ENGINEERING APPLICATION OF BIM IN SAVING WATER AND ENERGY CONSERVATION

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ABSTRACT

With the improvement of living standards, people are more and more eager to improve the efficiency of energy conservation and emissions reduction of buildings. Pursuant to this, the application of BIM technology in the water supply and drainage engineering of green buildings is proposed. Firstly, the BIM model is built to draw the axis network and axis height and transform the spatial position of family components, which is conductive to addressing the problem of the loss of engineering information. Then, the energy-saving pathways of green building water supply and drainage projects are analyzed, Concretely, the drainage energy consumption can be reduced by decreasing the overall head of the water pump. The pipe resistance and drainage efficiency can be respectively reduced and improved through reasonable selection of parallel drainage pipelines. Also, the principle of "avoiding the peak and filling valley" can be adopted to reduce pump operation in peak period and water draining in valley period, thereby saving drainage cost. By optimizing the control strategy of the drainage system and improving the utilization rate of water resources, the final results of the study show that BIM technology can realize 69% energy saving of the total savings in water supply and drainage engineering of green buildings, decrease cost consumption and improve the quality of water supply and drainage system, so as to make full use of limited water resources to achieve the effect of energy conservation and emission reduction.

KEYWORDS

BIM technology; Green building; Energy conservation and emissions reduction; Drainage engineering; Avoidance peak and fulling valley

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1. INTRODUCTION

Under the promotion of vigorous economic development [1], China's urbanization process is accelerating thereupon, and there are more and more high-rise buildings in the city [2]. In the construction of high-rise buildings, generally speaking, the funds used for water supply and drainage projects only account for about 10% of the overall investment funds [3], but the construction of water supply and drainage projects is crucial for high-rise buildings [4]. To evaluate the grade of a building, the planning and construction of its water supply and drainage system is a vital criterion [5]. Usually, the requirements for water supply and drainage pipelines depend on whether they are planned and arranged reasonably and whether they have an impact on the overall aesthetics of the building [6]. In addition to aforementioned requirements, the basic requirements for the design and arrangement of water supply and drainage pipelines are to be able to meet the requirements of safe water use for all residents, as well as the economic and energy-saving requirements of water supply and drainage pipelines [7].

However, there are also a lot of problems in the design of the water supply and drainage pipelines at the present stage [8]. For instance, the software commonly used by designers is two-dimensional CAD design software, which itself increases the difficulty in the design of water supply and drainage pipelines [9]. Designers, in this regard, need to conceive the three-dimensional structure of pipelines [10], and then express them through two-dimensional drawings. Again, the design of water supply and drainage pipelines generally involve in all kinds of basic Settings, but designers primarily have complicated work, and do not have enough time to optimize the design [11]. In addition to the difficulties in design, the fact that the data and specifications designed can only be completed by manpower, and a unified management system cannot be established also increases the difficulty in data management [12]. At the same time, the waste of resources in the construction of water supply and drainage engineering is extraordinary serious as well [13]. In 2000, some economists surveyed the waste of the global construction industry, and found that the waste of resources in the construction industry reached 30% [14].

Building information modeling (BIM) technology, as a fast-developing information technology can better solve these problems, which is mostly used in project management, known as the construction industry model of the rule changer [15], and capable of assuming a role in all phases of an engineering project (design, construction, operation and maintenance) [16]. According to 2015 Autodesk survey report [17], over the past three years, the use of BIM in the United States has increased by 35%[18], the use of BIM among engineers has increased by 64% [19], and the use of BIM technology in countries around the world has being on the rise. As a modern and efficient building construction technology, the application of BIM technology has a profound impact on the quality of architectural engineering design and construction quality [20]. Precisely, for the construction of energy-saving design, the application of BIM technology can not only achieve the improvement of its energy-saving design effect and level, but also have a significant impact on the green and sustainable development of the building field [21].

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With the improvement of urbanization development efficiency, water supply and drainage engineering has played an increasingly prominent role and gradually become the core element of urban development, attracting widespread attention [22]. In the construction process of water supply and drainage engineering of green buildings, it is necessary to carry out the construction without affecting the surrounding environment [23]. This is because the construction scope of water supply and drainage engineering is wide, and once it affects the surrounding environment, it will affect the urban development [24]. However, with the increase in the number of urban construction projects, water supply, and drainage projects also increase, resulting in a large consumption, and a desperate shortage of water resources [25]. Under such context, in order to reduce the consumption of water resources, it is urgent to apply energy-saving and water-saving technology to the construction of water supply and drainage engineering [26].

Literature [27] describes the characteristics of hydrogeology in rainy areas, points out the current situation of hydrogeology in rainy areas, and explains the main damage types and causes of the drainage system, including that water erosion causes structural damage, soil collapse at the outlet of drainage ditch causes damage to drainage structures, the overall instability of the jet channel slides along the bottom contact surface under the action of gravity, etc. Finally, the engineering prevention and control measures are given, including paying attention to adding stilling pool, emphasizing the comprehensive consumption of various forms along the stream channel, strengthening slope scatter flow drainage and vegetation ecological regulation, enhancing the canal seepage prevention and safety design, as well as reinforcing the natural slope ditch, and appropriately constructing sand dam, and flood peak retention pond. Through the research and analysis, some references and guidance may be brought about to the highway-related workers in rainy areas, so as to guarantee the good maintenance of the highway in rainy areas, promote the good use and operation of the highway in rainy areas, and bring better traffic conditions in rainy areas. Literature [28] puts forward a three-year action plan for improving the quality and efficiency of sewage treatment, focusing on the sewage collection system, that is, based on in-depth investigation, it focuses on solving the problems such as direct sewage discharge, indiscriminate sewage removal, full pipe flow of drainage pipes in dry days, low concentration of sewage treatment plant inlet water, and excessive mud accumulation in pipes, so as to ensure that sewage does not enter rivers, clean water does not enter pipes, overflow causes less pollution, and the control and elimination effect of black and smelly water bodies in cities and is improved. In literature [29], it is expounded that the installation and construction technology of water supply and drainage systems affect the service function of buildings, especially high-rise buildings, which is related to the construction cost and determines whether the construction plan can be carried out smoothly. Therefore, according to the actual requirements of the building, it is necessary to clear water supply and drainage system installation points, and improve the relevant technical level. Wherefore, this paper analyzes the installation of the water supply and drainage system and the problems of the construction clock, and puts forward countermeasures, hoping to provide help for the relevant personnel. Literature [30]

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comes up with a double-membrane water treatment technology, which is widely applied to the making of soft water and desalted water relying on the advantages of steady water quality, small environment pollution, small coverage area and high degree of automation. Generally, due to the limitation of process conditions, system water consumption will become the key to decrease the water consumption of per ton steel in steel industry. For this, combined with the water quality of water supply and drainage system, the double membrane water treatment technology is adopted to optimize water supply and drainage system, recycle ultrafiltration backwash water, reverse osmosis concentrated water and other kinds of drainage according to the water quality, which not only reduces the treatment cost, but also reduce the system water consumption, achieving a good performance..

At present, people's living conditions are getting better and better, making people more and more aware of the significance of energy conservation and environmental protection. In order to meet the needs of social and economic development and people's requirements for green building, this paper proposes the application of BIM technology in water saving and energy conservation of green building water supply and drainage engineering, and constructs a BIM model, aiming to effectively analyze the energy-saving ways of green building water supply and drainage engineering, and greatly improve the water resource utilization rate and work efficiency of the whole drainage engineering by avoiding waste and optimizing control. Rational use of BIM technology is able to achieve the purpose of energy conservation, and environmental protection, and improve the overall efficiency of construction.

2. BIM DESIGN

2.1. BIM MODEL

From the present stage of water supply and drainage pipeline design and management, the most important design of water supply and drainage is to meet the needs of the owners, which lacks the optimal selection of water supply and drainage design and construction, so it often leads to the waste of cost and energy consumption in the actual construction of water supply and drainage design scheme. With the continuous development of The Times, the water supply and drainage system is more and more complex, pipeline equipment involved in water supply and drainage system is more and more increasing, and the connection between these two is more and close. However, local optimization of water supply and drainage systems cannot ensure the optimization of the whole system.

In addition, with the continuous development of productivity, the social division of labor is becoming more and more obvious. From the perspective of the construction industry, the most important problem is the separation of design and construction. In the present stage of the construction industry, the designers mainly act as the providers of technology and drawings in the project, and the construction party generally serves as the executor of the design Party 's thinking. Due to the above

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reasons, there are a lot of problems in the actual production, such as the difficult implementation of the design scheme or increased project costs.

BIM is an important platform that can provide an advanced platform for all project participants to collaborate and communicate with each other. In order to demonstrate the superiority of BIM technology in water supply and drainage management of high-rise buildings, this paper takes a project as an example [31]. Figure 1 is the flow chart of BIM 3D modeling.

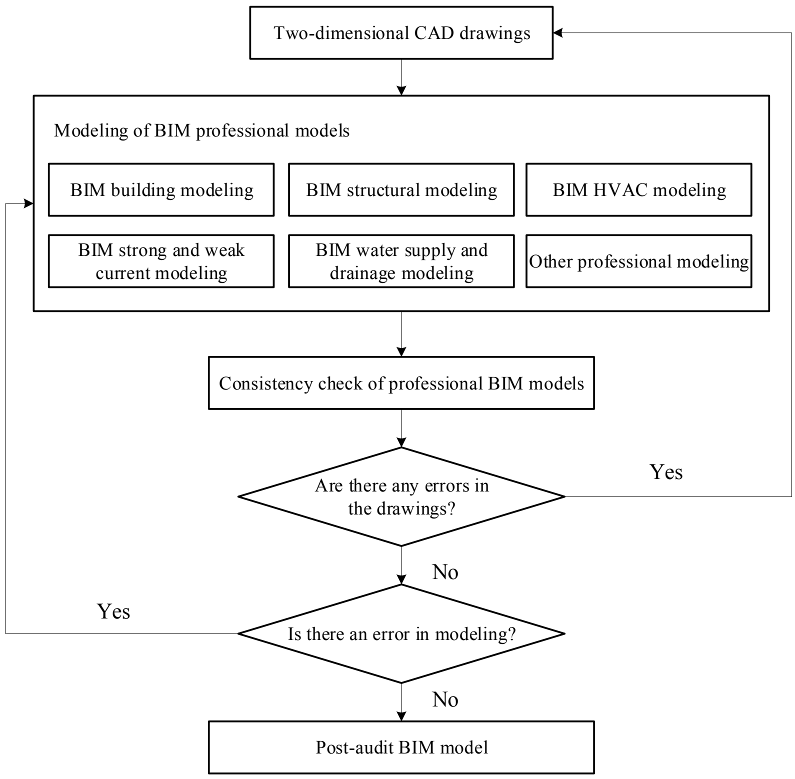

Figure 1 Flow chart of BIM 3D modeling

The establishment of various pipeline models of BIM technology is based on buildings and structural models, so is the establishment of water supply and drainage pipeline models used in this study. The assembly and construction of the model is the last step of the whole BIM model creation, as well as a specific application of the previous creation family. Since Revit family components are parameterized components, the transformation of family components can be realized only by calling the family components in the family library and modifying the parameters of family components or directly editing the model, so as to meet the requirements of the model construction.

2.2. LAYOUT OF MODEL AXIS NETWORK

After building the family components of each hydropower project, it is necessary to create a "construction sample" project in Revit and load the required family components to assemble and build the model. In the process of model assembly, the first thing is to build the axis pairs and elevations of the building in the Revit "structural template" according to various drawings, so as to determine the exact spatial position of each pressure pipe, corridor, control gate, workshop, and other auxiliary constructions in the whole model [32]. For this, the first is to find "axis network" option in the "baseline" menu under the "construct" tab. Then, it is to click the "modify/place axis network" tab, and draw the required axis network in the working interface according to the type of surface axis network in the "draw" tab, as shown in Figure 2. Similarly, elevations are drawn on the working interface according to the drawings, as shown in Figure 3.

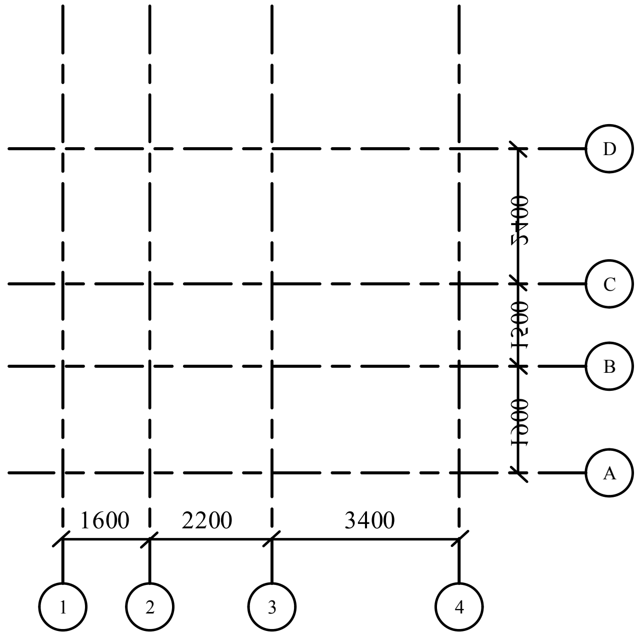

Figure 2 Model construction project axis network

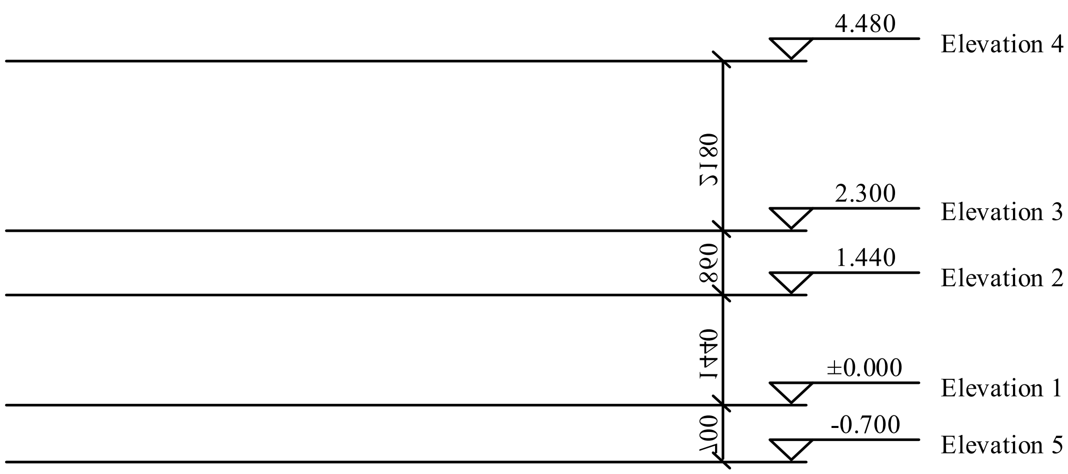

Figure 3 Model construction project axis height

Later, Revit will number each axis as a form of number. If a form of letter is necessary, it just needs to change the number of the first axis to a letter, and then the other axis will automatically be represented as a form of letter. When drawing a grid, you can enable the heads and tails of the axes to be aligned with each other, so that if you move the grid, all the aligned axes will move thereupon.

2.3. SPATIAL POSITION TRANSFORMATION

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When loading families or making nested families in the Revit project, it is sometimes necessary to change the spatial position relationship between them to complete the model construction. At the same time, there are also various constraints, such as alignment, rotation and movement. Using these constraint relations, different family components can be nested or assembled to appropriate positions quickly, and the changes of components can be realized through digital drive and constraint transmission.

In principle, the construction and nesting process of family components in the project is the process of exchange between the coordinate system of assembly space and family components, which can be obtained by a 4x4 pose matrix transformation:

$$(x_1, y_1, z_1, 1)^T = A(x, y, z, 1)^T$$

(1)

where, $(x_1, y_1, z_1, 1)^T$ is the global coordinate position of space, and $(x, y, z, 1)^T$ is the local coordinate position of space. The transformation matrix is A.

In translation change, the transformation matrix is expressed as:

$$A = \begin{bmatrix} 1 & 0 & 0 & dx \\ 0 & 1 & 0 & dy \\ 0 & 0 & 1 & dz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(2)

where, dx, dy, and dz all are translation variables.

The expression of the rotation matrix around the x -axis in the rotation transformation is:

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha & 0 \\ 0 & -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3)

The expression of the rotation matrix around the y -axis in the rotation transformation is:

$$A = \begin{bmatrix} \cos\beta & 0 & \sin\beta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\beta & 0 & \cos\beta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(4)

The expression of the rotation matrix around the z -axis in the rotation transformation is:

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$$A = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(5)

The above formulas are the matrix of rotational transformations around the x, y, and z axes in a rotational transformation. Any spatial transformation of family components can be obtained by a certain amount of translation and rotation transformation combination. Concretely, firstly, it is to classify the family components to be applied to the "construction template" project of the elevation and axis network created, and formulate the name and number of the family in the project. Then, it comes to determine the position of each dam section in space according to elevation and shaft network, and place it in the appropriate position by changing the direction of family components (translation, rotation), aligning the shaft network and setting it at the appropriate elevation and elevation view. Next, it is to adjust position to align and lock the network. Precisely, according to position of the dam section placed before, its corresponding equipment family (such as generator factory family") is respectively placed. If it can't be moved in the project, you can adjust the start and end points in properties through digital elevation to control the upper and lower position of families, so as to make the model to accurately position, and lock alignment. Finally, after all the assembly is completed, it is to check whether the components of each family are aligned and locked and whether the logical relationship of each family member is correct.

3. APPLICATION OF ENERGY-SAVING AND WATER-SAVING IN WATER SUPPLY AND DRAINAGE ENGINEERING OF GREEN BUILDING

3.1. ANALYSIS OF ENERGY-SAVING APPROACHES FOR DRAINAGE ENGINEERING

The total amount of electricity consumption by green building drainage is determined by the total amount of drainage and the efficiency of equipment operation. The level of energy consumption can be measured by operating efficiency such as water pump efficiency, transmission efficiency, motor efficiency, etc. Also, the circuit power factor can be improved by using reactive compensation capacitors, and the motor's performance can determine the motor efficiency. Therefore, the main factor affecting the drainage operation efficiency depends on the water pump and pipeline [33]. The drainage pump is connected with the motor by the shaft joint, and its efficiency is as follows:

$$\eta = \eta_d \cdot \eta_g \cdot \eta_s$$

(6)

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Where, η represents the system efficiency, η_d represents the motor efficiency, η_g represents the pipeline efficiency, and η_s represents the pump efficiency.

It can be seen from the above analysis that the efficiency of pipeline and pump mainly affects the efficiency of system operation, and the peak-valley division of industrial electricity consumption will also affect the consumption of the drainage system. Generally speaking, the consumption of electricity in the valley period will be much smaller than that in the peak period.

There are six basic elements in the centrifugal pump, namely flow Q, head H, power P, speed n, efficiency η and suction height H_t, of which n is usually set as a constant, and all the parameters taken have a certain relationship with each other. This relationship is expressed by curves $H-Q$, $N-Q$ and $\eta-Q$ as the pump characteristic curve.

The pump head is expressed as:

$$H_t = \frac{u_2^2}{g} - \frac{u_2 Q}{g A_2} \cot \beta_{2A}$$

(7)

The liquid flow power of the pump is expressed as:

$$P_s = \rho g Q H_t$$

(8)

The pump efficiency is defined as:

$$\eta_s = \frac{\rho g Q H}{P_s}$$

(9)

In the actual operation of the water pump, when the water flows through the pipeline, there will be mechanical losses due to friction and diffusion of the guide, as follows:

$$h_m = k_{mq} \cdot Q^2$$

(10)

where, Q represents the flow rate and k_{mq} represents the friction diffusion coefficient. Again, in the process of water flow, there is a deviation between the flow direction of liquid flow and the flow direction of water wheel blade design, thus resulting in impact loss, which is shown as follows:

$$h_g = k_g \left(Q_e - Q\right)^2$$

(11)

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where, Q_e is the theoretical flow rate and k_g is the impact loss coefficient. It can be deduced that the actual head of the pump is directly proportional to the square of the flow rate:

$$H = H_t - h_m - h_g = KQ^2$$
(12)

where, K is the sum loss coefficient. When the water flows through in the pipe network, there is a certain resistance of the pipe network needing to be overcome. The pipeline characteristic equation is:

$$H_W = R \cdot Q^2$$
(13)

where, R is the pipe network resistance coefficient. When R is constant, the resistance H_W is proportional to the square of the flow rate Q. Flow regulation has a serious effect on resistance. Among them, the loss of pipe network includes local resistance loss and resistance loss along the pipeline, for which the reduced value of R is needed to improve the operation efficiency.

After the selection and installation of the pump unit, the basic parameters have been determined. The operation condition of the pump can only be adjusted by adjusting the valve opening, but this way increases the additional power loss. The analysis shows that there are several ways to improve the working efficiency of drainage projects through optimization control:

(1) High-level drainage

Water pump drainage energy consumption is closely related to the head, the higher the head, the more work the pump does to lift the same amount of water inflow, and the greater the energy consumption is. Therefore, it is necessary to try to reduce the operating head when the operating conditions permit.

It can be concluded from Formula (8) that water pump drainage energy consumption P_s is related to flow rate Q and head H_t. If the drainage flow rate is fixed in unit time, then the head is an important factor affecting energy consumption. If conditions permit, reducing head can reasonably reduce energy consumption. The pump head is mainly composed of pump head and pressure-head head, so reducing the pump running head can be considered from these two aspects, that is, changing the inherent parameters of the pump (speed, impeller, etc.) to adjust the size of the pressure-head, and raising the water level of tank operation.

For the former idea, after the installation, the pump parameters has been shaped, and can't be adjusted through optimization control. Instead, pump motor frequency control operation can better adjust the operation performance, the feasibility of which will be dedicated to exploring in the following chapter.

Increasing the water level of the tank is also an effective way to improve the operation efficiency of the unit. Under the condition that working conditions permit, the storage water can be fully used to reduce the suction head by increasing the working water level, thus reducing the overall head of the pump and reducing the energy consumption of drainage.

(2) Reasonable optimization of drainage pipe combination

According to the pipeline characteristic equation (13), the head loss of the pipeline is proportional to the square of the flow rate, so, the greater the displacement of a coal mine, the greater the energy consumption. In this regard, the standby pipeline can be put into parallel operation to increase pipeline diameter and reduce pipeline resistance.

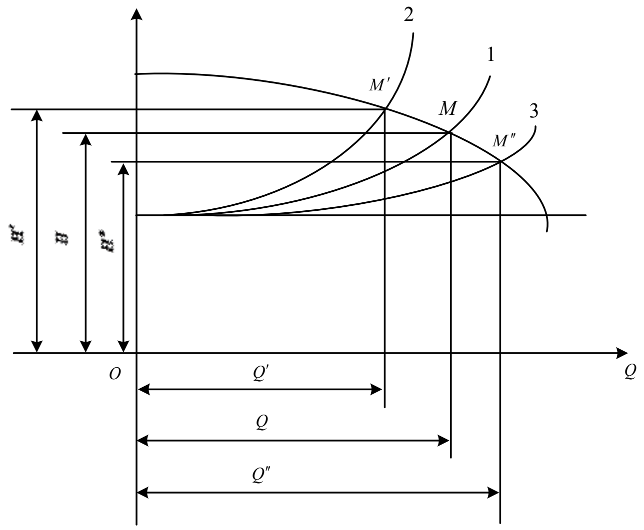

Figure 4 Pipeline parallel characteristic curve

It can be seen from Figure 4 that curves 1, 2 and 3 are performance curves of drainpipes, and other curves are pump head curves. Moreover, curve 3 is the parallel superposition of one pipe characteristic curve 1 and another pipe characteristic curve 2. The working point of the pump changes from M or $M^{'}$ to $M^{''}$, and the flow rate of the pump increases from Q or $Q^{'}$ to $Q^{''}$. When the actual pump head H is constant, the efficiency of the pipeline is improved, and the useless energy consumption to overcome the pipeline resistance is reduced.

According to the above analysis, when a single pump is running, a reasonable selection of drainage pipes in parallel drainage can effectively reduce pipe resistance and improve drainage efficiency.

(3) Avoidance peak and fulling valley

In the past few years, many buildings have focused on the drainage system optimization and energy saving on the operating efficiency of the system, looking for the optimal coordination among the factors that affect the efficiency, so as to achieve the purpose of reducing drainage electricity consumption. Currently, because the power supply department has adjusted the peak and valley price in some areas, the price difference varies widely thereby, and even in some areas, the valley price is only 1/5 of the peak price. Therefore, when draining water, it is best to try to avoid the peak period and make full use of the valley to drain water, which has been strongly proved that this method is an effective way to save energy.

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3.2. DRAINAGE SYSTEM OPTIMIZATION CONTROL STRATEGY

In commonly used control systems, controllers are established in accurate mathematical models, but in practical industrial applications, there are many factors affecting the operation of the system, and not all systems are linear, so it is quite difficult to establish an accurate model [34]. Aiming at this, the application of BIM technology can not only realize the improvement of its energy-saving design effect and level, but also have a significant impact on the green and sustainable development of the construction field.

The drainage system mainly controls the water pump unit, and the control parameters include the water storage quantity Q and the water inflow rate Q', in which the water storage quantity Q is a function of the water inflow rate Q'. Therefore, during control, attention should be paid to water storage Q and water inflow rate Q' at that moment. In addition, the randomness of the water inflow rate is very strong, so the appropriate control strategy should be selected based on the change in the water inflow rate Q'.

When the water inflow rate Q' is very small, it is necessary to fully combine high drainage with peak avoidance and valley filling, and dynamically decide the optimal pump opening time through optimal control theory, so as to reduce the consumption of drainage.

In the rainy season and peak season, or the process of mining, the water inflow rate Q' is large. When the water inflow rate Q' is greater than the drainage capacity of one pump, the drainage in the valley section can no longer meet the needs. Sometimes, multiple pumps are required to work 24 hours a day underground. Under this circumstances, the optimization control should focus on how to select the number of pump openings and determine the high drainage target water level. For the randomness and nonlinearity of the system, fuzzy control is chosen in this paper to realize optimization.

The drainage system is generally equipped with multiple water pumps. According to different water inflow conditions, it is necessary to determine the number of operating units, so as to improve the pump efficiency, as well as adopt the principle of "avoiding the peak and filling valley", reducing pump operation in peak period and draining water fully in valley period, so as to save drainage cost.

The research object of dynamic programming is the optimization of the decision process. According to the principle of optimality, regardless of the initial state and the initial decision, the remaining decisions must constitute an optimal strategy for the first decision. Combined with the drainage characteristics of the drainage system, the drainage process can be divided into several interrelated stages, in which decisions need to be made to achieve the best dynamic effect of the whole drainage process. The choice of decisions at each stage depends on the current situation and also affects future development. When the decision of each stage is determined, the decision sequence is thereby formed.

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Each drainage cycle is divided into N sections $(o:N-1)$, and the operation of units in each section remains unchanged. Assuming that the water level of the tank in section k is $X(k)(X_1 \le X(k) \le X_h)$, and k is a discrete-time variable. The function relation between water inflow and water level of the tank is:

$$f(k) = F[X(k)]$$

(14)

Suppose the water pump room has n pumps working in parallel, and the running state of the pump i at time k is $u_{i(k)}$, where $u_i(k)=0$ means shutdown, and $u_i(k)=1$ means operation.

Then, the control decision vector of the water pump room is:

$$U(k) = \{u_1(k).u_2(k), Lu_n(k)\}$$

(15)

The drainage capacity vector of the water pump is:

$$\Gamma = \{\gamma_1, \gamma_2, \Lambda, \gamma_n\}$$

(16)

The power consumption vector of the pump in each period is:

$$\theta = \{\theta_1, \theta_2, \Lambda, \theta_n\}$$

(17)

The electricity price $c(k)$ within a cycle (24h) is a function that changes with time, so the formula is:

$$c(k) = c(k+N)$$

(18)

The optimal control of the water pump room can be described as that in the drainage cycle, the optimal control vector $U^* = \{U^*(0), U^*(1), U^*(N-1)\}$ is selected to minimize the electricity expense in a cycle, then, the cost function is:

$$J = \sum_{k=0}^{N-1} c(k) U(k) \theta^T = \sum_{k=0}^{N-1} c(k) \left\{ \sum_{i=1}^{n} u_i(k) \theta \right\}$$

(19)

$$(k = 0, 1, \Lambda N-1, i = 1, \Lambda n)$$

(20)

The optimal performance functional expression is described as:

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$$J^* = \min\left\{ \sum_{k=0}^{N-1}\sum_{i=1}^{n} c(k)\, u_i(k)\theta \right\}$$

(21)

The optimal control process of drainage is regarded as a multi-order decision-making process, and then the multi-order decision-making process is shown as follows:

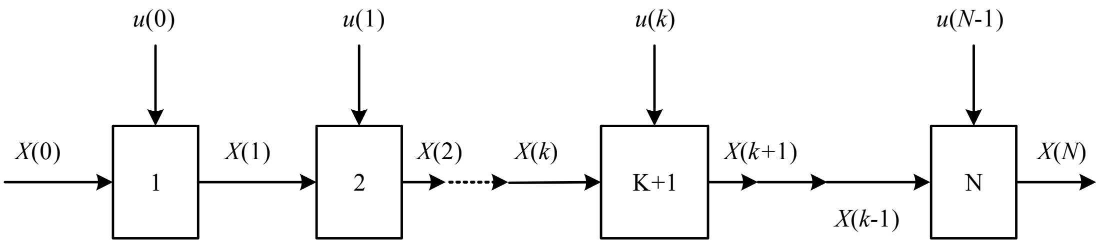

Figure 5 Schematic diagram of a multi-decision process

According to the optimality principle, the process of implementing an optimal decision by dynamic programming method is as follows. First of all, multi-stage decision problems are transformed into a series of single-stage decision problems, starting at the last state and ending till working backward to the beginning state.

With respect to drainage strategy, the system takes the tank water volume, water inflow rate and peak-valley period as dynamic variables of the dynamic programming method, and the working condition, efficiency and flow rate of the pump unit as static constants, where the dynamic variables refers to variable parameters of the control vector determined by the principle of optimality, and the optimal solution is to constantly optimize the control strategy through the change of variables. When the security conditions are met, the solution of the optimal control function is to minimize the energy consumption of the drainage system.

In connectiont o calculation of water inflow rate, considering that water inflow is a nonlinear function, the solution method of water inflow rate in the linear equation is not applicable here. Then, the piecewise method can be used to approximately fit the change curve of water inflow into a combination of countless linear curves, so as to solve the change rate of water inflow in a single period, which can be used as the prediction parameter of dynamic programming.

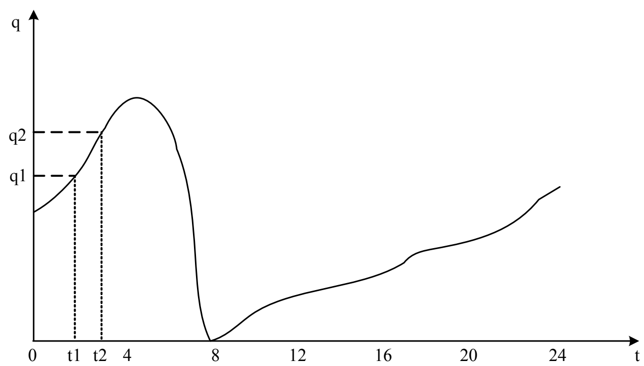

Figure 6 water inflow curve

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As can be seen from the figure, the variation of water inflow between t_1 and t_2 can be approximately regarded as a short straight line, and the water inflow rate at t_2 is approximately $v=(q_2-q_1)/(t_2-t_1)$.

Then, in terms of control logic, the optimal control process takes into account the present value of variables and the stored value of the previous moments, and makes a reasonable prediction, so as to give the optimal strategy. The underground drainage system is different from other units, which is mainly reflected in the uncertainty of the task (nonlinear change of water inflow and the limit of water level safety, etc.). Therefore, the system adopts multi-level decision-making and judgment step by step to give a reasonable strategy.

Layer 1: security

Coal mine safety production is the premise for the reasonable implementation of other optimization strategies. In order to ensure the normal discharge of water inflow, the upper limit of the water level is set. In this way, no matter in peak or valley period, as long as the upper limit is reached, the water pump will be started for drainage to prevent accidents.

This decision is an unconditional interrupt decision. If only the condition is met, the system will transform to the control interruption of water level over limit, and other control strategies will not override this decision.

Layer 2: warning

The estimated value of the water inflow rate is updated every 20 minutes during the operation of the system. If there is a sudden increase in water inflow rate, the system will transform to the corresponding interruption to determine the number of pumps that need to be started according to the water inflow volume and water inflow rate, and start the corresponding pumps to drain water in advance, so as to prevent accidents caused when the water volume suddenly increases and the personnel on duty cannot find it in time.

Layer 3: economic drainage

On the premise that the control policies of the first two priorities are met, the system is in a normal economic drainage state, revising the control strategy according to the updated tank water volume and water inflow rate every 20 minutes and giving the optimal control scheme.

Concretely, when it is at peak time, the electricity price is the highest, so it is better to try to store water.

When it is at a normal time, the first is to make a logical prediction, and then according to the current water inflow volume and water inflow rate, predict whether it is enough to drain out the water inflow in the tank within the valley time.

Then, when it comes to valley time, after reaching valley time, an appropriate pump start time shall be selected, and the best pump start time shall be calculated every 20 minutes, so that it is feasible to open the corresponding pump according to the

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principle of uniform wear, and drain out the water inflow before the end of the valley time.

For this, assume that the time required to start the drainage of water inflow in the tank at t_2 is t, then:

$$t = \frac{V + v\Delta t}{nQ}$$

(22)

Where, t is the drainage time, V is the water volume in the water tank, v is the water inflow rate, and Δt is the time difference between 7 o 'clock and the end of valley time. Then, a judgemnet for t is performed, in which $t > 7$ indicates that if two water pumps run together in the valley time, they cannot drain out all the water inflow, so it is necessary to start the water pump to drain water in advance, specifying the drainage time is at the moment when $\Delta t - t < 0.5$, that is, starting to drain water 30 minutes in advance. To ensure that the water inflow is drained out before the arrival of the peak time, it is better to store water as far as possible at the peak time. $t \le 7$ means that the water inflow can be discharged out within the valley time, without the need for drainage in advance.

The optimal pump starting time can be obtained by substituting $t = \frac{V + v\Delta t}{nQ}$ into the above formula, where n is judged according to the water inflow rate. When the water inflow is small, a water pump is started. Taking into account the power supply capacity of the pipeline and substation, a maximum of seven water pumps can be installed in parallel operation.

In order to increase the drainage rate of the drainage system, in the process of automatic control, the system can choose the pump with the highest efficiency to drain water. The real-time operating efficiency of pump during pump operation is defined as:

$$\eta = \frac{NQ}{3600P}$$

(23)

During each operation, the system should store the current operating efficiency of the pump to ensure that the results of the comparison are updated in real-time, and that the whole system can run efficiently.

3.3. AVOID OVER-PRESSURE FLOW

Over-pressure flow refers to the hydrostatic pressure generated by the water supply components exceeding the water inflow head, so that the actual flow is much larger than the rated flow. The flow beyond the rated flow will not bring normal benefits, only a waste. At present, more than half of the ordinary faucets have the problem that the actual flow exceeds the rated flow, that is, the over pressure flow, where the maximum of the actual flow of ordinary faucet can reach more than two times of the rated flow [35]. In this regard, the following techniques can be adapted to address it.

Limit the actual water pressure at water distribution point. Precisely, over-pressure flow may cause water resources and there is no attention on it. Although current specification provides the maximum pressure limit, it is only to aim at the point of view that too much pressure will cause damages, without attaching real importance to over pressure flow. Less strict demands for over pressure flow can not have a expected restriction effect. Therefore, it is necessary to strictly limit the pressure according to the specific conditions of the water supply system.

Adopt decompression technology. Installing decompression device to the existing water supply system can realize effective control of water pressure, and enable the water pressure to be in an allowable range, so as to avoid the occurrence of over pressure flow phenomenon. The pressure-reducing device comprises a pressure-reducing valve, a pressure-reducing orifice plate and a throttle plug. Among them, pressure reducing valve is generally installed in the household branch pipe. After its installation, the actual water output of each floor is reduced, and the flow and water pressure of each outlet point are also maintained evenly. Installation of pressure-reducing valve can play a significant decompression effect so that the flow on the basis of meeting the requirements is significantly reduced. Compared with the pressure reducing valve, the pressure reducing hole plate is simpler to reduce investment and easier to manage. Practice shows that its installation can bring remarkable water-saving effects. However, it can only reduce the dynamic pressure, where static pressure remains unchanged, and the downstream pressure changes with the change of upstream pressure. It lacks stability, and its structure is also prone to blockage. Now it is mainly used when the water quality is good and the water supply pressure remains stable.

Set water-saving faucet. When the pressure is the same, using a water-saving faucet can effectively improve the water-saving effect, such as touching-type water-saving faucet. Its switch control is shown in Figure 7.

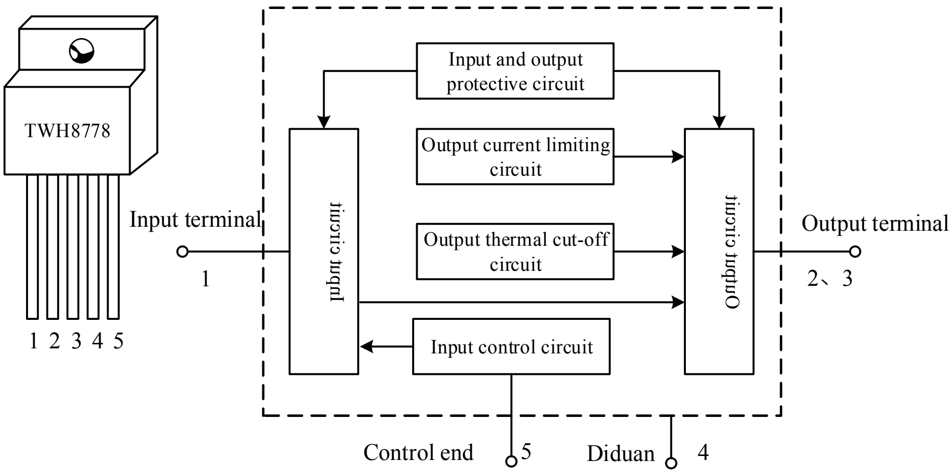

Figure 7. Touch-type water-saving faucet switch control

The maximum water-saving amount can reach 50%, generally being kept in the range of 20%~30%. If the static pressure is high, the use of an ordinary faucet will

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have a large amount of water, and at this time switching to water-saving faucet, will bring a huge amount of water saving.

3.4. AVOID EXCESSIVE INEFFECTIVE COLD WATER PRODUCED BY HOT WATER SYSTEM

Nowadays, people's living standards are getting higher and higher, and the functions of buildings are gradually improved. Hot water supply has become a basic function and even needs to be regarded as an important part of the water supply system. The results of the survey show that most hot water supplies have water wastage, `manifesting itself as that a lot of cold water is drained before hot water flows out. The cold water discharged has no benefits and belongs to invalid cold water, resulting in water waste [36]. Its causes include many aspects, which need to be considered from different links, so as to reduce its generation and emissions.

For new buildings, a branch pipe and riser pipe circulation model shall be chosen. Current specifications state that hot water circulation should be selected from the following modes, main pipe, riser pipe and branch pipe. At the same time, in the public bathroom, it is unnecessary to set circulating pipes. The choice of circulation mode largely determines the amount of invalid cold-water production. The water-saving amount of the riser pipe is less than that of the branch pipe, but its water-saving effect is better than that of the main pipe, and its investment can be recovered in 12.5 years. Pursuant to this, the use of riser pipes provides better water-saving effect than main pipes, and is more economical than branch pipes[37-38].

Although the main pipe has relatively low cost in terms of a backwater, its water-saving effect is not obvious, and its investment needs to be recovered after 12.7 years, longer than that of the riser pipe. Therefore, main pipes are not recommended, either with respect to cost or water-saving effect.

When the circulating pipe is not used, a lot of invalid cold water will be produced, which not only fails to meet the requirements of water-saving and energy-saving, but also affects the normal use, so it should be eliminated in the future design.

Based on the above analysis, and in view of the basic national conditions of China, the hot water system must adopt the circulation mode and abandon the main pipe mode for green buildings, and the existing hot water system without circulating pipe should be rapidly transformed. Now, there is still the phenomenon that the bathroom of a lot of buildings has no circulation mode in China, needing to produce and waste a lot of invalid cold water every day. The main reason for this is that the circulation - free systems are relatively simple and can reduce the cost, but in fact, they will increase the operation cost, reduce the service effect, and leads to the loss is outweighed by the gain. In this regard, we should speed up the transformation, and generally, there are the following solutions.

First of all, shorten the local pipeline length and do a good job of pipeline insulation. In current green building projects, local hot water supply is designed to have no return pipe in the system. When the distance between water heater and toilet is relatively far,

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before using hot water, a lot of cold water in retention at pipeline will be discharged. In addition, the hot water pipe lacks insulation measures, so that the water in the pipe quickly dissipates heat, and a lot of lower temperature water is releases when the water heater is started once more after a period of time of shutdown. On this account, ,the longer the length of the hot water pipeline is, the more the water wastes. To cope with this, the following measures can be adopted. Firstly, in the design process, not only the use function and layout of the building should be fully considered, but also the water-saving factors should be paid great attention to, and the hot water pipeline should be shortened on the basis of meeting the basic requirements. Secondly, a good job of thermal insulation of hot water pipeline is done, configuring backwater system.

Then, strictly implement the relevant technical specifications and design requirements, and build a sound management system. In addition to the suitable circulation mode, design, construction and management will also affect the discharge of invalid cold water. For this, during the design process, circulating pipes should be arranged in parallel, and when the project is a high-rise building, cold and hot water systems need to be zoned.

In order to avoid the waste of water caused by temperature regulation, it is recommended to set up a single system for bathrooms in public areas, and enable the temperature control installation assume a key role in water temperature control. Currently, many temperature-controlled units lack sensitivity, causing hot water to be too cold or too hot, and thus leading to a waste.. In this regard, it is recommended to popularize the use of new faucets with thermostat elements, so as to ensure that users can obtain the water meeting their requirements in the shortest time and to avoid water waste in the process of temperature regulation.

3.5. AVOID WATER WASTE CAUSED BY SECONDARY POLLUTION

Once secondary pollution occurs, not only the operation of the water supply system will be affected, but the entire system structures will also be affected by sewage. Coupled with, that a lot of tap water is used when cleaning the water supply system, it will inevitably leads to the waste. Therefore, effective measures should be taken to avoid secondary pollution.

For instance, to introduce variable frequency speed regulating pump, as well as pool, water pump and high-water tank,realizes water supply in a high-rise building, as shown in Figure 8. Pressurized water supply is the most commonly used water supply method for high-rise buildings at present, but the water quality of this method is poor because the water will be polluted during storage and transportation. After the introduction of frequency conversion speed regulating pump, pump can be directly sent to the users, without setting water tank, so as to avoid secondary pollution. The details are shown in Figure 9. At present, many areas in China have adopted this new measure, and the effect is very remarkable, being favored by owners.

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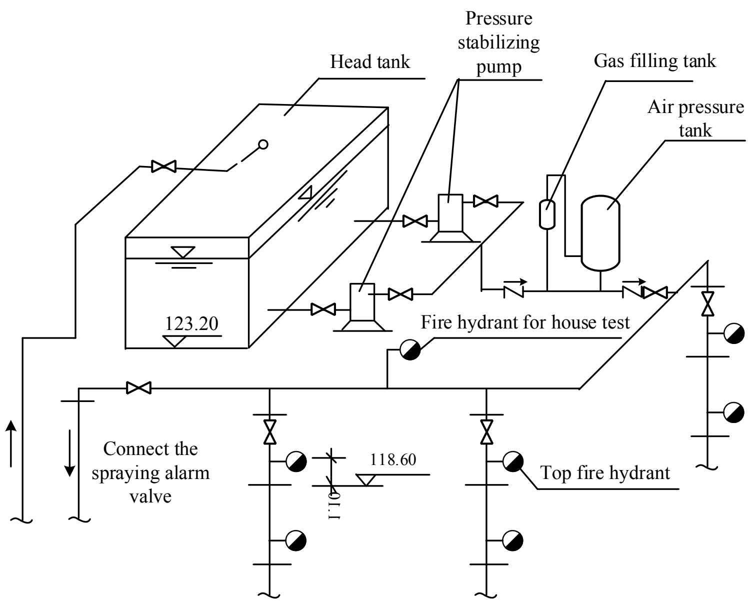

Figure 8. high-water tank

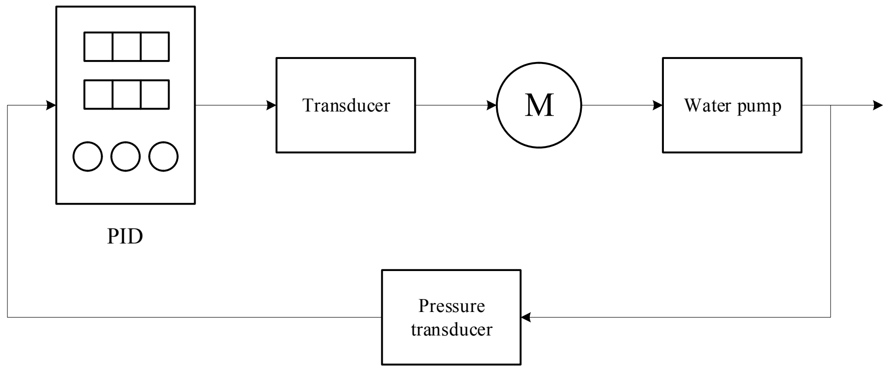

Figure 9. Simplified circuit of frequency conversion speed regulating pump

Separate living pool and fire pool area. Previously, many buildings prefer to merge two pools, which will make the volume of the pool become larger, and the actual water use volume is less than 1/5 of its total use volume. In this way, a large amount of domestic water will be stored for a long time, resulting in water quality changes. The results show that the water temperature is relatively high in summer, and the residual chlorine in the water will become zero after the water is stored in the water for more than 12 h, which enables the rapid breeding and reproduction of bacteria. Therefore, it is necessary to separate the living pool from the fire pool. For the volume of the pool, it is determined according to the actual water use situation.

Although the water supply mode of pool coupled with pump and tank has the problem of secondary pollution, the water quantity and water pressure are relatively stable, and the technology is mature and experienced, so it is impossible to abandon such mode. In this case, as long as the current standards and provisions having put forward are strictly implemented, we can effectively control the secondary pollution, ensure water quality, avoid waste, and achieve the effect of energy-saving and water-saving. These specifications primarily include material selection, piping design, construction design, backwash pollution control, etc.

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In summary, energy saving and water saving is the main goal of green buildings, which should be used in practical work to avoid over pressure flow, avoid excessive ineffective cold water in the hot water system and prevent waste of water caused by secondary pollution, so as to improve the utilization rate of water resources and get rid of energy waste on the basis of meeting the requirements of water supply.

4. RESULTS AND ANALYSIS

The construction engineering industry is an important support for China's economic development. In recent years, the number of green building projects has been increasing, and the scale of construction has been expanding, which has effectively driven the development of the regional economy. However, in the construction process, due to the influence of factors such as design and construction concepts, environmental pollution and waste of resources, the issues of construction engineering are becoming increasingly prominent. And also, in the new era, the improvement of energy-saving design quality of green building projects has become an inevitable requirement for the development of construction industry. Therefore, in this paper, combined with the existing literature and the current situation of water resources in a city, a risk evaluation system is established on the basis of hierarchical, systematic, representative and scientific principles, as shown in Table 1.

The development and utilization of water resources is a multi-level and complex problem involving ecological, economic and human activities. Therefore, the selection of evaluation indicators should not only consider the quantity and social economy of water resources but also involve the efficiency and level of development and utilization of water resources. Based on the existing literature and the current situation of water resources in a city, this paper establishes a risk evaluation system based on the principles of hierarchy, systematicness, representativeness and scientificity, as shown in Table 1.

Table 1. Risk evaluation system of water resources development and utilization

Target layer	Criterion layer	Index layer	Index connotation	Attribute
Risk evaluation of water resources development and utilization A	Current situation of water resources B_1	C_{11}/mm	Annual average precipitation	+
		$C_{12}/(m^3/people)$	Per capita occupancy	+
		$C_{13}/(m^3/m^2)$	Water consumption modulus	+
	Development and utilization level B_2	C_{21}/%	Development and utilization degree	_
		$C_{11}/(m^3/people)$	Water consumption per capita	_
		$C_{11}/(m^3/mu)$	Irrigation water consumption per mu	_

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		$C_{11}/(m^3/GDP)$	Water consumption per 10000 yuan GDP	_
	Socioeconomic level B_3	$C_{31}/\%$	GDP growth rate	_
		$C_{32}/\%$	Population growth rate	_

At present, since there is no systematic and perfect risk evaluation standard for water resources development and utilization, this paper divides the risk level into five standard systems, as shown in Table 2.

Table 2. Risk grade standards of water resources development and utilization

Risk level	I	II	III	IV	V
comprehensive value	<0.3	0.3~0.5	0.5~0.8	0.8~0.95	>0.95
Risk level	micro degree	light	moderate	high	extreme

According to the water resources report, government work report, statistical yearbook and other data in a city, initial values of the above indexes are extracted, and then based on the basic connotation and its properties, the corresponding formula is respectively adopted for the normalized processing, which is as follows. For the positive indicators, that is, the larger the evaluation value, the lighter the risk of water resources development and utilization, the normalization processing formula is:

$$r_{ij} = \frac{x_{ij} - (x_{ij})_{min}}{(x_{ij})_{max} - (x_{ij})_{min}}$$

(24)

For the negative index, that is, the smaller the evaluation value, the lower the risk of water resources development and utilization, the normalized treatment formula is as follows:

$$r_{ij} = \frac{x_{max} - x_{ij}}{(x_{ij})_{max} - (x_{ij})_{min}}$$

(25)

Where, r_{ij} represents the standard value of the i evaluation index in the j evaluation sample, and $(x_{ij})_{max}$ and $(x_{ij})_{min}$ are the maximum and minimum values of the same evaluation index x_{ij} in different evaluation samples respectively.

The initial values of each indicator are normalized by using Equations (24) and (25) respectively, and the membership degree of the risk indicators of water resources development and utilization in each region of a city can be obtained, as shown in Figure 10.

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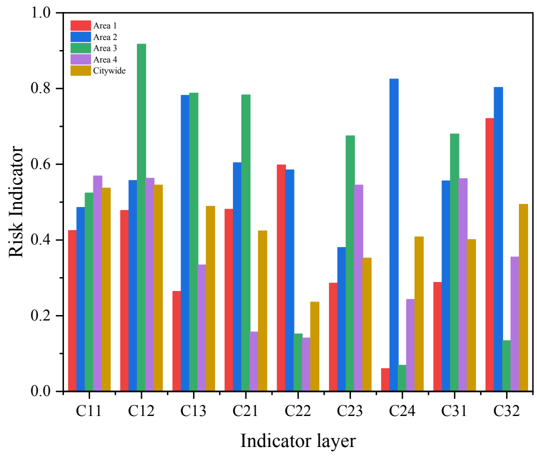

Figure 10. Membership degree of risk index of water resources development and utilization

According to the correlation and importance criteria between indicators , recursive calculation is carried out in the order from bottom to top to obtain the risk degree of each level of the evaluation system. The results are shown in Figure 11.

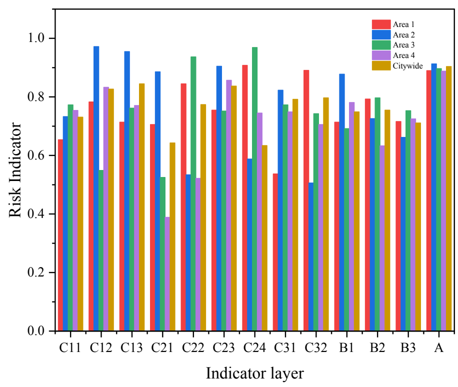

Figure 11. Evaluation results of development and utilization risk value

It can be seen from Figure 11 that the evaluation index C_{12} is 0. 971 in Area 2, which is extremely risky, indicating that the per capita water resources in this region are low and the level of development and utilization is weak. This index is in the range of 0. 548 ~ 0. 830 in other areas, which is wholly in the moderate level. Similarly, the level of other indicators in each region is analyzed successively. The index A, namely risk evaluation of water resources development and utilization is in the range of 0.88 ~ 0.91 in the whole evaluation samples, with that of Area 2 of the most prominent one, indicating that it is in a high-risk state. Besides, the comprehensive risk evaluation value in the citywide is 0.905, also indicating a high risk.

In order to better illustrate the application value of BIM technology in water supply and drainage management, this study evaluates and analyzes the application of BIM technology in water supply and drainage management. The project of this study is mainly based on the data of an engineering project. In order to protect the investment data of the project, percentage method is used in the analysis. After obtaining the summary of effective collision reports, in-depth analysis is made on all kinds of

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collisions, mainly analyzing their impact on the project cost, and finally, the cost loss caused by the collision is summarized and counted. Through the study of statistical data, it is found that if each detected collision can be solved perfectly, the return rate of investment of BIM technology in water supply and drainage management is higher. The figure below shows the proportion of cost savings for four different types of collisions involving water supply and drainage pipes.

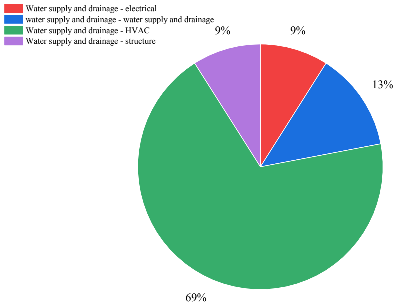

Figure 12. Cost saving ratio of four different types of collision

From Figure 12, it is not difficult to find that the collision cost saving of water supply, drainage and HVAC is the highest, accounting for 69% of the total savings, and the cost saving ratio of other collisions is similar. This also indicates that the design of water supply and drainage pipes should be strengthened in collaboration with HVAC professionals, so as to reduce costs and improve the quality of water supply and drainage system of the project.

BIM technology can play a optimization role at all life stages of green building projects. For this, we mainly divide the optimization analysis of BIM technology to water supply and drainage management into four stages for comparison. The first stage is the design phase, the second phase is construction deepening stage, the third stage is construction preparation stage, and the fourth phase is maintenance stage after operation.

In the first stage, BIM technology is mainly applied in the design of water supply and drainage project. To guarantee the valve of BIM technology in the first stage, after this stage is optimized, if there is still collision in other several stages, the value optimized will not be recorded in this stage.

The second phase is essentially a further deepening design with construction as the purpose. To further eliminate the collision problem of water supply and drainage pipes, the statistics still follow the principle in the first stage, that is, if the subsequent construction is affected, the value optimized will not be recorded in this stage.

The third stage is to formally perform construction management of water supply and drainage engineering after the optimization of the first two stages. In this stage, BIM technology is not only the collision optimization of water supply and drainage pipeline, but also includes the cost management and schedule management of water supply and drainage construction, and the optimization of construction scheme.

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The fourth stage is the management optimization of BIM technology in the maintenance stage of the overall operation of the building, including the optimization of data monitoring of all kinds of pipeline information.

5. DISCUSSION

This paper simply studies and analyzes the use of BIM technology in water supply and drainage management of high-rise buildings, and obtains the value of BIM technology in water supply and drainage management of high-rise buildings. However, there are still many applications of BIM technology to be studied and discovered.

Water saving and energy conservation is a major goal of green buildings. For this, it is recommended to feasible new technology and new measures to address the issues such as over pressure flow in the actual work, excessive invalid cold water caused by hot water system and the secondary pollution, so that on the basis of meeting the requirement of water supply, the utilization of water resources is improved, and the waste is avoided. Today, green building has become a major trend in the construction industry, but there is still a long way to go before it is truly universal.

6. CONCLUSION

Based on relevant data and regional water resources states, this paper establishes an evaluation system from the aspects of development and utilization, current situation of water resources and social and economic level, and applies catastrophe theory to perform scientific research on the risk of water resources development and utilization. Finally, the following conclusions are drawn:

(1)By studying the cost consumption at various stages of water supply and drainage engineering management of high-rise buildings pursuant to BIM technology, it can be drawn out that BIM technology has a great use value and assumes a significant optimization function in the water supply and drainage engineering management of high-rise buildings, where its cost saving accounts for 69% of the total.savings.

(2) By optimizing the design having been completed, it is found that the evaluation index C_{12} is 0.971 in Area 2, which is extremely risky, indicating that the per capita water resources in this region are low and the level of exploitation and utilization is weak. This index is in the range of 0.548 ~ 0.830 in other regions, which is wholly in the moderate level. Besides, the comprehensive risk evaluation value in the citywide is 0.905, indicating a high risk, and the index is in the range of 0.88 ~ 0 in other regions.

(3) Water saving and energy conservation is an important part of green building engineering design, and the deep application of BIM technology in its design process not only helps to improve the quality of energy-saving design, but also has a significant impact on the economic benefits of construction enterprises and the

sustainable development of the construction industry. Additionally, in the process of practice, the maximum volume of and energy conservation of green buildings can reach 50%. In this regard, designers should fully recognize the advantages of BIM technology design, and do a good job in the specific application of BIM technology in the design process, so as to achieve the improvement of BIM technology application level, to ensure the quality of energy-saving design at the same time, and to promote the further development of construction projects.

7. DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/ supplementary material, further inquiries can be directed to the corresponding author.

8. AUTHOR CONTRIBUTIONS

Wei Zheng, Yong Ye and Hongbing Zang conceived this idea. Wei Zheng established the BIM model, conducted data analysis with Yong Ye and Hongbing Zang, and then wrote a paper. All authors read and approve the final draft.

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10. CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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