Integration of Equipment Aging Influences on Water Quality Variation in Apartment Houses

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Abstract

The number of water vendors has increased rapidly in Taiwan recently. Even though the municipal water is good enough, the people always worry that the water quality might change from the building inlet point to the faucet outlet in a building. The primary purpose of this research is to verify this general impression and determined the actual water quality problems. This research project randomly chose 113 families using tap water in Taipei City. We selected six physical water quality indexes including pH value, residual chlorine, turbidity readings, watercolor, total density of solid and conductance for inspection and analysis. As a result, we have seen that water quality changes from the storage tank inlet point to the kitchen faucet outlet point in a building. Although the large majority of cases examined are within or near to quality measures, a few cases are still over the criteria for drinking water. People have a reason to worry about drinking tap water in buildings. Therefore, to offer a drinking water supply system additionally is a practical alternative to the present policy, and that would be better than to improve the water quality in existed water supply system.

Keywords：Municipal Water, Physical Inspection, Water Supply, Water Quality, Apartment Houses

1.INTRODUCTION

Our government currently has a policy to improve the tap water quality and to encourage people to drink tap water without boiling or other treatment in Taiwan. Most of the water supply systems in buildings are gravity fed by storage tanks. Storage tanks are usually fitted or constructed together with the building. There is a general impression that the tap water quality would worsen due to supply systems and storage devices in buildings. Although the Water Company always claims that municipal water is safe and potable, people have a bad impression of the tap water. The numbers of water vendors are increasing rapidly in Taiwan recently. Issues concerning the Taiwan water quality and water supply treatment system have been researched and discussed. Observations[1] in Taipei have indicated that most apartment houses still cover up the plumbing system during construction. Therefore, as the building is finished, maintenance or repair of the plumbing becomes troublesome and there is no easy way to deal with failures or blocks in the piping and equipment. This is one of the reasons why people have no confidence in the tap water. In this paper, we will verify this general impression, the actual water quality problems, and try to offer alternative considerations for building water supply systems.

A detailed investigation of the drinking water quality in Taiwan was performed by Y.J. Houng (1995). This research [14] chose 178 families from five regions of Kaohsiung City. Through questionnaires and experiments, this study indicated that 64.6% of these people selected commercial water including distilled water, R.O. water or mineral water to drink. Fifty-two point seven of these people used some type of water purifying device. This research also found that commercial water was no better than the tap water, but only 33.3% of these people chose tap water as their main drinking water. From this information, it is apparent that tap water has a bad reputation for citizens. Tap water quality in Taipei might be better than that in the Kaohsiung region, but this situation is similar all over Taiwan. The previous research [9,10,14][2] was concerned primarily with the city tap water supply system. In this study, we focused on the relationship between water supply devices, plumbing fixtures and the water quality in apartment houses.

2.MATERIALS AND METHODS

2.1 Quality of water supply

We have always had quality standards [3] for potable and nonpotable water equivalent to many other countries[12~13]. There is little difference between Taipei City and the other areas of Taiwan in the level of water quality. Potable water must be satisfactory for drinking, culinary, and domestic purposes and meet the requirements of the health authority. Nonpotable water may be used for flushing water closets and urinals and other fixtures not requiring potable water. Actually, the water supply system is not separated into potable water and nonpotable water in buildings. In Taiwan, there exists the “Taiwan water supply cooperative” and the “Taipei water supply cooperative” for managing the water supply works of this country. These two departments are semi-government organizations, with about 200 water resource locations under their management. As with potable water, the quality of municipal water must obey the requirements of the health authorities and water quality regulations. People have not treated the tap water from the faucet as potable water for a long time. The most critical reason is that people have always had low confidence in the distribution process and water supply devices in buildings. People worry that during the service process the water might be polluted or receive some unhealthy influence. Therefore, people prefer to use boiled water or mineral water for their potable water. The government has a policy to supply potable water to the public, but people treat the water as if it is nonpotable. One of the problems is that we do not know the influence of water supply devices and plumbing fixtures on the water quality in apartment houses [4,6,7,8].

2.2 Problems with plumbing fixtures

Field investigations were performed to determine the plumbing system-related issues in buildings. The first observation in Taipei indicated that the plumbing system in most apartment buildings is covered during construction with no access to the critical system junctions. Therefore, when the building is finished, the maintenance or repair of plumbing is very troublesome with no easy way to deal with failures or blockage in the piping and equipment. The only way to deal with a failure in the plumbing system is to tear down that portion of the building for repair or discard the entire system. This construction practice makes it impossible to modify or replace the system or any of its parts. The water supply piping will age after a period of usage. Metal piping material will become corroded. Current construction practices make it impossible to maintain or replace aging or damaged pipes and fixtures. When the water becomes polluted or major leaks occur, the building must be dismantled. Figure.1 shows a general aging case for plumbing fixture in current apartment building. In the past, designers did not consider the concept of building life cycle, and existing buildings had no explicit renewal schedule. In most renewal cases, as the investigation indicated, a worn or malfunctioning plumbing system is the major reason for the building renewal decision.

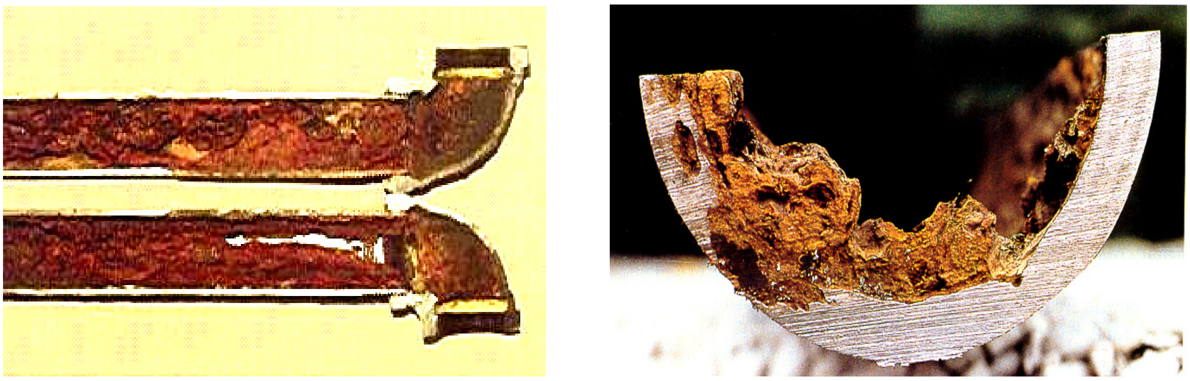


Figure.1 A general aging case for plumbing fixture

2.3 Investigation of circumstances and interviews

Three conditions must be satisfied in every building for plumbing installation. These conditions are good water quality, adequate water pressure and ample water supply. Here, we have simplified the composition of water supply systems and the equipment customarily used in Taiwan. Water supply systems roughly include storage devices, service piping, and terminal fixtures. Table.1 shows the basic composition of a water supply system in a building. The typical water supply system for a building in Taiwan is a gravity system with elevated tank, as shown in Figure.2. Pressure tanks with compressor and pump systems are also used. Very few families connect directly to the city mains of the municipal water system without any power device in buildings below 2 or 3 floors in height.

2.4 Plumbing fixture and piping aging

Table.1 Composition of water supply system in building

STORAGE	SERVICE PIPING	TERMINAL FIXTURE
BASEMENT TANK GROUND TANK ROOF TANK	SUPPLY PIPING CROSS CONNECTIONS VALVE PUMP	FAUCET SINK SHOWER WATER CLOSET
INLET POINT	DISTRIBUTION	OUTLET POINT

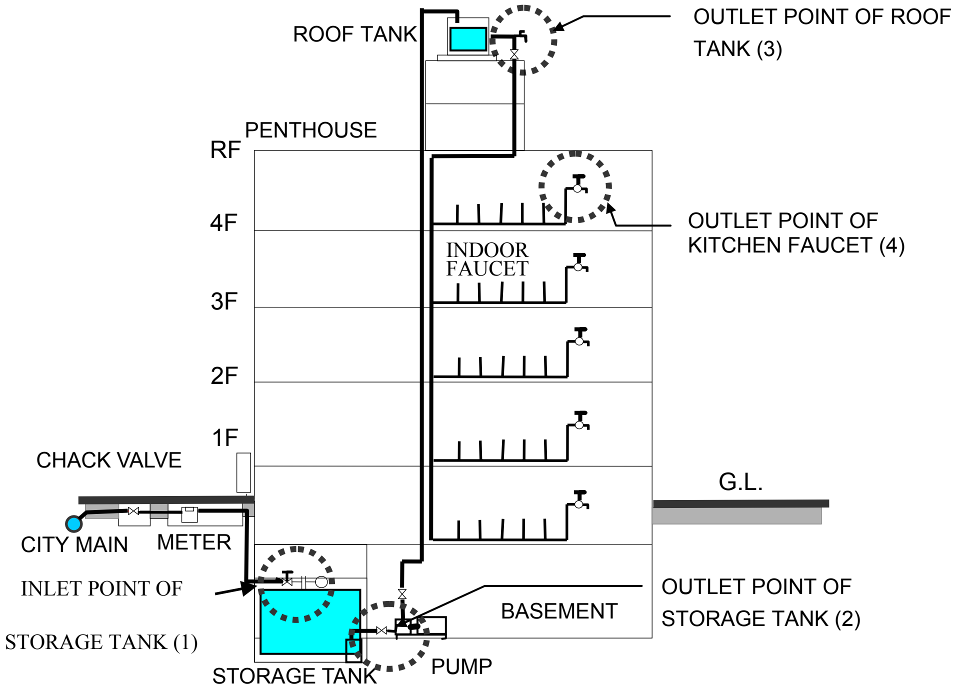


Figure.2 Scope of inspection and locations of water samples.
(Water samples from four check points from outdoor to indoor)

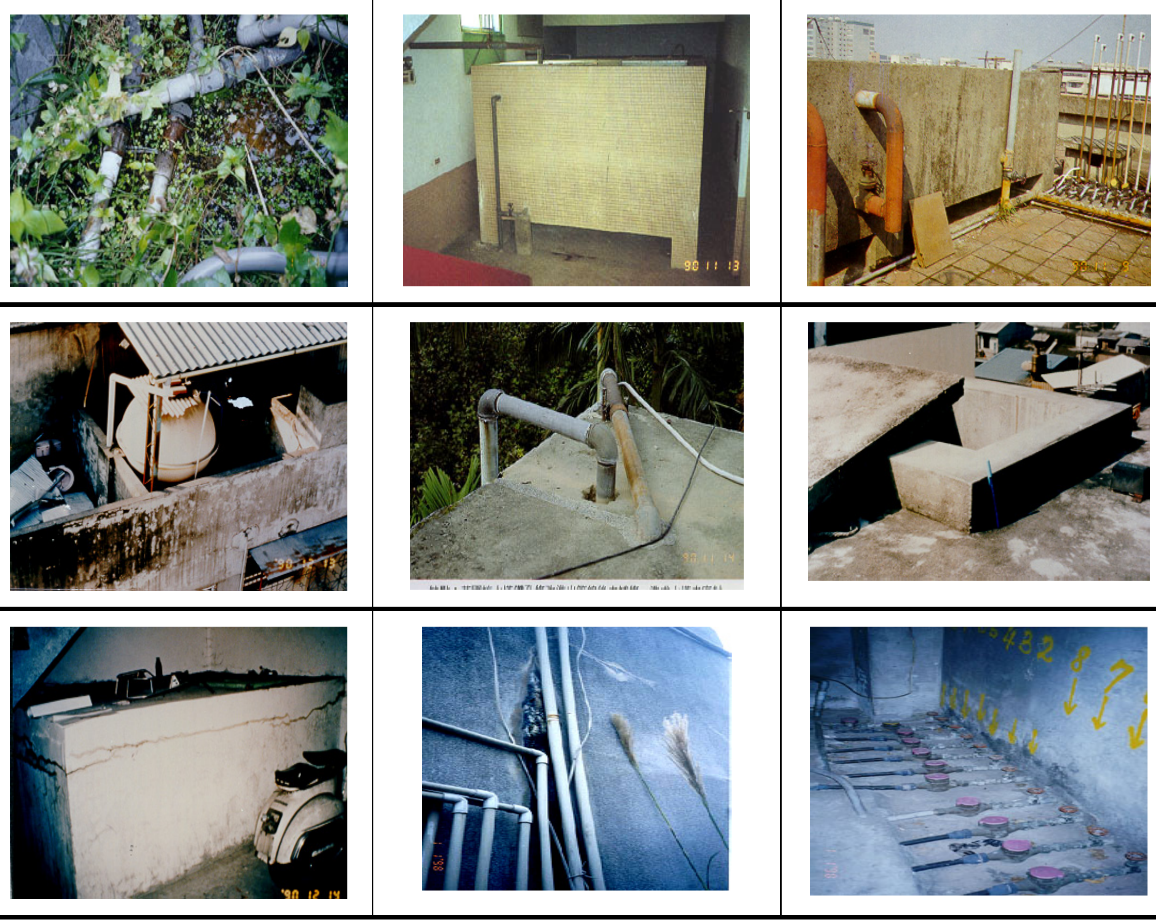
There are many methods for diagnosing the age of pipes. In this study, two detection instrument systems were used. The first was fiberscope video system that can go directly into the pipe and video the inside of the pipe. The corrosion or wear situation can be evaluated from this video record. The second system was an ultrasonic thickness instrument that can survey the thickness of a pipe from the outside to evaluate the corrosion and remaining thickness. The ultrasonic thickness instrument has a sensor that sends out an ultrasonic signal, detects the response time, and translates it to the thickness of the material through which it passed. With this instrument, the thickness can be determined without stopping the water, but the material must be known beforehand. As stated in the introduction, most plumbing systems are covered up during construction in Taiwan. Consequently, a field investigation is very difficult. In general, it is possible to get a complete pipe sample only when renewal work is in progress. Therefore, we acquired six samples as survey objects from the hot water piping in existed buildings. All of these samples were galvanized steel pipe. Because many existed buildings have galvanized steel piping systems and metal pipe always corrodes more easily than nonmetallic material, we selected galvanized steel pipe as the critical object in this study of plumbing system influence on water quality.

3.INVESTIGATION RESULTS

3.1 Observation of water supply device and plumbing fixture

During this field investigation, 113 apartment houses in the Taipei area were examined. The investigation items included fundamental data on the building, elevated tanks, storage devices, piping systems and water quality. Table 2 shows the pictures of plumbing fixture situation in some survey cases. There are a lot of problems happened in practical building water supply system of apartment houses.

Table 2. Pictures of plumbing fixture situation in some survey cases



The calculation of piping surviving thickness mainly shows corrosion rate, yearly corrosion degree and remnant life span. According to existing documents, the corrosion rate is the ratio of eroded thickness to original thickness, and the yearly corrosion degree is the average corrosion for one year. Here we used the calculation theory of metal pipe remnants thickness from past research, the corrosion rate (E_c) was defined as the following form:

$$E_c = \frac{t_0 - t_s}{t_0} \times 100\% ....(1)$$

Where E_c is corrosion rate (%), t_0 is the original thickness of pipe (mm) and t_s is the remnant thickness of pipe (mm). E_y is yearly corrosion degree (mm/year) and defined as the following form:

$$E_y = \frac{t_0 - t_s}{Y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

In the above equation, Y is the usage span of survey objects. In order to get the life span of survey objects, first, we have to define the permissible remnant thickness of piping. But the calculation of permissible remnant thickness of piping is a very complex topic with many parameters included material nature, location, water pressure etc.. The discussion of calculation parameters is another study issue not in the field of this paper. We quote the equation as below from existing documents for working out the permissible remnant thickness of general metal objects, and we also set the parameters for certain conditions in this study.

$$T_a = \frac{P \times D}{200 \times S \times M + 0.8 \times P} + C \ldots..(3)$$

Here T_a is the permissible remnant thickness, P is the maximum inside water pressure of pipe (in general it is 10 ㎏/㎝ ^{2}), D is the outside diameter of pipe(20mm or 25mm), S is the allowable stress (it could be 6.4 ㎏/㎝ ^{2} for welded stainless material) , M is the product constant of the pipe (it could be 0.85 for welded stainless material), C is abundance (in general it is about 0.5mm). In principle, remnant life span should be counted by the permissible remnant thickness, but we could consider that the maximum corrosion might be the critical assessment for life span. Then the remnant life span (Y_l)could be calculated by the following forms, where t_o is the original thickness of pipe and t_{smin} is the minimum remnant thickness.

$$Y_l = \frac{t_o - t_{s\min}}{E_y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Figure.3 is a diagram that shows the relationship between yearly corrosion degree and number of years usage. As this diagram indicates, the number of years usage increases the yearly degree of corrosion. There is a slight increase of about 0.04~0.05 (mm/year) as the number of years usage is below 16 and a steep rise as the number of years usage beyond 20. According to existing documents [11], the durability span for galvanized pipe is about 15~20 years, which closely agrees with the result of this survey. The same diagram indicates that the corrosion rate is less than 20% as the number of years usage is within 16 and near 40% as the number of years usage goes over 20. Note that the corrosion rate varies and will increase year by year. The remaining life span of pipe will decrease in reverse proportion to the corrosion rate. Aside from water transportation and supply, the function of piping systems is to prevent water leaking. In general, the secure durable life span for galvanized steel pipe could reach 25~30 years. In order to avoid leaks, the usual practice is to subtract 5 years for assessment reference. According to the interior diagnosis study, aged piping would pollute the supply water and produce leaks, consequently, an existing building must have the function and security of its piping system checked after 15~20 years usage.

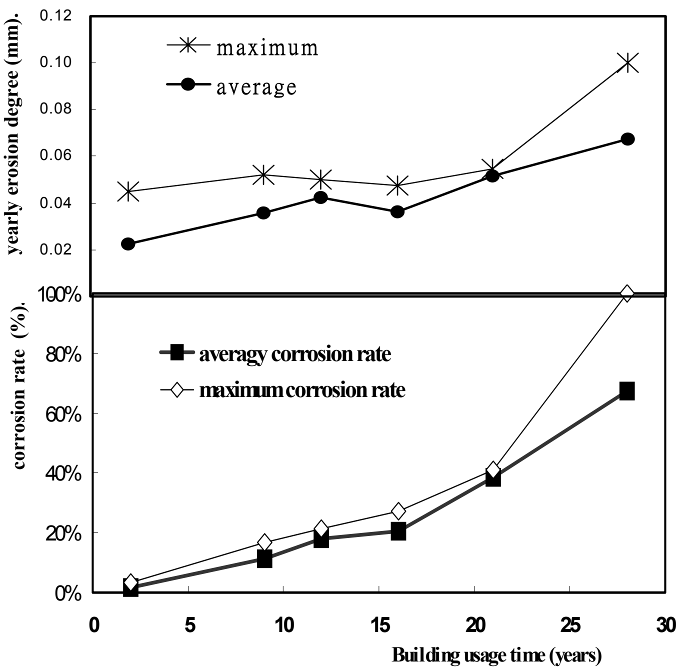


Figure.3 Relation of piping corrosion and building usage time

3.2 Physical water quality investigation

The difference in water quality from the inlet point of the storage device to the faucet outlet point can show something about water supply conditions in a building. We concentrated on the change from the municipal to the building water supply. Quantitative survey methods were used to observe and analyze the difference in water quality between the municipal water supply and the indoor faucet water. Figure.2 shows the total scope of the survey process and the locations where water samples were taken. The water samples were taken from four points in the building water supply system. The first place was the inlet point to the storage tank. The second was the outlet point from the storage tank. The third was the outlet point from the roof tank. The last place was the faucet outlet point in the kitchen.

It is reasonable to consider that water quality would worsen from the inlet point outdoors to the outlet point indoors in a building, and that the building usage life cycle point might be a critical factor. As the results, we have seen that water quality changes from the inlet point of the storage tank to the outlet point of the kitchen faucet in a building, which were shown in Table 3 and Figure 4. We also compared the relationship between the building age and the water quality individually, and the results are shown in Figure 6. In these observed cases, the building ages were from one year to twenty-three years old. The buildings that were built at the same time were put into a group using the average reading.

(1) pH value----Inadequate water pH value might cause bacteria propagation and metallic material corrosion. The potable water standard in Taiwan for pH value is between 6.5 and 8.5. We inspected water samples from kitchen faucets and found that 11 cases exceeded the standard requirement. As an overall observation, the pH values in these cases decreased exiguously from the outdoor inlet point to the kitchen faucet outlet point. Most of these cases did not exceed the standard for potable water.

(2) Residual chlorine ----Chlorine in potable water can restrain the propagation of bacteria or algae, but it is also not good for human health in excess of the standard amounts. The potable water standard in Taiwan for residual chlorine is from 0.2 to 0.8 ppm. We found that the residual chlorine in the municipal water largely decreased from the outdoor inlet to the indoor faucets. The water samples from the kitchen faucets showed low levels of residual chlorine. In addition, people boil water before drinking in Taiwan, which makes the residual chlorine nearly zero in drinking water.

(3) Turbidity reading----Water looking turbid would make people feel that it was dirty and that the water source might be polluted. We found that the turbidity reading increased from outdoor inlet to the kitchen faucet. The diagram shows that the increasing turbidity readings are correlated to the buildings age. The age of the building might be the factor that causes turbid water.

(4) Watercolor ----An aberration in watercolor might cause a psychological effect. The maximum potable watercolor authority of Taiwan is 15 (Pt-Co unit). All of these cases do not exceed the maximum potable water regulations in Taiwan and are minimally correlated to the building age.

(5) Total density of solid in water (TDS)----Total density of solid in the water is correlated to the condition of the water supply devices. Most of the water supply systems in Taiwan are gravity based with storage and roof tanks. The influence of these storage devices was therefore investigated. All of the observed cases did not exceed the maximum potable water regulations in Taiwan and the average increase in TDS reading was below 500 (ppm).

(6) Conductance reading----The ion density or particles in the water were checked using conductance readings. The diagram tells us that the conductance reading was slightly correlated to the building age. analysis

Table.3 Water Quality Variation of selected index from outdoor to indoor

Check point number （Water sample from outdoor to indoor）	No.1	No.2	No.3	No.4
pH Value	7.25 (±0.35)	7.13 (±0.34)	6.93 (±0.43)	6.85 (±0.47)
Residual chlorine (ppm)	0.78 (±0.32)	0.57 (±0.29)	0.40 (±0.28)	0.25 (±0.26)
Turbid reading (NTU)	0.64 (±0.35)	0.67 (±0.35)	0.72 (±0.33)	0.85 (±0.31)
Watercolor (Pt-Co unit)	4.20 (±4.41)	3.93 (±2.57)	4.29 (±3.04)	6.70 (±5.03)
Total density of solid (ppm)	52.3 (±28.1)	57.0 (±28.5)	63.1 (±25.5)	66.6 (±30.5)
Conductance (μ moh/cm)	184.4 (±23.3)	182.8 (±23.5)	186.2 (±23.1)	190.8 (±24.9)

Table value: Average(±STD), investigated in 1997.

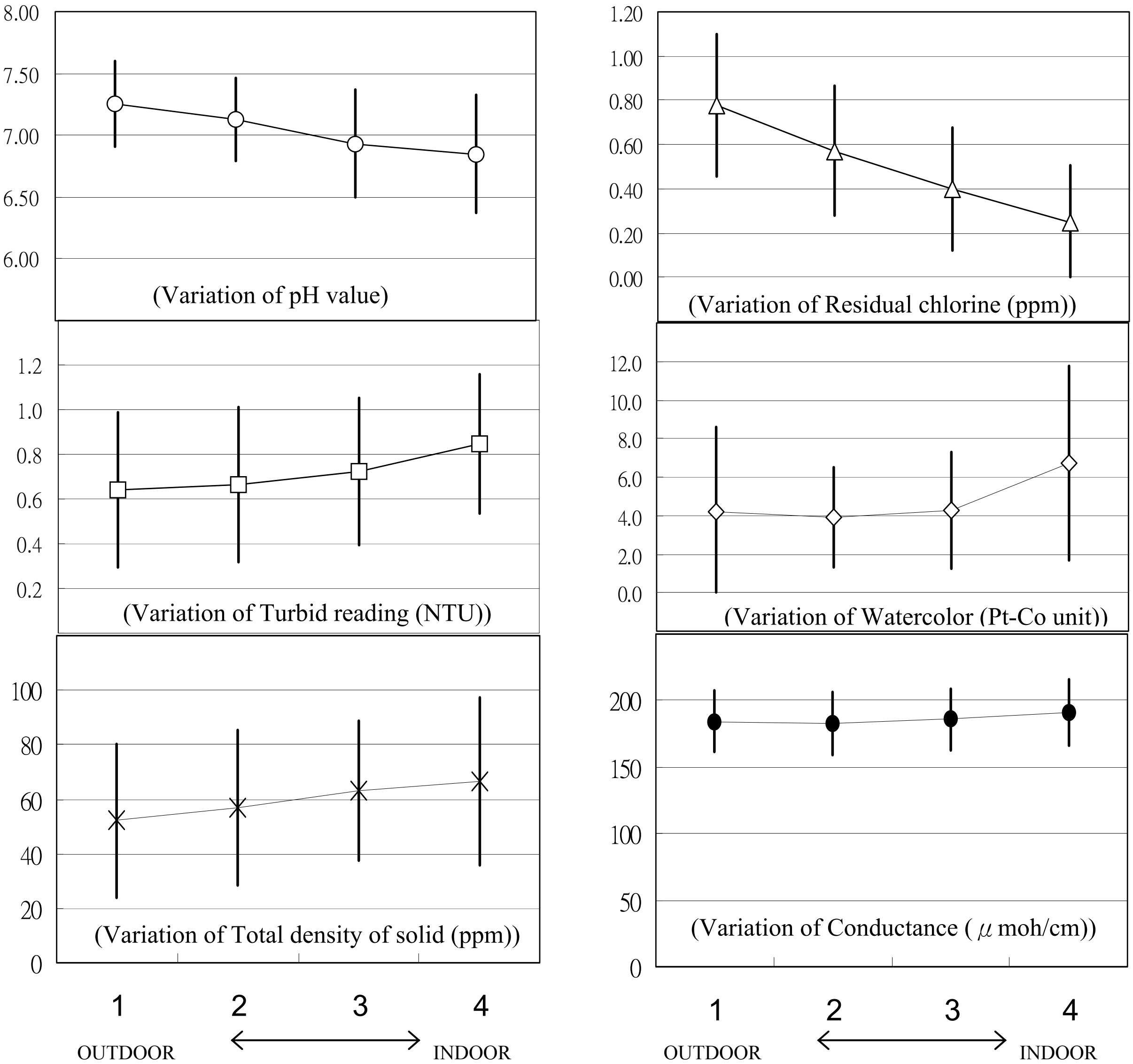


Figure.4 Water Quality Variation of selected index from outdoor to indoor

4.ANALYSIS AND DISCUSSION

4.1 piping aging and corrosion

Pipe aging would steeply rise after a certain period of usage and would worsen in proportion to the number of years used. We used a second-degree curve and regression equation to generalize this time relationship, as shown in Figure 5. Fifteen to twenty years was used as suggested life span for building piping systems and the distinct inspection stage base. As this diagram shows, we used the period before the suggested life span as the first stage, about 0~10 years, without obvious corrosion in the pipes. The second life span stage is about 10~15 years. In this stage, more ragged corrosion can be seen inside the pipes. If the corrosion rate from these practical cases were accurate, corrosion would reach to about 40%, which would influence the flow rate in the pipes and the water quality. This 40% corrosion would also speed up the continued corrosion of these pipes. Therefore, a diagnosis and piping system replacement would normally be performed during this stage. The third stage is the period over 20 years. Obvious aging and corrosion would be seen in this stage. There would also be a high risk for leaking. Table 4 shows the pictures of these conditions.

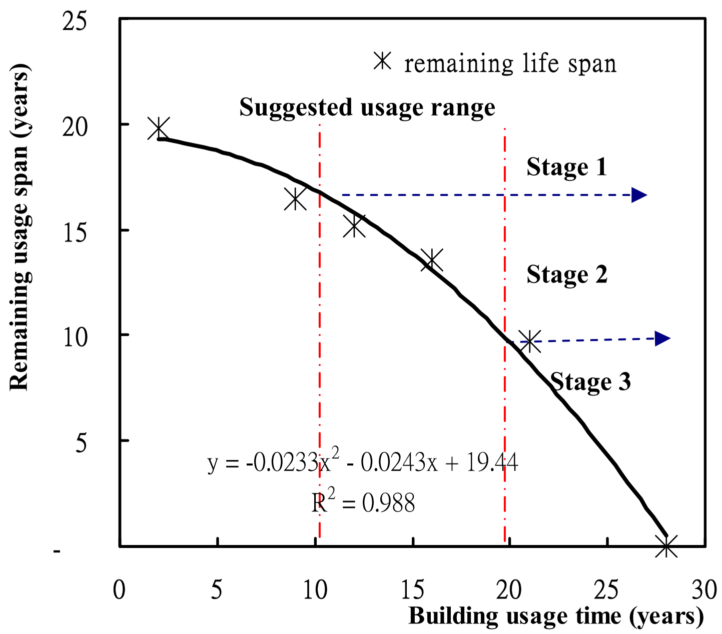
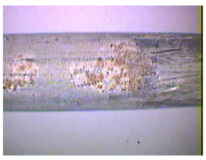
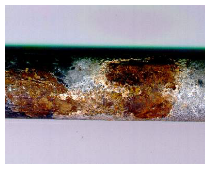
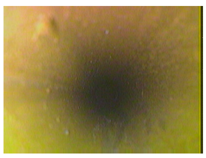
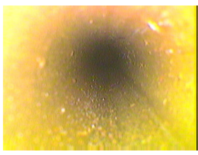
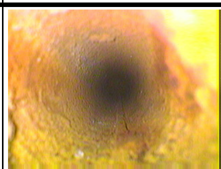


Figure.5 Time relationship of piping usage stage

Table 4. Aging and Corrosion view of pipe condition

Outside condition				
Inside condition				
Usage time	2 years	9 years	16 years	28 years
Usage stage	Stage 1		Stage 2	Stage 3
Survey command	●The surface has a little aging. ●Inside of pipe has some attachment material.		●Aging condition obviously increases. ●More rust could be observed.	●Serious aging condition could be observed.

4.2 The factors that influence water quality

After the water quality analysis in the buildings mentioned above, we isolated four factors that will cause a change in water quality from the outdoor inlet to the kitchen faucet, and examined these factors individually and analyze the correlation to the change in water quality in a building. We found that older buildings have worse water quality. Concerning the relationship between the storage and roof tank device materials, we also found that storage devices made of concrete cause a greater variation in water quality from the outdoor inlet to the kitchen faucet than other materials. Furthermore, a change in water quality with a cleaning frequency of once every three months is less than once per year. The more storage devices are cleaned, the less the variation in water quality from the outdoor inlet to the kitchen faucet (figures omitted). Piping materials are also considered a critical influence factor. Metallic pipes for hot water always have problems with corrosion and scale. Scale and corrosion could pollute the water or cause other water equipment problems.

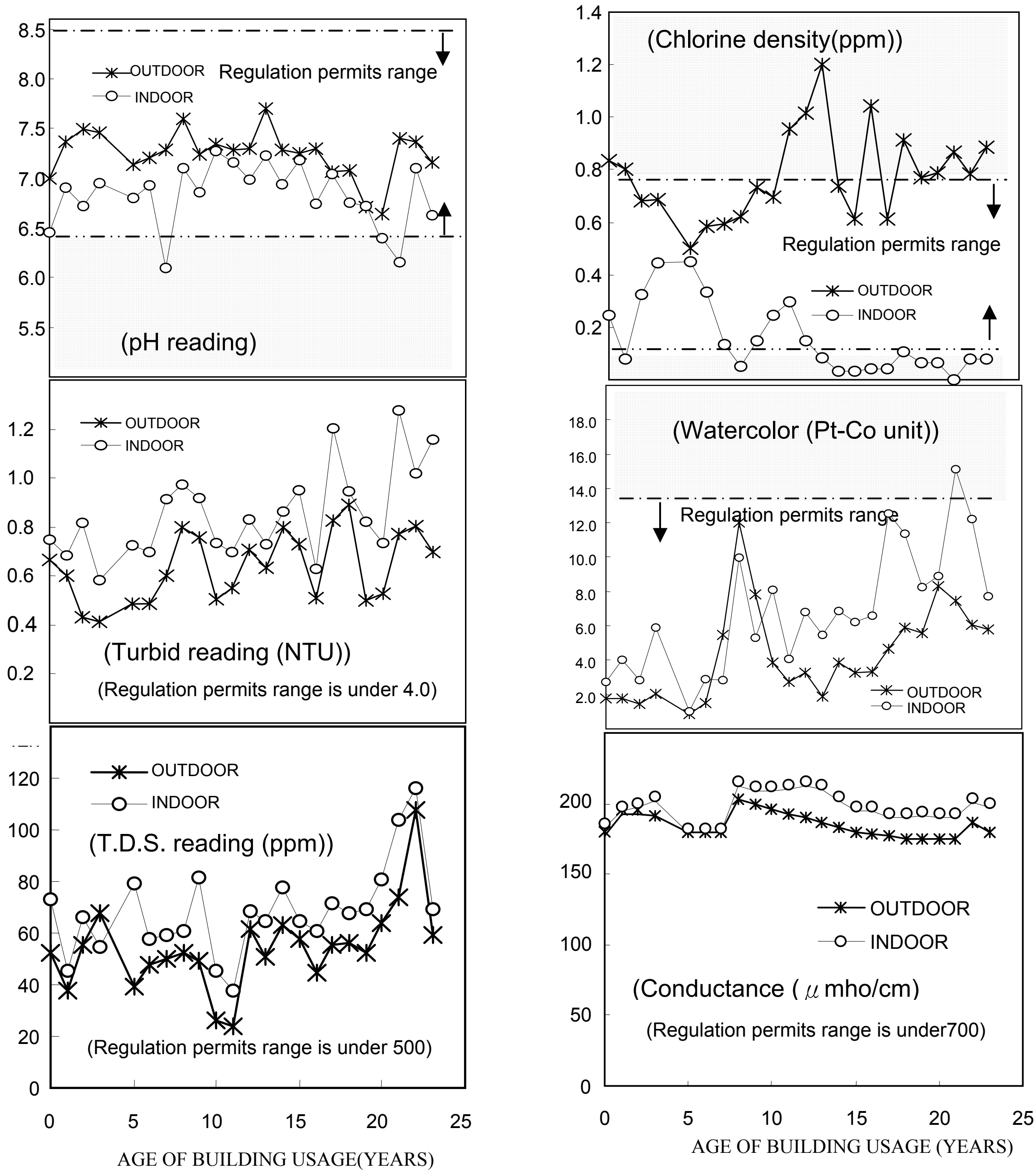


Figure.6 Water quality variation from outdoor inlet to indoor faucet

Physical indexes including pH value, residual chlorine (ppm), turbidity reading (NTU), color (Pt-Co unit), total density of solid (ppm) and conductance (μ mho/cm) were chosen as the representative characteristics for water quality in a building. The other parameters, such as total hardness and other chemical indexes were also examined. Microbiological contamination inspections are also important in maintaining good drinking water quality. The results also showed that in some of these cases the total bacterial count was over the criteria for drinking water. The supply process and devices in these buildings might cause these bacteria. This means that there are problems in building water supply systems. Because those cases were outside the municipal regulation standards, a serious threat is posed to people's health. More accurate inspection and verification of building water supply systems are necessary and that would not be included in this study.

So far, we have seen that water quality changes from the storage tank inlet point to the kitchen faucet outlet point in a building. Although the large majority of cases examined are within or near to quality measures, some cases are over the criteria for drinking water. Consequently, these water supply system devices might cause the water quality problems we pointed. People have a reason to worry about drinking tap water in buildings. The reasons why people have to boil water for drinking involve not only microbiological contamination, but also mistrust of the quality assurance measures adopted by the municipal authority. Improving the tap water quality and encouraging people to drink tap water without boiling or other treatment would be very difficult to carry out in Taiwan, because it is impossible to renew all of the water supply systems in every single building. It is possible to offer a drinking water supply system and maintain the tap water quality at the present level in existed water supply system. An independent drinking water supply might be possible for each building. We think that this is a practical alternative to the present policy.

5.CONCLUSIONS

The primary purpose of this research was to verify the general impressions and determine the actual water quality problems. This paper focused on the relationship between water supply devices and plumbing fixtures and the water quality in apartment buildings. We randomly chose 113 families using tap water in Taipei City, a basic investigation of water supply systems in general apartment buildings in Taiwan was completed with a physical inspection of the water quality from the outdoor inlet to indoor faucets in these buildings. As the result, we have seen that water quality changes from the storage tank inlet point to the kitchen faucet outlet point in a building. Although the large majority of cases examined are within or near to quality measures, some cases are over the criteria for drinking water. This means that the water supply systems might cause water quality problems. People have a reason to worry about drinking tap water in buildings. The reasons why people boil water for drinking is that they do not trust the quality assurance measures adopted by the municipal authority. Therefore, to offer a drinking water supply system additionally is a practical alternative to the present policy, and that would be better than to improve the existing water supply system. An alternative for the future water supply system was offered.

Acknowledgements

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REFERENCES

1.CHENG Cheng-li et al., 1998, Inference of Building Equipment and Piping to Water Quality in Apartment Houses-----Case Studies and Evaluation in Taiwan. CIB-W62 International Symposium, Rotterdam, The Netherlands, Water supply and drainage for buildings.

2.Chih-Hung Chen, 1998, Study on the inference of equipment to water quality. Master's Thesis National Taiwan University of Science and Technology.

3.EPA, 1998 Environment white paper. Environment Protection Administration, Taiwan, pp54-59.

4.Hirohumi Tamaru, 1995, Water become potable in housing building, Print in Japan.

5.J.J. Costello, 1984, Post precipitation in distribution system. AWWA, Vol.26, No.6,.

6.Kenzi Yamada, 1995, High quality water in building, Print in Japan.

7.Motoyasu Kamata, 1999 Hygienics & equipment for water supply and drainage in building. Print in Japan, TOTO,

8.Sadao Kozima, 1995, Search for delicious water, Print in Japan, NHK Books 487.

9.Thomas P. Konen, 1997, Water supply and drainage developments in the United States. CIB-W62 Symposium Yokohama Japan, Water supply and drainage for buildings.

10.Thomas P. Konen, Kurt Lipowski, 1996, The Influence of Water Quality on the Functional Performance and Durability of Plumbing Fittings. Technical Proceedings. Conventions, American Society of Plumbing Engineers, Westlake Village, California.

11.The Society of Heating, Air-Condition and Sanitary Engineers of Japan, 1995, Erosion & senility and durability, Japanese ASHRAE Handbooks. 12th edition, Vol.5, Chapter 6.

12.Vincent T. Manas, 1957, National plumbing code handbook, standards and design information.

13.WHO, 1993, Guideline for drinking-water quality. Vol.1, 2nd edition, World Health Organization, Geneva.

14.Yu-Jue Hong, 1997, An investigating and assessing study about the drinking water quality in five administration areas in Kaohsiung City. CIB-W62 Symposium Yokohama Japan, Water supply and drainage for buildings.

集合住宅給水設備老化對水質影響之研究

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摘要

近年來國內市售之飲用水販賣情況大幅成長，顯示部分民眾對自來水作為飲用水的不信任與疑慮。即使自來水水質處理達到飲用之法定標準，其中最令人擔心的還是來自建築物內供水系統過程中的污染。本論文主要目的在於探討建築物內給水設備的老化現象，並釐清建築設備供水過程中造成水質變動之問題。研究內容以抽樣調查方式，對大台北地區各種使用年限之集合住宅共113戶進行調查與檢測，並選定六項水質指標作為水質檢測評估之基準。研究成果顯示集合住宅內的供水設備系統，從蓄水池、水塔、配管到末端用水器具，水質明顯產生變化。雖然大部分調查案例之供水末端水質情況仍在法定基準範圍內，但是建築物內供水系統造成的水質變動與公眾飲水安全問題的確值得注意，國內建築設計上考量加強供水水質，積極導入上質水供應系統設備乃當務之急。

關鍵詞：自來水、物理性檢測、給水、水質、集合住宅