

# The choice of the optimal bath strategy based on linear programming

Wenjun Cao

School of North China Electric Power University Baoding, Baoding 071000, China;

916827591@qq.com

**Keywords:** bath strategy people's motions linear programming

**Abstract.** We divide the motions of people into three groups according to the intensity of the motions. We discuss the motions' influence on the velocity of water flow in the bathtub and the contact area between human body and water. On the basis of this, we put forward three plans for people to add hot water, then considering that the time to soak accounts for a big part of total time, so we discuss three plans under the condition that the person remains still.

## Introduction

The motions made by the person in the tub mainly influence the velocity of water flow in the bathtub and the contact area between human body and water. According to the intensity of the person's motion, we divide the motions into three parts:

- Remain still: when people soak in a tub, we assume he doesn't move and lies in the bathtub.
- Slight movements: motions like wash hair, which don't make big differences towards the velocity of water in tub. And we assume people can take any posture, so the area of contact part changes.
- Large movements: motions like wiping the body, which have a big influence on the velocity of water.

The influences on the velocity of water are reflected on the convective heat transfer coefficient between water and human body  $h$  and the convective heat transfer coefficient between water and bathtub wall as is shown in Table 1.

**Table 1.** The value of  $h$  and  $h_1$  under different situations

Types of motions		
Remain still	1000	1000
Slight movements	1100	1050
Large movements	1200	1100

## The ways for people to add hot water

We put forward three plans for people to add hot water:

- Plan A: the faucet is open through the whole process of bath and we adjust the flow velocity of hot water from faucet  $u$  to keep the temperature as close as possible to the initial temperature.
- Plan B: the person in tub opens the faucet at the beginning of the bath. When the temperature reach  $42^\circ\text{C}$  — upper limit of the suitable temperature for bath, close the faucet and water will get cool. We consider the person in tub opens faucet again when the temperature of water descends to  $38^\circ\text{C}$  (lower limit). Then repeat this process.
- Plan C: the faucet is not opened until the temperature descends to  $38^\circ\text{C}$  at the beginning, then open faucet to reheat water to  $40^\circ\text{C}$ , close it. And open it again when the water gets cooler to  $38^\circ\text{C}$  and repeat.

## The choice of the optimal strategy

Considering that the time to soak accounts for a big part of total time, so we discuss three plans

under the condition that the person remains still.

For plan A, we assume the change of the temperature is small enough to neglect, so through the whole process of bath. In this condition, the formula about heat transfer[1]:

$$\frac{dt_w}{dt} C_w V \rho = -[\alpha(t_w - t_a) + \beta(P_v^* - P_v) + \varepsilon \sigma (t_w + 273)^4] S_a - h(t_w - t_p) S_p - \frac{(t_w - t_a)}{\frac{1}{h_1} + \frac{\delta}{\lambda} + \frac{1}{h_2}} S_b + C_w \rho (t_{min} - t_w) u \quad (1)$$

is an equation with single variable  $u$  and we can easily get the solution.

For plan B, we divide the whole process into two parts based on the change of the temperature:  $40^\circ\text{C} - 42^\circ\text{C}$  and  $42^\circ\text{C} - 38^\circ\text{C}$ . As is shown in Table 3, the time of  $40^\circ\text{C} - 42^\circ\text{C}$  period is  $t_1$  and repeated times is  $n_1$ . The parameters of  $42^\circ\text{C} - 38^\circ\text{C}$  period is  $t_2$  and  $n_2$ .

**Table 2.** Parameters for plan B

The change of temperature	Time	Repeated times
$40^\circ\text{C} - 42^\circ\text{C}$	$t_1$	$n_1$
$42^\circ\text{C} - 38^\circ\text{C}$	$t_2$	$n_2$

We choose the volume of hot water people adds  $V$  as objective function and optimize our strategy. In plan B, the period that needs to add hot water is only  $40^\circ\text{C} - 42^\circ\text{C}$ , so we have:

$$(2)$$

We assume the total time for bath is 30 minutes (1800 seconds), thus we have the constrain condition:

$$(3)$$

And considering the continuity of the process of bath, we have:

$$(4)$$

We will give further discussion of the range of  $u$ . We also know  $u$  varies from 0 to [2], that is  $0 \leq u \leq 2$ .

Based on we have discussed above, we have the expression below to optimize the strategy:

$min:$

$$s.t.(5)$$

For plan C, we adopt the same method to analyze. There is a little difference of objective function, it is because the period to add hot water is  $38^\circ\text{C} - 40^\circ\text{C}$  in plan C. Therefore the objective function .

**Table 3.** Parameters for plan C

The change of temperature	Time	Repeated times
$40^\circ\text{C} - 38^\circ\text{C}$	$t_1$	$n_1$
$38^\circ\text{C} - 40^\circ\text{C}$	$t_2$	$n_2$

The optimal conditions for plan C are:

$min:$

$$s.t.(6)$$

## Summary

Based on what we have discussed above, we analyze the motions' influence on the velocity of water flow in the bathtub and the contact area between human body and water, then we put forward three plans for people to add hot water in the process of bath. Next we discuss three plans under the condition that the person remains still. Last, we get the expression below to optimize the strategy:

For plan B:

$min:$

$s.t.$

For plan C:

$min:$

*s.t.*

## References

[1] YANG Shi-ming, TAO Wen-quan. Heat Transfer (4th Edition) [M], Beijing: Higher Education Press, 2006.

[2] The maximum flow rate of faucet.

[http://assets.totousa.com/product-files/SS-00595\\_TL416SD.pdf](http://assets.totousa.com/product-files/SS-00595_TL416SD.pdf)

[3] Bowen L S. The ratio of heat losses by conduction and by evaporation from any water surface [J]. *phys. Rev*, 1926,27: 779-787.

[4] The steam pressure of saturated layer on the water surface

<http://wenku.baidu.com/link?url=Pa7OBKnM1AYw3LuEzrrjhCgrqrr7WuiqzH77VL1tiL30nGZTku pEFt1HEqvOcISAQkiECFY-MCDBksUFCIGzWWSVeH8pPsfwQcSdzYDvtq>

[5] The partial steam pressure of moist air

[http://wenku.baidu.com/link?url=vmeqCEPwzeqyUse\\_K-0eTLv2Sf7n0rDJUPspxu4I7ytk7wyjc2bp Xyxy3r\\_u8VZVpSxJTM\\_CCCKn\\_\\_guer7fPeW9KVtIV2JbpDDPQy0Qbu3](http://wenku.baidu.com/link?url=vmeqCEPwzeqyUse_K-0eTLv2Sf7n0rDJUPspxu4I7ytk7wyjc2bp Xyxy3r_u8VZVpSxJTM_CCCKn__guer7fPeW9KVtIV2JbpDDPQy0Qbu3)