Multifunctional Vegetated wall for thermal insulation and greywater treatment of buildings

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Abstract:

People are beginning to understand sustainable natural solutions in the last several decades to reduce floods and temperature in metropolitan areas, which have been rising owing to many factors like urbanisation and climate change.The population of cities has been growing as a result of fast urbanisation, which has also caused an increase in buildings and other man-made structures, which has contributed to an increase in urban heat. Recently, multifunctional walls and roofs have gained popularity as a means of combating urban heat and flood mitigation. Grey water is regarded as one type of wastewater and is the waste water produced by showers, kitchen sinks, and washing machines in residential, commercial, and industrial settings. Untreated wastewater discharge into the ecosystem has many negative repercussions, and grey water treatment is on the rise. The creation, analysis, and optimization of a model are the main topics of this study in order to enhance the functioning of a multifunctional vegetated wall.

Introduction:

Modern society is dealing with several challenges and global changes that are reshaping the urban environment. According to the UN report, the population is expected to touch 10 billion by the year 2050. Due to the increase in population there is an increase in impermeabilization of the natural surface along with climate change that is projected to increase the flood generation and intensity of urban heat.

To accomplish the Sustainable Development Goals, a variety of solutions have been put up to counteract and accommodate population growth and climate change. These solutions aim to build smart, sustainable, and resilient cities. To solve these issues, numerous organic and man-made solutions have been put forth and researched. A solution to cope with urban rainwater excess is water harvesting. Rainwater systems are nowadays used to mitigate extreme heavy rainfall events and provide water during drought situations.A green wall system that offers a variety of advantages to buildings and their occupants is known as a multifunctional vegetated wall. Layers of plants, soil, and a support framework that can be put on a building's exterior or interior make up these walls. A multipurpose vegetated wall's capacity to insulate buildings from heat is one of its main advantages. Reduced heat loss in the winter and increased heat gain in the summer are results of the plants and soil acting as a natural insulator. By doing this, building owners may use less energy and pay less for heating and cooling. The benefits of a multipurpose vegetated wall include thermal insulation as well as greywater treatment. A multipurpose vegetated wall can be used to treat greywater in addition to providing thermal insulation. Greywater is wastewater that can be cleansed and repurposed for non-potable uses, like irrigation, from sources like sinks, showers, and washing machines. Greywater can be cleaned up and reused by the flora and soil in the wall, which can serve as a natural filtration system. A multipurpose vegetated wall can also improve building aesthetics while reducing noise and improving air quality. The effects of urban heat islands can be lessened and wildlife habitat can be created by these walls. In general, a multipurpose vegetated wall is an inventive and sustainable way to enhance the efficiency and environmental effect of buildings.

OBJECTIVES:

Providing a sustainable and creative solution that enhances the energy efficiency and environmental impact of buildings is the overall goal of a multifunctional vegetated wall for thermal insulation and greywater treatment.

The specific objectives of multifunctional vegetated wall and grey water treatment of buildings are

1. By offering shade and evaporative cooling, urban heat island impacts can be lessened.
2. Reuse greywater for non-potable uses like irrigation by treating it through a natural filtration system provided by the vegetation and soil.
3. By minimising heat gain in the summer and loss in the winter, thermal insulation can help buildings use less energy and spend less on heating and cooling.
4. Enhance the aesthetic look of the buildings
5. Provide habitat for wildlife thereby increasing biodiversity of that place.

LITERATURE REVIEW:

1. **Multilayer blue-green roofs as nature-based solutions for water and thermal insulation management:**
   This study focuses on how nature-based solutions might be considered for water and thermal insulation management. Blue green roofs are mentioned along with other conventional and non-conventional technologies as a potential solution for better thermal insulation and water management. This essay focuses on case studies conducted by a Dutch company named Metropolder in four different Italian regions.

The world population is increasing day by day, resources required are also increasing. The United nation has predicted a population of 9.8 billion by the year 2050 which means more buildings and man made structures are going to be erected which will lead to increase in urban heat and urban heat island. To mitigate this problem various studies and solutions are being approached. As part of the Polder Roof field lab, a project supported by the European Climate-KIC programme, four MGR prototypes, called Polder Roofs and developed by the Dutch company Metropolder, have been installed in four Italian cities (Cagliari, Palermo, Perugia, and Viterbo) during Spring 2019.

This work has the potential to assess the four studies which have different parameters and different climatological conditions. These various settings were studied and analysed for a period of one year by using different parameters and different sensors according to the different setup. This study focused mainly on runoff generation and insulation properties. The runoff generation has been evaluated using two indices called MGR index of retention and GR index of retention. The thermal properties were studied using a combination of HOBO sensors and metropolder sensors. Four different indices were used to study and analyse the thermal insulation properties. They are average daily surface temperature ratio STRav,i, maximum daily surface temperature ratio STRmax, i, minimum daily surface temperature ratio STRmin,i, e daily temperature excursion ratio TERi.

By studying and analysing the four different case studies in four different Italian cities, the benefits and evaluation of multi layer blue green roofs were recorded in terms of runoff generation and thermal insulation properties.

2. **Blue Green Systems for urban heat mitigation: mechanisms, effectiveness and research directions:**

Introduction:

Urban heat island (UHI) effect is a phenomenon where urban areas experience higher temperatures compared to their rural surroundings. UHI can cause several environmental, social and health issues, such as increased energy consumption, decreased air quality, and heat-related illnesses. Blue-Green systems (BGS) have emerged as a potential solution for urban heat mitigation, as they can cool the urban environment by enhancing evapotranspiration, shading and reducing the amount of heat absorbed by surfaces. This literature review aims to explore the mechanisms, effectiveness and research directions of BGS for urban heat mitigation.

Mechanisms of Blue-Green Systems:

BGS uses natural elements such as vegetation, water bodies, and permeable surfaces to reduce UHI effect. Vegetation helps in shading and cooling by transpiration and evaporation. Water bodies act as heat sinks, and evaporative cooling helps to reduce air temperatures. Permeable surfaces allow rainwater to infiltrate into the soil, reducing surface temperature through evaporative cooling. These mechanisms help to cool the urban environment and reduce the heat absorbed by surfaces.

Effectiveness of Blue-Green Systems:
Blue Green Systems seem to have, in general, a positive impact on reducing urban heat effects. Their influence can be explained by their dominant cooling mechanisms and the magnitude of their influence varies depending on the specific System design, specificities of the urban area and background climatic conditions. At the local scale, road surface temperature can be reduced significantly by replacing conventional hard surfaces with previous or reflective pavements. Furthermore, heat storage reduction in the urban fabric, which is most relevant for nocturnal heat mitigation, can be achieved by adding greenery . Beyond the heat storage reduction, these measures ultimately contribute to reducing air temperature and improving human thermal comfort. However, their influence depends on the time of day and morphological and climatic factors. Improvement of daytime pedestrian thermal comfort can also be achieved by designing and ensuring ventilation corridors. Trees, when optimally positioned in urban street canyons, have been shown to have a significant impact in increasing human thermal comfort. Despite the usefulness of shading, particularly when space constraints inhibit the broader adoption of greenery and water bodies, detailed studies on adequate shading design are lacking. Water bodies/features can also have a positive impact in mitigating urban heat, especially during the day. The cooling potential of some stormwater-related Blue Green Systems, e.g., constructed urban wetlands, vegetated swales and bioretention systems, is, however, not yet fully understood and requires further investigation.

Conclusion:
BGS have emerged as a potential solution for urban heat mitigation, as they can reduce UHI effect by enhancing evapotranspiration, shading and reducing the amount of heat absorbed by surfaces. Several studies have shown that BGS, such as green roofs, green walls, and urban forests, can reduce air temperature by up to 2.28°C in urban areas. However, further research is needed to explore their effectiveness in different urban contexts and climates, as well as to assess their long-term effectiveness, maintenance requirements, and social and economic benefits.

3.**ASSESSMENT OF THE ENVIRONMENTAL LOADS OF GREEN FACADES IN BUILDINGS:**

The aim of this paper was to evaluate the environmental loads of a green façade, which was compared to other building exterior wall systems. Building exteriors now frequently feature green façades as a sustainable and aesthetically beautiful option. Vertical gardens known as "green façades" use vegetation to cover a building's outside walls. The goal of this literature analysis is to evaluate the environmental impacts of green building façades and contrast them with those of outside walls devoid of vegetation.

Vertical greenery systems can reduce the maintenance intervention frequency on the building envelope due to the limited fluctuation of wall surface temperatures. Heat transfer mechanism through a wall protected by plants is affected by the interposition of the green layer between the external environment and the building envelope. The outside of the plant layer acts as an optical filter. The air gap between the plant layer and the building wall acts as a thermal buffer that can reduce heat losses through the outer envelope of the building and can protect the building from dampness.

Method:
An environmental comparison was carried out among the green façade system and un-vegetated technical solutions, characterised by the same thermal effect of the green façade.Three unvegetated solutions were defined using different insulating materials. A double skin wall solution, characterised by an additional bricklayer and an unventilated air gap, was analysed as well. The effective thermal resistance of a plant layer of a green facade (Rplant), represents the effect of the vegetation layer in terms of an additional resistance applied to a bare wall. Life cycle analysis(LCA) was used to study and analyse the case studies.

Conclusion:
The environmental comparison was carried out between a green façade and un-vegetated conventional walls having the same thermal behaviour by means of additional insulation materials. The results showed that the environmental load of a green façade is among the most burdensome. Anyway, the environmental load of a green façade can be reduced by adopting some alternative constructive solutions

4. VEGETATIVE EXTERIOR FACADES FOR EVALUATION OF WALL THERMAL PERFORMANCE:

The aim of the article is to assess the thermal impacts of plants on heat transmission through building facades by developing a mathematical model of an outside wall with climbing vegetation. By lowering the exterior wall surface temperatures and heat flow through the façade, this model enables examination of how various plant physiological characteristics, including leaf area index, average leaf dimension, and leaf absorptivity, might improve facade thermal efficiency.

Method:

Plants atop walls can be utilised to minimise cooling loads by reducing conductive heat transfer through building envelopes and both (i) ambient air temperatures (reducing the heat island effect) and (ii) facade surface temperatures immediately behind the vegetation. By simulating the one-dimensional heat flux via the thickness of a vertical layer of vegetation, the proposed vegetated facade model can be used. The model takes into consideration convective heat transfer to and from plants, short-wave radiative transmission through the plant layer, long-wave radiative exchange between the plant layer and the environment, and evapotranspiration from leaves. The model depicts a layer of vertically growing plants with roots in the earth, such as flat vertical shrubs or vines growing against the outer wall of a structure without the need for soil or substrate.

The assumptions considered during the modelling were

- The model considers plants only during the growing season.
- Leaves are uniformly distributed and oriented in the vegetation layer.
- Individual leaf angles are not considered. Plant parameters including leaf absorptivity, leaf dimension, leaf area index, radiation attenuation coefficient, and plant stomatal conductance are constant and do not change with season.
- For calculating emitted radiation from the plant surface, the temperature of a leaf is assumed to be the same as air temperature.
- Heat flow through a layer of vegetation occurs only horizontally; vertical heat flux is not considered.
- External factors that may vary with height, such as wind speed, are assumed to be constant for the low-rise facades considered.
- The level of soil moisture at plant roots is constant; no precipitation is considered.
- Air beneath the stomatal pores is saturated with water.

The model does not consider wind reduction effects due to the lack of convective heat transfer coefficients at vertical vegetated facades.

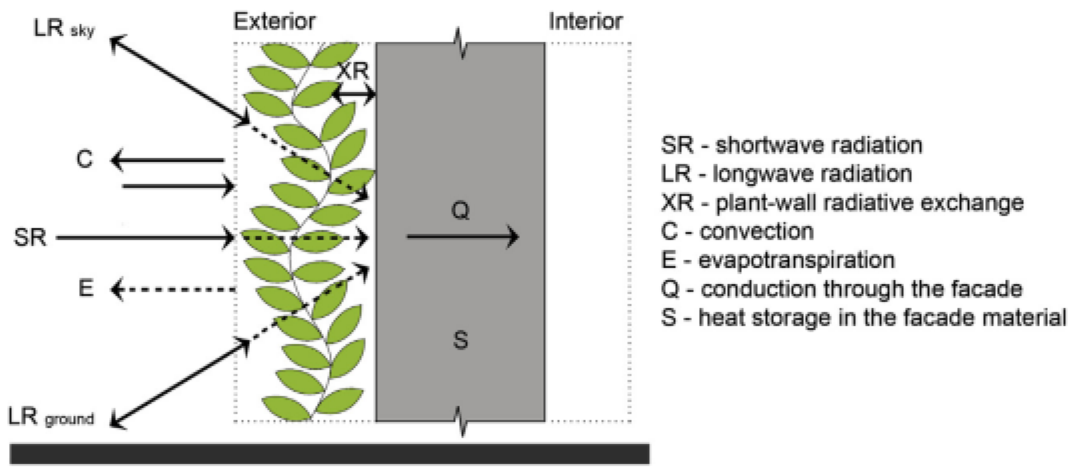
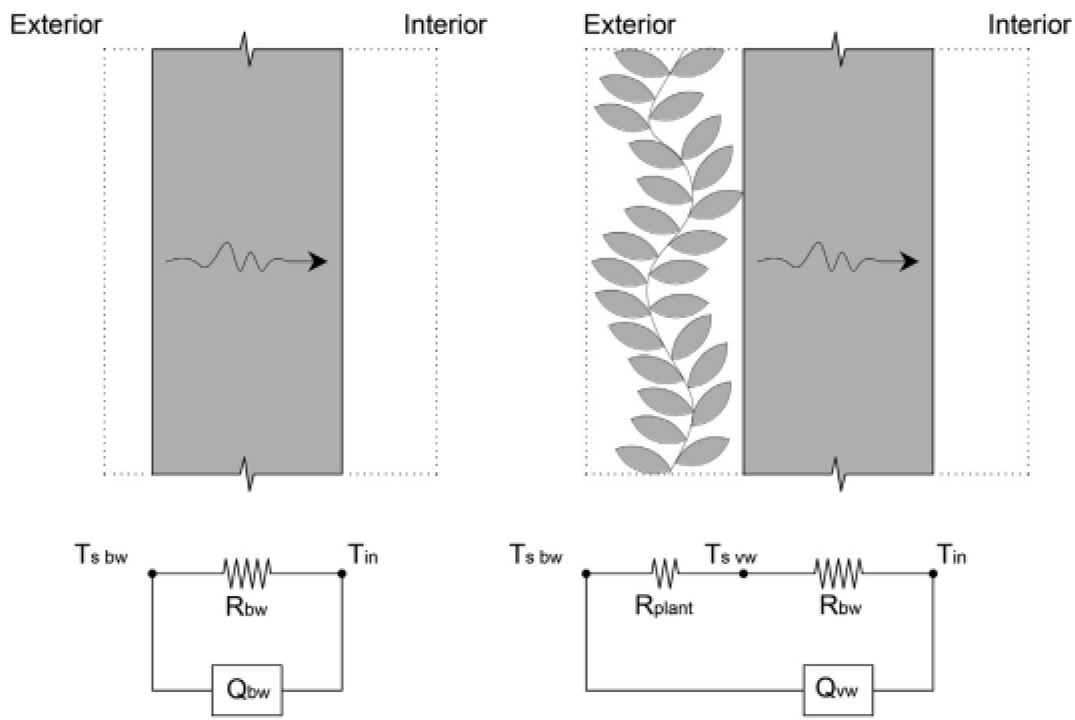


Fig. 1. Energy balance of a vegetated facade.



An experiment was conducted to validate the mathematical model . The experiment consisted of measuring the facade thermal performance of a building covered with climbing plants on the campus of Illinois Institute of Technology. Two exterior areas on the south facade were chosen, one densely covered another area with no plants. They were placed approximately 5m above the ground. The measurements were collected at a 1 min interval for four days. With the help of experimental setup, they were able to validate the surface temperature and temperature gradient.

Conclusion:
To simulate the thermal effects of a building facade covered with a layer of plants, a vegetated facade model has been created. The created mathematical model takes into account the thermal and physical processes that occur in a vegetated exterior wall, such as solar radiation transmission through the vegetation layer, infrared radiative exchange between the facade and the sky, ground, and vegetation layer, convection to and from the facade, evapotranspiration from the plant layer, heat storage in the facade material, and heat conduction through the facade. Results from a one-week experiment measuring the thermal characteristics of nearby vegetated and bare facades of an existing building on the Illinois Institute of Technology campus served as a validation for the model.

5. CHITOSAN BASED GREY WATER TREATMENT:
The term "grey wastewater" refers to the wastewater that is produced in bathrooms, showers, hand basins, laundry facilities, and kitchen sinks in homes, offices, and educational institutions. Furthermore, it's believed that around 75% of the total residential sewage is made up of grey wastewater. Grey wastewater discharge into ecosystems without treatment harms humans and other living things. Due to its high production compared to industrial operations, grey wastewater treatment is becoming increasingly important in many regions of the world.

Poly(-1-4)-2-amino-2-deoxy-d-glucopyranose, which is extensively distributed across marine and terrestrial invertebrates, is made through the deacetylation of chitin. Due to the amino ($NH2$) and hydroxyl (OH) groups present, chitosan is well known as a superior natural adsorbent/coagulant for wastewater treatment. These groups act as the centres for planning and responding in an efficient healing process. In addition, chitosan has other advantageous qualities such as being polycationic, nontoxic, biodegradable, having good adsorption capacity, and possessing antibacterial capabilities.

Methods:

The Thirugnanasambandham, Sivakumar, and Prakash Maran (2013) method was used to conduct experiments under a variety of operating parameters, including agitation speed (1-3 min), pH (2.5-5.5), chitosan dose (0.3-0.6 g/l), and settling duration (10-20 min). According to APHA standards, turbidity, BOD, and COD measurements were made.

In this study, the influence of process variables such agitation duration (1-3 min), pH (2.5-5.5), chitosan dose (0.3-0.6 g/l), and settling time was investigated and optimised using a Box-Behnken response surface experimental design (BBD) with four components at three levels. After conducting trials, a second-order polynomial equation was fitted to correlate the link between independent factors and responses, accounting for differences brought on by the linear, quadratic, and interaction effects of the process variables. This equation was used to forecast the optimal point. All variables in the model were assessed using the student's F-test, and the significance of the F-values at probability levels (p 0.05) were analysed. Pareto analysis of variance (ANOVA) was used to analyse the regression coefficients of the linear, quadratic, and interaction involved in the model as well as their impacts. Numerous statistical analyses, including sum of squares (SS), determination coefficient (R2), adjusted determination of coefficient (R2 a), anticipated determination of coefficient (R2 p), coefficient of variation (CV), and appropriate precision (AP), were used to assess the experimental data.

In order to create regression models and assess the suitability of different models (linear, interactive, quadratic, and cubic) to accurately represent the treatment process, BBD experimental data were analysed using two distinct tests, sequential model sum of squares and model summary statistics. Process variables like agitation time, Ph, chitosan dose, settling time were varied and effects of process variables were studied.

Conclusions:
In this work, BBD was used to investigate and optimise the effects of process factors on the removal of turbidity, BOD, and COD from grey wastewater, including agitation time, pH, chitosan dose, and settling time. The findings showed that every process variable significantly impacts the removal efficiency.

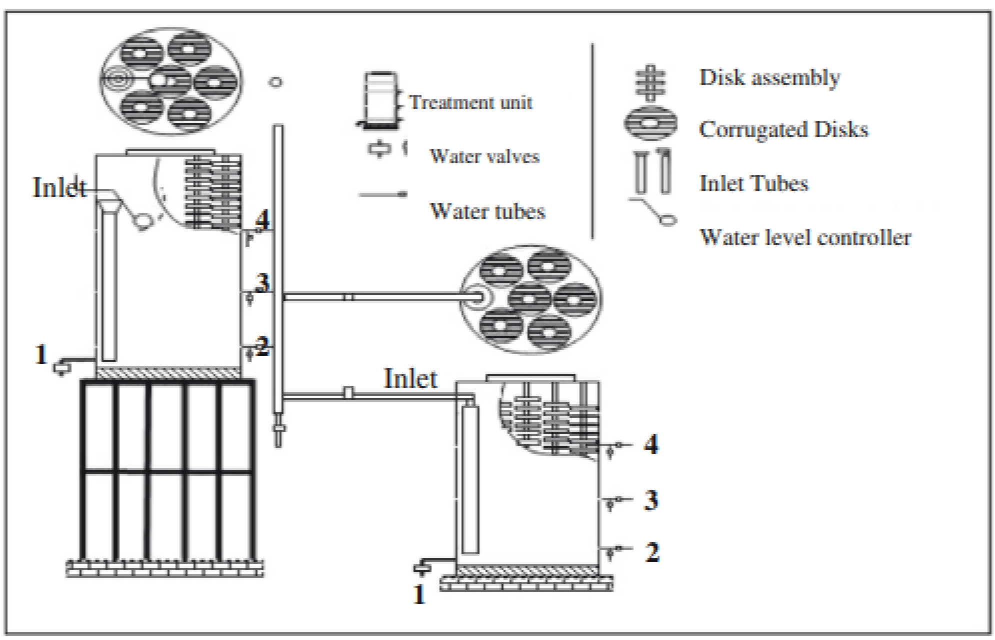
6. GREY WATER TREATMENT IN A SERIES ANAEROBIC - AEROBIC SYSTEM FOR IRRIGATION

Introduction:
Grey water is household wastewater that has been diluted and comes from the shower, laundry, and/or washbasins. However, some studies also consider the wastewater from the kitchen as part of greywater. This article focuses on a treatment technique that is reliable, easy to use, and uses the least amount of energy to purify grey water for irrigation. The end result is a system that is optimised and has an anaerobic unit that is operated in upflow mode, has a one-day operational cycle, a constant effluent flow rate, and varies the volume of the liquid.

Method:
The greywater production rate varies considerably over the day. So, to prevent the introduction of storage tanks, the system is designed as such to cope with the varying production rate. A system that has been optimised and includes an anaerobic unit operating in upflow mode, a one-day operational cycle, a constant effluent flow rate, and a variable liquid volume. The system is insulated to withstand cold conditions and has a mechanical aeration in the next aerobic step.

The 150-student dorm on the campus of the Jordanian university served as the source of the grey water, with its waste streams coming from the shower, laundry, and washbasins being discharged through a single output pipe to the sewer. Out of the 7–10 m3 day1 created, the outlet pipe was modified to directly discharge 1 m3 day1 into the pilot plant, with the remaining effluent being released to the sewer. During the university holidays, 21 days in winter and 30 days in summer, the inflow to the pilot plant was zero.

The design of an interior structure for the pilot plant's solids removal to boost solids retention in a brief hydraulic retention time (HRT) served as the foundation for the construction. Two Polyvinyl Chloride (PVC) tanks made up the pilot plant; the first served as the anaerobic unit and the second as the aerobic unit. The working volumes were 1.18 m3 and 0.98 m3, respectively, whereas the anaerobic unit had a volume of 1.2 m3 and the aerobic unit of 1.0 m3. In order to prevent overflow, a water level controller (5 cm) was supplied to the anaerobic tank, which caused a discrepancy in the working volume and empty space. The influent was introduced into the treatment system through gravitationally in a downflow or upflow method.
Two approaches were tested for aerating the aerobic tanks. One of the approaches used for aerating was using natural aeration aimed at direct contact with liquid and solid sludges with the air. The technique used was a combination of feed batch and surface distribution. The second approach was using mechanical aeration by pumping air continuously. Pumped air was regulated using a valve while maintaining the sludge at the lower level of the tank.



An autosampler collected daily composite samples from the inlet and the outlet valves. A collection tank was used to accumulate the daily aerobic affluent from where the sample was taken to different analysis.

The aerobic sludge serum bottles were aerated for 30 minutes each day for 10 days to produce aerobic conditions, then every three days for 10 days, and finally every 10 days until the experiment's conclusion. The starting and final COD, as well as the initial VS/TS ratios for the anaerobic and aerobic sludge, were calculated. In addition, the anaerobic sludge's VS/TS ratio was assessed at the conclusion.

nimum SRT, respectively.

$$SRT_{max} = \left(\frac{VX}{Q_s X_s}\right)$$

$$SRT_{min} = \left(\frac{VX}{Q_s X_s + Q_{eff} X_{eff}}\right)$$

SRT stands for sludge retention time

$$Q_{eff} = \left(\frac{\text{daily inflow volume}}{\text{discharge hours}}\right)$$

$$V_L = \sum_{t=0}^{t} Q_{in} t(\text{hr}) - \sum_{t=0}^{t} Q_{eff} t(\text{hr})$$

VL stands for liquid volume
Qin and Qeff are influent and effluent discharge

$$\frac{C_0 - C}{C_0} = (1 - \text{Exp}(-kt))$$

$$\frac{C_0 - C}{C_0} = \frac{k\theta}{(1 + k\theta)}$$

These two equations are used to calculate the COD values in a batch reactor in first order kinetic.

Conclusions:
The anaerobic unit treated raw grey, combined storage and treatment. The aerobic unit post treated the sludge from the anaerobic unit. The effluent quality complies with all parameters except pathogens.

RESULTS:
The research publications cited above were all carefully read, analysed, and numerous water and energy parameters were gathered and using the parameters, a general block diagram and process diagram were created.

WEFE COMPONENT	FUNCTION	INDICATOR	UNIT	METHODOLOGY	REFERENCES	AUTHOR
WATER	Water Bioretention	**Rainfall height**	mm	Tipping Rain Gauge	Multilayer blue-green roofs as nature-based solutions for water and thermal insulation management	Elena Cristiano
			mm	Disdrometer	Multilayer blue-green roofs as nature-based solutions for water and thermal insulation management	Elena Cristiano
			mm	Official Pluviometer	Multilayer blue-green roofs as nature-based solutions for water and thermal insulation management	Elena Cristiano
		Volume measurement	Litres	Metro Polder Station 350 L rain barrel	Multilayer blue-green roofs as nature-based solutions for water and thermal insulation management	Elena Cristiano
		Temperature	Degree centigrade	Temperature Sensors	Multilayer blue-green roofs as nature-based solutions for water and thermal insulation management	Elena Cristiano
		Moisture	m3m-3	Humidity Sensors	Multilayer blue-green roofs as nature-based solutions for water and thermal	Elena Cristiano

					insulation management	
	Water Infiltration	**Rainfall drop size**	mm	Hypodermic needle	https://doi.org/10.1016/j.agwat.2021.106756	Wei Qi
		Height	m	Scale	https://doi.org/10.1016/j.agwat.2021.106756	
		Rain intensity	mmh^-1	Peristaltic pump	https://doi.org/10.1016/j.agwat.2021.106756	
		Kinetic Energy	KJm^-3	Using velocity	https://doi.org/10.1016/j.agwat.2021.106756	
		Soil stability coefficient	-	Morin and Benyamini method: $I_t = (I_i - I_f)\, e^{-\gamma p t} + I_f$	https://doi.org/10.1016/j.agwat.2021.106756	
	Water Treatment	**COD and colourity**	mg/L	Spectrometer	https://doi.org/10.1016/j.cej.2020.125650	Zhenzhou Zhua
		Removal Rate	%	$R = \left(1 - \frac{C_p}{C_f}\right) \times 100\%$	https://doi.org/10.1016/j.cej.2020.125650	
		Permeate Flux	Litres per square metre hour	$L_p = \frac{V_p}{t\hat{A}\cdot A_m}$	https://doi.org/10.1016/j.cej.2020.125650	

		Filtration Resistance	M (litres per square metre hour)^-1	$FR = \frac{H}{L_p}$	https://doi.org/10.1016/j.cej.2020.125650	
		Hydrophilicities	Degree	Water contact angle	https://doi.org/10.1016/j.cej.2020.125650	
	Wastewater treatment	**COD**	mg/L	Closed reflux colorimetric method	https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/pdfdirect/10.1002/tox.20016	L. Howard
		BOD	mg/L	Metabolic Rate = Number of Organisms x 0.039 mg O2 / L	https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/pdfdirect/10.1002/tox.20016	L. Howard
		TDS	mg/L	measured by weighing the amount of solids present in a known volume of sample	https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/pdfdirect/10.1002/tox.20016	L. Howard
		TSS	mg/L	(dry weight of residue and filter − dry weight of filter alone, in grams)/ mL of sample * 1,000,000	https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/pdfdirect/10.1002/tox.20016	L. Howard
	Water Pollution	**Change in physical and chemical properties of water**	Richness of macroinvertebrate community	By using macroinvertebrates	https://www.water.wa.gov.au/__data/assets/pdf_file/0018/4527/12591.pdf	WATERWATCH WA, Publications.
		Metal pollution index	-	By using macroinvertebrates (Fish L. rohita and E. crassipes plant)	https://www.sciencedirect.com/science/article/pii/S1319562X21009311?via%3Dihub	Shams Tabrez

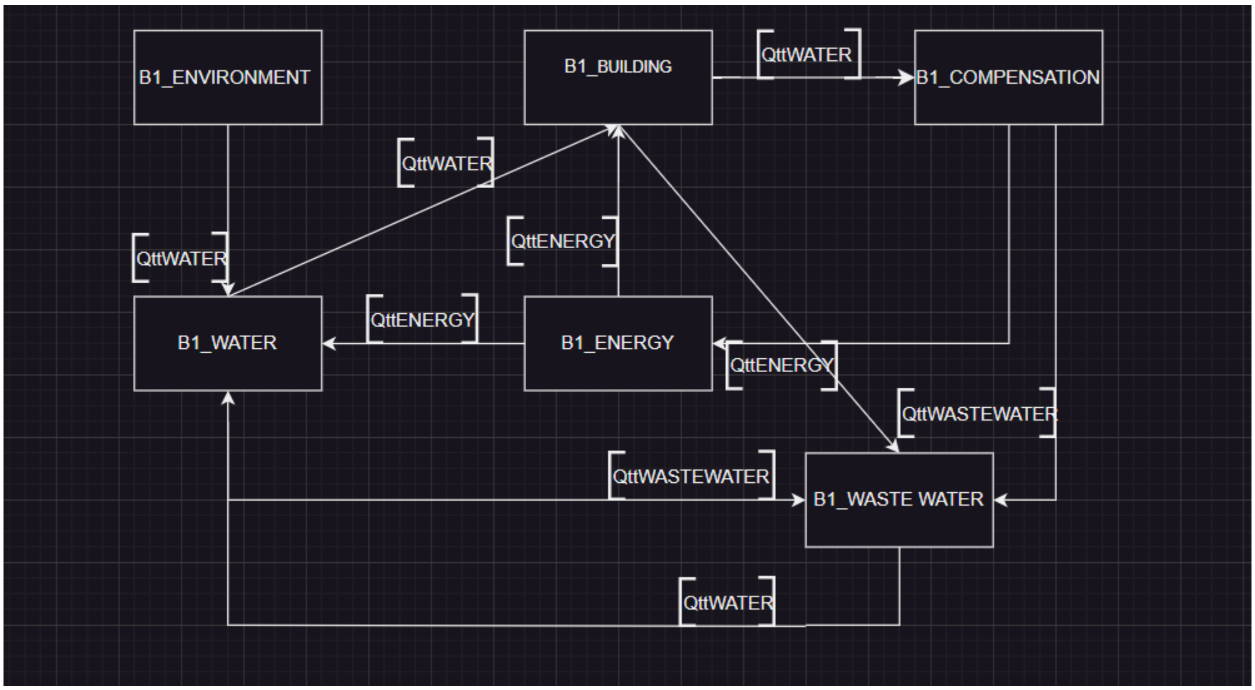
				$MPI = (Cf_1 \times Cf_2 \times \dots Cf_n)^{1/n}$		
		Water quality index	Number between 1 and 5	By using macroinvertebrates (Fish L. rohita and E. crassipes plant) $SIi = Wi \times qi$ $WQI = \sum SI_{i-n}$	https://www.sciencedirect.com/science/article/pii/S1319562X21009311?via%3Dihub	Shams Tabrez
		pH level of water	0 to 14	Litmus paper test	https://www.sciencedirect.com/science/article/pii/S1319562X21009311?via%3Dihub	Shams Tabrez
		Dissolved Oxygen	mg/L	Dissolved oxygen meter	https://www.sciencedirect.com/science/article/pii/S1319562X21009311?via%3Dihub	Shams Tabrez
	Groundwater pumping	**Groundwater level**	m	$H_0^2 - H^2 = \frac{Q}{2\pi K} W(u), \theta = KH$	Model of evapotranspiration and groundwater level based on photovoltaic water pumping system - ScienceDirect	Jun Zhang
		Energy required to pump groundwater	MJ	Energy required for photovoltaic pumping $R_n \cdot A \cdot n \cdot \eta \cdot \Omega = Q_t \cdot \rho \cdot g \cdot$	Model of evapotranspiration and groundwater level based on photovoltaic water pumping system - ScienceDirect	Jun Zhang
		Ground water budget	m^3	$V_{t+1} = V_t - W(V_t) - L(V_t) + R_t.$	https://doi.org/10.1029/2011WR010617	Ram Mukul Fishman
		Water Extraction Volume	m^3	Pulsed Pumping	Model of evapotranspiration and groundwater level based on	Jun Zhang

					photovoltaic water pumping system - ScienceDirect	
	Water Distribution	**Volume**	m^3	Flowmeter	http://hdl.handle.net/2117/112934 .	Ramon Pérez
		Emptying form factor	-	$AE\_E\_Cf\_AC = \sum_{j=0}^{k}\left(q_{X257}(j) - \frac{q_{X111}(j)}{ff_{AE}}\right) * \Delta$	http://hdl.handle.net/2117/112934 .	
	Drainage - runoff	**Measurement of runoff water through small area (Pipeline)**	m^3	1D conduit	Simulating the storm water runoff and drainage of the south urban district in the Taiyuan Basin with a 1D – 2D model	Y Q Long
		Measurement of runoff water through broad road and farms	m^3	2D meshes	Simulating the storm water runoff and drainage of the south turban district in the Taiyuan Basin with a 1D – 2D model	Y Q Long
		Measurement of runoff water through broad road and farms wide rivers	m^3	Both 1D conduit and 2D meshes	Simulating the storm water runoff and drainage of the south turban district in the Taiyuan Basin with a 1D – 2D model	Y Q Ling
	Desalination	**Salinity**	mg/L	Salinity meter	Desalination techniques — A review of the opportunities for	Stewart Burn

					desalination in agriculture	
		Sodium absorption ratio	-	$SAR = \frac{[Na^+]}{\left\{\frac{([Ca^{2+}] + [Mg^{2+}])}{2}\right\}^{1/2}}$	Desalination techniques — A review of the opportunities for desalination in agriculture	Stewart Burn

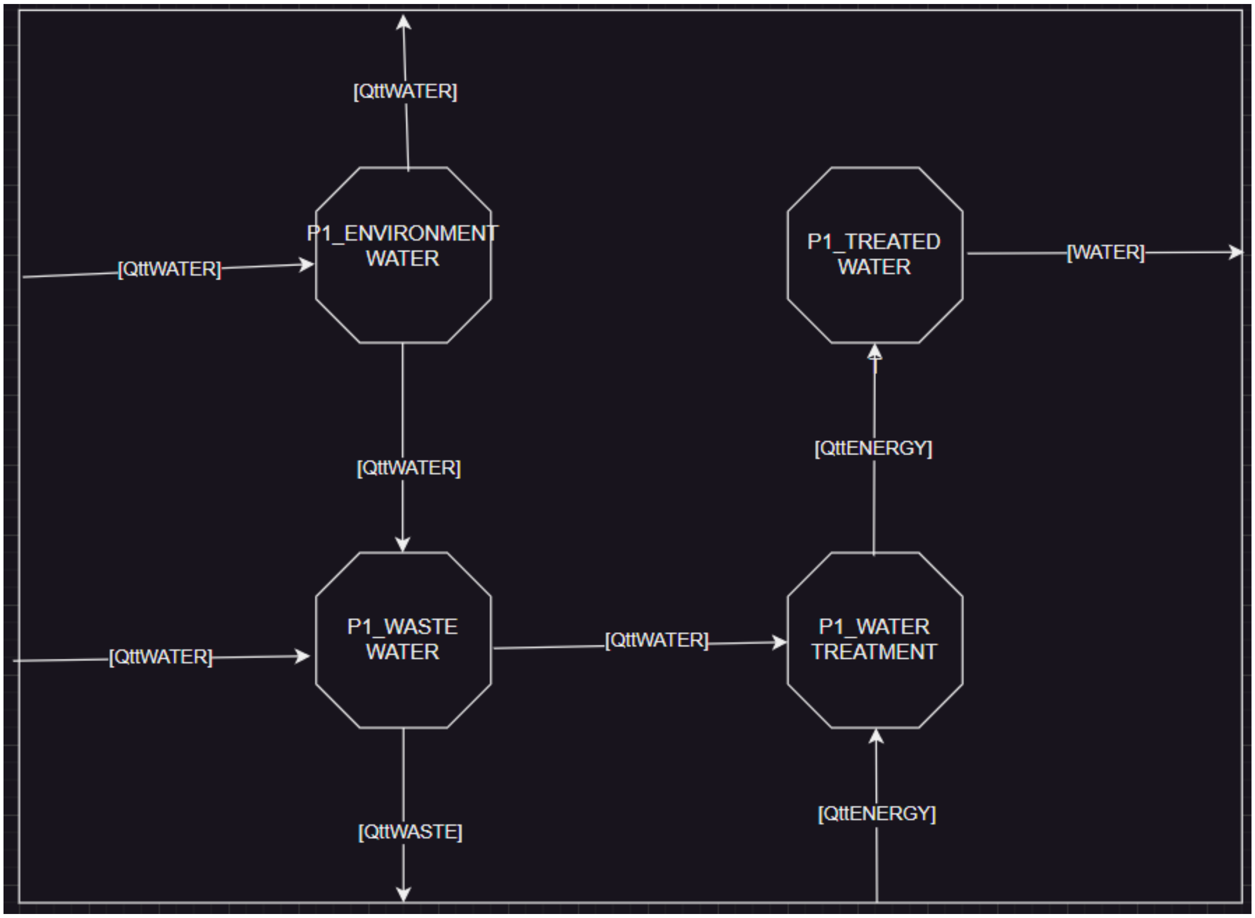
WEFE COMPONENT	FUNCTION	INDICATOR	UNIT	METHODOLOGY	REFERENCES	AUTHOUR
Energy	**Water infiltration**	Raindrop kinetic energy	KJ m^-3	Drops generated using hypodermic needle and varying height of the fall	Irrigation with Effluent Water: Effects of Rainfall Energy on Soil Infiltration	A. I. Mamedov
Energy Recovery	**Water Distribution**	Energy Recovered	kWh	$\Pr = \eta h.Qs.\Delta p$	https://doi.org/10.1007/s40430-021-03213-z	Davi Edson Sales e Souza
Energy	**Desalination techniques**	Energy cost for seawater feed	kWh/ m3	(Watts*hrs)/1000	Desalination techniques — A review of the opportunities for desalination in agriculture	Stewart Burn
		Electroconductivity	dS/m	Conductivity metre		
PAT parameters	**PAT used in desalination process**			$H = \frac{P_{in} - P_{out}}{\rho g}$ $P = M \cdot \frac{2\pi n}{60}$ $\eta = \frac{P}{\rho g Q H} \times 100\%$	https://doi.org/10.1007/s40430-021-03143-w	Bing Qi
Energy	**Pressurised irrigation system**	Energy consumed by the pump	kWh	$E = \left(\frac{\gamma QH}{\eta}\right)t$	https://link.springer.com/article/10.1007/s10098-021-02043-w#auth-Morteza-D	Morteza Delfan Azari

					elfan_Azari	
Energy	**Energy required to pump groundwater**	Energy required for photovoltaic pumping	MJ	$R_n \cdot A \cdot n \cdot \eta \cdot \Omega = Q_t \cdot \rho \cdot g \cdot H$	[Model of evapotranspiration and groundwater level based on photovoltaic water pumping system - ScienceDirect]()	Jun Zhang

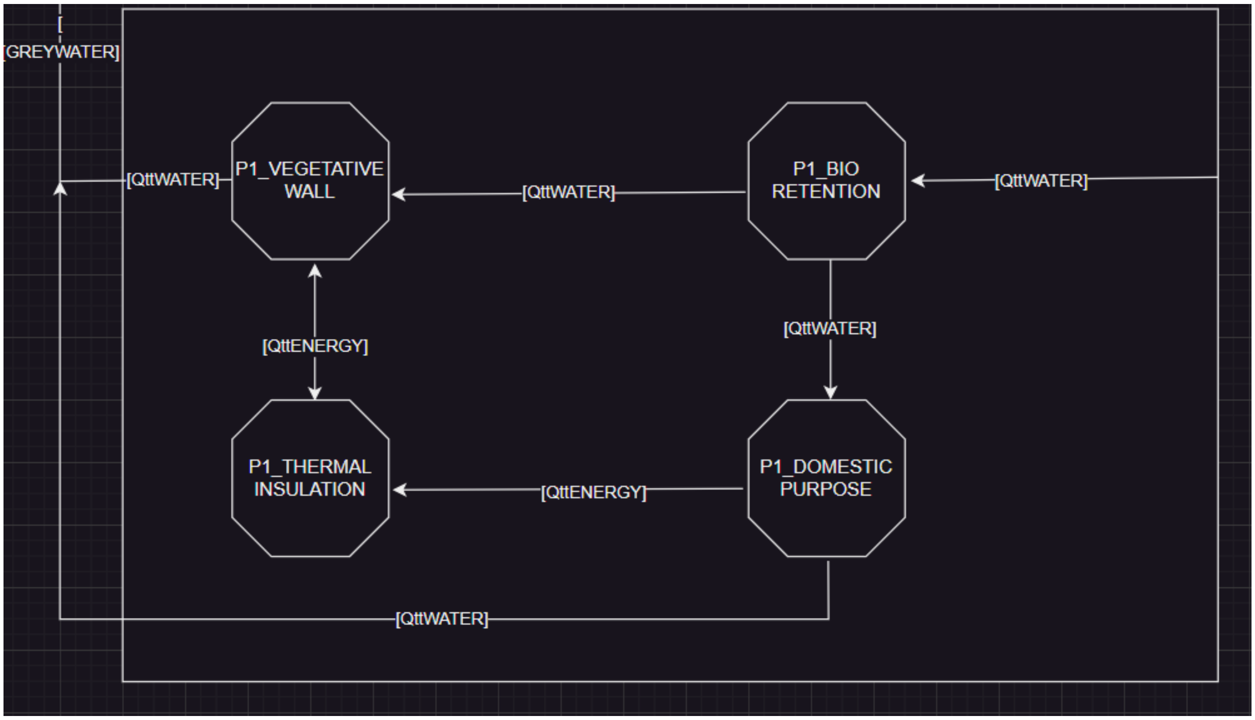


Using Visio and Draw.io with the parameters gathered, a generic block diagram was created. According to the block diagram that we are creating, the environment block can be understood. The environment in this block diagram illustrates the readily accessible water sources, such as wells, lagoons, rivers, ponds, etc.

From the water sources, water is supplied to the building for domestic purposes, while the water that is unfit for usage is sent to the water block where treatment of water is done and is resupplied and the water that is unfit for usage even after treatment is ejected out. The water and energy blocks are interrelated as some energy is required to pump out of the water and in some cases, water is used for energy production. Energy is also required for waste water treatment and for controlling the valves. Using the energy compensation block, we are trying to recover some energy using a pump as a turbine(PAT) in which water is made to flow with a certain pressure head with a certain height.



This is a detailed process diagram of the water block used in the generic block constructed. Qttwater represents the amount of water in litres and Qttenergy represents the amount of energy in Kilowatt per hour. Environment water is derived from water sources like rain, glaciers, rivers, ponds etc. The water from the environment is checked whether it can be used for domestic purposes or not. Water quality is checked using various parameters like BOD, COD, nitrate content, sulphur content etc. Based on the decision taken, water flow takes place in two different directions. If the water is deemed to be suitable for domestic purposes, water is supplied directly to the building and if not deemed suitable, water is sent to the waste water storage and then later sent to the treatment block where water is treated using various methods and sent to the treated water block. The treated water is sent to the building for domestic purposes, while the water which is deemed unsuitable even after treatment is ejected out.



The above block diagram consists of the process taking place in the building block. It consists of a vegetative wall, bio retention and living space. Water from the environment block or from the treated water block enters into the bioretention block from where we can use the water for different purposes either for domestic purposes or crop production. Water from bioretention can also be used for the vegetative wall which helps in thermal insulation of the building using cork or different materials with a vegetative layer. The wastewater from the vegetative wall and domestic purpose is sent to the waste water block as greywater where treatment of water takes place and recycling of the water is done. The vegetative wall also helps in reducing the urban heat and urban heat island. There is a two way interaction between vegetative wall and thermal insulation block in the process diagram. The absorbed heat is released into the environment or absorbed by the vegetative wall.

CONTRIBUTION TO WEFE NEXUS:

The concept known as WEFE (Water-Energy-Food-Ecosystems) Nexus acknowledges the interdependence of water, energy, food, and ecosystems. The following are some ways that a multipurpose vegetated wall for building thermal insulation and greywater treatment can benefit the WEFE Nexus:

1. Water: A wall made of vegetation can clean graywater, lowering the need for freshwater supplies. By easing the strain on freshwater supplies, particularly in areas where there is a shortage of water, this can help ensure water security and sustainability.

2. Energy: By providing thermal insulation to structures, a green wall can lessen the demand for energy-guzzling heating and cooling systems. This can improve energy efficiency and sustainability by lowering energy use and greenhouse gas emissions.
3. Food: Although a vegetated building wall may not directly contribute to food production, it can offer habitat for animals such as pollinators and other creatures that are crucial to preserving the ecosystems that sustain agricultural and food production.
4. Ecosystems: A vegetated wall can boost biodiversity in urban areas, provide habitat for wildlife, and serve to lessen the detrimental effects of urbanisation on ecosystems. This may support the sustainability and health of the environment.

Overall, by fostering sustainability and resilience across the water, energy, food, and ecosystems sectors, a multifunctional vegetated wall for thermal insulation and greywater treatment of buildings can support the WEFE Nexus.

CONCLUSIONS:

The multifunctional vegetated wall for thermal insulation and building greywater treatment has been described in general detail in this report. The paper has emphasised the many advantages of the vegetated wall, including its capacity to offer thermal insulation, treat greywater, enhance the aesthetic value of buildings, and lessen the effects of urban heat islands. The report has also covered the vegetated wall's contribution to the Water-Energy-Food-Ecosystems Nexus concept, acknowledging its potential to advance sustainability and resilience in a number of different industries. We also created a generic block diagram and process diagram for the building and the water and explaining about the relations and interactions between them.

The multifunctional vegetated wall is a sustainable and creative solution that has major advantages for the built environment, as this report has emphasised. The vegetated wall is a viable answer to the problems facing metropolitan regions by lowering energy use, preserving water resources, and enhancing ecosystem health. In order to fully grasp the potential of the vegetated wall and to enhance its performance, the paper also covered the significance of ongoing research and development in this field.

The multifunctional vegetated wall is crucial for achieving sustainability and resilience in the built environment, as this paper concludes. The vegetated wall presents a promising approach for developing sustainable and habitable communities because of its many advantages and potential for fostering the Water-Energy-Food-Ecosystems Nexus.

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