User's Guide for the Vertical City Weather Generator (VCWG v1.4.7)

Amir A. Aliabadi, Mojtaba Safdari, and Kadeem Dennis
Atmospheric Innovations Research (AIR) Laboratory
School of Engineering, University of Guelph, Guelph, Canada
http://www.aaa-scientists.com
aaliabad@uoguelph.ca

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1 About VCWG

The Vertical City Weather Generator (VCWG) is a software that predicts the urban micro-climate and building performance variables 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. More details on the model can be found at the Atmospheric Innovations Research (AIR) laboratory website at www.aaa-scientists.com and corresponding publications [Moradi et al., 2021, Moradi, 2021, Aliabadi et al., 2021, Moradi et al., 2022, Aliabadi et al., 2023, Safdari et al., 2024].

VCWG v1.4.7 is similar to VCWG v1.4.6, with the additional capability that it can allow for simulations considering natural ventilation. This documentation accompanies the journal article published for this topic [Safdari et al., 2024].

2 Thoery

Natural Ventilation (NV) is formulated in the context of the building sensible and latent load calculation. 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. When natural ventilation is deployed, the model enhances the infiltration rate V_{inf} [m^3 s^{-1}] and thus captures the physics properly.

The buildings are arranged in rows with a separation of 30 m maintained in each horizontal direction (x and y). Temperature, specific humidity, and wind (the x and y components) data within the urban roughness sub-layer were extracted along the vertical direction (z) from VCWG. The buildings are low-rise residential units designed with dimensions of 13.8 m × 13.8 m × 6 m. Each story features two windows on each side, with an equivalent area of 26.4 m^2 per facade. The

NV system model assumes a single equivalent window on each building side and is based on the ASHRAE Handbook - Fundamentals. The calculation of the NV system air flow rate is performed by the following formula:

$$Q = CAU, \tag{4}$$

where Q [m^3 s^{-1}] is flow rate, $C = 0.5$ [-] is a coefficient describing the effectiveness of windows (it can be assumed to be 0.5 to 0.6 for normal winds and 0.25 to 0.35 for diagonal winds), A [m^2] is the free area of inlet openings, and U [m s^{-1}] is the wind speed normal to the facade. Once Q is known, it can be added to the base infiltration rate V_{inf} [m^3 s^{-1}] in the VCWG model.

3 Setting the Climate Forcing Files

To run the VCWG, it is required to put the weather file (*.epw) of the region of interest in the directory e.g. "/resources/epw/ERA5-Toronto-2020.epw". This file can be downloaded from EnergyPlus (https://energyplus.net/) or prepared using alternative datasets. In the released version of the software it is prepared using the ERA5 data product from the European Centre for Medium-Range Weather Forecasts (ECMWF) [Aliabadi and McLeod, 2023].

4 Setting 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 building renewable and alternative energy configurations. In the released version of the software there are 12 input parameter files for Toronto; "initialize_Toronto_1.uwg" to "initialize_Toronto_12.uwg" are associated with 12 months from January to December 2020. In these files, the starting month, starting day, and the duration of the simulation in number of days are set. For each month, it is desired to start the simulation 3 days before the start of the month and then discard the first 3 days of data as spin up data. For example, to simulate February, one can start from Month = 1 (January), Day = 29 (3 days before start of February), for nDay = 31 (28 days in February plus 3 days for spin up). The January simulation is an exception because the ERA5 dataset only contains data in 2020, so for January we cannot start 3 days earlier in 2019. The user is able to change the parameters to define and run a simulation of interest. Currently two sets of input parameter files are distributed: "Toronto-2020-Base" lists parameters for a base case building with no natural ventilation, and "Toronto-2020-NV" lists parameters for a building with natural ventilation.

To consider the renewable energy options for the model, variable "Adv_ene_heat_mode" should be set. To include only photovoltaic panels and wind turbine, this parameter should be set to 3. For inclusion of other renewable energy options (solar thermal, building integrated thermal energy storage, phase change materials, and energy recovery), this variable should be set to 1 for heating mode and 0 for cooling mode of operation. To consider natural ventilation only, this variable should be set to 2. Additionally variable "hvac" should be set to 1. This variable specifies the ventilation system: 0 is used for fully conditioned system, and 1 is used for mixed mode natural ventilation and conditioned system. Other parameters needed for natural ventilation are related to windows: “XWindowWidth”, “XWindowHeight”, “XWindowZCoord”, “XWindowScreen”, “XWindowOpenArea”, and the same variables in the Y direction. It is assumed that pairs of windows are used for natural ventilation on each pair of facades (X and Y directions).

There are three more files in which input parameter specifications may be made. 1) To change the building envelop properties (e.g. resistance values) and HVAC equipment specification (e.g. coefficient of performance and thermal efficiency) the file “LocationSummary” in directories “/resources/DOERefBuildings/BLD1” through “/resources/DOERefBuildings/BLD16” should be modified corresponding to building type. Note that in the released version of the software the appropriate folder is “/resources/DOERefBuildings/BLD6” for mid rise apartment. Also note that only the last column of the spreadsheet is advised to be modified corresponding to custom values. i.e. the users are discouraged to change values in the other columns. 2) To change the ventilation and infiltration rates, the appropriate file “ZoneSummary” in directories “/resources/DOERefBuildings/BLD1” through “/resources/DOERefBuildings/BLD16” should be modified corresponding to building type. Note that in the released version of the software the appropriate folder is specified for the mid rise apartment as “/resources/DOERefBuildings/BLD6”. 3) To change the set points for temperature and relative humidity, the appropriate file “Schedules” in directories “/resources/DOERefBuildings/BLD1” through “/resources/DOERefBuildings/BLD16” should be modified corresponding to building type. Note that in the released version of the software the appropriate folder is specified for the mid rise apartment as “/resources/DOERefBuildings/BLD6”. The temperature and relative humidity set points are specified for building under either cooling or heating mode operation.

If desired, new view factors can be obtained by running “/UWG/Run_RayTracing.py” and copy and paste the results from file e.g. “/UWG/ViewFactor_Toronto.txt” into the input file e.g. “/resources/parameters/initialize_Toronto_0.uwg” or other initialization files.

5 Running VCWG

There are two options for running VCWG v1.4.7: the single and serial modes. The single mode only runs the model given one set of input parameters, while the serial mode allows running the model for 12 consecutive months, requiring 12 initialization files. For the single mode, in the python file “/VCWG/VCWGv1.4.7.py” located in the main directory, the user is required to change the name of weather file and the name of the initialization file to the ones located in the directories of “/resources/epw” and “/resources/parameters/”, respectively. This run produces hourly results that are saved in directory “/Output/”. For the serial mode, in the python file “/VCWG/VCWGv1.4.7Serial.py” located in the main directory, the user is required to specify 1 weather file and 12 input parameter files for each month of the year. In addition, the user should specify the 12 file names for the output files for building performance metrics for the entire month to be saved in directory “/Output/”. In either simulation mode, it takes a few minutes to generate the output files located in the “/Output/” directory. It is recommended to discard the first 72 hours (3 days) of simulation for each month (except for January) as spin-up period while considering results after this period.

“VCWGv1.4.7.py” and “VCWGv1.4.7Serial.py” are designed to run on Python 2.7.13. This version of Python can be downloaded from "https://www.python.org/downloads/release/python-2713/". For example, for a 64-bit Windows operating system the installation file will be "python-2.7.13.amd64". The following packages and versions can be used: numpy 1.14.3, scipy 1.1.0, matplotlib 2.2.2. Note that other packages may also work. "UWG/Run_RayTracing.py" 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: numpy 1.19.5, scipy 1.1.0, matplotlib 3.1.1. Note that other packages may also work.

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