Natural Comfort is an early stage tool that provides design guidance for improving comfort in passive, naturally ventilated commercial buildings in warm and hot climates. It provides an estimate and precision intervals for the fraction of occupied hours that a building will be uncomfortable. A result of 0 means never uncomfortable, while 1 means always uncomfortable. A building is represented by 38 input parameters. The estimate is made by a support vector regression (SVR) metamodel fit to ~50,000 EnergyPlus simulations. The development, technical details, performance, and applications of the model that Natural Comfort implements can be found in Rackes, Melo, and Lamberts, "Naturally comfortable and sustainable: informed design guidance and performance labeling for passive commercial buildings in hot climates," *Applied Energy*, 2016.

Natural Comfort is appropriate for small to medium commercial buildings in climates that have little to no heating demand during the day. Commercial buildings without central heating systems should be good candidates. If your building is in a climate cold enough that it has central heating, the model is not appropriate. This criterion generally encompasses commercial buildings in the tropics, and up to perhaps 30° latitude or even higher in many parts of the world. As for the building itself, it should have a rectangular form, not exceed 16 m in height, and have windows available to all occupied spaces.

The program is implemented as a Python routine. The following sections explain how to execute the program, describe formatting and acquisition of inputs, detail the definitions and allowable ranges of all inputs, and give some advice for input value selection and which parameters are likely to be most influential.

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Running the program

The Natural Comfort program is a Python routine that reads in inputs from an input CSV file and writes outputs to an output CSV file. The Python routine also accesses a CSV of support

vectors and coefficients. The program was developed in Python 2.7, and is written in plain Python (i.e., it does not require NumPy or Pandas). The program can be run from an interactive Python environment, or can be called from the command line in Linux, Macintosh, or Windows operating systems (that have Python installed). If the program is called without arguments, it will assume by default that an input file called inputData.csv and a parameters file called svm_parameters.csv both exist in the current directory, and will write to a file called outputData.csv also in the current directory:

```
usr$ python comfort.py
Reading from inputData.csv

Percent of occupied hours exceeding upper limit of ASHRAE 55-2013 adaptive comfort zone for
80% acceptability:
# [estimate, p_2_5, p_15_9, p_84_1, p_97_5]
1 [84.4, 66.8, 77.9, 89.2, 93.9]
2 [83.3, 65.0, 76.6, 88.4, 93.3]
3 [54.2, 30.9, 43.9, 64.1, 75.8]
4 [4.3, 1.1, 2.6, 6.7, 11.6]
Completed and written to outputData.csv. Total time: 3.69 s
```

Other paths and filenames can be passed as three optional arguments. The first is the name/path of the input file (default: inputData.csv). The second argument is the name/path of the output file (default: outputData.csv). The third argument is the name/path of the SVR parameters file (default: svm_parameters.csv). This parameters file should not be changed, but a path can be provided if desired so it does not have to be in the execution directory. These arguments allow the user to read, write, and store the parameters and comfort.py anywhere, even in four separate directories, rather than having to copy and paste the code. For example:

```
usr$ python comfort.py myInputDir/myInputData.csv myOutputDir/myOutputData.csv
myParamDir/svm_parameters.csv

Reading from myInputDir/myInputData.csv
Percent of occupied hours exceeding upper limit of ASHRAE 55-2013 adaptive comfort zone for
80% acceptability:
# [estimate, p_2_5, p_15_9, p_84_1, p_97_5]
1 [84.4, 66.8, 77.9, 89.2, 93.9]
2 [83.3, 65.0, 76.6, 88.4, 93.3]
3 [54.2, 30.9, 43.9, 64.1, 75.8]
4 [4.3, 1.1, 2.6, 6.7, 11.6]
Completed and written to myOutputDir/myOutputData.csv. Total time: 3.66 s
```

(For paths and files that have spaces, use quotes, e.g. `python comfort.py "my Input Directory/my input file.csv"`.)

Outputs

The program outputs the hot exceedance hour fraction (EHF_{hot} in the paper), or the fraction of occupied hours that exceed the ASHRAE 55-2013 80% acceptability comfort zone upper limit. The screen output gives these fractions as percentages, but they are written as decimal fractions to the output CSV. For each input row (each building), there is one output row with five

values. The first output ("estimate") is the best estimate from the SVR model. The remaining four are percentiles of the predictive distribution based on error characterization of the SVR model. They are the 2.5th, 15.9th, 84.1st, and 97.5th percentiles of the predictive distribution. The 2.5th and 97.5th percentiles bound the 95% precision interval, or the interval within which the true value should fall 95% of the time. The 15.9th and 84.1st percentiles bound the precision interval that corresponds to plus-or-minus one normal standard deviation.

Inputs and input file

The input file is a CSV with 38 columns and as many rows as desired, plus a header row. Each row represents a building—a parameter combination—that will be simulated. The header rows have required names that cannot be changed, and the order of the columns cannot be changed. An example input file, exampleInputData, is provided. (Running it should produce the output shown in the two command line boxes above.) The file inputData_template includes just the headers and basic instructions. You can copy the template file, rename it with desired input file name, and fill in your input information starting below the headers.

Methods for getting weather inputs

The first nine inputs are weather inputs. These can be input manually if desired when specific data are available. Alternatively, a file called climateInputsForBrazil.csv is included in the download package and has the required data for 428 locations in Brazil. These data were derived from all EnergyPlus EPW files available for Brazil at http://climate.onebuilding.org (versions downloaded November 24, 2015).

For other countries or future weather files, we also provide a third way to calculate weather inputs via a Python routine called calcWeatherInputs.py that reads an EnergyPlus EPW file, and outputs the required values to the screen. The only argument is the EPW file path:

```
usr$ python calcWeatherInputs.py "/Applications/EnergyPlus-8-3-0/WeatherData/BRA_AL_Maceio-
Palmares.Intl.AP.829930_TRY.1962.epw"

Maceio-Palmares Intl AP at latitude -9.52 and longitude -35.78
Tout ToutDailyVar ToutAnnualVar CDD18 CDD25 radDirNorm radDiffHoriz windSpeedMet  elevation
24.2476    8.2534    6.65    2282.0417    378.375    183.8023    98.6026    2.0489     115.0
```

These data can be copied to the input CSV file. If you are working with multiple files, there is also a routine (readAndWriteMultipleFiles) defined in calcWeatherInputs.py that will accept a directory, find all files with .epw extensions in the directory and nested folders, summarize their weather data, and save all the needed inputs to a single CSV file. This routine must be called in a Python workspace or by another script. See documentation in calcWeatherInputs.py for usage and details.

Below individual inputs are described in more detail.

Weather inputs

1. Tout

Average annual temperature.

Min: 10 °C
Max: 30 °C
Default: 23 °C

2. ToutDailyVar

Calculate the difference between a day's maximum temperature and its minimum temperature for every day of the year. This is the average of those 365 values.

Min: 3 °C
Max: 15 °C
Default: 9.2 °C

3. ToutAnnualVar

Calculate the 365 average daily temperatures. This is the difference between the maximum and the minimum of those 365 values.

Min: 3 °C
Max: 28 °C
Default: 11.9 °C

4. CDD18

Cooling degree days with base 18 °C balance temperature.

Min: 0 K·days
Max: 3800 K·days
Default: 2100 K·days

5. CDD25

Cooling degree days with base 25 °C balance temperature.

Min: 0 K·days
Max: 1600 K·days
Default: 440 K·days

6. radDirNorm

Average annual direct normal solar radiation.

Min: 40 W/m^2
Max: 200 W/m^2
Default: 110 W/m^2

7. radDiffHoriz

Average annual diffuse horizontal solar radiation.

Min: 70 W/m^2
Max: 130 W/m^2
Default: 100 W/m^2

8. windSpeedMet

Average annual wind speed at the meteorological station. This speed will later be corrected for regional terrain effects and for local site sheltering.

Min: 0 m/s
Max: 50 m/s
Default: 2 m/s

9. elevation

Elevation above sea level.

Min: 0 m
Max: 3000 m
Default: 350 m

Building dimension inputs

10. bldgLength

The length of the building, which should be the longer of its two plan dimensions.

Min: 13 m
Max: 200 m
Default: 50 m

11. bldgDepth

The depth of the building, which should be the shorter of its two plan dimensions.

Min: 8 m
Max: 50 m
Default: 30 m

12. floorHeight

The floor-to-floor height. This variable times Nfloors must not yield a building height greater than 16 m.

Min: 2.75 m
Max: 4.25 m
Default: 3.50 m

13. Nfloors

The number of floors (stories). This variable times floorHeight must yield a building height greater than 16 m.

Min: 1
Max: 5
Default: 1

14. roomSize

The average occupied room floor area.

Min: 9 m^2
Max: 400 m^2
Default: 25 m^2

15. stairFracFPA

The fraction of the total building footprint area that is taken up by stairwells. For example, a 20 m by 40 m building with two 3 m by 4 m stairways would have a stairFracFPA of $(2 \times 12\ m^2) / 800\ m^2 = 0.03$. The number of stories does not affect this fraction. The value is error-checked and required to be zero for single story buildings. There is no requirement for it to be greater than zero for multistory buildings, but there were no multistory buildings without staircases in the simulation dataset to which the SVR model was fit.

Min: 0
Max: 0.28
Default: 0

16. WWR

The building's window-to-wall ratio.

Min: 0.05
Max: 0.70
Default: 0.25

17. shadingAngle

The shading angle measured from the vertical wall. A value of 0° means no shading, while 45° means the shade depth equals its height above the base of the window. (It is the complement of the "vertical shadow angle" measured from the horizontal).

Min: 0°
Max: 45°
Default: 0°

Construction inputs

18. extWallAbs

Solar absorptance of exterior walls.

Min: 0.2
Max: 0.8
Default: 0.5

19. extWallU

Overall thermal transmittance or *U*-value of exterior walls.

Min: 0.1 $W/m^2 \cdot K$
Max: 5.0 $W/m^2 \cdot K$
Default: 1.8 $W/m^2 \cdot K$

20. extWallCT

Area-normalized thermal capacity or thermal mass of exterior walls.

Min: 40 $kJ/m^2 \cdot K$
Max: 500 $kJ/m^2 \cdot K$
Default: 270 $kJ/m^2 \cdot K$

21. roofAbs

Solar absorptance of the roof.

Min: 0.2
Max: 0.8
Default: 0.5

22. roofU

Overall thermal transmittance or *U*-value of the roof.

Min: 0.1 $W/m^2 \cdot K$
Max: 5.0 $W/m^2 \cdot K$
Default: 1.8 $W/m^2 \cdot K$

23. roofCT

Area-normalized thermal capacity or thermal mass of the roof.

Min: 10 $kJ/m^2 \cdot K$
Max: 400 $kJ/m^2 \cdot K$
Default: 200 $kJ/m^2 \cdot K$

24. SHGC

Solar heat gain coefficient of the windows.

Min: 0.2
Max: 0.8
Default: 0.5

25. windowU

Thermal transmittance or *U*-value of the windows.

Min: 1.0 $W/m^2 \cdot K$
Max: 6.0 $W/m^2 \cdot K$
Default: 3.5 $W/m^2 \cdot K$

Internal gain inputs

26. roomELPD

Combined equipment and lighting power density for occupied rooms.

Min: 1 W/m^2
Max: 25 W/m^2
Default: 13 W/m^2

27. publicELPD

Combined equipment and lighting power density for public spaces like corridors and stairwells.

Min: 1 W/m^2
Max: 15 W/m^2
Default: 8 W/m^2

28. occDensity

The number of occupants per m^2. Only include occupied spaces, i.e., do not divide the number of occupants by the whole building area. Typical values for offices range from about 0.02 to 0.10 occupants per m^2, while for schools a default density of 0.35 occ/m^2 is given by ASHRAE 62.1-2013.

Min: 0.01 occ/m^2
Max: 1.00 occ/m^2
Default: 0.35 occ/m^2

29. dayStart

The day starting hour.

Min: 6 (6:00 a.m.)
Max: 10 (10:00 a.m.)
Default: 8 (8:00 a.m.)

30. dayEnd

The day ending hour.

Min: 14 (2:00 p.m.)
Max: 22 (10:00 p.m.)
Default: 18 (6:00 p.m.)

Ventilation inputs

31. windAlpha

A correction factor for wind speeds measured at remote meteorological states, using boundary layer theory to account for regional terrain roughness. See table at end of this document for recommended values.

Min: 0.10

Max: 0.40
Default: 0.22

32. averageShelter

A correction factor for local sheltering obstacles. This should be the average value for the building taking into account all directions. A value of 1 means no shelter, while 0 means complete shelter. See table at end of this document for recommended values.

Min: 0.3
Max: 1
Default: 0.8

33. windowMaxOpenFrac

The maximum fraction that windows can open, which would be roughly 0.5 for double-hung windows or sliders, and approximately 1 for casement or awning windows. Alternatively, the total area of openings in the façade when all windows are as fully open as possible, divided by area of glazing.

Min: 0.2
Max: 1.0
Default: 0.6

34. NVW_WWR

The WWR of night ventilation windows, or windows that are intended to be left open 24 hours a day (without security, water, or pest concerns). This value cannot exceed the total WWR (see Building dimension inputs).

Min: 0
Max: 0.17
Default: 0

35. PW_width2height

The width of primary windows (the typical windows that account for most of the glazing in the building) divided by their height. Greater than unity for wide strip windows, less than unity for tall, thin windows.

Min: 0.1
Max: 50
Default: 3

36. PW_Cd

Discharge coefficient for primary windows. The default value is typical.

Min: 0.4
Max: 0.8
Default: 0.6

37. interiorELAperLen

The effective leakage area (ELA) between occupied rooms and public spaces like corridors, per length of shared wall. See table at the end of this document for representative values.

Min: 0.0001
Max: 0.4
Default: 0.01

38. ceilFanAirSpeedDelta

The air speed enhancement above 0.3 m/s (still air) provided by ceiling (or wall-mounted) fans. In other words, the air speed expected to be produced by fans, minus 0.3 m/s. ASHRAE 55-2013 allows comfort zone upper limit extensions for elevated air speeds from 0.6 to 1.2 m/s; these would correspond to ceilFanAirSpeedDelta values of 0.3 and 0.9 m/s respectively.

Min: 0 m/s
Max: 0.9 m/s
Default: 0 m/s

Selected input guidance

windAlpha (31) and averageShelter (32)

Recommended values for the terrain modifier windAlpha, for large local or regional terrain adjustments, and for the shelter coefficient, for local obstacles, are listed below. For the shelter coefficient, shelter in all directions should be determined, and then averaged to determine averageShelter.

Atmospheric boundary layer parameters[a]		
Terrain description	**Exponent α**	**Thickness δ (m)**
Large city centers, in which at least 50% of buildings are higher than 25 m, over a distance of at least 0.8 km or 10 times the height of the structure upwind, whichever is greater	0.33	460
Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger, over a distance of at least 460 m or 10 times the height of the structure upwind, whichever is greater	0.22	370
Open terrain with scattered obstructions having heights generally less than 9 m, including flat open country typical of meteorological station surroundings	0.14	270
Flat, unobstructed areas exposed to wind flowing over water for at least 1.6 km, over a distance of 460 m or 10 times the height of the structure inland, whichever is greater	0.10	210

Local site sheltering[b]	
Shielding description (for each direction)	**Shelter coefficient *s***
No obstructions or local shielding	1.0
Light local shielding with few obstructions within two structure heights	0.9
Heavy shielding, many large obstructions within two structure heights	0.7
Very heavy shielding, many large obstructions within one structure height	0.5
Complete shielding	0.3

a. See ASHRAE Handbook of Fundamentals or EnergyPlus Engineering reference.

b. See: (a) Sherman MH. Air Infiltration in Buildings. Lawrence Berkeley Laboratory, University of California (dissertation), 1980; and (b) Wilson DJ, Walker IS. Wind shelter effects on air infiltration for a row of houses, Château Laurier, Ottawa, Canada: 1991, p. 335–46.

interiorELAperLen (37)

The following table gives some reasonable values for interior leakage areas. A tightly closed door (or the most stringent code requirement) spaced every 10 m gives interiorELAperLen of 0.0006–0.0008 m^2/m. On the other hand, a completely open typical door every 5 m gives an interiorELAperLen of 0.42 m^2/m. (Note 0.4 m^2/m is the technical max of this variable.)

ELA of internal connections between occupied and public spaces, per corridor length of between connections

	ELA (m^2) reference $C_d = 1$	ELAperLen one element every 3 m	ELAperLen one element every 5 m	ELAperLen one element every 10 m
Elements from Persily and Ivy, 2001				
Door, closed, tight	0.0075	0.0025	0.0015	0.0008
Door, closed, typical	0.0140	0.0047	0.0028	0.0014
Door, closed, undercut	0.0410	0.0137	0.0082	0.0041
Door, open, small	1.3000	0.4333	0.2600	0.1300
Door, open, typical	2.1000	0.7000	0.4200	0.2100
Code requirements of components, from Orme and Leksmono, 2002				
Orme Table 4, 25th pctl	0.0061	0.0020	0.0012	0.0006
Orme Table 4, median	0.0072	0.0024	0.0014	0.0007
Orme Table 4, 75th pctl	0.0111	0.0037	0.0022	0.0011
Orifice openings (assumed real C_d of 0.6, adjusted to reference $C_d = 1$)				
0.1 m by 0.1 m opening	0.0060	0.0020	0.0012	0.0006
0.5 m by 0.2 m opening	0.0600	0.0200	0.0120	0.0060
1 m by 0.2 m opening	0.1200	0.0400	0.0240	0.0120
0.5 m by 0.4 m opening	0.1200	0.0400	0.0240	0.0120

Advice on influential parameters

In the paper, we concluded that the most important variables were CDD18, occupant density, the ceiling fan air speed, and the size of the building's footprint area, and the number of floors. In nearly all cases, CDD18 will be set. If the building size and number of floors are still flexible, smaller footprint buildings will be more comfortable—in general even if the cost for doing so is more stories and greater occupant density. There is an illustration of this in the paper (Section 4.6, see Figure 9).

Assuming the climate zone and building form are fixed, among design variables we have calculated the most influential for eight subgroups of commercial buildings. We recommend testing variations in those variables first. The number in parentheses in the table is a measure of how influential each variable is.

Mild climates (CDD18 < 2267 K·days)			
Smaller footprint (FPA < 1385 m^2)		**Larger footprint (FPA > 1385 m^2)**	
Single story	**Multistory**	**Single story**	**Multistory**
ceilFanAirSpeedDelta (0.24)	occDensity (0.29)	occDensity (0.31)	occDensity (0.39)
occDensity (0.19)	ceilFanAirSpeedDelta (0.16)	roofAbs (0.18)	WWR (0.12)
roofAbs (0.19)	roomELPD (0.09)	roomELPD (0.10)	roomELPD (0.11)
roomELPD (0.09)	NVW_WWR (0.09)	ceilFanAirSpeedDelta (0.09)	NVW_WWR (0.06)
windowMaxOpenFrac (0.07)	windowMaxOpenFrac (0.08)	WWR (0.09)	windowMaxOpenFrac (0.05)
SHGC (0.04)	SHGC (0.06)	dayEnd (0.07)	ceilFanAirSpeedDelta (0.04)
NVW_WWR (0.04)	dayEnd (0.04)	windowMaxOpenFrac (0.04)	dayEnd (0.04)
dayEnd (0.04)	Nfloors (0.03)	NVW_WWR (0.03)	Nfloors (0.03)
roofCT (0.03)	roofAbs (0.03)	roofCT (0.02)	floorHeight (0.02)
shadingAngle (0.02)	shadingAngle (0.03)	floorHeight (0.01)	roofAbs (0.02)

Hot climates (CDD18 > 2267 K·days)			
Smaller footprint (FPA < 1385 m^2)		**Larger footprint (FPA > 1385 m^2)**	
Single story	**Multistory**	**Single story**	**Multistory**
ceilFanAirSpeedDelta (0.45)	ceilFanAirSpeedDelta (0.43)	ceilFanAirSpeedDelta (0.34)	ceilFanAirSpeedDelta (0.31)
roofAbs (0.14)	occDensity (0.14)	roofAbs (0.21)	occDensity (0.21)
occDensity (0.12)	NVW_WWR (0.09)	occDensity (0.17)	roomELPD (0.14)
SHGC (0.06)	roomELPD (0.08)	roomELPD (0.11)	NVW_WWR (0.07)
roomELPD (0.06)	SHGC (0.06)	WWR (0.03)	windowMaxOpenFrac (0.05)
NVW_WWR (0.04)	windowMaxOpenFrac (0.05)	dayEnd (0.03)	WWR (0.04)
windowMaxOpenFrac (0.03)	roofAbs (0.02)	windowMaxOpenFrac (0.03)	roofAbs (0.04)
dayStart (0.02)	shadingAngle (0.02)	NVW_WWR (0.02)	SHGC (0.03)
shadingAngle (0.02)	extWallAbs (0.02)	SHGC (0.02)	Nfloors (0.02)
floorHeight (0.01)	extWallU (0.02)	roofU (0.01)	dayEnd (0.02)

Note: Due to EnergyPlus modeling limitations, shading increases should be prioritized with or before the SHGC; see Section 4.1.

Citations, licensing, and contact information

All materials related to Natural Comfort, including Python code, templates, and this user's guide copyright (C) 2016 Adams Rackes (aer37@drexel.edu or adamsrackes@gmail.com). Visit the Laboratory for Energy Efficiency in Buildings at http://www.labeee.ufsc.br/ for additional tools.

If using this work, including the model, user's guide, weather file utilities, or the paper itself, please cite as (refer to indexing or research websites for exact volume and page numbers):

> Rackes, A., Melo, A.P., and Lamberts, R. (2016) Naturally comfortable and sustainable: informed design guidance and performance labeling for passive commercial buildings in hot climates. *Applied Energy*.

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