A Study of Laboratory Energy Efficiency Measures

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ENERGY EFFICIENCY CONSULTANTS
AND SUSTAINABLE DESIGN ENGINEERS

Learning Objectives

- Review typical laboratory facility EEMs
- Understand the challenges in naming and categorizing Energy Efficiency Measures (EEMs)
- Learn methods for analyzing and refining EEM descriptions using R and AI tools
- Evaluate the effectiveness of revised EEM naming conventions through testing metrics
- Apply recommendations for implementing standardized EEM naming in practice
- Identify potential implementation of EEM naming for I2SL AIM and Fume Hood Challenge

Presentation Agenda

01 Background

02 Methods

03 Results

04 Discussion

05 Future Work

01 Background

The “Database”

- Selection of energy audits from the past 20 years at GBA
- Higher education laboratory buildings
- Stand alone labs
- Healthcare laboratories
- Hotels - not included in this analysis
- Commercial property – not included in this analysis
- Other – municipal/county government, financial institution, industrial, residential, etc.

- 2,141 Measures
- 227M kWh savings
  - 10M therms
  - 30M ton-hours purchased cooling
- $38M (Raw values not inflated)
- $215M project cost (Raw values not inflated)
- $12M incentives/rebates
- 5.3 year total simple payback (Raw values not inflated)

Uses for a Structured Database of EEMs

- Tool to help facility owners and operators gauge potential for retrofits in support of decarbonization and cost reduction efforts
- Justify more energy audits and retro-commissioning projects
- Compare EEM effectiveness to Lab Benchmarking results
- Prioritize facilities for use with I2SL AIM tool
- Separate data analytics effort for matching building characteristics
- Facilitate use of AI and data analytics

Example Measures

Occupancy Sensors for Laboratory Air Flow Reduction
Laboratory Area Occupancy Sensors
VFD's for LAB AHU's
Demand Control Ventilation for Laboratories
Reduce Supply Airflow in Vacant Laboratories
Aircuity for Laboratory Airflow Control
Smart Lighting in Laboratories
VFDs for Laboratory Supply and Exhaust
Replace Incandescent Candelabra Lighting
Install Air Quality Monitoring in Laboratory Spaces
Vary Lab Air Flow Using Contaminate Sampling
ER/Cath Lab Chiller Replacement
Optimize Lab Airflow
Lab Occupancy Sensors
Modify Controls for Labs with Phoenix Air Valves
KCBD: Reduce Lab Minimum Airflow
Laboratory AHU Heat Recovery Control Modification

Basis Study

ASHRAE Research Project 1836-RP: Developing a Standardized Categorization System for Energy Efficiency Measures

EEM or ECM: Energy Efficiency/Conservation Measures

ASHRAE Research Project Report
1836-RP

Developing a Standardized Categorization System for Energy Efficiency Measures

Approval: January 2023

Contractor: University of Cincinnati

Principal Investigator: Amanda Webb
Authors: Apoorv Khanuja

Author Affiliations, University of Cincinnati

Sponsoring Committee: TC 7.6 - Building Energy Performance

Co-Sponsoring Committee: BEQ & SSPC 100, Energy Efficiency in Existing Buildings

Co-Sponsoring Organizations: N/A

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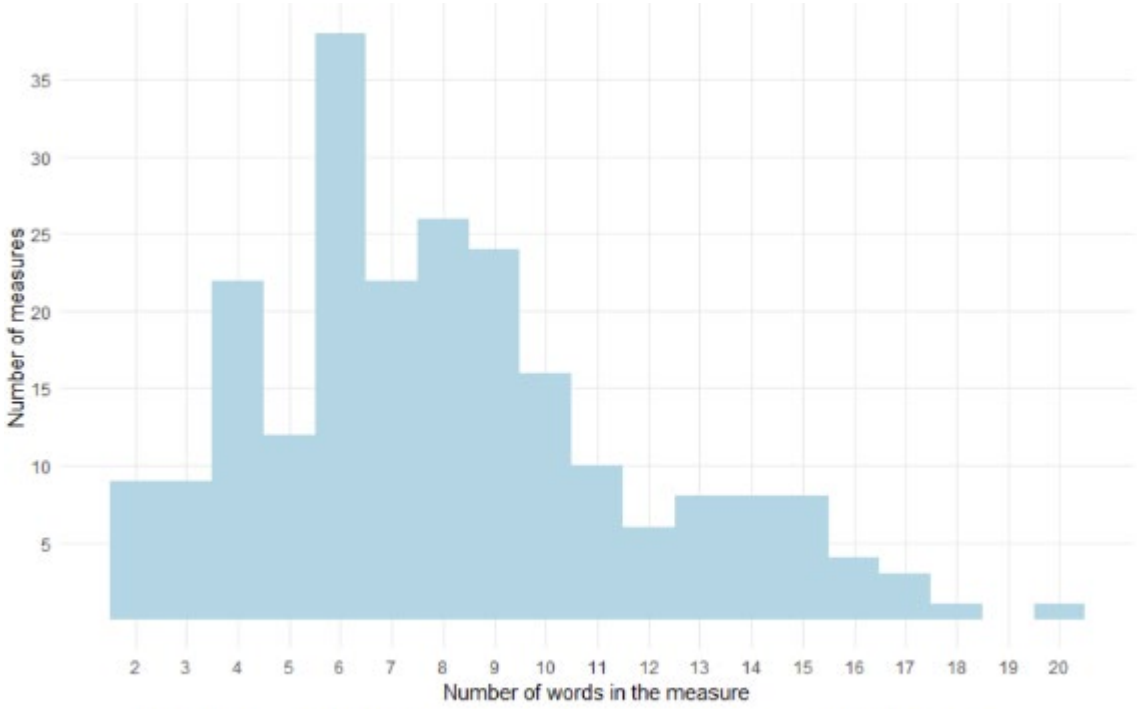


Figure 1 Frequency distribution of word length in measure names.

Table 2. Sample Water Conservation Measures

Word Count	Measure Name
2	Add insulation
4	Adjust tank toilet float
6	Add single-pass cooling equipment insulation
8	Adjust and maintain automatic sensors on faucets/showerheads
10	Add nearby clocks or distribute material to encourage shorter showers
12	Check the operation of the single-pass cooling equipment water control valve
14	Add automatic control to shut off single-pass cooling equipment system during nights/weekends
16	Adjust the film processor flow to the minimum acceptable rate for Photographic and X-Ray Equipment
18	Recycle rinse bath effluent as make-up for the developer/fixer solution for Photographic and X-Ray Equipment
20	Install reactors: membrane bioreactor; sequencing batch reactor; moving bed biofilm reactors; submerged fixed bed biofilm reactor; or rotating biological contactors

Important Findings for Clarity

- Reduce description length
- Use small list of verbs
- Name a building element or action item
- Phrase as a command (lead with actionable verb)

Current Status

Current GBA EEMS:

- Wordy
- No verbs – often just naming equipment
- Poorly formatted
- Not uniform – often refer to specific equipment by tags

02 Methods

Methods

Current GBA EEMS:

- Wordy
- No verbs – often just naming equipment
- Poorly formatted
- Not uniform – often refer to specific equipment by tags
- Proposal to use R to analyze data and replicate the original study's results

Methods

ACTION VERB	USE CASE	SYSTEM	INCLUDED ITEMS
Install	New Equipment	Lighting	Lights
Replace	Removing and Adding Better Equipment	Air Distribution	HVAC, Fans, Ventilation
Retrofit	Upgrading Equipment	Cooling	Chillers, Water Towers
Adjust	Controlling or Refining Equipment	Heating	Boilers, Hot Water
Remove	Eliminating Equipment	Water	Sewer, Condenser
Repair	Maintaining or Refurbishing Equipment	Energy	Batteries, Generation
		Envelope	Caulking Doors and Windows, Weatherization
		Controls	BAS, schedule, Setpoint
		Misc.	Specific Systems: Labs, Hotels, Data

Methods

Methods Tried

- Uniformat – set of descriptors used in original study
  - Not relevant enough for GBA use and requires standalone database
- Part of speech tagging – grammatically changing descriptions by identifying nouns, verbs, and adjectives
  - Current descriptions too fragmented to be effectively labeled
- AI renaming – giving descriptions to Copilot to rename
  - Not as predictable and difficult to manipulate spreadsheet
- Word Identification – stepping through spreadsheet and matching words
  - Current descriptions cause error

Current Method

- Using Copilot to identify key words to match and opportunities to shorten/clean descriptions
- Use R to systematically change spreadsheets, flagging any errors

Using R

1. Install RStudio version 4.5.1
2. Install Java – uses some of the libraries
3. Install Libraries
4. Change file directories in beginning of code
5. Run code in R

Github:

https://github.com/tbradshaw-GBA/EEM-Naming

Explanation of Code

```
# Define original word vectors for action categories
install <- c("install","use","add","insulate","implement","provide","seal","select","create","apply","make","add","added")
replace <- c("replace","replaced","replacing","convert","replacement")
retrofit <- c("retrofit","retrofits","upgrade","improve","change","modify","convert","conversion")
adjust <- c("adjust","adjustments","reduce","set","turn","minimize","increase","lower","optimize","reset",
            "supply","avoid","correct","vary","refine","modification","modifications","modify","revise","comissioning")
remove <- c("remove","removes","eliminate","separate","removal")
repair <- c("repair","repairs","clean","check","maintain","refurbish","fix")
weatherize <- c("weatherize","caulk","seal")
```

```
# Define original word vectors for system categories
lighting <- c("Lighting","light","lumen","occupancy","florescent","lamp","lamps")
airDistribution <- c("Air Distribution","ventilation","airflow","airflows","ahu","duct","hvac","exhaust","vfd",
                     "ahu's","ahus","VAV","variable air volume","VS","fan","fans","supply","air handling unit","air handling un
                     "economizer","variable air volume")
coolingSystem <- c("Cooling System","chiller","chw","cw","chilled","cooling","cool","thermostat")
heatingSystem <- c("Heating System","heat","heater","heating","boiler","hw","thermostat","reheat","hot water","steam")
controlSystem <- c("Controls", "BAS","automation","user based","user based controls","setpoint","control",
                   "controls","sensor","sensors","schedule")
waterSystem <- c("Water System","sewer","condenser","pump")
energySupply <- c("Energy Supply","battery","generate","generation","generator","solar","wind","nuclear")
Envelope <- c("Envelope","window","windows","door","doors","caulk","building")
```

Explanation of Code

```
# Loop through each row
for (i in 1:nrow(originalList)) {
  row <- originalList[i, ]
  desc_raw <- as.character(row[[desc_index]])

  # Remove all dash-followed segments (from each dash to the next space or end of string)
  desc_clean <- gsub("\\([^)]*\\)", "", desc_raw)
  desc_clean <- gsub("-\\d[^ ]*", "", desc_clean)
  desc_clean <- gsub("'[^ ]*", "", desc_clean)
  desc_clean <- gsub("â€“[^ ]*", "", desc_clean) # removes weird thing â€“
  desc_clean <- gsub("â[^ ]*", "", desc_clean) # removes weird thing â
  desc_clean <- gsub("&[^ ]*", "", desc_clean) # removes &
  desc_clean <- gsub("%[^ ]*", "", desc_clean) # removes %
  desc_clean <- gsub("/", " ", desc_clean)
  desc_clean <- gsub("\\b\\d+\\s+(through|and)\\s+\\d+\\b", "", desc_clean, ignore.case = TRUE) # Remove patterns like "number

  # cleans abbreviations
  desc_clean <- gsub("(?<=^|\\s)S(?=\\s|$)", "AHU", desc_clean, perl = TRUE)   # replaces S-### with AHU
  desc_clean <- gsub("(?<=^|\\s)VS(?=\\s|$)", "AHU", desc_clean, perl = TRUE)   # replaces S-### with AHU
  desc_clean <- gsub("(?<=^|\\s)CH(?=\\s|$)", "Chiller", desc_clean, perl = TRUE)   # Ch with Chiller
  desc_clean <- gsub("(?<=^|\\s)\\w(?=\\s|$)", "", desc_clean, perl = TRUE)   # Remove single-character tokens
  desc_clean <- gsub("\\b\\d+\\b", "", desc_clean, perl = TRUE)  # remove single number tokens

  # removes location specifics
  locationList <- c("area", "lab", "laboratory", "office", "elevator", "lobby", "vending machine", "ER", "cath", "stairwell",
                    "stair","halogen","parking garage","kitchen","cafeteria","surgery","hall","ballroom","garage")
  pattern <- paste0("\\b(", paste(locationList, collapse = "|"), ")\\b")
  desc_clean <- gsub(pattern, "", desc_clean, ignore.case = TRUE)

  # Tokenize cleaned description
  desc_text <- if (!is.na(desc_clean)) tolower(unlist(strsplit(desc_clean, "\\s+"))) else character(0)
```

Explanation of Code

```
# Match action category
matched_action <- ""
for (category in names(actionCategories)) {
  matched_tokens <- intersect(desc_text, actionCategories[[category]])
  if (length(matched_tokens) > 0) {
    matched_action <- actionLabels[[category]]
    # Remove all matched action tokens from desc_text
    desc_text <- desc_text[!desc_text %in% matched_tokens]
    break
  }
}
if (matched_action == "") matched_action <- "Install!"

# Match system categories (allow multiple systems)
matched_systems <- c()

for (category in names(systemCategories)) {
  matched_tokens <- intersect(desc_text, systemCategories[[category]])
  if (length(matched_tokens) > 0) {
    matched_systems <- unique(c(matched_systems, systemLabels[[category]]))
  }
}
```

Explanation of Code

```
# Repeated trimming based on prepositions, colons, and dashes
repeat {
  if (nrow(pos_data) == 0) break

  # Define all marker tokens
  marker_tokens <- c(",",";", ":", "-", "–", "to", "in", "on", "at", "by", "with", "from", "of", "for")

  # Identify positions of any marker tokens
  marker_indices <- which(tolower(pos_data$token) %in% marker_tokens)

  if (length(marker_indices) == 0) break  # No more markers to trim

  trimmed <- FALSE
```

Explanation of Code

```
# Normalize spacing again after removal
desc_clean <- gsub("\\s+", " ", desc_clean)
desc_clean <- trimws(desc_clean)

# Remove adjectives
if ("tag" %in% names(pos_data) && nrow(pos_data) > 0) {
  pos_data <- pos_data[pos_data$tag != "JJ", ]
}

# Final description
truncated_text <- paste(pos_data$token, collapse = " ")
matched_action2 <- gsub("!", "", matched_action)
raw_description <- paste(matched_action2, truncated_text)
cleaned_description <- remove_hanging_punctuation(raw_description)
modified_description <- capitalize_words(cleaned_description)
```

Testing Data Sets

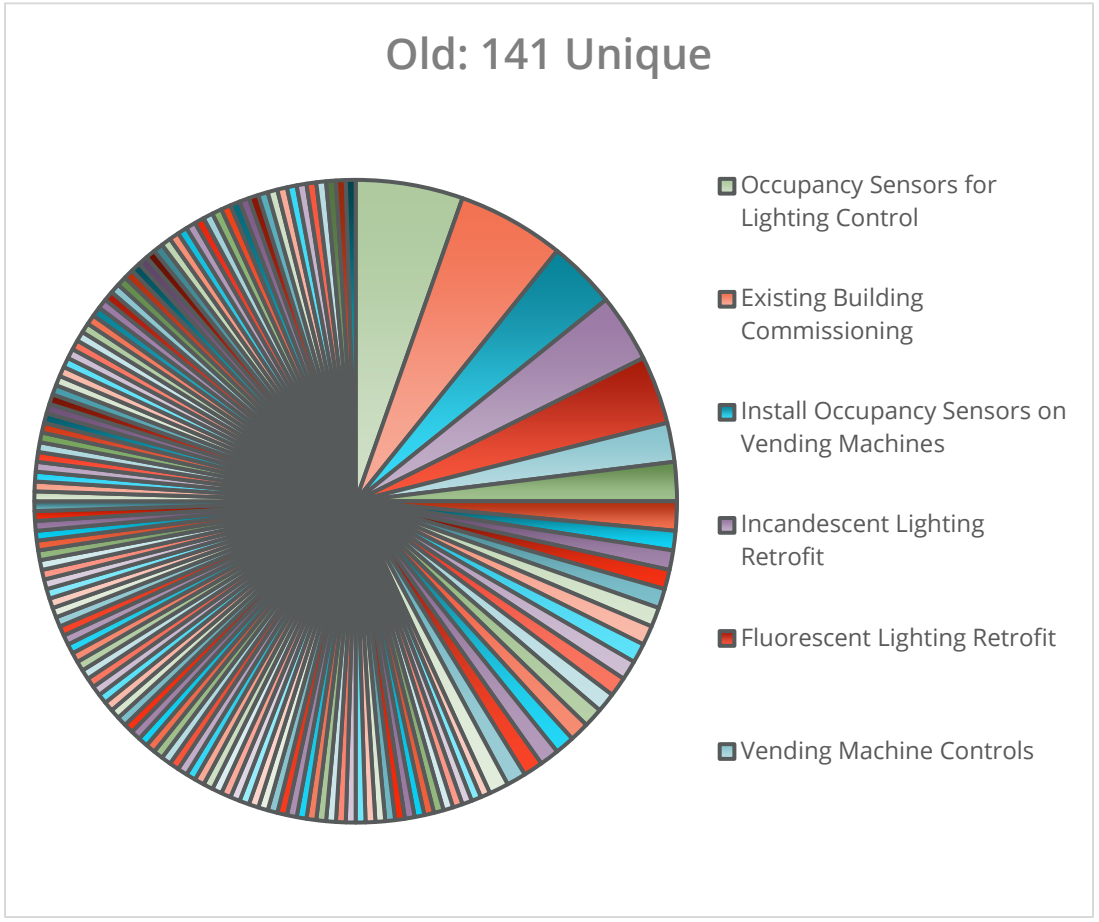
Segment	Terms	Unique Terms	Ratio
Laboratories	204	141	69%
Hospitals	611	480	79%
Full data set	2141	1436	67%

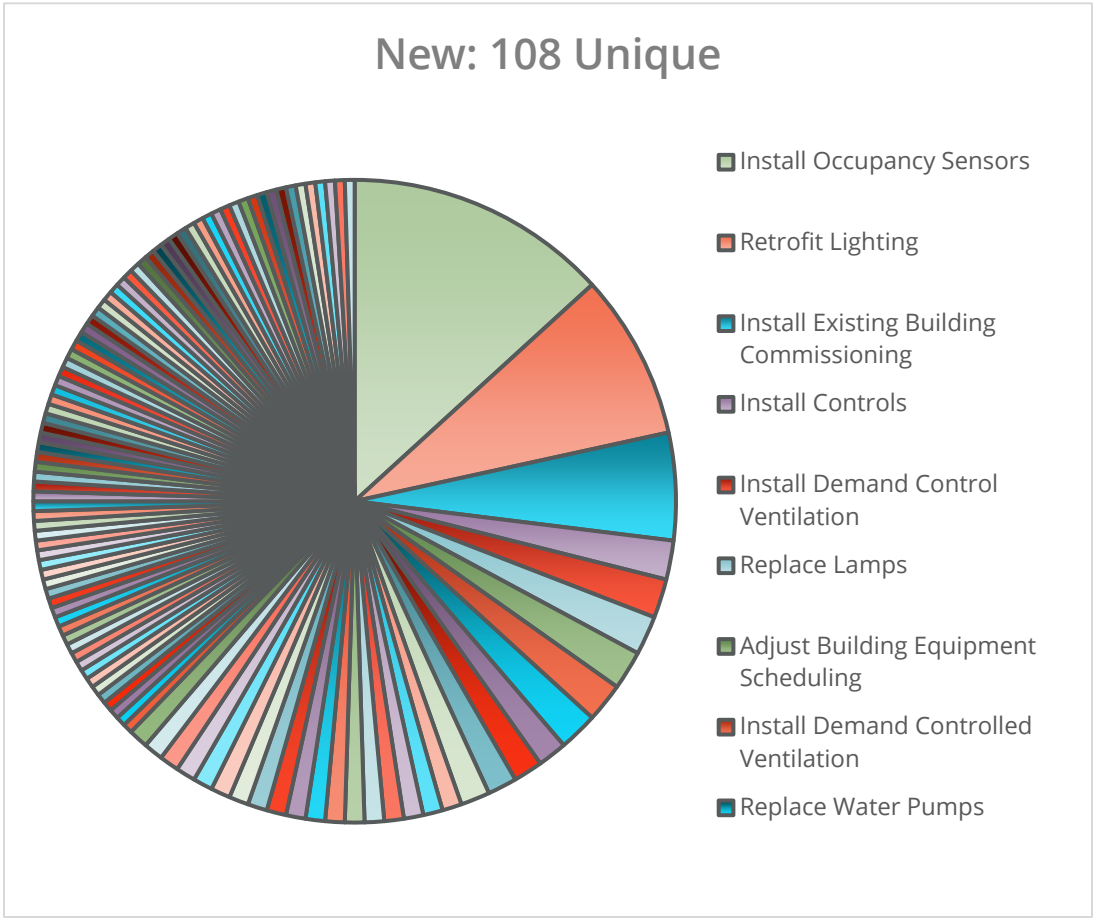
Testing Metrics

1. Before/After Description Distribution
2. System Categorization
3. Action Categorization
4. Uncertainty

03 Results

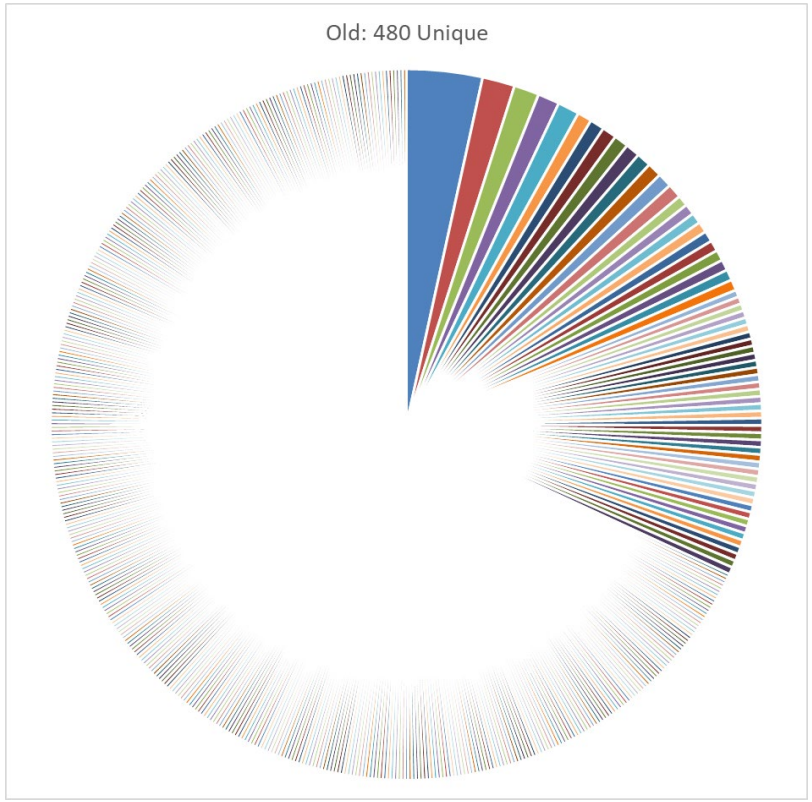
Laboratory Test Set - Unique Terms

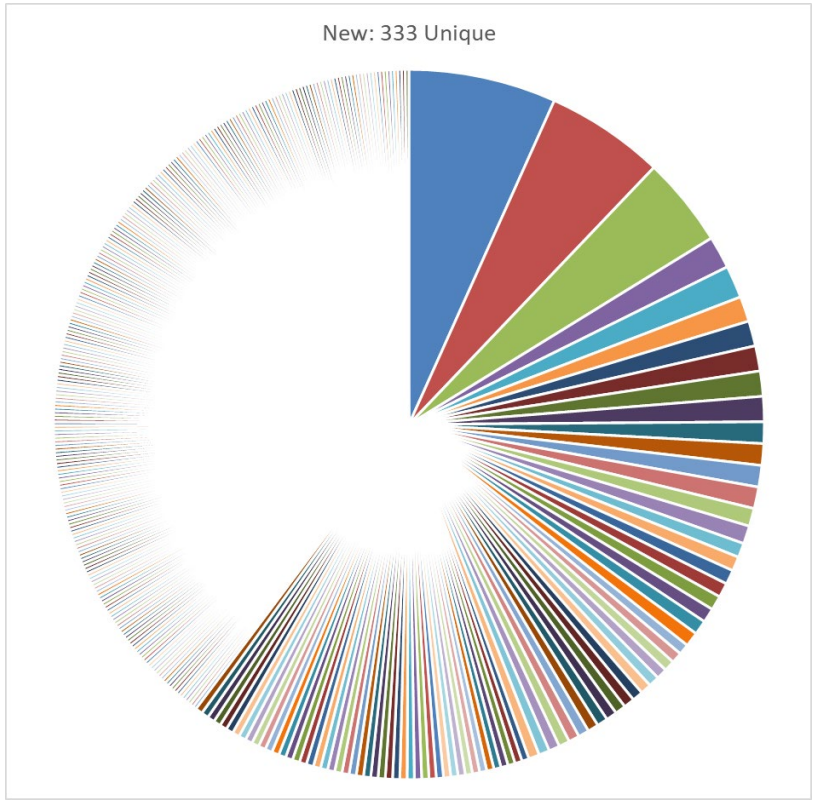




Hospital Test Set - Unique Terms

ORIGINAL LIST	REVISED LIST





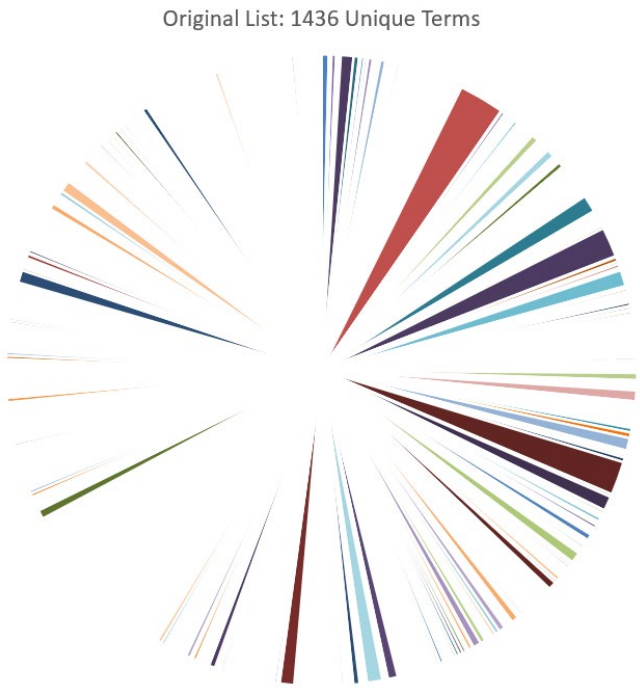
Hospital Top Measures after First Pass

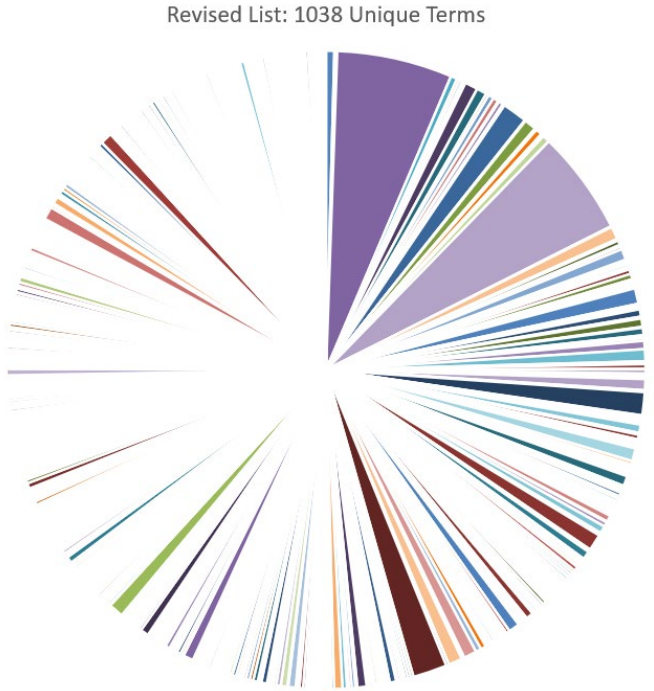
Lighting Retrofits	21	Install Occupancy Sensors	41
Occupancy Sensors for Lighting Control	9	Retrofit Lighting	33
Variable Kitchen Exhaust	7	Replace Ahu	25
Install Occupancy Sensors on Vending Machines	6	Install Ahu	9
LED Exit Sign Retrofit	6	Install Heat Recovery	9
Radiant Heating with Setbacks	4	Replace Chiller	7
Supply Air Temperature Reset	4	Install Vfds	7
Refine Building Equipment Scheduling	4	Install Vfd	7
Reset Chilled Water Temperature	4	Install Exhaust	7
Vending Machine Occupancy Sensors	4	Replace Vav	7
Reset Condenser Water Temperature	4	Retrofit Ahu	6
Occupancy Sensors for Lighting Control - Corridors and Large Rooms	4	Adjust Water Temperature	6
Occupancy Sensors for Lighting Control - Private Offices	4	Adjust Condenser Water Temperature	6
Variable Kitchen Exhaust and Make-Up	4	Retrofit Led Exit Sign	6
Add Heat Pump Water Heater to Existing Domestic Water Heater	3	Install Heating	5
Install COâ,, Sensors to Vary Outside Air Flow	3	Replace Water Pumps	5
Fluorescent Lighting Retrofit	3	Replace Lighting	4
Steam Boiler Control Upgrades	3	Retrofit Parking Lot Lighting	4
Stairwell Lighting Upgrade	3	Adjust Air Temperature	4
Wall Pack Replacement	3	Adjust Building Equipment Scheduling	4
Bi-Level Stairwell Lighting	3	Install Cooling Tower Fans	4
Variable Primary CHW Flow	3	Replace % Oa Cav Ahu Ahu	4

- Occupancy sensors were consolidated to good effect
- The description of where the sensors are should be a sub-description
- Lighting retrofits also collected but moved down to second position
- Still a few hallucinations “Install Cooling Tower Fans”

Full List Test Set - Unique Terms

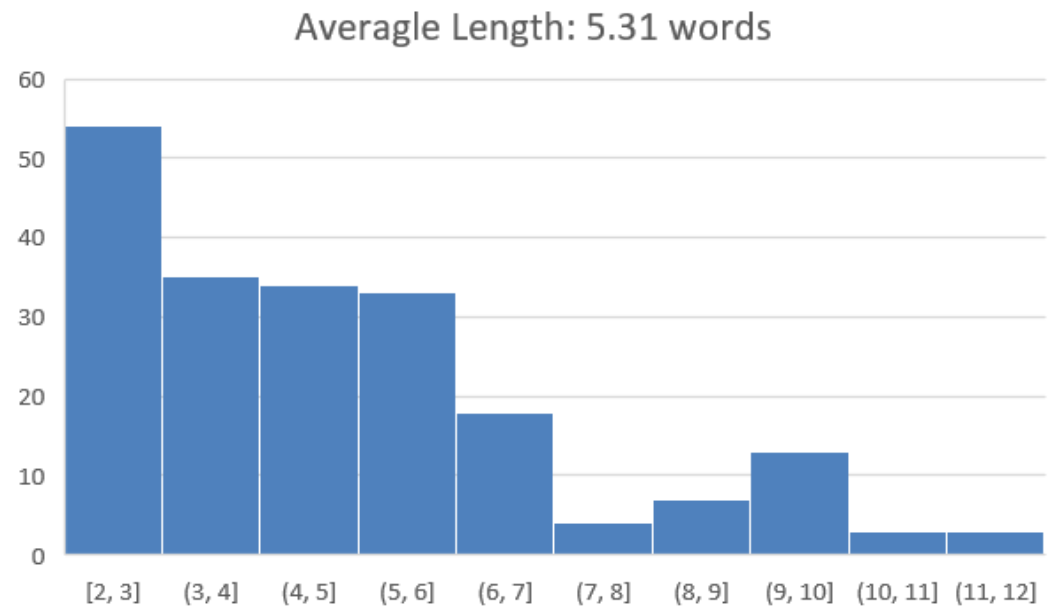
ORIGINAL LIST	REVISED LIST

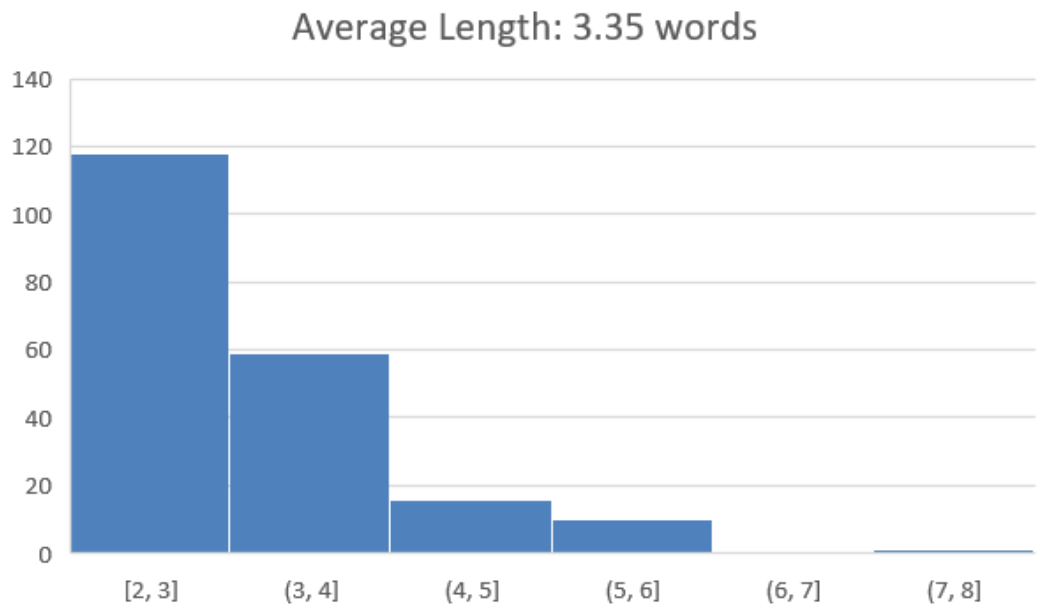




Laboratory Test Set – Description Length

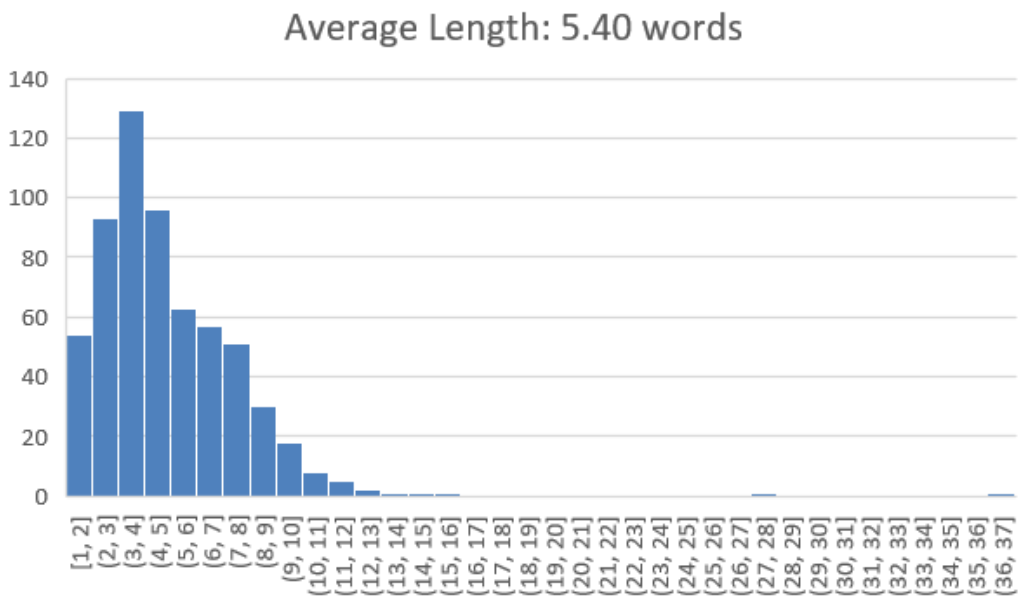
ORIGINAL LIST	REVISED LIST

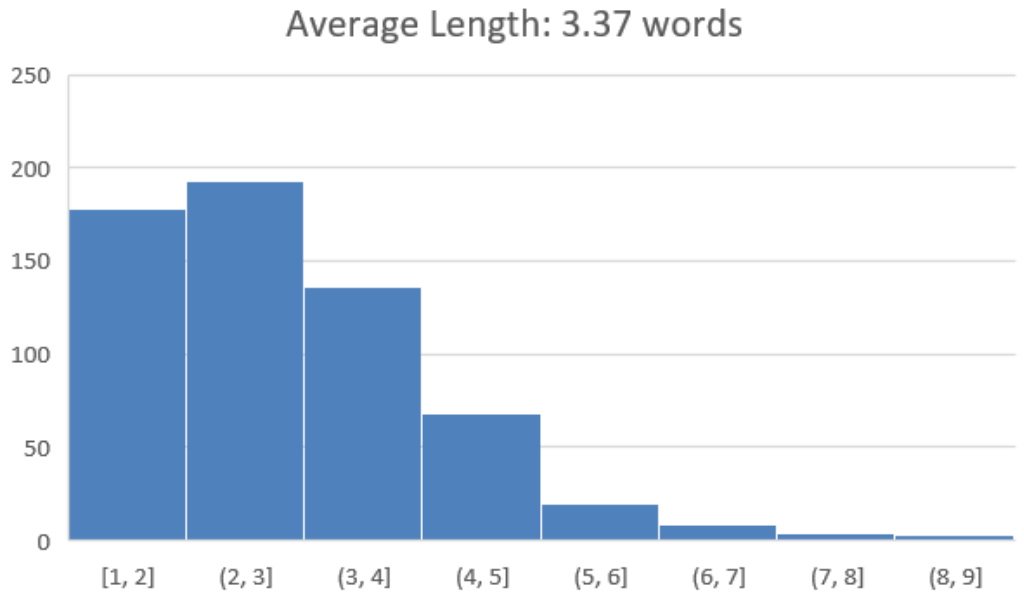




Hospital Test Set – Description Length

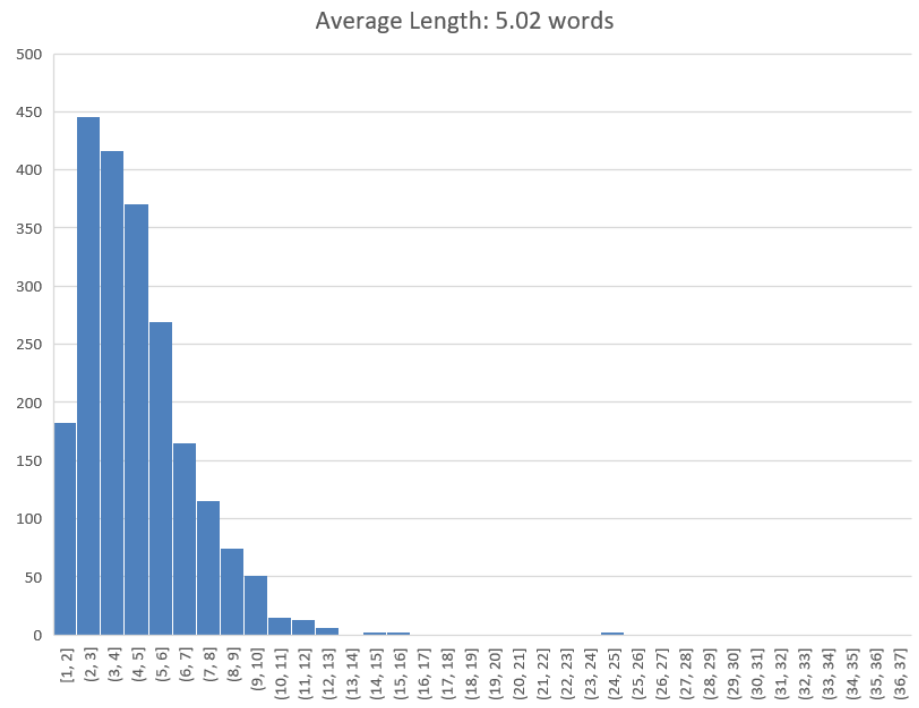
ORIGINAL LIST	REVISED LIST

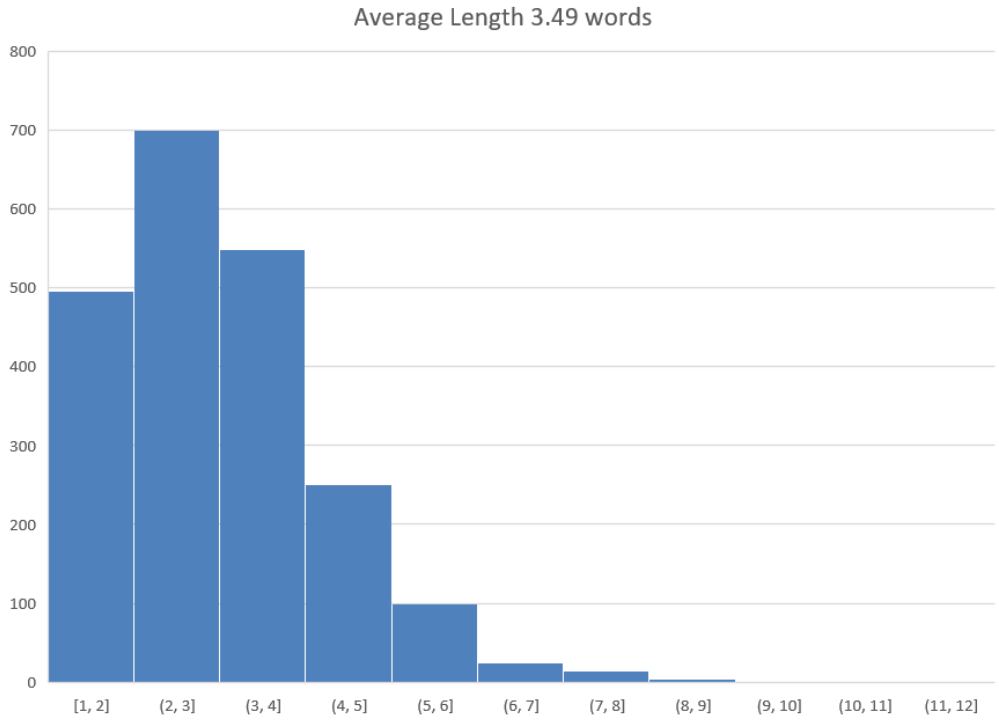




Full List Test Set – Description Length

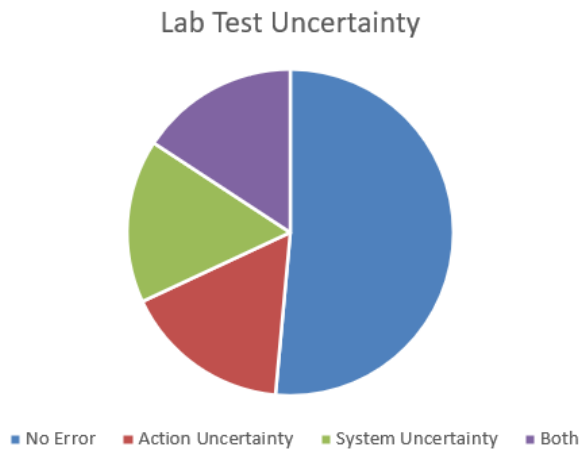
ORIGINAL LIST	REVISED LIST

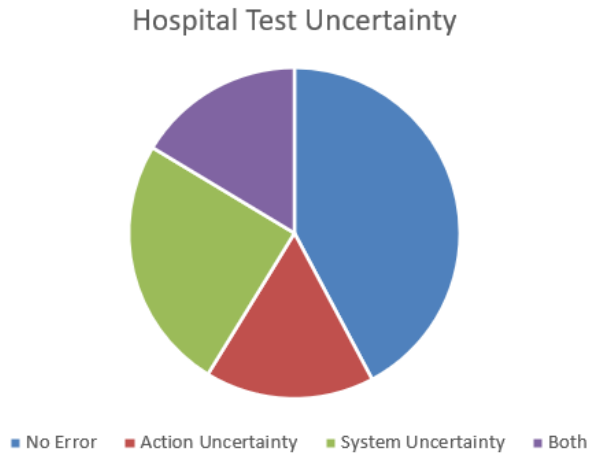


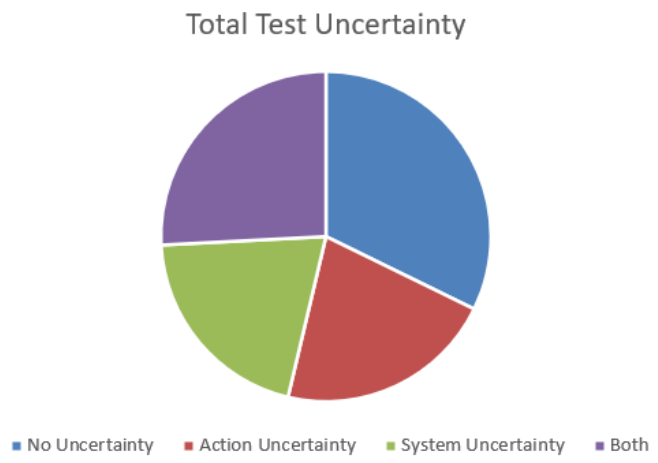


Uncertainty

LABORATORY	HOSPITAL	FULL LIST
No Error: 51% Action Default: 17% System Uncertainty: 16% Both Action and System Uncertainty: 16%	No Error: 42% Action Default: 17% System Uncertainty: 24% Both Action and System Uncertainty: 16%	No Error: 32% Action Default: 21% System Uncertainty: 20% Both Action and System Uncertainty: 25%





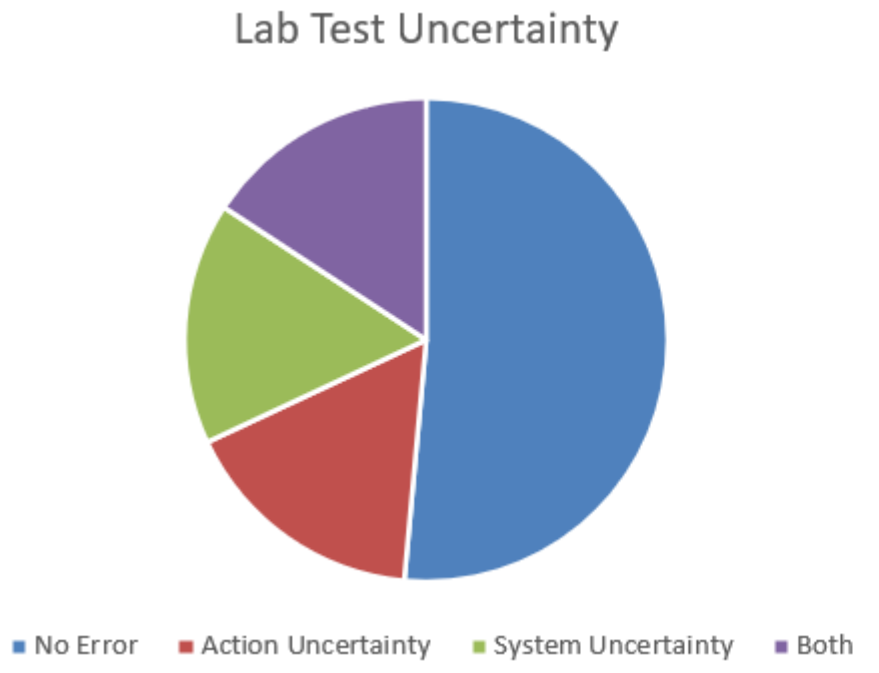


04 Discussion

Examining Error

Manually combing through the smallest test set reveals much smaller margins of error

- Of 40 defaulted actions, only 16 did not make sense for a given measure
- Of 39 flagged dual system matches, only 6 were mischaracterized
- Of 203 total descriptions, only 10 had grammatical errors



Pros/Cons

PROS	CONS
• Most effective on smaller datasets • More finely tuned and less variance in naming • Shortens long descriptions – far more succinct	• Still too many descriptions to provide typical list • Some descriptions may misinterpret original description • Liberally flags uncertainty • Requires Manual Cleaning

Recommendations

This program is useful for sorting and standardizing measure names but less useful for determining a set list of measures

A set list of measures could be discerned by filtering measures by system and picking out the most common actions and equipment

Manually clean any list before implementing officially

This program ensures uniformity and consistency but sacrifices certainty in favor of avoiding gross mischaracterization that may be harder to find down the line

To most accurately characterize the full list, run more smaller tests for specialized building groups

Larger sets sacrifice accuracy due to less specific training

Recommendations

- Use shortened descriptions as a prefix to prescribed measures to provide both specific recommendations to the client as well as typical naming
  - This program could then easily sort any name into concise groups
- Retrofit controls: modify controls for labs with (mfgX) Air Valves

Generated Description	Original Description
Retrofit Controls	Modify controls for labs with (mfgX) Air Valves
Replace Heat Recovery Loop	Convert heat recovery loop to variable volume pumping
Install Occupancy Sensors	Occupancy sensors in offices and common areas

Thank You & Questions

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