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Short Communication

Smart Heating, Ventilating, Air-conditioning and Refrigeration by Web-based Geographic Information System

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Abstract

Objective: Heating, ventilating, air-conditioning and refrigeration (HVAC&R) systems currently account for a significant portion of energy consumption. The HVAC&R system contributes the largest energy consumption in a building, so it is essential to optimize energy consumption to improve energy saving worldwide.

Methods: The web-based geographic information system (GIS) enables the seamless sharing of spatial data across the globe, accessible anytime and anywhere via the World Wide Web. The set of remote reading networked sensors, advanced modems, and data loggers facilitate the intercommunication for the geodatabase of HVAC&R's facilities. The integration of remote sensing technology and the Internet of Things, grounded in GIS establishes a control loop dedicated to energy conservation. This method is a pioneering concept in control science, offering significant potential for enhancing design, maintenance, and energy management practices. It empowers energy users with real-time control over their energy consumption, making a substantial advancement in this field.

Results: In this work, the model of HVAC&R control in context with web-based GIS showed that the regression mathematical analysis in compliance with the computational method holds the capacity to predict energy consumption and evaluate energy loss.

Conclusion: In regression analysis, the *P* was found to be 0.991 for the percentage of dissatisfaction, 0.977 for energy use intensity, and 0.962 for data envelopment analysis efficiency. Additionally, the curve estimation showed that the power function was utilized in regression analysis processes.

Keywords: energy loss, internet of things, geographic information system, HVAC&R, energy saving

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1 INTRODUCTION

In the 21st century, the global focus on energy conservation has led the international community to employ networked sensors and the Internet of Things (IoT) in conjunction with the geographic information system (GIS) for the management of thermal, refrigeration, and air-conditioning industries. Presently, the engineering of heating, ventilating, air-conditioning, and refrigerating (HVAC&R) emphasizes intelligent operation methods[1].

1.1 Why are Networked Sensors and IoT Based on the GIS?

The installations, proper operation, use efficiency, and cost-effectiveness of the HVAC&R facilities rely on georeferenced mapping. The purpose of the operation is to ensure the proper use of the HVAC&R equipment throughout its lifespan. Scientific utilization of the facilities requires up-to-date map information through a web-based GIS (Figure 1). Given the vast amount of data, updating facility map information in GIS format allows for rapid extraction of various data points. A robust, efficient database of servers can solve many problems faced in HVAC&R. Conversely, if facility information is manually recorded, there is a risk of it being forgotten over time.

Beyond software, GIS is a science that classifies the geodatabase of HVAC&R facilities, followed by meticulous analysis with different software. This science has recently found its place in engineering systems. The use of GIS in systems development plans by employers is also on their agenda.

In many countries, the HVAC&R development association has integrated GIS into their plans for HVAC&R development. This includes providing training to energy professionals and energy utilities. Therefore, experts should first prepare scanning, editing, and layered facilities maps, ensuring they accurately depict subsequent changes[2,3].

1.2 Energy Consumption Management

Energy consumption management is the science of controlling and optimizing energy consumption through the integration of networked sensors. The IoT devices such as switches, control valves, and actuators, are integrated for energy consumption. They also allow for remote control of the users' equipment. This equipment is centrally managed by an equal text interface while enabling advanced programming functions (such as turning on and off the remote heating appliances, controlling the stove, changing lighting conditions, etc.). IoT devices are also available for surveillance and the mechanical, electrical, and electronic systems in various buildings (e.g., public and private, industrial, industrial, and residential) and building automation systems.

The present work delves into two main fields in this area[4-6]:

- Energy-saving by "smart buildings".
- Real-time monitoring to reduce energy consumption.

By creating extensions in HVAC&R / ArcGIS-ArcMap software, the work investigated troubleshooting, control, and optimization of power consumption through the online control model in context with the World Wide Web (Figure 2)[7,8].

1.3 Industrial Internet of Things (IIoT)

The IIoT is one of the most important and widely used areas of IoT deployment in the HVAC&R system. IoT, signifying the application of technology in industrial sectors and its utilization as a smart industrial network, is pivotal in industrial settings. Through the integration of all objects in industrial units online, it establishes a cohesive network for information exchange, control, and monitoring. This technology is identified as one of the five major technologies set to profoundly impact the future of industrial automation across all industries, including HVAC&R systems.

In this work, design factors such as thermal resistance of walls, temperature factor, and energy consumption unit were investigated. The consumption data, temperature, and power consumption factors on energy use intensity (EUI) factors such as input, output, and efficacy were evaluated using the regression model. Factors including total heat power, occupancy rate, unit income level, and unit energy income contribute to increased energy consumption, and temperature factors can lead to energy consumption decrease. In addition, mathematical analysis of the regression model yielded a framework for managing energy consumption and saving energy through a multi-factor analysis method[9,10].

1.4 Operating Principles and Process for HVAC&R Control by Web-based GIS

The key to smart control of HVAC&R systems lies in the measurement of parameters such as temperature, humidity, air velocity and pressure. These data were received by local area networks (LAN) and wide-area networks (WAN) through networked sensors, advanced modems, and data loggers. LAN intercommunicates data in district area, and WAN operates in a wide computer network worldwide. The networked sensors are installed

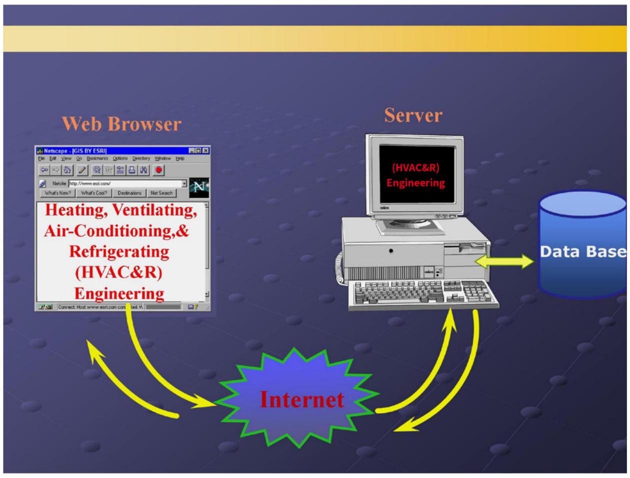

Figure 1. Networked sensors, IoT and GIS for energy saving.

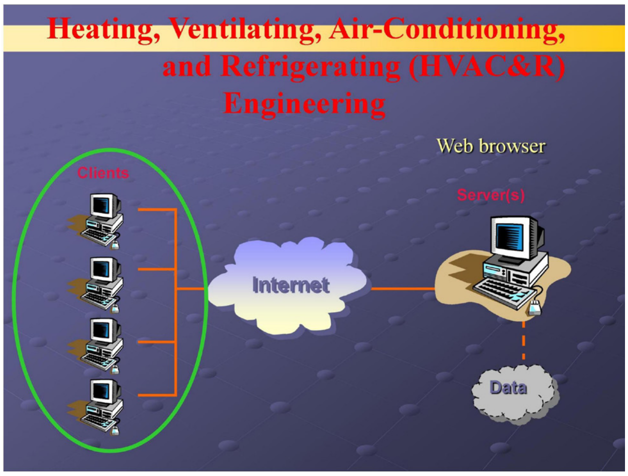

Figure 2. Energy consumption management by web-based GIS.

on the path of the hot water conduit in the heat generator or the path of the chilled water conduit in the chiller. The networked sensors also are positioned on the path of the collector of the facility and the external environment of the building. Through web-based GIS, the parameters of HVAC&R can be scrutinized in relation to their spatial coordinates. The georeferenced analysis of HVAC&R can be used for the computation of EUI and energy consumption (kBtu).

2 RESEARCH METHODS

In this work, geodatabase values of energy consumption web-based GIS model were analyzed. First of all, the classes and subclasses data of facilities were recorded in GIS. These procedures were instrumental in empowering the intelligent model with the following aims:

- Quick handling of HVAC&R system accidents.
- Energy saving by control of HVAC&R system facilities.
- Recording geodatabase of HVAC&R system data by using GIS.
- Ability to track and execute HVAC&R system analyses.

This work also investigated the energy-saving status of three building groups using the web-based GIS. This study employed an online control model to optimize energy consumption by determining EUI. To examine energy intensity, this work used the web-based GIS for better visualization of system components, ease of change, and ability to filter data for the three groups' design (Table 1). This procedure provided maintenance, energy management, and commissioning of the buildings and compared the intensity of the building energy consumption for the three groups while optimizing their energy consumption.

Implementing online control of the HVAC&R system led to modern, comfortable, and smart buildings. It not only contributed to energy savings through the use of standardized equipment but also facilitated various intelligent processes in smart homes, including:

- Ability to define intelligent scenarios.
- Load management and energy consumption of buildings.
- Ability to control and execute commands remotely via phone, and internet.
- Control of HVAC&R heating, cooling, and air conditioning systems.

2.1 Research Tools

The research tools included: meters for consumption data; temperature meters; sensors for power consumption factors on EUI factors; Global Positioning System (GPS) for collection of geospatial data; GIS software; remote sensing (RS) facilities; advanced modems; data loggers; networked sensors. The smart building control management systems included the following components:

2.1.1 Building Automation System

It encompassed the array of systems for controlling and monitoring building equipment, aimed at reducing both labor and energy consumption.

2.1.2 Energy Management System

This referred to the combination of manual and automatic control systems for monitoring building equipment, designed to conserve both labor and energy consumption.

2.1.3 Facility Management System (FMS)

In the case of a specific building system, the main functions of the FMS encompassed tasks such as fire alarm, security, or control, particularly within the domain of HVAC&R.

2.1.4 Building Management System

The set of smart control management systems included

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Table 1. Minimum Heat Resistance of Non-light Transient Wall R (W/m²·K)

Group	Group	Group	Building Group in Terms of Energy Savings	
1.5	2.1	2.8	Style	Wall
1	1.4	1.9	Heavy	
0.8	1.1	1.5	Adjacent to uncontrolled space	
2.7	3.7	5	Style	Ceiling
2.2	3	4	Heavy	
1.7	2.3	3.1	Adjacent to uncontrolled space	
1.6	2.2	3	Style	Floor
1.3	1.8	2.4	Heavy	
1	1.3	1.8	Adjacent to uncontrolled space	
2	2.7	3.7	Peripheral insulation	Floor foam
0.9	1.3	1.7	Insulation all below the surface	

building maintenance and planning.

2.2 Formulation

The heat transfer formula is the following Equations (1) and (2)[11,12]:

$$\dot{Q} = h.A.(T2 - T1)\ (1)$$

Where:
$\dot{Q}$: Overall heat transfer rate.
A: Surface area where the heat transfer takes place (m^2).
$T2$: Temperature of the surrounding fluid (K).
$T1$: Temperature of the solid surface (K).
h: Heat transfer coefficient (W/m^2·K).

$$q = {}^{d\dot{Q}}/_{dA}\ (2)$$

Where:
q: Heat flux (W/m^2), i.e., thermal power per unit area.

The transfer coefficient is the following Equation (3):

$$h = {}^{q}/_{\Delta T}\ (3)$$

Where:
ΔT: Temperature difference.

A simple method for determining an overall heat transfer coefficient that is useful to determine the heat transfer between simple elements such as walls in buildings or across heat exchangers, as shown below [Equations (4) and (5)]:

$$^{1}/_{U.A} = \left(^{1}/_{h_1}.A_1\right) + \left(^{dx_\omega}/_{k.A}\right) + \left(^{1}/_{h_2}.A_2\right)\ (4)$$

Where:
U: The overall heat transfer coefficient (W/m^2·K).
A: The contact area for each fluid side (m^2).
k: The thermal conductivity of the material (W/m^2·K).
dx_ω: The wall thickness (m).

$$P = U.A.T\left(^{W}/_{K}\right)\ (5)$$

Where:
P: Total thermal power (W).
U: Heat transfer coefficient (W/m^2·K).
A: Area (m²).
T: Temperature (K).

2.3 Data Envelopment Analysis (DEA) Method

A multi-factor productivity analysis method was employed to assess the relative efficiency of a specific building by decision-making units (DMUs). These DMUs contain a homogeneous set of equipment, allowing for the evaluation of performance across various objects. The purpose of this work is to derive a building energy efficiency score (Tables 2 and 3) for each DMU. Regression analysis was conducted to explore the relationship between dependent and independent variables.

This research was a quasi-experimental study, and the researcher intends to use EUI in the GIS space. The research was conducted by field method using regression analysis. In addition to using regression analysis or analysis of variance, ANOVA and *t*-test are defined for the research model. The parameters of the regression model are[13-19]:

- Input EUI (kWh/m^2).
- Outputs percentage of dissatisfied (PPD) DEA score.
- Efficiency.

2.4 Regression Method

Regression analysis is essential for estimation and forecasting in the engineering field. It stands out as one of the most widely used statistical techniques. The use of one variable to predict another variable is called regression. Through regression, a known and

Table 2. Results of the Computational Model of Energy Use Intensity (Inputs)

Working Time (Hours)	Input (EUI) (kWh/m^2)	Building Code
9	78	101
11	80	102
8	80	103
7	80.8	104
9	79	105
8	81	106
7	80.4	107
39%	1.20%	Difference (%)

Table 3. Results of the Computational Model of Energy Use Intensity (Outputs)

DEA Efficiency Score	Outputs CO_2 (ppm)	Outputs Percentage of Dissatisfied (%)	Outputs Occupancy Density
0.77	799	17.1	0.2
1	866	17.5	0.21
0.87	777	33.2	0.2
0.43	901	34.1	0.24
0.73	821	20.8	0.18
0.88	920	35	0.2
0.71	790	19.9	0.19
82%	43%	77%	42%

predicted variable is employed to forecast the values of another unspecified variable. It determines the rate of change in one variable due to the influence of another, thereby quantifying the alteration in the dependent variable. Regression can be conducted with either one or two variables. Single-variable regression has one independent variable and one function variable, but two-variable regression involves one function variable and two independent variables. To begin with, there must be a linear relationship that forms the scatter plot of the original concept. The hypotheses of this work encompass the following points[20-23].

2.5 Hypothesis One

There was a significant relationship between input (independent variable) and outputs (dependent variable) [Equation (6)]:

$$Output = f(Input) \quad (6)$$

Dependent variable: Outputs / PPD.
Independent variable: Input / EUI.

2.6 Hypothesis Two

There was a significant relationship between DEA and input (independent variables) and outputs (dependent variable) [Equation (7)]:

$$Outputs = f(DEA\ Efficiency, Input) \quad (7)$$

Dependent variable: Outputs / PPD.
Independent variables: DEA, Input / EUI.

3 RESULTS AND DISCUSSION

This work employed a web-based GIS integrated with networked sensors, advanced modems, data loggers, RS, and IoT to establish a computational model for HVAC&R. The spatial data and non-spatial data were recorded as queries and fields based on the GIS through relationship classes definition. Figure 3 illustrates the geodatabase analysis, representing block height as EUI and energy consumption in kBtu. The GIS-ready for HVAC&R systems was established through the flowing procedures (Figure 3):

- Convert graphics data from DWG format to SHP.
- Completing the non-spatial and spatial information layers.
- Preparation of conceptual model.

The dependent variable (PPD) correlation with the independent variables (EUI and DEA) is presented in Figures 4 and 5. Interactive graphs for PPD and DEA reveal both the strength and nature of their correlation. Through curve estimation via regression analysis, the regression function was determined. The 3D scatter diagram (Figure 4) for PPD, EUI, and DEA, and the interactive graph for PPD and DEA (Figure 5) visually demonstrates how the regression line aligns with the overall distribution of points in the nominal coordinate

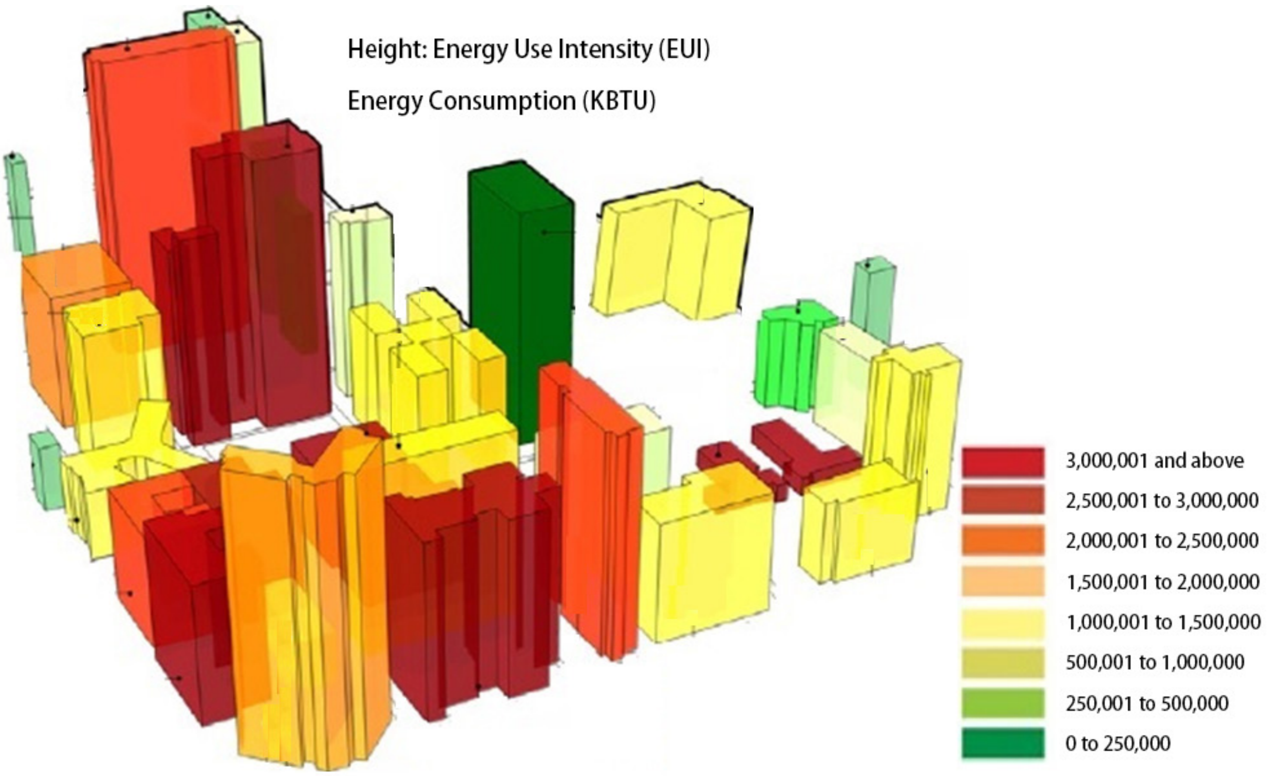

Figure 3. Energy use intensity results.

system.

The curve estimation method derives regression functions described by [Equations (8)-(14)]:

$A = 2.5086 - 0.0218x$ Linear function, (8)

y = -0.9070 + $133.945f^{-1}(y)$ Inverse function, (9)

$y = 1.6549\text{-}0.0001x^{-0.0001}$ Quadratic function, (10)

$A = 40.1875e^{t} + 0.9514$ Compound function, (11)

$y = 2.3\text{E}+07x^{-3.9311}$ Power function, (12)

$y = f^{0}(-4.1690, X, 0.0499)$ S function, (13)

$y = 0.0249x+1.0511$ Logistic function, (14)

Due to the parameter limitations, the power function is shown in (Table 3). The PPD varied with the EUI, as shown in Equations (15) and (16).

$f(x) = y = cx^{p}$ (15)

$y = 2.3\text{E}+07x^{-3.9311}$ (16)

Where:
y: PPD.
x: EUI.

c and *p*: The parameters are determined by the linear least-squares method using data from the ten parameters tested.

The *P* is the level of marginal significance within a statistical hypothesis test representing the probability of the occurrence of a given event. The *P* is used as an alternative to rejection points and signifies the smallest level of significance at which the null hypothesis would be rejected. In this work, the following procedure was done for the *P* evaluation:

- The experiment's expected results.
- The experiment's observed results.
- The experiment's degrees of freedom.
- Comparison of expected results to observed results with chi-square.
- A significance level.
- Approximation of the *P* by using a chi-square distribution table.
- Approximation the of *P* for the R experiment.

Based on the hypothesis and the experimental results, if the *P* is lower than the significance value, it suggests that the observed results would be highly improbable if there were no meaningful relationship between the manipulated variables. In this work, the *P* for three variables including PPD, EUI and DEA efficiency are as the flowing (Tables 4 and 5):

(1) *P* for PPD:
Chi 2 = 1.200, DF = 7

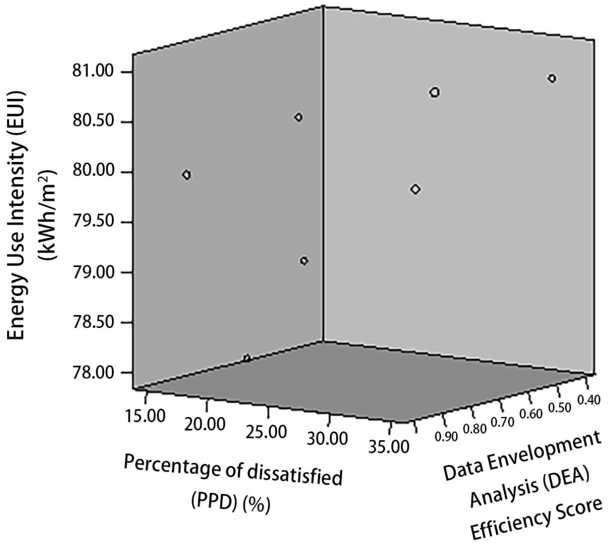

Figure 4. 3D scatter diagram for PPD, EUI, DEA.

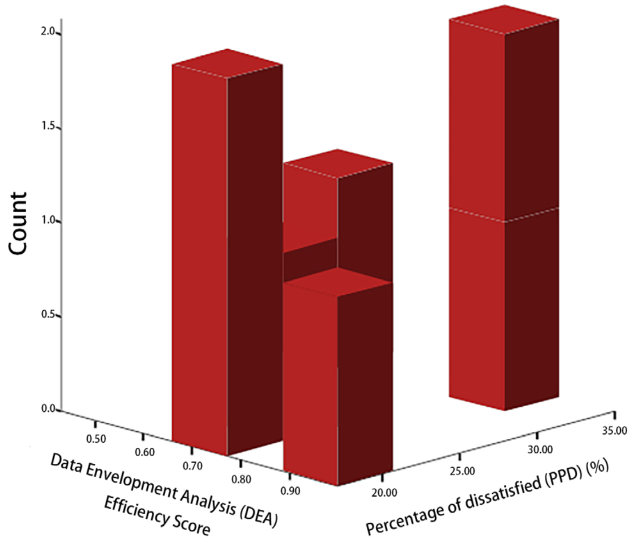

Figure 5. Interactive graph for EUI, PPD, DEA.

The *P* equals 0.991.

By conventional criteria, this difference is considered to be not statistically significant.

(2) *P* for EUI:

Chi 2 = 1.200, DF = 6

The *P* equals 0.977.

By conventional criteria, this difference is considered to be not statistically significant.

(3) *P* for DEA efficiency:

Chi 2 = 0.000, DF = 9

The two-tailed *P* equals 0.962.

3.1 Comparison of the Results of This Work with Other Experts' Works

Today, researchers are employing a combination of a mathematical model (statistical regression analysis), GIS in mapping, advanced control technology (IoT), and smart systems to achieve energy saving in HVAC&R systems. This approach, which falls under the domain of smart control science, has garnered widespread attention and study from experts worldwide. The present work investigated the optimization methods for energy consumption in HVAC&R systems. Upon comparing the results with other studies, similarities emerge in the application of smart control science for energy saving in HVAC&R systems[24]. However, this work focused more on data intercommunication through geospatial WAN, as opposed to LAN. While LAN facilitates data exchange in a localized area, WAN operates across a broader global network of computers, enabling energy consumption monitoring via RS. The main rationale for this selection lies in GIS's remarkable capacity to swiftly process vast datasets, delivering analytical results and decision-making capabilities in mere seconds. A group of researchers has previously explored this method[25]. The results of their work align closely with the present work, especially on IoT and GPS applications in worldwide communications and control for energy saving in HVAC&R systems.

3.1.1 Practical Examples for Smart HVAC&R Control

In the context of heating and cooling system control, the information received from the sensors aligns with the predetermined control parameters. The burners or chillers are activated at the designated times. The hot water or chilled water consumption is managed through the operation of burners, and circulation pumps are controlled. The hot water or chilled water condition can be controlled in the thermal facilities both in summer or in winter mode by web-based HVAC&R (Figure 6).

4 CONCLUSION

The present work evaluated energy consumption and energy loss within HVAC&R facilities, conducting energy audits of buildings and establishing consumption patterns in energy. The research method in this work was documentary-analytical, and the type of research was analytical-practical, providing practical solutions to the issues examined. The results underscored the significance of RS technology and emphasized the necessity of applying web-based GIS. This work used GIS-based intensity for better visualization of system components. This procedure facilitated the classification of buildings and allowed for a comparison of energy consumption intensity across three groups while optimizing energy usage.

Therefore, the achievements of utilizing the RS of HVAC&R facilities and the energy audit of buildings in the present work for the facility industry can be outlined as follows:

(1) Scientific management by analyzing the received data on a variety of hydraulic and thermodynamic parameters.

(2) Upgrading of HVAC&R installation systems' technical

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Table 4. Test Statistic & *P* Calculation

Parameters	Percentage of Dissatisfied	Energy Use Intensity	DEA Efficiency
Chi-square	1.200	1.200	0.000
df	7	6	9
Asymp. Sig.	0.991	0.977	0.962

Table 5. Regression Results for DEA, PPD and EUI

DEA Efficiency Score	Percentage of Dissatisfied (%)	Energy Use Intensity (kWh/m²)
0.77	17.1	78
1	17.5	80
0.87	33.2	80
0.43	34.1	80.8
0.73	20.8	79
0.88	35	81
0.71	19.9	80.4

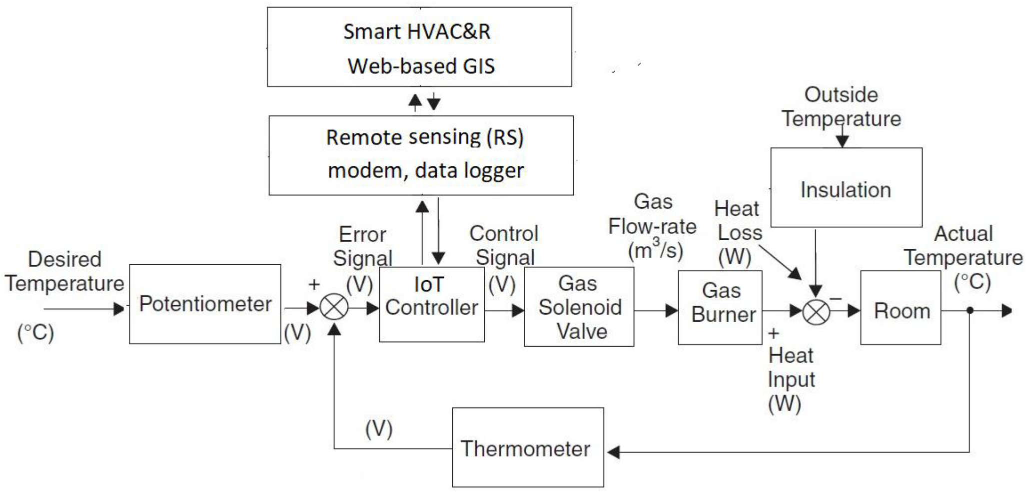

Figure 6. HVAC&R control system; hot water and burner control.

and health safety coefficient and the following capabilities: (a) Elimination of unwanted energy usage; (b) Controlling HVAC&R facilities at different times of the day; (c) Reduce depreciation and increase the efficiency of HVAC&R; (d) Alert system for periodic equipment reviews; (e) Regulation of HVAC&R equipment such as the building's thermal load demand and so on; (f) Deactivate HVAC&R by work schedules or by outdoor temperatures; (g) Ability to remotely control and monitor the status of HVAC&R; (h) Alarm system with event logging; (i) Statistical reporting of HVAC&R performance; and (j) Investigation and control of peak consumption.

Suggestions for future works are as follows:

Machine learning in context with web-based GIS for energy saving in HVAC&R systems. The combination of artificial methods applications (artificial intelligence, deep learning, and neural networks) in compliance with the computational method holds the potential to predict energy consumption and evaluate energy loss in different models of HVAC&R.

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Conflicts of Interest

The authors declared there is no conflict.

Data Availability Statement

All relevant data are included in the paper or its supplementary information.

Author Contribution

Asli KiH and Asli KaH contributed equally to this manuscript. Both authors contributed to writing the article, read and approved its submission.

Abbreviation List

DEA, Data Envelopment Analysis
DMU, Decision-making unit
EUI, Energy use intensity
FMS, Facility Management System
GIS, Geographic information system
GPS, Global Positioning System
HVAC&R, Heating, ventilating, air-conditioning and refrigeration
IIoT, Industrial internet of things
IoT, Internet of things
LAN, Local area networks
PPD, Percentage of dissatisfied
RS, Remote sensing
WAN, Wide-area networks

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