User's Guide for the Vertical City Weather Generator (VCWG v3.0.0)

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The Vertical City Weather Generator (VCWG) is a software that predicts the urban microclimate in relation to a nearby rural climate given the urban characteristics. VCWG predicts vertical profiles of temperature, wind speed, humidity, and turbulence kinetic energy as well as the building energy performance metrics in an urban area. VCWG v3.0.0 builds on VCWG v2.0.0 with 1) additional calculation of latent loads for the building energy system and 2) implementation of a fuzzy logic control system for indoor temperature and humidity setpoints, which adapt to occupancy, electricity price, and outdoor temperature/humidity. More details on the model and forcing datasets can be found at the Atmospheric Innovations Research (AIR) laboratory website at www.aaa-scientists.com and corresponding publications listed by [Moradi et al., 2021, Moradi, 2021, Aliabadi et al., 2021, Moradi et al., 2022, Aliabadi et al., 2023, Safdari et al., 2024, Safdari et al., 2025].

1 License

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Building sensible and latent load calculations are performed carefully [Safdari et al., 2024]. The sensible load,

$$\text{Sensible Load} = \pm\left[Q_{\text{vent}} + Q_{\text{inf}} + Q_{\text{int}} + Q_{\text{mass}} + Q_{\text{wall}} + Q_{\text{ceil}} + Q_{\text{win}} + Q_{\text{tran}}\right], \tag{1}$$

involves ventilation load Q_{vent}, infiltration load Q_{inf}, internal heat from occupants and equipment Q_{int}, heat from the building's mass Q_{mass}, heat from walls Q_{wall}, heat from ceilings Q_{ceil}, heat conduction through windows Q_{win}, and radiant heat passing through windows Q_{tran} [W]. Except for Q_{int}, which is scheduled in VCWG, the other terms are parameterized using the heat balance method:

$$\begin{aligned}
Q_{\text{vent}} &= V_{\text{vent}}\rho_a c_{pa}(T_{\text{outdoor}} - T_{\text{set}}) \\
Q_{\text{inf}} &= V_{\text{inf}}\rho_a c_{pa}(T_{\text{outdoor}} - T_{\text{set}}) \\
Q_{\text{mass}} &= A_{\text{bui}} h_m (T_{\text{mass}} - T_{\text{set}}) \\
Q_{\text{wall}} &= A_{\text{wall}} h_w (T_{\text{wall}} - T_{\text{set}}) \\
Q_{\text{ceil}} &= A_{\text{bui}} h_c (T_{\text{ceil}} - T_{\text{set}}) \\
Q_{\text{win}} &= A_{\text{win}} U_w (T_{\text{outdoor}} - T_{\text{set}}) \\
Q_{\text{tran}} &= A_{\text{win}} S \times SHGC,
\end{aligned} \tag{2}$$

where V_{vent} and V_{inf} [m^3 s^{-1}] are ventilation and infiltration air flow rates, ρ_a [kg m^{-3}] is density of air, c_{pa} [J kg^{-1} °C^{-1}] is heat capacity of air, A_{bui} [m^2] is building footprint area, T_{mass}, T_{wall}, T_{ceil}, T_{set}, and T_{outdoor} [°C] are mass, wall, ceiling, set-point, and outdoor temperatures, A_{bui}, A_{wall}, and A_{win} [m^2] are building footprint, wall, and window areas, h_m, h_w, and h_c [W m^{-2} °C^{-1}] are convective heat transfer coefficients, U_w [W m^{-2} °C^{-1}] is the window U-value, S [W m^{-2}] is the shortwave radiation flux through the window, and $SHGC$ [-] is the solar heat gain coefficient for the window. The sensible load is met by the building's sensible cooling/heating equipment. The latent load,

$$\text{Latent Load} = \pm\left[Q_{\text{latvent}} + Q_{\text{latinf}} + Q_{\text{latint}}\right], \tag{3}$$

involves latent heat from ventilation Q_{latvent}, latent heat from infiltration Q_{latinf}, and latent heat from internal heat from occupants and equipment Q_{latint} [W]. These loads are met by the building's humidification/dehumidification equipment. Except for Q_{latint}, which is scheduled in VCWG as a fraction of sensible heat from occupants and equipment Q_{int}, the other terms are parameterized using the humidity balance method

$$\begin{aligned}
Q_{\text{latvent}} &= V_{\text{vent}}\rho_a L_v (q_{\text{outdoor}} - q_{\text{set}}) \\
Q_{\text{latinf}} &= V_{\text{inf}}\rho_a L_v (q_{\text{outdoor}} - q_{\text{set}}),
\end{aligned}$$

where L_v [J kg$_v^{-1}$] is latent heat of vaporization for water, and q_{outdoor} and q_{set} [kg$_v$ kg^{-1}] are outdoor and set-point specific humidities, respectively.

The Weather-Adaptive Fuzzy Control (WAFC) system [Safdari et al., 2025] defines four sets of temperatures for setpoint under heating and cooling modes separately; i.e. under cooling mode $T_{LL} < T_L < T_H < T_{HH}$ are different than those under heating mode. However, the relative humidity setpoints are the same under both heating and cooling modes. These are $RH_{LL} < RH_L < RH_H < RH_{HH}$. For temperature and relative humidity setpoints, the control algorithm decides to 1) converge to the outdoor conditions, 2) converge to comfort levels L or H, or 3) converge to setback levels LL or HH. The decision is reached by consider electricity price, occupancy, building sensible heating/cooling loads, building latent heating/cooling loads, and outdoor temperature/humidity.

3 Input Dataset

Note: before distributing the forcing datasets, permission should be requested from the data owners. For forcing the model few options are available. For top forcing from a spreadsheet, an excel file is needed from the folder e.g. "/resources/TopForcing/Vancouver2008_ERA5_Jul.csv", which contains latitude, longitude, time difference from UTC, time, air temperature, barometric pressure, incoming longwave, incoming shortwave direct, incoming shortwave diffuse, rain fall, relative humidity, wind direction, and wind speed. This data comes from an ERA5 data product. Inclusion of latent and sensible heat fluxes are not required, but currently they are supplied for July in this dataset for the purpose of evaluating the model. Then VCWG will process this excel file and creates a new EPW formatted file. It learns the format from file "/resources/epw/rawEPW.epw" and creates the new forcing file as "/resources/epw/TopForcing.epw".

Alternatively the model can be forced near the surface in a rural area. In this case it is required to put the weather file (*.epw) of the region of interest in the directory e.g. "/resources/epw/Basel.epw", "/resources/epw/ERA5_Basel_Jun.epw", "/resources/epw/ERA5_Basel.epw", or "/resources/epw/ERA5-Toronto-2020".

In the released version of the software ERA5 datasets are prepared using the ERA5 data product from the European Centre for Medium-Range Weather Forecasts (ECMWF):

(https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5).

In this implementation of the software, we will use the rural forcing option using the EPW file "ERA5-Toronto-2020". This file is generated using the Vatic Weather File Generator (VWFG v1.0.0) software [Aliabadi and McLeod, 2023].

4 Input Parameters

VCWG can take input parameters from the files located in the directory "/resources/parameters/". These files contain the required parameters of the case study including urban characteristics, vegetation parameters, view factors, simulation parameters, and hydrological parameters. For example, the files "initialize_Toronto_1.uwg" to "initialize_Toronto_12.uwg" are used associated with running a simulation for 12 month in year 2020. Variable "OPTION_RAY" should be set to 0 to obtain new view factors or otherwise to 1. Variable "Rural_Model_name" should be set to 1 for MOST or 2 for top forcing. Variable "EB_RuralModel_name" should be set to 1 for formulation of Louis or 2 for formulation of Penman Monteith in determination of terms in the surface energy balance model in the rural area. Variable "Tdeep_ctrl" should be set to 1 for using the force restore method or 2 for using climate data in forcing the deep soil temperature in the urban area.

If desired, new view factors can be obtained by changing the variable "OPTION_RAY" value from 1 to 0. This will create a new file for view factors in e.g. "ViewFactor_Toronto_MOST.txt". Otherwise, the view factors are taken from the same location by a previous run.

The electricity pricing scheme in this implementation of VCWG follows the Time Of Use (TOU) approach in Ontario. In this scheme the electricity price varies as Off-Peak (lowest price), Mid-Peak (medium price), and On-Peak (highest price). The season, hour of the day, and day of the weak determine the price scheduling. These are defined in the following variables:

```
# ====================================================
# Time of Use (TOU) for Ontario
# ====================================================
TOU_Low_Summer,    # Low price hours [0-7] & [19-24]
0, 7, 19, 24,
TOU_Medium_Summer, # Medium price hours [7-11] & [17-19]
7, 11, 17, 19,
TOU_High_Summer,   # High price hours [11-17]
11, 17,
TOU_Low_Winter,    # Low price hours [0-7] & [19-24]
0, 7, 19, 24,
TOU_Medium_Winter, # Medium price hours [7-11] & [17-19]
7, 11, 17, 19,
TOU_High_Winter,   # High price hours [11-17]
11, 17,
```

Next, to enable or disable the SmartThermostat and SmartHumidistat (WAFC system) you can use a value of 1 for these variables. Otherwise, using values of 0 will run VCWG having fixed setpoint for temperature and humidity under heating and cooling modes. The settings below will enable the WAFC system:

```
# ====================================================
# Control switches
# ====================================================
OPTION_RAY,1,         # 1: read view factors from file, 0: calculate view factors
Rural_Model_name,1,   # 1: Rural MOST, 2: Top Forcing
EB_RuralModel_name,2, # 1: Louis, 2: Penman_Monteith
Tdeep_ctrl,1,         # 1: Force restore method, 2: Climate data
SmartThermostat, 1,   # Thermostat Type; 0 : Fixed and regular 1: Variable and smart
SmartHumidistat, 1,   # Humidistat Type; 0 : Fixed and regular 1: Variable and smart
```

Next, the "No Smart" and "Smart" setpoints are read from the script below. Note that this version of VCWG only allows for simulations of fully conditioned buidlings. For simulations using natural ventilation please use VCWG v1.4.7.

```
# ====================================================
# Building Energy Model
# ====================================================
glzR,0.4,                  # Glazing Ratio (0 - 1)
```

```
autosize,0,                 # autosize HVAC (1 for yes; 0 for no)
sensOcc,100,                # Sensible heat per occupant [W]
LatFOcc,0.3,                # Latent heat fraction from occupant (normally 0.3)
RadFOcc,0.2,                # Radiant heat fraction from occupant (normally 0.2)
RadFEquip,0.5,              # Radiant heat fraction from equipment (normally 0.5)
RadFLight,0.7,              # Radiant heat fraction from light (normally 0.7)
hvac,0,                     # HVAC TYPE; 0 = Fully Conditioned
h_floor,3,                  # Floor height [m]
coolTempSetpointDay, 300.15,            # No smart [K]
coolTempSetpointNight, 300.15,          # No smart [K]
heatTempSetpointDay, 295.15,            # No smart [K]
heatTempSetpointNight, 295.15,          # No smart [K]
dehumRHSetpointDay,50                   # No smart [%]
dehumRHSetpointNight,50,                # No smart [%]
humRHSetpointDay,40,                    # No smart [%]
humRHSetpointNight,40,                  # No smart [%]
heatTempSetpointHighHigh,300.15,        # Smart [K]
heatTempSetpointHigh,297.15,            # Smart [K]
heatTempSetpointLow,294.15,             # Smart [K]
heatTempSetpointLowLow,291.15,          # Smart [K]
coolTempSetpointHighHigh,303.15,        # Smart [K]
coolTempSetpointHigh,300.15,            # Smart [K]
coolTempSetpointLow,297.15,             # Smart [K]
coolTempSetpointLowLow,294.15,          # Smart [K]
RHSetPointLow,40,                       # Smart [%]
RHSetPointHigh,60,                      # Smart [%]
RHSetPointLowLow, 25,                   # Smart [%]
RHSetPointHighHigh, 70,                 # Smart [%]
```

5 Execution

Various options are available to run VCWG. Using "Run_VCWGv3.0.0.py" runs VCWG in a single run mode, ideal for a single month simulation. The single mode only runs the model given one set of input parameters. Key variables are set as follows. The script uses this information to find the relevant EPW file, view factors file, parameters file, etc.

```
# Automatically generate file names based on city and year
city = "Toronto"        # Define the city name
year = 2020             # Define the year
month_number = 1        # Specify the month number (1-12)
```

If top forcing is needed, "epwFileName" should be set to "None". If top forcing is not needed, "TopForcingFileName" should be set to "None". The code first checks if there is any "epwFileName", if not, then it checks for "TopForcingFileName". So an experienced user may still keep the “TopForcingFileName” if they are intending for an “epwFileName” to be used. File “ViewFactorFileName” is generated and over written, if the “OPTION_RAY” value is set to 0 in the initialization file. Otherwise, view factors are taken from “ViewFactorFileName”.

Using “Run_VCWGv3.0.0Serial.py” runs VCWG for 12 months in on single CPU. In another word, this option runs 12 months sequentially and can be very time consuming to complete one full year of analsysis.

Uring “Run_VCWGv3.0.0Parallel.py” simultaneously runs simulations for multiple months on available CPUs of a computer, and then it automatically writes the results for each month. This option utilizes the available computing power so simulations for a full year can be conducted faster.

6 Results

The outputs of the simulation are going to be saved under the “Results” directory. A sub-folder is automatically generated by the date/hour of simultion. You can rename this folder according to the case you are running. The output is hourly. There are many output files pertaining to climate variables and building performance metrics. It is recommended to discard the first 72 hours (3 days) of simulation as spin-up period while considering results after this period (except for the month of January). Writing the simulation results requires the creation of a “Results” folder; preferably empty. Otherwise the entire simulation will run and then stop with an error: “Results folder not found.” In this implementation of the VCWG software it is interesting to check the files: “BEMTorontoJan.txt”, “BEMTorontoFeb.txt”, ..., “BEMTorontoDec.txt”. These files quantify whether or not running the WAFC system results in saving energy for a building compared to fixed setpoints for temperature and humidity.

7 Python Versions

VCWG is designed to run on Python 3.6.1. This version of Python can be downloaded from the following link “https://www.python.org/downloads/release/python-361/”. For example for a 64-bit Windows operating system the installation file will be “python-3.6.1-amd64”. The following packages and versions can be used: pandas 1.1.4, numpy 1.19.5, scipy 1.1.0, matplotlib 3.1.1. Note that other package versions may also work.

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