Domestic Water Heater Attached to Facades of Tall Buildings Exposed to Solar Radiation

Marcelo R. Errera, Ph.D. **Aloisio L. Schmid, Dr.-Ing.** **Patricia B. Errera**

ABSTRACT

This work deals with the architectural and constructional challenge of a domestic water heater (DWH) to be attached to a vertical facade exposed to solar radiation, preferably the western or northwestern (southwestern for the Northern Hemisphere) facades of tall buildings. The novelty of this device is to make use of insolation on tall facades and the hydraulic potential available in tall buildings to install individual units along the height. Those units consist of a set of collector-tanks that can be attached directly to the bathroom walls at each storage site. The advantages of the facade domestic water heater (FDWH) are that (1) it heats water during the afternoon, (2) the water is heated locally and next to the user, (3) it absorbs part of the excess afternoon heat during the summer, and (4) it is an alternative for a roof central solar collector. This solution is attractive to cities such as Curitiba, which decided to expand linearly along the axes northeast-southwest and east-west. Aesthetics and heat needs are presented and discussed. Three architectural solutions are also presented and discussed.

INTRODUCTION

This paper discusses the conceptual, energetic, and architectural issues of a new type of solar domestic water heater, which takes advantage of the large vertical area of tall buildings. This new heater has been named *facade domestic water heater* (FDWH). The original idea for this particular device came from Schmid (1998) after previous observations that had resulted in studies such as Schmid and Pereira's (1999).

This study is part of an ongoing project funded by a governmental research foundation and a solar water heater manufacturer (FINEP 2001). The project is divided into two main phases. Phase one, which resulted in this paper, deals with conceptual and functional aspects of the water heater and also with aesthetics and the constructional impact in the architecture of tall buildings. In phase two, a prototype will be built and tested under various conditions of insolation, hydraulics, materials, and use. Costs, savings, and operational constraints will then be estimated.

The idea of heating water by solar energy is not new and there is a great variety of solar domestic water heaters already available in the market. In North America, solar domestic water heaters date back to the 1930s, but they became more popular to homeowners in the 1970s (Anderson 1976).

The advantages of solar energy over electricity and gas heaters are well know (e.g., Anderson 1976). In Brazil, people typically prefer electrical showers ranging from 4 to12 kW and up to 12 min, 30 L baths. There are also a considerable number of gas water heaters (LPG or NG) that consume at least (30 L $\times$ 1kg/L/12 min $\times$ 4.18 kJ/kg $\times$ 30°C/LHV_{gas}kJ/m^3 $\times$ 1/60 min/h) m^3/h of LPG per bath. The savings in power (electrical energy) can be of the order of 2 kWh per bath (8kW $\times$ 0.25 h). More importantly, those savings can occur during peak hours (5:00 p.m. to 9:00 p.m.).

The benefits of solar energy are dramatically increased in larger scales of utilization. Isolated and individual efforts in the direction of the use of renewable energy resources are welcome to reduce the environmental impact of human activity but rarely translate into an actual contribution because of the small scale. The large concentration of inhabitants in urban zones of tall buildings presents the opportunity to create a

Marcelo R. Errera is an assistant professor in the Department of Mechanical Engineering and **Aloisio L. Schmid** is an assistant professor in the Department of Architecture and Urbanism, Brazilian Federal University at Paraná, Curitiba, Brazil. **Patricia B. Errera** is a licensed architect and independent consultant in passive solar architecture, Curitiba, Brazil.

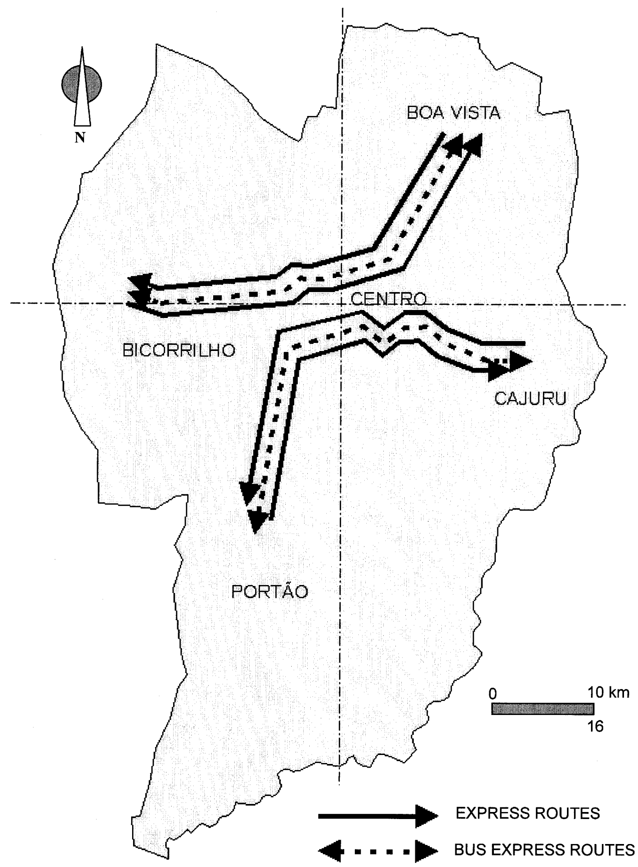

Figure 1 *Curitiba urban area showing the routes off which tall buildings are allowed (CENTRO is downtown Curitiba).*

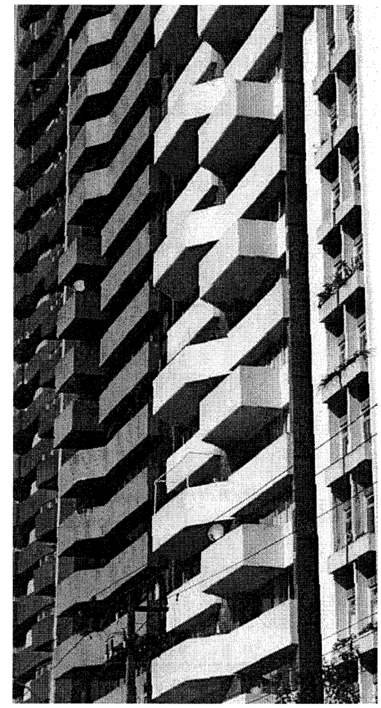

Figure 2 *Northern tall building facades showing the amount of insolation over the apartments and also the architectural elements, such as balconies and room and bathroom windows (buildings with no side gaps.)*

larger scale of energy (electrical power) savings. Regardless of whether the solar collector will be on the roof of those buildings or on the west-northwest (southwest for the Northern Hemisphere) facade, the opportunity to also establish a market scale is remarkable. A noticeable market development has already been reported in the city of Belo Horizonte. However, most collectors are placed on the roof.

For Curitiba, a city of 1.2 million persons in South Brazil, the concentration of buildings will lie on the northeast-southwest and east-west axes of the city, as shown in Figure 1. That will lead to a great amount of tall facades exposed to solar radiation.

Figure 2 shows a typical northern facade of buildings off the main routes depicted in Figure 1. Architectural elements, such as balconies, are also typical in Brazilian architecture.

Most solar DWH systems were designed for single-family residences, which usually present a reasonable roof area per person (RAP) ratio. Vertical buildings, on the other hand, lead to a very low ratio. For instance, for a 200 m^2 roof-area house for four people, the RAP ratio is 50 m^2/person. On the other hand, a typical (Brazilian) tall building of 20 stories of 500 m^2 roof area with an average of 12 people per story results in approximately 2 m^2/person. The roof area cannot solely be used by solar collectors since other utilities and frequently top-floor apartment terraces take most of the area.

Tank collectors (Speicherkollektor or Speiko) were proposed and developed in Freiburg, Germany, and a high performance was achieved (Häberle and Romme 1995).

The insolation on the west and northwest facades year-round is very attractive for purposes of late afternoon and early evening showers. For the sake of brevity, all the assumptions made in this paper refer to the Southern Hemisphere so one should consider southern orientation in place of northern if the interest is focused on the Northern Hemisphere.

The solar heat available in the city of Curitiba for day-long periods year-round is presented in Figure 3. Curitiba lies on the 25°S parallel. Neither losses due to the atmospheric absorption nor gains due to indirect diffuse or reflective heating were specifically considered. The chart shows a narrow range of insolation for the west facades that will guarantee uniform heating year-round for most of the tall buildings off the main routes in Curitiba (Figure 1).

In the next section, the conceptual aspects of the FDWH are presented and discussed. Afterward, some of the constructive issues are covered. Also presented are architectural alternatives for facades on which lie a "dark gray" vertical strip of the device in study. This paper is then concluded in the last section where the main advantages, limitations, and challenges are presented and discussed.

THE FACADE (SOLAR) DOMESTIC WATER HEATER

The FDWH was initially conceived for mild climate regions such as Curitiba, where the minimum temperature in the winter never reaches freezing temperatures.

The concept of the FDWH is illustrated in Figure 4. The device consists of a series of vertical round tanks (Hüeblin and Böhler Filho 2000), working both as tanks and absorbers. There is one water inlet at the bottom of the first pipe (tank) and one outlet on the top of the last tank. A supplemental electrical heating element is placed on the top of the last tank. The device can be considered a batch heater. The basic dimensions are L × H × W. The heaters are individualized for each apartment's bathroom. The heater is an easy-to-install one-piece unit that functions also as an external wall of bathrooms. How that works is the subject of the next sections.

Since the heater works as a wall and should not take useful area from the bathroom, which would cause the real estate industry to account significant losses, its width (*W*) is set to 0.2 m (almost 8 in.). Along the width *W*, there should be space for outside and inside insulation and the tanks. The inside insulation can be a flat thin slab, but the exterior insulation should be a compromise between transmittance and thermal resistance. The prototype will be built with two types of exterior transparent insulation, namely, glass panels (glazing) and a new material.

The heater dimensions are also subject to the height between stores (*H*). Therefore the collector area is approximately given by $L \times H$, where *L* is the frontal length. For typical values of H = 2.5 m and L = 1.5 m, a collector area, A_c, of about 3.75 m^2, will be available.

In the quest for ideal insulation conditions for the heater, one must observe the minimum water requirements. Equation 1 expresses the water volume of the heater regarding the width of the insulation and tube wall thickness.

$$V_w = n_{tanks} \times H \times \frac{\pi(W - e_{in} - e_{out} - g - 2t)^2}{4} \tag{1}$$

where

V_W = volume of water in the heater, m^3

n_{tanks} = number of cylindrical tanks within the heater

H = height of the collector part, m

W = width of the wall, m

e_{in}, e_{out} = thicknesses of the internal and external insulation, m

g = gap between the collector and the insulation, m

t = thickness of the pipe, m

The number of tanks, n_{tanks}, is determined by the horizontal dimension (*L*) and wall thickness (*W*) available for the heater, which, in turn, will be determined by the dimensions of the bathroom.

Based on Equation 1 and the proportions shown in Figure 4, namely, e_{in} = 0.02 m, e_{out} = 0.07 m, g = 0.01 m, and t = 0.003 m (~ 1/8 in.), the volume of water is of the order of 190 liters. According to Lechner (1991), 220 to 300 L (60 to 80 gal) of water can fully supply a three-person household in a day.

The considered heating is about 30°C over the ambient temperature. The net heat gain demand is given by Equation 2.

$$Q_w = V_w \times 1\frac{\text{kg}}{\text{L}} \times 4.18\frac{\text{kJ}}{\text{kg}} \times 30°\text{C} = 125.4 \times V_w \quad [\text{kJ}] \tag{2}$$

where

Q_W = net heat demand, kJ

In other words, to heat (or preheat) 190 liters of water to 30°C, 15.8 MJ (or 4.41 kWh) of heat are necessary. That

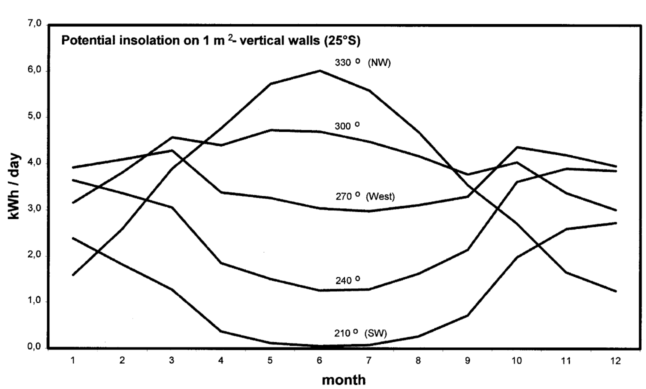

Figure 3 *The potential of solar heat in the city of Curitiba for vertical walls for orientations ranging from 210º to 333º (north 360º and south 180º).*

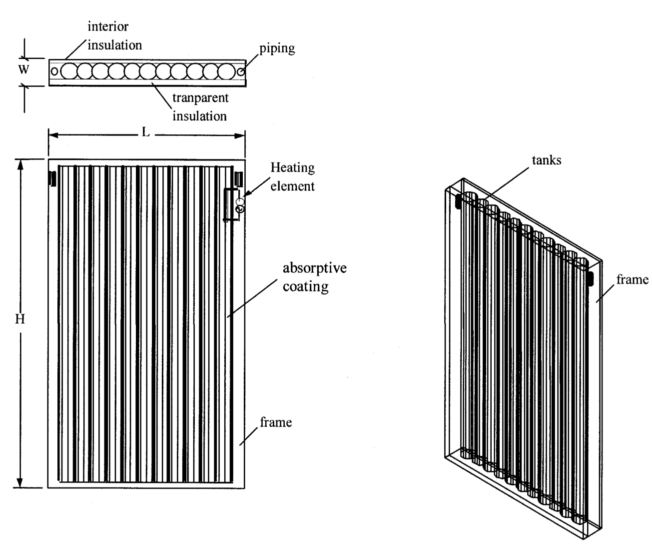

Figure 4 *Schematic illustration of the facade domestic (solar) water heater.*

amount of heat must be accumulated in no more than five hours (west facades in winter afternoons).

From Figure 3, one reads that the available insolation goes up to 6 kWh per day per m^2 depending upon the wall orientation and the season. Discounting atmospheric absorption (no larger than 50%), a range of 0 to 3 kWh per day per m^2 of solar heat is obtained.

If the external area of the heater ($A_c = 3.5\ m^2$) is considered with the atmospheric losses, the readings of the chart of Figure 3 can be multiplied by a factor of 1.75 ($3.5 \times 50\%$) to result in total heater energy gain. For instance, in the winter (June 21st), a west bathroom wall is subject to approximately 5.25 kWh/day of sun heat, which should be enough for heating 190 liters of water, as the figures under Equation 2 show. The back-of-envelope calculations above also show that there is a surplus heating (5.25 – 4.41 = 0.84 kWh/day) that can be lost to the ambient. In terms of thermal insulation to the ambient, it would require a material R-value of 0.6 m^{2}°C /W (50 W/m^2 for a 30°C temperature difference). For more precise calculations, the transmittance of glazing ought to be considered.

Another important aspect of the FDWH concept is the sense of water flow and temperature distribution. Two kinds of tank ensembles will be studied in the prototype, namely, one using a head water feeder at the bottom (tanks in parallel) and a collector on the top of the ensemble and another using intermediary links (tanks in series). Before analyzing the two possibilities, it is worth keeping in mind that the heater was devised to work in the late afternoon (batch regime) and, therefore, there will probably not be a continuous water flow except of the internal convective streams (unless the shower is in use).

The parallel layout functions like most common solar collectors. Cold water is fed at the bottom of the tanks and rises by natural convection. Such configuration is very likely to work like any other solar collector, but internal descendent flow might occur due to the larger diameters of these tubes. Furthermore, the full increase in water temperature must occur in each one of the tanks (Figure 4 does not show details of feeding possibilities).

The other layout considered was to set the tanks in series. In that case, the tanks will be linked to each other in such a way that the cold water pushes the hot water out with little risk of mixing. That also works to thermally stratify the water—hotter water closer to the outlet near the electric heating if ever used.

For the series layout to work properly, water must flow from its inlet on one side of the tank ensemble to the other. Some tanks are fed at the bottom, others at the top. The sequence starts with bottom feed at the first tank. Water rises by natural convection and feeds the next tube by the top; the cold water will then fall, mixing with pre-existing water. The way that is better will be revealed after further experimentation and analysis.

In sum, the FDWH was conceived to fully replace regular bathroom walls; it can also be classified as a batch-type device and provides west-facade potential of around 3 kWh/m^2·day (winter), which should be enough to heat or preheat to 30°C around 200 liters of water. It was initially devised for showers but can also supply all household water needs when applicable. The preliminary calculations showed the facade domestic water heater to be thermally feasible.

CONSTRUCTIONAL ASPECTS OF THE HEATER

The main constructional aspects of the FDWH are that it works as an external wall, that it must sustain a head of at least 2.5 m column-of-water, that the tanks (round tubes) must sustain the load of water weight, and that the whole piece must be attached to the building structure in a safe and permanent way. Other issues, such as a possible pressure reducer, thermal resistant sealing, indoor side suitable to decorative coatings, complementary heating device with a thermostat, long-life insulation material, and cleaning possibilities ought to be considered.

The heater must be structurally sound and independent to work as a wall. The prototype will have a rigid frame of "L-shaped" steel beam. The frame will be cemented in the building's main structure. Most of the buildings in Brazil have concrete structure, which will help the fixation of the main frame. The heater frame must allow cable lifting.

There must also be intermediate supporters for double-panel glazing or transparent thermal insulation material due to the large area (around 3.5 m^2) of the collector.

The tanks will be made of stainless steel round tubes with an approximately 3 mm (1/8 in.) thick wall. The tanks will be linked to each other by small pipes on the top and bottom or by a header at the bottom and a collector at the top.

The linkage must lead the water to flow from the heater inlet to the outlet. A supplemental pressure head from the building piping may guarantee the flow sense; however, it is important that the convective streams do not rise on the main building pipes.

A pressure reduction valve that also restrains back flow to the piping may be necessary and will be considered in the prototype.

There will be the case where the bathroom external wall is so narrow that part of the total area should be dedicated to a window (Figure 5a). In that case, the heater piece should permit fitting many standard types of glass windows.

A supplemental heating device must be installed for periods without sun. The heating is linked to a thermostat that would automatically turn it on. Therefore, the heater unit must present internal electrical wiring with an external connection to electrical power. It may be desirable that the electrical system be deactivated by a switch so that cleaning and maintenance can be safely performed.

All the material must last long since the acquisition and installation costs might not be low. It is very likely that the external insulation will deteriorate faster and the dark coating will loose its absorptive properties.

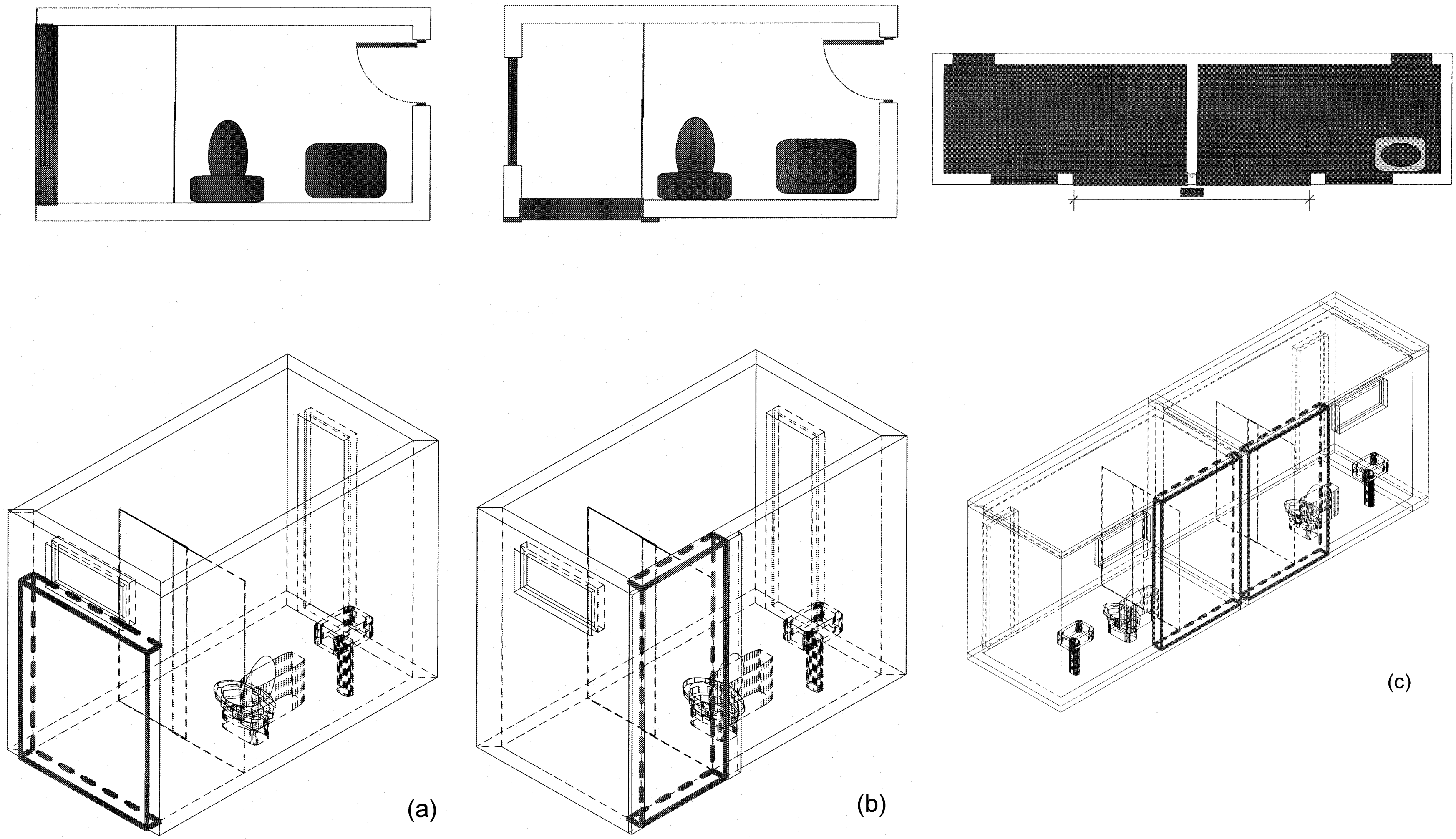

Figure 5 *Three different floor plans for bathrooms in apartment buildings: (a) heater unit and glass window share the little available area of the exterior wall of the bathroom, (b) narrow heater unit, but with full height, and (c) the heater with large width and height dimensions in contiguous bathrooms.*

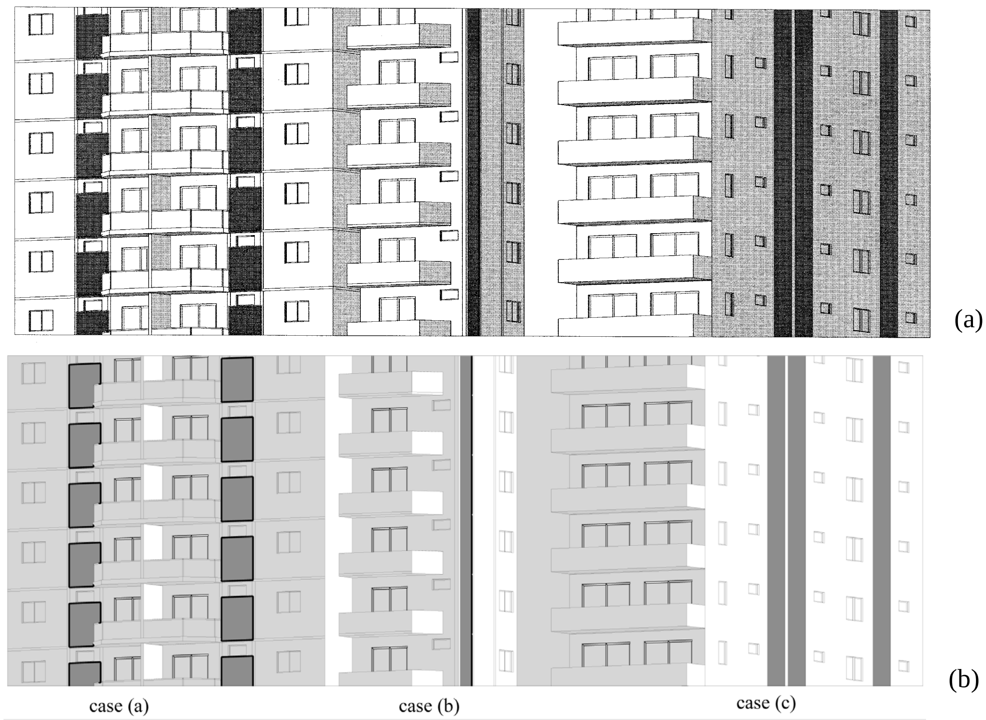

Figure 6 *Counterpart of Figure 2 with apartment buildings side-by-side in the front north facade: (a) insolation at noon and (b) insolation in late afternoon.*

The whole system must be accessible for cleaning from inside the building. The internal coating (e.g., tiles) must be somewhat easy to remove by a specialist. Another important cleaning issue is the internal surfaces of the tanks. Many ways are being considered to clean inside the tanks and the piping. One of them is to schedule maintenance and cleaning for the whole building at one time. Then water can be chemically treated to erode and absorb the impurities.

In sum, the heater must be a one-piece device, structurally sound and safe, to be fixed on the main building structure. The tanks and piping should resist pressure head, corrosion, and scaling. Cleaning and maintenance issues will be considered.

In the next section, the architectural issues inside and outside the heater, as well as the aesthetic implications, will be discussed.

IMPACT OF FDWH ON THE ARCHITECTURE

In this section, it is shown that the facade domestic water heater can fit the architecture trends of Brazilian urban environments. This issue is very important because many effective alternatives pointing to the concept of sustainable buildings do not often adapt to cultural and functional preferences. Hence, one of the greatest concerns with this new idea is how an ordinary homeowner will respond to the FDWH.

A preliminary study started with the design of three different floor plans for bathrooms in apartment buildings (Figure 5). Case A, corresponding to Figure 5a, concerns the situation in which the exterior wall of the bathroom is narrow so the heater unit and glass window must share the total available area. In that case, there will be limited heat gain. That will call for either a reduction of the water capacity or for north-oriented walls.

Another bathroom floor plan, case B, considered external issues. The building for which that bathroom was designed is in the middle of the block, flanked by two others. That building also presents a narrow front facade. Those two constraints led to placement of the heater unit at the front corner of the building. The heater unit also takes the full height available.

The third case, C, presents a larger apartment building that lies on the corner of the block. That building will have two facades exposed to solar radiation. That apartment was assigned two contiguous bathrooms in which FDWHs were installed. The bathrooms face west.

In all the three cases, the FDWH was fitted to the interior architecture and floor plans. Since the FDWH internal surface must be suitable for decorative coatings, homeowners should not notice any difference. That will resolve interior issues. Next, the outer appearance will be discussed.

The FDWH presents itself as a “dark gray,” slightly reflective strip on the facades, as shown in the simulations presented in Figure 6. This last figure is the counterpart of the photograph shown in Figure 2.

The impact of the external appearance of the three different floor plans are shown in Figure 6. The front facades face north, and the right side of building C faces west.

For case A, in which the heater units leave space for glass windows, two series of dark gray rectangles are present. Similar facades are common in Brazilian apartment buildings. The narrow building considered for case B presents a continuous dark gray strip lying on the corner. The building on the rightmost side shows a set of three dark strips that correspond to a mix of case C and its variation. Those continuous strips will break the monotonous pattern of flat single color facade. Three-dimensional solutions for the facade can also take place, as the bathroom walls can be moved slightly outward.

Figure 6 also shows a rough simulation of the insolation at noon (a) and in later afternoon (b). The intent was to demonstrate that FDWH might work the range of northwest orientation and fit front or side facades.

CONCLUSION

In this paper, the facade domestic (solar) water heater (FDWH), its conception, limitations, construction, and architectural-associated issues were introduced. This is the initial part of an ongoing project that contemplates building a prototype and evaluating its performance.

It was shown that for typical dimensions of $1.5 \times 2.5 \times 0.02$ m walls, there will be enough insolation on west facades to heat 190 liters of water to 30°C (54°F).

The heater will be a one-piece unit that will be lifted and assembled directly onto the main structure of the building. A supplemental electrical heating element was considered. Each heater unit is independent.

Three different bathroom floor plans were discussed. Regarding architecture, the greatest advantage of the FDWH is that it blends itself into the facade of the buildings as does any other finishing. That can be explored in the design process as a new element of composition.

After the prototype is built and tested, there will still be a process of making the heater economically attractive for builders and homeowners.

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