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Development of an online calculator for cool roof and green roof

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Abstract

Cool and green roofing strategies are proven to reduce the cooling load in air-conditioned spaces and improve thermal comfort in unconditioned spaces. Calculators that use simulated models to estimate cost savings are used to evaluate various roof configurations. Currently available online calculators that estimate savings provide limited possibilities for locations and roofing options. In this paper, we present a unified online calculator which can simulate both cool as well as a green roof over flat and sloped roofs for all locations for which weather data is available on the EnergyPlus website. It provides an option to simulate an unconditioned building which helps the user to know monthly Fanger Predicted Mean Vote and Indoor Air Temperature. This calculator includes various cool roofing options with different Solar Reflectance Index values and green roofs with different plant and soil properties. It also supports parametric simulations and provides a graphical view of roof insulation thickness v/s energy savings, for different insulation thickness values where multiple simulations are needed to run. We use distributed tasks queues to handle requests at peak calculator usage.

Introduction

With an increase in the growth of construction of buildings, urban heat island effect is a major point of concern. Unconventional roofs known as high albedo roofs and green roofs can provide a solution to this. (Garg et al. 2016) Experimental studies in the past show a significant reduction in energy consumption for conditioned buildings and increased comfort levels in unconditioned buildings with the use of cool roofs. For performing simulations, various parameters such as building location, building type, roof type, HVAC systems are considered. The US Department of Energy and Oak Ridge National Laboratory have developed several cool roof calculators for the United States and surrounding locations which either use DOE 2.1E or uses a lookup table based on the data resulted in experimental facilities in the US. Efforts to make green roof calculator (David J Sailor and Bass 2014) for the US and few locations of Canada has also been made in the past. In this context, Online tool for analyzing benefits of a cool roof over conventional roofs in India using EnergyPlus has been developed by ("IIIT Hyderabad Publications" n.d.; Garg et al. 2016). This calculator is an update to this work which brings everything at the same place. The calculator uses (Garg et al. 2016) simulation model of cool roof and provides an additional feature of a sloped roof and a vegetated roof.
In Table 1, we made a comparison of various calculators available online.

1

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Key features added in this version of the calculator are:

- Online distributed EnergyPlus simulation tool
- Simulation monitoring tool for administrator
- Performs simulations for green roof and sloped roof
- Updated system design, framework and user interface
- Applicable for all climate zones across the globe

Background

Cool roof

A roof that reflects and emits solar radiation back to the sky rather than transferring it into the building even under high solar loads is termed as a cool roof. ("Cool Roof Rating Council" n.d.) It helps in reducing the cooling load in a conditioned building and maintains thermal comfort in an unconditioned building. A study(Konopacki and Akbari 2001) shows the energy savings achieved in a building depends on various parameters such as the location, orientation, shading, roof type, wall type, ventilation, equipment load, occupancy, and operational schedules. The use of cool roof rather than a dark or high albedo roof is highly advantageous. In a study (Akbari, Menon, and Rosenfeld 2009), it is estimated that increasing the use of cool roofs will induce a negative climate forcing on the earth which is equivalent to 44 Gt of CO_2. There are already a few internet-based calculators developed for understanding the use of cool roofs. Roof savings calculator developed by Oak Ridge National Laboratory(ORNL)("Roof Savings Calculator | ORNL" n.d.) uses DOE-2.1E and AtticSim simulations tools and ("Cool Roof Calculator" n.d.) uses a lookup table based on data from experimental facilities in the US. ("Roof Savings Calculator | ORNL" n.d.) is no longer available online for free and requires a license to use it.

Green roof

A green roof is a technique in which vegetation is grown on rooftops and is widely used as a method to reduce storm-water runoff. This is not modern technology, Romans used trees on top of buildings, such as the mausoleum of Augustus and Hadrian. In (Peck 2002) efforts have been made to study different types of green roofs consisting of many vegetation types each require different depths for growing medium. Usually, there are three types of green roofs: intensive, semi-intensive and extensive and different types of vegetation known as Moss-Sedum, Sedum-moss-herbaceous plants, Sedum-herbaceous-grass plants, and grass-herbaceous plants; these types of vegetations require 2–20 cm depth of medium for growing and are used in Extensive green roofs. (Banting et al. 2005) The extensive roof is the cheapest among all in terms of setup and maintenance, as it can be self-retained. A study (Li and Yeung 2014) conducted in a residential building of Cairo and Egypt between a green roof and a normal roof system demonstrated an annual energy savings of 15%–32% depending on the soil thickness and the thermal conductivity of the soil. The energy savings depends upon various properties such as building type, roof type, leaf area density, plant height, irrigation rate and maintenance (Kamel Basil et al., n.d.). To justify any installation, we need to survey whether it is worth investing.

An online green roof calculator ("Green Roof Energy Calculator - Urban Climate Research Center" n.d.) for the US and few locations of Canada has been developed by (David J Sailor and Bass 2014) to provide a solution to the market with an easy-to-use web-based tool.

Tool Comparison

Calculator	Weather Data	Simulation Engine	Roof	Building type	HVAC	Output
Cool roof IIIT	World ("Weather Data | EnergyPlus " n.d.)	EnergyPlus v8.9 ("EnergyPlus | EnergyPlus" n.d.)	• Green • Cool • Sloped	• Office • Institute • Retail • Residential (24 hr , night only)	• PTHP • PSZHP • Aircooled • Watercooled	• Tabular • Graphical
Cool roof ORNL("Cool Roof Calculator")	US, Pacific Territories, Puerto Rico, Canada	DOE-2.1E	• Cool	• Facilities (small,medium)	• PTHP • Fuel	• Numerical
Roof Savings("Roof Savings Calculator | ORNL")	US	DOE-2.1E+ AtticSim	• Cool • Sloped	• Residential • Commercial	• PTHP • Natural Gas Furnace	• Tabular
Green roof energy calculator("Green Roof Energy Calculator)	US, Canada	EnergyPlus v3 and v6	• Green	• New, Old Office • New, Old Residential	• Undefined	• Tabular

Table 1. Online calculator comparison

Methodology

The methodology used in the development of the online tool is mainly divided into three parts: 1) Web Client, interface to get simulation parameters from users and display results. 2) Django app, a backend program which interfaces with Task queues, database, and Web client. 3) Task manager, it schedules and executes the tasks in a distributed manner. The system design of the tool is shown in Figure 1. In this section, we give a detailed description of each part of the system.

Web Client

The web client is a collection of webpages that act as an interface to run simulations and display results. We use HTML and CSS to build webpages and forms. We provide 3 different types of simulation panel: Simple, Detailed and Parametric. Simple simulation form takes minimal inputs to create simulation, Detailed simulation form provides users with deeper control over simulation parameters, whereas Parametric simulation provides the same control as Detailed form, apart from that it allows users to pass additional variable known as k-value of insulation which performs simulation on multiple thickness values and the user can pick a suitable insulation thickness corresponding to the energy savings. We do form validation using JQuery(js.foundation n.d.) and notify the user if any field is incorrectly filled. If all fields are valid, then we send the valid form data to Django App using POST API request which it exposes. Figure 3 shows a screenshot of the input form. After successfully submitting simulation information, we redirect to a page that prompts the user to wait for the simulation. Meanwhile, we use AJAX request to check the status of the simulation with Django App every 10 seconds. If and when the simulations are finished we automatically redirect to a results page. For Simple and Detailed simulation, we display annual energy comparison of end uses (interior lighting, fans, pumps, equipment) tabular comparison for both the roofs and show heating, cooling savings/month graphically for better analysis (example figure 5 and 6). For Parametric simulation, we show Thickness vs Energy savings graph. All the graphs are generated using Google Charts("Charts" n.d.). A user can pick an option of email results, where we send them the results upon the completion of simulations.

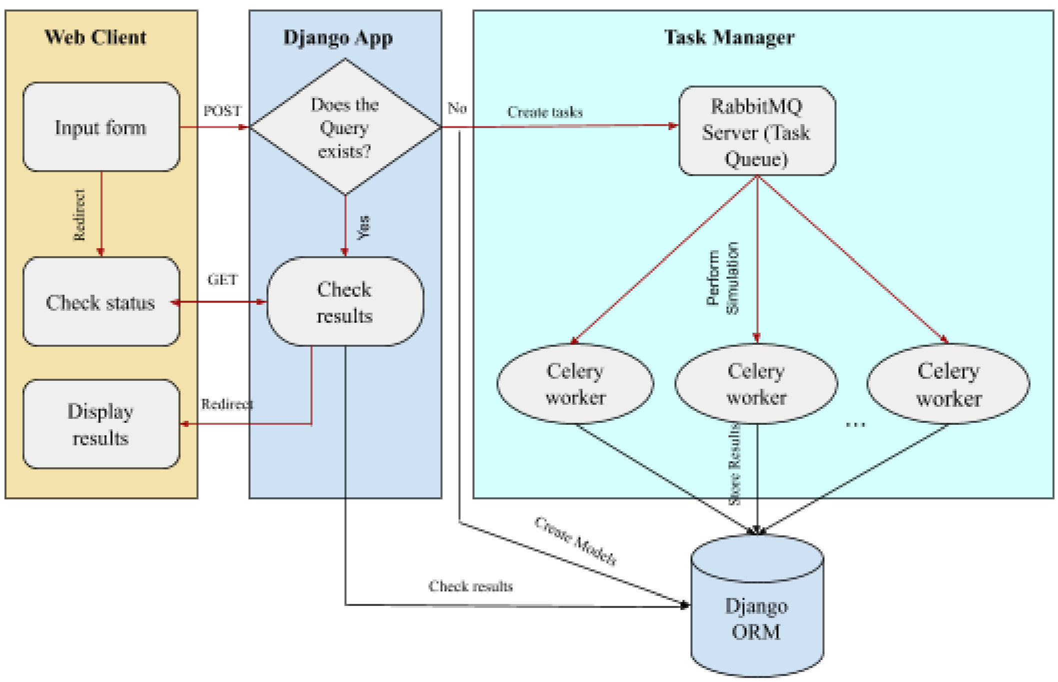

Figure 1. System Design

Django App

Django (“The Web Framework for Perfectionists with Deadlines | Django” n.d.) is a Python orientated high-level web framework which follows Model-View-Controller (MVC) architecture and provides an ORM to interface with Database. Additionally, we use Rest framework (“Home

- Django REST Framework" n.d.) to expose CRUD (Create - Read - Update - Delete) RestAPIs. It is these APIs that are used by Web Client to create a simulation and check the status of the simulation. Both Django App and Web Client are hosted on the same server which we call Master. In other words, Django MVC is used to serve pages for the Web Client. After receiving the simulation request, we check if any of the requested simulations have already been performed. If the simulation has already been performed then we directly redirect to the results page, we call this Caching, this helps us reduce the load on the distributed system. If the simulation is not already performed, we dispatch request for these simulation using Celery ("Homepage | Celery: Distributed Task Queue" n.d.), to be computed in Slave or Worker servers. Whenever the Web client request for the status of a simulation, it checks of results for all simulations are populated in the database, if all results are available then we redirect to Results webpage.

Task Manager

Celery is an open-source asynchronous (background) task queue which uses a distributed system for passing messages to the machines. It also supports scheduling and focuses on real-time operations. It is an easy to use API for building distributed python apps. It is compatible with major messaging queues (RabbitMQ, Redis), databases (Django ORM, MongoDB, MySQL) and monitoring interfaces (Flower, Clearly). We use Celery to create our distributed framework. Multiple Django servers which are enabled with Celery are running on Slaves or Workers servers. We use RabbitMQ ("Messaging That Just Works — RabbitMQ" n.d.) message queues to connect all the celery workers, and they are all connected to the same database as well. Whenever a free worker encounters a task on the message queue (Task queue), it dequeues that task and retrieves the simulation parameters from the common database (Simulation parameters are populated in the DB by Django App). Upon completion of the task, it populates the Database with results, which are later accessed by the Django App. We use EnergyPlus v8.9 to simulate energy consumption. The ease of deploying new Celery workers makes the framework highly scalable. A new worker can be added easily by just installing the requirements and connecting to the message queue and task manager. We also use Flower ("Flower - Celery Monitoring Tool" n.d.) to provide the administrator with detailed statistics about the task queue usage.

Framework

The supervisor("Supervisor: A Process Control System" n.d.) is a client/server that provides a platform for users to monitor and control numerous processes in Linux based operating systems. Administrator is given the privilege of controlling django, flower and celery app in any system/computer using this tool. This can be configured in a way which can start any program at boot time, it makes the system persistent. Supervisor is used to control Django and Flower app at the master node and Celery worker in the slave node (figure 2).

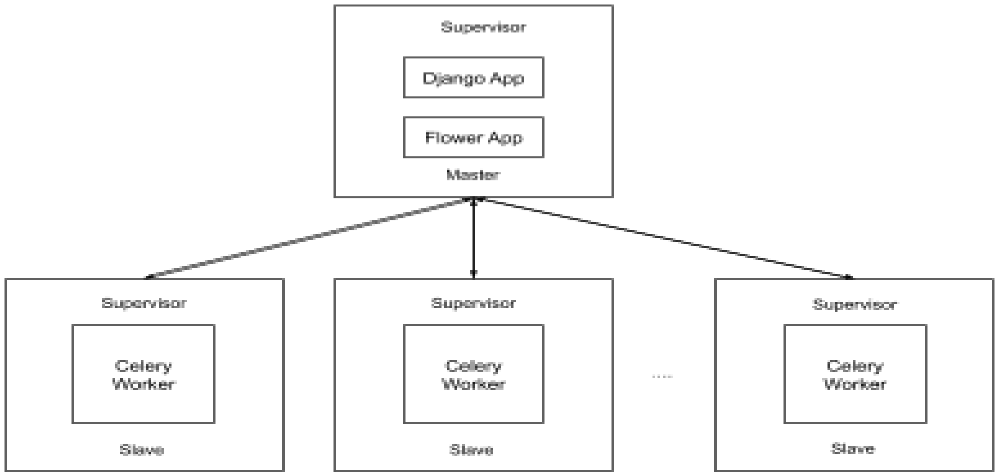

Figure 2. Framework

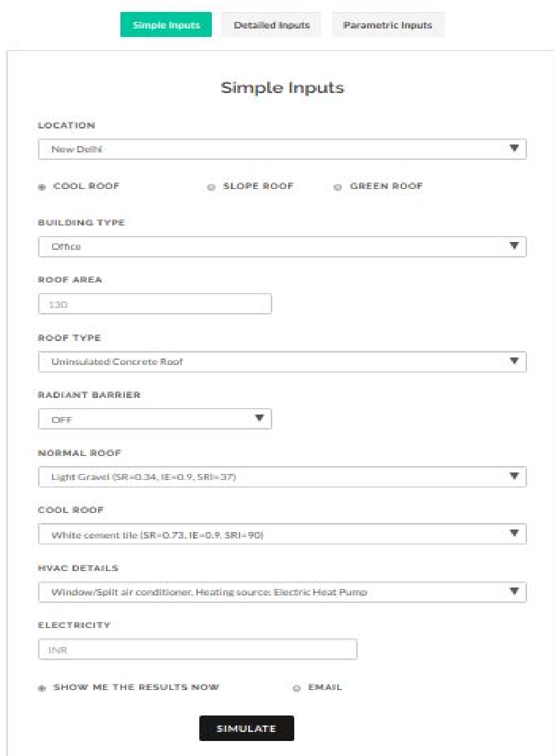

Figure 3. Application Interface

Model setup

The model used by (Garg et al. 2016) has been used for cool roofs. Occupancy schedule for different types of buildings is also described. All the models are square having 5 zones in total which includes 4 perimeters and 1 core zone (figure 4). This new version of the calculator has added support for green roof model (Sailor 2008) on a five-zone building and sloped roof calculator on a one-zone building. EnergyPlus v7.2 simulation models have been updated to v8.9.

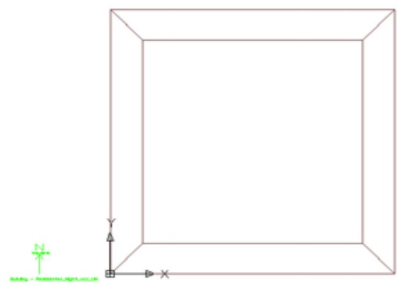

Figure 4. Top view of the Cool roof and Green roof model. Source : (Garg et al. 2016)

Results

Benefits of the cool roof have been shown in (Garg et al. 2016). A comparison of normal, cool and green roof is analysed globally and few results are shown in Table 3. Input parameters for cool and green roof is provided in table 1 and 2. We observed heating penalties in cool roofs for most of the regions and cooling penalties in green roofs for cold climatic conditions.

Cool roof	Building type	Office
	Roof area	2000 meter^2
	Roof type	Uninsulated concrete roof
	Radiant Barrier	Off
	Normal roof	SR-0.34 , IE=0.9,SRI=37
	Cool roof	SR-0.8 , IE=0.91,SRI=100
	HVAC	Window/Split AC, Heating Source: Electric Heat Pump

Table 1. Input Parameters for cool roof simulation

Green roof	Building type	Office
	Roof area	2000 meter^2
	Roof type	Uninsulated concrete roof
	Radiant Barrier	Off
	Normal roof	SR-0.34 , IE=0.9,SRI=37
	Height of Plant	0.8 meters
	Leaf Area Index (LAI)	1 (Dimensionless)
	Soil Thickness	0.6 meters
	The Conductivity of Dry Soil	0.3
	HVAC	Window/Split AC, Heating Source: Electric Heat Pump

Table 2. Input Parameters for green roof simulation

Energy savings v/s normal roof (in kWh/m^2 per annum)						
City	Cool Roof			Green Roof		
	Heating	Cooling	Total	Heating	Cooling	Total
Phoenix	-3.16	31.37	28.21	2.96	20.6	23.56
Cairo	-1.62	27.39	25.77	0.85	15.46	16.31
Kuwait City	-1.54	28.3	26.76	0.83	25.3	26.13
Delhi	-1.86	33.23	31.37	0.49	24.89	25.38
Kuala Lumpur	0	24.38	24.38	0	17.48	17.48
Singapore	0	22.91	22.91	0	12.75	12.75
Dublin	-5.39	3.41	-1.98	26.86	-7.26	19.6
London	-5.96	6.02	0.06	25.7	-5.7	20
San Francisco	-5.51	11.68	6.17	5.57	-4.06	1.51
Adelaide	-3.43	16.29	12.86	3.18	-0.31	2.87

Table 3. Energy Savings in different climatic conditions

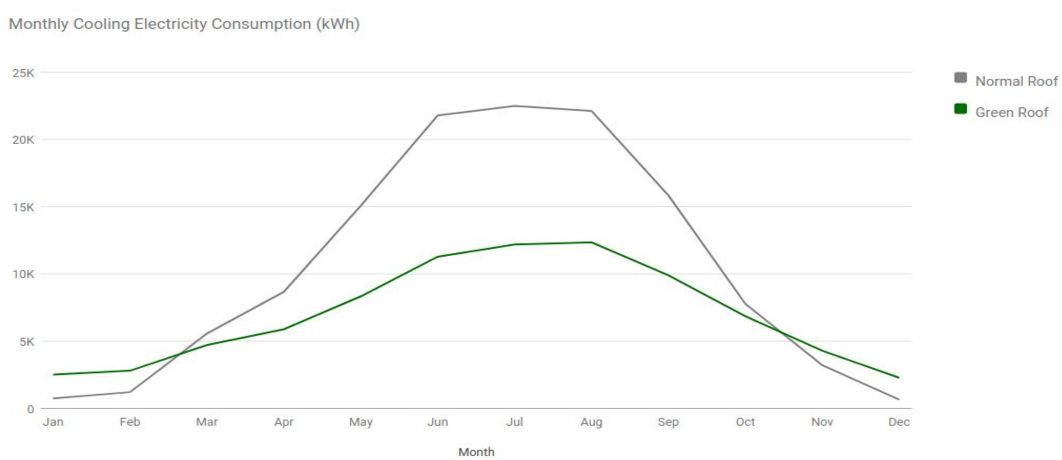

Figure 5. Annual cooling loads(kWh) of green roof v/s normal roof (Phoenix, Arizona)

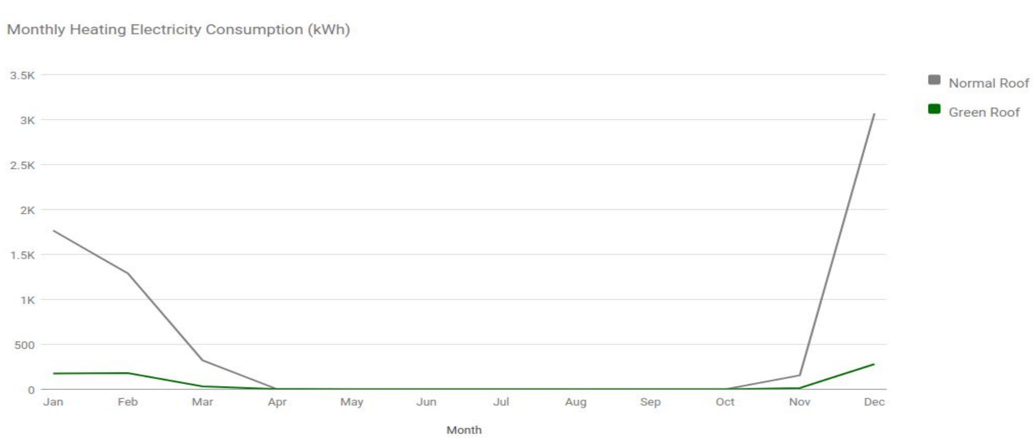

Figure 6. Annual heating loads(kWh) of green roof v/s normal roof (Phoenix, Arizona)

Conclusion

We have developed a simple and easy-to-use online application which analyses energy savings and comfort analysis of unconventional roofs over normal roofs. This application can be used to study the performance of a building considering various roofs, HVAC systems and works for all locations provided in EnergyPlus weather data. It has been designed in a way that multiple users with multiple requests can operate the tool at the same time. We also provide registered user, an interface to view/edit completed simulations which can further help in analyzing various queries at the same place in less time. Hence, We provide a platform for architects, developers, researchers, students, house owners or any organization to see the impact of cool roofs and green roofs across the globe.

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