72%)		
	<i>Carbon Footprint: CO2</i> Savings (%)	271 tons		75 tons 196 tons		
	<i>Annual Energy</i> Savings (%)	\$ 88,500		\$ 11,652 \$76,848 (87%)		
	<i>Annual Maintenance \$</i> Savings (%)	\$22,200		\$ 7,800 \$14,400 (65%)		
	<i>Annual Husbandry \$</i> Savings (%)	\$660,000		\$533,000 \$127,000(19%)		
	<i>perDiem/cage</i> Savings (%)	\$0.38⁷		\$0.26² \$0.12⁵ (32%)		

CONCLUSION – *per Diem*

- Barrier Facility
 - Space, Energy Use, and Operating Costs

	6,000 Cages	IVC	EVC+ LPD, HR	EVC + DC	EVC + W2S	EVC + SV
Room Design	Surface Area (Holding Area) Density HVAC ACH / Noise Attenuation Plug Load & Lighting	3,750 nsf 1.6 cages/sf 12,000 cfm 19 / yes 11 kW			1,054 nsf 5.7 cages/sf 3,000 cfm 17 / no 1 kW	
	<i>First \$</i> Savings (%)	\$728,250			\$192,450 \$535,800 (73%)	
Population Density	HVAC & Plug Load [kWh]	356,800			98,800 (72%)	
	<i>Carbon Footprint: CO2</i> Savings (%)	271 tons			75 tons 196 tons	
	<i>Annual Energy</i> Savings (%)	\$ 88,500			\$ 11,000 \$77,500 (88%)	
	<i>Annual Maintenance \$</i> Savings (%)	\$22,200			\$ 7,800 \$14,400 (65%)	
	<i>Annual Husbandry \$</i> Savings (%)	\$660,000			\$541,000 \$119,000(18%)	
	<i>perDiem/cage</i> Savings (%)	\$0.38⁷			\$0.26³ \$0.12⁴ (32%)	

CONCLUSION – *per Diem*

- Barrier Facility
 - Space, Energy Use, and Operating Costs

	6,000 Cages	IVC	EVC+ LPD, HR	EVC + DC	EVC + W2S	EVC + SV
Room Design	Surface Area (Holding Area) Density HVAC ACH / Noise Attenuation Plug Load & Lighting	3,750 nsf 1. ⁶ cages/sf 12,000 cfm 19 / yes 11 kW				1,054 nsf 5. ⁷ cages/sf 3,000 cfm 17 / no 1 kW
	<i>First \$</i> Savings (%)	\$728,250				\$215,300 \$512,950 (70%)
Population Density	HVAC & Plug Load [kWh]	356,800				76,100 (78%)
	<i>Carbon Footprint: CO2</i> Savings (%)	271 tons				58 tons 213 tons
	<i>Annual Energy</i> Savings (%)	\$ 88,500				\$ 9,375 \$79,375 (90%)
	<i>Annual Maintenance \$</i> Savings (%)	\$22,200				\$ 7,800 \$14,400 (65%)
	<i>Annual Husbandry \$</i> Savings (%)	\$660,000				\$576,000 \$84,000 (12%)
	<i>perDiem/cage</i> Savings (%)	\$0.38⁷				\$0.27² \$0.11⁵ (30%)

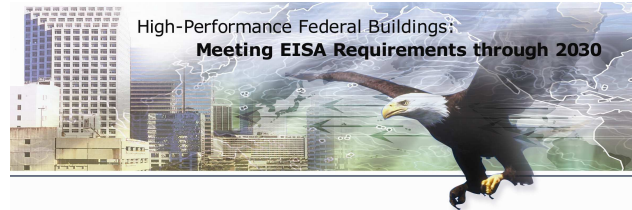
CONCLUSION – *per Diem*

- Barrier Facility
 - Space, Energy Use, and Operating Costs

	6,000 Cages	IVC	EVC+ LPD, HR	EVC + DC	EVC + W2S	EVC + SV
Room Design	Surface Area (Holding Area)	3,750 nsf	1,054 nsf	1,054 nsf	1,054 nsf	1,054 nsf
	Density	1. ⁶ cages/sf	5.7 cages/sf	5.7 cages/sf	5.7 cages/sf	5.7 cages/sf
	HVAC	12,000 cfm	3,000 cfm	3,000 cfm	3,000 cfm	3,000 cfm
	ACH / Noise Attenuation	19 / yes	17 / no	17 / no	17 / no	17 / no
	Plug Load & Lighting	11 kW	1 kW	1 kW	1 kW	1 kW
	<i>First \$ Savings (%)</i>	\$728,250	\$175,650 \$552,600 (76%)	\$175,650 \$552,600 (76%)	\$192,450 \$535,800 (73%)	\$215,300 \$512,950 (70%)
	HVAC & Plug Load [kWh]	356,800	98,800 (72%)	98,800 (72%)	98,800 (72%)	76,100 (78%)
Population Density	<i>Carbon Footprint: CO2 Savings (%)</i>	271 tons	75 tons 196 tons	75 tons 196 tons	75 tons 196 tons	58 tons 213 tons
	<i>Annual Energy Savings (%)</i>	\$ 88,500	\$ 11,652 \$76,848 (87%)	\$ 11,652 \$76,848 (87%)	\$ 11,000 \$77,500 (88%)	\$ 9,375 \$79,375 (90%)
	<i>Annual Maintenance \$ Savings (%)</i>	\$22,200	\$ 7,800 \$14,400 (65%)	\$ 7,800 \$14,400 (65%)	\$ 7,800 \$14,400 (65%)	\$ 7,800 \$14,400 (65%)
	<i>Annual Husbandry \$ Savings (%)</i>	\$660,000	\$576,000 \$84,000 (12%)	\$533,000 \$127,000(19%)	\$541,000 \$119,000(18%)	\$576,000 \$84,000 (12%)
	<i>perDiem/cage Savings (%)</i>	\$0.38⁷	\$0.28¹ \$0.10⁶ (26%)	\$0.26² \$0.12⁵ (32%)	\$0.26³ \$0.12⁴ (32%)	\$0.27² \$0.11⁵ (30%)

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