Development and validation of statistical models for occupancy detection in an office

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NEED4B
New Energy Efficient Demonstration for Buildings

Why occupancy detection in Buildings?

- **ENERGY SAVINGS**

  30 to 42% energy savings with appropriate management of Heating, Ventilation and Air Conditioning Systems HVAC with occupancy detection (Dong et al, 2009; Erickson et al, 2011)

- **Security**
- **Occupant behavior**

Typical approach for Sensing Occupancy

Passive Infrared Sensor (PIR)

Estimated Accuracy ≈ 97-98%

Sensor may be triggered by air currents or fail to detect presence when occupant does not move.

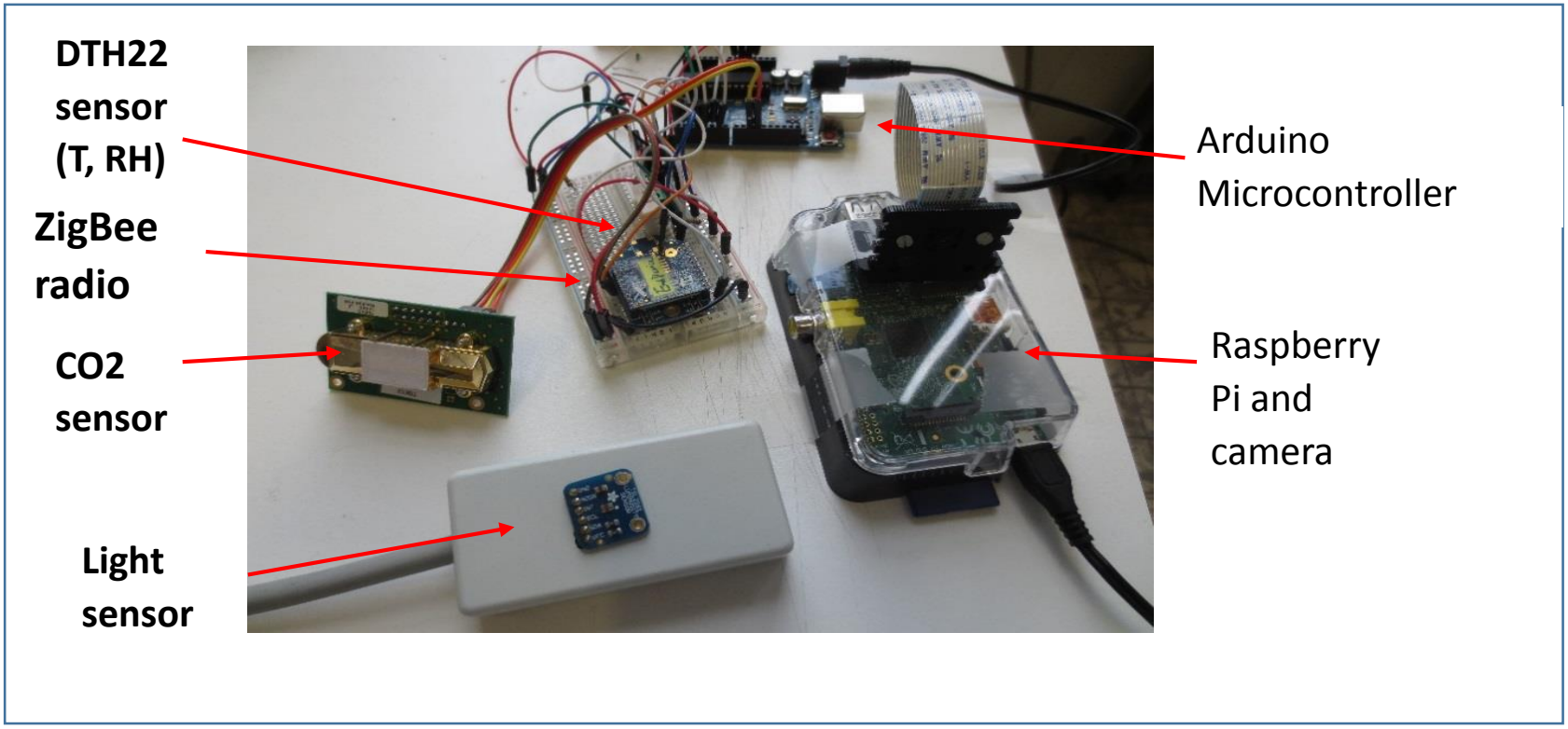
Digital Cameras

Privacy concerns

Alternative Solution (to use the already installed sensors)

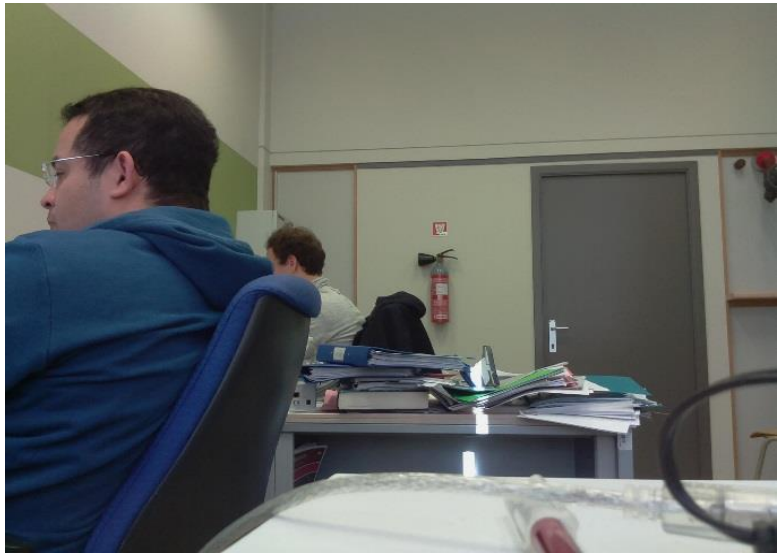
- Many HVAC monitoring systems already measure :
  - Temperature
  - Humidity + calculated humidity Ratio f(T,RH,pressure)
  - CO_2
  - Light

Experimental data collection



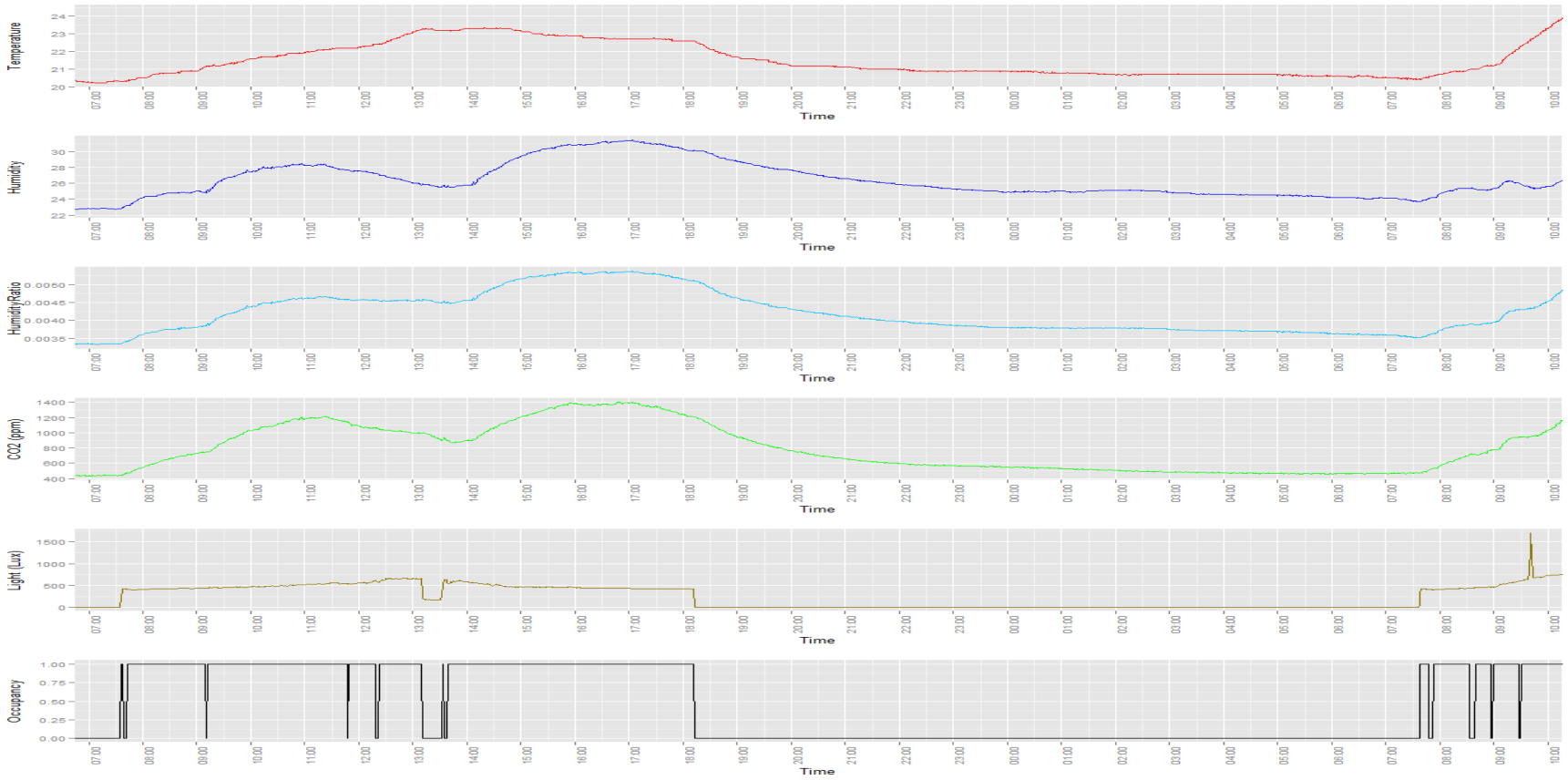
Location of the sensors

5.85m x 3.50m x 3.53 m

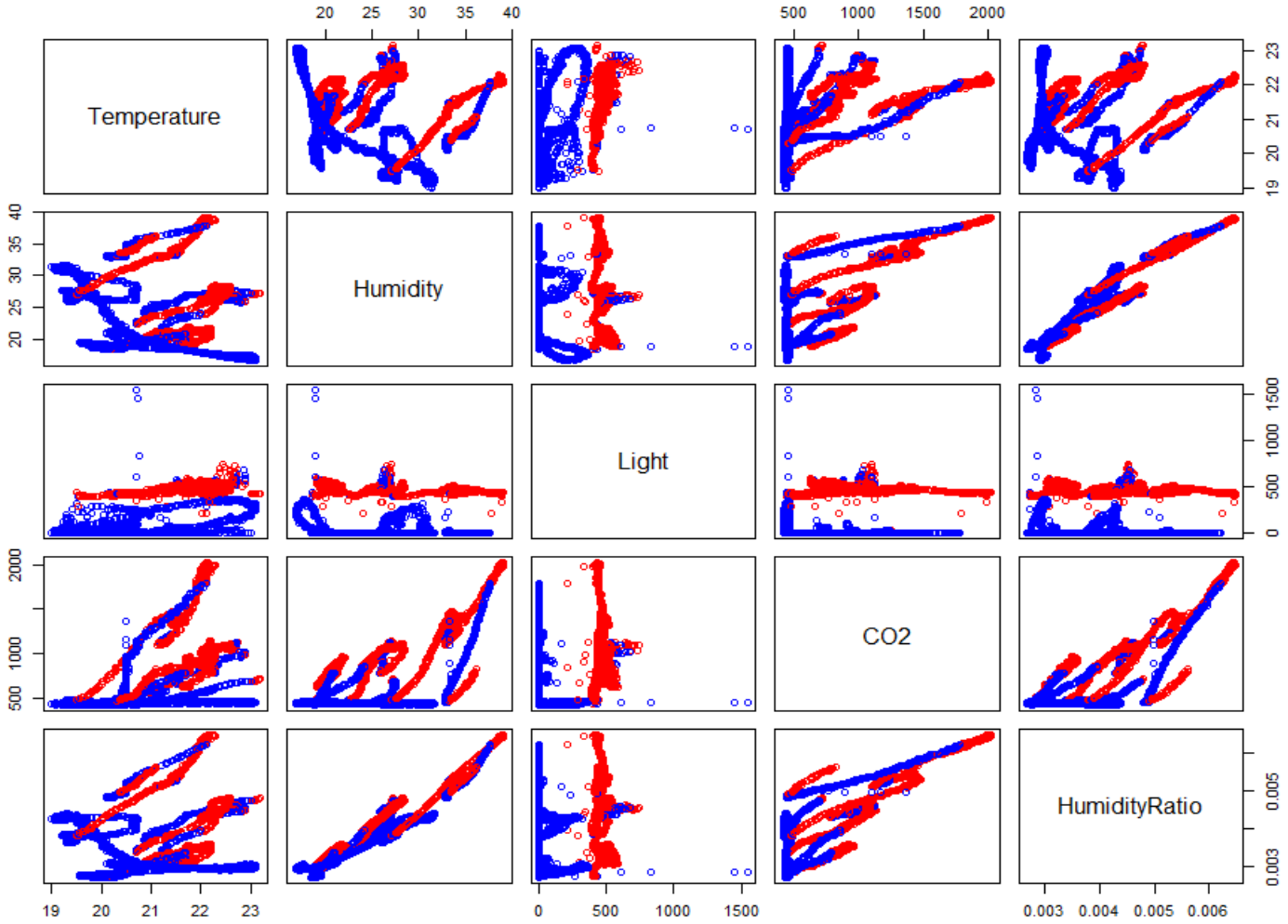


Sample of 1 picture manually tagged

1 Day Profiles



Pairs Plot. Some Show Good Separation Status!



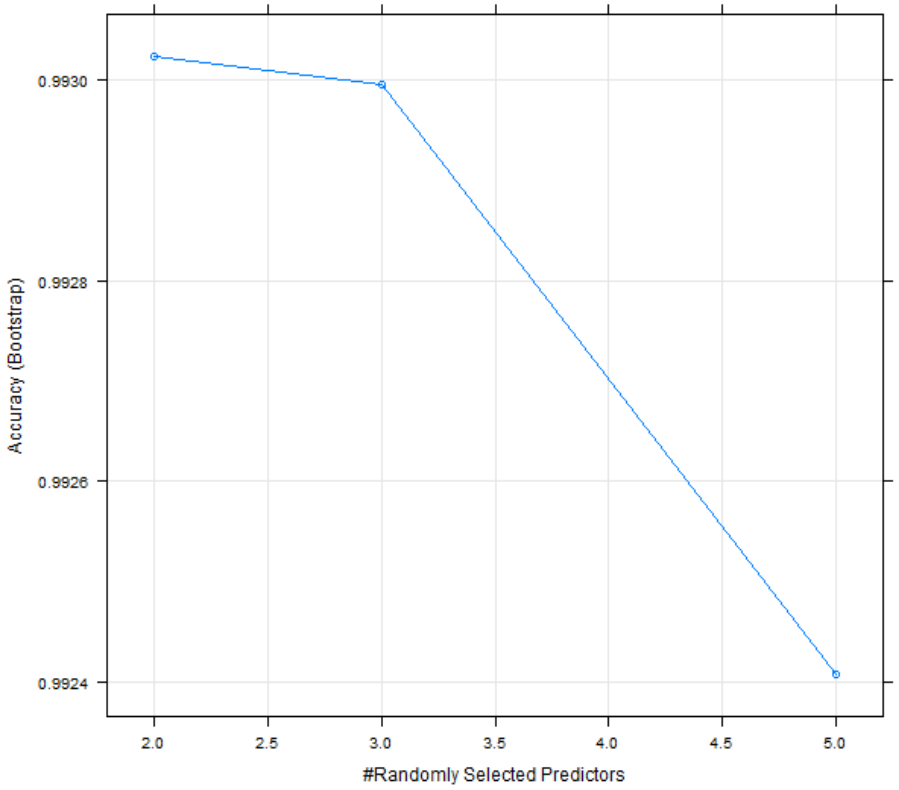
3 Data Sets

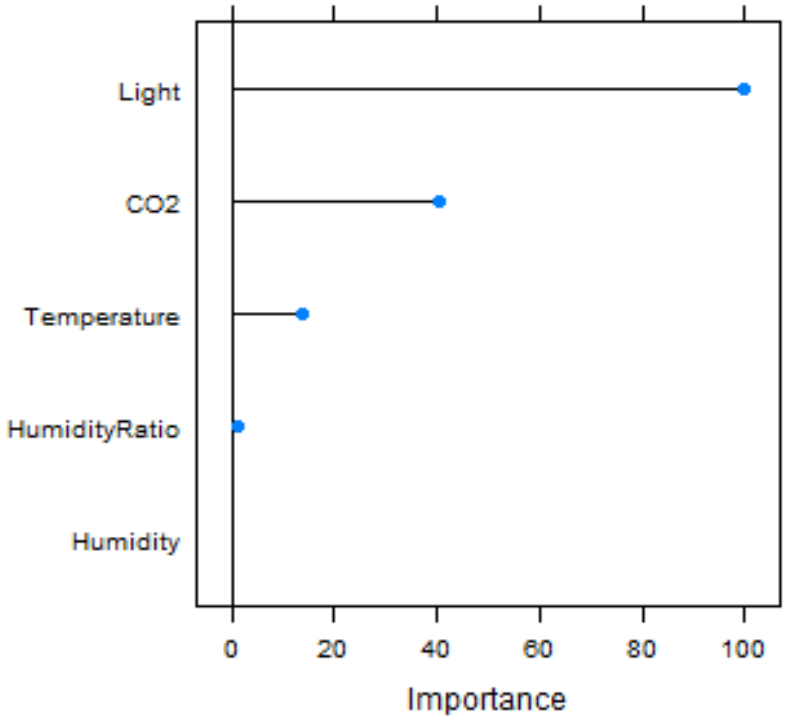
Data set	Number of Observations	Comment
Training	8143 of 7 variables	Measurements taken mostly with the door closed during occupied status
Testing 1	2665 of 7 variables	Measurements taken mostly with the door closed during occupied status
Testing 2	9752 of 7 variables	Measurements taken mostly with the door open during occupied status

Trained models with CART, Random Forests, GBM and LDA

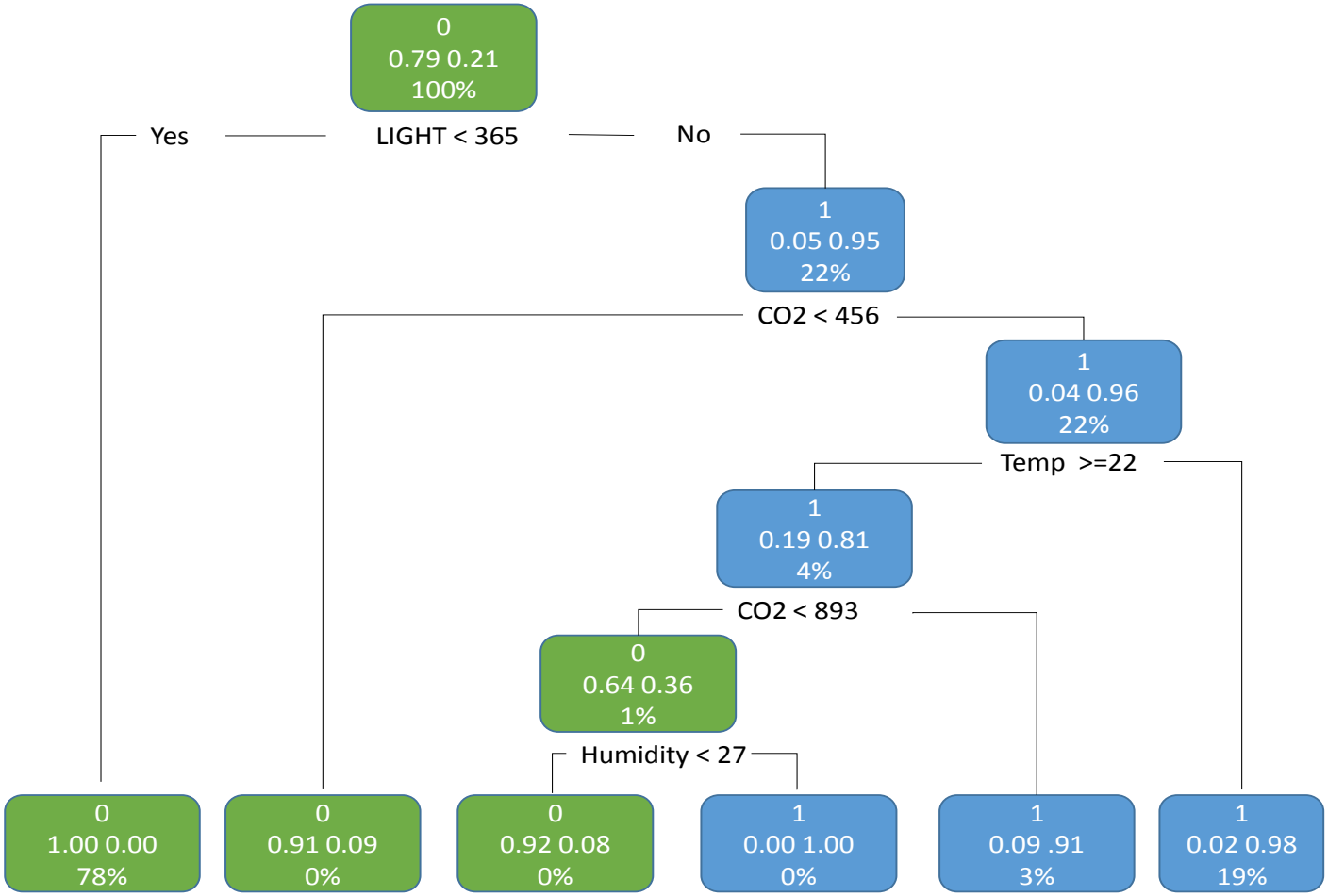
Model	Parameters	Accuracy Training	Accuracy	
			Testing 1	Testing 2
Random Forest	T, φ, Light,CO_2,W	100.00%	95.05%	97.16%
GBM	T, φ, Light,CO_2,W	99.62%	94.26%	95.44%
CART	T, φ, Light,CO_2,W	99.30%	95.57%	96.47%
LDA	T, φ, Light,CO_2,W	98.80%	97.90%	98.76%
Random Forest	T, φ, CO_2, W	99.98%	69.31%	32.68%
GBM	T, φ, CO_2, W	97.80%	87.35%	46.02%
CART	T, φ, CO_2, W	93.05%	84.65%	78.96%
LDA	T, φ, CO_2, W	91.91%	85.33%	73.77%

Model	Parameters	Accuracy Training	Accuracy	
			Testing 1	Testing 2
Random Forest	φ, Light	99.96%	92.35%	94.36%
GBM	φ, Light	99.21%	94.71%	99.01%
CART	φ, Light	98.86%	97.86%	99.31%
LDA	φ, Light	96.78%	97.78%	97.79%
Random Forest	Light, CO_2	99.95%	92.61%	97.41%
GBM	Light, CO_2	99.14%	94.26%	98.81%
CART	Light, CO_2	98.89%	97.82%	99.31%
LDA	Light, CO_2	97.53%	97.86%	97.86%


0.9930
0.9928
0.9926
0.9924
Accuracy (Bootstrap)
2.0
2.5
3.0
3.5
4.0
4.5
5.0
#Randomly Selected Predictors


Light
CO2
Temperature
HumidityRatio
Humidity
0
20
40
60
80
100
Importance

CART Model


0
0.79 0.21
100%
Yes
LIGHT < 365
No
1
0.05 0.95
22%
CO2 < 456
1
0.04 0.96
22%
Temp >=22
1
0.19 0.81
4%
CO2 < 893
0
0.64 0.36
1%
Humidity < 27
0
1.00 0.00
78%
0
0.91 0.09
0%
0
0.92 0.08
0%
1
0.00 1.00
0%
1
0.09 .91
3%
1
0.02 0.98
19%

Conclusions

- High Accuracies with CART, LDA and Random Forest (95-99%)
- Using all the predictors can reduce Random Forest Performance
- Light is an important parameter to measure
- The following Variable Pairs predict the occupancy accurately
  - Temperature and Light – LDA (97.9-97.79%) test sets
  - Light and CO2 - LDA (97.86%)
  - Light and Humidity - LDA (97.78%)
- A light sensor costs around $6

Acknowledgments

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