

Is there a maximum age to be a construction worker?

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Abstract

The loss of physical capacity caused by age is of common knowledge. Looking at the changing age distribution in different countries everybody involved in the construction industry has to reconsider his own opinion of the aging workforce and therefore it is also one of the main topics for occupational health and safety.

Knowledge on ergonomics postulates a decline of physical working capacity in connection to the age of a person. Looking at the main indicators of workload – e.g. heart rate (HR), oxygen uptake (VO₂) and energy expenditure (EE) - the ergonomic literature provides different limits, which can be calculated based on a person's age and other personnel parameters. Within this paper some key limits are presented to protect the workers from exhaustion and equations are provided to calculate limits for different ages. Afterwards different sources for the determination of the workload are demonstrated and compared to before presented limit values. It will be shown that for specific trades of the construction industry the workload exceeds the limits even within the group of young workers.

The combination of knowledge on workload specific data with the individual's limits can lead to a different work distribution. Additionally occupational health and safety goals can be reached, by preventing injuries, incidents and accidents when the workload is observed and maybe reduced used in the early stage of the project scheduling.

Keywords: workload limits, heart rate, energy expenditure, aging worker, OHS.

1. Introduction

Investigating the aging population it becomes clear that without any thoughts on the special needs and interests of elderly people, a lot of workforce gets lost for physical (high demanding) work. De Zwart et al. (1995) showed the problem between the decline of the physical working capacity and stable physical working demands (See Figure 1). Whilst the capacity decreases by referring age, the demands remain on the same level for the whole work life. Especially when no measures were set to take the age of labourers into account.

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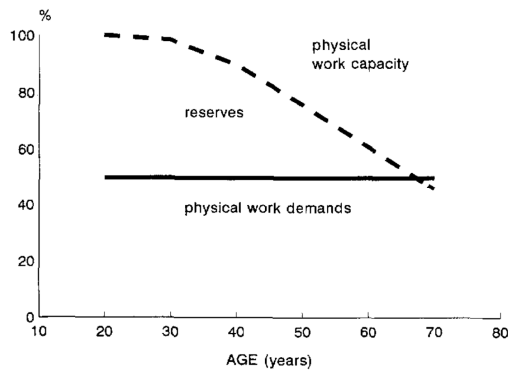


Figure 1: Relation between physical work capacity and physical work demands with age (Ilmarinen et al. 1991 in: De Zwart et al. 1995)

Especially the construction industry with its high physical straining tasks - for example in refurbishment projects with little or no machinery support - could get into big troubles if the workload is not integrated in the work flow and task distribution planning process. The possibility to integrate workload into scheduling and distributing breaks according to the work flow was shown in different resources but hardly used until now.

2. Literature review

2.1 Aging of the population

The population of the world is still growing; it increased in the period from 1950 to 1970 by more than 50 %. Since 1975 two areas of growth can be seen: (1) in the developed countries (mostly found in Europe, North America, Asia and Oceania) the growth remained on a low level and in some countries a decrease started; (2) in the less developed countries (mostly found in Africa, South America) the population growth is on a high level and especially the growing of the city-population is much higher than in the developed countries. The current population of the world counts about seven billions people and prognoses say that it will rise until 2050 up to more than nine billions.

Beside the rise of the population the demographic dividend will be an important factor to have a reservoir of trained workers for the various economies in different countries. In the following figures the demographic dividend for the World, North and South America are displayed for the years 2010 and 2050 (US AID 2012):

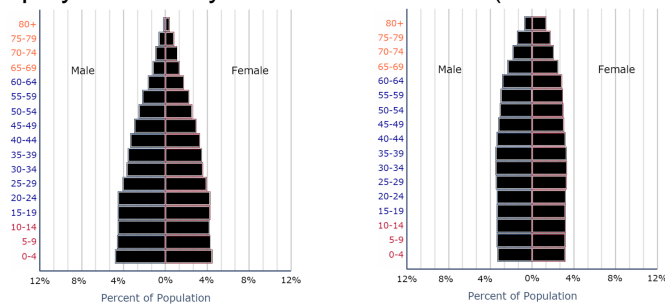


Figure 2: Demographic dividend for the population of the World in 2010 and 2050 (US AID 2012)

Comparing 2010 and 2050 for the entire world only a small change can be stated for the ages between 15 to 64 years: 2010 approx. 80% of the population and 2050 approx. 83%.

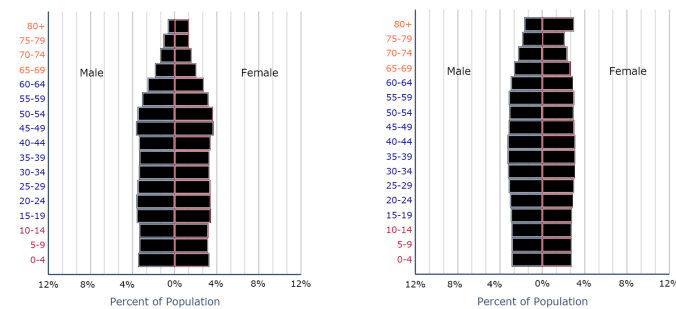


Figure 3: Demographic dividend for the population in North America in 2010 and 2050 (US AID 2012)

However when looking at individual regions, the change within 40 years can easily be seen: Examining a high developed region like North America, it can be seen that the change in the age distribution is not that big but the share of older people (> 64 years) is growing from 6.3% up to 9.5% of the population.

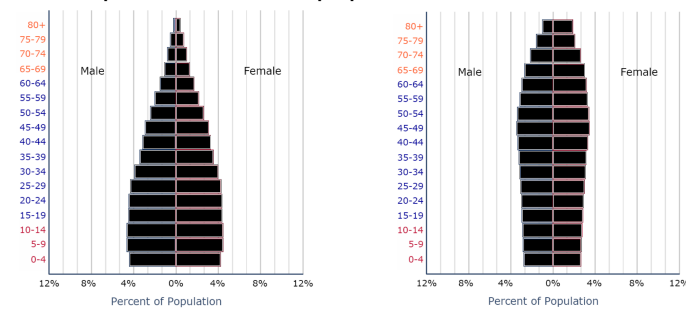


Figure 4: Demographic dividend for the population in South America in 2010 and 2050 (US AID 2012)

The trend in South America is much more recognizable and again the share of older people is growing rapidly (from 3.3% up to 8.4%). Additional to the demographic dividend the McKinsey Global Institute (2012) shows the distribution of global labor markets.

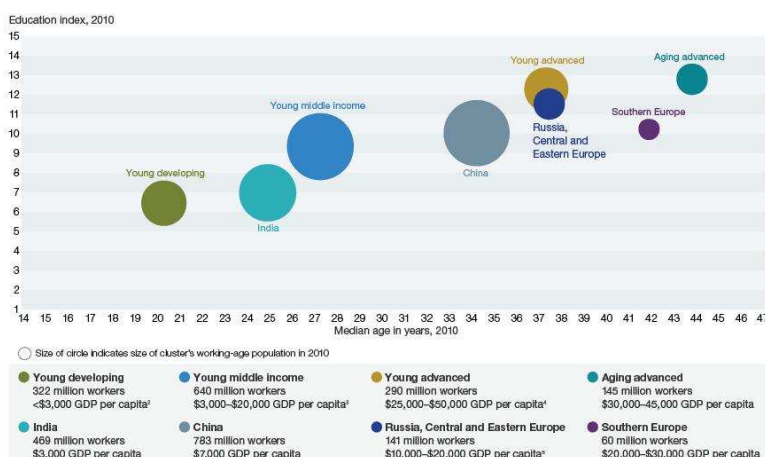


Figure 5: Global labor markets clustered and positioned in terms of age profile and educational attainment (McKinsey Global Institute, 2012)

Figure 5 presents eight clusters of labor workforce, positioned in terms of mean age and education. Again, a trend can be seen by a lower amount of older labor in the more educated regions worldwide.

2.2 Workload limits

These demographic changes are even worse for the construction industry, as within a lot of manually performed tasks have to be fulfilled and cause fatigue according to the level of strain. To keep the workload within an acceptable range different limits to protect labor workforce are stated.

2.2.1 Individual limits:

These limits arise due to the physical conditions (e.g. age, weight, height and muscle strength) and can be defined as a value over the resting heart rate ($HR_{rest} + 40$ bpm) (Müller 1962; Kuhlmann 1986; Abdelhamid and Everett 1999) They can also be established by the heart rate at the first lactate turn point (HR_{LTP1}) (Pokan et al. 1997; Hofmann and Tschakert 2011; Wultsch et al. 2011) as well as the amount of the oxygen uptake ($\%VO_{2,max}$) (Åstrand 1960; Legg and Myles 1981) or the energy expenditure as a function of work time ($EE(t)$) (Bink 1962; Lehmann 1962; Wultsch et al. 2011).

1. Determination of HR_{LTP1} : An accurate determination of heart rate at LTP1 may only be provided through a cycle ergometric analyse, as the HR_{LTP1} depends on the individual. Even though, this limit was published the first time in 1994 (Hofmann et al. 1994), there is no general formula in the literature until now. Schlagbauer (2012) provided an equation based on seven studies investigating 17 different volunteer groups – resulting in a total of 458 participants – carried out by various literatures (Hofmann et al. 1994; Hofmann et al. 1995; Pokan et al. 1997; Hofmann et al. 1997; Hofmann et al. 2001; Hofmann et al. 2005; Wultsch et al. 2011). The result was a highly significant correlation ($p\text{-value} \leq 0.001$) for the multiple regression analysis of the data series for P_{max} , HR_{max} and HR_{LTP1} , which leads to the following equation:

$$HR_{LTP1} = 2,420 + HR_{max} * 0,635 + P_{max} * 0,018 \quad (1)$$

Therefore the determination of the maximum power (P_{max}) can be undertaken by laboratory tests but these are not always executable; instead the expected maximum power ($P_{max, calc}$) can be predicted as an approximation using weight (W), height (H) and age (A) for male by the equations (Wonisch et al. 2008):

$$P_{max, calc} = 6,773 + 136,141 * KO - 0,916 * KO * A \quad (2)$$

$$KO = 0,00714 * W^{0,425} * H^{0,725} \quad (3)$$

2. For the limit of VO_{2max} Legg und Myles (1981) presented an overview and stated levels between 21 % and 50 % depending on the research design and the investigated

volunteers. Åstrand (1960) did the only investigation connected to the construction industry and set the limit at 40 % VO_{2max} ; therefore this limit will be used later on.

- Using the energy expenditure (EE) as a limit, Bink (1962) introduced an equation to calculate the maximum working energy expenditure (WEE) according to the length of the workday (t) and the individual aerobic capacity (a) based on the findings of Åstrand (1960):

$$WEE = [\log 5700 - \log (t)] / 3,1 * a \quad (4)$$

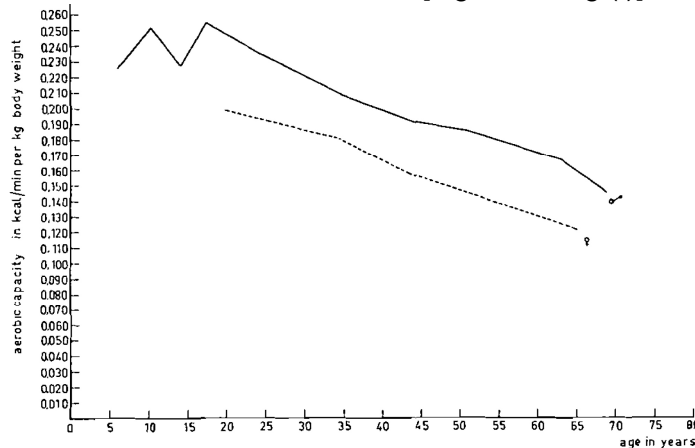


Figure 6: Aerobic capacity according to Åstrand (1960)

2.2.2 Absolute Limits:

Established literature also provides limits which are stated for all laborers, independently on the workers physical conditions. The best known limits are the mean heart rate of a 8h workday ($HR_{mean,8h}$) (Brouha 1967; World Health Organization 1969), the volume of oxygen uptake (VO_2) (Abdelhamid and Everett 2002) and the energy expenditure (EE) (Müller 1953; Lehmann 1962; Bink 1962; Legg and Myles 1981; Oglesby et al.1989; Åstrand and Rodahl 1986):

- The limit of the heart rate is set for 110 bpm as the mean heart rate for 8 hours of work according to the finding of Brouha (1967) by the world health organization (1969).
- The limit for VO_{2max} is set for 1 l/min as the mean amount of the oxygen uptake for an 8 hour work day Abdelhamid and Everett 2002).
- The Limit for the energy expenditure (EE) was set with 5 kcal/min as the mean energy expenditure for an 8 hour workday (Oglesby et al. 1989). This value includes a basal metabolism value of 1 kcal/min. Additional Mueller (1953), Lehmann (1953), Bink (1962), Legg und Myles (1981) and Åstrand und Rodahl (1986) presented investigation results for WEE (8h) and set a value of 4 kcal/min.

Taking one of these limits, it is the decision of the user which kind of problem he wants to solve: (a) using the absolute limits the individuality of a person is negotiated but these limits can be used easily for a lot of people; (b) using the individual limits it is much more an intrusion into privacy and some very personal information has to be used or tests have to be

computed. Also the effort to calculate the limit for every individual rises enormously when computing the limits for a lot of laborers.

This shows that both methods have their fields of application but when the decision is made for one of the limits the circumstances and limitations should be kept in mind. The later application of different limits will show the big differences that can occur using them.

2.3 Impacts by age on the limits

The age has an effect on a lot of biological measures (see figure 7); in connection within the above presented limits the maximum heart rate (HR_{max}), the maximum oxygen uptake (VO_{2max}) are two important parameters which decline with the age of a person.

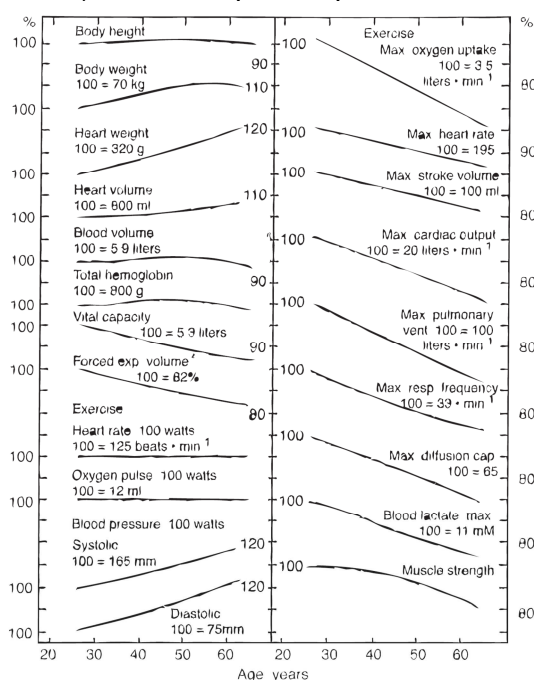


Figure 7: Variation in some biological measures with age (Åstrand 2003)

2.3.1 Calculation of the maximum heart rate (HR_{max})

The calculation of HR_{max} can be performed by using the formula by Åstrand (1960):

$$HR_{max} = 211,30 - 0,922 \cdot \text{Age} \quad (5)$$

It can be seen, that the age is for this parameter the only and directly connected influence and therefore a problem can arise when a limit is set without a regard to the age.

2.3.2 Calculation of the maximum oxygen consumption (VO_{2max})

VO_{2max} can be calculated based on three different methods:

- (a) Jackson and Ross (1996) combined the influence of age, height, weight, sex and the trainings level (SRE, range 0-7) and discovered the following equation (6):

$$VO_{2,max} = [(56.363 + (1.951 \cdot \text{SRE}) - (0.754 \cdot \text{BMI}) - (0.381 \cdot \text{age}) + (10,897 \cdot \text{sex}))^{\text{weight}} / 1000 \quad (6)$$

(b) Duque et al.(2009) combined height, weight, sex and physical activity during leisure (PALT, range 1-4) in equation (7):

$$VO_{2,max}=[(35.3377-(0.475411*BMI)+(0.155232*PALT)+7.98682*sex)]^{*weightt}/_{1000} \quad (7)$$

(c) Bradshaw et al. (2005) used sex, age, body mass index (BMI), perceived functional ability (PFA, range 2-26) and current physical activity level (PA-R, 1-10) and explored equation (8):

$$VO_{2,max}=[(48.0730+(6,1779*sex)- (0.2463*Age)-(0.6186*BMI)+(0.7115*PFA)+(0.6709*PA-R)]^{*weightt}/_{1000} \quad (8)$$

Like for the calculation of HR_{max} the age is also integrated in the equations for VO_{2max} which has a major impact on the parameter when used as workload limit.

2.3.3 Calculation of the maximum working energy expenditure (WEE)

Bink (1962) provided a formula to calculate the maximum working energy expenditure (WEE) in connection to the length of a workday. As an input he used the information of the aerobic capacity (a) according to Åstrand (1960), which can read off her drawing (see figure 6). Again the age is the only input variable for the aerobic capacity; looking at figure 6 a decline starting at the age of about 20 years can be found.

2.3.4 Estimating the resting heart rate

Identifying the resting heart rate (HR_{rest}) is not as quite simple as the determination of HR_{max} as there are no definite researches to determine HR_{rest} so far. For estimation, the numbers in table 1 can be used, as they present usual HR_{rest} for different training levels and ages.

Table: 1 resting heart rate according to age and training level (Topendsports 2012)

Resting Heart Rate for MEN						
Age	18-25	26-35	36-45	46-55	56-65	65+
Athlete	49-55	49-54	50-56	50-57	51-56	50-55
Excellent	56-61	55-61	57-62	58-63	57-61	56-61
Good	62-65	62-65	63-66	64-67	62-67	62-65
Above Average	66-69	66-70	67-70	68-71	68-71	66-69
Average	70-73	71-74	71-75	72-76	72-75	70-73
Below Average	74-81	75-81	76-82	77-83	76-81	74-79
Poor	82+	82+	83+	84+	82+	80+

2.4 Calculation of different limits based on the age of a construction worker

Using the equations presented above the limits for different ages were calculated as following. All input parameters were kept for all calculations at the same level and were therefore set as: sex: male; height: 185 cm; weight: 85 kg; SRE: 3; PALT: 2; PFA: 15; PA-R:

5; Training level: average. Using the equations 1 and 4 to 7 the results for different ages are presented in table 2:

Table 2: Limits for different age according to different literature

Age	HR _{LTP1}	HR _{rest+40}	40 % VO _{2,max}			WEE (8)	HR (8h)	VO _{2,max}	EE (8h)	WEE (8h)
	eq. (1)	Table 1	eq. (5)	eq. (6)	eq. (7)	eq. (4)				
	bpm	bpm	l/min	l/min	l/min	kcal/min	Bpm	l/min	kcal/min	kcal/min
18	130.65	110	1.62	1.09	1.63	7.22	110	1	5	4
20	129.41	111	1.59	1.09	1.61	7.13	110	1	5	4
25	126.31	112	1.53	1.09	1.57	6.78	110	1	5	4
30	123.22	113	1.46	1.09	1.53	6.63	110	1	5	4
35	120.12	114	1.40	1.09	1.48	6.19	110	1	5	4
40	117.02	114	1.33	1.09	1.44	5.89	110	1	5	4
45	113.92	115	1.27	1.09	1.40	5.60	110	1	5	4
50	110.82	116	1.20	1.09	1.36	5.45	110	1	5	4
55	107.72	115	1.14	1.09	1.32	5.16	110	1	5	4
60	104.62	114	1.07	1.09	1.27	5.01	110	1	5	4
62	103.38	112	1.05	1.09	1.26	4.86	110	1	5	4
65	101.53	111	1.01	1.09	1.23	4.42	110	1	5	4

The results presented in table 2 show the differences between the limits. Especially the individual characteristics have a big influence, but have no direct impact on the absolute limits.

3. Workload of construction work activities

After the identification of various limits, different sources for the workload of construction labor are presented. They will be compared to the calculated limits in table 1.

One source is Hettinger et al. (1982), who presented tables to calculate EE for different physical work. For the construction industry some of their results are presented:

Table 3: EE of different trades (Hettinger et al. 1982)

Work	Laying bricks	Concreting work	Reinforcement work	Preparation work
EE [kcal/min]	2.10-2.70	2.91-6.64	2.82-4.99	2.80-5.97

Combined with the distribution of tasks provided by Zimmermann and Haas (2009) a mean EE can be calculated. They stated that 39 % of the work day were main activities; 37 % were additional activities; 13 % were personnel depended interruptions (PI); and 11 % were other interruptions times (OIT). Setting an EE of 1.3 kcal/min for PI and 1.8 kcal/min for OIT a mean EE for the workday can be calculated with 2.38 for bricklaying and 8.43 for concreting work.

Abdelhamid and Everett (1999) also investigated the energy expenditure and presented different EEs: for bricklaying 2.5-4.0 kcal/min; for carpentry work 4.0 kcal/min; for resting on

the job 1.5 kcal/min; and for Painting inside 1.9-2.4 kcal. In a later paper Abdelhamid and Everett (2002) presented more values for EE and additional measurements of the heart rate (HR) for different trades, which are presented in table 4.

Table 4: Range of energy expenditure and heart rate by construction trade (Abdelhamid and Everett 2002)

Trade	Range of average energy expenditure	EE for the example worker (85kg)	Heart rate	
			mean	SD
	kcal/kg*min	[kcal/min]	bpm	
Bricklayer	0.028 - 0.055	2.38 - 4.68	104 $\square \pm \square$	10
Carpenter	0.031 - 0.081	2.64 - 6.89	109 $\square \pm \square$	23
Cement finisher	0.027 - 0.073	2.30 - 6.21	107 $\square \pm \square$	29
Drywall installers	0.035 - 0.062	2.98 - 5.27	114 $\square \pm \square$	21
Electrician	0.027 - 0.055	2.30 - 4.68	98 $\square \pm \square$	11
Glazier	0.042 - 0.048	3.57 - 4.08	120 $\square \pm \square$	2
Ironworker	0.019 - 0.071	1.62 - 6.04	112 $\square \pm$	17
Laborer	0.023 - 0.084	1.96 - 7.14	115 $\square \pm \square$	15
Pipe fitter	0.022 - 0.064	1.87 - 5.44	105 $\square \pm \square$	12
Sheet metal worker	0.030 - 0.065	2.55 - 5.53	102 $\square \pm \square$	17

Schlagbauer et al. (2011) also investigated the load of bricklaying and concreting work and presented results of the observed working days for 8 laborers: (i) mean values for HR: 93.62 – 110.24 bpm; (ii) mean values for VO_2 : 0.69 – 1.22 l/min; (iii) mean values for EE: 3.43 – 6.51 kcal/min.

4. Comparison of the investigated results with limits for different ages

In the next two figures different workload levels from the findings presented previously were compared to calculated limits presented in table 4:

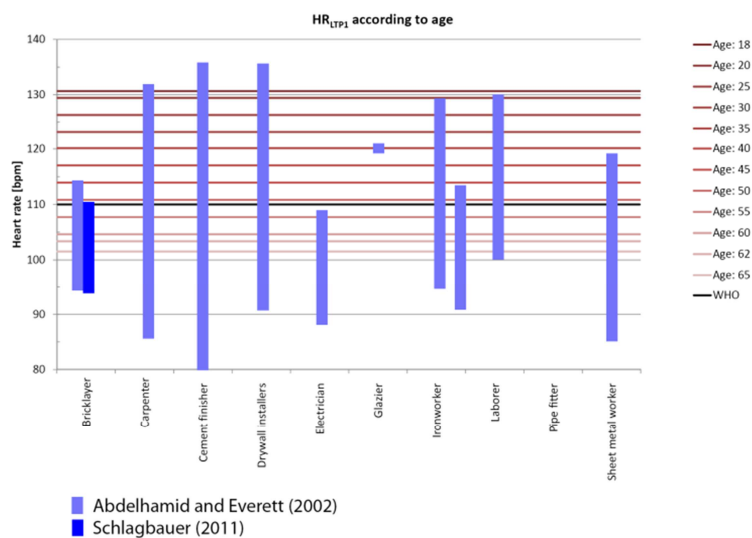


Figure 8: Comparison between HR_{LTP1} for different ages and workload of trades

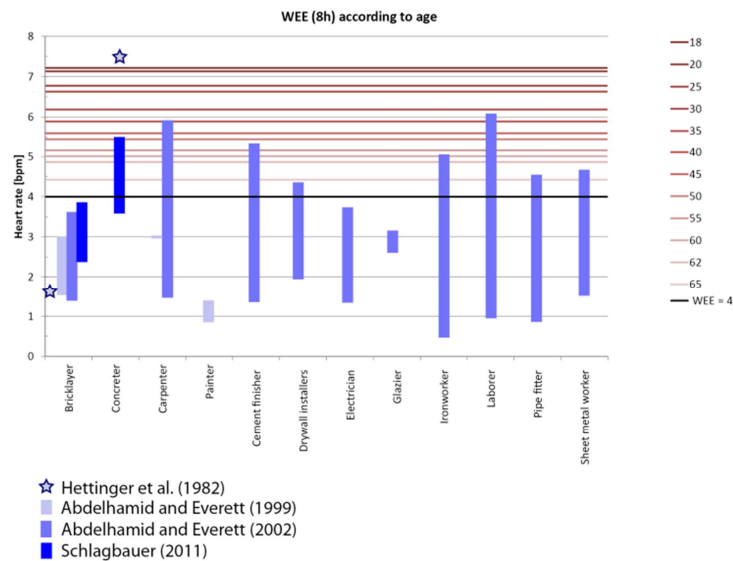


Figure 9: Comparison between WEE(8h) for different ages and workload of trades

Based on the facts presented in figures 8 and 9 it can be stated that by performing different trades the workload does exceed the individual and absolute limits.

Looking at the heart rate it becomes notable that for three of the presented trades (Carpenter, Drywall installers and Cement finisher) even the limits of an 18 year old worker are exceeded and the maximum heart rate of all presented trades do exceed the limit of a 55 year old worker.

The comparison of the energy expenditure shows a slightly different result (see figure 7); five trades (bricklayer, painter, drywall installers, electrician, glazier) do not reach the calculated limit for an 65 year old healthy worker, but the absolute limit of 4 kcal/min is reached or even exceeded by nearly all displayed trades.

5. Conclusion

The loss of physical capacity according to a higher age is of common knowledge but within the construction industry until now only little investigated. But looking at the changing age distribution in the developed countries everybody involved in the construction industry has to consider the fact of the aging of the work force and how he wants to handle the change.

Beside the right work assignment health and safety of labourers is a main topic for the future. Different research results show, that when the workload is close to or over the individual workload level the injury, incident or accident rate rises disproportionately.

In order to prevent these increases in injuries, incidents and accidents the workload should be integrated into work flow planning and project scheduling. But until only a few useable data sets are provided but until now hardly used as they are often unknown by the companies. So, this has to be one of the goals for further researches: provide new and applicable information for all parties involved.

Using this knowledge the amount of money spent on healthcare and recovery training as well as absence time can be reduced and will have a positive impact on the whole economy. But it is important, that these researches don't stay in the scientific community but were brought to the people who are affected by these solutions. There the unions in combination with insurance companies are requested to support and strengthen the starting researches worldwide.

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