Research Conducted with Georgia Tech Facilities Department and Analysis of Old Civil Engineering Building

A Report

Presented to

The Institute Engineer of Georgia Tech

By

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Executive Summary

The Building Energy Simulation group of the George W. Woodruff School of Mechanical Engineering was assigned the task of simulating the Old Civil Engineering (Old C.E.) building as a follow up to the leadership in energy and environmental design (LEED) submittal. The corrected energy model for the simulation of Old C.E. was accomplished with the aid of eQUEST simulation and was compared against the theoretical LEED submitted Trane Trace simulation and actual measured energy from the campus wide data logging system. The eQUEST model was corrected for current equipment, actual weather and occupancy to accurately represent the building at its current state of operation. The metric used for comparison is kBTU/sq.ft./year and the results from the simulation are as follows:

- The actual metered energy and the theoretical LEED submittal differ by a severe amount of 24.8%.
- The corrected eQUEST model compared to the actual metered energy shows that the Old C.E. building is operating 7.3% more efficiently than the corrected model.
- A 3.18% relative error was present when comparing the number of degree days of the real weather data to that of the averaged TMY2 file.

Table 1 shows consumption rates and normalized degree day (D.D.) results for the eQUEST and Trane Trace models and the actual metered energy. The methodologies employed in this research are outlined in this report and will provide a basis to the standardization of the Georgia Tech Facilities measurement and verification policy for future and existing buildings.

Table 1: Comparison Table of results

	Consumption (kBTU/year)	kBTU/sq.ft./year	kBTU/sq.ft./Real D.D.	kBTU/sq.ft./TMY2 D.D.
Metered Results	2427897.7	79.2	0.023	0.024
LEED Submittal	1823300.0	59.5	0.017	0.018
eQUEST Model	2620890.0	85.5	0.025	0.026

Introduction

Over the past few years Dr. Sheldon Jeter's graduate students have been conducting energy studies for the Georgia Tech Facilities department under the guidance of Donald P. Alexander. The building energy simulation group have worked together to gain a better understanding and working knowledge of the components necessary to accomplish our goals, namely measurement and verification. The approach of these studies is to utilize the campus wide network of monitoring software to verify results that are observed in energy models which are created to represent the real performance of buildings. To capture the effects of real world events, the energy simulations that will be created or have been created will use real data for the occupancy, weather and changes in equipment. The group's latest simulation which incorporated this approach is the Old Civil Engineering building. We as a research group have been working with the facilities design and construction department in the preparation and selection of monitoring equipment for one of the newest Georgia Tech buildings, the Clough Undergraduate Learning Commons. This research task has brought about new ways of monitoring the concentration of CO_2 within conditioned spaces and has given the Georgia Tech community a building in which HVAC experiments and studies can be conducted. This report will outline the Old C.E. energy model and its results to show that the incorporation of real world data into energy models has value.

Part I: Old Civil Engineering Energy Model Calibration

Background

The Old C.E. building was originally constructed in 1937 as a Public Works Administration project developed by the architecture staff at Georgia Tech. Over the lifetime of the building it has been remodeled three times with the most recent renovation occurring in 2008. This renovation consisted of removing existing mechanical equipment and interior furnishings. The 2008 renovation was proposed for Leadership in Energy and Environmental Design (LEED) certification and Gold certification was achieved. As a new criterion for LEED certification, reevaluation of the building's total energy performance must be performed to maintain certification status. This follow up will compare the actual energy performance to the original LEED submittal and to the corrected model.

Objective

Reevaluate the LEED certification submittal of the Old Civil Engineering building by what is outlined in the measurement and verification (M&V) report. From this evaluation, an eQUEST energy model will be developed that will incorporate the latest equipment, actual weather conditions, and actual occupancy schedules of the building and will be compared against actual metered data for consumption. This follow up study will show the actual performance of Old C.E. compared to what was originally submitted in the LEED report and to the outcome of the eQUEST model. From this analysis and energy modeling, a procedure will be developed for future modeling projects, most immediately the Clough Undergraduate Learning Commons (CULC).

Procedure

The first step in reevaluating the Old C.E. building was to obtain the most current record set of drawings and documents from the Old C.E. renovation project manager, Gary Petherick. This data will be used as the basis of inputs to the eQUEST model and will be compared against the model inputs of the LEED submitted model. Inputs from the LEED energy model will be used but will be corrected for actual weather, occupancy and equipment. Further corrections to the model will be obtained from an energy audit for the consumption of plug loads. Actual energy consumption will be obtained from the campus wide measuring systems Ion and Metasys and processed to the time intervals in which the eQUEST model runs. The processed data will then be compared against the results from both the theoretical LEED submitted model and corrected eQUEST model.

Uncertainties

The uncertainties associated with the creation and evaluation of an energy model is based on the readings from the metering network and model results. Power measurement devices that log the electrical consumption have uncertainties associated with its accuracy in reading the power consumption. The electrical meters have an independent certification by the American National Standards Institute (ANSI) standard of C12.20 which states that the meter must be within or below an accuracy of 0.2 % to 0.5% for electrical power readings (Ion). Previous work into error propagation of the heating and cooling measuring devices has been outlined in Rachel Valade thesis titled *Development and Verification of a Simplified Building Energy Model*. Her analysis shows that the error of the heating load estimate is 3% and the cooling load estimate to have an error of 3.6% (Valade p. 63 – 64). The uncertainties associated with eQUEST are presented in a study conducted by the Energy Systems Laboratory of Texas A&M which shows that the comparison of results from the DOE-2 simulation engine varies by 0% to 5% on whole building energy use (Habrel, Cho 3).

Analysis: Modeling Creation and Guidelines

The creation of an eQUEST model was developed based on guidelines that were reviewed with the Institute Engineer, Don Alexander. Model inputs were based off on the inputs used in the LEED submittal and direct observation from an energy audit of the building. Thermal zoning of the Old C.E. building was simplified and was based on expected use. Labs, classrooms and spaces considered other were the principal zones that were selected and modeled accordingly in the eQUEST model. Once the zones were selected, the totalizing of the electrical and mechanical equipment must be accomplished to obtain the airflows and energy density values of each zone.

Airflows within each space were calculated from the as-built construction HVAC documents and were verified by the Metasys system. The calculation of the lighting energy density values, W/sq.ft., for each zone was calculated as product of the number of fixtures and its wattage value then divided by the zone's square footage. The calculation spreadsheets of all zones for the mechanical equipment are shown in appendix A and the lighting load estimates are shown in appendix B. To estimate the plug loads of Old C.E., an energy audit was performed on August 21st, 2010 to obtain the model numbers of each power consuming device for each representative zone. Computers, monitors and other miscellaneous equipment were cataloged and estimated for their energy consumption. The estimation of energy density values for each zone is shown in appendix C.

The mechanical system in the eQUEST model was based off of the mechanical drawings from the as-built documents. A single line thermodynamic diagram showing the connections of the mechanical systems is shown in appendix D. The heating, ventilating and air-conditioning system within Old C.E. is a variable air volume system with energy recovery. Inputs for the mechanical equipment were based on the schedules listed in the as-built drawings. The heating and cooling system of the Old C.E. modeled as a separate boiler and chiller arrangement.

Determination of the occupancy load for each simplified zone was estimated by counting the number of seats per zone as shown on the furniture plans. This information was utilized in determining the occupant density, area/person, for each zone. To determine the schedule of classes that were to take place within the Old C.E. building, the department of space and planning was contacted to determine the amount of students registered for courses that were held in the Old C.E. building.

Analysis: Processing of Metered and Weather Data

The data obtained from the Ion and Metasys database had to be processed into the desired time intervals in which the eQUEST model runs, 1 hour. Electrical meter readings were taken every 15 minutes and summed over the entire hour for the entire year. The electrical consumption data for Old C.E. had to be additionally processed to take out the meter readings from the Navy ROTC building because of the sub-metering on the main Old C.E. electrical panel. An excel visual basic code was developed to accomplish this task and is outlined in Appendix E.

Steam meter readings were processed by calculating the number of clicks the condensate meter read. Every click on the condensate meter registered as 100 gallons of condensate from the building. Estimation of the heating load, as shown in equation 1, was accomplished with the use of Steamtab, an excel add-in.

$$\dot{Q}_{Heat} = C_{ft^3\_gal}\,\rho_{\underset{180F}{cond}}\left(h_{sat\,vapor} - h_{sat\text{-}liq}\right)$$

Where, $C_{ft^3\text{-}gal}$ is the conversion from ft^3 to gallons, $\rho_{cond\,180F}$ is the density of the condensate at 180°F, $h_{sat\text{-}vapor}$ is the enthalpy of the saturated vapor at 50 psi and $h_{sat\text{-}liq}$ is the enthalpy of saturated liquid at 180 °F. Calculation of the chilled water consumption was determined from the ion datalogging database by obtaining the k-ton/hour cooling flow. The meter for the cooling flow reads as an incremental meter logging every k-ton of cooling for every 15 minutes. The entire year's cooling flow was calculated from the beginning and end of the simulation year and multiplied by 12,000 to convert from tons of cooling to BTU's of cooling.

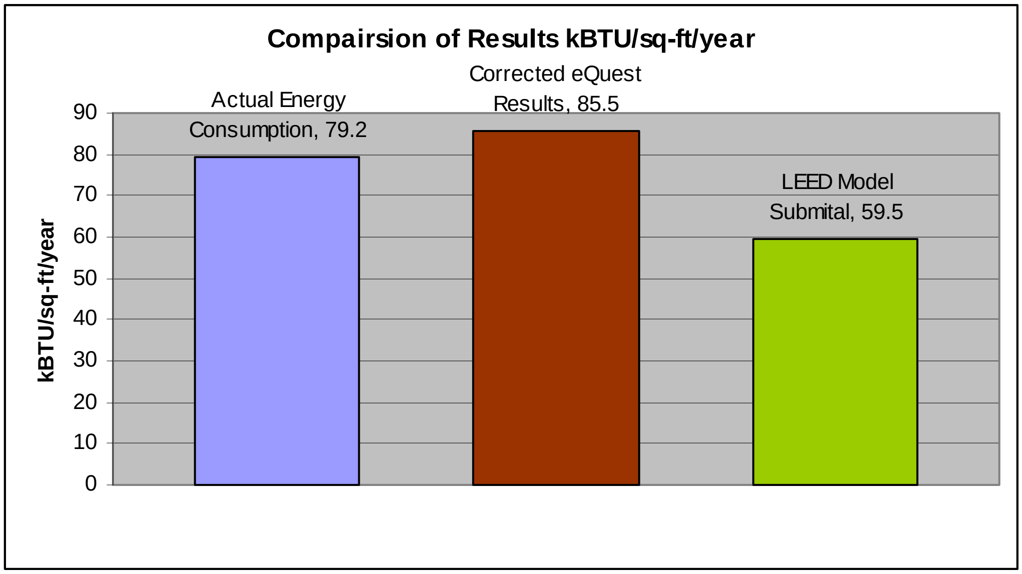
The usage of averaged typical meteorological year (TMY2) files for the weather in simulation causes the building loads to be underestimated in simulation. To overcome this obstacle the actual weather that occurred near the building was selected from the University of Georgia College of Agriculture and Environmental sciences weather database. The University of Georgia weather station located at Clark Atlanta University was selected for its close proximity to the Georgia Tech campus. The purchased weather data from the Clark Atlanta University had to be also processed to average 15 minute intervals to 1 hour intervals. The weather converter program eQ_WthProc was utilized to convert the processed weather data into the desired TMY2 binary format. The energy consumption comparison between the actual weather and TMY2 averaged data for the corrected eQUEST simulation is shown in the following section.

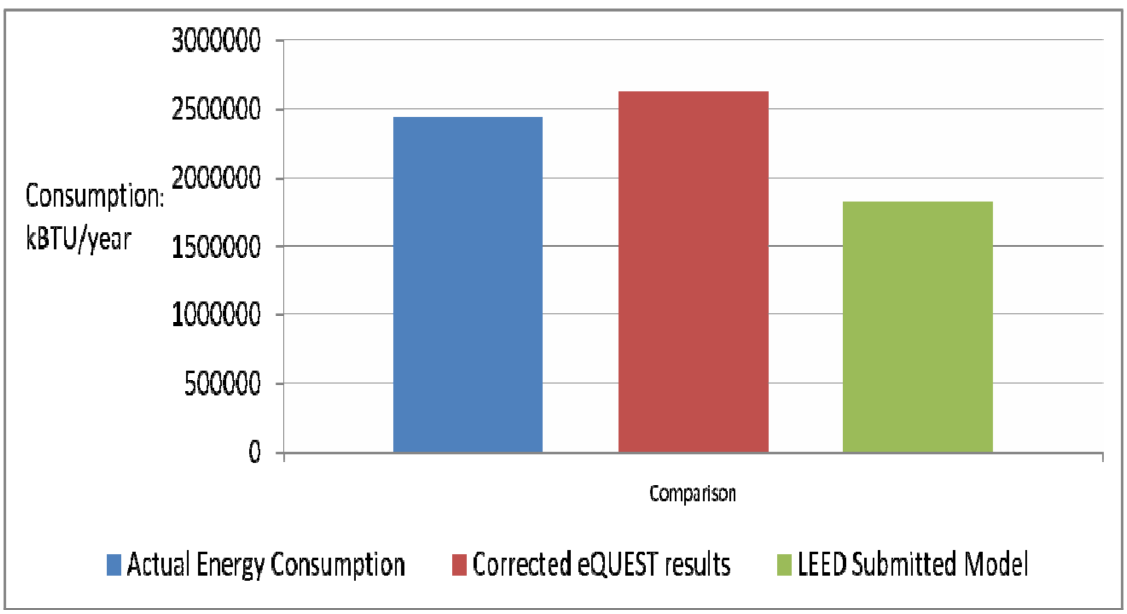
Analysis: Model Results and comparison

The energy performance results comparing the actual metered results, the theoretical LEED results and the corrected eQUEST model results are shown in table 1 with corrections for normalizing the weather.

Table 1: Comparison of model results to the actual metered readings

	Consumption (kBTU/year)	kBTU/sq.ft./year	kBTU/sq.ft./Real D.D.	kBTU/sq.ft./TMY2 D.D.
Metered Results	2427897.7	79.2	0.023	0.024
LEED Submittal	1823300.0	59.5	0.017	0.018
eQUEST Model	2620890.0	85.5	0.025	0.026





As shown in table 1, the actual metered results are severely higher than the theoretical LEED submittal by 24.8%. The corrected eQUEST model compared to the actual metered readings shows that the actual building is performing more efficiently by a relative error percentage of 7.3%. To show the effect of using actual weather data compared to the averaged TMY2 weather, table 2 shows the consumption, degree days and comparison metrics for both weather sets.

Table 2: Comparison of weather files

	Consumption (kBTU/year)	Degree Days	kBTU/year/D.D.	kBTU/year/GSF
Actual Weather	2620890	3401.9	770.4	79.1
TMY2 Weather	2534190	3296.8	768.8	76.5

The results from the weather files show that the number of degree days is higher than the TMY2 weather file. Comparing the actual weather to the average TMY2 weather file, there is a 3.18% relative difference in the amount of degree days. A 3.41% relative error is present when comparing the kBTU/year/GSF calculation and these differences are potentially due to the hotter and colder months of the actual year which was from September 2009 to August 2010.

Part II: Work Conducted with the Georgia Tech Facilities Department and Future Work

Research is the pursuit of gathering data for the advancement of knowledge. The Building Energy Simulation Group of the George W. Woodruff School of Mechanical Engineering has set out to gather data from new and renovated buildings to advance the knowledge of how buildings operate. One obstacle that must be overcome through this research is the integration of real world knowledge to that of the theoretical world of building operation. By having an experienced team of engineers and professors, this research can lead to discoveries that might potentially save more energy and overall cost of building operation. Over the past three years Dr. Sheldon Jeter and Don Alexander have been actively involved in this pursuit with the help of hard working graduate students. Their work has produced a better understanding of the measurement and verification of building operation. Another integral resource that has provided the data of building operation is the campus wide datalogging systems of Johnson Controls and Ion.

The work of the current Energy Simulation Group began in the fall of 2009 at a meeting with Don Alexander, Sheldon Jeter and representatives from Newcomb and Boyd. This meeting consisted of the measurement and verification of one of Georgia Tech's newest building the Clough Undergraduate Learning Commons (CULC). The next couple of months consisted of more meetings, familiarization of the campus datalogging network, development of simplified energy models, and learning the fundamentals of building thermodynamics. Measurement and verification was the research topic our lab chose to accomplish not because of its challenges but because it allowed one to become more innovative in their approach to solving problems. A majority of the discussions that were encountered at these meetings was an active way of solving the problem of CO_2 measurements for outdoor air intake into buildings.

The current trend of CO_2 monitoring is to use CO_2 sensors that measure at one point within an occupied space to modulate fresh air intake while maintaining acceptable indoor air quality. Through our discussions we came to the conclusion that the best way to determine what the CO_2 concentration was within buildings was to go the source of the CO_2 production, human beings. By counting the number of people that enter and exit a space and knowing their normal rate of CO_2 production will actively solve this problem. This technique to solving how a building is to be monitored for its fresh air make up was so novel in its approach that it gained attention from the local chapter of American Society of Heating, Refrigeration and Air-Conditioning Engineers.

The Building Energy Simulation Group then set out to find what type of sensor would be best for counting people. After extensive literature review of counting systems, it came down to two different types of sensors: camera or infrared. To test these two types of counters, both a camera counting system and an infrared sensor were bought with the money appropriated by the facilities department. The testing of both sensors produced reasonable results but the infrared sensor was more reliable and had a less intrusive way of counting people. A report outlining the testing that was conducted for the infrared sensor is shown in appendix E.

The measurements that are to be taken in CULC were the main purpose of the meetings and from this a new way of measuring building energy consumption was developed. The metering of CULC would consist of subdividing the electrical consumption into the lighting, mechanical, receptacle or plug loads and photovoltaic energy production. This subdivision allows for a better resolution of how much electricity is being consumed and produced by each principle component of the building's electrical load. Further metering of the airflows within the CULC allowed for more accurate readings of air handler performance. All of the principle airflows in and out the air handling units allowed for better calibration of the CO_2 monitoring system. Another monitoring point that allowed for better readings of building energy consumption was a steam meter. This allowed for more active readings of the steam rate because previous forms of monitoring were measurements of the steam condensate from the building.

With this new building came new forms of HVAC technology which could be researched. Chilled beam technology is relatively new in the United States and studies to show its effectiveness have not been conducted extensively. Two of the physics labs within the CULC will contain chilled beam labs. These two labs along with two other non chilled beam physics labs will be monitored for their subdivided energy consumption. This study will advance the knowledge of chilled beam operation and their effectiveness in laboratory applications.

Through the specification of monitoring equipment, a SMART measurement and verification (M&V) plan will be developed to set guidelines and standards for the Georgia Tech Yellow Book. The plan will consist of making calibrations to the energy model that was submitted for LEED certification. This plan sets out to make a calibrated energy model that would incorporate the metered results of the people counters, electrical data and airflow measurements. This processing of data would allow for more accurate results from energy simulations and development of a plan to do this would allow for better follow up studies of building operation.

Future buildings that will incorporate the research approach of SMART M&V will be the Hinman and Carbon Neutral buildings. The Hinman building is the first building to apply the people counting technology on a whole building scale and will be the first to involve the calibration of an energy model with real occupancy data. Research will consist of verifying the people counting technology accuracy and correct operation of the metering equipment for electrical, heating and cooling consumption. The Carbon Neutral Energy Solutions Laboratory building is the next building to be proposed for sub-metering of the electrical consumption, metering of the heating and cooling systems and the use of people counting technology. The Carbon Neutral building is still in the design stage and will be a good point for the implementation of new strategies in M&V implementation. The only obstacle facing the use of people counting technology in the Carbon Neutral building is the requirement of USA made products being used in the construction. The current manufacturer of the people counting technology is located in Canada and is technically not allowed on the project. Selection of another manufacturer of people counting technology will have to be used for this project if it is to be used on the Carbon Neutral building.

The continuous monitoring of the GT weather station will be performed concurrently with the Hinman and Carbon Neutral M&V projects. The trending of the weather data will not only benefit the weather files used in the Building Energy Simulation Group energy models but also the facilities engineering staff and outside consultants performing the same task. Further testing of the people counting technology will also be performed during this time and will be implemented in the Love classroom building room 184. Calibration of the people counting technology will be performed with the use of highly reliable CO_2 sensors installed within the HVAC ducts of LOVE 184. This work will aid in the preparation of the mobile infrared people counting sensors that will be implemented across campus to trend areas in which the people counting technology could be used. This work along with the CULC follow up studies will provide enough resources and work to ensure that the Building Energy Simulation Group will advance the use of new innovative ways of calibrating energy models for follow up studies of Georgia Tech buildings.

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Appendix A: Calculation Spreadsheet of Ventilation equipment per zone

Zone	VAV box ID	Heating Coil Capacity (MBH)	CFM max	CFM min
Level G Offices	G-8	19.6	530	215
	G-7	9.5	615	245
	G-6	11.4	750	300
	G-5	11.4	660	260
	G-4	7.7	530	215
Total		59.6	3085	1235
Comp Class G07	G-1	24.2	1575	630
	G-2	24.2	1575	630
Total		48.4	3150	1260
Comp Class G10	G-3	38.3	2180	870
Level 1 Offices	1-3	25.7	1470	585

	1-2	19.1	1090	435
	1-4	17.6	1000	400
	1-5	8.8	450	180
	1-6	23.1	1320	525
	1-7	13.4	770	305
	1-8	14.3	825	330
	1-9	14.3	825	330
	1-13	9.2	525	210
	1-14	7	400	160
Total		152.5	8675	3460
Classroom 104	1-1	25.1	1430	570
Level 2 Offices	2-2	8.8	600	200
	2-3	13	740	295
	2-4	9.7	550	220
	2-5	19.6	1110	440
	2-6	19.1	1000	400
	2-7	9.9	645	255
	2-8	11.4	750	300
	2-9	11.4	750	300
	2-10	23.1	1320	525
	2-11	7.5	325	130
	2-12	10.6	425	170
Total		144.1	8215	3235
Classroom 204	2-1	25.1	1280	570
Classroom 304	3-1	7.9	460	180
Classroom 310	3-6	7.1	460	285
Zone	**VAV box ID**	**Heating Coil Capacity (MBH)**	**CFM max**	**CFM min**
Level 3 Offices	3-2	12.5	720	285
	3-3	8.2	530	210
	3-4	12.5	720	285
	3-5	8.4	560	220
	3-7	7	400	160
Total		48.6	2930	1160
PhD upper Floor	1-10	35.2	2000	800
	1-11	24.4	1395	555
	1-12	17.6	1005	400
Total		77.2	4400	1755
PhD Lower Floor	G-9	21.1	1200	480

Appendix B: Lighting Load Estimation Spreadsheet per Zone

Zone	Type of Fixture	Amount	Wattage	Zone	Type of Fixture	Amount	Wattage
Level G Offices	B3	18	1512	Classroom 204	C	2	56
	B4	2	216		B4	6	648
	C	4	112		Total		704
	D	4	224		W/sq.ft.		1.482
	G1	11	352	Classroom 304	B1	6	324
	G2	5	160		G1	2	64
	K2	12	648		F	1	54
	Total		2416		Total		442
	W/sq.ft.		0.609		W/sq.ft.		1.147
Comp Class G07	B2	14	784	Classroom 310	B1	6	324
	G1	4	128		G1	1	32
	J2	4	56		F	1	54

	Total		912		Total		410
	W/sq.ft.		0.493		W/sq.ft.		1.194
Comp Class G10	B2	12	672	Level 3 Offices	AE	4	640
	Total		672		B2	4	224
	W/sq.ft.		1.035		B3	12	1008
Level 1 Offices	AE	4	640		G1	13	416
	B2	4	224		J3	3	42
	B3	28	2352		K2	5	270
	C	8	224		QE	2	104
	D	4	224		L	1	56
	G	14	448		C	1	28
	J3	4	56		Total		2330
	K2	6	324		W/sq.ft.		0.739
	QE	2	104	PhD upper Floor	A2	1	96
	Total		4596		A2E	1	42
	W/sq.ft.		0.657		B4	6	648
Classroom 104	C	2	56		U	1	28
	B4	6	648		Total		786
	Total		1430		W/sq.ft.		0.498
	W/sq.ft.		1.482	PhD Lower Floor	A3E	1	42
Level 2 Offices	AE	4	640		G2	2	64
	B2	4	224		J2	3	42
	B3	28	2352		T	3	150
	C	8	224		R	3	162
	D	4	224		Total		460
	G	14	448		W/sq.ft.		0.282
	Type of Fixture	**Amount**	**Wattage**				
Level 2 Offices	G4	6	192				
	J3	4	56				
	K2	7	378				
	QE	2	104				
	L	2	112				
	Total		4954				
	W/sq.ft.		0.707				

Appendix C: Plug Load Estimate per Zone

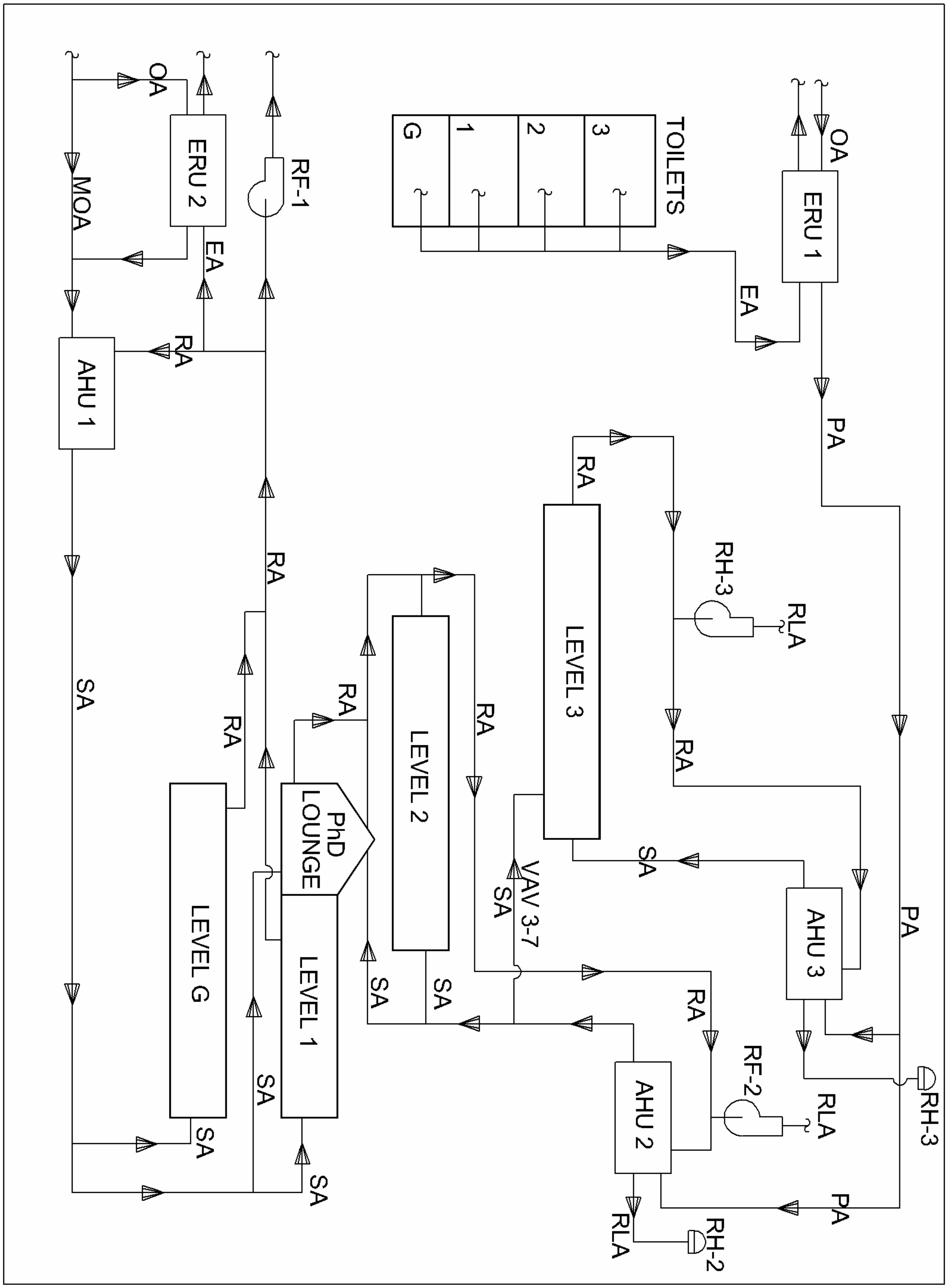
<table>
<tr><th>Zone</th><th>Item</th><th>Amount</th><th>Wattage</th><th>Zone</th><th>Item</th><th>Amount</th><th>Wattage</th></tr>
<tr><td rowspan="5">Level G Office</td><td>Monitor*</td><td>1</td><td>31</td><td rowspan="5">Level 2 Office</td><td>Monitor*</td><td>1</td><td>31</td></tr>
<tr><td>CPU 755*</td><td>1</td><td>130</td><td>CPU 755*</td><td>1</td><td>130</td></tr>
<tr><td colspan="2">Number of Offices</td><td>12</td><td colspan="2">Number of Rooms</td><td>7</td></tr>
<tr><td colspan="2">Total Wattage</td><td>1932</td><td colspan="2">Total Wattage</td><td>1127</td></tr>
<tr><td colspan="2">W/sq.ft.</td><td>0.364941</td><td colspan="2">W/sq.ft.</td><td>0.436252</td></tr>
<tr><td rowspan="6">Computer Room G07</td><td>Monitor*</td><td>31</td><td>961</td><td rowspan="4">Classroom 204</td><td>Projector+</td><td>1</td><td>100</td></tr>
<tr><td>CPU 760*</td><td>31</td><td>3441</td><td colspan="2">Number of Rooms</td><td>1</td></tr>
<tr><td>Printer*</td><td>1</td><td>46</td><td colspan="2">Total Wattage</td><td>100</td></tr>
<tr><td colspan="2">Number of Rooms</td><td>1</td><td colspan="2">W/sq.ft.</td><td>0.210084</td></tr>
<tr><td colspan="2">Total Wattage</td><td>4448</td><td rowspan="4">Level 3 Office</td><td>Monitor*</td><td>1</td><td>31</td></tr>
<tr><td colspan="2">W/sq.ft.</td><td>2.241344</td><td>CPU 755*</td><td>1</td><td>130</td></tr>
<tr><td rowspan="2">Computer Room G10</td><td>Monitor*</td><td>9</td><td>279</td><td colspan="2">Number of Rooms</td><td>7</td></tr>
<tr><td>CPU 760*</td><td>9</td><td>999</td><td colspan="2">Total Wattage</td><td>1127</td></tr>
</table>

	Number of Rooms		1
	Total Wattage		1278
	W/sq.ft.		1.967667
Level 1 Office	Monitor*	1	31
	CPU 755*	1	130
	Number of Rooms		19
	Total Wattage		3059
	W/sq.ft.		0.43725
Classroom 104	Projector+	1	100
	Number of Rooms		1
	Total Wattage		100
	W/sq.ft.		0.210526
Level 2 Office	Monitor*	1	31
	CPU 755*	1	130
	Number of Rooms		19
	Total Wattage		161
	W/sq.ft.		0.436252
Classroom 204	Projector+	1	100
	Number of Rooms		1
	Total Wattage		100
	W/sq.ft.		0.210084

	W/sq.ft.		0.298622
Classroom 304	Projector+	1	100
	Number of Rooms		1
	Total Wattage		100
	W/sq.ft.		0.259403
Classroom 310	Projector+	1	100
	Number of Rooms		1
	Total Wattage		100
	W/sq.ft.		0.291121
PhD Lounge Upper	Monitor*	11	341
	CPU 755*	11	1430
	Printer*	1	420
	Number of Rooms		1
	Total Wattage		2191
	W/sq.ft.		1.341292
PhD Lounge Lower	Monitor*	12	372
	CPU 755*	12	1560
	Fridge***	1	420
	Microwave**	1	900
	Number of Rooms		1
	Total Wattage		3252
	W/sq.ft.		1.868381

*:U Penn (2010), +: Projectorreview (2010), **: OkSolar (2010), ***: Busy Trade (2010)

Appendix D: Thermodynamic Diagram of OLD C.E. Mechanical System



Appendix D: Processing of Raw Data

The following code shows the calculation routines necessary to compute the electrical consumption of a building from the Ion database.

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Sub electrical Consumption compiler()

'

' compiles the electrical consumption

'

' Keyboard Shortcut: Ctrl+t

'

ActiveCell.FormulaR1C1 = "=R[1]C[-1]-RC[-1]"

   Range("C2").Select

Selection.AutoFill Destination:=Range("c2:c35040"), Type:=xlFillDefault

   Range("c2:c35040").Select

ActiveCell.FormulaR1C1 = "=SUM(RC[-1]:R[3]C[-1])"

   Range("D6").Select

   ActiveCell.FormulaR1C1 = "=SUM(RC[-1]:R[3]C[-1])"

   Range("D10").Select

Selection.AutoFill Destination:=Range("d2:d35040"), Type:=xlFillDefault

   Range("d2:d35040").Select

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

   Selection.Delete Shift:=xlUp

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

   Selection.Delete Shift:=xlUp

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

   Selection.Delete Shift:=xlUp
```

```
ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

    Selection.Delete Shift:=xlUp

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

    Selection.Delete Shift:=xlUp

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

    Selection.Delete Shift:=xlUp

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

    Selection.Delete Shift:=xlUp

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

    Selection.Delete Shift:=xlUp

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

    Selection.Delete Shift:=xlUp

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

    Selection.Delete Shift:=xlUp

ActiveCell.Range("A1:A3,A5:A7,A9:A11,A13:A15,A17:A19,A21:A23,A25:A27,A29:A31,A33:A35,A37:A39,A41:A43,A45:A47,A49:A51,A53:A55,A57:A59,A61:A63,A65:A67,A69:A71,A73:A75,A77:A79,A81:A83,A85:A87,A89:A91,A93:A95,A97:A99").Select

    Selection.Delete Shift:=xlUp

End Sub
```

Appendix F: Testing of Infrared People Counting Sensor

TO: Don Alexander, PE; Institute Engineer, Facilities Georgia Institute of Technology

FROM: Bill Elkins, EIT; M&V Research Engineer, Georgia Institute of Technology

DATE: August 17th, 2010

SUBJECT: Results from the testing of the INFODEV people counting sensors

Over the past month, my research associate, Anthony Gray, and I have conducted three separate tests to determine the effect of single and multiple occupants and objects passing through the infrared (IR) beam of the INFODEV people counting system. The sensor that was tested in these experiments was the DA-200 IR sensor mounted on the interior side of the entrance door for the administration section of the facilities building. The results from these tests are to provide observations that might potentially produce errors and potential advantages for which Georgia Tech anticipates using these sensors.

On July 25th a series of experimental passages of a single occupant were made through the monitored doorway. Five different types of passages were made during separate 15 minute reporting intervals. A normal passage represents walking straight through the doorway at regular walking speed. A slow passage is also straight, but at a pace a lot slower than regular speed. A fast passage is also straight, but at a pace much faster than regular speed. An angle passage entails walking through the doorway following a slanted path that clips the left door jam and the corner of the wall were the hall turns. Finally, a half passage represents opening the door and walking right under the doorway and then turning around. Table 1 shows the results of the experiment.

Table 1: Results from IR Testing on July 25th, 2010

IR People Counter Testing 7/25/10							
Time		Passage Type	IR		Actual		Miss Counts
Hour	Minute		In	Out	In	Out	
12	45	Normal	10	10	10	10	0
1	0	Slow	10	10	10	10	0
1	15	Fast	5	4	5	5	1
1	30	Angle	10	8	10	10	2
1	45	Half	1	1	5	5	0*

* Half passages are not considered missed unless the In and Out counts do not correspond.

The testing of a single occupant through the IR sensor only miscounted when the sensor was operating under adverse walking conditions. These results show that when a single occupant enters the space at normal walking speeds and orientations the counter is precise. Although results of when the occupant walked at a faster pace or entered at a sharp angle were not in agreement with actual numbers, these entries and exits are not under normal conditions. It will be shown later that the sensors still operate fairly well under prolonged use and various conditions.

The second experiment was conducted on August 12th from 6:15 AM to 8:15 AM. We first tested the effects of orientation on how people passed through the IR beam in relation to how close they were to each other. As shown in figure 1, the orientations that were tested were the occupants were front to back (Test 1), side by side (Test 2) and staggered in a diagonal format (Test 4).

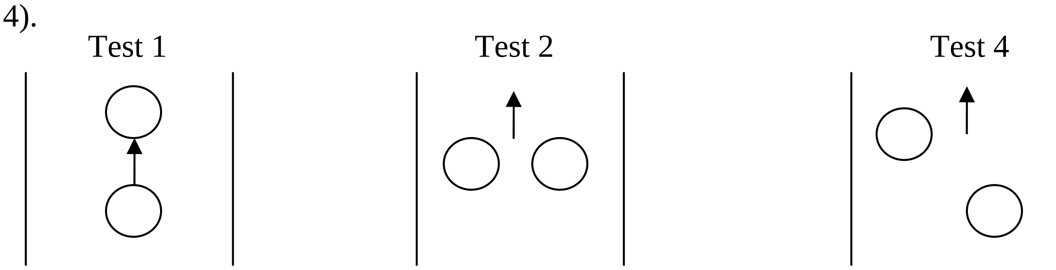

Figure 1: Orientations of occupants entering and exiting through the IR sensors

The sensors were tested for each orientation with 10 entries and 10 exits. It was determined that if occupants were close to one another, within 1” to 3”, that the sensors counted those two occupants as one, except for test 1. Test 1 produced accurate results for the counting of the occupants by only missing one occupant entering the space. Although the results for test 2 and 4 are not desirable, the potentiality of people walking so close to another is not a likely situation when entering a doorway. In a later test (Test 5), test 4 was redone with a larger gap, 12” to 14”, between the two occupants and results were precisely the number of occupants that entered and exited the space.

To test the effect of objects passing through the IR beam, a chair was pushed by an occupant through the IR beam multiple times. The chair was pushed, at arm’s length, by the occupant for 10 entries and 10 exits through the beam, as illustrated in figure 2.

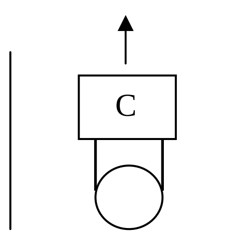

Figure 2: Orientation of occupant pushing chair through IR beam

The results from this test (test 3) produced results that show that the chair and the occupant were counted separately. It was estimated that the residual heat left in the chair from when a laptop was placed in it might have set off the sensors. Test 3 was conducted again later in the testing session, 1 hour later, and the same number of entries and exits were performed. This test (test 6) produced the same results of counting the chair and the occupant separately.

To ensure that the effect of arms being extended produced different results, test 7 was conducted with the occupant extending their arms out in the same fashion as pushing chair through the IR beam. 10 entries and 10 exits were performed for this test and the results were precisely the same as counted. The results and recorded numbers from both the IR counts and observed counts for experiment 1 are shown in table 2 with the tests labeled.

Table 2: Results from IR testing on August 12th, 2010

IR People Counter Testing 8/12/10											
Test	Time		IR Measurements				Observed				Comments
	Hour	Minute	In	Out	Change	Occup.	In	Out	Change	Occup.	
	6	15	1	1	0	0	3	1	2	2	Missed 1 in
1	6	30	22	21	1	1	21	21	0	2	
2	6	45	14	11	3	4	23	21	2	4	Side by Side Tends to Count Just One
3	7	0	19	22	-3	1	12	13	-1	3	Person Pushing Chair Tends to Double Count
4	7	15	13	12	1	2	20	20	0	3	Close Staggered Also Tends to miss
5	7	30	23	22	1	3	23	22	1	4	Normal Staggered worked perfect
	7	45	3	0	3	6	3	1	2	6	Missed 1 Out
6	8	0	20	23	-3	3	12	13	-1	5	Chair Still Double Counted
7	8	15	15	12	3	6	15	12	3	8	Arms Out Worked Fine

The third experimental test of the IR sensors was conducted on August 15th from 4:45 PM to 6:00 PM. The purpose of this test was to verify if an occupant pushing a chair through the IR beam produced similar results as seen on August 12th. The first test was similar to test 6 on August 12th, where a chair with no radiant heat present was pushed through the sensor. 10 entries and 10 exits were performed and the results produced the same effect of counting the chair and occupant separately. To validate the previous test, test 7 on August 12th, with an occupant extending their arms out and passing through the sensor. Eleven entries and eleven exits were performed under these conditions and the results were the same to the number of observed counts.

The final test, Test 3, was used as a control test where the occupant would enter and exit the space while opening the door. This was performed for 10 entries and 10 exits. The results from this test showed that the sensor counted exactly the same number of entries and exits as the observed counts. The results from the second experiment produced similar results to what was witnessed on August 12th and the results from the experiment are shown in table 3.

Table 3: Results from IR testing on August 15th, 2010.

IR People Counter Testing 8/15/10											
Test	**Time**		**IR Measurements**				**Observed**				**Comments**
	Hour	**Minute**	**In**	**Out**	**Change**	**Occup.**	**In**	**Out**	**Change**	**Occup.**	
	17	0	2	0	2	2	1	0	1	1	Chair counted as a person
1	17	15	20	20	0	2	10	10	0	1	Double count of chair
2	17	30	11	11	0	2	11	11	0	1	Arms extended out
3	17	45	10	10	0	2	10	10	0	1	Control test of opening door
	18	0	0	2	-2	0	0	1	-1	0	Leaving of space

Over the past 23 days the total counts of the IR sensors have been tabulated to show the relative error of the sensors based on the number of counts it conducted for one day. The results from these recorded observations are presented in table 4 for every day since July 27th. It can be seen that the sensors show a good agreement with the amount of ins and outs that were seen. The residual column shows the left over counts where the sensor had a residual number of people left in or out of the space. By taking the residual amount over the total counts we determined that the DA-200 INFODEV sensor produced a relative error of at most 2.51%. This result shows that the sensors are a reliable source for estimating the amount of occupants that are present within the space.

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Table 4: Overall Counts as of August 16th, 2010

Date	Sum of In	Sum of Out	Residual	Total Counts	Error
7/27/2010	102	102	0	204	0.00%
7/28/2010	103	98	5	201	2.49%
7/29/2010	102	97	5	199	2.51%
7/30/2010	121	117	4	238	1.68%
7/31/2010	0	0	0	0	-
8/1/2010	0	0	0	0	-
8/2/2010	94	90	4	184	2.17%
8/3/2010	94	93	1	187	0.53%
8/4/2010	97	95	2	192	1.04%
8/5/2010	111	105	6	216	2.78%
8/6/2010	99	101	-2	200	1.00%
8/7/2010	0	0	0	0	-
8/8/2010	0	0	0	0	-
8/9/2010	117	116	1	233	0.43%
8/10/2010	111	108	3	219	1.37%
8/11/2010	127	129	-2	256	0.78%
8/12/2010	210	214	-4	424	0.94%
8/13/2010	108	108	0	216	0.00%
8/14/2010	0	0	0	0	-
8/15/2010	43	43	0	86	0.00%
8/16/2010	123	118	5	241	2.07%

In conclusion, the DA-200 INFODEV IR sensor produced accurate results for the purposes of our research, namely the counting of occupants into a conditioned space. The testing of single and multiple occupant entry show that the sensors work well under normal conditions but under adverse conditions, the IR sensor still performed adequately. The relative error produced by the sensors on a daily basis showed that the sensors were within allowable tolerances for the counting of occupants. The effect of a chair being pushed through the IR beam produced the effects of counting as a person potentially due to a temperature difference between the chair and floor. The result of pushing a chair through the IR sensor needs to be investigated in further detail by potentially changing the temperature sensitivity of the IR sensor. Overall we are satisfied that the IR sensors produced accurate results over an extended period of time and look forward to testing in other locations in the future.

Cc: Dr. Sheldon Jeter, PE; Associate Professor, Georgia Institute of Technology

Dr. Dennis Sadowski; Research Engineer, Georgia Institute of Technology

Mr. Anthony Gray; Research Associate, Georgia Institute of Technology